Electrical Maintenance Hints

Volume 3

Power Apparatus Maintenance

Compiled and Edited by John G. Bishop

Westinghouse Electric Corporation
Printing Division
Trafford, Pennsylvania

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Notice to the user of this book

The safe maintenance or repair of any electrical apparatus requires a thorough knowledge of engineering safety and repair techniques, and familiarity with the particular features of the apparatus involved. This book cannot, and does not deal with the numerous details of every manufacturer's apparatus necessary for safe repair or maintenance. The inexperienced electrician or unqualified layman should not expect this book to provide sufficient instructions to permit him to safely repair any electrical apparatus. Use only qualified electrical repair personnel to do any work required, and refer those workers to the manufacturers' warnings and instructions before starting any work.

Severe or fatal electrical shock or burn can result from failure to properly service or repair equipment.

Safety
Disclaimer of Warranties and Limitation of Liability

There are no understandings, agreements, representations, or warranties, express or implied, including warranties of merchantability or fitness for a particular purpose.

The information, recommendations, descriptions, and safety notations in this document are based on Westinghouse experience and judgment with respect to maintenance hints. **This information must not be considered to be all inclusive or covering all contingencies.** If further information is required, the equipment or material manufacturer must be consulted.

This document is furnished in "as is" condition. **No warranties, express or implied, including warranties of fitness for a particular purpose, of merchantability, or warranties arising from course or dealing or usage of trade, are made regarding the information, recommendations, descriptions, and safety notations contained herein.** In no event will Westinghouse be responsible to the user in contract, in tort (including negligence), strict liability or otherwise for any direct, special, indirect, incidental, or consequential damage or loss whatsoever, including but not limited damage or loss of use of equipment, plant or power system, cost of capital, loss of profits or revenues, cost of replacement power, additional expenses in the use of existing power facilities, or claims against the user by its customers resulting from the use of the information, recommendations, descriptions, and safety notations contained herein.

Warning

Warnings, recommendations, and instructions contained in this book may not apply to equipment designed and built after the book was written. The manufacturers' applicable instructions should be consulted in all instances.

Warning: This document is not all inclusive. It does not cover all contingencies. Read and follow the manufacturer's instructions before attempting to handle, store, install, use, or service any equipment. Failure to follow these instructions can result in severe personal injury, death, or damage to property.

Warning: Hazardous voltage, vapor, hot oil, and other hazardous conditions can be present in electrical equipment and related systems. Competent trained personnel are required to handle, store, install, use, or service any equipment. Failure to follow this warning can result in severe personal injury, death, or damage to property.

Warning: Follow the safety instructions given in Volume 1 Chapter 5 and throughout the book. Failure to do so can result in severe personal injury, death, or damage to property.

Preface

This set of books is intended to provide a condensed treatment of acceptable maintenance practice on the most commonly used types of electrical equipment. Where specific references or examples were required, products manufactured by the Westinghouse Electric Corporation or components used in such products have been used.

Since this book is directed to the maintenance of electrical equipment an attempt has been made to make it applicable to older as well as new apparatus and devices.

For the user's convenience the book has been bound in four volumes, 1 General Maintenance, 2 Industrial Equipment Maintenance, 3 Power Apparatus Maintenance, 4 Reference Material and Tables and Formulas. An additional volume entitled Index, is supplied to help you locate specific topics. It consists of a volume/chapter listing, followed by a detailed index.

Page numbering reflects this organization.

1:1.1
The first digit indicates the volume
The second digit the chapter
The third digit the page

Metal-Enclosed Low-Voltage Power Switchgear

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Metal-Enclosed Low-Voltage Power Switchgear

Metal-enclosed switchgear with low voltage a-c power air circuit breakers controls and protects circuits through 600 volts. The switchgear assembly is arranged to meet the requirements of the individual application. Each breaker unit is divided into two or more compartments containing one or more drawout air circuit breakers. An instrument compartment may be included that may contain potential transformers, instruments, meters, relays, and secondary control devices. The rear of the unit contains busses and main cables.

Metal-enclosed switchgear is designed, manufactured, and tested in accordance with industry standards. It is available for both indoor and outdoor installation.

Proper installation, operation, and maintenance are necessary to assure continued satisfactory service from the equipment. It should not be installed in places where it will be called upon to operate at voltages, currents, or fault capacities greater than those for which it was designed, or where the environment is unsuitable.

Personnel responsible for supervision, operation, or maintenance should be familiar with the appearance, operation, and maintenance of each piece of equipment contained in or mounted on the switchgear.

1.1 ANSI Definitions of Switchgear

The American National Standards Institute (ANSI) has made a definition of switchgear which is universally accepted. This definition establishes three categories with sub-divisions.

A. Metal-Enclosed Power Switchgear

1. *Metal-Clad Switchgear*
2. *Station-Type Cubicle Switchgear*
3. *Metal-Enclosed Interrupter Switchgear*
4. *Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear*

B. Metal Enclosed Bus

1. *Non-Segregated Phase*
2. *Segregated Phase*
3. *Isolated Phase*

C. Switch Boards

1. *Power*
2. *Control*

This chapter covers A-4, Metal Enclosed Low-Voltage Power Circuit Breaker Switchgear.

ANSI (C 37.20-2.1.1) defines Switchgear as "A general term governing switching and interrupting devices and their combination with associated control, metering, protective, and regulating devices; also assemblies of these devices with associated interconnections, accessories, and supporting structures used primarily in connection with generation, transmission, distribution, and conversion of electric power."

ANSI (C 37.20-2.1.2) defines a Switchgear Assembly as "an assembled equipment (indoor or outdoor) including, but not limited to, one or more of the following: switching, interrupting, control, metering, protective, and regulating devices, together with their supporting structure, enclosures, conductors, electric connections, and accessories."

ANSI (C 37.20-2.1.2.1) states an "Enclosed Switchgear Assembly is one that is enclosed on all sides and top."

ANSI (C 37.20-2.1.3) defines Metal-Enclosed Power Switchgear as "a switchgear assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) containing primary power circuit switching or interrupting devices, or both, with busses and connections and may include control and auxiliary devices. Access to the enclosure is provided by doors or removable covers.

1.2 Safety Precautions

Metal-enclosed power circuit breaker switchgear assemblies are strongly built and provided with many safety features. When all doors are closed and all covers properly installed, there is heavy gauge steel between the power circuits and nearby personnel. Nevertheless, switchgear contains power circuits with high fault capacity which are dangerous. When any door is open or any cover removed, it is possible to make contact with bare conductors or terminals which may be live when the assembly is energized or if a separate power source is connected. The voltages and power levels available in this equipment make this kind of exposure extremely dangerous. All power should be turned off or adequate protective equipment should be used. Not only should the main bus be de-energized but all other circuits should be checked for feedback from other sources. Necessary steps should be taken to insure that power stays off until doors and covers are again properly installed.

Only qualified persons should attempt to install, operate, or maintain this equipment. In addition to hazards inherent in the switchgear assembly itself, operation by unqualified persons may cause damage to connected equipment and its operators.

A. **To perform work** on this type of equipment requires training and experience in high current circuits. Only electrical workers familiar with the construction and operation of such equipment, and the hazards involved should be permitted to work on switchgear. (per Qualified person definition, Article 100 NEC.)

B. **Danger: Primary and secondary circuits must be de-energized before attempting any maintenance. Failure to de-energize will expose workers to serious electrical hazard that will cause severe personal injury or death, and substantial damage to property.**

C. **Danger: Do not remove any access covers unless the circuits to be exposed have been de-energized. To do so will expose workers to serious electrical hazard that will cause severe personal injury or death, and substantial damage to property.**

D. **Danger: After maintenance, every current transformer secondary circuit must be completely connected or shorted. Failure to do so will cause severe personal injury or death, and substantial damage to property when the switchgear is re-energized.**

E. **Never** insert a breaker, without arc chutes and barriers, into an energized metal-enclosed cell beyond the test position. For maximum safety insert only a completely assembled breaker into an energized cell.

F. **Never** leave a breaker in an intermediate position in a compartment. The breaker must be fully in the Disconnected, Test, or connected position because control circuits may be either improperly connected (or disconnected) and may cause electrical failures.

G. Make sure that all switchgear hardware is in place and bolted tightly before inserting a breaker into its compartment.

H. Always use the handles provided on the front of the breaker panel when moving a breaker into or out of a cell. Keep hands away from top and side barriers.

I. Connect the switchgear to the station ground before applying any power.

J. If any relays are included, remove all blocking. Check control circuits (except potential and current transformer circuits) for grounds and short circuits before applying power.

K. In case of fire do not use liquid fire extinguishers until all circuits have been totally de-energized.

L. If outdoor switchgear is to be stored prior to installation, provision must be made for energizing the space heaters to control condensation inside the switchgear.

If indoor switchgear is to be stored prior to installation, it must be protected from the weather and kept free of condensation.

1.3 Construction

The following descriptions of construction are based on current Westinghouse designs. Metal-enclosed low-voltage power switchgear built at other times or by other manufacturers will vary from these descriptions. The manufacturer's specific instructions should always be consulted before any work on switchgear is attempted.

A. Indoor Metal-Enclosed Low-Voltage Switchgear

Indoor metal-enclosed switchgear with drawout air circuit breakers is factory assembled and tested. It is designed to require minimum installation time and labor. Shipments are made with the line-up complete or divided into shipping groups to suit the handling facilities at the receiving point. Figures 1 and 2 illustrate typical indoor and outdoor metal-enclosed switchgear.

The switchgear is made up of a stationary structure consisting of one or more free-standing units mechanically and electrically joined to make a single coordinated unit. Each unit consists of three major parts, a Front Enclosure, a Bus Compartment, and a Cable and Terminal Compartment. Refer to Figure 3. The structure is referred to as the fixed element

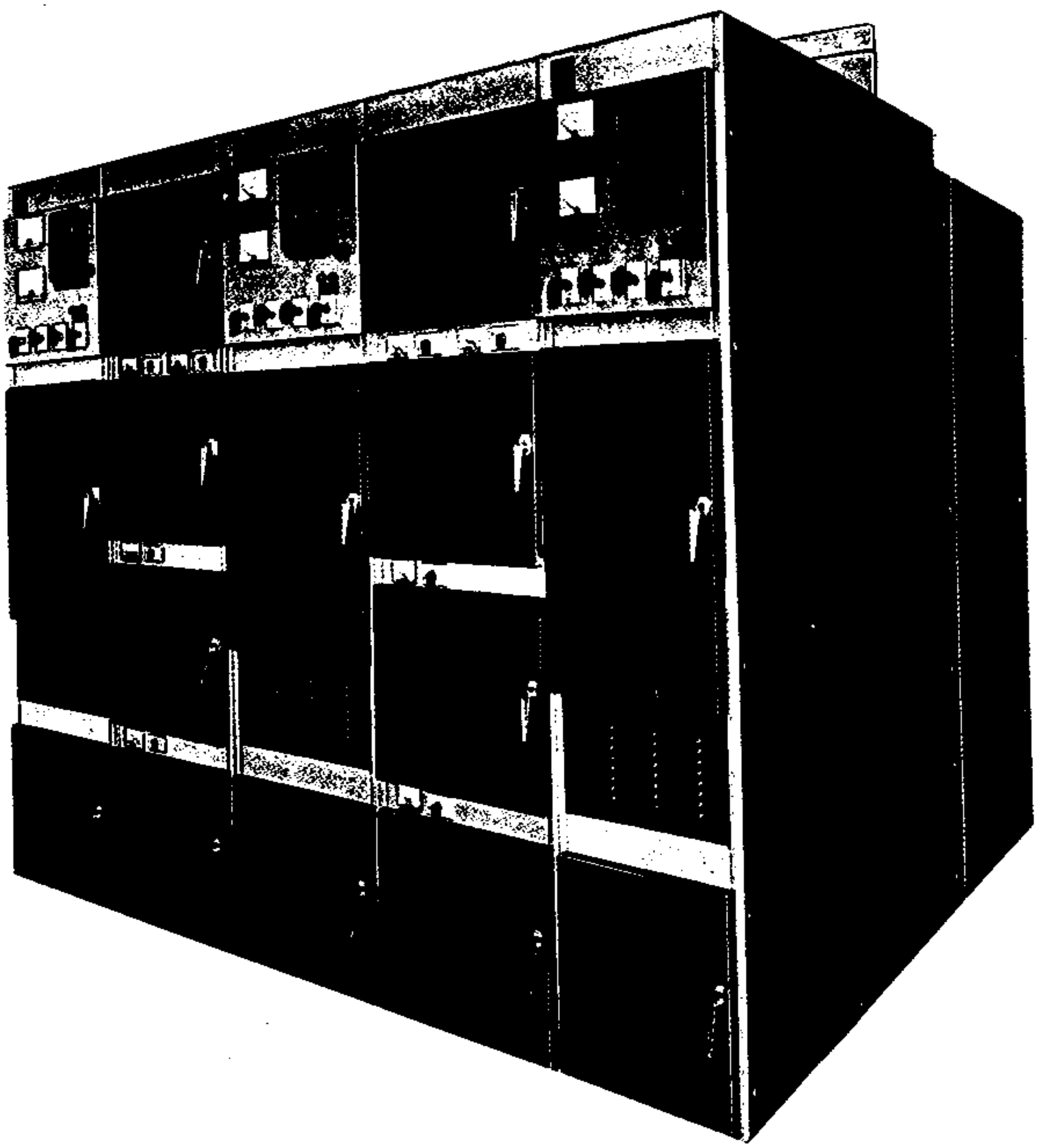


Fig. 1 – Typical Indoor Metal-Enclosed Low-Voltage Power Switchgear

and the drawout breakers housed in the Front Compartment are referred to as the Removable Elements.

In most switchgear installations the line-up is close coupled to a main transformer to form a coordinated secondary unit substation. These substations may be single-ended with only one transformer or double-ended with a transformer at each end. If the transformer is the liquid-filled type the bus transition connections will be made in either a reduced size transition unit or a full sized auxiliary unit on indoor equipment.

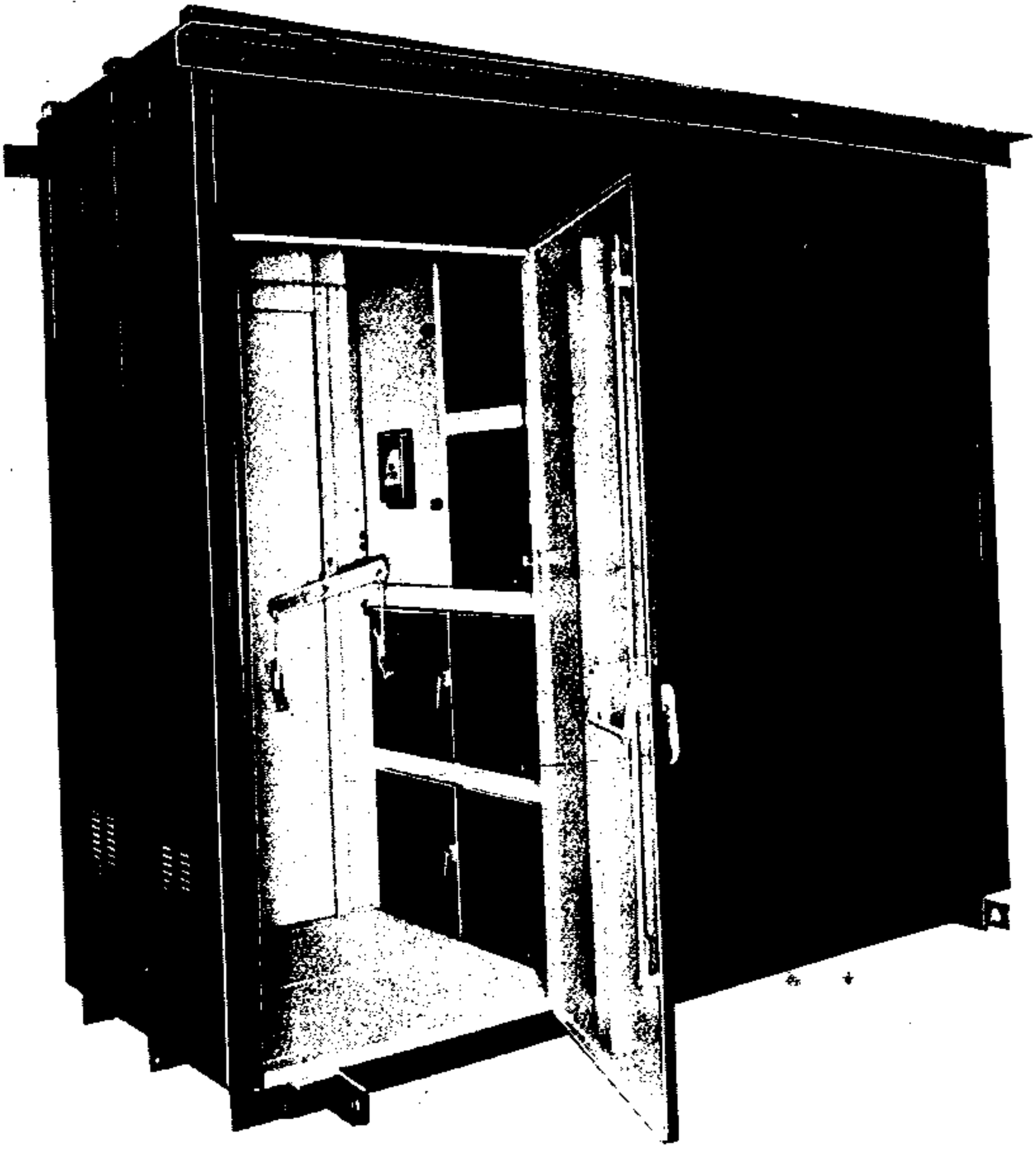


Fig. 2 – Typical Outdoor Metal-Enclosed Low-Voltage Power Switchgear

1. *The front compartment* of the unit structure may serve as an auxiliary to house instruments, relays, switches, and their auxiliary equipment, or it may be divided into individual cells to house the drawout air circuit breakers. The breaker cells provide for four positions of the breakers, *Connected, Test, Disconnected,* and *Remove.*

In the *Connected* position both primary and secondary disconnecting devices are engaged. This is the operating position.

In the *Test* position only the secondary disconnecting devices are engaged and the circuit breaker can be operated without energizing the power circuit.

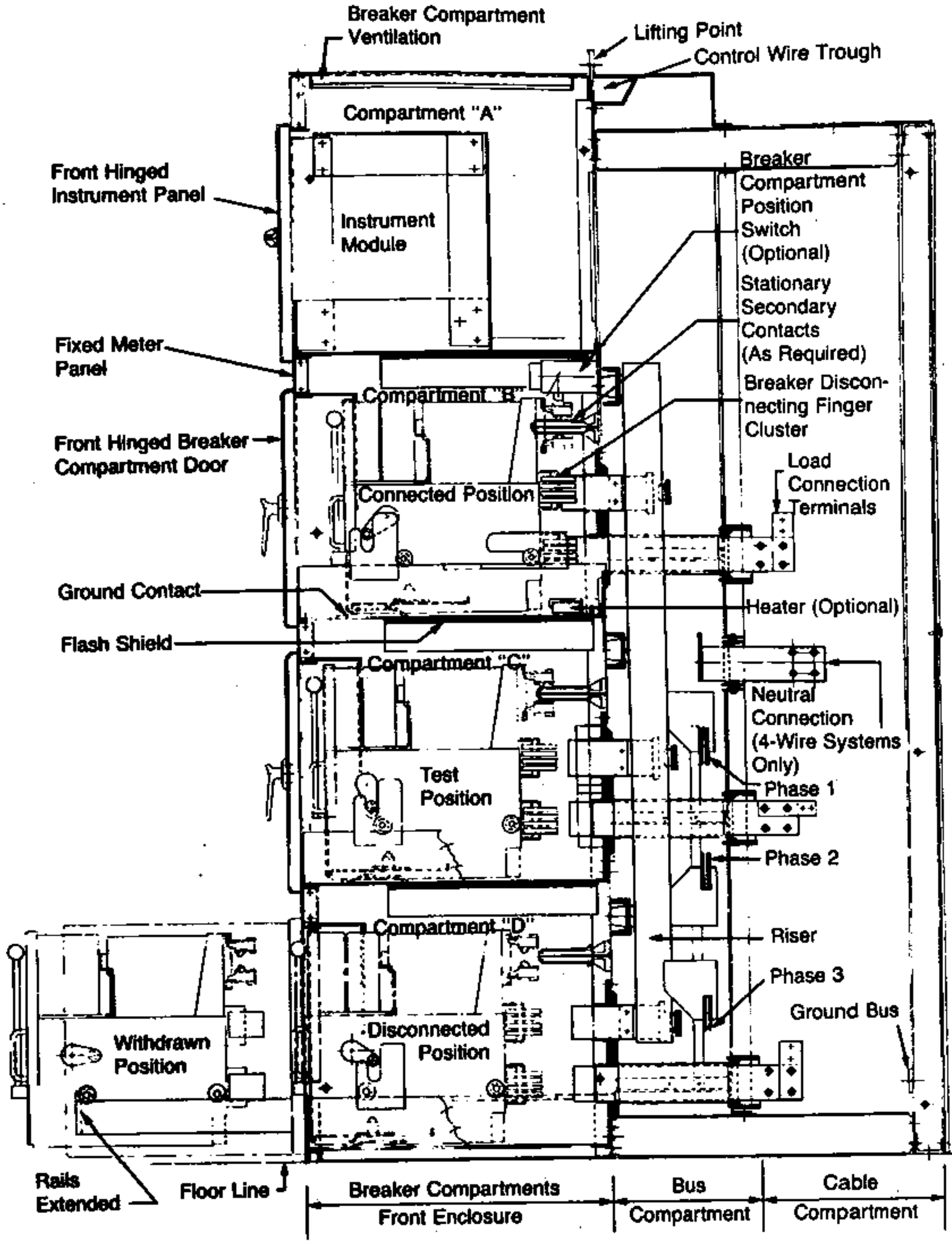


Fig. 3 – Diagram of a Typical Switchgear Unit – Side View Showing Major Compartments

In the *Disconnected* position both the secondary and primary disconnecting devices are disengaged and the entire circuit breaker is isolated.

There is an additional position, *Remove,* which will allow the circuit breaker to roll free of the cell on extended rails, ready for complete removal.

The compartment door can be closed and locked with the breaker in any of the first three positions, or with the breaker removed and the rails retracted.

There may be between vertical units, bolted-in panels that may be blank or may be used for mounting small instruments, instrument switches, pushbuttons, lights, or other devices.

a. *Metering Current Transformers*

Danger: Current transformer secondary must be shorted or the circuit de-energized by opening the breaker before any maintenance work is started. If secondary circuits of current transformers are left open and these circuits are energized, a dangerously high voltage is developed across the transformer secondaries or in bus and cable compartments. Failure to short the secondary circuits or de-energize the circuit will result in severe personal injury or death, and substantial damage to property.

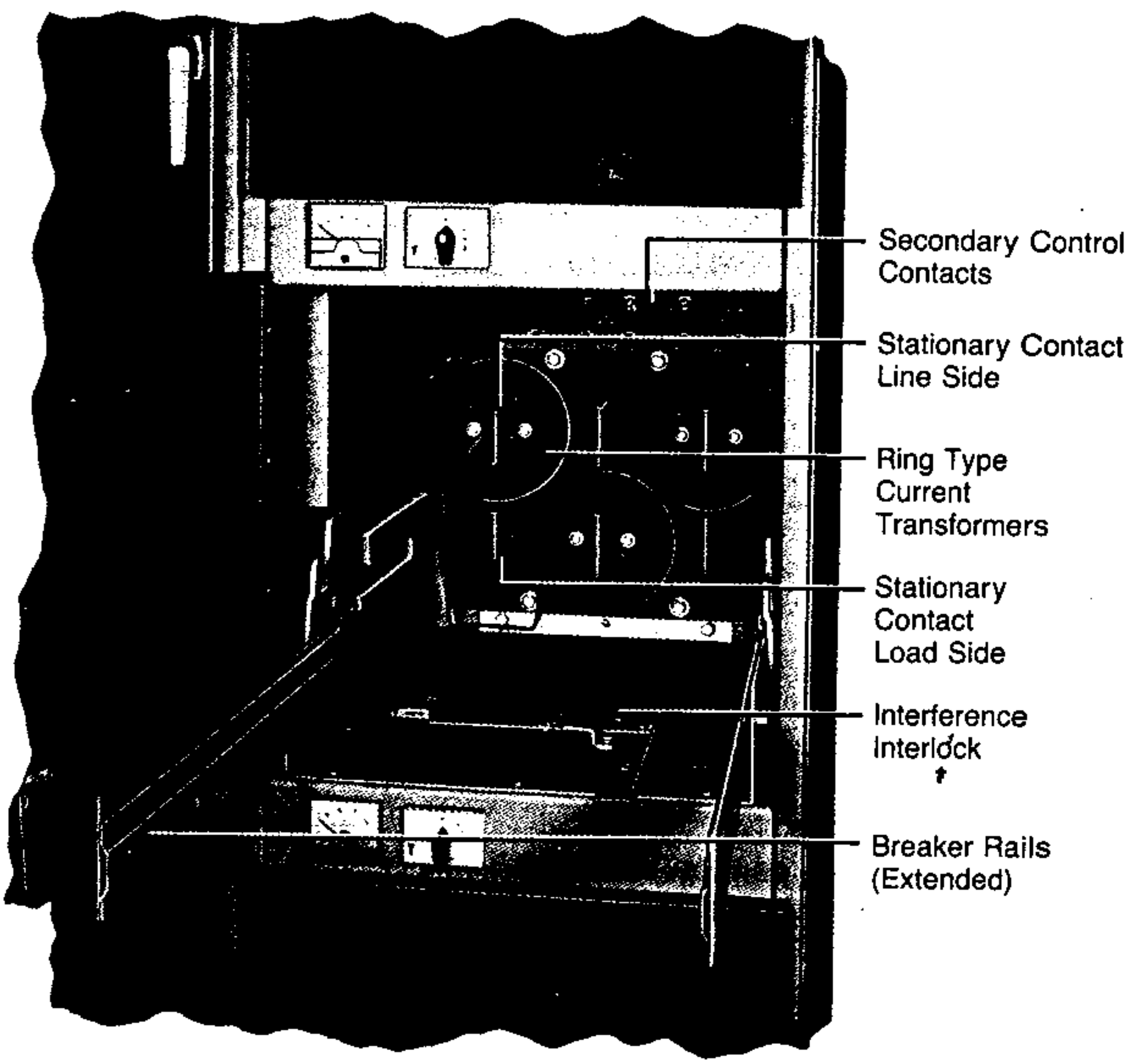


Fig. 4 – Drawout Air Circuit Breaker Compartment

When required for metering, current transformers may be positioned around the stationary main contacts, as shown in Figure 4. These transformers may be used to feed a small ammeter and transfer switch on the meter panel or a meter on the front instrument panel. The manufacturer's instruction literature should be consulted for specific connection and wiring information. Figure 5 shows a typical unit with an instrument panel and meter panels.

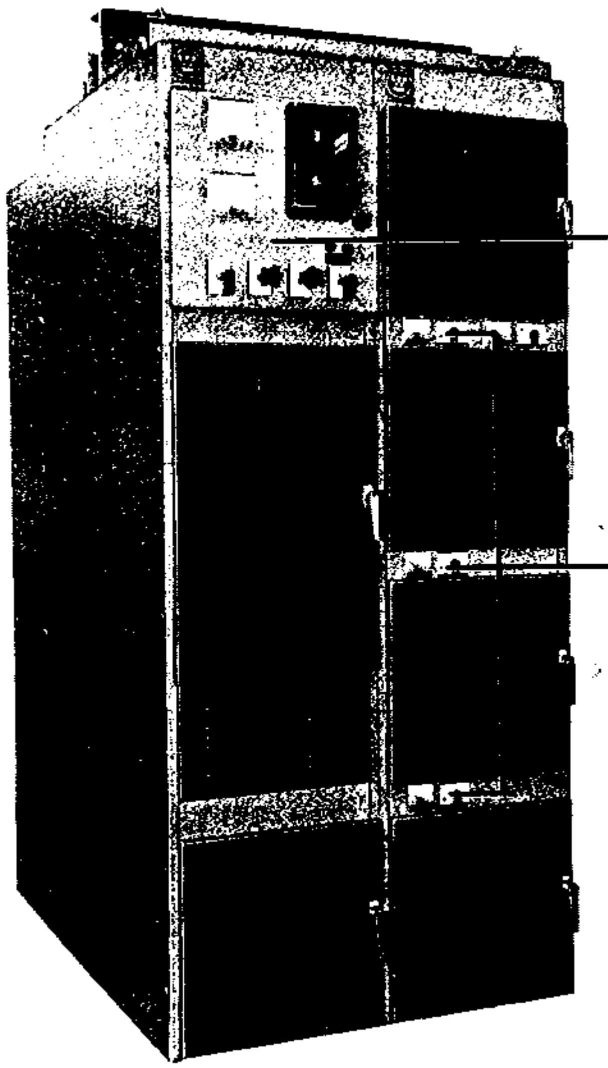


Fig. 5 – Indoor Switchgear with Hinged Instrumental Panel and Fixed Meter Panels

b. *Control Equipment*
Space in the instrument compartment, behind the instrument panel may contain such control devices as potential transformers, a control power transformer, fuses, relays, and secondary control devices.

The potential transformers provide low voltage for metering and are protected by fuses. The control transformer provides ac control power to circuit breakers, space heaters, fans, housing lights, and utility receptacles. Control transformers are protected by primary and secondary fuses.

c. *Fixed Meter Panels*

For feeder circuit instrumentation, small ammeters, with or without ammeter switches, may be mounted on the horizontal stationary panels separating breaker compartment doors. These ammeters are directly connected to the nearby breaker circuits for monitoring currents. See Figure 6.

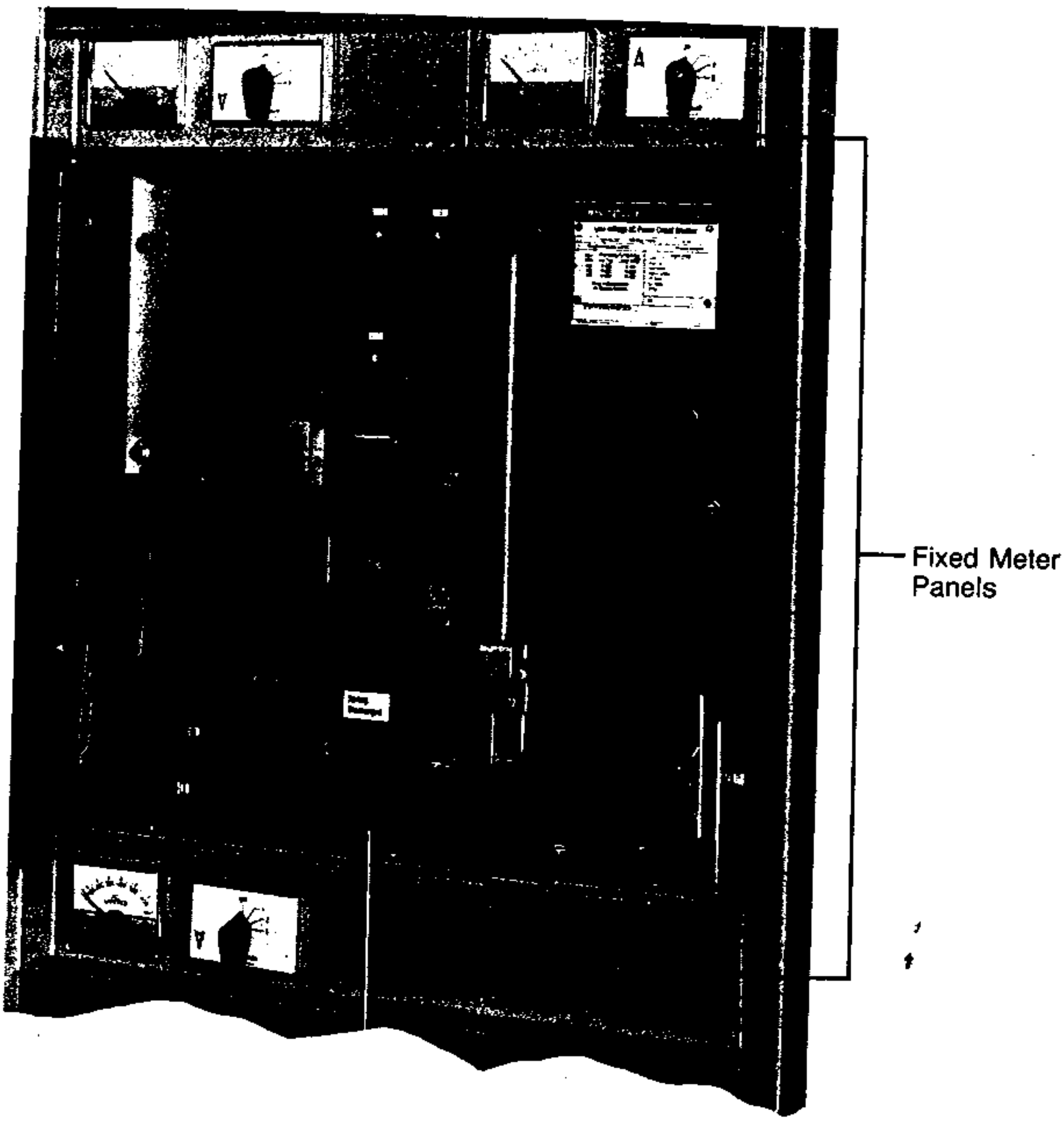


Fig. 6 – Fixed Meter Panel

2. *The Bus Compartment,* located immediately behind the front compartment, contains the horizontal main bus that ties the units together electrically, and the vertical bus that feeds the individual breaker compartments.

3. *The Cable and Terminal Compartment* forms the rear of the switchgear unit. It provides room for cable installation and terminal connections. Copper bars extend the load side of the stationary disconnecting contacts into the cable compartment. The ends of these bars have standard NEMA drilling for standard connectors. This drilling will accommodate either single or multiple terminals on each phase. On higher current installations busway may be connected to the copper bars.

On four wire systems an insulated neutral bus extends the length of the line-up and includes a tap for the outgoing neutral cable in each unit, shown in Figure 3. A link to the ground bus may be found in one of the units if it is a grounded four wire system. A current transformer may be located in this grounding connection for use with ground detection systems.

Figure 7 illustrates a typical cable and terminal compartment.

a. *Ground Bus Connection*
Warning: A permanent low resistance ground must be provided. Failure to make this grounding connection can result in severe personal injury or death, and substantial damage to property.

Standard ground bus consists of a copper bus bar (normally $.25 \times 2$ inch) bolted to the rear frames of the units, near the floor, and extending the length of the line-up. This bus bar will be equipped with an appropriate terminal for connection with the station ground. If the line-up is split into shipping groups proper splice plates and hardware will be furnished to bridge the breaks.

b. *Customer's Connections* are provided for control terminal blocks mounted on the rear of the frame. This also makes the connections readily accessible for inspection. Refer to Figure 8.

4. *Ventilation*
The front unit doors are slotted to provide for entrance of ventilating air and grill work at the top of the unit allows exhausting of the warmed air. The top grill work is equipped with a drip pan that prevents foreign material from reaching the equipment.

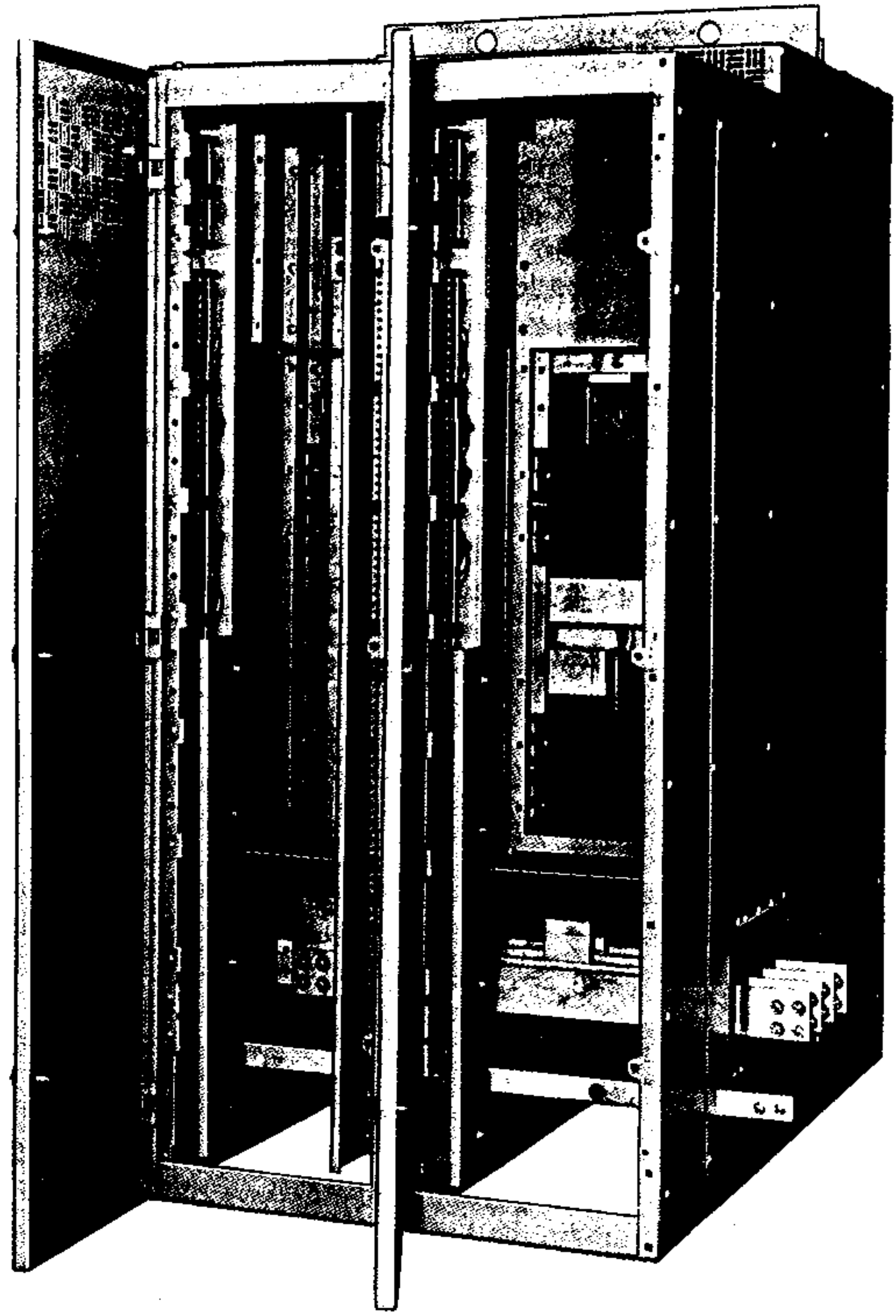


Fig. 7 – Rear View of Switchgear Showing Power Bus and Terminal Connections

B. Outdoor Metal-Enclosed Low-Voltage Switchgear

Outdoor switchgear consists of standard indoor switchgear assembled in a heavy gauge weatherproof enclosure. Enclosures are of two types, walk-in enclosures which provide an aisle in front of the switchgear panels, and aisle-less enclosures. See Figure 9.

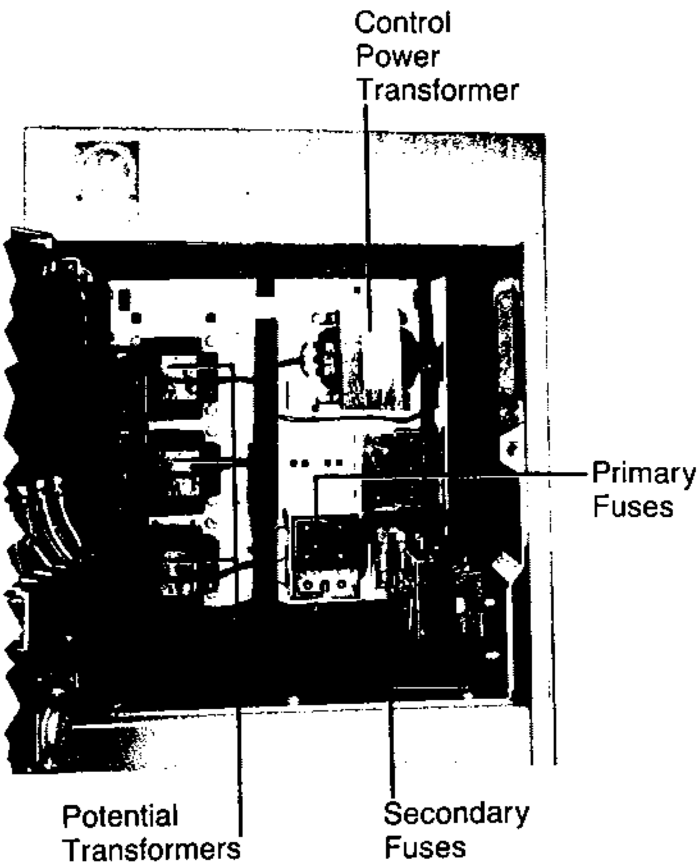


Fig. 8 – Control Equipment Installed in the Instrument Compartment Behind the Instrument Panel

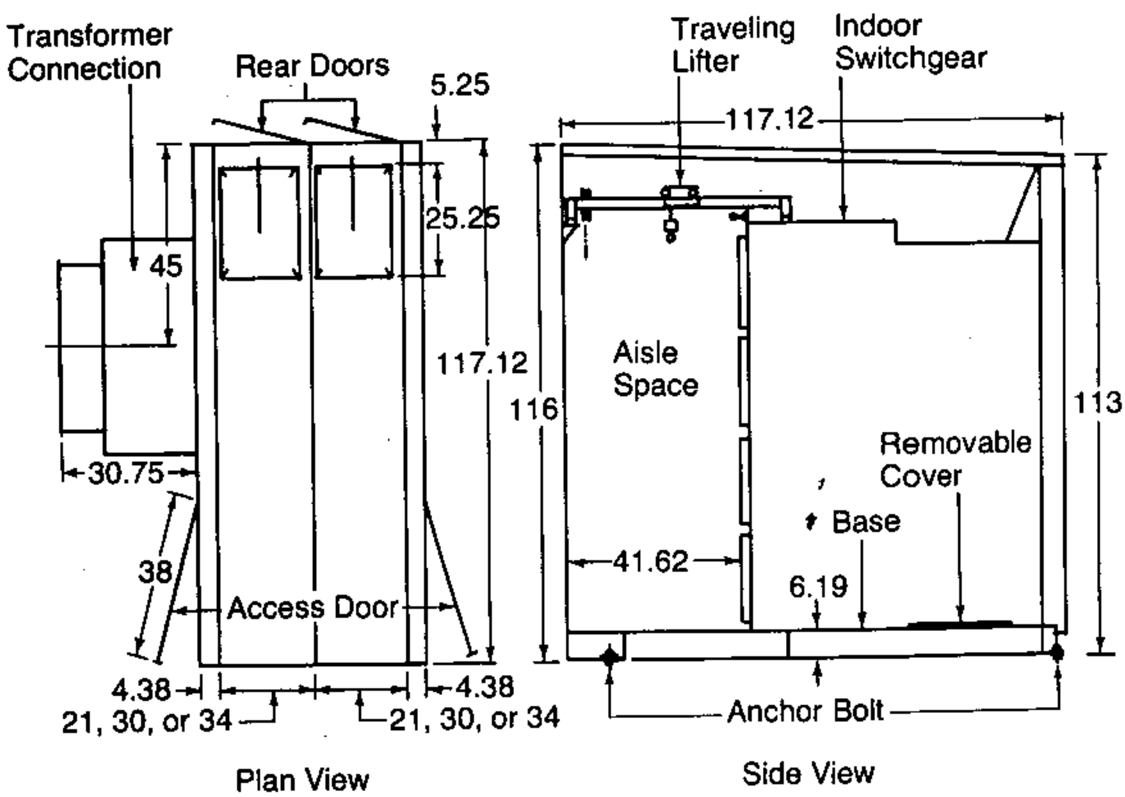


Fig. 9 – Walk-in Outdoor Switchgear Enclosure

Outdoor switchgear is inherently weatherproof and has a rigid fabricated base requiring no special covering or skids for shipment. If the assembly is separated into more than one group for shipping, the matching ends are rigidly braced and provided with weatherproof covering.

If the outdoor switchgear is close-coupled to a liquid filled transformer, it will be through a standard transition throat.

To minimize condensation, heaters are supplied with outdoor switchgear. Heaters are generally located in the front and rear compartment. Because they are on all the time, they operate at half their rated voltage for longer life.

The walk-in enclosure has large entry doors at both ends which can be securely locked. The aisle doors have panic hardware which allows the doors to be opened from the inside even when they are padlocked on the outside.

Provision is made for lifting and removing breakers, with a permanent or portable cantilevered or bridged lifter.

These enclosures are usually provided with filtered ventilation openings, interior lighting, and convenience electrical outlets.

1.4 Receiving, Handling, Storage, Installation

Metal-enclosed switchgear is shipped in one or more groups, depending on the number of units, the total length, and the limitations of the handling facilities at the receiving and installation site. Shipping groups of indoor switchgear are bolted to skids. If the shipment will be by open rail car or open truck, it will be enclosed in a weatherproof cover. Each crate or box or shipping unit is clearly identified and its weight shown. Shipping papers will list each group, crate, or box and its contents. All units are given commercial tests at the factory before shipment.

A. Receiving

Upon arrival at destination, the switchgear should be carefully checked; the actual material received against the shipping list. This check should be made prior to discarding the packing material to avoid possible loss of small parts.

If damage is found or suspected, claims should be filed as soon as possible with the transportation company that made final delivery, and the manufacturer.

If the switchgear is to be installed as soon as received, it is recommended that the unpacking and handling be done as outlined under *B. Handling*. If the switchgear is to be stored for sometime, it is advisable to unpack sufficiently to check completeness and condition of the shipment. The protective packing used for shipping is not adequate for temporary outdoor storage. See *C - Temporary Storage*.

B. Handling

For ease of handling by crane, each indoor shipping group is equipped with a lifting bar or other facility with holes to accept crane hooks. On long line-ups a spreader should be used with the crane sling to prevent any horizontal compressive load on the lifting bar. The lifting bar is located at the approximate center of gravity, but variations in equipment may cause a slight tilt. The lifting bar may be removed after installation is complete.

It is preferable to lift groups of switchgear into position by crane. If a crane is not available, they can be skidded into place on rollers. The longitudinal skids provided at the front and rear of the shipment group may be used when rolling the group sideways, but for front-to-back rolling additional temporary skids must be installed in this direction.

Notice: Never let the rollers engage the switchgear directly, distortion and damage may result.

One method of removing the rollers and skids and lowering the switchgear into place is the use of long wedges fabricated from 4 × 4 lumber. With a large pry-bar each corner may be lowered alternately along the wedges in increments of a fraction of an inch. Pry slots are located in the front of the structure for this purpose. See Figure 10.

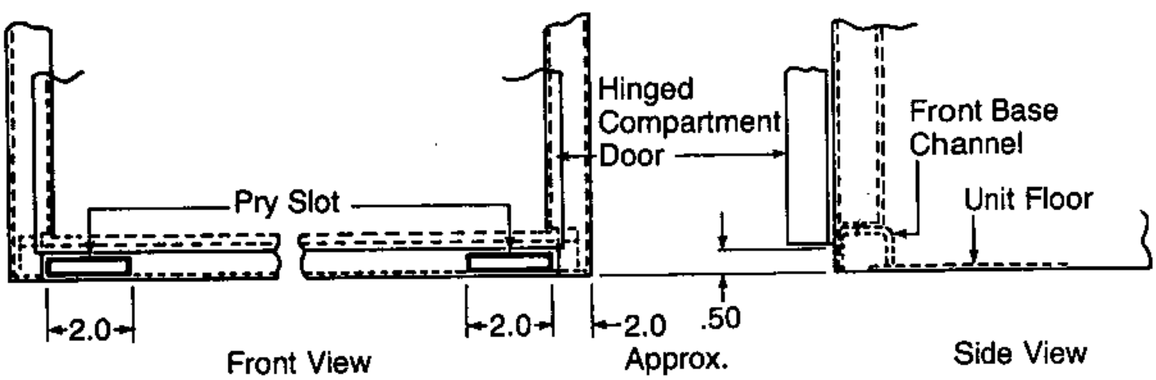


Fig. 10 – Location of Pry Slots at Lower Front of Structure

Handle all switchgear with extreme care, whether crated or uncrated. The drawout air circuit breakers may be shipped in their compartments and the panels may contain delicate instruments, meters, or relays which can be damaged by rough handling. Care must be exercised to avoid breakage and scratching or marking the panel finish.

If indoor switchgear will be exposed to dust and dirt during construction around it prior to being placed in service, it should be covered for protection. Removable elements should be stored in their compartments or covered separately.

Outdoor switchgear is equipped with lifting lugs attached to the base and cable spreaders at the upper portion of the end walls to expedite crane lifting. It may be placed on rollers for moving. No additional skids are necessary.

C. Temporary Storage

Indoor switchgear that cannot be installed and put into service immediately should be stored in a clean, dry location, preferably indoors in a heated building. Trouble and delay will be avoided by having good storage facilities arranged in advance of receipt. The stored equipment should be accessible only to authorized persons, and should be quickly available when required in the erection schedule. Conditions such as dampness, changing temperatures, cement dust, and corrosive atmosphere should be guarded against.

Outdoor storage of indoor switchgear is not recommended, even for a brief period, and should be avoided if possible.

If it is necessary to temporarily store indoor switchgear outdoors, special precautions will be required to keep it clean and warm enough to prevent condensation. It will be necessary to cover the switchgear and install temporary heating equipment. Approximately 250 watts per unit are required for average conditions to control condensation.

Notice: The weatherproof covering which may have been provided during shipping is not adequate protection for outdoor storing.

Outdoor switchgear requires a minimum of care during outdoor storage. The location should be reasonably free from dust and corrosive gases and the space heaters which are standard with this apparatus should be energized to prevent condensation. Additional protection will be necessary for exposed ends at shipping breaks if the equipment is shipped in more than one group.

Notice: During storage, switchgear shipping groups, whether indoor or outdoor, and whether stored indoors or outdoors should be placed on smooth and level surfaces to prevent strain and possible distortion and misalignment.

D. Installation

Proper installation is of prime importance. The manufacturer's instruction literature should be carefully studied. In most instances the drawings will be sent sometime prior to shipment of the gear to allow adequate planning. These drawings will include general assembly, front view, plan view, floor plan, wiring schematic and connection diagrams.

1. *Location*

In locating the switchgear, consideration must be given to the aisle space required at the front and rear of the equipment, and space at the ends of the line-up. The recommended minimum aisle space will be shown on the floor plan drawings furnished by the manufacturer. The space at the front must be sufficient to permit opening doors, withdrawal and insertion of breakers and their transfer to other compartments by means of the hoist. The space at the rear must be sufficient for installation of cables, inspection, and maintenance.

a. Foundation

Metal-enclosed switchgear is fabricated in welded fixtures and assembled on true and level bedplates to assure alignment and ease of operation of moving parts. Since tolerances and adjustments are kept to a minimum, the gear must be installed on a smooth level base. Extra care in laying out and preparing the foundation will result in reduced installation time and costs, and help to assure good performance.

The station floor or foundation must be strong enough to support the weight of the equipment without sagging. Actual weights of the specific line-ups should be obtained from the manufacturer before foundation preparation is started. Adequate safety factors must be used. If the foundation is subject to vibration, special mounting must be installed to prevent the transmission of vibration or shock to the equipment.

The preferred method of anchoring indoor switchgear is to fasten it to steel channels which are properly embedded in concrete floor. Detailed floor plans for locating and drilling this steel are supplied by the manufacturer.

Installations subject to seismic accelerations require special foundations. This is a usual requirement in nuclear generating stations wherever located.

Outdoor switchgear foundations must be smooth, level, and stable under all weather and temperature conditions. They must be capable of supporting the weight of the line-up with an adequate margin of safety.

b. Floor Steel
Anchor bolts, floor steel, and all other foundation material are supplied by the purchaser. A 4-inch (5.4 lbs./ft.) structural channel is recommended as minimum for the average line-up of switchgear. It is suggested that the channel be installed with its web at the top and horizontal. When large unit-substation transformers are part of the installation, the floor steel under the transformer should be installed in accordance with the transformer manufacturer's instructions.

Notice: The front and rear channels must be set level and aligned with each other, and must be level over their entire length to avoid distortion of the switchgear structure. The finished floor may have a slight pitch away from the channels, but in no instance should the finished floor be higher than the top of the channels.

Each unit is attached to the floor channels by either bolting or welding. If bolting is to be used the mounting bolts must be placed in the floor steel before the concrete is poured to assure that the tapped holes will not fill with concrete. See Figure 11 for anchor bolt details. Welding is a quick and easy method of securing the switchgear in place and eliminates the layout and drilling and tapping of mounting holes in the channels.

Floor channels are not required for outdoor switchgear. Hold-down lugs are supplied when the outdoor gear is to be bolted.

c. Conduits
Provision must be made in the foundation for the conduits that carry the main cables, control wiring, and ground cable when such conduits enter the switchgear from below. The specific floor plan for the line-up must be used for determining the final conduit layout, spacing of floor channels, and floor space required for each switchgear unit.

Caution: When laying out and preparing the foundation, avoid encircling loops of reinforcing or building steel around single phase conductors rated 600 amperes or more. This precaution will prevent overheating due to induced currents which can cause personal injury and damage to property.

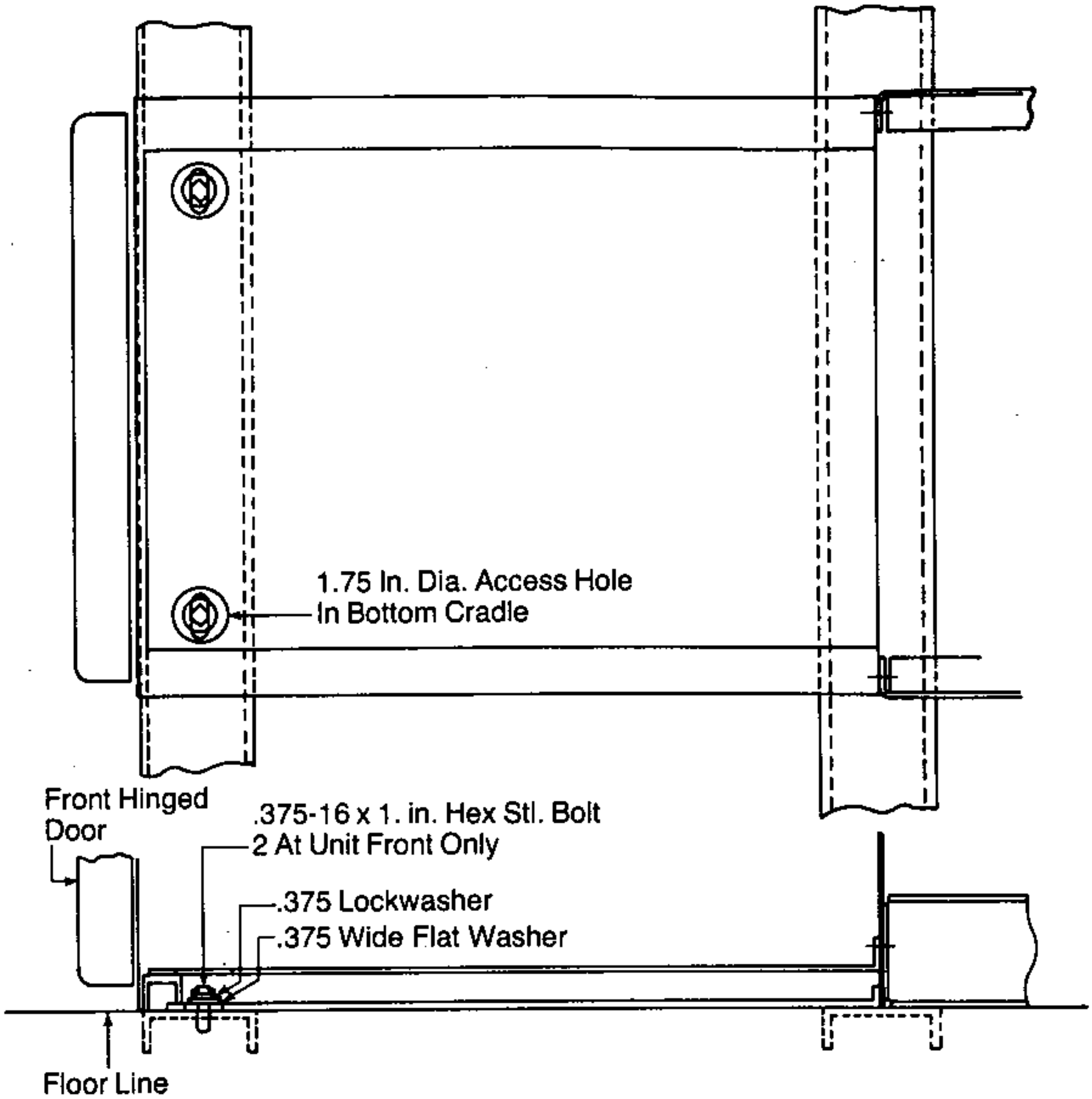


Fig. 11 – Anchor Bolt Detail

Moving units into place will be simplified if the conduits are flush with the concrete surface and appropriate extension sleeves added after the units are in place. Otherwise it is necessary to raise the units on timbers high enough to clear the tops of the conduit. Conduits should project above the floor approximately two inches for indoor switchgear.

Consideration should be given to installing conduits for future circuits at this time.

d. Shipping Skids
If possible, the shipping skids should remain on each group until it is at or near its final location. This allows using pipe rollers for moving and lessens the chance of distortion during final positioning.

e. Shipping Braces
Before the air circuit breaker can be withdrawn from its compartment for the first time, the shipping brace must be removed from the lower part of the panel. This brace is an angle, usually painted yellow for identification. During shipment the front wheels of the breaker are held approximately 1/16-inch above the compartment rails to avoid possible strain and distortion. The breaker is held intermediate between Disconnect and Test by means of its levering device.

Notice: Preliminary operation and inspection of breaker units are covered in detail in the manufacturer's instructions.

2. *Final Assembly*
When correctly installed, the units for both indoor and outdoor metal-enclosed switchgear conform to the following:

a. Front panels form a straight line, and when transformers and/or other gear are included, the fronts of that gear should line up to form parallel planes.

b. Units are correctly spaced from center to center and plumb.

c. The entire assembly of housings is securely attached to floor channels or base pad.

d. Shipping groups are securely bolted together and all bus and control wiring connections properly made.

One way to line up the units is to establish a base line a few inches in front of the housings, and parallel to the final location. Equalize the distances from the front of the housings to the base line. This places the line-up parallel to the base line.

Check the plumb of the units by dropping a plumb line from the exact center of the horizontal steel member at the top front of the unit. It should align with the center of the bottom cross channel.

After the first group has been located, the second group should be moved into position and similarly aligned vertically and horizontally. The steel housings are bolted together in a number of places with hardware supplied. It will facilitate assembly to locate the bolt head in the right hand unit with the nut and washers in the left hand unit, or the reverse, as long as a consistent pattern is maintained. These should be tightened in line with the torque values shown in Table 1.

3. *Connections*

a. Bus Connections

Connections of main and neutral buses and ground bus at shipping-group breaks are made by means of bolted splice plates. All necessary hardware and splice plates will have been included in the shipment. There will be provision at the ends of the line-up, if not adjacent to transformers, for future expansion by means of bolted joints.

b. Ground Bus Connections

Warning: A permanent low resistance ground is essential for adequate protection. A poor ground may be worse than none since it gives a false feeling of security to those working with the equipment. Failure to establish an adequate ground can cause injury or death by electrocution and damage to property.

Ground bus connections are provided in one or more of the units. These are for connection to the station ground. These connections should be as direct as possible and should not be run in metal conduit. The grounding conductor should be capable of carrying the maximum line-to-ground current for the duration of the fault.

Notice: It is recommended that the installer consult *Electric Power Distribution for Industrial plants,* **IEEE Std. 141, and** *Grounding of Industrial Power Systems.* **IEEE publication 141,** *Westinghouse Electrical Maintenance Hints, Vol. 1, Chapter 8, Current Grounding Practice* **and** *NEC* **articles 100, 200, and 250.**

For solidly-grounded large substations and generating stations the ground resistance should be one ohm or less. For smaller substations and industrial plants the resistance should be less than five ohms. NEC (1981) article 250 states that the maximum resistance shall not exceed 25 ohms.

The bolting areas of all conductors are silver plated or tin plated to assure optimum connection. In some atmospheres the silver may tarnish. This does not reduce its effectiveness. Dirt, grease, and other foreign material should be removed from surfaces before they are joined. The silver-plated contact surfaces should be wiped clean with a clean cloth and a non-flammable cleaning solvent such as trichloroethane (methyl chloroform).

Warning: Avoid breathing solvent vapors or prolonged contact with skin. These solvents are highly toxic and readily absorbed into the human system. Failure to observe this precaution can result in severe personal injury or death by poisoning or asphyxiation.

If any of the steel barriers separating the bus and cable compartments have been removed they should be in place before feeder cables are installed. Bolts should be securely tightened to prescribed torque values to prevent vibration during operation.

c. Main Power Connections

Metal-enclosed switchgear is usually supplied with solderless cable connectors for terminating the main power cables. Before making up the connections the phase of each cable must be determined. Normally switchgear is supplied with connections for phase sequence 1-2-3 or A-B-C, unless otherwise specified.

When forming cables for termination within switchgear assemblies, avoid sharp turns, corners, and edges to prevent damage to or weakening of the cable insulation. The cable manufacturer's instructions should be followed closely in determining the bending radius of a cable.

Caution: It is essential that phase rotation and phase angle be the same when two systems are to be paralled. Otherwise substantial damage to property can result. Phase rotation must be in accordance with the manufacturer's drawings so instruments, meters, and relays will function properly.

Adequate electrical and mechanical clearances must be provided between cables, conduits, and bus. Where cables enter a unit they must be securely lashed and supported to withstand any short circuit forces, and to prevent any strain or mechanical load on terminals. Cable supports as required may be attached to the frame of the switchgear assembly.

d. Bolt Tightness

All bolts holding structural members, barriers, and covers are installed at the factory tightly enough to assure rigidity of the assembly and to prevent rattling of covers and panels when the equipment is energized. When bolts are loosened or removed during installation or inspection, care should be taken to solidly tighten them when replaced.

Bolts installed in bus joints and connections are usually high strength steel. Silicon bronze hardware is sometimes supplied if specified. The reliability of current conducting joints is dependent on the tightness of the joint. Great care must be taken in making or remaking bus joints in the field to assure tightness. Table 1 gives the recommended bolt tightness.

Table 1
Bolt Tightness for Bus Connections

Bolt Material	Torque in Foot-Pounds for Bolt Size .25-20	.31-18	.38-16	.50-13	.62-11
High Strength Steel	5	12	20	50	95
Silicon Bronze	5	10	15	40	55

e. Control Connections
All interunit control wires that cross a shipping break must be re-connected to their correct points on the terminal blocks provided. The terminal blocks and wires will have been properly identified at the factory and will be shown on the connection diagrams supplied by the manufacturer.

Any control connections to remote mounted relays, control switches, instruments, or other devices will have been brought to a set of terminal blocks located on the rear frame of the unit.

Control wiring should be checked with the connection diagram to make certain all connections have been made, all fuses installed, current transformer circuits completed, and loose connections tightened. Before applying control energy, all control circuits should be checked, except current and potential transformer secondary circuits, to make sure they are not grounded, and to make sure all circuits are clear.

If the control power source is other than a self-contained control power transformer, the cables from the source to the switchgear must be of adequate size to avoid excessive voltage drop during operation.

f. Moving Parts
There are few moving parts in the stationary structures of metal-enclosed switchgear, and most of these are factory installed. It is recommended that all moving parts be carefully operated by hand (even if normally automatically operated) to assure that there is no binding due to distortion or misalignment, or that no other damage has occurred during shipment and installation. If the switchgear has been in storage, foreign matter may have accumulated or lodged in moving parts.

g. Removal of Blocking and Bracing
Some equipment, such as meters and relays, must be thoroughly checked for blocking or bracing which must be removed. This requires careful inspection of all compartments.

h. Key Operated Interlocks

Key operated interlocks are sometimes supplied in conjunction with disconnecting switches, other circuit breakers, external equipment, and special compartments where access is to be denied unless the circuit in the compartment containing the interlock is withdrawn to the disconnected position. The operation of these key interlock schemes is generally described by a note or a keying chart on the assembly drawings. To facilitate manufacture and installation a key is normally supplied with each lock.

Warning: Before placing switchgear with key operated interlocks in operation, the key scheme must be carefully checked and only the proper keys left in the locks. All extra keys must be removed and stored where they are not available to unauthorized personnel.

Improper use of the keys will defeat the interlocking system and can result in severe personal injury or death, and substantial damage to property.

1.5 Pre-Operation Test and Inspection

After the metal-enclosed switchgear and the apparatus it will control have been installed and all interconnections made, the equipment should be given a final inspection and test before it is placed in service. This is a necessary safety and operating assurance.

Danger: Do not connect switchgear to the power system when preliminary tests are being made. Verify that the switchgear is de-energized before proceeding. Hazardous voltages may be present which will cause severe personal injury or death, and substantial damage to property. If disconnect switches are not available, line leads must be disconnected to assure the equipment is de-energized and remains de-energized during these tests.

A. Test Equipment

The test equipment required will depend on the size and type of gear. Portable voltmeters of the multi-scale type will be needed. For large complex installations, ammeters should be available in the event trouble develops. Although insulation resistance will vary greatly due to the many parallel paths in equipment of this type, an ohmmeter and a megohmmeter will be needed to assure there is no insulation breakdown in the system. Initial insulation resistance values should be determined and recorded for comparison with values found later during periodic inspection and maintenance. A continuing comparison record is valuable to help detect any progressive deterioration of insulation. A simple portable test bell or test light may be useful in making circuit continuity checks.

B. Wire and Bus Connections

Wire connections, accessible bolted bus connections, and insulated joints should be examined to make sure they have not loosened or been damaged during shipping or installation.

The connections to equipment apart from the switchgear, such as remote control and interlock circuits and auxiliary switches, should be tested to make sure they are correct. The extent to which this is necessary depends on the thoroughness of the installation work. There must be definite assurance that connections are correct before any attempt is made to operate either the switchgear or the equipment it controls.

If the line-up is equipped with heaters, they should be energized to confirm their operation.

C. Relays

Any relays contained in hinged instrument panels will have been checked at the factory and will probably have been set at minimum for shipment. The final settings of the relays should be coordinated with other parts of the system in accordance with local standards and operating practice. If it becomes necessary to modify relay settings, the relay manufacturer's instruction literature should be consulted and these procedures followed. These instructions may show typical connection diagrams which may not completely agree with the connections as installed in the gear. The switchgear manufacturer's connection diagrams should be followed.

D. Covers

The covers for meters, relays, and other devices which have to be removed during the course of installation require careful handling. They should be kept clean and should be replaced as soon as possible to keep dust and dirt from collecting on vital parts.

E. Drawout Breakers

The testing and calibration of air circuit breakers must be performed in strict conformance with the circuit breaker manufacturer's instruction. Some manufacturers and electric service companies have special test sets designed for calibrating and testing breakers.

F. Lifting the Breaker

When it is necessary to lift the breaker off the rails, all lifting should be done with the lifting apparatus provided.

Notice: Do not attempt to lift a breaker with ordinary crane hooks, ropes, chains, or similar means, as vital parts such as wiring barriers, and arc chutes might be damaged. Figure 12 shows a top-of-switchgear lifter in place. The lifter has specially shaped hooks and spreader. With the hooks and spreader in place, actual lifting can be done with a crane, chain block, or with lifting mechanisms designed for the purpose. The breaker must be pulled completely to the end of the rails.

Lifting devices, whether switchgear mounted or truck mounted, should be used only for lifting. Do not attempt to transport the circuit breaker while it is suspended.

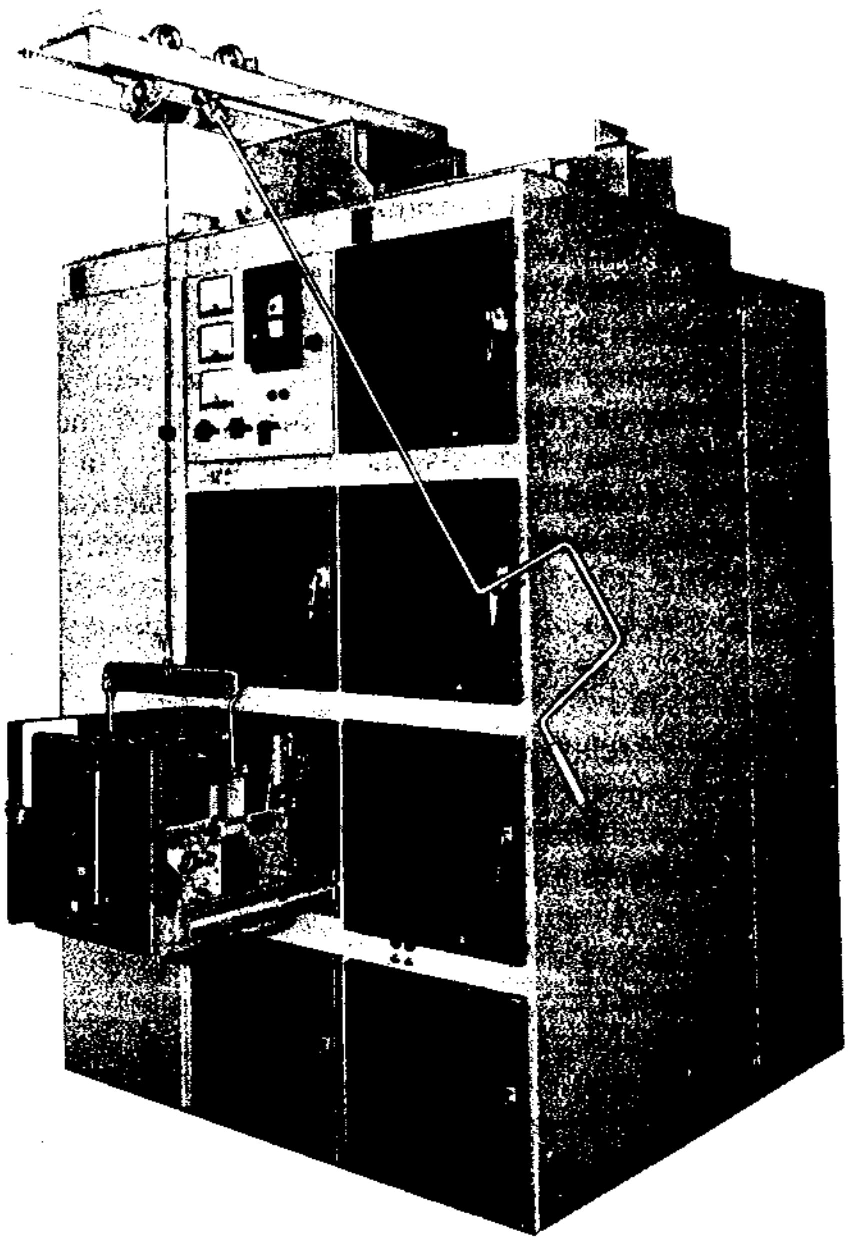


Fig. 12 – Top of Switchgear Traveling Lifter

1.6 Inspection and Maintenance

Warning: Do not attempt to inspect, maintain, or repair switchgear unless any circuit which will be exposed has been de-energized and precautions taken to assure it will remain de-energized as long as it is exposed. Verify that the equipment is de-energized before proceeding. Failure to follow this warning could result in severe personal injury or death.

A. General Precaution

All connections should be considered energized until the crew expecting to do the work on them is assured that the circuits have been de-energized, and every precaution taken to make certain they will remain de-energized as long as work is being done. Switches that have been opened to de-energize circuits to permit work on equipment should be locked open or blocked open and visible warning signs placed on them.

Parts which normally carry high currents should not be worked on until they have been disconnected from the system and connected to the ground bus. Provision should be made at installation for connecting adequate flexible ground leads to every part of the switching equipment. This is the responsibility of the purchaser.

A good, reliable ground connection is necessary for every switchgear installation. It should be of sufficient capacity to handle any abnormal condition that might occur on the system and should be connected directly to the station ground, independent from grounds used for any other apparatus. See *Ground Bus Connections*.

B. Access to High-Current Parts

Metal-enclosed switchgear is designed to provide isolation between the breaker compartment and the primary line terminations. Access to high-current parts is provided by removable covers and barriers.

Warning: Do not remove any covers or barrers to high-current parts unless the parts to be exposed have been de-energized and precautions taken to assure it will remain de-energized while exposed. Failure to do this can cause severe personal injury or death.

C. Main Disconnecting Contacts and Current Transformers

The stationary main disconnecting contacts and the current transformers are located on the breaker compartment rear wall. They are easily exposed by drawing out the breaker.

Warning: Do not expose any contacts or transformers unless the upper and lower high voltage parts have been de-energized and precautions taken to assure they will remain de-energized during the exposure. Failure to do so could cause severe personal injury or death.

D. Maintenance

To assure high quality performance a definite maintenance schedule, systematically followed, is required. Plant, operating, and local conditions vary to such an extent that an individual schedule must be established to suit the conditions of each installation. Any program established should meet the following general requirements, **E** through **O.**

Warning: Do not attempt any inspection or maintenance unless all primary and control circuits have been de-energized and grounded and precautions taken to assure they will remain so until all work is completed. Failure to do so can cause severe personal injury or death, and substantial damage to property.

E. Individual Devices

The maintenance schedule for individual devices such as circuit breakers, relays, meters, and instruments, should be based on the recommendations in the device manufacturer's instruction literature for the device. These maintenance operations should be coordinated with the overall maintenance program to cause minimum operating inconvenience and circuit shutdown.

F. General Inspection

The switchgear installation should be given a thorough cleaning and maintenance inspection at least annually. If plant, operating, and local conditions are abnormal more frequent inspection and maintenance may be necessary. The following require attention:

G. Buses and Connections

Warning: Do not remove covers from the primary termination compartment unless the primary circuits are de-energized and precautions taken to assure they will remain so while the covers are removed. Failure to do so can cause severe personal injury or death, and substantial damage to property.

After the primary circuits have been de-energized and the primary termination compartment cover removed, megohmmeter readings between phases and to ground should be made. This should be done both before and after cleaning. Insulation should be inspected for damage or deterioration. Dust should be removed from all parts, supports, and enclosure surfaces. A vacuum cleaner with a long nozzle is useful. Wipe clean with non-flammable cleaning solvent and clean cloth.

Warning: These solvents are very toxic and readily absorbed into the human system. Avoid breathing solvent vapors or prolonged contact with skin. Failure to observe this precaution can result in severe personal injury or death by poisoning or asphyxiation.

After cleaning, second meghommeter readings of insulation resistance should be made and recorded for comparison with past and future readings. This practice will help to detect any trend toward lowered insulation resistance.

H. Main Disconnecting Contacts and Secondary Contacts

After de-energizing all circuits, each breaker should be removed from its cell and the primary contacts and their supports thus exposed wiped clean with non-flammable solvent and clean cloth. The warnings given for exposing primary contacts and use of solvents must be heeded.

Inspect the contacts for signs of wear or heating. Discoloration of the surfaces is not harmful unless corrosion due to atmospheric conditions is severe and deposits are left on the surfaces. Any deposits must be removed by scrubbing with a clean cloth, or the contacts must be replaced.

Each breaker, while out of its cell, should be checked in accordance with the breaker manufacturer's instructions.

Secondary contacts should be given the same inspection and maintenance as the primary contacts.

I. Control Contactors

Contacts on control contactors should be inspected and dressed or replaced if the surface is worn or pitted. Unless high repetitive duty has been experienced little further attention should be required.

J. Relays, Instruments, Other Panel Mounted Devices

Individual devices should be maintained in accordance with the device manufacturer's instructions. All relay covers should be removed and the relays inspected for dust and dirt. This operation can most readily be done by relay test personnel during periodic relay tests. Control switches and instrument switches should have their contacts checked.

K. Secondary Wiring

All secondary wiring connections should be checked for tightness, including those at the current and potential transformers and at the terminal blocks where circuits leave the switchgear. A check should be made to assure all secondary wiring is properly connected to the switchgear ground bus where so indicated.

L. Mechanical Parts

Mechanical parts should be visually inspected and manually operated. This includes such parts as truck operated cell switches, position interlocks, emergency trip linkage, and hinged doors. Examine levering-in arms and rail extensions.

M. Ventilation

All labyrinths, grill work, and air passages should be inspected and any obstructions or dirt removed. The air space under the switchgear is necessary for entrance of ventilating air and must be kept always free of any obstruction.

N. Lubrication

The lubrication of the drawout breaker is covered in the breaker manufacturer's instructions. Other than this there is generally little requirement for lubrication. Main and stationary disconnecting finger clusters should be cleaned periodically and kept dry. No grease or other lubricant should be applied to these contact surfaces.

O. Abnormal Conditions

Local conditions such as high humidity, salt laden atmospheres, corrosive gases, heavy dust, or severe circuit operating conditions are abnormal and will require more frequent inspections.

A series of inspections made at 90 day intervals at the time the gear first goes into operation will build an experience upon which to establish an inspection and maintenance schedule to fit the need.

In some locations conditions may be so bad the the frequency of maintenance will interfere with operating and production schedules. In such cases consideration may be given to the advantages of enclosing the switchgear in a relatively tight room and to supplying a sufficient quantity of clean air to maintain a positive pressure in the room. Under such conditions maintenance schedules may be established on a more normal basis. Such an arrangement might also provide for cooling the air where the ambient temperature is high, thus further improving operating conditions.

Warning: Failure to inspect, clean, and maintain switchgear at recommended frequencies can result in failure of equipment to operate properly in fault conditions. This can cause severe personal injury or death, and substantial damage to property.

1.7 Renewal Parts

A set of consumable spares such as fuses and lamps is normally included with the accessories in the original shipment. Experience will tell what parts should be carried in stock for the maintenance of each installation.

When ordering parts, identification is critical. Include all information possible, manufacturer's identifying number, often stamped on the part, the order identification number of the installation, and a description. Specify the device, the rating, the order number of the housing, and the date of the original order.

For more detailed information on testing and inspection of switchgear, refer to Chapter 2.

Volume 3
Chapter 2

Metal-Clad Switchgear

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Metal-Clad Switchgear

Medium voltage metal-clad switchgear with magnetic air circuit breakers controls and protects high voltage circuits up to 15 kV. The switchgear assembly is composed of housings arranged to meet the requirements of individual applications. The housings contain equipment such as buses, instrument transformers, relays, secondary control devices, and air circuit breakers.

Metal-clad switchgear is designed, manufactured, and tested in accordance with industry standards. It is available for both indoor and outdoor installation.

Proper installation, operation, and maintenance are necessary to assure continued satisfactory service. It should not be installed in places where it will be called upon to operate at voltages, currents, or fault capacities greater than those for which it is designed, or where the environment is unsuitable.

Personnel responsible for supervision, operation, or maintenance should be familiar with the appearance, operation, and maintenance of each piece of equipment contained in or mounted on the switchgear.

2.1 ANSI Definition of Metal-Clad Switchgear

The American National Standards Institute has stated the universally accepted definition of metal-clad switchgear as having the following characteristics:

A. The main switching and interrupting device is of the removable type, arranged with a mechanism for moving it physically between connected and disconnected positions and equipped with self-aligning and self-coupling primary and secondary disconnecting devices.

B. Major parts of the primary circuit, such as the circuit switching or interrupting devices, buses, potential transformers, and control power transformers are completely enclosed by grounded metal barriers. Specifically included is an inner barrier in front of, or a part of, the circuit interrupting device, to ensure that no primary components are exposed when the unit door is opened.

C. All live parts are enclosed within grounded metal compartments. Automatic shutters prevent exposure of primary circuit elements when the removable element is in the disconnected, test, or removed position.

D. Primary bus conductors and connections are covered with insulating material throughout.

E. Mechanical interlocks are provided to ensure a proper and safe operating sequence.

F. Instruments, meters, relays, secondary control devices and their wiring are isolated by grounded metal barriers from all primary circuit elements with the exception of short lengths of wire such as at transformer terminals.

G. The door through which the circuit interrupting device is inserted into the housing may serve as an instrument or relay panel and may also provide access to a secondary or control compartment within the housing.

Note 1: Auxiliary units may be required for mounting devices or for use as bus transition.

Note 2: The term metal-clad, as applied to switchgear assemblies is correctly used only with switchgear conforming fully to the definition of metal-clad switchgear given in ANSI C 37.20-2.1.3 (above). All metal-clad switchgear is metal-enclosed but not all metal-enclosed switchgear is metal-clad.

2.2 Recommended Safe Practices

Metal-clad air circuit breaker switchgear assemblies are strongly built and provided with many safety features. When all doors are closed and covers properly installed, there is heavy gauge steel between the live parts and any nearby personnel. Nevertheless, metal-clad switchgear contains power circuits with high fault capacity which are dangerous. When any door is open or any cover removed it is possible for contact to be made with parts which may be live when the assembly is energized or if a separate power source is connected. The voltages and power levels available in this equipment make this kind of exposure extremely dangerous. All power should be turned off or when it is absolutely necessary to work on energized equipment, adequate protective equipment should be used. Not only should the main bus be de-energized, but all other circuits should be checked for feedback from other sources. Use a "hot stick" to verify that all circuits are de-energized before proceeding. Necessary steps should be taken to insure that power stays off until all doors and covers are again properly in place.

Only qualified persons should attempt to install, operate, or maintain this apparatus. In addition to hazards inherent in metal-clad switchgear, operation by unqualified persons may cause damage to connected equipment and its operators.

A. **To perform work** on this equipment requires training and experience with high current circuits. Only electrical workers familiar with construction and operation of such equipment and the hazards involved should be permitted to work on metal-clad switchgear, (see NEC Article 100 for a definition of a Qualified Person).

B. Danger: Primary and secondary circuits must be de-energized before any maintenance is attempted. Failure to do so can cause severe personal injury or death, and damage to property.

C. Danger: Do not remove any access covers unless the circuits to be exposed have been de-energized. To do so can cause severe personal injury or death, and damage to property.

D. Danger: Do not remove or manually raise the shutter in a circuit breaker compartment unless all the main contacts have been de-energized. To do so can expose personnel to severe personal injury or death and cause damage to property.

E. Danger: Do not attempt to close a circuit breaker with the maintenance closing handle on a live circuit. It cannot be closed rapidly enough to avoid severe arcing and burning and possible breaker failure.

F. Danger: Do not attempt any work within this equipment without assuring that all circuits have been and will remain de-energized. To do so will expose workers to severe personal injury or death and damage to property.

G. Danger: Do not attempt to disconnect or open the secondary circuit of a current transformer carrying load current because a dangerously high voltage is developed. Either de-energize the circuit by opening the circuit breaker or short circuit the secondary of the current transformer before proceeding with the work.

After maintenance make certain every current transformer secondary circuit is completely connected or is shorted. An open-circuit secondary can produce dangerously high voltages when power current is flowing through the current transformer.

Exposure to high voltages can cause severe personal injury or death, and substantial damage to property.

H. Never insert a breaker without arc chutes and barrier into an energized cell beyond the test position. For maximum safety insert only a completely assembled breaker into an energized cell. If it is necessary to put a breaker without arc chutes and barrier into the test position in an energized cell, take steps to insure that it cannot be inserted beyond this position, such as padlocking the levering-in shaft.

I. Never leave a breaker in an intermediate position in a cell. Always have the breaker fully connected or withdrawn.

J. Keep fingers away from top and sides of the barrier when moving breaker into or out of the cell.

K. Connect the switchgear to the station ground before energizing.

L. In case of fire do not use liquid fire extinguishers until all circuits have been totally de-energized.

M. If any relays are included make certain all blocking has been removed.

Check secondary control circuits (except current and potential transformer circuits) for grounds and short circuits before applying any power.

N. If outdoor switchgear is to be stored prior to installation, provision must be made for energizing the space heaters to control condensation inside the gear.

If indoor switchgear is to be stored prior to installation it must be kept free of condensation and protected from the weather.

2.3 Construction

The following descriptions of construction are based on current Westinghouse designs. Metal-clad switchgear built at other times and by other manufacturers will vary from these descriptions. The manufacturer's specific instructions should always be consulted before any work on switchgear is attempted.

Metal-clad switchgear is an assembly of units arranged to meet the requirements of the application. A typical assembly includes both circuit breaker units and auxiliary units.

A circuit breaker unit has provision for a removable circuit breaker. It also includes high voltage equipment, primary connections, low voltage equipment, and control devices. A hinged instrument panel is located at the front of the circuit breaker unit.

An auxiliary unit has no provisions for a circuit breaker. It contains miscellaneous equipment which cannot be contained in the circuit breaker unit. A hinged instrument panel is located at the front of auxiliary units.

Metal-clad switchgear is available for both indoor and outdoor installation. The circuit breakers and general design are similar for indoor or outdoor installation. In general outdoor metal-clad switchgear is constructed by assembling a weatherproof enclosure onto and around standard indoor units.

The construction described in the following paragraphs is of a typical metal-clad switchgear assembly. Not all assemblies manufactured by all builders will be exactly as described here.

A. Indoor Metal-Clad Switchgear

Indoor metal-clad switchgear is made up of two types of units, a breaker unit and auxiliary unit. The breaker unit consists of a breaker/bus module, line module, control module, and an upper rear module (if required). See Figure 1 for front and Figure 2 rear view. A sectional drawing of a breaker unit is shown in Figure 3.

The breaker/bus module contains major functioning equipment such as the circuit breaker, stationary disconnect contacts, main bus, and current transformers. Additionally this module contains such devices as the levering-in device, shutter, interlocks, and auxiliary switches as required.

The line module is attached at the rear of the breaker/bus module and provides space for line terminations such as cable connectors and potheads.

The control module is located above the breaker/bus module and provides housing for control function devices such as control relays, molded case circuit breakers, fuses, terminal blocks, and mechanically operated cell switches.

The upper rear module, when provided, is located behind the control module and contains such equipment as potential transformers, lightning arresters, and special buses.

Normally these modules are of welded construction and are bolted together.

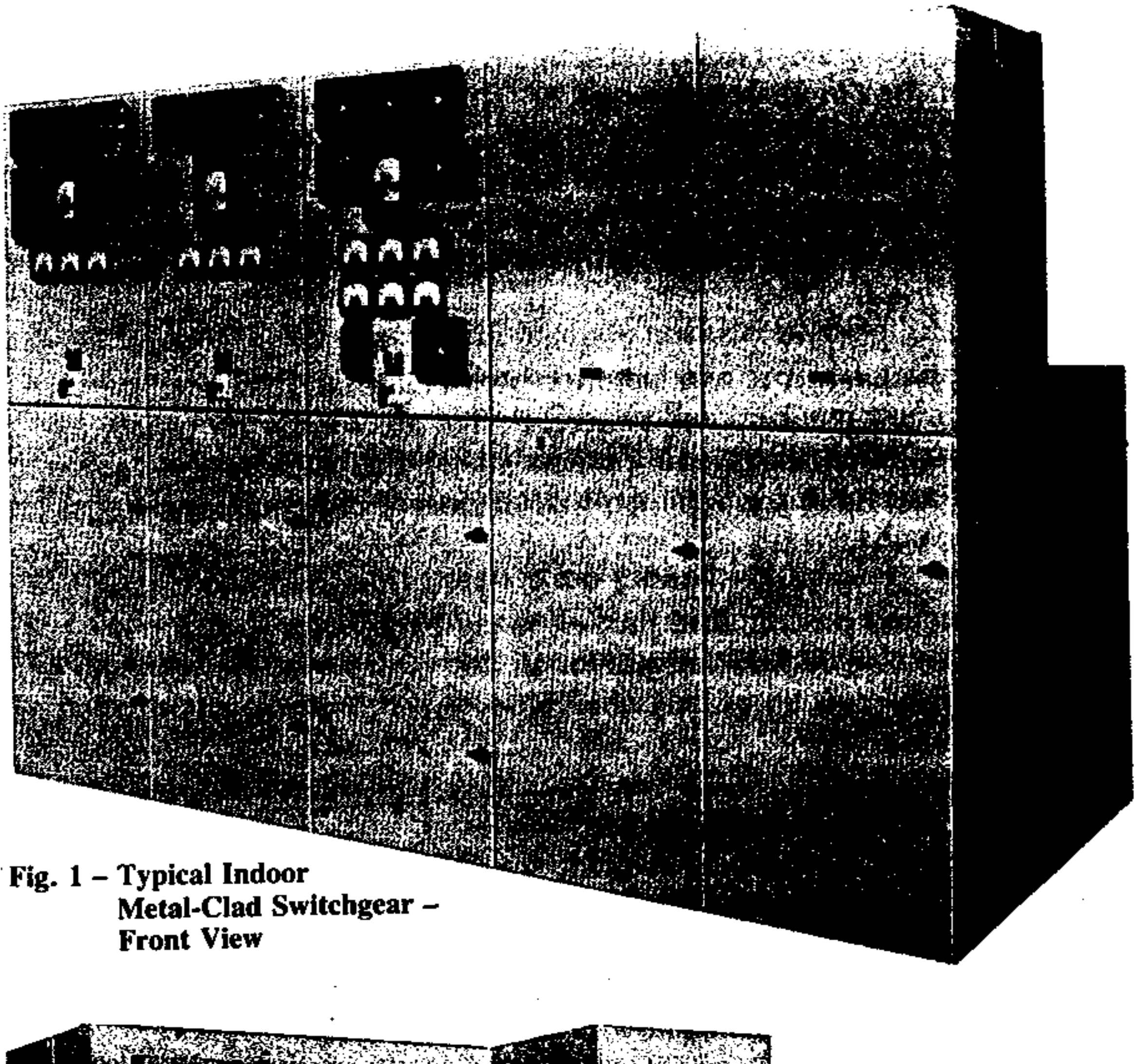


Fig. 1 – Typical Indoor Metal-Clad Switchgear – Front View

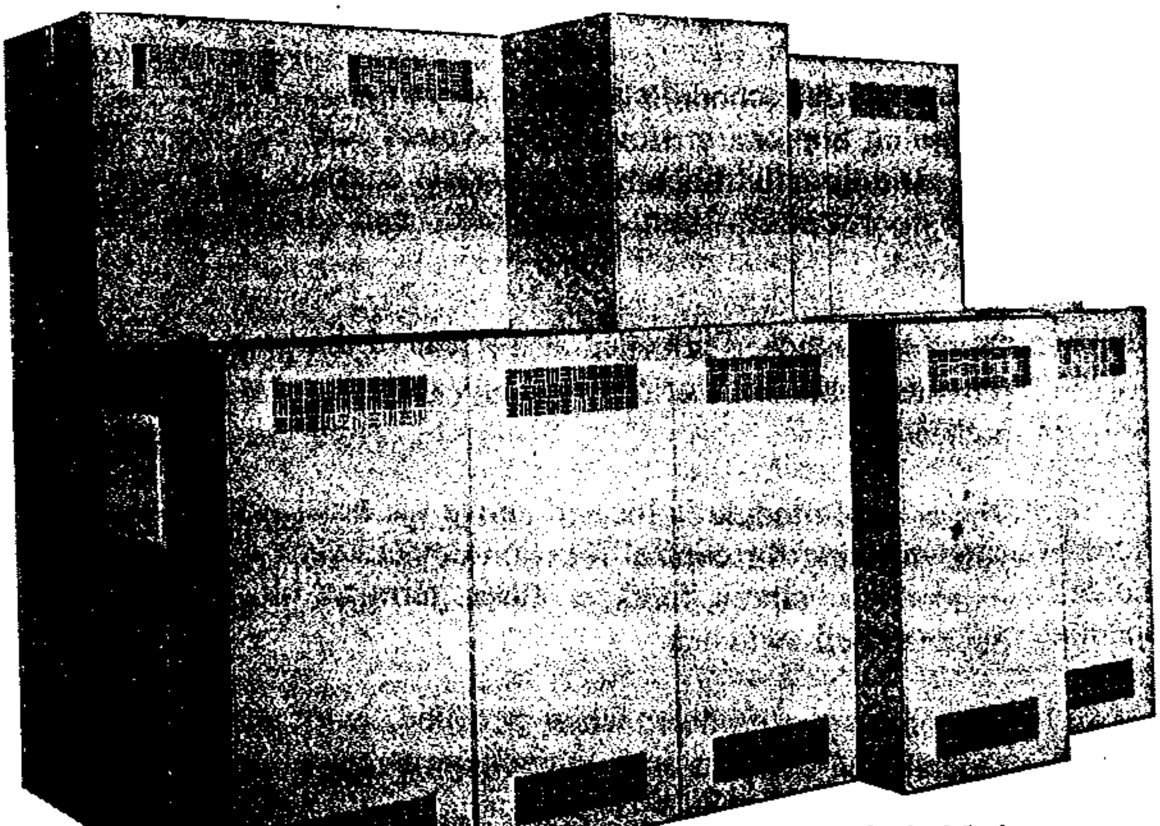


Fig. 2 – Typical Indoor Metal-Clad Switchgear – Rear View

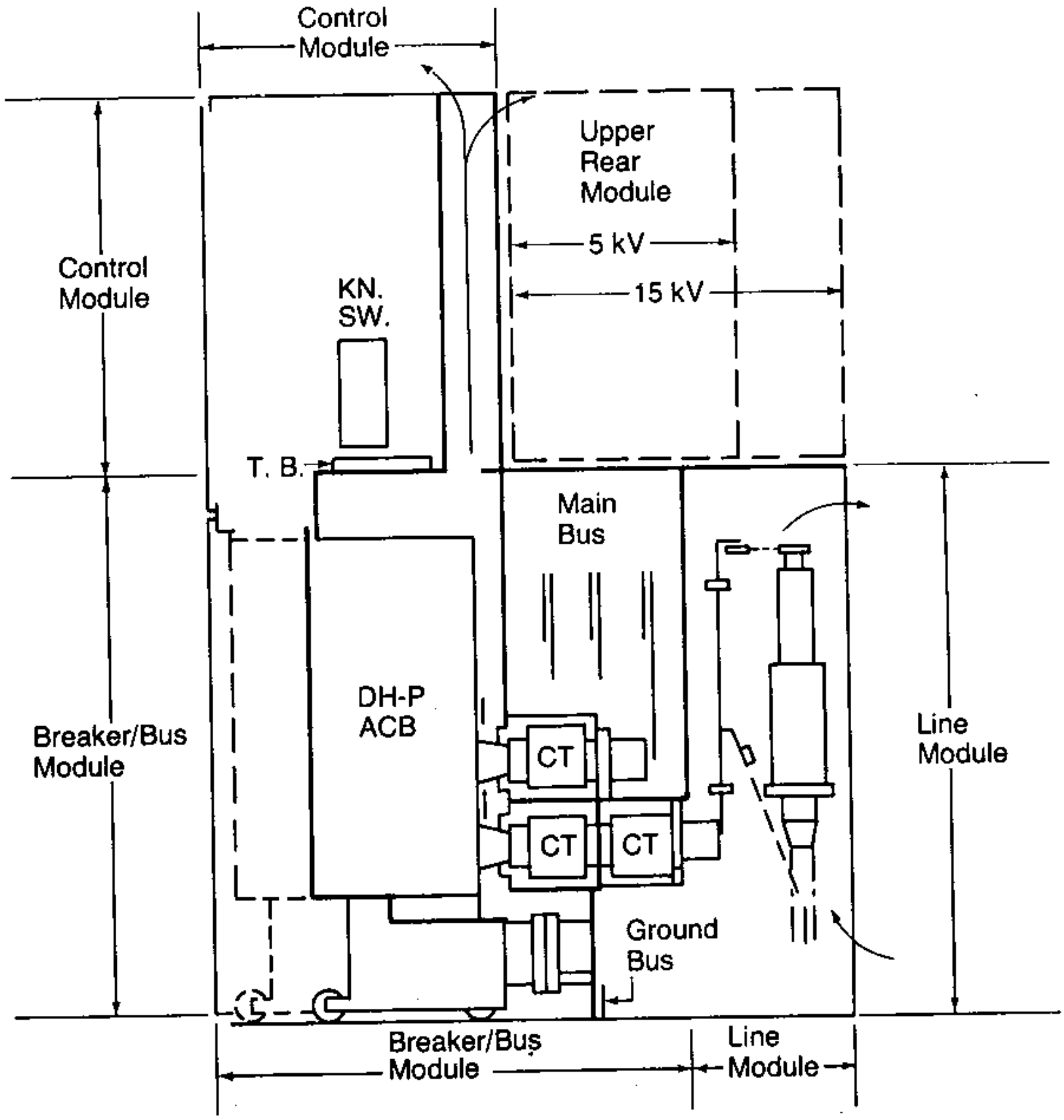


Fig. 3 – Circuit Breakers/Bus Unit Diagram

A combination of these modules forms a metal-clad unit. Internal compartments provide metal isolation between secondary control devices, the circuit breaker, the main bus, and the primary line terminations.

Danger: Access to the primary equipment is provided by bolt-on covers which should not be removed unless all circuits to be exposed are de-energized. Failure to take this precaution can cause severe personal injury or death, and substantial damage to property.

A typical auxiliary unit is composed of modules similar to those in a breaker/bus unit, see Figure 4. This unit may contain current and potential transformers but it could contain a battery tray, surge equipment, or motor field equipment. An auxiliary unit will never house an air circuit breaker.

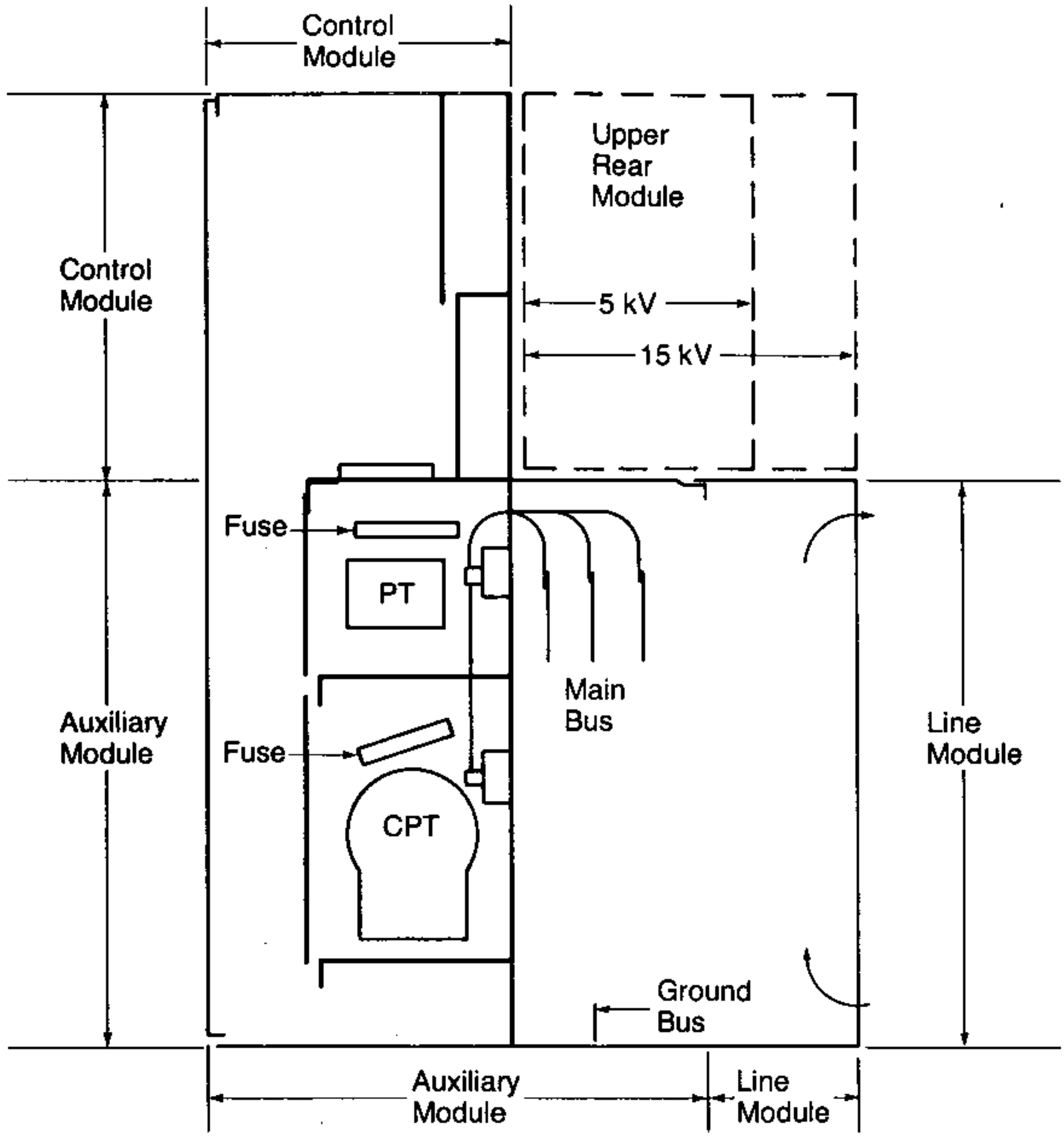


Fig. 4 – Auxiliary Unit Diagram

B. Outdoor Metal-Clad Switchgear

Outdoor metal-clad switchgear is available in two forms of enclosure, walk-in and aisle-less. In either form it is essentially a weatherproof enclosure built around an indoor assembly. Figure 5 illustrates a typical walk-in enclosure and Figure 6 a typical aisle-less enclosure.

The walk-in enclosure provides a weatherproof aisle, in front of the units and big enough to allow interchanging circuit breakers between units. The enclosure is equipped with lights, switches, and service receptacles. The doors at either end of the aisle can be opened from inside even if locked on the outside.

In both walk-in and aisle-less switchgear the enclosures are tamper proof and both are equipped with heaters to control condensation.

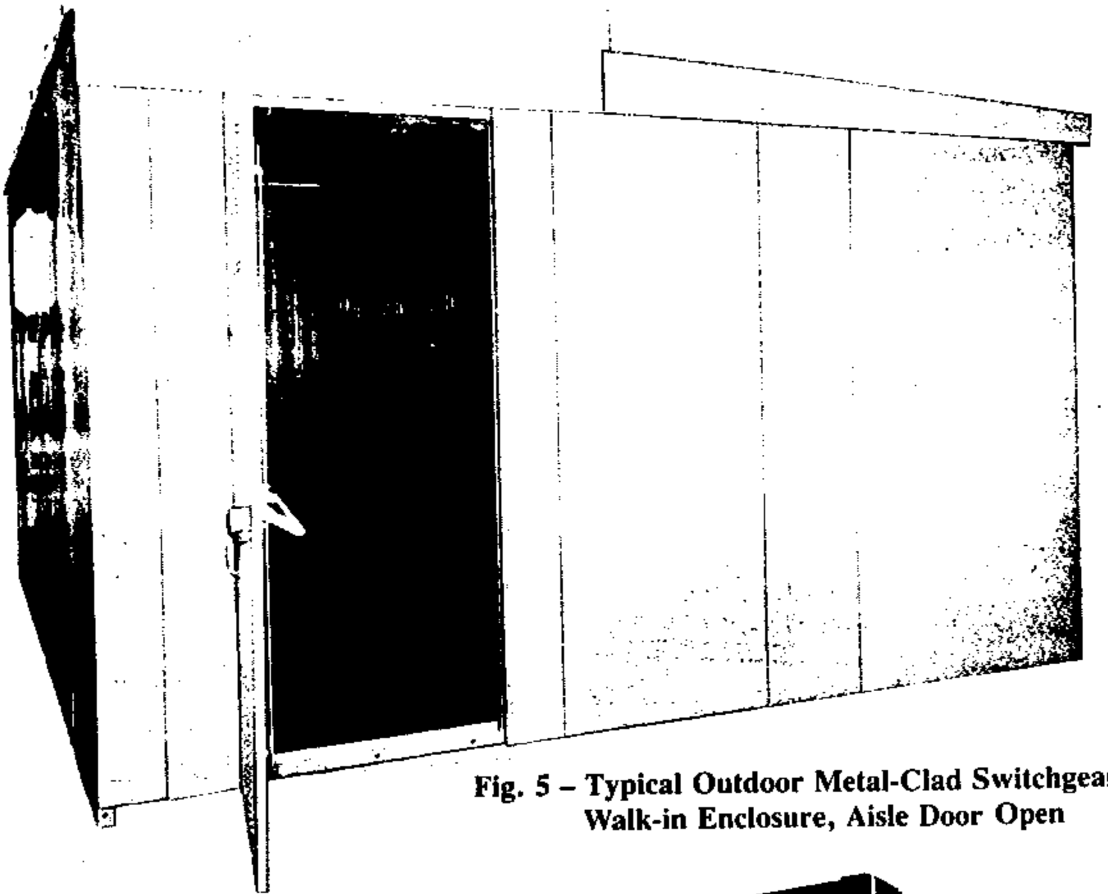


Fig. 5 – Typical Outdoor Metal-Clad Switchgear – Walk-in Enclosure, Aisle Door Open

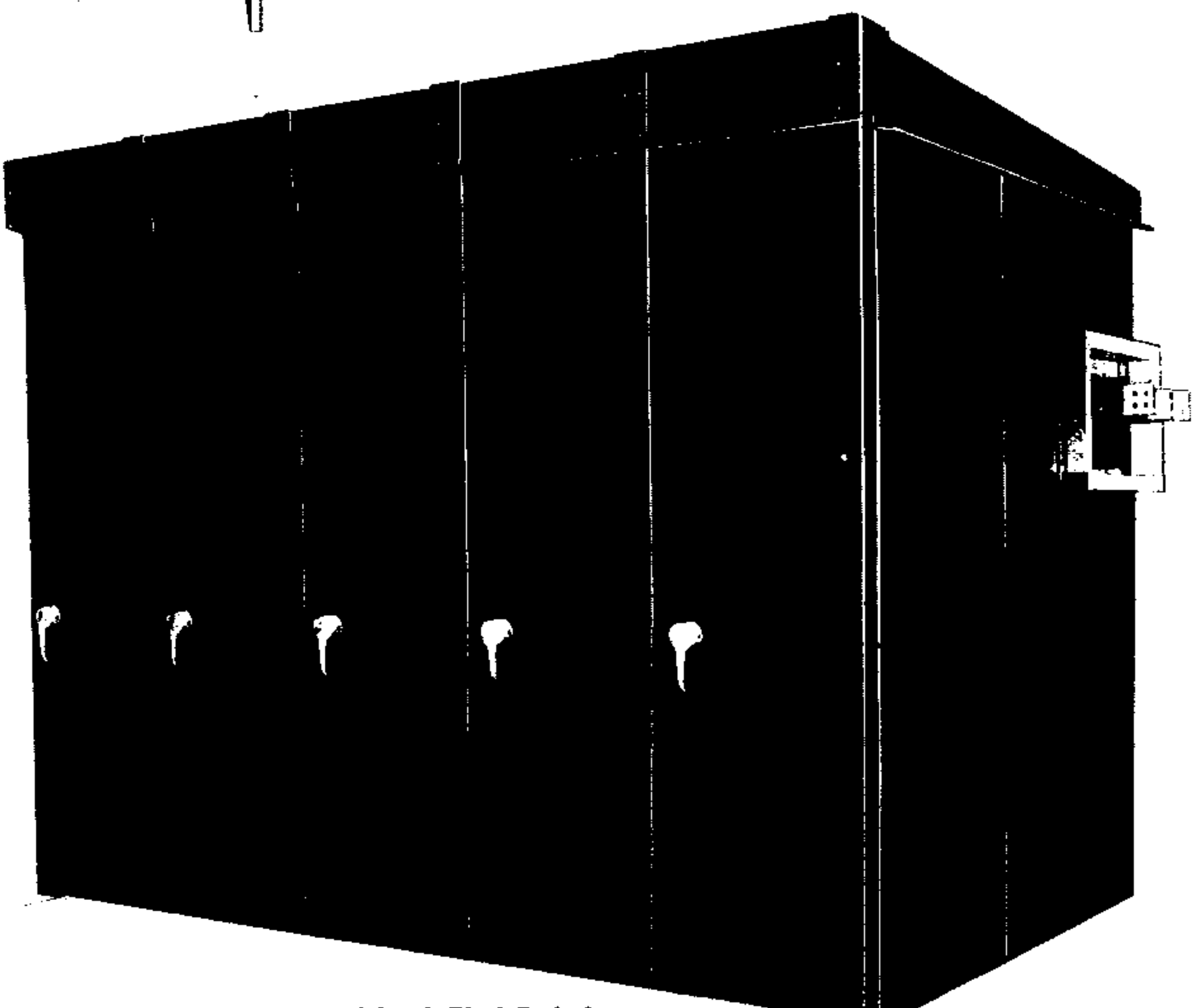


Fig. 6 – Typical Outdoor Metal-Clad Switchgear – Aisle-less Enclosure

Outdoor metal-clad switchgear assemblies are welded or bolted to rigid steel base frames and ready to be mounted on a concrete pad foundation, or for the walk-in enclosure, pillar, footer, or pier mounting. (See under Installation for more complete information.)

C. Ventilation

1 - *Indoor Switchgear*

Figures 3 and 4 show typical ventilation schemes for metal-clad switchgear units. At the rear the line module panels have grills at the top and bottom to allow ventilating air to move through by convection. A chim-

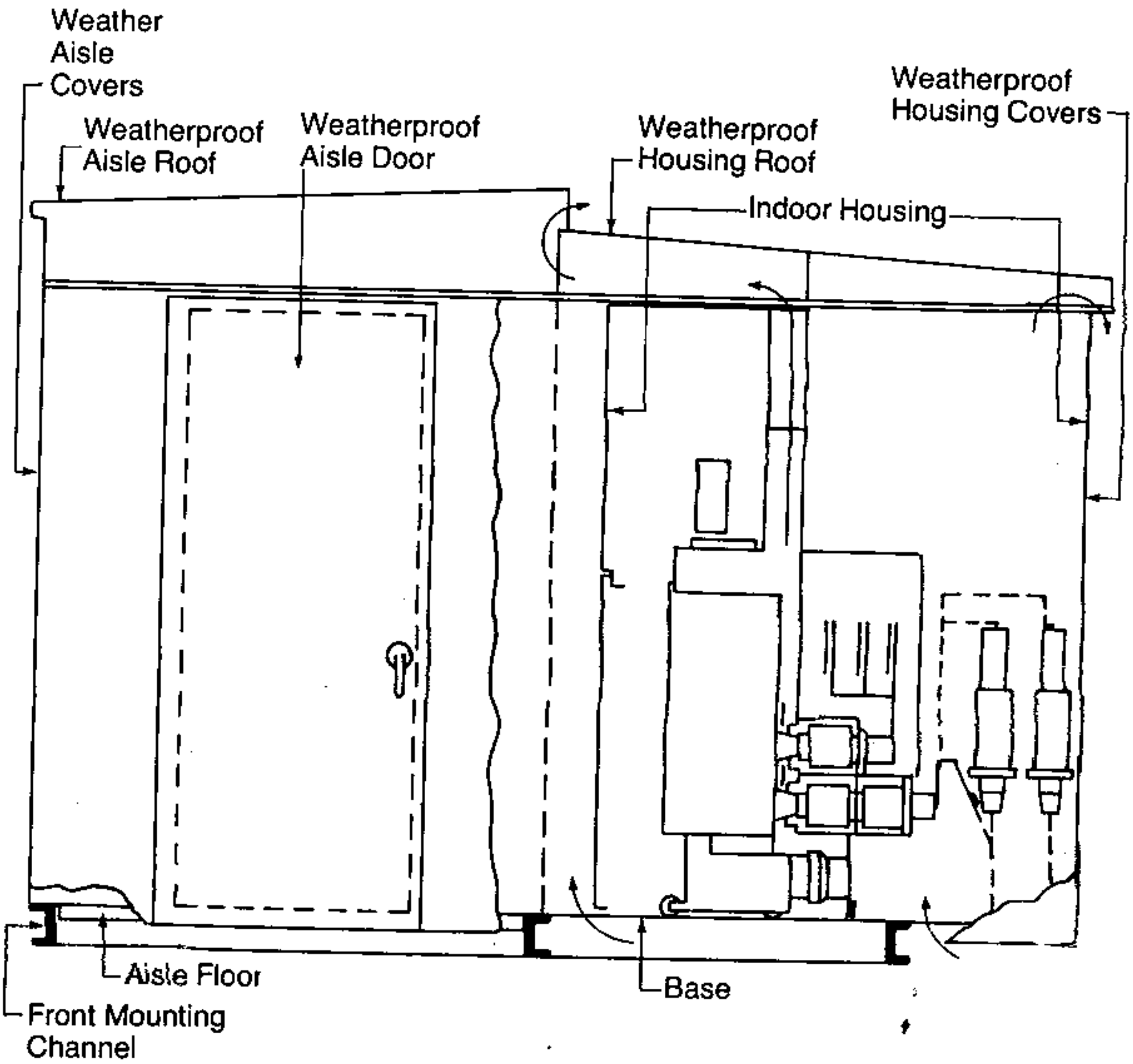


Fig. 7 – Outdoor, Walk-in Metal-Clad Switchgear – Breaker Unit Diagram

ney and grillwork over the breaker allows for expansion of gases resulting from breaker operation and ventilation of the breaker compartment.

2 - *Outdoor Switchgear*

Figures 7 and 8 show typical ventilating arrangements for outdoor metal-clad switchgear. Ventilating air enters through screens from beneath the units and vents through screens under the roof overhang.

3 - *Space Heaters*

Outdoor metal-clad switchgear is furnished with space heaters in the lower modules to control condensation. They operate at half-voltage to assure long life.

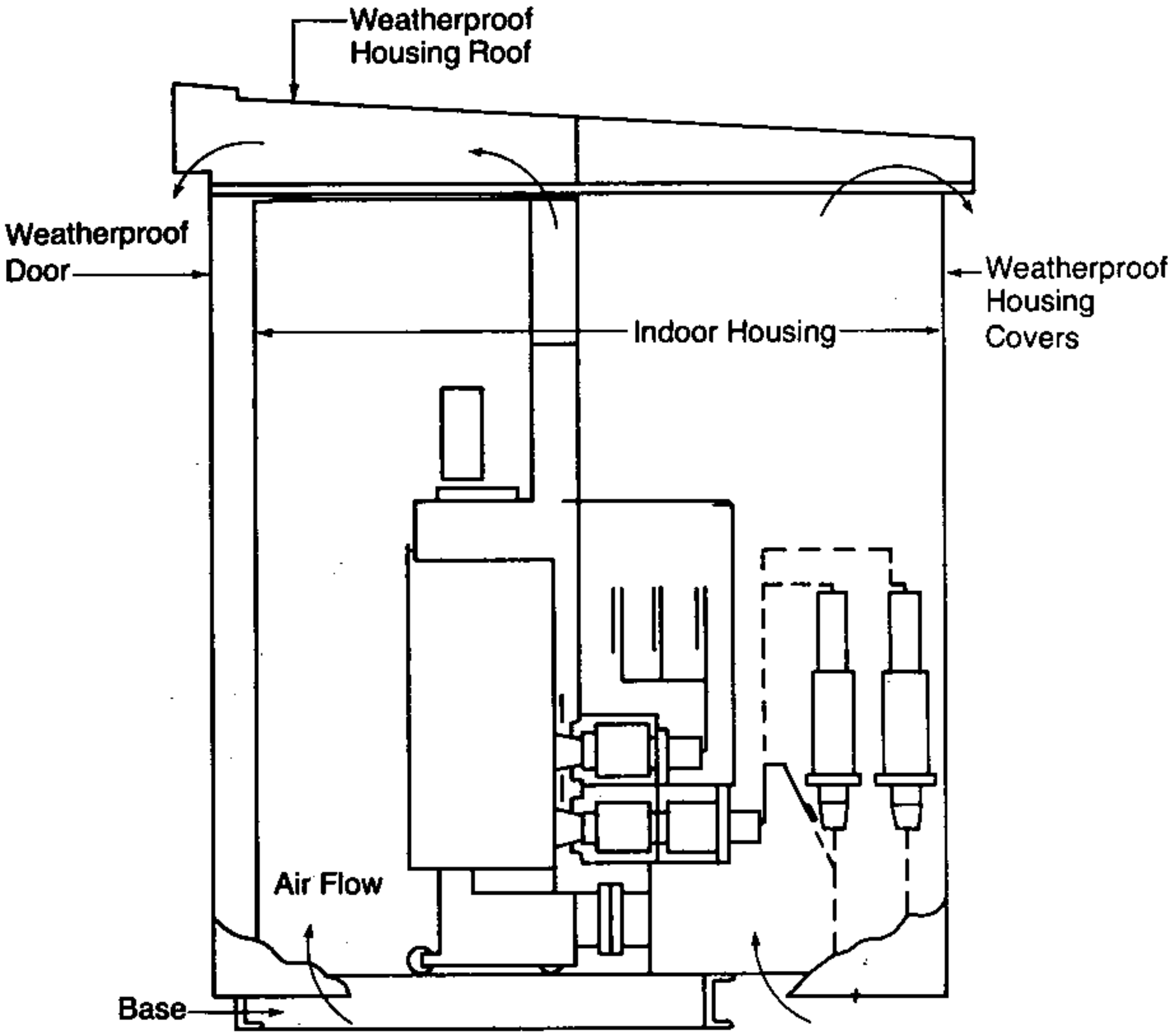


Fig. 8 – Outdoor Aisle-less Metal-Clad Switchgear – Breaker Unit Diagram

D. Instrument Panels
Instruments are mounted on hinged panels on the front of the switchgear modules. Figure 9 shows a typical indoor or walk-in outdoor instrument panel. The upper panel on which the instruments are mounted covers the control module. The lower panel covers the breaker/bus module and is not used for instruments. In aisle-less outdoor housings there is a single full length hinged panel immediately behind the weatherproof door upon which the instruments are mounted as shown in Figure 10.

E. Control Equipment
The control module will contain such equipment as a fuse for control power cutoff, terminal blocks for control leads, capacitor trip devices, control and instrument fuses, resistors, auxiliary relays, and molded case circuit breakers. At the rear of this module there may be a potential transformer mounted in a separate compartment. Figure 11 shows a typical control module above a breaker/bus module, the control module door and the transformer compartment doors are open.

F. Insulating Shutter Over Main Contacts
In the breaker module where the main contacts are located, there is a shutter that automatically opens when the breaker is moved into the connected position and closes when the breaker moves to the disconnected position. See Figure 12.

Warning: Do not manually raise or remove this shutter unless main contacts have been de-energized and safety procedures taken to assure they will remain de-energized. Failure to exercise this precaution may result in danger to life and damage to property.

G. Current Transformers
Current transformers are mounted around the main contact supports as shown in Figure 13. They are front removable if the primary circuit is de-energized. When necessary additional current transformers may be mounted in the line module.

Current transformers have polarity marks to indicate the instantaneous polarities of the primary and secondary windings. Connections to the current transformers are shown on schematic and wiring diagrams supplied, as required to give correct polarity for proper operation of the instruments and relays.

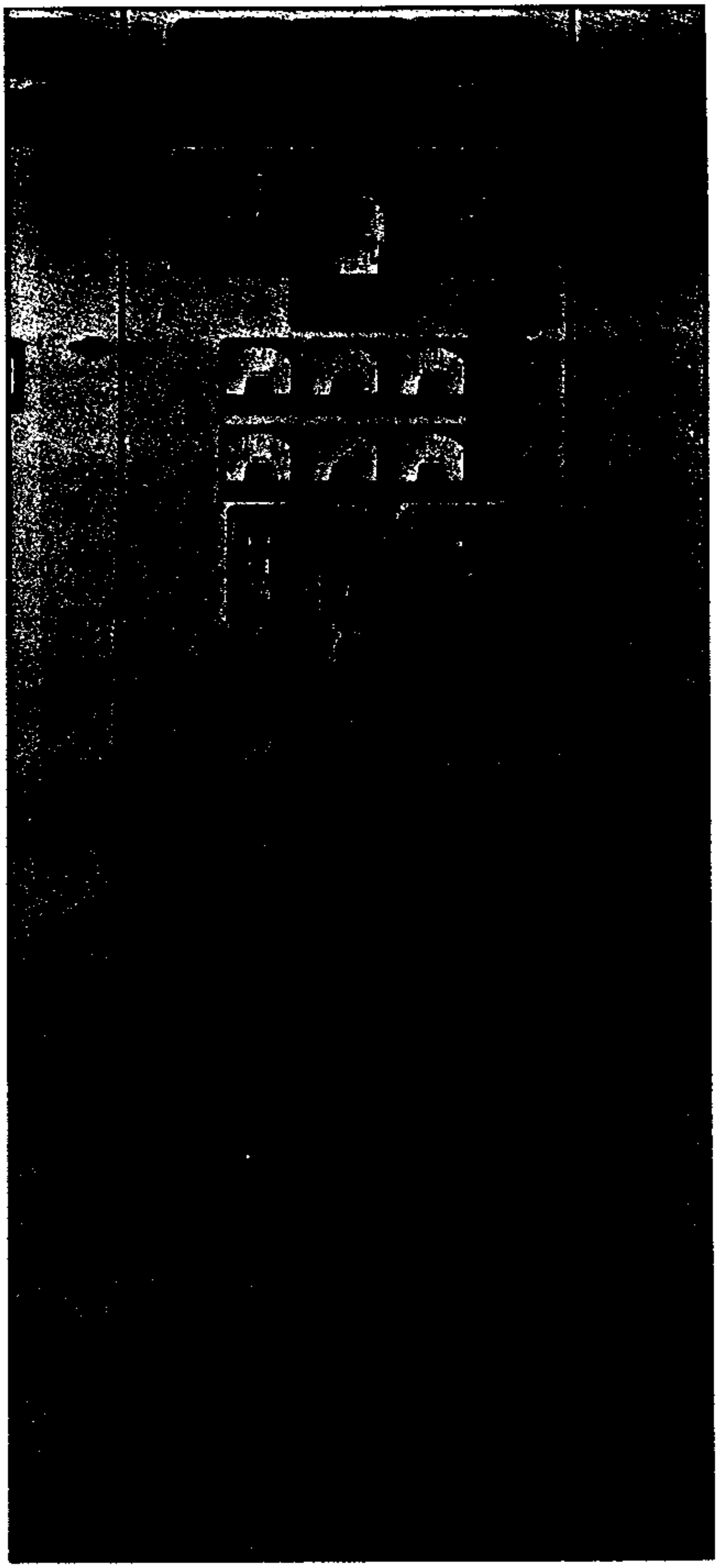


Fig. 9 – Typical Instrument Panel – Indoor and Outdoor Walk-in Housings

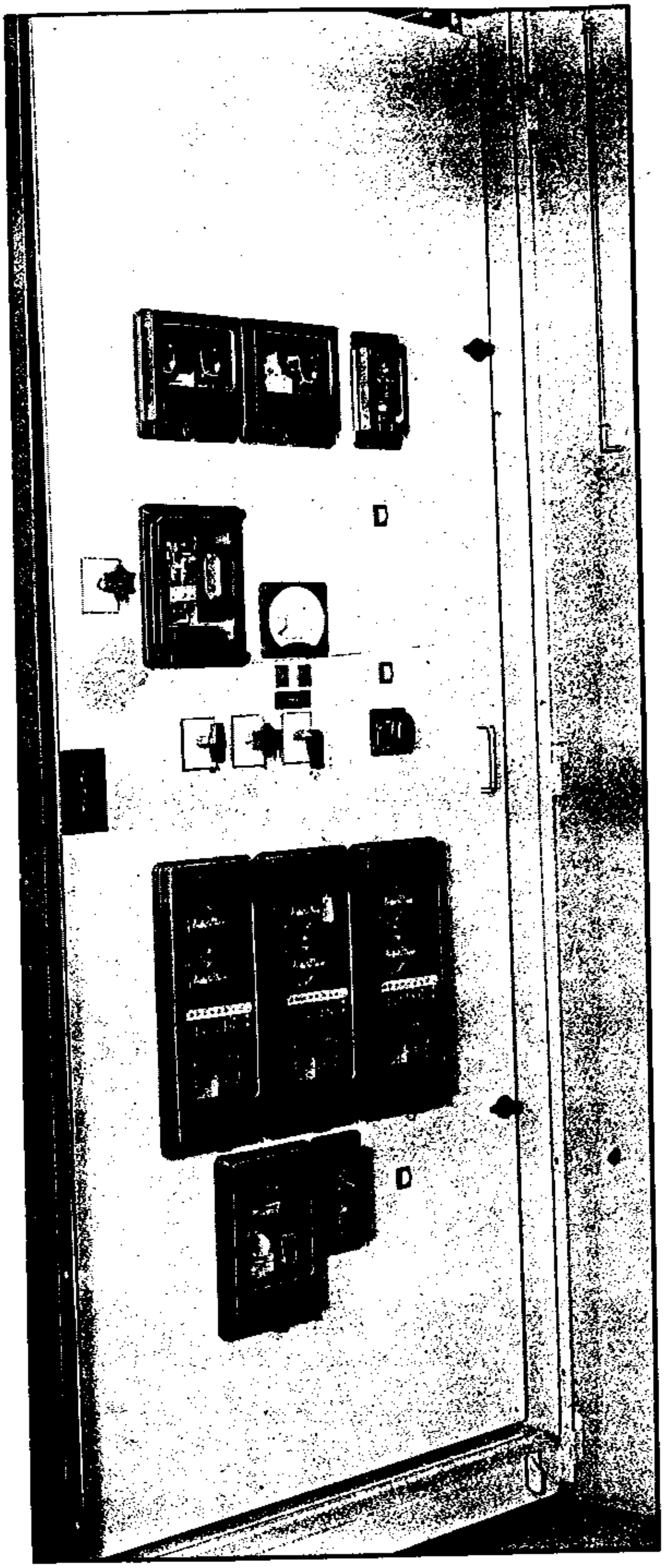


Fig. 10 – Typical Instrument Panel – Outdoor Aisle-less Housing

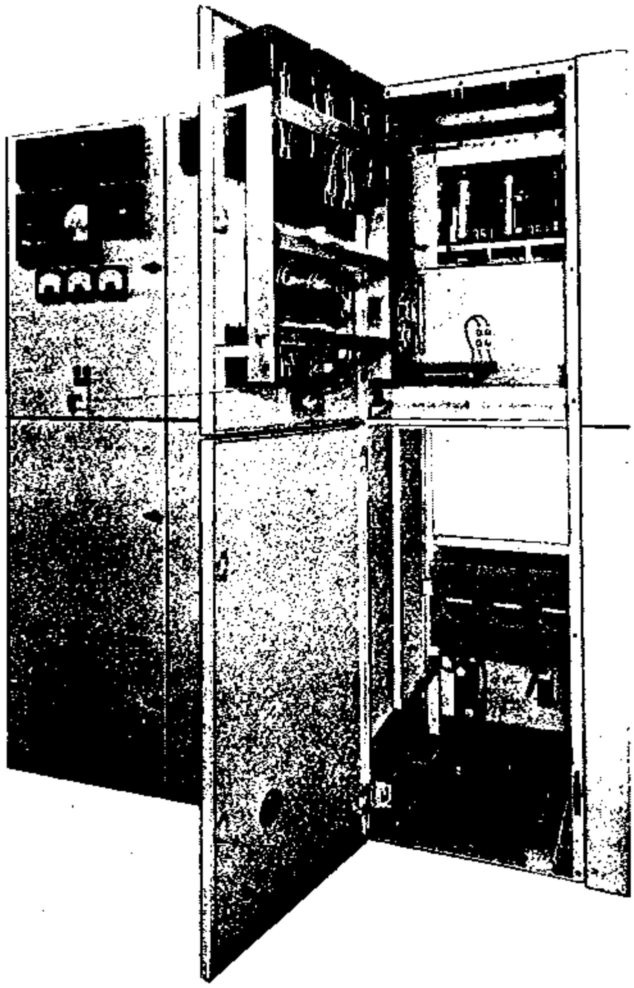


Fig. 11 – Control Module Above a Breaker Module – Potential Transformer Compartment Door Open

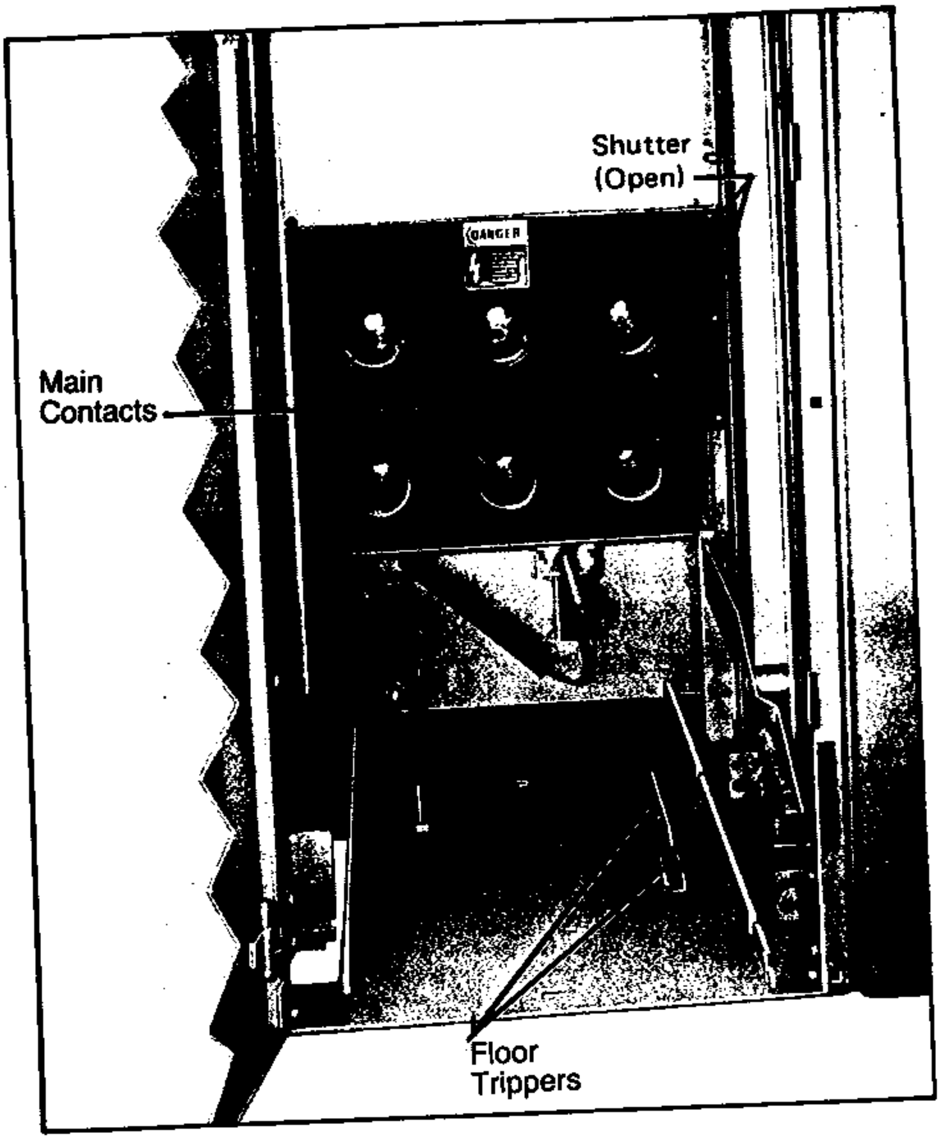


Fig. 12 – Circuit Breaker Compartment with Breaker Removed and Main Contact Shutter Open

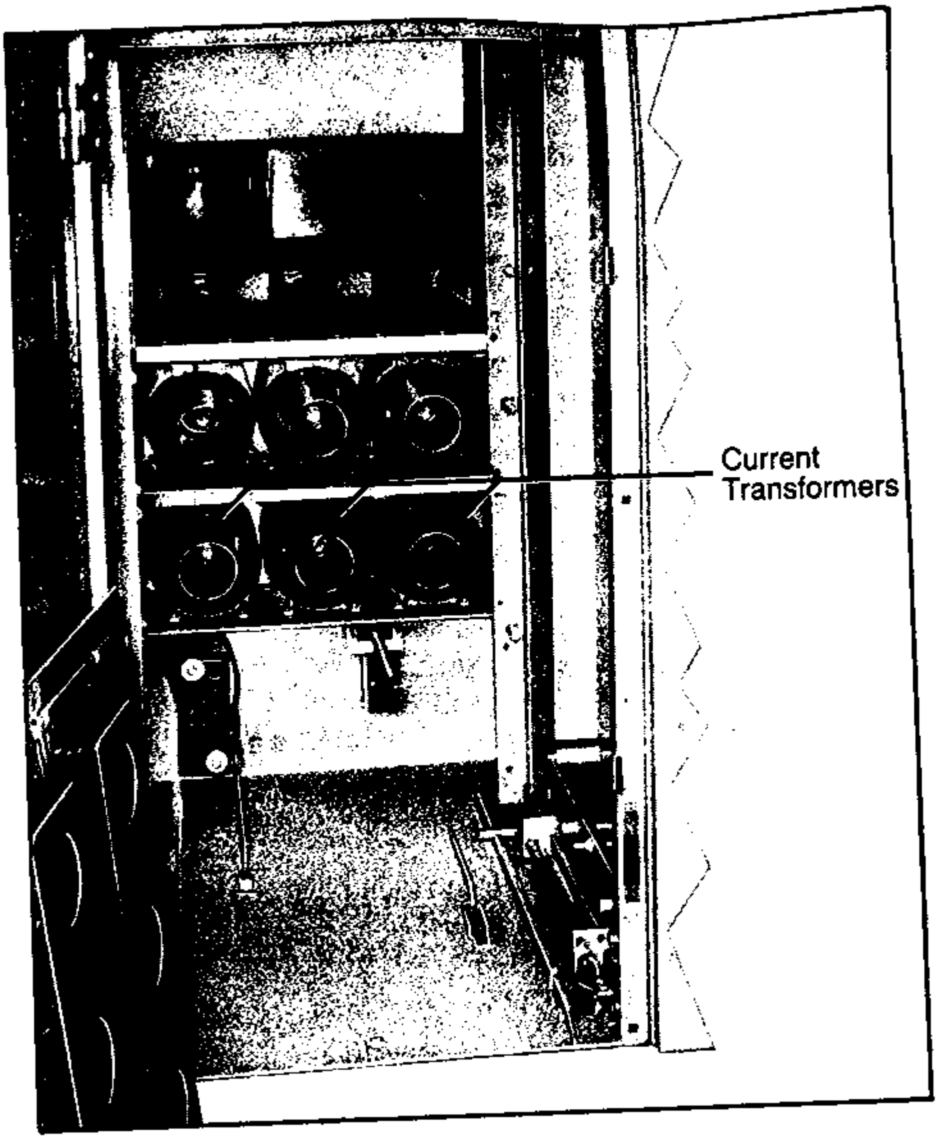


Fig. 13 – Breaker Module with Breaker and Barriers Removed to Show Current Transformers, Disconnects, Main Bus, and Taps

H. Buses

1. *Main Bus and Main Bus Taps*
The conductors of main bus will be either copper or aluminum. The bus, joints, and taps are insulated. The joints are silver or tin plated and bolted. The bus supports are porcelain.

The main bus is accessible from either front or rear by removing bolt-on covers.

Warning: Do not remove bolt-on covers or expose bus, joints, or taps unless the primary circuit has been de-energized. Failure to observe this warning can cause severe personal injury or death, and substantial damage to property.

2. *Ground Bus*
The ground bus consists of a copper bus bar that runs along the rear of the unit. It is equipped with an appropriate terminal to connect it to the station ground. The circuit breaker is connected to an extension of the ground bus when it is in the test or disconnected position.

I. Breaker Compartment

1. *The main disconnecting contacts* located at the rear of the breaker compartment engage with the main disconnecting contacts of the breaker when the breaker is in the connected position. The breaker contacts are usually self-aligning finger clusters.

2. *Levering-in Device*
The breaker is moved in and out of the compartment by a mechanical device, usually a screw which advances or retracts the breaker as the screw, or its nut, is turned.

There is a guide rail which serves along with the levering-in device to align and position the breaker in the connected position. The guide rail may also function as a part of the latching mechanism to position and provide a positive stop for the circuit breaker in the test position.

3. *Tripping Devices*
There are tripping devices in the breaker compartment, usually at the bottom, designed to assure that the breaker is automatically tripped or in a trip-free position when it is inserted or withdrawn or moved between connected and test positions.

4. *Breaker Position Interlock*

The breaker position interlock functions to prevent putting the breaker into the test position. This interlock is equipped with a key lock to assure that the breaker will be inserted into the test position only deliberately and with knowledge of the hey holder.

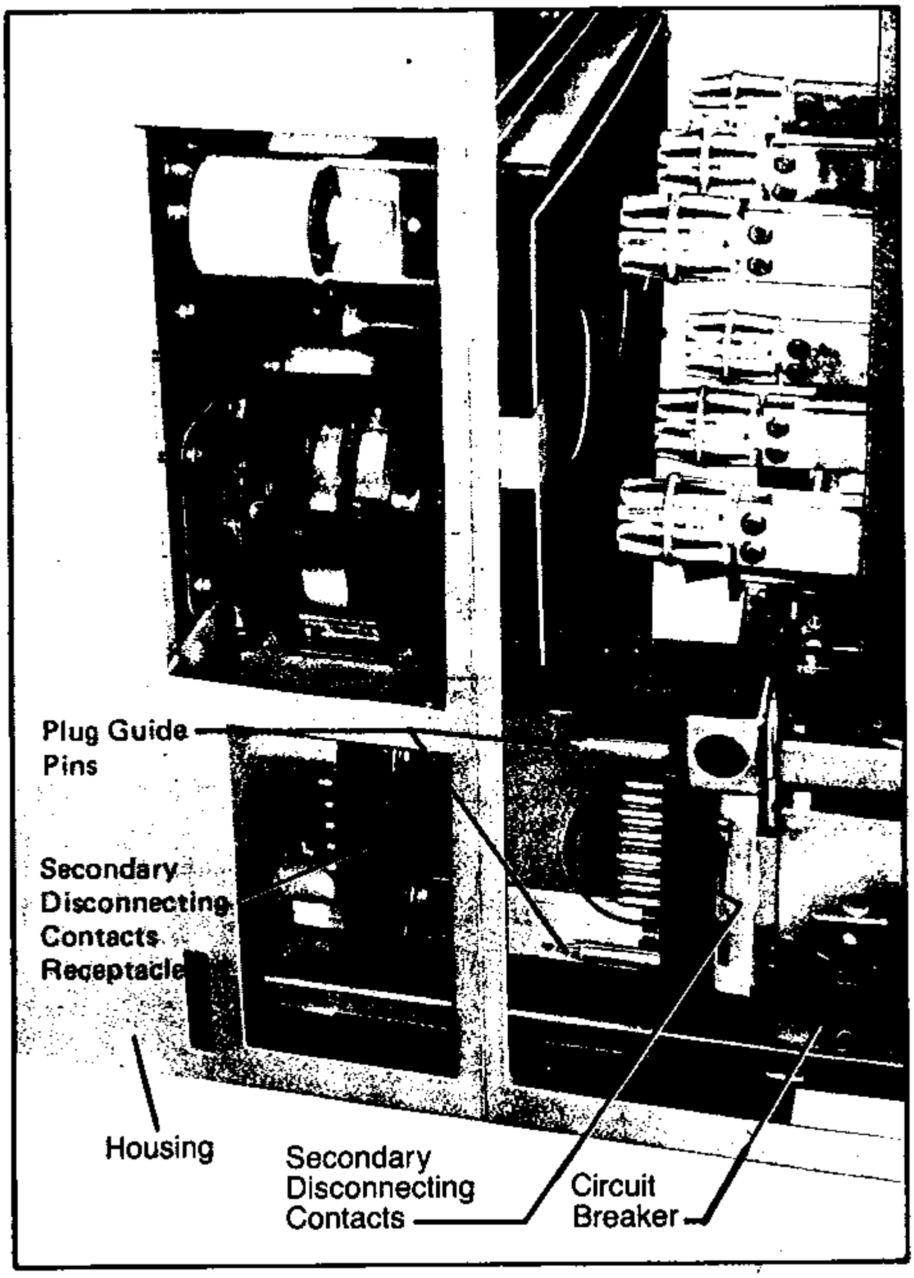


Fig. 14 – Receptacle and Plug for Secondary Disconnects

Warning: Keep keys to interlocks in safe storage where they are accessible only to authorized people. Failure to do so can result in use by unauthorized people at inappropriate times which can cause severe personal injury or death, and substantial damage to property.

5. *Secondary Disconnecting Contacts*
The control wiring is arranged for drawout disconnecting by means of a female receptacle in the cell that matches a male plug on the rear of the breaker. There are additional guide pins on the plug that align with holes in the receptacle. This arrangement of pins and holes polarizes the secondary contacts and aids in aligning. See Figure 14.

J. Line Conductors - Customer's Connections

Space is available in the line module for the customer's primary connections and ground connections. Figure 15 shows solderless cable terminals. The line module may be equipped with potheads, connections to a bus run, or other connection arrangements. After the cables or other devices are installed the connections must be insulated. Refer to Figure 16 for typical connection taping diagrams.

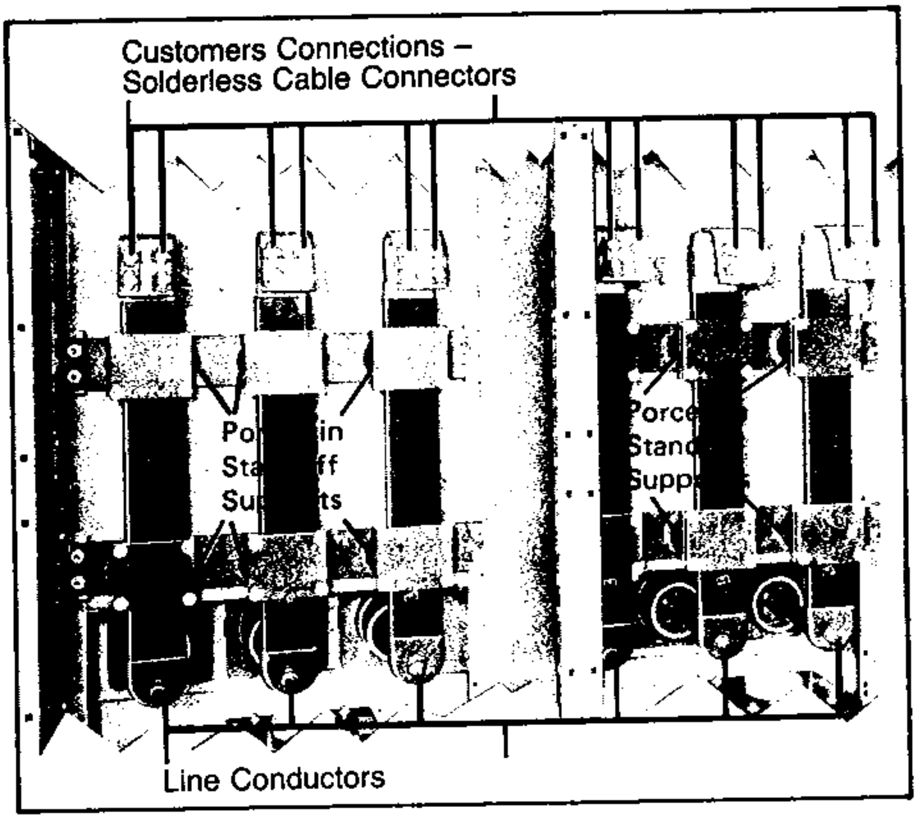
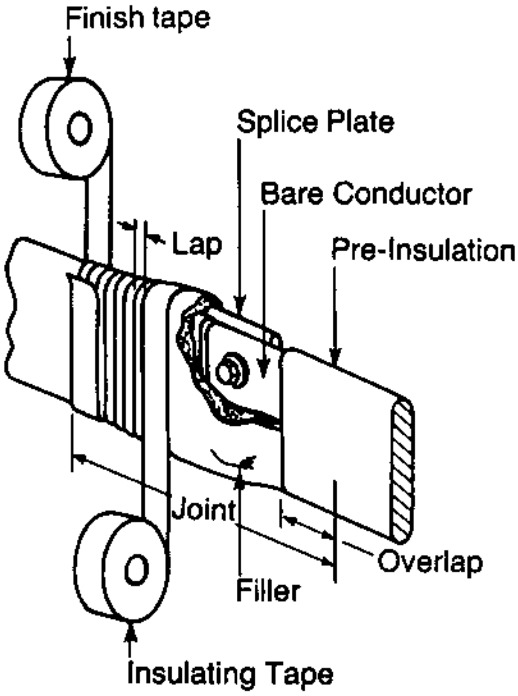
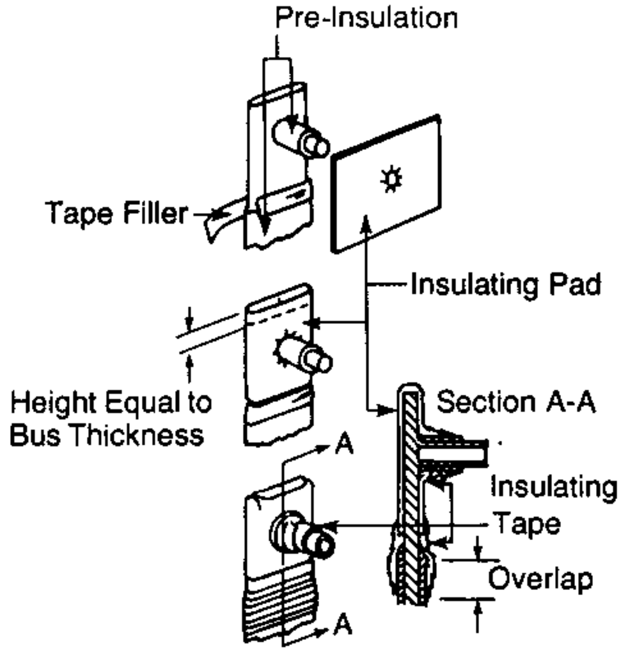


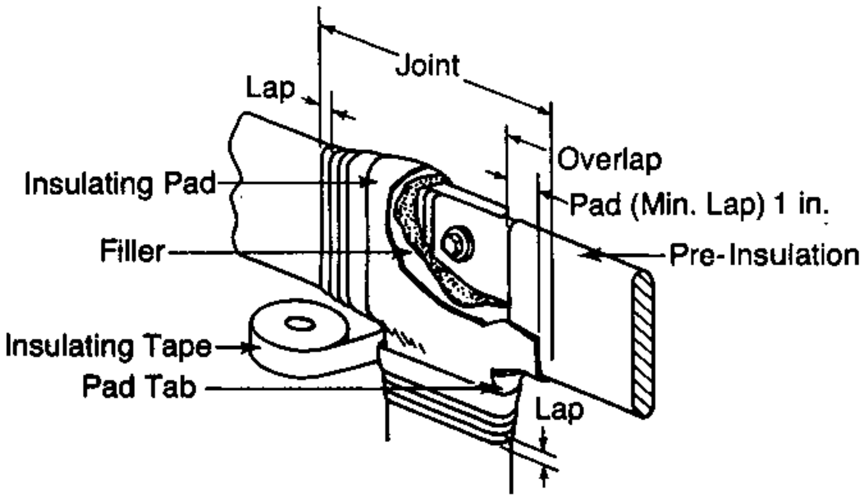
Fig. 15 – Line Conductors and User's Connections – Solderless Connectors Shown



Typical Tape Joint

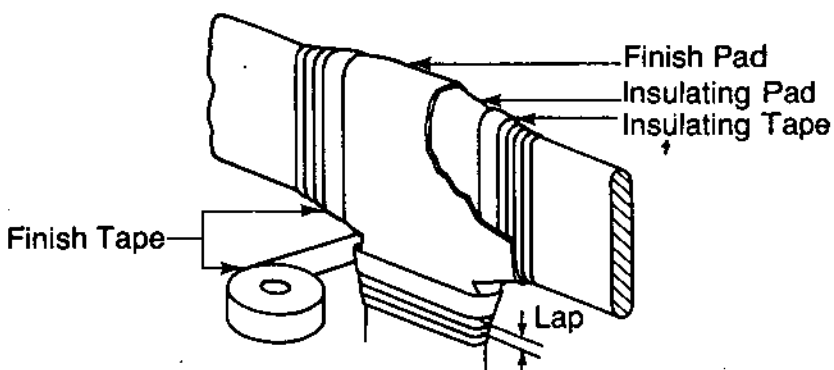


Typical Tape Joint
No Hardware



Insulating Tape and Pad

Typical Tape and Pad Joint



Finish Tape and Pad

Fig. 16 – Connection Taping Methods

K. Disconnecting Transformers

Disconnecting potential and control transformers up to 15 kVA, single phase, are enclosed in their own compartments. They are mounted on a cradle which is linked to the compartment door. When the door is closed, both the primary and secondary disconnecting contacts are engaged. When the door is opened the linkage rotates the cradle disconnecting both primary and secondary contacts, and the grounding fuses and high voltage winding of the transformers. A shutter drops to block access to the primary contacts, and a catch secures the door in the open position. In this position the fuses may be removed. Figure 17 shows a potential transformer mounted in an upper rear module.

L. Disconnecting Fuses

When the control power transformer is larger than 15 kVA single phase, it is fixed mounted, usually in an auxiliary unit, and fuses are mounted in their own compartment nearby. The fuses are mounted on an insulated cradle linked to the compartment door so the primary contacts are engaged when the door is closed and automatically disconnected and grounded when the door is opened. A catch secures the door open. In this position the fuses may be removed.

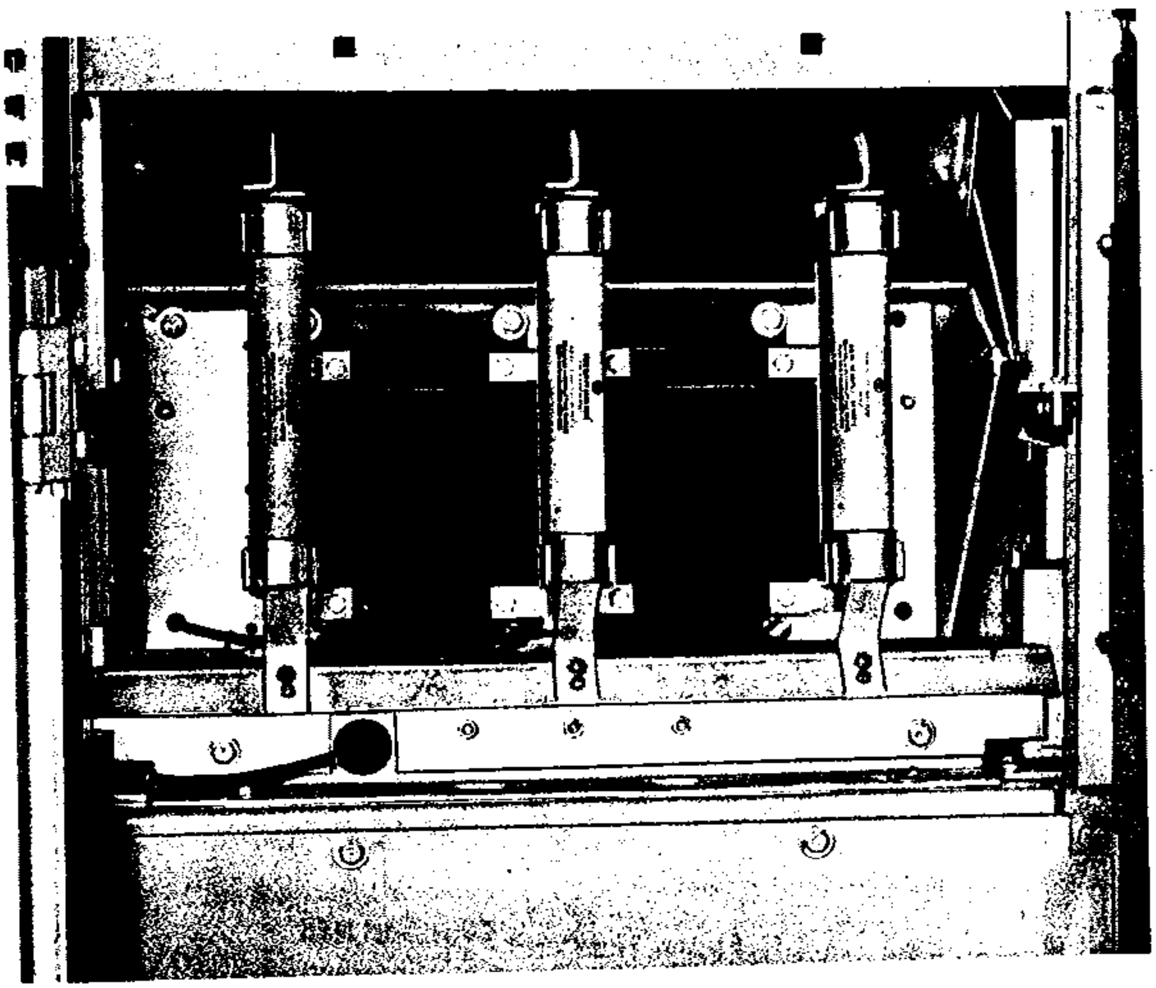


Fig. 17 – A Potential Transformer Mounted in an Upper Rear Module

M. Control Power Transformer Door Interlock
A control power transformer door interlock requires that the transformer secondary breaker be opened before the compartment door can be opened to disconnect the primary fuses.

If the control power transformer or disconnecting fuses are in an auxiliary unit, the secondary breaker is usually mounted above the compartment in such a way that a mechanical interlock is provided between the compartment door and the breaker. If the devices are located away from the secondary breaker a key type interlock is provided to perform the same function.

N. Accessories
Warning: Use these accessories only in strict compliance with the manufacturer's instructions; failure to do so can result in severe personal injury or death.

Any metal-clad switchgear installation will be supplied with a variety of tools and accessories to assist in handling and testing breakers and other devices. Included will be such tools as:

Maintenance handle for manually opening and closing the breaker;

Levering-in crank for shifting the breaker in its compartment;

Spanner nut wrench to remove, replace, and tighten main contacts;

Test plugs for use with relays and meters;

Test cable for electrically operating the breaker when it is out of its compartment;

Turning dolly used with indoor installations for handling the breaker when it is outside its housing;

Transport truck used with outdoor aisle-less switchgear for handling the breaker outside the housing;

Arc chute lifter used on same breakers to tilt the arc chute;

Test cabinet used for operating the breaker when outside its housing;

Ground and test devices permit access to stationary primary contacts in the housing allowing various tests and connections to either bus or outgoing line.

2.4 Receiving, Handling, Storage

Metal-clad switchgear is shipped in groups of one or more housings. A shipping group may be a complete assembly or only a part of an assembly, depending on size, weight, and the handling facilities at the destination. Indoor shipping groups are bolted to wooden skids and shipped via weather protected carrier. Outdoor shipping groups do not require skids. The floor, roof, and end sections of outdoor switchgear may be shipped separately for on-site assembly. Breakers, and accessories will be packed and crated separately.

A. Receiving

When metal-clad switchgear reaches its destination the material received should be checked against the shipping list to make sure everything has been received. Unpacking, before unloading, should go far enough to allow inspection for damage. If damage is found or suspected, the manufacturer should be notified and claim filed with the delivering carrier.

If the gear is to be immediately installed, the following procedures should be followed. If it is not to be immediately installed, follow procedures recommended under Storage (2.4, C).

B. Handling

Limitations of size, weight, or convenience may require that a switchgear line-up be shipped in groups. There may be, on a large complex installation, as many as seven shipping groups. Shipping groups will be equipped with lifting angles, jack supports, lifting lugs, and other arrangements to allow for handling by crane, dolly, or roller.

Notice: When lifting a shipping group by the lifting angle a balancing chain should be used because the angle is not in the exact center of gravity. When lifting outdoor switchgear by lifting lugs the spreaders must be used to prevent the group upsetting. The group must not be lifted by the spreader alone. Refer to Figures 18 and 19.

C. Storage

Indoor metal-clad switchgear that cannot be installed and put into service immediately should be stored in a clean dry place, preferably indoors in a heated building. Proper storage facilities should be arranged in advance of receipt of the shipment. The stored equipment should be accessible only to authorized persons and should be quickly available when needed in the erection schedule. Conditions of dampness, changing temperatures, dust, and corrosive atmosphere should be avoided.

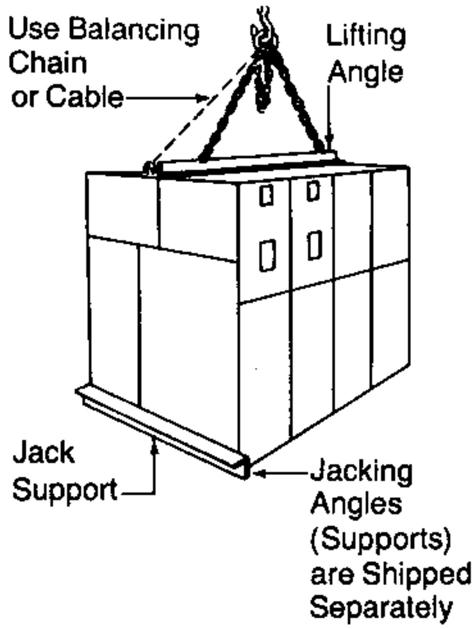


Fig. 18 – Handling an Indoor Shipping Group

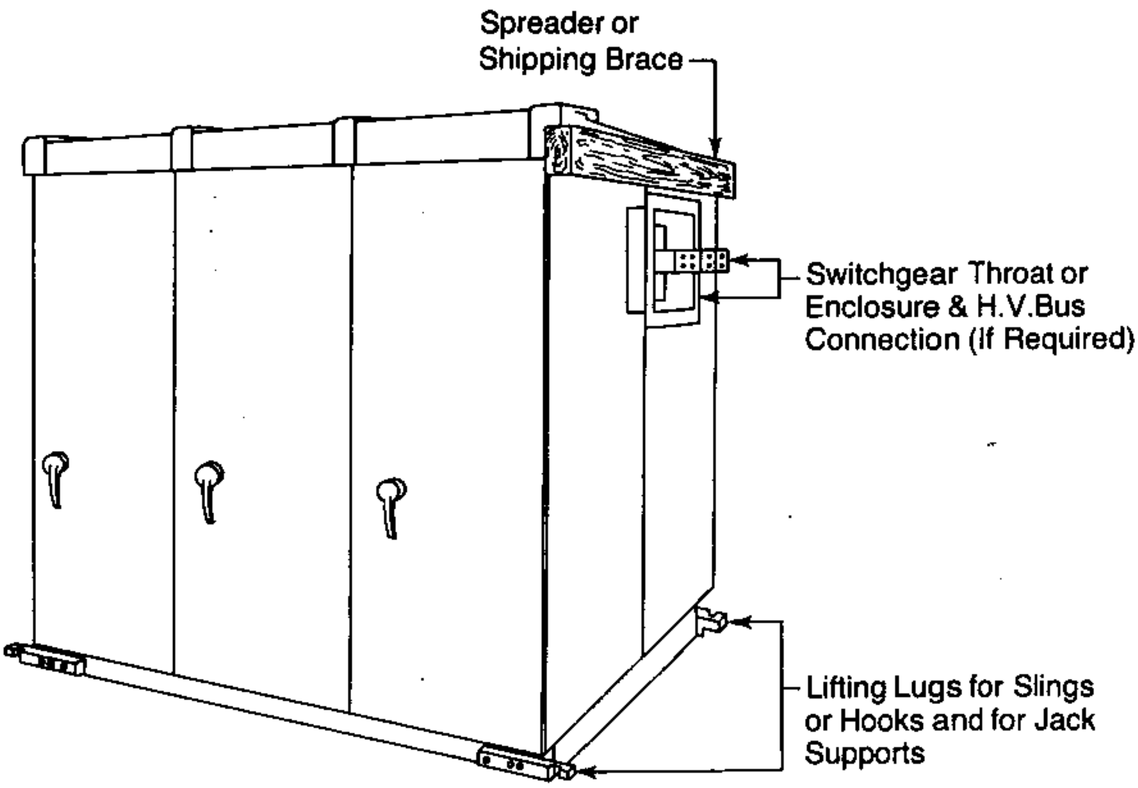


Fig. 19 – Handling an Outdoor Shipping Group

When it is necessary to temporarily store indoor switchgear outdoors special precautions must be taken to keep it clean, and warm enough to prevent condensation. It will be necessary to cover the equipment with a weatherproof cover and install temporary heating equipment. Approximately 250 watts per switchgear unit are required under average conditions to control condensation.

Notice: The wrappings and covers provided for shipment are not adequate protection for outdoor storage.

Outdoor metal-clad switchgear requires a minimum of care during outdoor storage. The storage location should be reasonably free from dust and corrosive gases, and the space heaters with which it is equipped should be energized. Additional protection is necessary at the exposed end at shipping breaks if the shipment consists of more than one shipping group.

Notice: Be sure the shipping groups are resting on smooth level surfaces to prevent strain and possible distortion and misalignment. This applies to all types both indoor and outdoor.

2.5 Installation

The manufacturer will supply floor plans, wiring diagrams, schematic diagrams, foundation plans, and weights and dimensions with the installation instructions. All this material should be carefully studied before any installation work is attempted.

A. Foundations

The foundation upon which the switchgear is to be mounted may be a concrete floor, pad, footers, or pillars depending on the type of gear. It must have sufficient strength to support the weight of the structure and the breakers plus the shock or impact resulting when breakers open under short circuit conditions. The manufacturer will supply weight information to which should be added an adequate safety factor.

1. *Indoor Foundations*

The foundation should be made of steel channels embedded in a level concrete floor. The steel channels must be in a true, flat, and level plane throughout their entire length to prevent distortion of the switchgear structure.

The preferred method of anchoring indoor metal-clad switchgear is to bolt it to the embedded steel channels. Detailed floor plans for locating and drilling the steel are supplied by the manufacturer.

The finished floor may have a slight pitch away from the channels, but in no instance should the finished floor be higher than the top of the channels.

Special attention should be given to the accurate leveling of the floor adjacent to the housings on the breaker drawout side. The convenience and speed of insertion and removal of the circuit breakers will be aided by a smooth, hard floor.

When installing metal-clad switchgear on existing floors it is recommended that a new finish floor with embedded channels be poured. An alternative is that slots should be cut in the existing floor for embedding and leveling the supporting channels.

2. *Outdoor Foundations*
Outdoor metal-clad switchgear has an integral base frame of steel channel. It is necessary only to install a suitable foundation upon which to bolt down the line-up. The foundation must be smooth, level, and stable under all weather and temperature conditions. It must be capable of supporting the weight of the switchgear with an adequate margin of safety.

The foundation may be a simple concrete pad, footers, or pillars. The recommended foundation for aisle-less outdoor switchgear is a full concrete pad under the assembly extending at the front to provide a breaker drawout area. If the aisle-less foundation is footers or pillars, a breaker drawout pad at the front of the line-up is required.

Details of the foundation bolting plan are supplied by the switchgear manufacturer.

B. Floor Plan and Conduit Layout
Provisions must be made in the foundation for conduits which carry the main cables, control wiring, and ground cable when these conduits enter the switchgear from below. The floor plan or base plan is supplied by the manufacturer and must be followed in making the conduit layout, spacing of floor channels, and determining space requirement. Conduits should project above the finished floor approximately two inches for indoor switchgear and eight inches above the foundation for outdoor

switchgear. Moving the groups into place will be simplified if the conduits are approximately flush with the concrete, and extensions added after the groups are in final position.

If more than one control conduit is required per housing, the conduits must be aligned in the space allotted to them on the floor plan. It is a good precaution to provide a blocked out slot in the floor or to provide clearance holes around the secondary conduits so minor bending of the conduits can be done when the switchgear is installed. This gives some flexibility in making connections.

Caution: Avoid encircling loops of reinforcing or building steel around single phase conductors rated 600 amperes or more. This precaution will prevent overheating due to induced currents which can cause severe personal injury and damage to property.

C. Shipping Groups

The following are recommended procedures and operation sequences for installing shipping groups:

1. *Remove crating and packing material.* Do not remove skids from indoor groups if rollers are to be used. For outdoor groups careful attention should be given to the manufacturer's instructions about aisle shelters and shipping brackets.

2. *When three or more shipping groups* are to be arranged in a continuous assembly, the center shipping group must be installed first. Other groups should then be installed in each direction from the center of the line-up.

When installing a unit substation or power center which includes metal-clad switchgear, the power transformer and the adjacent metal-clad switchgear group should first be lined up and positioned, additional groups can then be installed.

3. *Move the first group into position* by crane or by pipe rollers. If rollers are used they should hold the group high enough to clear the conduits projecting from the floor. If main cables enter at the bottom of outdoor groups it may be necessary to remove some of the rear and floor panels.

4. *Establish a base line* a few inches in front of the group and parallel to the final position of the group. Equalize the distances from the front of the housings to the base line. This makes the group parallel to the base line.

5. *Check each housing* with a level both laterally and longitudinally. These checks should be made on the floor of the housing on the paths along which the circuit breaker wheels will travel. Check each housing for plumbness using a plumb line.

If housings are not level or plumb the cause may be poor leveling of foundation members. Poor indoor leveling can be corrected by inserting shims at the points where the individual housings are attached to the steel floor channels. Poor outdoor foundation leveling can be corrected by inserting shims at the point where the base frame is fastened to the foundation.

Switchgear will operate successfully on a true and flat foundation which has a uniform slope of no more than 1/8 inch in three feet. The floor of the housings must be parallel to the foundation and the vertical center line of the housings must be perpendicular to the floor.

6. *Subsequent groups* should be moved into position and installed as described above. The groups should be bolted together and given a final level and plumb check. The entire line-up should then be attached to the foundation by bolting or welding.

7. *Special care should be taken* in positioning walk-in outdoor switchgear shipping groups to assure the aisle parts will fit properly and maintain the weather tight integrity of the installation.

8. *All lifting angles, lugs,* and shipping braces should be removed.

D. Power Transformer and Bus Run Enclosure Connections

Switchgear assemblies are often installed adjacent to power transformers to form unit substations on power centers. Also, switchgear frequently ties into bus runs. In these cases, the connection of the switchgear to the transformer or the bus is a part of the installation. There are five general types of enclosure connections between switchgear and power transformers or bus runs. The manufacturer supplies a drawing showing the proper assembly of these connections.

1. *Flange-less Connection*

Figure 20 shows a flange-less connection. It may be used for either indoor or outdoor connections. A crimped and formed band is used to join the mating enclosures. Installation consists of aligning the enclosures, aligning the band (top to bottom) and bolting in place. For outdoor installations gaskets are supplied.

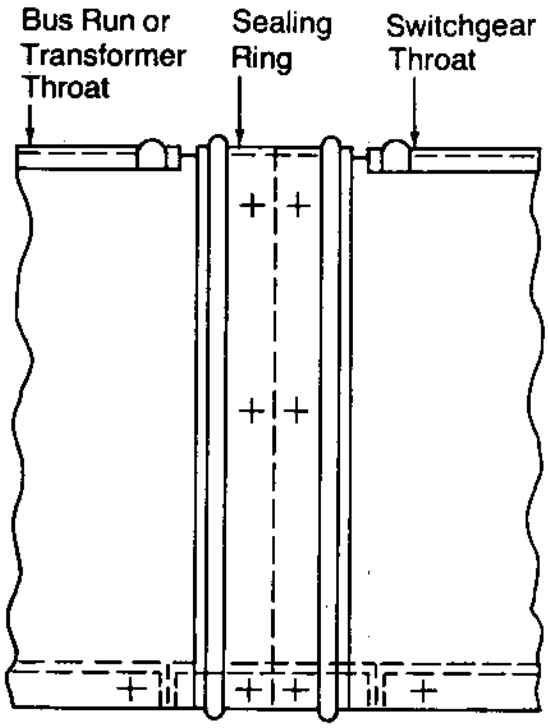


Fig. 20 – Flange-less Enclosure Connection

2. *Undrilled-flange Connector*
This enclosure connection is generally used for outdoor installations between transformers or generators, and switchgear where it is desirable to isolate the switchgear from vibration. The flanges are turned inward and not drilled. A sealing ring assembly with felt and cement is furnished for weatherproofing the connection. To install, align the mating flanges, cement the felt to the outside surfaces of both flanges so any gap between them is sealed. Slide the frame of the sealing ring down from the top and secure in place by bolting on the bottom section. See Figure 21.

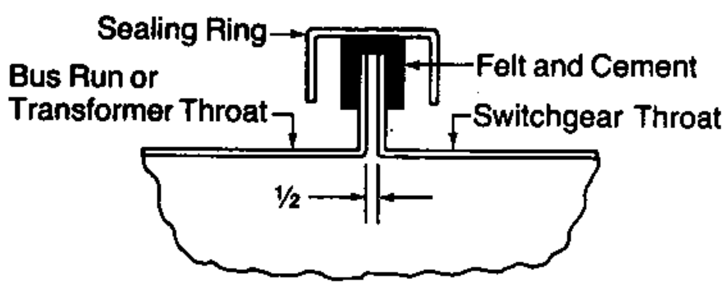


Fig. 21 – Undrilled Flange Connection

3. *Drilled-flange Connection*
This enclosure connection will be found in both indoor and outdoor installations. The flanges of the indoor type are turned inward and the flanges of the outdoor type are turned outward. To install the indoor type align the mating flanges and bolt together. To install the outdoor type align the mating flanges, insert the gaskets between the flanges and bolt together. If a sealing ring assembly is to be used as shown in Figure 22, bolt the flanges together, cement the felt to the outside surfaces of both flanges, and slide the frame of the sealing ring down from the top and bolt on the bottom section.

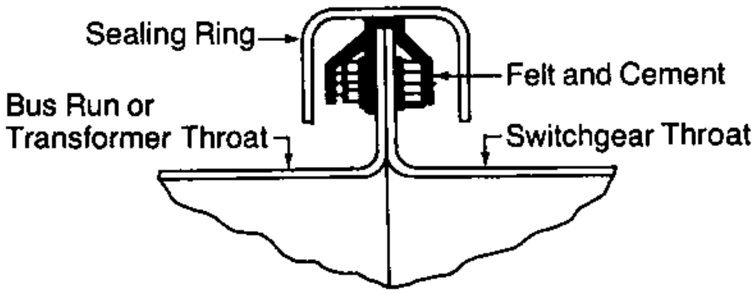


Fig. 22 – Drilled Flange Connection

4. *Box Enclosure Connection*
This device generally encloses connections and transitions between outdoor switchgear and outdoor power transformers. The manufacturer's instructions, supplied with either the transformer or the switchgear should be followed.

5. *Close-Coupled Connection*
This method is used only on indoor installations. It generally is used to enclose connections between indoor transformers and indoor switchgear. For both dry-type and liguid-filled transformers the connection and transition compartment may be part of either the transformer or the switchgear. To install, align the switchgear housing against the transformer transition compartment, butt together, and secure with tie bolts.

E. High Voltage Bus Connections
High voltage bus connections that must be made in the field are those between switchgear and power transformers or bus runs, and between switchgear shipping groups.

High voltage insulation is required on all metal-clad switchgear conductors within the switchgear and up to and including the joint to non-switchgear equipment.

High voltage bus connections within power transformer or bus run enclosures require insulation if the connection is to metal-clad switchgear, or where electrical clearances warrant it.

Warning: Give special attention to the adequacy and maintenance of insulation of joints using flexible connectors. Flexible connectors tend to flex and bow, particularly under short circuit conditions, reducing electrical clearances. This can result in severe personal injury or death, and damage to property.

Switchgear high voltage bus connections at shipping group breaks must be made in the field. At the group break, sections of the bus are removed, identified, and packed and shipped separately. At the time of installation, after aligning and bolting together the power transformer or bus run enclosures and the switchgear shipping groups, the following procedure is to be followed:

1. *Clean the silverplated contact surfaces* with crocus cloth and wipe with non-flammable solvent.

Warning: Do not breath cleaning solvent vapors and avoid direct contact with the skin. These solvents are highly toxic and readily absorbed into the body. Failure to observe this warning may result in bodily harm or death from poisoning or asphyxiation.

2. *Bolt bus bars together* using splice plates or flexible connectors and hardware supplied. Recommended bolt tightness is shown in Tables 1 and 2 below:

Table 1
Bolt tightness for bus and connections

	Torque in foot-pounds for Bolt Diameter in inches					
Bolt Material	**1/4**	**5/16**	**3/8**	**1/2**	**5/8**	**3/4**
Heat Treated Steel	5	12	20	50	95	125
Silicon Bronze	5	10	15	40	55	—

Table 2
Torque in foot-pounds for Bolt Diameter for Flexible Shunt Connections

	Bolt Size and Torque in Foot-Pounds				
Bolt Material	**.250-20**	**.312-18**	**.375-16**	**.500-13**	**.625-11**
Heat Treated Steel	6	15	25	60	115
Silicon Bronze	6	12	18	50	65

3. *Insulate the joint* or connection in accordance with procedures shown in Figure 16.

F. Main Power Connections

Warning: Phase rotation and phase angle must be the same when two systems are to be paralleled to avoid possible damage to equipment. Phase rotation must be in accordance with the drawings so the instruments, meters, and relays will function properly.

Warning: Avoid sharp turns, corners, and edges when forming cables within switchgear assemblies, to prevent damage to, or weakening of cable insulation. Follow the cable manufacturer's instructions precisely in determining minimum bending radii and proper tapering of insulation to establish necessary voltage gradients. These instructions vary with the size and type of cable and with the service voltage for which the cable is designed to operate. Failure to follow these instructions can result in severe personal injury or death and substantial damage to property.

1. *Solderless Cable Connectors*
Solderless connectors are normally furnished for terminating non-leaded cable. The complete connection must be insulated in accordance with the cable manufacturer's recommendations or in accordance with instructions in Figure 16.

Insulating clamps may be supplied. They separate the cables and support their weight. The cable manufacturer's instructions provide the exact details for terminating the specific type of power cable. If the exact outside diameter of the cable is provided to the switchgear manufacturer the cable clamps may be custom drilled to fit, otherwise they will be supplied with pilot holes and drilling to size must be done at installation. After drilling, the insulating clamps should be saw-cut longitudinally through the centerline of the drilled holes to facilitate installation and assure proper clamping action.

2. *Potheads*
Connections of cable into potheads should be made in accordance with the pothead manufacturer's instructions. Flexible connectors should be used to connect the pothead aerial lugs to conductors in the switchgear, this will avoid strain on the pothead insulators. The complete joint, including the flexible connectors should be taped as illustrated in Figure 16.

3. *Zero Sequence Current Transformers*
When zero sequence current transformers (BYZ) are provided, the power cables must pass through the transformer and terminate at the

switchgear terminals or at a pothead in accordance with the switchgear manufacturer's instructions.

G. Ground Bus Connections

Notice: It is recommended that the installer consult *Electric Power Distribution for Industrial Plants,* **IEEE Std. 141, and** *Grounding of Industrial Power Systems,* **IEEE publication 141;** *Westinghouse Electrical Maintenance Hints,* **Vol. 1, Chapter 8** *Current Grounding Practice;* **and** *NEC* **articles 100, 200, and 250.**

Warning: A permanent low resistance ground is essential for adequate protection. A poor ground may be worse than none since it gives a false feeling of security to those working on the equipment. Failure to establish an adequate ground can result in severe personal injury or death, and damage to property.

Ground bus in metal-clad switchgear is assembled in sections with a joint in each housing. The section at a shipping break is removed and packed separately. It must be reinstalled in the field. Terminals are provided on the ground bus in one or more housings, they are for connecting the switchgear ground bus to the station ground. The connection to the station ground should be as direct as possible and should not be in metal conduit. It should be of sufficient size to carry the ground fault current of the installation.

For larger substations and generating stations the ground resistance should be one ohm or less. For smaller substations and industrial plants the resistance should be five ohms or less. The NEC states (1981) that the maximum resistance shall not exceed 25 ohms.

H. Secondary Connections

Internal secondary and control wiring on metal-clad switchgear is factory connected. Wiring to remote apparatus is factory connected to terminals or terminal blocks. Secondary and control cables from remote apparatus must be field connected to these terminals.

It is recommended that the loading of control buses be checked with an ohmmeter to guard against short circuits in the control wiring. This check should be made before initial energizing. If an ohmmeter is not available, serious damage to the control wiring may be prevented by temporarily connecting a small fuse, approximately one fourth the normal circuit rating, in series with the control source for the initial energizing check.

Openings in the sides of control modules provide access for control connections between housings. When shipment is made in groups, the cross connections are factory installed in one group, coiled, and identified for connecting to the adjacent group in the field.

Openings or couplings in the housings provide access for connections between switchgear and power transformers and for heater connections between switchgear and bus runs when required. When no conduit is supplied, the cross connections are factory installed in one housing, coiled, and identified for connecting to the adjacent group. Where conduit is supplied, the conduit and the wire between adjacent assemblies must be installed and connected in the field.

I. Potential and Control Power Transformers

Warning: Do not energize the switchgear until the following safety procedures have been completed. Failure to carry out these procedures can result in injury or death by electrocution and damage to equipment.

1. Remove shipping bolts on each side of the rotating assembly.

2. Connect operating link to bracket on door. This link will have been detached for shipment.

3. Check primary and secondary contact engagement with test light or bell. Contacts should make when door is a minimum of half an inch from fully closed.

4. Check that fuse ground contacts make in fully disconnected position.

5. Check fuses for continuity and proper contact in fuse clips.

6. Check mechanical interlocking of control power transformers for correct operation. If should not be possible to open the transformer compartment door without first opening the breaker in the secondary circuit of the transformer.

J. Disconnecting Fuses

Disconnecting fuses are ready for operation as received, but the following should be checked before placing in operation:

1. Contact engagement. Check with test light or bell.

2. Operation of mechanical interlock.

3. Continuity of fuses and proper contact in fuse clips.

K. Key Interlocks

Warning: Make sure the key scheme has been checked and that only the proper keys are left in locks. Make sure all extra keys are removed and stored where they are not accessible to unauthorized people. This procedure is a necessary safety precaution since improper use of keys will defeat the interlocking system and expose people to severe injury or death and equipment to damage.

Keylock interlocks are often supplied in conjunction with disconnecting switches, dummy breakers, and special compartments to which access is to be denied unless the circuit breakers controlling power to these non-switching devices have been withdrawn to the test position. The operation of the key interlock schemes is generally described in a note or keying chart on the drawings supplied by the switchgear manufacturer.

L. Moving Parts

There are few moving parts in metal-clad switchgear and most of these are factory installed. It is recommended that all moving parts be operated manually to assure that they move freely and sustained no damage in shipping, handling or storage.

M. Un-Blocking

Many pieces of equipment are blocked or braced for shipment. Devices such as meters and relays, disconnect transformers, and fuses must be examined and all blocking and bracing removed. The time dials of the relays will have been set at zero to close the relay contacts for shipment.

N. Pre-Operation Test and Inspection

After the switchgear and the apparatus which it is to control have been installed and all inter-connections made, the switchgear should be given a final inspection and test before being put into service. Care must be taken to prevent the controlled equipment from being connected to the system while preliminary tests are being conducted.

Danger: This equipment must not be connected to the power system while preliminary tests are being conducted. If disconnects are not available, line leads must be disconnected and remains disconnected during these tests. Failure to take this precaution can result in severe personal injury or death and damage to equipment.

1. *Test Equipment*

The test equipment required will depend on the size and type of gear. Portable voltmeters of the multi-scale type will be needed. For large complex installations ammeters should be available in the event trouble developes. Although insulation resistance will vary greatly due to the many parallel paths in equipment of this type, an ohmmeter and a megohmmeter will be needed to assure there is no insulation breakdown. Initial insulation values should be determined and recorded for comparison with values found later during periodic inspection and maintenance. A continuing comparison record is valuable to help detect any progressive deterioration of insulation. A simple portable test light or test bell will prove useful in making circuit continuity tests.

2. *Wire and Bus Connections*

Wire connections, accessible bolted bus connections, and insulated joints should be examined to make sure they have not loosened or been damaged during shipping or installation.

Connections to equipment apart from the switchgear, such as remote control and interlock circuits and auxiliary switches, should be tested to make sure they are correct. The thoroughness of this will depend on the quality of the installation work. There must be definite assurance that the connections are correct before any attempt is made to operate the switchgear or the apparatus it controls.

If the line-up is equipped with heaters they should be energized to confirm their operation.

3. *Relays*

Relays will have been checked at the factory and adjusted to the recommended setting. Final settings should be coordinated with other parts of the system in accordance with local standards and practice. If it becomes necessary to modify relay settings, the relay manufacturer's instruction literature should be consulted. The relay manufacturer's instructions may show typical connection diagrams and may not agree in detail with the connections furnished. The switchgear manufacturer's connections should be used.

Covers for meters, relays, and other devices which have been removed during the course of installation require careful handling. They should be kept clean and should be replaced as soon as possible to keep dirt from entering and collecting on vital parts.

After the switchgear has been installed and put into operation the drawings supplied with the equipment should be reviewed and marked to show any revisions made during installation. A set of marked drawings should be returned to the manufacturer so the permanent record can be corrected.

2.6 Inspections

Inspection and maintenance operations on metal-clad switchgear divide into two broad areas; the circuit breaker, and the cell equipment. Inspection and preventive maintenance are recommended on:

A. Circuit Breaker

Insulation
Contacts
Arc Interrupters
Mechanical Parts
Auxiliary Devices

B. Cell Equipment

Insulation
Cell contacts and joints
Circuit breaker control
Auxiliary equipment, relays, meters, etc.
Mechanical parts (especially for outdoor switchgear).
Ventilation of outdoor switchgear
Finish of outdoor switchgear

C. Inspection Schedule

The manufacturer's instruction literature will usually provide information on in-service inspection and maintenance. Experience with the equipment under service conditions may indicate that inspection periods can safely be extended.

It is a good general rule for feeder breakers in distribution service to be given several exercising operations at six month intervals and a complete inspection once a year, unless experience indicates otherwise.

2.7 Maintenance Tests — Insulation

Danger: Do not attempt to make insulation tests until the switchgear has been de-energized and assurance made that it will stay de-energized during the course of the tests. Failure to take this precaution will result in serious injury or death, and damage to property.

The insulation systems of metal-clad switchgear are designed to withstand operating voltage for several decades. During this time the insulation will be subject to conditions that cause a gradual decline in the resistance capability.

Frequent cleaning is necessary to maintain the resistance of the insulation system. Dirt alone is not a serious threat, but combined with moisture, including condensation, it causes electrical leakage. This leads to tracking and eventual flashover. Figure 23 illustrates the effect of voltage leakage on bus supports and bus bars.

Fig. 23 – The Effect of Voltage Leakage on Bus Bars and Supports

It is important to know the condition of the primary (high voltage) insulation. This is especially true for older installations and switchgear installed in unfavorable locations where the effects of deterioration may become a threat. The methods of testing insulation as a part of the maintenance program are important. The most useful insulation tests are:

Low voltage d-c resistance measurement with a megohmmeter at 600 to 2500 volts, d-c.

High potential test, direct-current.

High potential test, alternating current.

Power factor tests.

The direct-current resistance and power factor tests give an indication of whether the insulation is still qualified for the power circuit voltage. A low insulation resistance as shown in a megohmmeter reading, or a high power factor measurement are indications of a low voltage withstand ability. High potential tests are a direct measurement of voltage-withstand ability.

A — Power Factor Insulation Tests — General

The power factor insulation test has been frequently mis-applied in situations where it will not give a true indication of insulation condition. Power factor in insulation testing is basically the same as power factor in measurement. A piece of insulation with electrodes or terminals attached is equivalent to a capacitor in parallel with a resistor. When voltage is applied a small current flows. The measured current flow through the capacitance is wattless as in a lossless capacitor. The current passing through the resistance of insulation is pure loss current. Power factor is the ratio of power in watts to the product of the voltage and current, volt-amperes. ①Mathematically it is the cosine of the phase angle between the total current and the resistance component of the current. In insulation measurement the numerical value of the power factor is usually small, in the order of a few percent, zero being perfect. The term dissipation factor is sometimes used. It is the tangent of the loss angle, complement of the phase angle. For small phase angles the values are the same for practical purposes.

For power factor measurements to be meaningful in judging absolute withstand capability of insulation systems, it is necessary first to establish a statistical correlation between power factor, voltage withstand capability, and service life for the kind of system being tested.

The key in the insulation measurement is the heat developed in the insulation by dielectric loss. Power factor is not a measure of dielectric loss. When correlations with dielectric strength and service life are established, power factor becomes an indirect way of evaluating loss.

When dielectric losses develop enough localized heat to create disintegration of the insulating material, a failure or dielectric breakdown exists. In normal good quality insulation, the dielectric losses are distributed fairly uniformly in relation to the electrostatic field. In poor quality insulation the losses may be concentrated in small areas. It is possible that two pieces of insulation with the same power factor measurement may have widely different dielectric strengths. Dielectric strength is the primary objective of insulation therefore a measure of power factor is not an adequate evaluation of insulation quality. Power factor measurements must be correlated with dielectric strength, otherwise measurements of power factor at intervals serve only for comparison to indicate progressive deterioration of insulation.

① ASTM methods of test for alternating-current loss characteristics and dielectric constant of solid electrical insulating materials. ASTM D150-65T.

B — Power Factor Tests —
Air Circuit Breakers, Metal-Clad Switchgear

When properly made and evaluated, power factor tests are useful in detecting signs of insulation deterioration. Great care must be used in making measurements and it must be understood that the power factor numerical values may have little absolute value. If there is an increase in power factor values measured once a year it may well indicate a deterioration of the insulation. Power factor values are used chiefly for comparison so they should be measured under conditions as nearly identical as possible. In making comparisons of power factor measurements, allowance must be made for differences in temperature and humidity, so both temperature and humidity should be measured and recorded when power factor measurements are made. Power factor values tend to be higher when temperature and humidity are higher.

As a general rule, on an air circuit breaker, only the bushings should be power factor measured. The arc chutes and other ground insulation, including operating rods and braces, should be disconnected to isolate the breaker.

Power factor measurement of arc chutes can be misleading and is seldom worth the effort. The arc chute is a complex of insulation parts, it has relatively great surface and bulk, with many areas of small gaps between materials of different dielectric constants, which produce high dielectric stress on small air gaps. In most arc chute designs power factor measurement will show a capacitance of only a few picofarads. These characteristics can indicate that the arc chute has a high power factor compared to the condenser bushings, but it may still have an adequate dielectric strength and service life.

Power factor measurement of other components of the breaker, lift rods, braces, and pole unit supports, has no practical value. Their capacitance is so low that accurate measurement in place is difficult. This measurement is subject to the same misleading results as the measurement of the arc chutes.

C. High Potential Insulation Tests

The high potential test should be the primary field insulation test used on switchgear installations. It should be separately applied on the magnetic breaker and the stationary gear. ANSI Standards② specify that field tests be made at 75 percent of the factory production tests. The standard factory withstand test is specified to be 60 hertz for one minute. ANSI has tabulated values of direct current test voltages approximately equivalent to the corresponding 60 hertz withstand test values. The dc tests are not required but are permitted.

② ANSI Standards, C-37.20-7.2.2.1 and 7.2.4.2 switchgear assemblies including metal enclosed bus.

Warning: Do not conduct direct-current high potential tests on switchgear unless the manufacturer approves, and then only with great care. Failure to consult with the manufacturer may result in severe personal injury or death, and substantial damage to the apparatus.

The alternating-current high potential test is the preferred test because it subjects the insulation to the same type of heat-conductive alternating stress the insulation must endure in service.

Tests of insulation resistance using a megohmmeter are not reliable indications of high voltage insulation quality. In complex apparatus this test can indicate low values of insulation resistance because of numerous parallel paths. The megohmmeter reading can also indicate high resistance value when the insulation has very little dielectric strength.

In all instances, consult the switchgear manufacturer before making any test not in accordance with the instructions supplied with the equipment.

Preventive maintenance is the best way to keep insulation in useful operating condition:

Keep it dry.

Keep it clean.

Do not subject it to higher than rated voltage.

2.8 Circuit Breaker Maintenance

Danger: Do not attempt any maintenance activities on switchgear unless it has been confirmed that the switchgear is de-energized and precautions taken to insure that it will remain de-energized while the work is being done. Failure to do so can result in severe personal injury or death, and substantial damage to property.

A. Contacts

The functioning of the circuit breaker depends on the contacts. Most magnetic breakers have at least two distinct sets of contacts on each pole, main contacts and arcing contacts. Some have an intermediate pair of contacts which open after the main current carrying contacts and before the arcing contacts. When closed practically the entire load current passes through the main contacts. High overload or short circuit current must also pass through the main contacts during opening or closing of faulted lines. If the resistance of these contacts becomes high they will overheat. Foreign material may become embedded in the surfaces, spring pressures holding them in contact may weaken, or they may become pitted. Any of these conditions will cause excessive current to be diverted through the arcing contacts with consequent overheating and burning as shown in Figure 24.

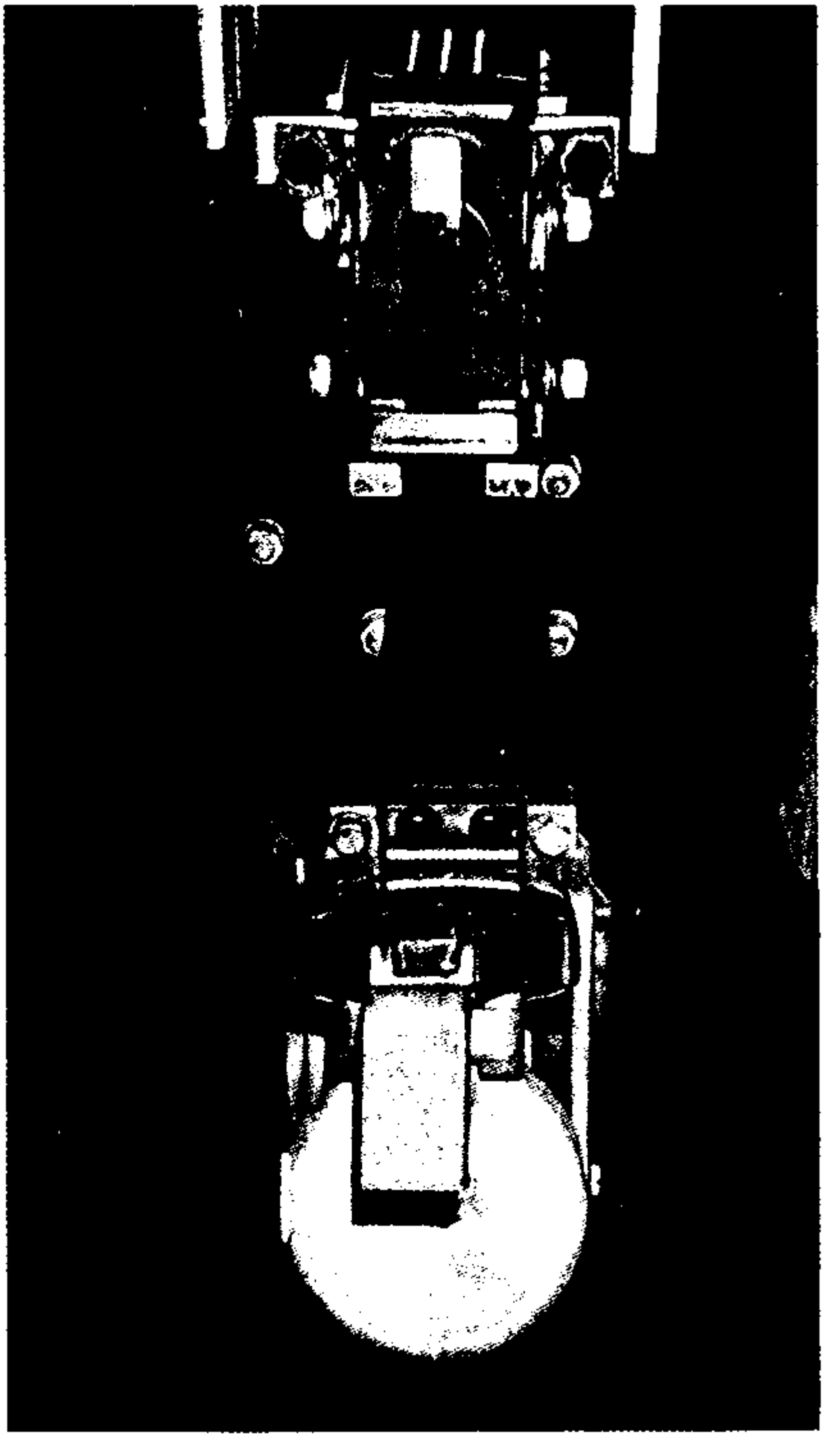


Fig. 24 – Contact Burning and Pitting – Found on a First Inspection

Arcing contacts get their name from the fact that they are the last to open so any arcing normally originates with them. In circuit interruption arcing contacts carry current only momentarily, but that current may be equal to the interrupting rating of the breaker. In closing against a short circuit, the arcing contacts may carry much more current than the short circuit interrupting rating of the breaker. The arcing contacts must make positive contact when they are touching. If contact is not positive the main contacts may be badly burned when interrupting heavy faults.

Warning: Make sure the arcing contacts make positive contact. Failure to do so could result in failure of the breaker to interrupt a fault current.

On magnetic air breakers the arc is quickly removed from the arcing contacts by a magnetic blowout field and travels to arcing horns or runners in the arc interrupter. The arcing contacts will eventually burn enough to require replacement. These contacts should be replaced well before they reach the point that there is danger of burning through the tips into base metal. Contact replacement should always be done in accordance with the manufacturer's instructions.

General rules for maintaining contacts on all types of circuit breakers are:

Keep them clean.

Keep pressure normal. Reference manufacturer's instructions.

Keep them smooth.

Keep them in alignment.

B. Arc Interrupters

Magnetic arc interrupters on air circuit breakers are built with only inorganic materials exposed to the arc. Ceramic materials line the throats of the interrupters in the vicinity of the arcing contacts. These interrupter plates or fins cool and disperse the arc flame. No matter what material is used, arcing can melt and vaporize it.

The arc also melts and vaporizes the contact metals and some of the metallic vapors and some oxides condense on surrounding insulating surfaces, decreasing their insulation resistance. Repetitive arc interruptions will lower the insulation resistance to the point where leakage will increase and under extreme conditions fail to hold open circuit voltage.

Any insulation maintenance test should include a test across the terminal connections of each arc chute. An a-c high potential test across the arc chute gives the best indication of service condition. Do not make a d-c high potential test and do not rely on a megohmmeter reading.

C. Operating Mechanisms

The operating mechanism functions to open and close the breaker contacts. It consists of a series of linkages connected to a power operating mechanism, either a solenoid or a spring device. Most breakers contain one or more solenoids or electromagnets for tripping. Tripping is mechanically independent from the closing device so the breaker can be tripped even though the closing device is in the closed position. This combination is called a mechanically trip-free mechanism.

The mechanism opens the breaker when the tripping coil is energized. This is usually when an overvoltage condition exists. Some breakers are supplied with undervoltage tripping devices which will open the breaker upon a loss or decrease of either main power or control voltage.

Inspection of the operating mechanism should include hand closing of the breaker to make sure all parts operate freely. If dirt or foreign matter accumulates around pins, in bearings, latches, or movable parts they will not work freely. The breaker may fail to open under an overload or fault condition. Maintenance should always include making sure all parts are clean.

Inspection should include a check for wear. Excessive wear usually results in loss of travel of the breaker contacts. Adjustments are provided for wear in some parts but with others replacement is the only remedy.

On infrequently operated breakers it is recommended that they be given a few exercise operations once or twice a year.

2.9 The Stationary Switchgear Structure

Danger: Do not undertake any inspections of the interior of switchgear unless it has been confirmed that the switchgear is de-energized and precautions taken to insure it will remain de-energized during the inspection period. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Auxiliary equipment should be inspected periodically. Control relays and switches should be tested for operation. Protective relays should be checked for operation and setting on a regular schedule to assure they are coordinated with other relays in the system and that they operate to trip only the circuit or circuits in trouble.

Bus supports and bus insulation must be kept clean and dry. All bus supports, control wiring, instrument transformer leads, mountings, and all other devices should be inspected for tightness at regular intervals. On encapsulated joints inspection should be made for signs of overheating and distress.

Under normal atmospheric conditions a thorough inspection and maintenance check should be made once a year. Abnormal conditions may require more frequent inspection. Under extreme conditions such as exposure to salt spray in coastal areas, and atmospheres with high chemical vapor content, carbon or graphite dust, iron oxides or other conducting dusts, it may be necessary to locate the switchgear in a tightly closed air conditioned room equipped with air filters. Switchgear should never be situated where it will pass through the dew point. Heat losses in the equipment when under load will normally keep it above the dew point. When the switchgear is not energized the space heaters should be kept on.

2.10 Inspection

An important factor in system reliability is a regular switchgear inspection and maintenance program. All switchgear in the installation should be included and provision should be made for scheduled maintenance at least once a year. The ultimate long term performance of switchgear depends on the reliability of its insulating components. A careful inspection of all insulation should be a part of the scheduled annual maintenance.

A. Inspection Frequency

An annual inspection of the entire switchgear assembly during the first three years is considered a minimum for installations in normal circumstances. Inspection frequency can eventually be increased or decreased, depending on environment, observation, and experience. It is good practice to follow the manufacturer's recommendations regarding inspection and maintenance until sufficient knowledge has been accumulated to permit modifying the recommended practice. Experience proves it is better to stay on the conservative side, inspecting frequently then gradually extending the interval if conditions warrant.

These factors will influence decisions on when to inspect switchgear insulation:

Number of shutdowns scheduled;

frequent emergency shutdowns involving switchgear;

long periods of sustained overloading or abnormal operating conditions, numerous switching operations, or power surges;

numerous feeder, bus, or system faults;

extremes in atmospheric conditions in the plant;

frequency of maintenance requirements and schedules for related equipment, either component parts of the switchgear or apparatus connected to the switchgear circuits.

time is the most important factor but other indicators, including the number of breaker operations, may be used as a guide.

B. Partial Inspection

Danger: Do not attempt to make partial inspections of switchgear circuits that are not de-energized and precautions taken to insure that they will stay de-energized during the inspection. Failure to take this precaution can result in severe personal injury or death, and damage to property.

Non-critical circuits can be taken out of service, leaving the main bus energized. A visual insulation inspection of secondary bus risers and supports on the load side of the switchgear can be made since the breakers are in the open position.

When operating conditions make a full shut-down impractical, a partial inspection may force a decision to schedule a total outage for maintenance to avoid total failure.

Conditions in those areas accessible for visual inspection are not always indicative of conditions in other areas that cannot be inspected under energized conditions. A partial inspection is not an adequate substitute for a full shut-down inspection.

Warning: Partial inspections are to be made only by qualified, experienced personnel who are familiar with the construction and operation of the apparatus and the hazards involved. If such people are not available do not undertake the procedure. Failure to take this precaution can result in severe personal injury or death, and damage to property.

C. Records

A record of each inspection and maintenance activity should be kept. The record should show:

Date, time, and names of people making the inspection;

whether full or partial inspection and exactly what was inspected;

pertinent environmental data; weather conditions (outdoor switchgear), temperature, humidity (indoor switchgear), and general atmospheric conditions. When equipment is de-energized for longer than one day, environmental data should be recorded for each day of outage;

any unusual conditions or apparent changes observed since last previous inspection;

all maintenance procedures performed or needed, with specific reference to apparatus location. Identify the switchgear by its unit number and the main bus, breaker, phase, or device requiring maintenance.

Notice: When the switchgear is de-energized for any extended period it is recommended that the switchgear temperatures be maintained above the dew point. If the gear is equipped with heaters they should be energized, if not, portable heaters should be installed if needed to maintain temperature. Records should show this procedure was followed.

2.11 How to Inspect Switchgear

Switchgear inspections should be made only by qualified persons. Only electrical workers familiar with the construction and operation of switchgear and with the hazards involved should be permitted to inspect or work on it.

There are many things to look for when inspecting switchgear, some require very close scrutiny to detect.

A. Energized Equipment

Sounds — listen for popping or crackling sounds produced by electrical discharges or sparking, and for humming noises of vibration caused by electrical resonance.

Visuals — with lights out, look for blue or purple corona halos. Orange or red sputter arcs are created by intermittent sparking. (Note: Under darkened conditions it may require several minutes for the eyes to adjust and see these electrical displays. They are generally of low intensity, merely a glow in the dark.)

Odor — Ozone, produced by corona or overheating of organic materials can be detected by smell.

B. De-energized Equipment
Physical Damage — look for cracks, breaks, de-laminations, warping, blisters, flaking, or crazed insulations. Check for warped or distorted insulated bus, bent structural frame work.

Foreign Objects — check for any objects out of place, loose hardware, mislaid tools, etc.

Signs of Moisture — look for powdery deposits, carbon tracks, moisture stains, rust, or flaking paint or varnish. They are signs of moisture. Find the source and take preventive action.

C. Inspection Equipment
In addition to safety equipment, inspection equipment should include: Controlled lighting of sufficient intensity and focus to illuminate inspection areas without glare or reflection. Too much light can mask surface conditions.

Hand Mirror — to inspect inaccessible areas a hand mirror about 2 x 3 inches with an eight to twelve inch handle.

Knife or scraper for collecting deposits and an envelope to store them in for later identification.

Magnifying glass or low power pocket microscope for close inspection.

D. What to Inspect
Although inspection should be directed primarily at the insulation details, it is advisable to inspect the condition of all structural members close to insulation. This is recommended because, for instance, water from a leaking roof or steam line can travel for some distance before finding an opening and finally finding an insulating surface.

Inspection should be made before any cleaning or dust removal and repeated after cleaning. Telltale signs are left in dust which can reveal of otherwise hidden conditions. Moisture droplets leave tiny craters in dust even when not leaving a stain. Dust can cover some signs so re-inspection after cleaning is also necessary. For example a carbon track starting to form on a bus support may be completely hidden under a layer of dust.

The entire insulating structure should be carefully inspected. Special attention should be given to areas where distress is most likely to occur:

Boundaries between two contiguous insulating members,

boundaries between an insulating member and the grounded metal structure,

taped or compound insulated splices or junctions,

bridging paths across insulating surfaces; phase-to-phase or phase-to-ground,

hidden surfaces such as the adjacent edges between upper and lower members of split type bus supports or the edges of a slot through which a bus bar passes,

edges of insulation surrounding mounting hardware, either grounded or floating.

E. Evaluating Inspections

In evaluating inspections certain basics should be considered:

The first object of the inspection procedure is to make observations that can be used to determine the cause and severity of any condition noted.

The second objective is to develop a program of restoration and correction. If affected components cannot be restored to original effectiveness they should be replaced.

Many conditions take time to develop, sometimes relatively long periods. Usually symptoms of adverse conditions are not continuous, especially in early stages. Signs may be random and intermittent or regular and predictable.

The observed symptoms may not be signs of current conditions. They may be remnants of problems that have been corrected. These signs should be noted and watched to see if they recur.

2.12 Most Common Causes of Insulation Distress

A. Physical Damage

Broken or cracked insulating supports can allow the supported components to be subjected to mechanical stresses for which they were not designed, resulting in ultimate failure.

Damaged or contaminated insulation materially reduces voltage striking and creepage distances, ultimately resulting in flashover.

Physical damage can result from many causes:
Mishandling during shipment, storage, installation.

Overloading or inadequate maintenance.

Mechanical forces induced by heavy faults.

Thermal cycling of insulation.

Strains induced by improper mounting of insulators.

Some of these conditions result from degradation of mechanical properties from other causes.

B. Heat

Temperatures even slightly over design levels, if sustained for prolonged periods, can greatly shorten the effective electrical life of organic insulation materials, it will also cause physical deterioration resulting in lower mechanical strength.

Localized heating (hot spot) is hard to detect because the overall temperature of area is not raised appreciably. Examples are loosely bolted bus connections and void spaces in a taped or compounded joint.

Since inspections in which interior temperatures can be checked are made with the equipment de-energized, temperature is not a reliable indicator of damaging heat.

Observed signs should be used as a more reliable basis for detecting damaging heat:

Discoloration usually a darkening of materials or finishes,

crazing, cracking, or flaking of varnish,

embrittlement of tapes and flexible insulations,

de-lamination of taped conductors or laminated insulations,

generalized carbonization of materials or finishes,

melting, oozing, or exuding of substances from within an insulating assembly.

C. Moisture

Moisture should be controlled or eliminated if possible. Obvious sources such as leaking roofs and pipes can be readily dealt with, but high humidity, fogs and mists, and moisture in the air generally are difficult to deal with. Moisture can eventually penetrate and be absorbed into many types of organic insulating materials, increasing their electrical losses. Sealing coats of varnish can materially reduce this problem. Care must be taken to assure the integrity of the finish materials and to seal all vulnerable areas such as the saw cut edges of laminated insulations which absorb moisture more readily than molded surfaces, and taped joints and splices which are more open to moisture penetration.

Surface moisture, especially when combined with dust, deposited on surfaces of insulation can form electrically conducting films. These films permit leakage currents to flow due to high electrical field intensities in the vicinity of high voltage buses and connections. See Figures 23 and 25. Conducting films can form even on inorganic insulating members.

Detection of moisture usually depends on signs. Some indications are:

Droplet depressions on dust-laden bus,

dust patterns similar to an auto in a light sprinkle after traveling a dusty road,

deposits which remain after water has evaporated,

rust anywhere on the metal housing,

actual condensation on metal surfaces even when the insulation is apparently dry.

The term moisture includes any vapor which can readily conduct leakage currents. These vapors are often present in industrial atmospheres, they are not limited to water vapors.

The chief source of moisture is highly humid air subject to climatic cycling. A drop in temperature, as between daylight and dark, can cause relatively still air to pass through a dew point resulting in condensation. Sudden temperature drops can cause condensation even inside a building and inside switchgear housings.

Within a switchgear assembly the humidity and temperature may vary considerably. Air is not always free to circulate from compartment to compartment; some areas carry heavier electrical loads; end structures

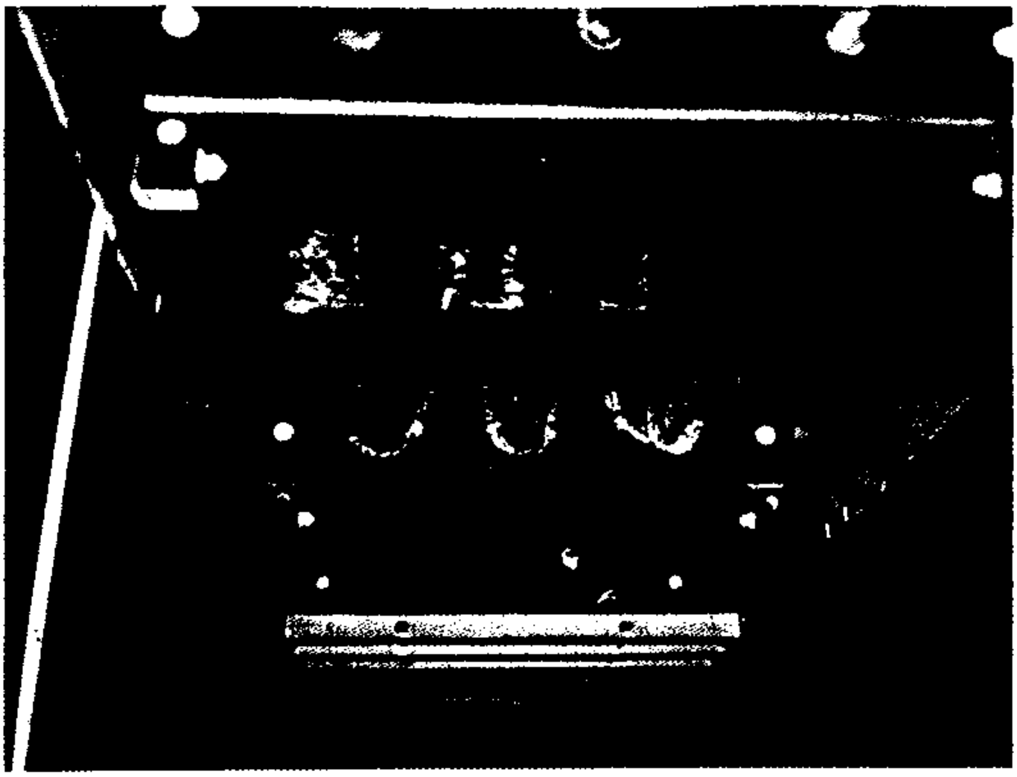


Fig. 25 – Damaging Effect of Voltage Leakage Caused by Dirt and Moisture (Photographed After Cleaning)

are usually cooler than those surrounded by loaded structures on both sides. These temperature and humidity differences result in different dew points. Sudden drops in temperature may cause condensation in some parts of a switchgear assembly and not in others.

D. Corona

Switchgear is designed to be corona-free and with rare exceptions corona is not a problem. It is desirable to be able to recognize it should it occur. Corona is an electrical discharge occurring in gaseous atmospheres. Pressure, temperature, humidity, and the types of gases present affect breakdown levels. In metal-clad switchgear, if corona occurs it is usually localized in tiny air gaps between high voltage bus bar and its insulation, or between two contiguous members. Corona can be detected without instruments:

A visible pulsating blue or purple haze (or halo) may surround the over-stressed air gap. The halo is generally of low intensity and invisible except in the dark.

Popping, crackling, or frying noises may accompany corona discharge.

Corona ionizes the surrounding air, converting oxygen to ozone. It has a distinctive penetrating odor.

Corona may be detected by the erosion of organic materials adjacent to an over-stressed gap. A white powdery deposit is present along the edges of the eroded area. In some materials corona deterioration has the appearance of worm-eaten wood.

Radio interference may be a sign of corona. If the audible noise level increases as the radio is moved closer to the switchgear, corona could be the cause.

Corona discharges are undesirable for a number of reasons:

Ionization of the air releases ions and electrons which bombard nearby organic materials, affecting their molecular and chemical structures.

Ozone formed by corona is a strong oxidizing agent. It can react with many materials.

Nitrogen in the air also reacts to ionizing, and when ionized under humid conditions it forms nitric acid.

When presence of corona is confirmed, the switchgear manufacturer should be consulted for recommended remedial action.

E. Tracking
Tracking is an electrical discharge caused by voltage bridging insulators, phase-to-phase or phase-to-ground. Usually a surface phenomenon, it can occur internally in some materials. Materials known to track internally are never applied in metal-clad switchgear. Figure 26 illustrates signs of tracking on an air circuit breaker bushing.

Tracking is revealed by several signs:

Active streamers or sputter arcs may occur on insulation surfaces adjacent to high voltage conductors. These arcs are tiny, usually intermittent, and of variable intensity. One or more irregular carbon lines (trees) eroded into the insulation surface is a sign that tracking has occurred.

Materials specifically designed to resist tracking seldom if ever exhibit carbon lines. After extensive bombardment by electrical discharges these materials develop erosion craters. Refer to Figure 27.

Tracking can originate from either the high voltage or ground terminal. It will not necessarily progress in a regular pattern or by the most direct path.

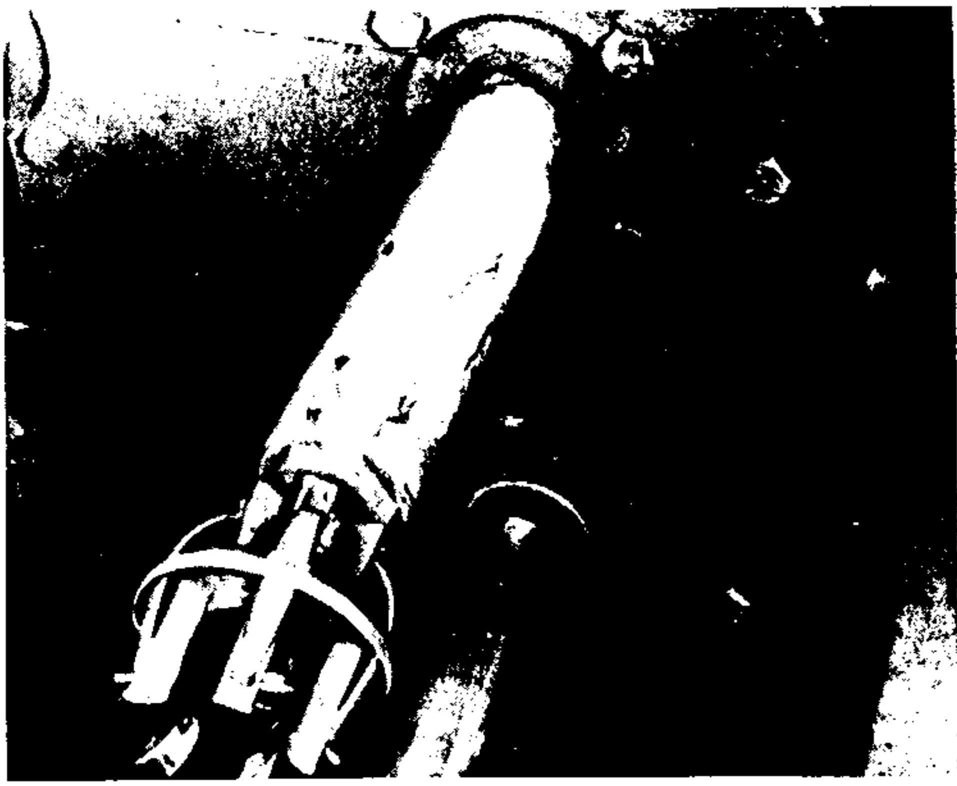


Fig. 26 – Signs of Tracking on an Air Circuit Breaker Bushing

For tracking to occur five conditions must exist. Eliminate any one condition and tracking will cease.

1. Appropriately high temperature.

2. High local field intensity or gradient.

3. Contamination on the insulating surface.

4. Moisture on the insulating surface.

5. Susceptible insulating material forming a bridging link over which leakage current can flow.

Tracking damage is caused by the locally intense heat generated by the leakage current. These currents flow through any contaminated moisture film on the bridging insulating surface. As long as the film is broad and continuous the heat generated is spread over a wide area and quickly dissipated. This heating accelerates evaporation and the continuous film breaks up into small isolated pools. Each break in the film acts to interrupt the flow of the leakage current causing a tiny arc. The arc, though small, creates high local heating.

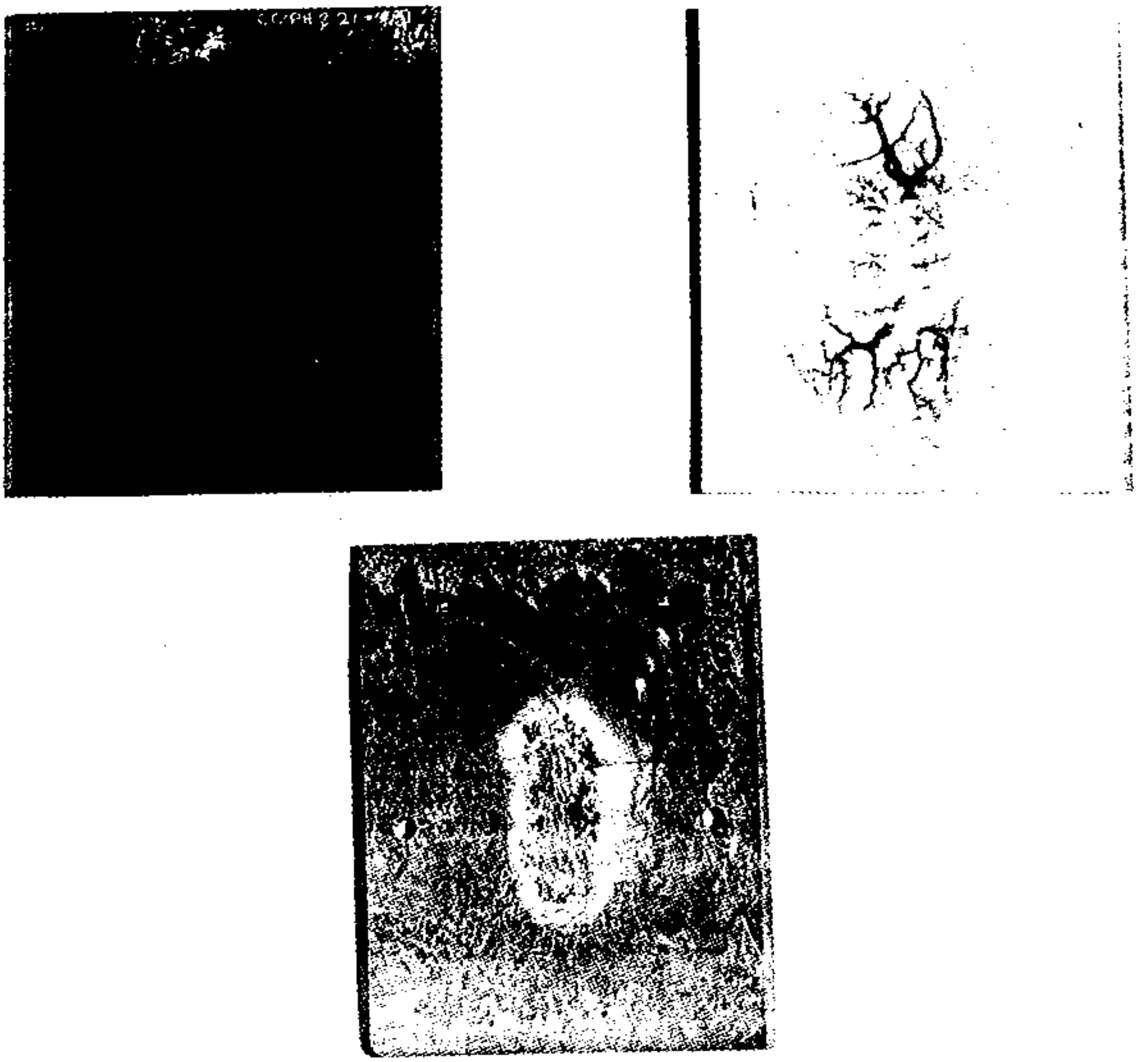


Fig. 27 – Dust-Fog Tests for Tracking
upper left – Typical Phenolic Material
4-Hours or Less of Dust-Fog Test
upper right – Typical Track Resistant Glass-filled material
10-20 Hours of Dust-Fog Test
lower – Track Resistant Polyester
more than 100 Hours of Dust-Fog Test

The intense heat of the leakage current arc is sufficient to cause a molecular and chemical breakdown of the underlying insulation. On organic materials a frequent by-product of arcing is carbon. Most inorganic materials, such as porcelain, are not affected by this type of arcing.

Some organic materials can be treated to resist tracking, but if the degrading stresses are persistant, the effect is a gradual erosion, starting before a carbon deposit is visible. Since carbon will conduct it can eventually reduce creepage distance and establish conditions for a flash-over. Cleaning and re-insulating a carbon path extends the life of any insulation damaged by tracking.

Volume 3
Chapter 3

Switchgear Air Circuit Breakers

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Chapter 3

Switchgear Air Circuit Breakers

The basic working component in any switchgear is the circuit breaker. With few exceptions these are air circuit breakers. There are some applications where oil circuit breakers are mandated. These are applications where arc interruption in air is prohibited due to explosive atmospheric conditions. Safety regulations for coal mines, many chemical processes, bottled gas plants, refineries, and explosives factories normally require either oil circuit breakers or air circuit breakers in explosion proof enclosures.

Functionally, the low voltage breaker (208/480/600V) and the medium voltage breaker (4160/7200/13,800V) are similar. In specifics of design the breakers are quite different due to the requirements of higher voltages and currents. Both low and medium voltage breakers have high speed opening and closing of contacts and almost instantaneous arc interruption through the use of arc quenching systems. Usually, in a modern air circuit breaker arcs are extinguished before the moving contacts reach the fully open position, between one and a half to five cycles of a 60 hertz system.

3.1 Low-Voltage Air Circuit Breakers

Low-voltage power circuit breakers are used at service voltages of 208/480/600 volts and in frame sizes from 225 to 4000 amperes. Interrupting ratings at 4000 amperes are as high as 200,000 amperes asymetrical at 600 a-c volts, 3 phase.

A. Safety Procedures

Circuit breakers are complex electrical devices containing high speed, high energy operating mechanisms. They are designed to operate within the current and voltage limitations shown on the nameplate.

1. Danger: Do not apply air circuit breakers to systems with either currents or voltages exceeding the limits shown on the nameplate. To do so can overload the breaker and cause severe personal injury or death or substantial damage to property.

2. *To perform work* on this equipment requires personnel with training and experience in high voltage circuits. Only qualified electrical workers familiar with the construction and operation of such equipment and the hazards involved should be permitted to work on these circuit breakers. See NEC article 100 for definition of a qualified person.

3. **Danger: Do not disconnect by-pass or make inoperative any interlocks with which the breaker is equipped. To do so can result in severe personal injury or death, or substantial damage to property.**

4. **Warning: When operating a breaker outside its cell, without arc chutes and barriers, keep hands, arms, head, and tools clear of the contact path of travel. Severe bodily injury and property damage can result from being struck by moving contacts either opening or closing.**

Never put a breaker into a cell without barriers and arc chutes in place.

5. **Warning: Always make sure all switch hardware is in place and tightly bolted before inserting a breaker into its cell. Failure to do this can result in severe personal injury or death, or substantial damage to property.**

6. *Do not lift the breaker* with any device except the breaker lifting adapter. To use ordinary crane hooks, ropes, or chains may damage the breaker, and add the risk of dropping the unit.

7. **Caution: Use the handle on the front of the breaker when moving it into or out of the cell. Keep fingers and hands off top, sides, or bottom of the breaker to avoid bodily injury.**

8. **Warning: Be sure the breaker contacts are open and the closing springs discharged before doing any maintenance work on the breaker, and after the work is completed. Failure to take this precaution is both a mechanical and electrical hazard that could result in severe personal injury or death, and substantial damage to property.**

9. **Warning: Never leave a breaker in an intermediate position in a cell. Always have the breaker in either the *Disconnected Test,* or *Connected* position because control circuits may be either improperly connected or disconnected. This may result in electrical failures which can be hazardous to people and equipment.**

10. **Warning: Before operating the breaker in the test position, be sure that closing the breaker will not cause another electrically interlocked breaker to trip, or have any unintended effect on the electrical system.**

11. *Avoid trip-free operation* when possible because it causes more shock to some parts of the breaker than normal closing. If the breaker is levered out from *Test* position to *Remove* position with the closing springs charged, a trip-free closing operation will take place automatically but the contacts will not close. When a power-operated breaker is removed from its cell it must go through a trip-free operation.

B. Construction

The description in the following paragraphs is written around current Westinghouse designs. Breakers built at other times or by other manufacturers will vary from these descriptions. The manufacturer's specific instructions should always be consulted before any work on circuit breakers is undertaken.

1. *Basic Breaker Assembly*

The basic breaker assembly consists of a chassis, a control panel, an operating mechanism, a levering-in device, various interlocks, and three insulated pole unit assemblies mounted on a base.

The control panel on the front of the breaker contains a breaker position indicator, breaker open/closed indicator, levering device shutter and shaft, breaker trip plate, closing spring charge/discharge indicator, and for solid state trip units, trip test terminal access, and trip controls. There is also a closing spring charge handle, a close bar for manually closing the breaker. See Figure 1.

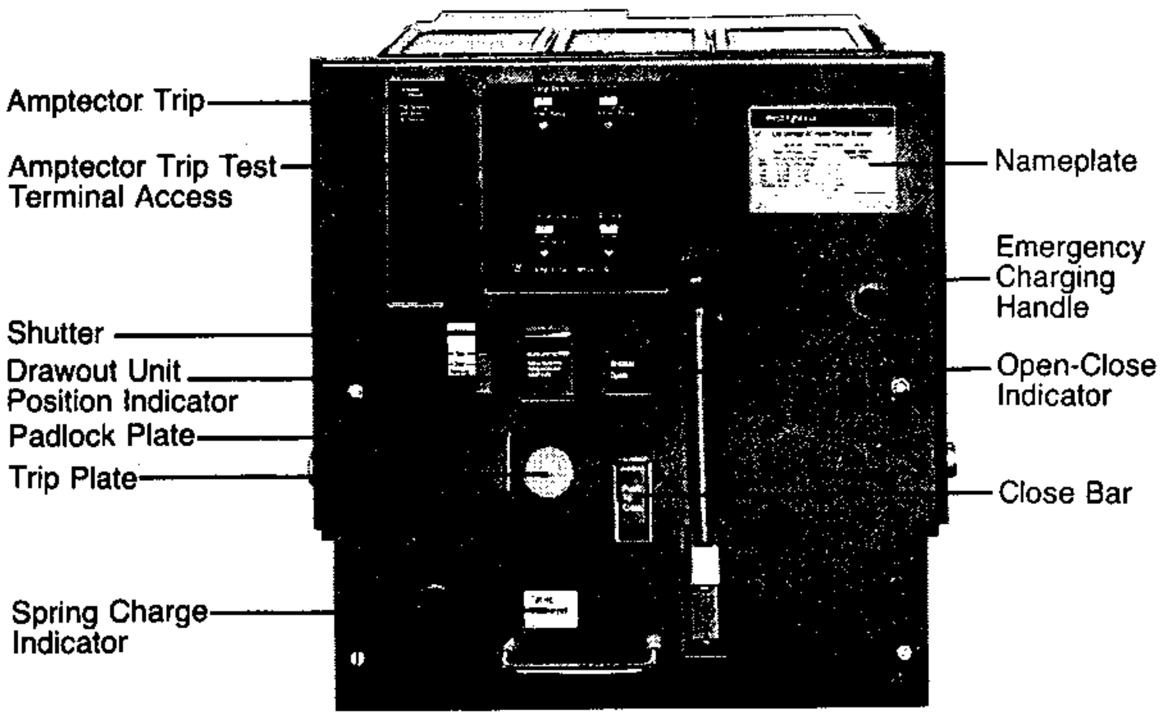


Fig. 1 – Typical Low-Voltage Air Circuit Breaker – Front View

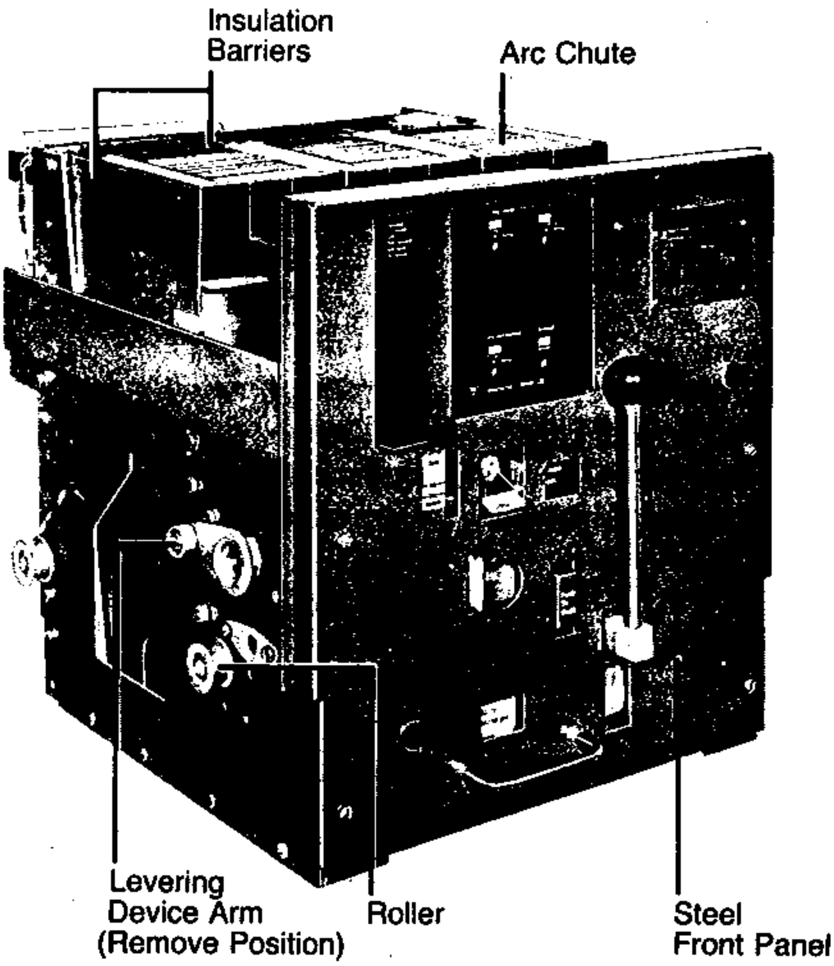


Fig. 2 – Typical Low-Voltage Air Circuit Breaker – Left Side Showing Arc Chutes, Barriers, and Levering-In Device Arm

2. *Arc Chutes*
The arc chutes are mounted on top of the pole units and vented into the atmosphere. The steel splitter plates, insulating spacers, and plates are assembled into an insulating arc chute jacket. See Figure 2.

3. *Trip Units*
Low-voltage air circuit breaker trip units are of two types, solid-state and electro-mechanical. While the solid-state devices are the most recent development, there are still many breakers with electro-mechanical trip units in service and being manufactured.

a. Solid-State Trip Units
The solid-state trip unit operates on low level signals from current sensors. Solid-state circuitry makes it easy to give a reliable inverse time characteristic for overloads and to more closely match the time-current capabilities of equipment. Adjustable controls facilitate setting the required pickup and time delay.

Solid-state tripping action is achieved by the combination of three components, a current detector which continuously monitors current output from current transformers, acting as sensors, mounted on each phase of the breaker. When current flow on any phase of the distribution system reaches a pre-determined setting, the detector responds by starting a timing function or by supplying a pulse of current to the actuator. The actuator is a solenoid device which moves, strikes a trip bar and causes the breaker to open. This scheme provides a flexible system covering a wide range of tripping characteristics.

Figures 3, 4, and 5 illustrate a typical solid-state trip unit. There are in this design six adjustable controls. They can be screw-driver set for the following.

Long-delay current pick-up

Long-delay time

Short-delay current pick-up

Short-delay time

Instantaneous current pick-up

Ground current pick-up ground-delay time

The term pick-up is used to mean the magnitude of current at which the trip unit begins timing.

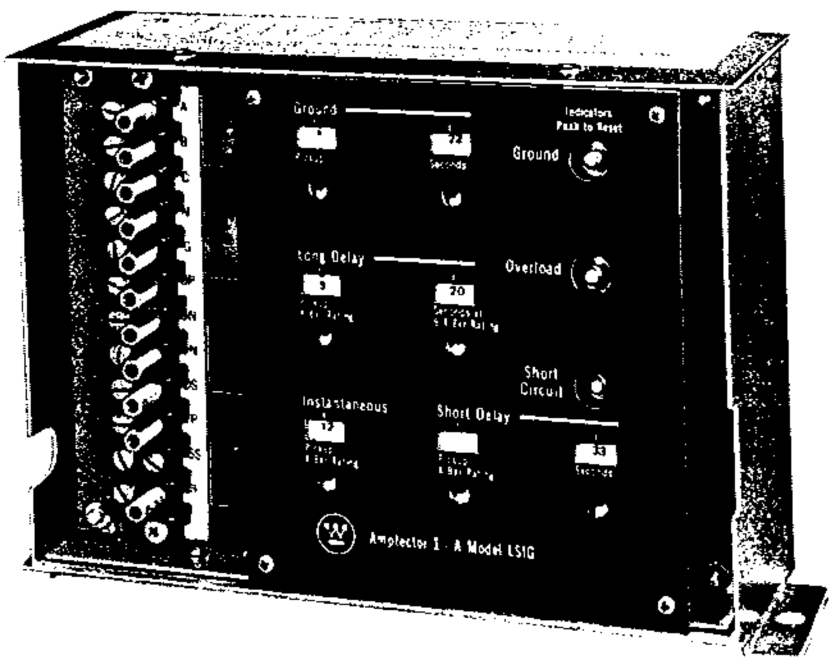


Fig. 3 – Typical Solid-State Trip Device (Westinghouse Amptector IA Shown)

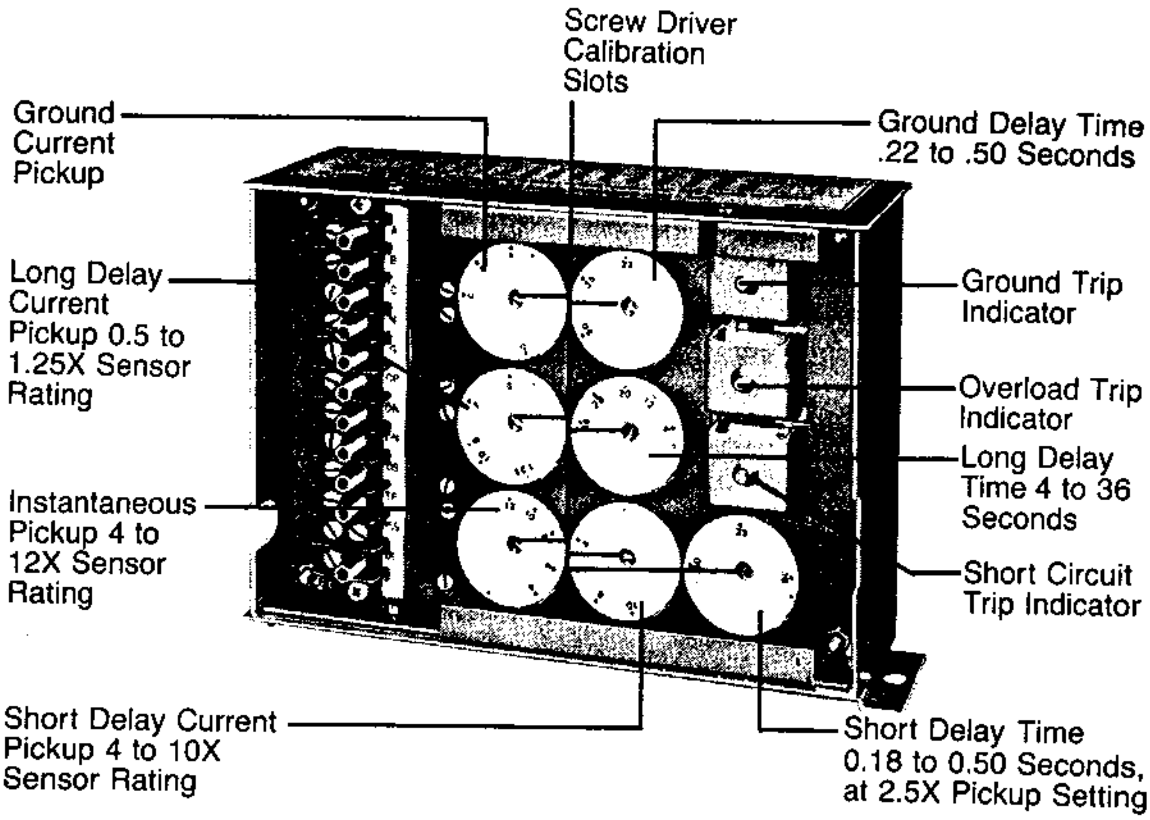


Fig. 4 – Solid-State Trip Unit with Cover Removed (Westinghouse Amptector IA Shown)

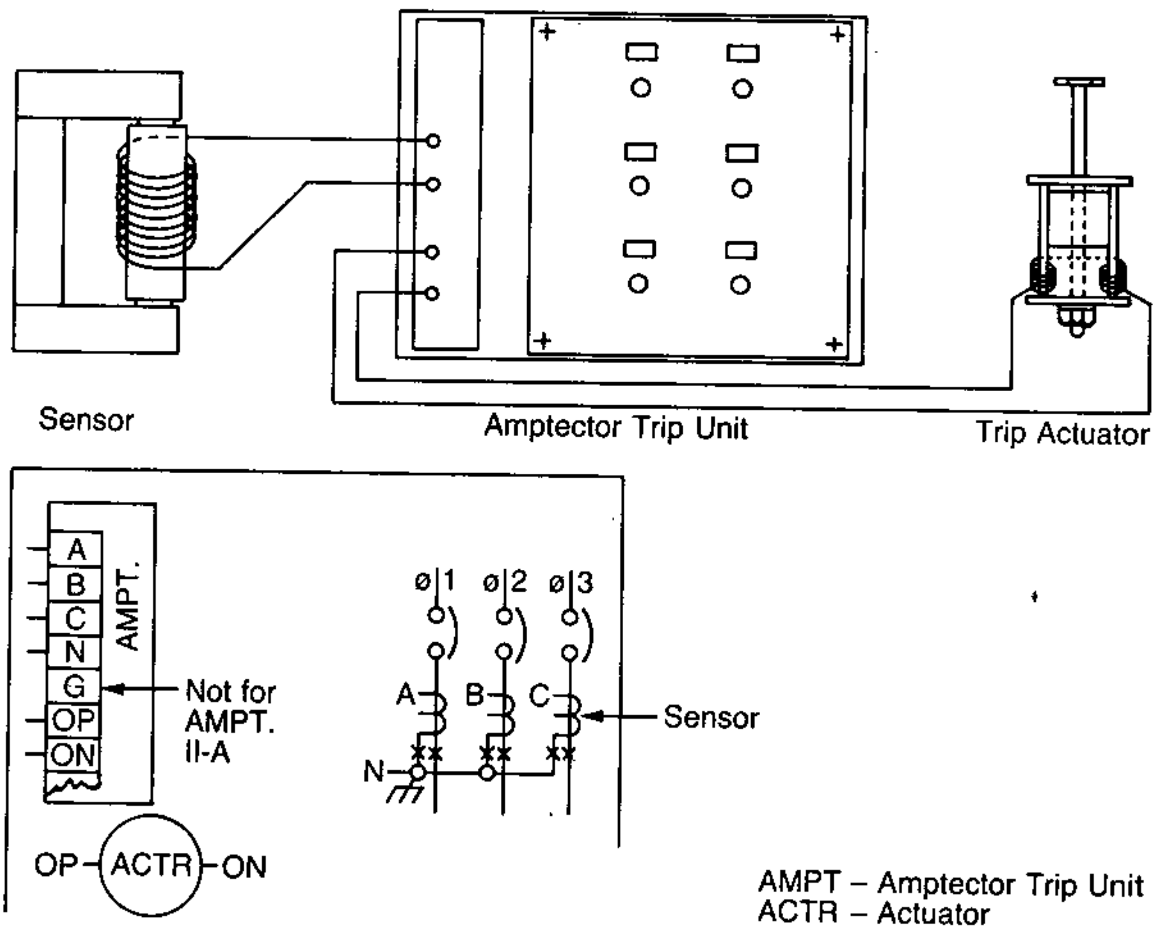


Fig. 5 – Schematic of a Solid-State Trip Unit (Westinghouse Amptector IIA Shown)

b. Electro-mechanical Trip Units
The electro-mechanical trip unit uses stored energy in the form of compressed springs to perform both the opening and closing operations. The breaker is tripped by the magnetic release of a trigger mechanism which releases the stored energy of the spring to open the breaker contacts.

The stored energy mechanism performs two functions; it stores closing energy by compressing or charging the closing spring, and it applies the released energy to simultaneously charge the opening springs. The closing springs may be charged by an electric motor or manually.

Danger: Keep hands, arms, head, and tools out of the area where contacts travel. The stored energy in the springs, when released causes the mechanism to move with great force. Severe personal injury will result if struck.

Danger: Disconnect or de-energize electrical control power before attempting any maintenance closing operations. Discharge springs by manually closing and tripping before attempting any maintenance closing. Failure to take these precautions will result in severe personal injury or death, and substantial damage to property.

Danger: Verify that tripping power is available and energized before applying closing power on circuit breakers having independent closing and tripping control power circuits. Failure to observe this precaution can result in the breaker being closed but providing no protection because of the inability to trip. This condition could cause severe personal injury and substantial damage to property.

Warning: Do not attempt to manually close the breaker against a live circuit. Proper closing speed cannot be obtained and the result may be severe personal injury and burning of the breaker contacts.

The manufacturer's instructions should be consulted for the specific details of the breaker trip mechanisms.

C. Receiving, Handling

1. *Receiving*
Switchgear circuit breakers may be shipped completely assembled and inside their compartments. If the circuit breakers are not shipped in the switchgear assembly, they will be packed separately in individual cartons or crates. These packages must be handled with care to avoid hidden damage.

Upon receipt, the breakers should be inspected for any evidence of damage in shipment. If damage is found or suspected it should be reported immediately to the delivering carrier and to the manufacturer.

2. *Handling*

If the breakers are shipped separately they must be put in place in the switchgear compartment.

Notice: Do not attempt to lift the breaker with ordinary crane hooks, ropes, chains, etc. Vital parts such as wiring, barriers, and arc chutes may be damaged. Figure 6 illustrates the use of a specially designed breaker lifter supplied by the breaker manufacturer. This is the only method of lifting that should be used.

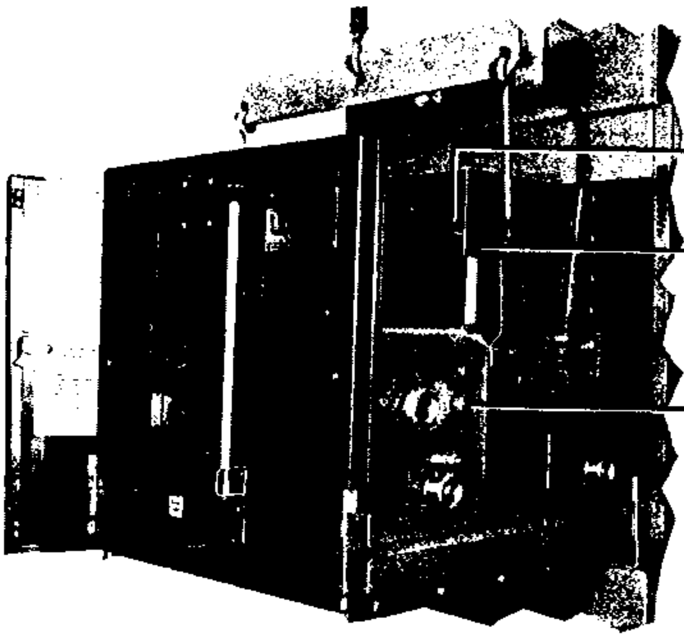


Fig. 6 – A Breaker Lifter in Use

Before lifting the breaker, the extension rails must be put in place, after which the breaker may be lifted and placed on them.

If the breaker was shipped in the compartment, the extension rails must be put in place before the breaker can be withdrawn from the compartment.

Before the circuit breaker can be withdrawn, all shipping braces must be removed. To prevent possible distortion and mis-alignment, the breaker in shipment is lifted by a shipping brace so its wheels do not rest on the rails. This shipping angle must be removed before the breaker can be lowered to the rails. Using the levering-in device the breaker can be moved from the shipping position, part way between *Disconnect* and

Test, toward the *Remove* position. At the point where position indicator has reached the *Remove* position, the levering-in device can be removed and the breaker pulled onto the rail extensions by hand. All shipping covers used to protect the breaker in transit should be removed and discarded. The breaker can then be returned to its compartment.

3. *Preliminary Examination*

Warning: Read and become familiar with the manufacturer's instructions and examine the breaker as it stands out of its compartment, before attempting to operate it. Failure to do this can result in improper operation, severe personal injury and substantial damage to property.

The complete drawout element includes the circuit breaker and its auxiliaries. The breaker has four major components:

Operating mechansim

Contacts operated by the mechanism

Arc chutes which interrupt the arc which is a result of the breaker opening under load or short circuit conditions

Tripping device, solid-state or electro-mechanical

The breaker auxiliaries in the drawout element are:

Interphase insulating barriers which isolate the arc chutes from each other and from ground.

Drawout element frame and rollers.

Levering-in device for positioning the breaker in the compartment.

Main disconnecting contacts which connect the breaker to power source and load.

Secondary contacts which connect the control circuits to the electrical operating part of the drawout element.

Interlocks which guard the safety of operation.

Drawout element position indicator.

Open-close indicator

Spring charge indicator

Steel front cover

Nameplate with complete rating information

There may also be:

Current limiters

Isolating transformers connected in parallel with the current limiters

Combination Blown-Limiter Indicator and Anti-Single Phase device, connected to the isolating transformers and actuated by the blowing of one or more current limiters.

Each breaker is equipped with a spring-type stored energy closing mechanism. This mechanism closes the circuit breaker contacts with the required speed and force, independently of the operator. The spring must be charged or cocked before the breaker will close. The springs are released by a latch. The breaker is opened by springs, which were charged by the closing action when the tripping latch is released.

D. Basic Operation

Following the preliminary examination the breaker should be given a trial mechanical operation.

1. *Levering-in Device*

The trial mechanical operation starts with the breaker standing on the compartment rails in front of the compartment. The first step is to move the breaker into the compartment. The breaker position indicator should be in the *Remove* position. The crank can be inserted into position on the levering shaft by pushing the *Trip* plate and depressing the levering shaft shutter simultaneously. See Figure 7. Turning the crank clockwise will advance the breaker into the compartment. As the breaker moves in the position indicator should register *Disconnect*, then *Test*, then *Connect*.The movement of the levering device arms and the operation of the entire mechanism should be monitored during this movement.

Rotation of the levering-in crank counterclockwise will withdraw the unit from the *Connected* to the *Test* position, then to the *Disconnect*, and finally the *Remove* position. At this point when the crank is removed from the worn shaft, the shutter will remain open and the trip plate will remain trapped by the shutter.

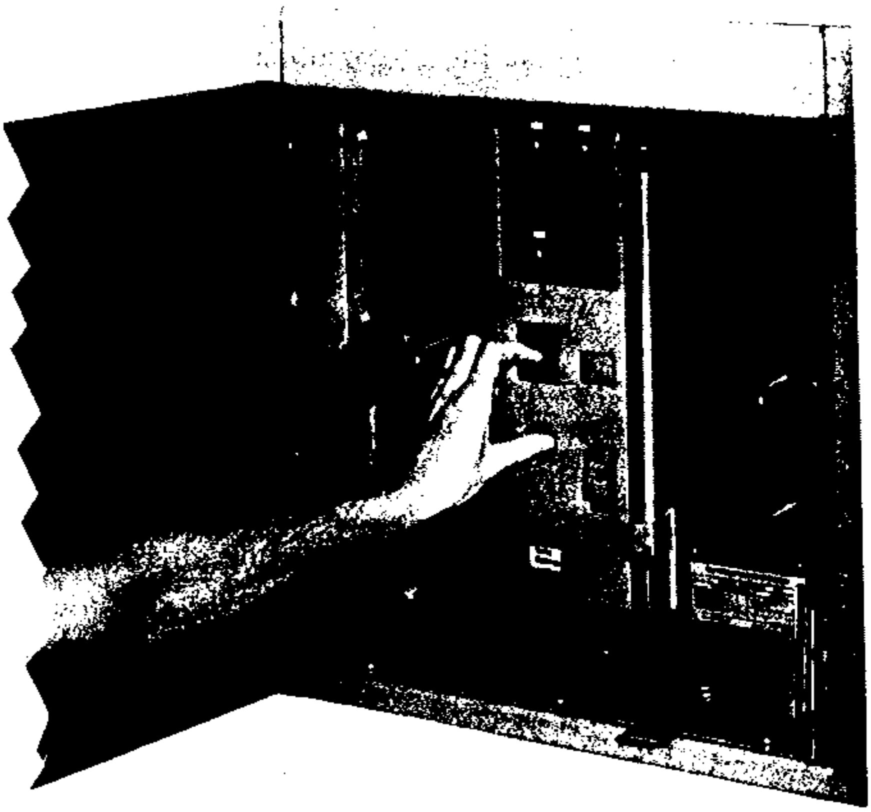


Fig. 7 – Depressing the Trip Plate and Opening the Levering-In Shutter Simultaneously with One-Hand

Notice: If the breaker is moved out from the *Test* position to the *Remove* position with the closing springs charged, a trip-free closing operation will take place but the breaker contacts will not close. When a power-operated breaker is removed from a cell it must go through a trip-free operation.

2. *Charging the Closing Springs*
The closing springs must be charged before the breaker can be closed. The closing springs can be charged only when the breaker is in the *Test* position. At any other position the breaker will go through a trip-free operation without closing the contacts.

Caution: Hold breaker to prevent tilting when hand charging the closing springs when the breaker is on the extended rails. Failure to do this may cause the breaker to fall with resulting injury and damage.

On manually operated breakers, the closing springs are charged by a single downward stroke of the spring-charge handle. After a 90 degree rotation the resistance on the handle will disappear and a metallic click will signal that the closing spring latch is in place. At this point the closing spring is charged and the indicator should so indicate.

Warning: Do not release the charging handle before the charging is completed. To do so may allow the handle to fly upward with great force which could cause severe personal injury and damage to the breaker.

Notice: Power-operated breakers, when being levered into the compartment, will have the spring-charge motor run and charge the spring automatically as the *Test* position is reached.

3. *Closing the Breaker*
The breaker can be closed only when the following conditions are met:

Closing springs charged.

Levering arms in either test or connect position.

Levering-in crank has been removed and shutter closed.

Undervoltage trip (if any) is energized.

Blown limiter (if any) is reset.

If these conditions are met the breaker may be closed by pushing the close bar. When the breaker is closed the breaker position indicator will show *Breaker Closed* and the spring-charge indicator will show *Spring Discharged.*

Notice: If closing is attempted with the levering arms in other than the *Test* or *Connected* positions with or without the crank in place, a trip-free operation is performed but the breaker contacts do not close. This operation causes more shock to the mechanism than normal closing and should be avoided if possible.

4. *Opening the Breaker*
There are three ways a breaker can be opened:

By hand operation of the trip plate on the breaker or on the compartment door.

Automatically by overload, short circuit, or undervoltage.

Breakers equipped for power operation can be tripped electrically by a shunt trip device energized by handswitch or relay.

For purposes of the initial mechanical trial operation, the hand operation of the trip plate is the preferred method. The breaker position indicator should show *Breaker Open.*

To complete the mechanical trial operation the spring charging and opening and closing operations should be repeated several times. The levering-in device should be operated moving the breaker to its various positions several times.

E. Inspection Procedure
There is considerable similarity between various manufacturer's low voltage power circuit breakers. This is due to the fact that they must meet certain ANSI and other code requirements. A typical inspection should include the following, regardless of who manufactured the breaker. When checking tolerances, making adjustments, or replacing worn or expended components, the manufacturer's instructions should be carefully followed.

1. *Withdraw the breaker* from the compartment, remove barriers and arc chutes. Blow clean with low pressure dry air. Wipe accessible areas with clean dry cloths. Use non-flammable cleaning solvents where necessary.

Warning: Do not breathe cleaning solvent vapors or permit prolonged contact with skin. These highly toxic substances are readily absorbed into the body and can cause severe illness or death by poisoning or asphixiation.

2. *Inspect the contacts.* Normal switching and fault interruptions and arcing from motor in-rush currents will cause some pitting of contacts. When the contacts are badly burned, they should be replaced. Avoid filing or dressing contact faces. Always replace contacts in pairs, never mix old and new contacts.

Warning: Do not use emery cloth to clean contacts. Emery contains conductive material that may encourage tracking and eventual flashover. This can result in severe injury and damage to property.

3. *The arc chutes* are subject to deterioration since the slots gradually erode with arc interruptions. The heavier the fault interruption, the faster the erosion. When the steel splitter plates have as much as one-fourth inch of their material eroded away at the top of the slot, they should be replaced. The extent of the erosion can be determined by comparing a plate near the center with one at the end. Badly burned insulating plates should be replaced at the same time.

The throat of the arc chute enclosure will become sooted and burned from arc interruptions. Damaged areas should be cleaned with sandpaper and the enclosure blown out with compressed air before new plates are installed. Badly damaged arc chutes should be replaced.

4. *The operating parts* have a long life expectancy and original factory adjustments can be expected to last for the life of the breaker. Factory adjustments should not be altered.

Maintenance adjustments are those which must be made to compensate for contact deterioration, or replacement of broken or worn parts.

5. *Inspection of mechanical parts* should include a check for missing pin retainers, loose nuts, bolts, or screws, worn or damaged parts. Any adjustments which must be maintained for proper operation will be described in the manufacturer's instructions. After adjustments have been made or parts replaced, all locknuts should be tightened to retain the adjustment setting.

6. *When replacing breaker contacts,* certain tolerances must be maintained to assure positive seating. Most contacts are closed with a controlled amount of rocking motion called wipe. This action has a polishing effect on the contacts and maintains them in proper relationship as they wear. Contact spring pressure is very important in maintaining proper electrical continuity. Contact springs are subject to weakening due to contact overheating.

When there are evidences of contact overheating, discoloration from burning and pitting, the cause should be determined immediately. Some causes are weak or broken contact springs, contacts not closing simultaneously, inadequate overtravel to maintain pressure. The contacts on each pole of a circuit breaker should make and break within the limits established by the manufacturer. Contact misalignment should be corrected as soon as discovered.

7. *Any inspection* should include a check for evidence of friction. Infrequently operated breakers can become immobilized by accumulations of rust or corrosion. Improper lubricants or lack of lubrication can produce sluggish action. Oil based lubricants should generally be avoided as they accumulate dust which causes wear and binding. Carefully follow the breaker manufacturer's recommendations on the type of lubricant and the frequency of lubrication.

Evidence of friction in the operating mechanism can often be revealed by the following procedure:

With the breaker out of the cell or in the test position, and using the hand closing lever, slowly advance the closing mechanism to a point where the contacts just touch but the breaker does not lock in. Then slowly raise the handle and observe the return of the mechanism to the open position. If the breaker hesitates or stops at any point during this slow opening operation something is binding. Check thoroughly to locate the source of friction or binding.

Occasionally there is mechanical interference caused by loose hardware allowing a part to shift into a binding position. There could also be rust or corrosion on a close fitting pin or bearing surface. Sometimes hardened grease will cause the binding. If this is the case a penetrating oil or petroleum solvent should be applied and the breaker exercised until it operates freely. Lubricate after using a solvent, making sure the lubricant reaches all areas affected by friction, then wipe off excess.

Dismantling the breaker mechanism to correct binding is not recommended unless the people performing the work are experienced in repairing breakers. In the absence of expert breaker repair people, the manufacturer's field service people should be called in.

8. *A routine part of any inspection* should be a check for wear. If a breaker is required to operate frequently, wear of moving parts is a probability. Breakers are designed to open and close at great speeds and with great force.

Contact wear, burning, and pitting should be checked at all inspections. To avoid prolonged arcing on opening and closing, breakers are designed so the arcing contacts are the first to touch on the closing cycle and the last to part when the breaker opens. When the breaker opens, the main contacts, which carry the load current, separate first, with little or no arcing. This is because the load current is transferred to the auxiliary or secondary contacts, then to the arcing contacts. The result of this opening-closing sequence is that secondary and arcing contacts must be replaced more frequently than main contacts.

Warning: Keep hands, fingers, head, and tools away from any moving part of a breaker being test operated. Severe injury and accidental amputation can result from the great forces in the opening and closing operation.

9. *Most breakers have some kind of anti-bounce device* to cushion the opening stroke and reduce the impact shock of metal to metal contact. These shock absorbing devices should be checked and properly adjusted to be effective. If the shock absorbers are not properly cushioning the shock, it is transmitted to all the parts of the breaker, pins can shear, retainers can work loose, parts can be bent or distorted and the operation of the breaker seriously impaired.

10. *When a breaker is removed,* the compartment should be inspected. If items of hardware, bolts, nuts, cotter pins, washers, springs, or similar hardware are found, a determination must be made of whether they came from the breaker, and suitable replacement made. Accessible nuts, bolts, and screws should be tightened but not overstressed when the breaker is inspected.

F. Testing

Electrical checks are limited to closing and trip coils on many breakers. Some breakers have many electrical auxiliaries or accessories which are coordinated with breaker operation or are used as auxiliary trip devices.

1. *Undervoltage Trip*

This is an electro-mechanical device that trips the breaker when the voltage on its coil falls below 30 to 60 percent of normal. The standard type has instantaneous trip but some have a non-adjustable time delay.

2. *Overcurrent Trip Switch*

This device provides a signal indicating when the breaker has tripped due to phase or ground overcurrent. Normal tripping by remote or hand operation, or by shunt or undervoltage trip impulse does not cause it to operate.

3. *High Load Switch*

This solid-state device picks up at a predetermined value of overcurrent, lower than the breaker overload trip setting, and gives advance notice that overload conditions exist. The pick-up point is adjustable between 60 and 100 percent of the trip unit's long delay pick-up setting. A non-adjustable time delay setting of 60 seconds requires that the pick-up current on this device be maintained for that interval before the relay contacts operate to trip the breaker. If load-current falls below the pick-up point within the time interval, the device automatically re-sets. Being solid-state, no maintenance is required.

4. *Auxiliary Switches*

Auxiliary switches serve many purposes, there may be several mounted on a breaker. They are used mostly on control circuits as alarm switches. One is used in nearly all cases as a cut-off switch in the solenoid coil of electrically operated breakers.

5. *Electrical Lock-Out Devices*
There are electrical lock-out devices on low-voltage breakers to prevent reclosing if the coil is not energized. This is a trip-free safety device.

In the key interlock attachment, the key cannot be removed unless the low-voltage breaker is locked in the open position and the high voltage breaker is locked out of the cell. These are both personnel safety devices.

6. *Reverse Current Trips*
Reverse current trips on low-voltage breakers protect direct-current equipment from reversal in current flow. The device is commonly installed in place of the center pole on a three-pole breaker. It is a magnetic device influenced by the potential coil which magnetizes the armature and the main current which magnetizes the frame. When the current flows in the foward direction, armature movement is prevented by a stop. When the current reverses, the armature rotates in the opposite direction and trips the breaker. After tripping by the reverse current, the armature is reset by opening the potential coil circuit. For this reason the coil is always connected through an *a* contact of the auxiliary switch.

Other devices such as pushbuttons to trip or close the breaker, and other pilot control devices must be inspected and kept in good operating condition. Rear mounted secondary disconnect contacts, where used, should be checked at each inspection.

The breaker should never be forced into its compartment. The guide rails should provide correct alignment for contact through the stab or finger cluster bus connectors. If resistance is encountered when levering the breaker in, it should be removed, alignment reassured and the breaker then levered in.

On drawout breakers the rear connectors, stabs or finger clusters, should be checked at each inspection. Poor contact or corrosion can result in overheating and burning.

If the contact is loose, arcing may take place which may ultimately cause the breaker to fail for lack of contact. Arcing behind the barrier can cause a phase-to-ground or phase-to-phase failure followed by fire or explosion. Arcing from a bus connection fault ceases only after something burns up or a primary breaker ahead of the switchgear trips and interrupts power to the switchgear.

3.2 Medium Voltage Air Circuit Breakers

Medium voltage air circuit breakers for switchgear application are designed for metal-clad switchgear assemblies having maximum voltages of 4.76 kV, 8.25 kV, and 15.0 kV.

A. Safety Precautions

These circuit breakers are complex high voltage electrical devices containing high speed, high energy operating mechanisms. They are designed to operate within the current and voltage limitations shown on the nameplate and must not be applied to systems with currents or voltages exceeding those limits.

1. Danger: Do not apply air circuit breakers to systems with currents or voltages exceeding the limits shown on the nameplate. To do so can overload the breaker and cause severe personal injury or death and substantial damage to property.

2. *To perform work* on this equipment requires personnel with training and experience in high-voltage circuits. Only qualified electrical workers familiar with the construction and operation of such equipment and the hazards involved should be permitted to work on these circuit breakers. See NEC Article 100 for definition of a qualified person.

3. Danger: Do not disconnect, by-pass, or make inoperative any interlocks with which the breaker is equipped. To do so destroys safety systems and can result in severe personal injury or death, and substantial damage to property.

4. Warning: When operating a breaker outside its cell without arc chutes and barriers, keep hands, arms, head, and tools out of the area where contacts travel. Severe personal injury and property damage can result from being struck by moving contacts, either opening or closing.

5. Warning: If it is necessary to put a breaker without arc chutes or barriers into an energized cell in the test position, take positive steps to assure that the levering-in mechanism is made inoperative. Movement of the breaker could cause electrical failure, severe personal injury or death, and substantial damage to property.

Never insert a breaker without arc chutes and barriers into an energized metal-clad cell beyond the test position.

6. Warning: Always make sure all switch hardware and shunt strap bolts are in place and properly tightened before inserting the

breaker into its cell. Failure to do this can result in improper operation and severe personal injury or death, and substantial damage to property.

7. *Do not lift the breaker* with any device except the breaker lifting adapter. To use ordinary crane hooks, ropes, or chains may damage the breaker and add to the risk of dropping the unit.

8. Warning: Never attempt to close a breaker by hand on a live circuit. Manual closing is not fast enough to prevent severe arcing and burning, resulting in damage to the breaker contacts and ultimately breaker failure and possible severe personal injury.

9. Caution: Keep fingers and hands off top, sides, or bottom of the breaker when moving it into or out of the cell to avoid bodily injury.

10. Warning: Never leave a breaker in an intermediate position in a cell. Always have the breaker in either the *Disconnected, Test,* or *Connected* position because control circuits may be improperly connected or disconnected, this may result in electrical failures which may be hazardous to people and property.

11. Warning: Be sure the breaker is open and the closing spring discharged before attempting any maintenance work on the breaker, and after the work is completed. Failure to take this precaution creates both mechanical and electrical hazards that could result in severe injury or death and damage to property.

12. Warning: Before operating the breaker in the test position, make sure that closing the breaker will not cause another electrically interlocked breaker to trip or have any unintended effect on the electrical system.

13. Warning: Do not attempt to close the breaker with the maintenance closing handle if the closing spring is charged. Always remove the maintenance closing handle immediately after using it to close the breaker. The closing springs in a breaker store a great deal of energy that can cause the maintenance handle to fly with great force which could cause severe injury and property damage.

B. Construction

This description is written around current Westinghouse designs. Breakers built at other times and by other manufacturers will vary from these descriptions. In all cases the manufacturer's specific instructions should be consulted before any work on circuit breakers is undertaken. See Figures 8, 9, 10, and 11.

1. *Basic Breaker Assembly*
The basic breaker assembly includes a chassis, a control panel, an operating mechanism, a puffer assembly, a levering-in device, various interlocks, and pole unit assemblies.

a. Control Panel
Mounted on the front of the breaker are the controls needed for operation. They are: tripping magnet, tripping trigger, closing spring release magnet, spring release trigger, latch checking switch, auxiliary switches, control relay, motor cut-off switch, and operation counter.

b. Arc Chutes
Each arc chute contains arc runners, ceramic interrupter stacks, ceramic arc shields, blowout coils, various baffles and deflectors, and a magnet structure, all assembled in an insulating arc chute jacket. Figure 8 illustrates, in section, a pole unit with the arc chute in place.

c. Barrier Assembly
The barrier assembly is made up of a grounded steel front panel and several insulated side panels to shield the pole units and arc chutes from each other and from ground.

d. Puffer
The puffer is located in the breaker chassis just below the pole units. In addition to its function as a puffer, the casting serves as a tie unit for the chassis side sheets, the mounting surface for the pole units, and various other components. A cavity in the casting serves as the puffer and as a dashpot.

e. Accessories
Accessories provided with the breaker usually include a handling dolly, a maintenance lever, a levering-in crank, and an arc chute lifter.

Since the major components and accessories vary with the type and rating of the breaker, packing lists provided with the shipment, and detailed instructions from the manufacturer should be checked and consulted.

C. Receiving, Handling, Storing

1. *Receiving*
Upon receipt, the packaging, crates, or cartons, should be inspected for signs of damage or rough handling. The packaging should be opened

carefully and contents inspected for damage, taking care that any loose items are not discarded with packing material. The contents of each package should be checked against the packing list.

Examine the breaker, arc chutes, and barrier for any signs of shipping damage. Report all damage to the delivering carrier and to the breaker manufacturer as soon as it is discovered.

2. *Handling*
The circuit breaker shipping containers are designed to be handled by an overhead lifting device and rope sling or by a lift truck. If the containers must be skidded, it is preferable to use roller conveyors or individual pipe rollers.

Once the breakers have been removed from the shipping containers, careful handling is required. They should be rolled on their wheels, using the handling dolly provided for maneuvering. If necessary, the basic breaker assembly may be lifted by attaching hooks in the places on the chassis indicated for lifting. Spreader bars should be used when lifting to prevent damage.

The arc chutes should be handled in their cartons until time to mount them on the breaker. Great care is required in handling the arc chutes to prevent cracking or breaking the ceramic parts.

Once out of the carton, arc chutes must be carefully handled to avoid damage, especially if the arc horn protrudes from the bottom. If the arc chutes must be placed on the floor, they should be laid on their sides or set on spacers to protect the arc horn.

Arc chutes for larger breakers are provided with lifting lugs so an overhead lifting device can be used to mount them on the breaker.

Barrier assemblies once removed from their shipping cartons may be moved by hand, but two people are required. Holes are provided for overhead lifting and that method is recommended.

3. *Storage*
If the circuit breaker is not to be immediately mounted in metal-clad switchgear, maximum protection can be attained by returning the basic breaker, arc chutes, and barrier to their original shipping containers after checking to assure there is no shipping damage.

Outdoor storage is not recommended. If unavoidable the outdoor location must offer protection from the weather, and must be dry. Containers must be arranged to permit free circulation of air and temporary heaters should be used to minimize condensation. A heat level of 400 watts for each 100 cubic feet is recommended. Heaters should be distributed uniformly throughout the space and located at the lowest level.

Indoor storage should be in a building with sufficient heat and ventilation to prevent condensation. If the building is not heated, the requirements for outdoor storage apply.

If breakers are stored out of their shipping containers, they must be protected from dust, dirt, and moisture.

Completely assembled circuit breakers may be stored in their switchgear compartments in the test position.

D. Basic Operation
Most circuit breakers are equipped with spring stored energy operating mechanisms. Normal operation is to charge the closing spring and then close the breaker by releasing the spring. The opening springs are charged by the releasing of the closing spring. These actions, the start of the electric motor to charge the closing spring, and the tripping of the breaker, are initiated by a spring release coil and a trip coil. The spring-charging motor is automatically started when control power is applied to the breaker.

These operations can all be done by hand when control power is not available.

Caution: Check possible hazards related to lack of tripping power before closing the circuit breaker when control power is not available. Protective relays may operate to energize the trip circuit but the breaker will not trip due to lack of tripping power. This results in nullifying the protective function of the breaker.

Warning: Keep hands, arms, head, and tools out of the area where contacts will travel when manually charging, closing, or tripping the circuit breaker. The spring stored energy in the operating mechanism is released with great force and can produce severe injury and damage to any object in the path of the moving parts.

Caution: Disconnect or de-energize electrical control power before attempting any maintenance closing operations. Discharge closing springs by manually closing and tripping the breaker before attempting any maintenance operation. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Warning: Remove the maintenance handle from the main shaft immediately after closing the breaker and before any additional operations are attempted. If breaker should trip with the handle in place, it would be thrown with the full force of the opening springs. This can result in severe personal injury, and substantial damage.

1. *Electrical Closing and Tripping*
The spring-charging motor is energized when control power is applied to the breaker. The motor will charge the closing spring in approximately 5 seconds and will automatically shut off. The spring release coil can then close the breaker. Immediately following the discharging of the closing spring, the charging motor will be re-energized to charge the spring again. The release of the closing spring provides the energy to charge the opening springs. After the breaker has been closed, the energizing of the trip coil will trip the breaker.

Caution: Always verify the availability of tripping power before applying closing power on circuit breakers having independent closing and tripping control power circuits. Failure to do this may render the breaker incapable of tripping thus defeating its protective function.

2. *Stored Energy Mechanism*
The spring stored energy system performs two functions: It stores closing energy in the compressed spring, and it applies the released energy to close the breaker and simultaneously to charge the opening springs. The mechanism may rest in any one of four positions:

Breaker open, closing spring discharged

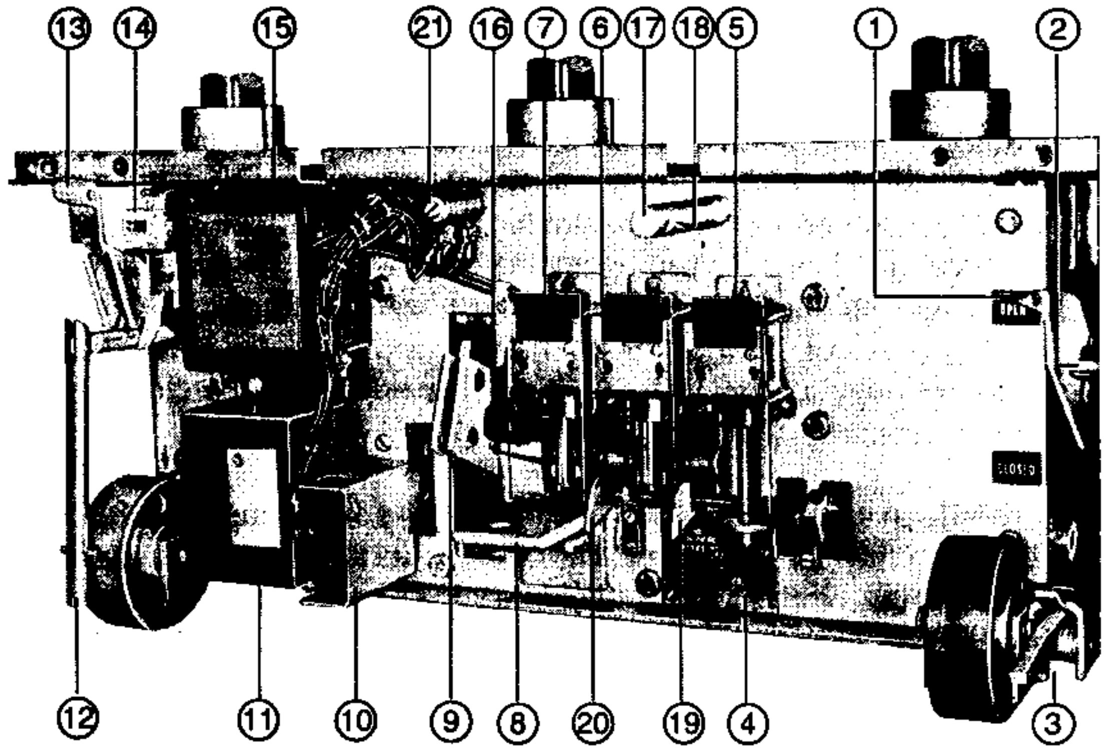
Breaker open, closing spring charged

Breaker closed, closing spring discharged

Breaker closed, closing spring charged.

The primary component of the mechanism is the crankshaft assembly which compresses the spring. The shaft is driven by an electric motor or the spring can be manually charged by a ratcheting lever. When the spring is completely compressed it is latched in place. The latch can be released either electrically or manually.

The mechanism panel is located on the front of the breaker chassis. See Figure 8. Mounted on the panel are the closing spring release magnet and the trip magnet, the auxiliary switch, operation counter, control relay, motor cut-off switch, closing spring charge indicator, latch check switch, breaker position indicator, and breaker nameplate. Undervoltage and transformer trip devices may also be mounted here.

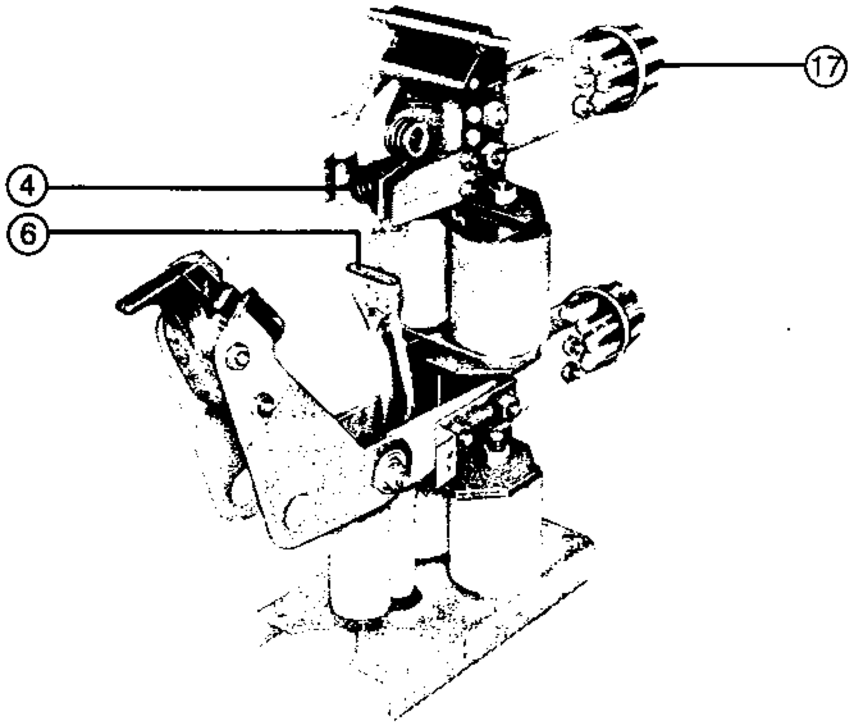


1. Breaker Position Indicator
2. MOC Switch Operating Pin
3. Rail Latch
4. Breaker Nameplate
5. Additional Trip (Optional)
6. Spring Release Magnet
7. Tripping Magnet
8. Turning Dolly Bracket
9. Manual Ratchet Lever
10. Motor Cut-off Switch and Closing Spring Charged – Discharged Indicator
11. Control Relay (Behind Cover)
12. Secondary Contact Hand Operating Rod
13. Secondary Contact Handle
14. Operation Counter
15. Auxiliary Switches (Behind Cover)
16. Latch Checking Switch
17. Levering-in Device Operating Shaft
18. Levering-in Device Pin
19. Spring Release Trigger Cam
20. Tripping Trigger Cam
21. Resistor Assembly

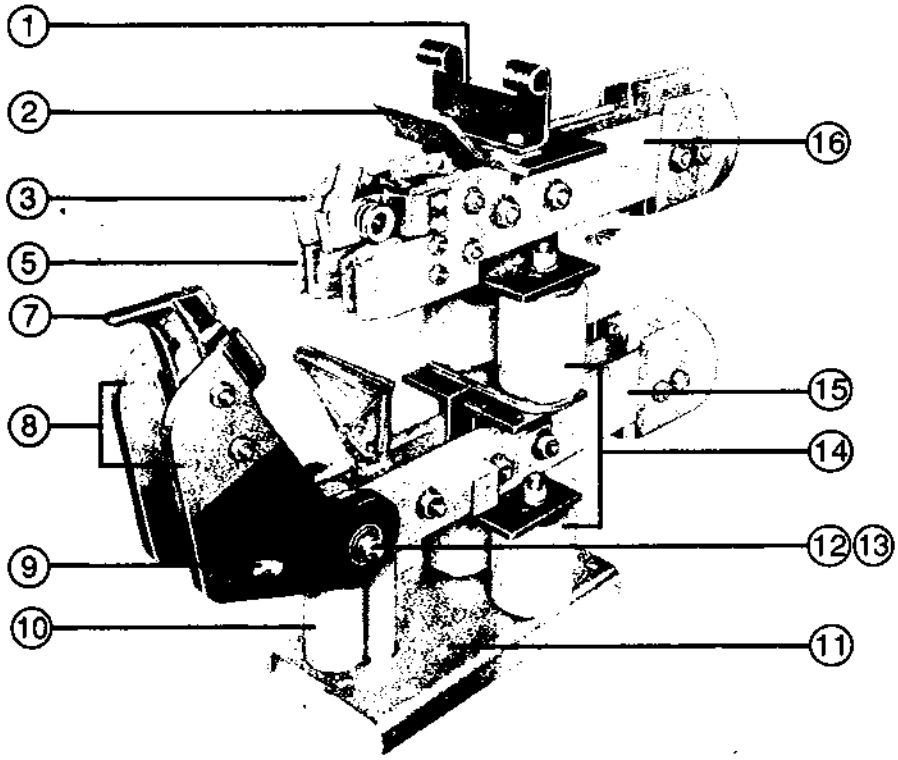
Fig. 8 – Stored Energy Mechanism Panel

The Pole Units

Pole units as shown in Figure 9, are made up of a base, insulated supports for the breaker studs, the moving contact assembly, the stationary contact assembly, and the arc chute hinge assembly.



A. 8.25 and 15.0 kV, 1200 Amperes

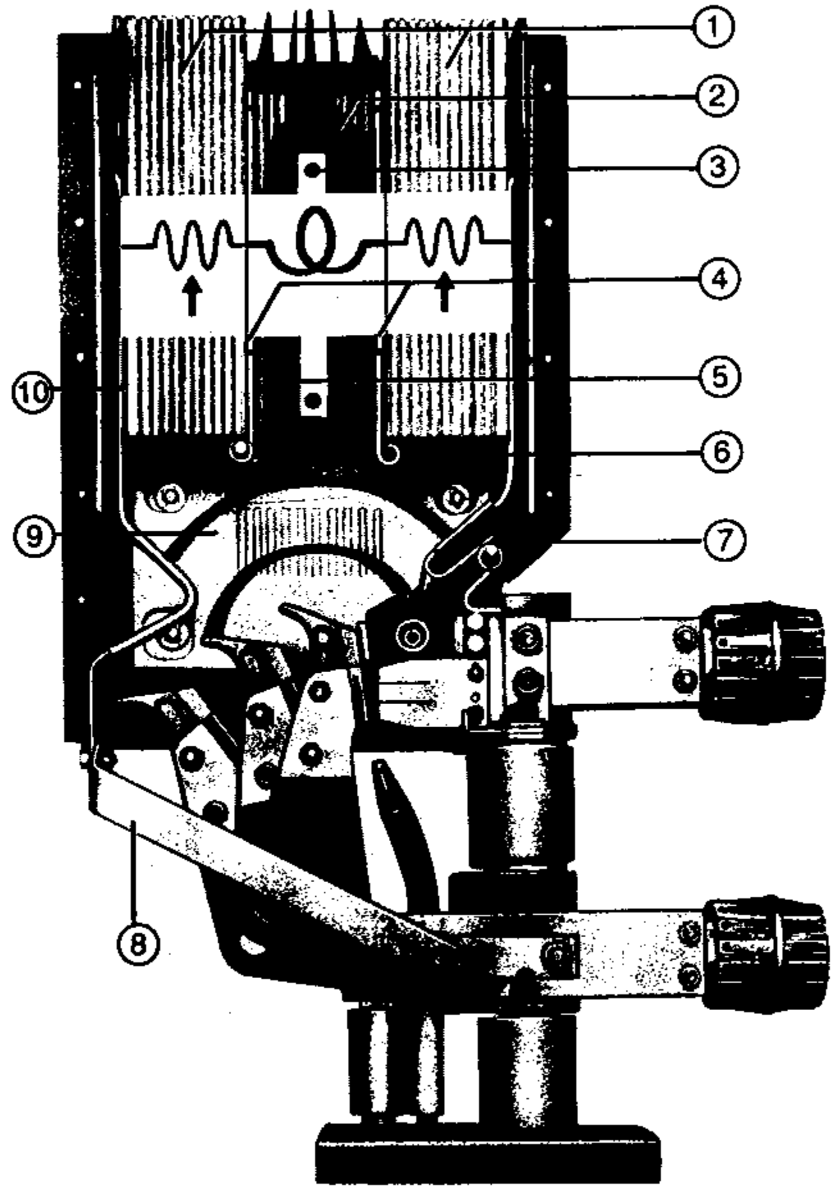


B. 8.25 and 15.0 kV, 3000 Amperes

1. Hinge Bracket
2. Rear Arc Horn Contact
3. Stationary Arcing Contact Assembly
4. Kickout Spring
5. Stationary Main Contacts
6. Puffer Tube
7. Moving Arcing Contact
8. Moving Main Contact Blades, Left Hand and Right Hand
9. Contact Operating Rod Pin
10. Hinge Support
11. Pole Unit Base
12. Hinge Pin
13. Hinge Spring
14. Porcelain Posts
15. Lower Conductors
16. Upper Conductors
17. Primary Disconnecting Contact Finger Cluster – 1200 Amperes

Fig. 9 – Pole Units

Arc Chutes
Arc chutes are functionally much the same, the sizes vary with the breaker rating. Figure 10 is a cut-away drawing of a pole unit with an arc chute in place. Figure 11 illustrates an arc chute being mounted. Larger arc chutes must be lifted with an overhead lifting device.



1. Main Interrupter Stacks
2. Blowout Coil
3. Blowout Magnet Core
4. Center Arc Horns
5. Transfer Stacks
6. Rear Arc Horn
7. Rear Arc Horn Disconnecting Contact
8. Shunt Connector
9. Ceramic Arc Shield
10. Front Arc Horn

Fig. 10 – Pole Unit with Arc Chute – Section View

When breaker contacts first part during an opening operation, an arc is drawn across the gap. As the gap increases, the arc elongates and moves upward. The arc terminals move quickly transferring the arc to the arc horns where it climbs upward within the arc chute. The portion of the arc that impinges on the two center arc horns and the transfer stacks is drawn upward and extinguished. The arc, broken into two major segments connected through the blowout coils, sets up a strong transverse magnetic field between the pole faces of the blowout magnet.

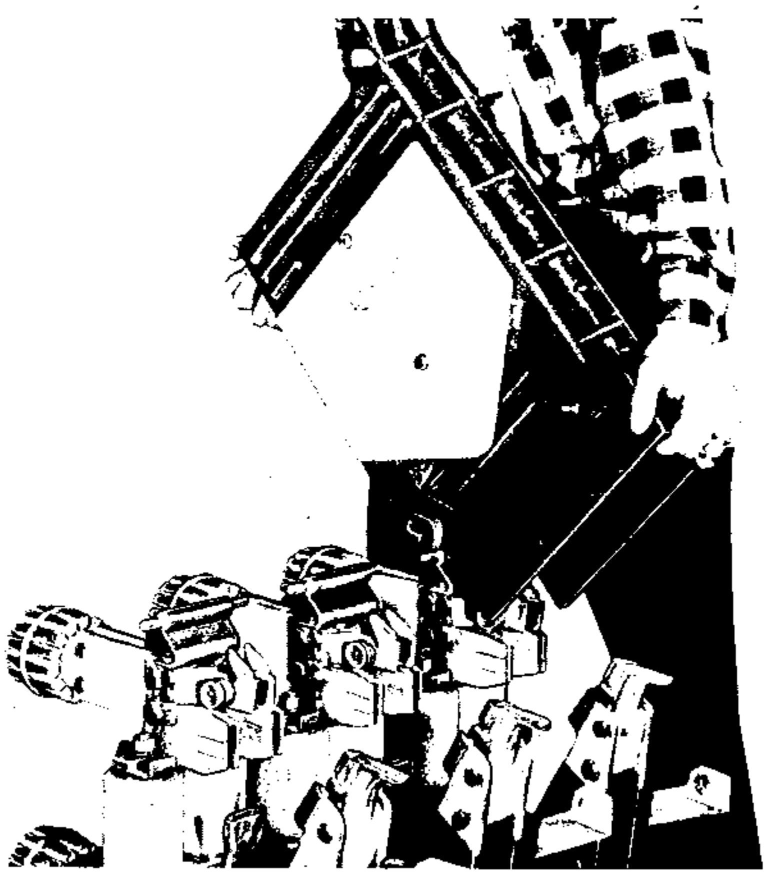


Fig. 11 – Arc Chute Being Installed

The interaction between the arc current and the transverse magnet field produces an upward thrust forcing the two arc segments into the main stacks where they are broken up and extinguished.

Interphase Barriers

The interphase barrier is an assembly of insulating sheets mounted on a grounded steel front plate. When mounted, the insulating sheets form a barrier between pole units which gives phase-to-phase and phase-to-ground insulation and separation of hot conducting gases during interruption. The front plate provides a barrier between breaker live parts and operating personnel.

Levering-in Device

The levering-in device functions to move the breaker between *Test* (disconnected) position and *Connected* (engaged) position. A rotating levering nut mounted on the circuit breaker engages a lead screw mounted on the rear wall of the cell. Turning the nut then moves the breaker between *Test* and *Connected* positions in the compartment. A slotted tube covers the lead screw and is keyed at the slotted end to the rotating nut so when the tube turns the nut turns on the lead screw. The other end of the tube accepts the levering-in crank handle.

Puffer

The function of the puffer is to blow the arc upward into the arc chute, on low current interruptions. It is located just below the pole units. It consists of a casting with a cavity in which a piston drives air out three holes and tubes to the breaker contacts. It is mechanically linked to the breaker mechanism so it operates automatically as the breaker opens.

Near the end of the piston stroke, after it has passed the three outlet holes, it acts as a dashpot, compressing the remaining air in the cylinder and cushioning the shock of the breaker opening.

3. *Secondary Contacts*

Breaker control wiring is arranged for drawout disconnect and can be connected when the breaker is in the test position by extending the secondary contact plug.

4. *Ground Contact*

The ground contact is an assembly of spring-loaded fingers which provide a disconnectable means of grounding the breaker chassis after it has been inserted into the cell. Refer to Figure 12.

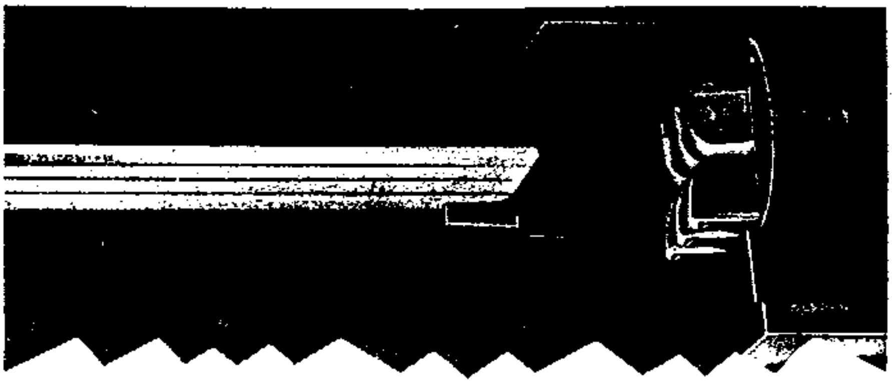
5. *Breaker Position Indicator*

All breakers are equipped with a position indicator to show if the breaker is open or closed. This usually is a lever assembly operating directly from the main shaft of the breaker operating mechanism.

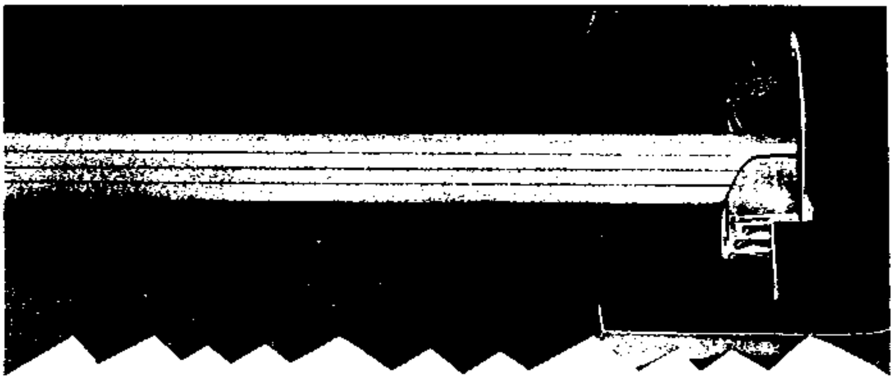
6. *Interlocks*

Warning: Do not by-pass or make inoperative any interlocks. Hazardous voltage can cause severe personal injury or death, and substantial damage to property.

The number and type of interlocks varies greatly with breaker and switchgear specifications. Their purpose is to prevent improper operation by permitting only proper procedure. The manufacturer's instructions should be carefully studied before any attempt is made to work on any interlock system.



A. Ground Contacts – Disengaged



B. Ground Contacts – Engaged

Fig. 12 – Ground Contacts

7. *Undervoltage Attachment*

The undervoltage attachment is an electro-mechanical device that trips the breaker when the voltage falls below 30 to 60 percent of normal. It consists of moving and stationary cores held together magnetically. As the coil voltage drops, a spring overcomes the magnetic attraction and the moving core travels downward to release the tripping lever.

Warning: Exercise care when working on a breaker with an undervoltage attachment. The breaker will trip when the control source is de-energized. The breaker may be closed manually but cannot be latched closed. This creates a mechanical hazard unless clearly understood and proper care taken. Failure to exercise care can result in severe personal injury or death, and damage to property.

8. *Accessories*

The number and variety of accessories is great. Some that are common to most air circuit breakers for switchgear application are:

a. Maintenance Handle
Caution: Do not attempt to close the breaker with the maintenance handle when the breaker is in the housing. To do so could cause damage to the breaker, the housing, and injury to the operator.

The maintenance handle is used to close the breaker contacts during maintenance only. It can also be used to charge the breaker closing spring.

b. Turning Dolly
Caution: Do not use the turning dolly to move the breaker in or out of the cell. To do so could result in damage to the breaker, the rails, and interlocks.

The turning dolly is used to maneuver the breaker when it is out of the cell on the floor.

c. Arc Chute Lifter
Used to tilt the arc chutes during maintenance so the arc chutes and contacts may be examined.

d. Levering-in Crank
Used to move the breaker between *Test* and *Connected* positions.

E. Initial Inspection and Operation

Before attempting to put a breaker into service it should be carefully checked. Since breakers are adjusted, inspected, and tested at the factory, they should require no further adjustment. If inspection reveals obviously dangerous conditions or maladjustments, the manufacturer's instructions should be consulted before attempting corrective action. The following is a minimum list of inspections to be made before start up:

Examine breaker for loose or obviously damaged parts.

Operate the breaker manually. Follow manufacturer's instructions.

Notice: Do not charge the closing spring at this time.
Operate the breaker electrically. Follow manufacturer's instructions.

F. Installation

Position the breaker near the metal-clad switchgear cell.

Warning: Make sure the breaker is open and the closing spring discharged before starting to assemble the arc chutes and barrier. Failure to do this can create a mechanical hazard that could result in severe personal injury, and substantial property damage.

1. *Mount Arc Chutes*

Generally, the procedure for mounting is the same for all arc chutes. There are differences in detail of hinge arrangement, shunt straps, and supports due to size and weight differences. The manufacturer's instructions should be consulted for specifics.

2. *Connect Shunt Strap*

Warning: Be sure connection is tight at both ends of the shunt. Failure to firmly tighten either of these connections could cause excessive heating or severe arcing during circuit interruption, either of which could cause failure of the breaker and substantial damage to property.

3. *Mount Barrier*

Mounting of barrier assemblies is generally similar for all breakers. Differences in specifics are due to differences in design detail. The manufacturer's instructions give proper procedures for the specific breakers. The installation of the barrier is not a precise operation, reasonable care is required to assure that the barrier is properly positioned and aligned. Once the barrier is aligned, all bolts and fasteners should be tightened to maintain the alignment. A final adjustment may be required to line up the barrier with the cell at the time of insertion.

4. *Position Breaker*

Position the breaker in front of the cell. For general movements of the breaker and for positioning it in front of the cell, use the turning dolly. Do not attempt to lift the breaker after the arc chutes and barrier are mounted.

Caution: Keep hands clear of top edge of the front barrier. Use the handles on the front panel for back and forward movement only. Failure to follow this precaution can result in severe injury including possible amputation of fingers.

Examine the connecting finger clusters for any sign of damage, clean off any dirt or protective wrapping, but do not apply any grease to the fingers.

Check the secondary contacts for alignment.

Make sure the cell is clean and clear of any obstruction.

Inspect the levering screw and make sure the levering nut is adequately lubricated.

5. *Move Breaker to Test Position*
Line up breaker with the guide channel and guide rail and remove dolly. Do not start breaker into cell with the turning dolly. This could cause damage to the levering-in mechanism. Push breaker into cell until it engages the stop which prevents further movement. This puts the breaker in the *Test* position.

6. *Engage Secondary Contacts*
Consult the manufacturer's instructions for engaging secondary contacts and follow closely.

Notice: When secondary contacts engage,the motor will charge the closing spring if the control circuit is energized.

7. *Operate Breaker in Test Position*
Close and trip the breaker electrically using the control switch on the cell door. The control of the breaker is so arranged that the closing spring will recharge after each closing operation.

8. *Lever Breaker into Cell*
After tripping the breaker it can be levered into the cell.

Warning: Before moving the breaker into the cell, make sure the arc chutes have been properly installed and the main barrier properly in place. The pole unit parts are live at full circuit voltage when the breaker is in the fully engaged position. Exposure to these parts may result in severe personal injury and damage to property.

Crank the breaker in until the crank turns free and the breaker stops moving. It is then in the *Connected* position.

9. *Remove the Breaker*
To remove the breaker, first trip it. The mechanical interlock prevents moving the breaker in or out if it is closed.

Crank the breaker out from the *Connected* position to the *Test* position. When the crank turns freely and the breaker no longer moves forward it can be pulled forward until it latches in the *Test* position. Press the rail latch and free the breaker from the cell.

G. Routine Inspections

Effective maintenance is based on an inspection program that permits routine examination at regularly scheduled intervals. There are various methods for calculating proper inspection intervals. They all are based on three inter-related factors:

Time since last inspection

Number of load switching operations

Number of short circuit switching operations

A determination should be made as to the maximum for each of these factors and the inspection made when any one of them reaches that predetermined maximum.

1. *Inspections Based on Time*

It is recommended that a circuit breaker be inspected at the end of its first year of service. It will have been in service long enough to provide a record and an indication of future inspection periods. This initial time period is flexible but in no instance should a breaker go without inspection beyond three years.

2. *Inspections Based on Load Switching*

Table 1 below gives maximum recommended number of operations between inspections.

Table 1

Continuous Current Rating Amperes	Number of Operations		Fault Operation		Nonfault Operation	
	Max. Between Inspections	No Load Mechanical Duty	Full Load	Inrush	Full Load	Inrush
1200	2000	10,000	1000	750	5000	3000
2000	2000	10,000	1000	750	3000	2000
3000	1000	5000	500	400	2500	1500

3. *Inspections Based on Short Circuit Switching*

Experience over years of circuit breaker service has allowed the projecting of probabilities of magnitude of short circuit currents or breaker will be called upon to interrupt. In Table 2 below, the *Most Likely* short circuit as a percentage of the maximum short circuit interrupting rating of the breaker is shown with the maximum number of such interruptions permissible without inspection and maintenance.

Table 2

Most Likely Short Circuit. % of Capacity	**Accumulated Short Circuit** Interruptions
Greater than 50①	1①
50	2
40	3
35	4
28.5	6
24.5	8
20 and less	12

① If the short circuit interrupted is greater than 50% of the rated maximum of the breaker, inspection should always be made after one interruption.

4. *Unusual Service Conditions*
The time and numbers of operations recommended above were based on the assumption of normal service conditions, ambient temperatures in the range of +40C to −30C, altitudes below 1000 meters (3300 feet), and relatively clean and dry conditions.

Unusual service conditions such as exposure to damaging fumes, abrasive dust, explosive atmospheres, steam, salt spray, or high moisture will usually reduce the time intervals and number of operations between inspections. When highly unfavorable conditions exist, the breaker manufacturer should be consulted for recommendations.

5. *Capacitor Switching*
Capacitor switching applications produce in-rush currents and interrupting currents similar in character to fault switching. It is recommended that inspection be made after 500 capacitor switching operations or one year, whichever comes first. Experience may permit extending these intervals. Major maintenance can be anticipated after a total of 2500 to 3000 capacitor switching operations.

6. *Inspection and Maintenance Procedures*
When the maximum time or operations interval has been established, it should not be exceeded unless changing operating conditions warrant. Maintenance should always include removal of the breaker from the cell and a general visual inspection of condition, a cleaning to remove dust, dirt, and contaminants. Servicing should also include exercising operations, testing, adjusting, lubrication, general tightening.

7. *Mechanical Operation*
Mechanical operation should be quick, snappy, and positive. If there are any signs of sluggishness or looseness of operation, the barrier should be removed and the breaker operated manually to identify the source of the trouble. The manufacturer's maintenance instructions should be consulted for proper corrective action.

8. *Low Level Load-Current Switching Duty*
When breaker duty includes a low level of short circuit switching but numerous interruptions of 100 amperes or less, there is a tendency for soot and metal spray to accumulate in the arc chutes. Inspection procedures should include checking for this condition and the manufacturer's maintenance instructions followed for cleaning.

9. *Moderate to High Level Switching Duty*
Circuit breakers having duty where currents of 1000 amperes and greater are regularly switched, will show a tendency toward glazing and eroding of the ceramic parts of the arc chutes. The amount of this eroding and glazing varies directly with the magnitude of the currents. Since this duty tends also to burn and erode the breaker contacts, both the arc chutes and the contacts should be inspected anytime either is inspected.

10. *Total Breaker Life*
Operating duty, environment, and adequacy of the inspection/maintenance program all affect the total life of the breaker. It is clear from Table 2 that the mechanical life expectancy is much greater than the electrical life. Breaker life is more accurately calculated in numbers of operations than in years. As the breaker grows older more time must be allowed for maintenance as parts require replacement and more maintenance procedures are necessary. The inspection/maintenance program will have to be flexible enough to provide for these aging factors and for changing duty conditions. Good maintenance records are invaluable in such a program.

G. Renewal Parts

The circuit breaker manufacturer will supply a list of recommended spare parts. This list will be the result of long experience with the breaker and knowledge of the replacement requirements. These recommended spares should be stocked and replaced as used.

When parts are required, they should be ordered from the manufacturer giving complete identification. The nameplate information on the breaker should be given, The name and number of the part if available. The manufacturer's renewal parts information on the breaker should be kept in the Maintenance Department file on the equipment.

Volume 3
Chapter 4

Liquid Immersed Power Transformers

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Chapter 4

Liquid Immersed Power Transformers

The power transformer plays a critical role in electrical distribution. These transformers step up voltage for long distance transmission and step down voltages at substations for local distribution. Interconnections of systems and formation of power networks have required transformers capable of handling constantly higher voltages and higher kVA ratings.

Transformers are of two general types based on the magnetic circuit in the unit, core form and shell form.

In the core form transformer the magnetic circuit forms the center or core of the transformer. This design is generally used on power transformers in the lower current and kVA rating ranges.

In the shell form transformer the magnetic circuit surrounds and forms a shell around the windings. The interleaved stack of rectangular coils extends above and below the magnetic circuit. This design is used in heavy current ratings (furnace transformers) and transformers of higher kVA ratings, 200,000 kVA and above.

Descriptions and procedures given here are based on current Westinghouse designs. Transformers manufactured at other times or by other manufacturers may vary in detail.

Figures 1 and 2 show Typical Power Transformers.

4.1 Safety Precautions

Warning: Read the manufacturer's instructions carefully before attempting to handle, install, use, or service a transformer.

In addition, the following general precautions must always be followed in the installation, operation, and maintenance of transformers. Failure to follow the manufacturer's instructions and these precautions can result in severe personal injury or death, and damage to property.

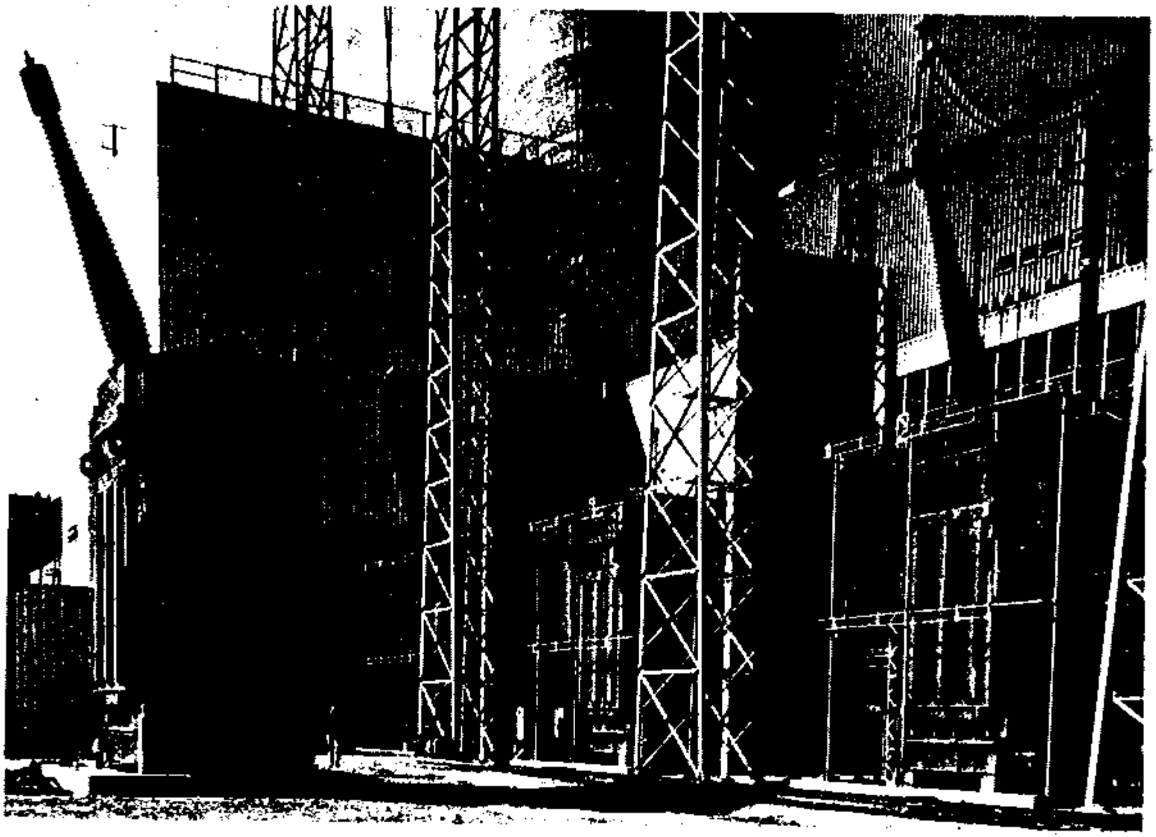


Fig. 1 – A 765 kv Generator Step-up Transformer, Shell form

A. Do not operate the de-energized tap changer when the transformer is energized. To do so will result in arcing with a possibility of subsequent rupture of the transformer tank.

B. Do not come close to or touch the transformer when it is energized. The bushings and equipment connected to the bushings are at high voltages. Coming too close to live parts can result in electrocution.

C. Do not enter the transformer tank or breathe the internal atmosphere until there is absolute assurance that there is enough oxygen in the internal atmosphere to support life. Oxygen content lower than 19.5 percent can cause drowsiness, injury, or death. Transformers shipped filled with gas are not safe to enter.

Do not enter a transformer tank unless there is another person outside the tank standing watch at the tank entrance.

D. Do not loosen any covers or fittings until the internal pressure of the transformer has been reduced to a zero gauge reading. Internal pressure must always be relieved slowly through the proper valves. Failure to reduce pressure can cause the cover of fitting being removed to become a hazardous flying object.

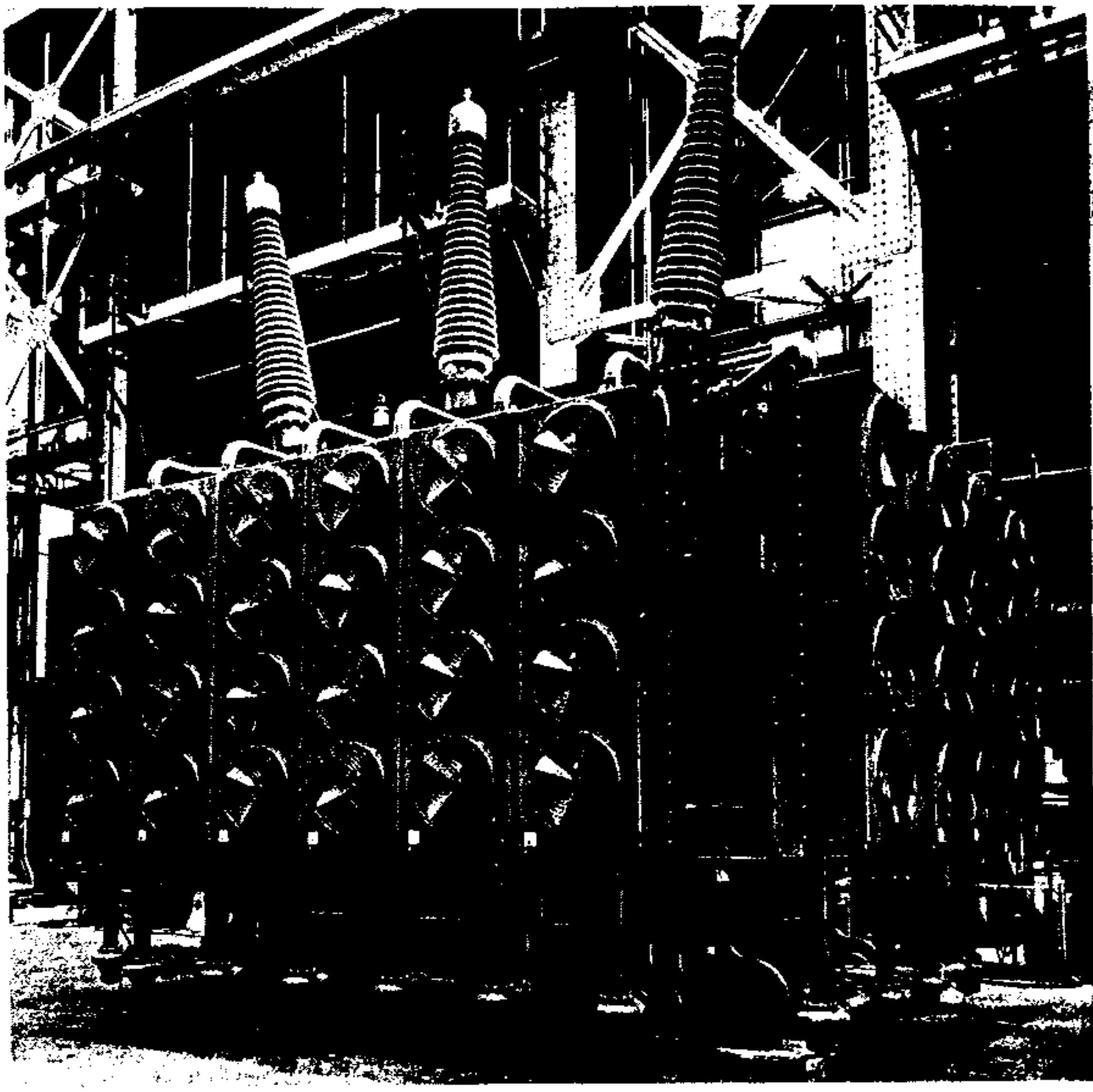


Fig. 2 – A 531 Ton, 1,300,000 KVA Power Transformer. It Measures 34 Feet High and 44 Feet Long – Shell Form

E. Do not energize a current transformer unless it is connected to a load and grounded. If not connected, current transformers will produce high voltages which can damage the transformer and cause severe injury or death. The secondary of a current transformer should always be connected to a load or shorted. Grounding provides additional protection to personnel.

F. Do not undertake any work on the control cabinet or accessories connected to the cabinet unless the voltage supply has been disconnected and will remain disconnected during the work period. The control cabinet and accessories contain high voltages. Failure to disconnect can result in serious injury or death by electrocution and damage to property.

G. Lift and jack the transformer only at the provided lifting eyes and jacking pads. Consult the manufacturer's instructions for locations. To attempt to lift or jack at other locations can cause the transformer to fall resulting in damage to property and severe injury or death to people.

H. Do not use external valves, piping, or fittings for climbing or support, they will not support a person's weight. Failure to heed this precaution can result in severe injury or death and damage to property.

I. These grounding precautions must be observed. Failure to do so can result in severe injury or death by electrocution, and damage to property.

The transformer tank must be grounded at all times.

Windings must be grounded except when electrical tests are being made or the transformer operated.

Bushings must be grounded after installation and during oil filling.

All oil handling equipment and vacuum pumps must be grounded. Equipment grounds should be maintained for six hours after oil filling.

All test equipment must be grounded.

J. Do not touch any leads or bushings when connected test equipment is energized. High turn ratios can transform very small voltages into dangerous output voltages which can cause severe injury or death.

K. The condenser bushings must be de-energized and fully discharged before attempting to ground them. They may retain an electrical charge after the transformer has been disconnected. This charge can cause severe injury or death.

L. Do not open any valves or plugs on the transformer or its accessories while the transformer is energized, except oil or gas sampling valves. To do so may cause the oil level to drop below the minimum which can result in an internal flashover, causing possible severe injury or death and damage to property.

M. The cooling equipment must be operating any time the transformer is energized. If the cooling equipment is not operating, dangerous pressures and temperatures can develop inside the transformer. This can cause severe injury or death, and damage to property.

N. Keep fire extinguishers available for emergency use, especially at the top of the transformer when work is being done inside the tank. Smoking must be prohibited on the transformer or near oil handling equipment.

The use of a fire extinguisher inside the transformer will usually severely damage or destroy transformer insulation.

O. Exercise care when walking or working on the top of a transformer as it is likely to be slippery due to an oil film. A fall from the top of the transformer can cause severe injury or death.

4.2 Location

In determining the location of a power transformer, consideration must be given to:

Stability of foundation
Transformer Cooling Method
Proximity of obstructions
Accessibility
Ease of Inspection

The Transformer mounting base must have stability adequate for the weight of the unit, free from all possibilities of subsidence, ground slippage, or earth tremors. The base must be located to adequately support the transformer as recommended by the manufacturer.

The cooling method of the transformer must be considered in determining required space.

A. Transformer Cooling Methods

Iron and load losses from air and oil cooled transformers must be dissipated by radiation and convection. The most frequently employed method is the use of the transformer tank surface, smooth or corrugated, supplemented by tubular coolers. The oil in which the transformer is immersed carries the heat to the tank surface and the cooling tubes where it is absorbed by the surrounding air. This basic method has variations in the form of cooling fans, water circulating through coils in the oil, and combinations of these systems. The standard nomenclature for transformer cooling methods is:

ANSI cooling classes of transformers

Liquid-immersed, Air-cooled

1. Liquid-immersed, self-cooled: class OA

2. Liquid-immersed, self-cooled/forced-air-cooled: class OA/FA
3. Liquid-immersed, self-cooled/forced-air-cooled/forced-air-cooled: class OA/FA/FA.

Liquid-immersed, Air-cooled/forced-liquid-cooled
1. Liquid-immersed, self-cooled/forced-air cooled/forced-liquid-cooled: class OA/FA/FOA.
2. Liquid-immersed, self-cooled/forced-air-forced-liquid-cooled/forced-air-forced liquid cooled: class OA/FOA/FOA.

Liquid-immersed, Water-cooled
1. Liquid-immersed, water-cooled: class OW.
2. Liquid-immersed, water-cooled/self-cooled: class OW/A.

Liquid-immersed forced-liquid-cooled
1. Liquid-immersed, forced-liquid-cooled with forced-air cooler: class FOA.
2. Liquid-immersed, forced-liquid-cooled, water-cooled: class FOW.

B. Transformer Cooling Space Requirements

An OA, air-cooled, transformer requires from 24 to 36 inches clearance on all sides for adequate air circulation. If located indoors, adequate ventilation must be provided to allow heated air to escape, with inlets near the bottom and outlets near the top. One square foot of opening should be provided for each kW of transformer loss.

A forced-air-cooled transformer, FA, requires approximately twice the space needed by an OA transformer.

Forced oil, forced air, FOA, transformers require two to three times the clearance space as the FA types. Space requirements can be reduced somewhat by use of baffles to direct the air upward.

Water cooled transformers with convection circulated oil, OW, or pumped oil, FOW, require no special air space since nearly all the heat of the losses is carried away in the cooling water.

These space requirements are based on 30C average and 40C maximum ambient air in 24 hours for air-cooled transformers, and water temperature of 25C for water cooled units.

Nameplate kVA ratings for OW, OA transformers should be reduced by 1.5% for each degree C above standard cooling medium temperature. For FA, FOA, and FOW units, the nameplate kVA rating should be reduced 1% for each degree C.

4.3 Preparing for Receiving

The first step in transformer installation is planning to receive the shipment. The transformer manufacturer's instructions should be carefully studied and followed. These instructions should include such necessary information as:

dimensions
weight
bushing location
cooling system configuration
control cabinet location
loading and shipping conditions such as disassembly of parts and accessories that will require reassembly, and separate shipments.

Meetings should be held with all people involved with receiving and installing the transformer to review procedures and to assure the proper equipment is available to meet all of the manufacturer's requirements including installation.

Sight preparation and location on the mounting pad will be determined by considerations such as cooling requirements, weight, dimensions, accessibility, and ease of inspection. The over-riding consideration may be the cooling requirements. See **4.2** for complete transformer cooling systems definitions.

All necessary tools, equipment, and test instruments must be on hand including:

Vacuum pump, of the size recommended by the transformer manufacturer. Larger transformers require at least 300 cfm capacity with a blank-off pressure of .02 Torr.

Oil filter and blotting paper

Oil de-gassing equipment when called for in the transformer manufacturer's recommended procedures

Piping and/or hose

Thermocouple gauge or aneroid absolute pressure gauge

Oil dielectric test set required by ASTM D877. For further information on oil tests refer to *Westinghouse Electrical Maintenance Hints*, **Volume 1 Chapter 6,** Insulating Materials.

Sterilized dry bottles for oil samples

Low voltage explosion-proof lights with oil resistant cords

Humidity gauge

Megohmmeter (1000 volts)

Transformer Turns Ratio test set (TTR)

Oxygen-gas analyzer

Dew-point instrument

Nitrile rubbers for working inside transformer tank

Dry-nitrogen cylinders or dry air cylinders

Oil-storage tank (size to store oil to be taken from transformer)

Oil heaters (during winter or if transformer is to be dried out)

Drop cloth for packing unit

Clean, lint-free rags

Fire extinguishers

4.4 Receiving Power Transformers and Accessories

Power transformers are shipped in a variety of ways due to customer requirement, weight and size of equipment, ability of the carrier to deliver, point of delivery, and facilities available to the receiver to handle the unit from the delivery point to the job site.

Power transformers are usually shipped F.O.B., point of shipment thus making the carrier and the purchaser responsible for the equipment in transit. The receiver should be certain that he is represented at the delivery point by persons qualified to inspect the equipment and verify that it is in acceptable condition. If possible representatives of the supplier and the carrier should be present and, if involved, the installing contractor.

Equipment the size of power transformers is most frequently shipped by rail. Some manufacturers ship only on specially-built cushioned cars and all cars used are marked not to be humped.

A visual inspection must be made on the car. If there is any evidence of damage a claim should be immediately entered on the carrier. Check for the following:

Has the transformer shifted from the original loading position in either direction?

Have anchoring or tie rods been bent, loosened, or broken?

Has there been damage to the transformer case, cover, drain valves, cooler valves, or any external accessories mounted on the transformer? If any damage is observed, document with photographs of the affected areas.

Does the transformer have positive pressure in the tank? Check with pressure vacuum gauge. There should be positive pressure because large transformers are shipped filled with dry nitrogen or dry air to protect against moisture and to reduce the weight of the unit for ease of handling.

If there is not positive pressure in the tank there is reason to suspect leaks and possible contamination. The tank should be checked for moisture with a dew point instrument. The curve shown in Figure 3 shows acceptable dew point limits.

The dew point can be measured using an apparatus such as an Alnor Dewpointer or a Parametrics Aluminum Oxide Hygrometer. In making dew point measurements, at least 24 hours should elapse after the transformer has been sealed and filled with dry gas following vacuum or draining of oil, so the gas can come to equilibrium with the surfaces of the insulation. Measurements of dew point made at intervals several hours apart may be helpful in determining when equilibrium is reached. An estimate must be made of the average temperature of the transformer insulation. The preferred time to determine the insulation temperature is early in the morning when the liquid temperature indicator and the winding temperature indicator provide accurate estimates of the internal gas temperature. These temperatures should be within a few degrees of the ambient temperature; if not, the temperature of the transformer base should be used as an estimate of the insulation temperature. If the dew point measurement must be made later in the day, some judgemental factor will be required to allow for weather conditions and exposure of the transformer to wind and direct sun.The gas in the transformer should be at a slight positive gauge pressure, preferably not higher than 5 psi, when the dew point is measured.

1 Enter Curve at Insulation Temperature °C Left or °F Right
2 Move to Dew Point Line
3 Read the Maximum Acceptable Dew Point, °F on Bottom, °C on Top
4 Use This Curve for Pressure Between 0 and 5 PSI.

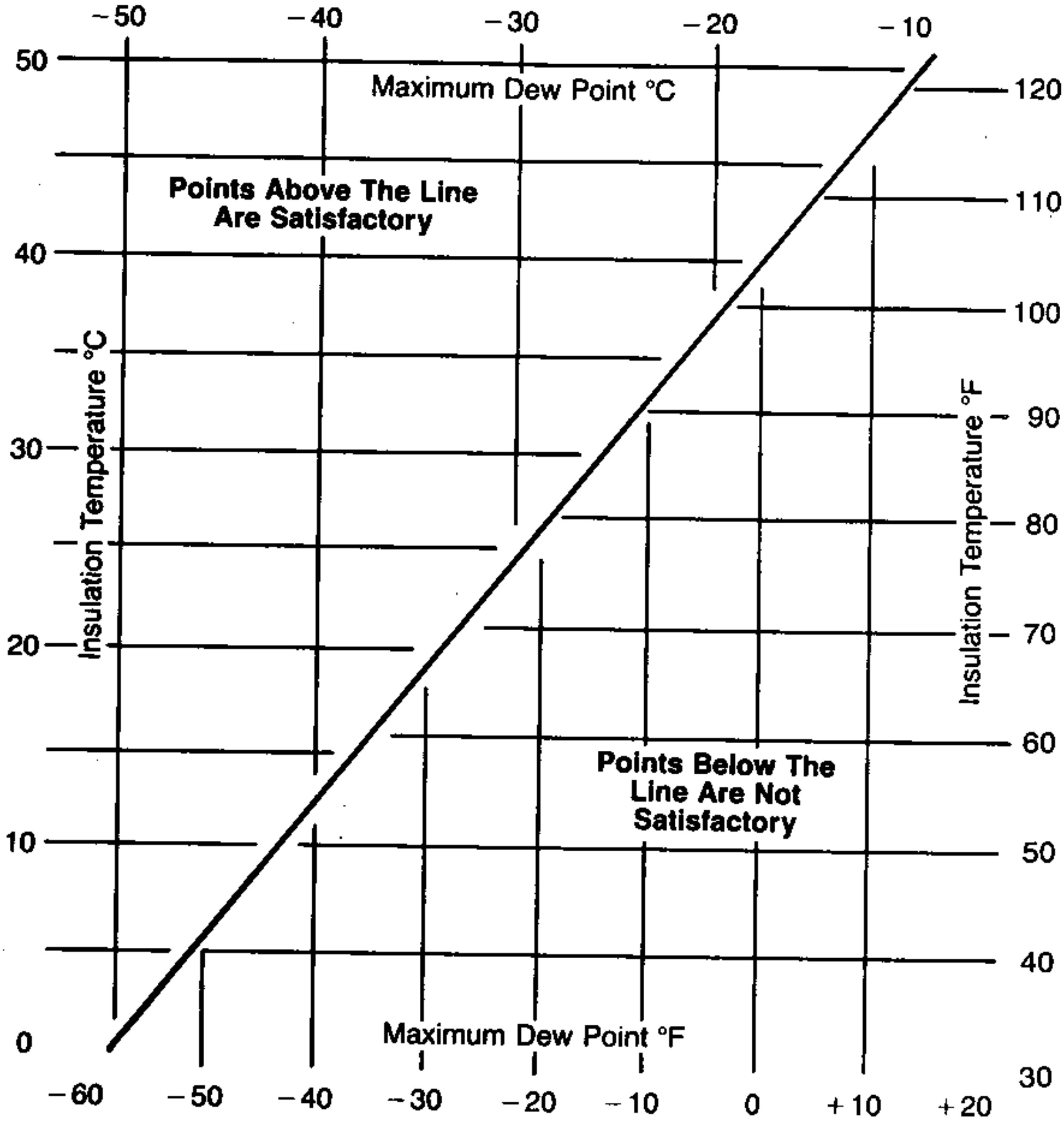


Fig. 3 – Dew Point Limits

Is there evidence of oil leaks? Smaller units are shipped filled with oil.

Does the impact recorder on the car indicate any Zone 3 or higher impacts? If so there is a possibility of internal damage and an internal inspection is indicated. File a hidden damage claim with the delivering carrier.

Has everything listed on the shipping bill of material been received? The detail equipment, dismantled parts and accessories, which were separately loaded and shipped, must be carefully inspected for damage.

4.5 Job Site Transportation

Job site transportation should be by crane if possible, otherwise the transformer can be skidded or rolled into place by winch. Refer to the manufacturer's outline drawing to make sure the transformer is resting on jacking lugs or places designated for jacking or for weight bearing. Pulling should always be by pulling eyes supplied on the unit. If winching on skids, rails, or rollers, two winches should be used, one pulling, one paying out slack. The transformer should never be allowed to tilt more than 15 degrees from vertical.

Special handling is required for units shipped laying on their sides and for units to be pedestal mounted.

Transformers should be supplied with the required lifting lugs, jacking points, and pulling eyes. The manufacturers outline drawings and installation instructions should supply necessary information.

4.6 Testing Before Energizing and Standard Field Tests

Warning: Tests must be made only by qualified experienced personnel. Failure to do so can cause severe personal injury or death, and damage to property.

The following tests should be made before the transformer is energized. The results of these tests should become part of the permanent record of the transformer. They will allow for comparison with future maintenance test comparison checks.

When performing insulation resistance tests with a megohmmeter it is always advisable, before starting to test, to check the megohmmeter for infinity after it has been leveled on a solid base. Always check the zero setting on a power factor bridge before and after testing.

The value of the insulation resistance and power factor testing in the field is to allow a comparison with the factory tests and previous field tests. To do this the field measurements must be corrected to the equivalent values at 20 C. This is the temperature to which the original test measurements were corrected. Table 1 provides these correction factors.

Warning: Never make megohmmeter tests with the transformer under vacuum or without oil. To do so can cause severe personal injury or death, or damage to property.

The greater the vacuum, the lower the spark-over level unless the vacuum is perfect. At the vacuum levels normally reached in the field, it is most likely that the megohmmeter readings will be zero; ie, creeping or flashing to ground will occur. Breakdown strength under vacuum is a function of both pressure and distance.

Megohmmeter readings made on a unit not immersed in oil will give values that may be misleading and will not agree with readings taken with the unit under oil. Readings taken with the unit immersed are ¼ to ½ those taken with the unit in air.

Table 1

Temperature Correction Factors for Megohmmeter Readings.

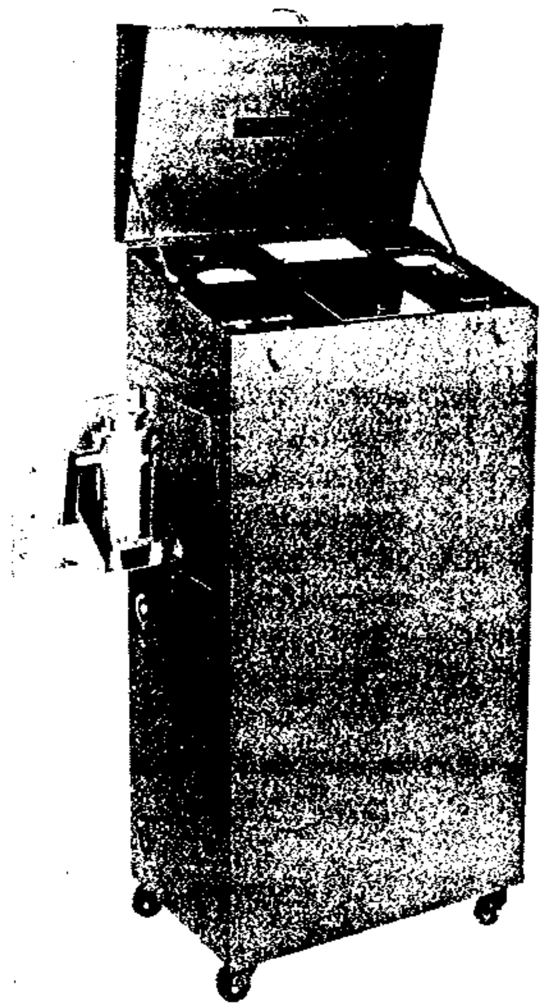
Temperature		**Transformers**
C	F	Oil Filled
0	32	.25
5	41	.36
10	50	.50
15.6	60	.74
20	68	1.00
25	77	1.40
30	86	1.98
35	95	2.80
40	104	3.95
45	113	5.60
50	122	7.85
55	131	11.20
60	140	15.85
65	149	22.40
70	158	31.75
75	167	44.70

Example:

If the megohmmeter readings were 2200 megohms at 20C as reported by the manufacturer, field tests at 25C would give readings of about 1570 megohms and field tests at 45C would give megohmmeter readings of about 391 megohms.

For procedure for insulation resistance measurement by megohmmeter refer to **4.11.**

In addition to megohmmeter testing there are available test sets for maintenance testing of electrical apparatus. These test sets are capable of testing for dielectric loss and power factor of solid and liquid insulation, bushings, windings, arresters, circuit breakers, cable, and bus. See Figure 4.



Courtesy Doble Engineering Co.

Fig. 4 – A Dielectric Loss and Power Factor Test Set

A. Insulation-Resistance Test.

A megohmmeter insulation-resistance test, made in the field and compared with measurements made at the factory will tell you if a transformer is sufficiently dry to energize. Insulation-resistance measurements are made on each winding with all other windings grounded. No windings with external bushings should be left floating during insulation-resistance measurements. Normally-grounded windings must have the ground removed if you want to measure insulation-resistance to the other grounded windings. If it is not practical to remove the ground, as in the case of solidly grounded neutrals, the insulation resistance of the winding cannot be measured; treat it as part of the grounded circuit.

Table 2

Insulation resistance temperature correction factors for units in oil

Transformer temp deg C	Correction factor	Transformer temp deg C	Correction factor
95	89.0	35	2.5
90	66.0	30	1.8
85	49.0	25	1.3
80	36.2	20	1.0
75	26.8	15	0.73
70	20.0	10	0.54
65	14.8	5	0.40
60	11.0	0	0.30
55	8.1	−5	0.22
50	6.0	−10	0.16
45	4.5	−15	0.12
40	3.3		

Note: The field-tested value times the correction factor yields equivalent value at 20C

Table 3

Typical Insulation resistance in oil at 20C for various transformer voltage classes

L-L Voltage Class

kV	Megohms
1.2	32
2.5	68
5	135
8.66	230
15	410
25	670
34.5	930
46	1240
69	1860
92	2480
115	3100
138	3720
161	4350
196	5300
230	6200
287	7750
345	9300

If field measurements of insulation resistance indicate a wet transformer, dry it out before energizing. Moisture is the greatest enemy of insulation and the cause of many transformer failures. There are many methods for drying out transformer insulation in the field; all of them require considerable equipment and one to four weeks of drying time, depending on the size of transformer and the degree of wetness.

B. Oil Tests.

Test all oil in each shipping container (drums, tank truck, or railroad car). The dielectric strength, power factor, water content, interfacial tension, and neutralization number should be determined. If tests cannot be made at the site, certified test reports from the supplier should be available for tests made on samples taken from each shipping container, showing that the oil meets specifications.

The electrical strength of the oil, measured per ASTM D877, must be at least 30 kV.

The power factor must not exceed .05 percent.

Water content must not exceed 35 ppm.

The interfacial tension must be 40 dynes minimum.

The neutralization number must not exceed 0.03 mg.

For additional information on transformer oil refer to *Westinghouse Electrical Maintenance Hints,* **Volume 1, Chapter 6,** Insulating Materials.

C. Core-to-Ground Test.

Test core form transformers only with core and coils under oil.

The core in a core-form transformer is normally insulated from the tank except for a single strap connection. To measure the core-to-ground insulation, check first for multiple grounds. Usually, the core ground strap is connected on the underside of the cover, near a manhole; it can be readily disconnected, and a 1000 volt megohmmeter used to measure resistance, core-to-tank. A core under oil should measure 200 megohms. A reading of only several ohms suggests a dead ground that may require repair. A reading of 300 to 400 ohms usually indicates foreign material between core and tank.

Clearing core grounds, caused by foreign matter, is done by applying a fused, low a-c voltage between the core strap and the tank. This should be a 5 kVA, 110-120 volt alternating current. This a-c voltage will cause an arcing that can be heard inside the transformer. If improvement is shown after several applications of the a-c voltage, repeat until the ground is cleared and a reading of 200 megohms is obtained. Successful clearing of the core ground can be verified by performing a 1000 volt high potential test.

D. Winding Ratio Test.
Check the transformer ratio on all windings and at all tap positions to assure that no damage has occurred in transit that has changed the ratios. A transformer turns ratio (TTR) test is the easiest way to do this.

An alternate method of testing turn-to-turn ratios is to use a low voltage alternating-current supply.

Warning: Check the nameplate to make sure that hazardous voltages will not be introduced by a large turn-ratio winding. Failure to do this can result in severe injury or death by electric shock, and damage to property.

Ratio tests of under-load tap changers may be difficult to measure with a TTR set on bridging positions, because some tap changers have a preventive autotransformer feature. The high exciting current may produce incorrect readings. A 480 volt supply may overcome this difficulty.

The turns ratio test results should agree with the nameplate within 0.5 percent.

E. Insulation Power Factor.
Measurement of insulation power factor is really a measurement of insulation dryness. A standard capacitance bridge should be used to measure the capacitance between windings, and between windings and ground, together with the power factor or loss angle of capacitances.

Insulation power factors vary widely with temperature, so a correction factor is required to permit comparison of field tests with factory data given at 20C. The correction formula is:

$$\frac{\text{PF @ Field Test Temperature}}{\text{K Factor @ Field Test Temperature}} = \text{PF @ 20C}$$

Insulation power factor temperature correction for factory test value correction

Table 4

degree C	K factor
10	0.80
20	1.00
30	1.25
40	1.55
50	1.95
60	2.42
70	3.00

The field-test value is divided by the K factor to find the equivalent of the 20C factory value. A typical value of insulation power factor (corrected to 20C) is 2% or less. No standards have been established for an acceptable power factor. An evaluation of dryness can be made by comparing readings made in the field with the factory tested dryness readings.

The power factor of windings next to the core may be higher than readings of the other windings due to losses from dielectric current flowing through the core.

F. Oxygen Content of Gas Space Above Transformer Oil

All oil filled transformers must have provision for variations in liquid volume with temperature change. Most use a gas filled space above the oil in the main portion of the tank. This space is usually equal to at least 10 percent of the total liquid volume. The space is filled with inert gas (usually dry nitrogen) to prevent outside atmosphere from contaminating the oil. Filling the space with dry nitrogen drives out the oxygen from the space and prevents the oxygen's deteriorating and sludge forming effects on the oil. It also eliminates the danger of secondary explosion from the accumulation of oxygen. Dry nitrogen eliminates moisture from the space thus avoiding the potential of insulation failure due to moisture.

In one type of transformer tank construction the gas space is large enough to allow safe expansion and compression of the gas as temperatures vary. A relief device is supplied to vent the gas space if the pressure exceeds a pre-set limit.

Another type of transformer tank allows the gas to flow into the tank from a cylinder to maintain a constant positive pressure in the space, independent of changes in the oil volume. In this system gas is added automatically if pressure falls below a pre-established level (0.5 psg).

When the pressure rises above a pre-set level (6.5 psg) the space is vented through a relief device.

Dry nitrogen should contain less than 0.3 percent moisture by weight and the impurity content should be less than 0.3 percent by volume. Nitrogen should be introduced into the gas space until the oxygen content is less than 3 percent of the gas space.

G. Final Check Before Energizing
Before energizing a final check should be made for oil leaks, air leaks; wrong direction of rotation of fan motors, fans, and pumps; position of valves, oil level, forgotten shipping braces, tools, etc.

If current transformers are included in the main unit, check the wiring to make sure the shorting jumpers have been removed and the current transformers connected on the secondary to a continuous circuit.

After energizing, the transformer should be allowed to soak on the line for a few hours before being connected to a load.

Warning: Check output voltages of 3 phase transformers before allowing them to soak, especially if protected by fuses. A fuse may blow from current in-rush and single-phase the transformer input. This can result in high ferroresonant overvoltages and subsequent insulation failure. Fuse failure may not change the sound level of the unit. Failure to make this check can result in severe injury or death by electric shock or explosion, and damage to property.

After a week in service the bottom oil should be tested for moisture and the gas space for oxygen.

4.7 Taking the Transformer Out of Service

Warning: Do not attempt to perform any work on a transformer before it has been de-energized and solidly grounded, and will remain so. Failure to follow this precaution can cause severe injury or death by electric shock, and damage to property.

Before starting work on a transformer that has been in service the unit must be: de-energized, grounded, gas pressure relieved, nitrogen purged, and dry air introduced.

4.8 Working Inside the Transformer Tank

Warning: Do not enter a transformer tank before the gas pressure is relieved and the nitrogen gas completely replaced with clean dry

air. Failure to follow this precaution can cause severe injury or death by asphixiation.

The atmosphere inside a transformer tank will not support life until the nitrogen or gas has been expelled and replaced with clean dry air. A minimum of 19.5% oxygen is required to support life.

When working inside a transformer tank all personnel must be dressed in clean, dry clothing, wear clean cloth shoe coverings or Nitrile over-shoes, and have empty pockets.

All tools must be secured with handlines. Any lines, hoses, pipes, or filter presses introduced into the tank must be clean and dry. The top of the core and coils must be packed with clean dry cloths to catch any falling objects.

Outdoor transformers must never be opened during periods of rain or rapidly changing weather conditions unless the opening is completely protected from the weather by a double-door air lock.

Danger: Do not attempt to perform any work on a tap changer before it has been de-energized and will remain so. Failure to follow this precaution will cause severe personal injury or death, and damage to property.

All inspections must be thorough, tap changer position, connections to bushings, lightning arresters, and grounds must be checked. Primary and secondary bus or leads must be securely connected before re-energizing. A final check must always be made for any metal object that may have been dropped or left behind.

4.9 Exterior Inspection

All gauges, valves, and fittings must be periodically checked for operation, accuracy, and tightness. Relief pressure valves and breathers must be inspected to be sure their passageways are clear and not obstructed or restricted by paint or foreign material such as bird or insect nests.

All switches must be operated and contacts checked if possible. With the control de-energized, cam switches must be hand operated and contacts inspected. Operation of the mechanical stop must be checked with the handcrank.

Control wiring connections must be verified, and control cabinet weather tight integrity confirmed.

It is most important that all tests be made only on clean, dry equipment and above the dew point. See 5.4 for procedure to determine dew point.

4.10 Condensation

Warning: Do not open a transformer tank until the transformer has been de-energized and solidly grounded. Failure to do so can cause severe injury or death.

Because of the effect of moisture on insulation resistance, it is advisable not to open a transformer tank if the relative humidity is above 65%. High humidity increases the probability of condensation on insulated surfaces inside the transformer tank if the tank is opened. Insulation resistance is always affected to some extent by the moisture in the atmosphere even when the equipment temperature is above the dew point. Significant changes in atmospheric pressures will cause changes in insulation resistance due to variations in the atmospheric vapor pressure. When internal work is being done in the transformer, circulate dry air in the tank from a connection near the bottom. Access openings should be covered (but not sealed) just enough to prevent the entrance of moisture or other foreign material.

4.11 Insulation Resistance Measurement by Megohmmeter

A method of measuring insulation resistance is by megohmmeter. This instrument is very convenient and indicates resistance directly. To secure uniform results a regular procedure should be followed.

Recommended practice in measuring insulation resistance is to follow these steps in the sequence shown:

Make sure both tank and core iron are grounded
Short-circuit each winding at the bushing terminals.

Measure resistance between winding and all other windings, with all windings grounded except the one being measured. Windings are never left floating for insulation resistance testing.

Grounded windings must have the ground removed so the insulation resistance can be tested. If the ground cannot be removed, as with solidly grounded neutrals, the test cannot be made. Such a winding is treated as part of the grounded circuit.

Factory insulation resistance readings are corrected to an equivalent resistance at 20C in oil. Cool windings have a higher insulation resistance and insulation resistance is lower when the winding is submerged in oil. Table 1 shows correction factors for windings in oil at field temperatures other than 20C. Table 3 shows typical resistances of various voltage classes. When recording insulation-resistance test results the instrument reading, oil temperature, outside air temperature, and humidity should be shown.

Tests should be made from windings to ground and between windings as follows:

A. Two winding transformers

1. High to low and ground
2. Low to high and ground
3. High and low to ground

B. Three winding transformers

1. High to low, tertiary, and ground
2. Low to high, tertiary, and ground
3. Tertiary to high, low, and ground
4. High and low to tertiary and ground
5. Low and tertiary to high and ground
6. Low and tertiary to high and ground
7. High, low, and tertiary to ground

Permanently connected windings, such as autotransformers and regulators should be considered as single winding.

Example: With a three-winding transformer, the high-voltage, tertiary-voltage, and low-voltage windings are each short-circuited by connecting their terminals together. The high-voltage winding insulation resistance is measured by connecting the high-voltage terminals to the line or resistance terminal of the megohmmeter, and the low-voltage and tertiary-voltage windings are connected together and to ground, and to the ground terminal of the megohmmeter. The guard terminal of the megohmmeter, if it has one, is not used but left floating. The resistance thus measured is commonly designated H-LTG, **B.4** above.

The megohmmeter should have an output of at least 1000 volts. The maximum resistance measured must be within the rating of the instrument. The megohmmeter should have a 20,000 megohm scale. Readings at the extreme upper range of the scale tend to be inaccurate. When such readings are encountered, use an instrument capable of measuring a higher resistance. The measuring lead should be air insulated from all other leads and from ground or grounded objects to prevent misleading results due to measuring the conductor insulation resistance instead of the transformer winding insulation resistance.

Do not measure control wiring with a 1000 volt megohmmeter, use a 500 volt instrument.

4.12 Planned Maintenance

A planned maintenance program on power transformers will assure maximum trouble free life for the equipment, and long range economy of operation.

The following should be checked periodically: Bushings, paint, oil level, fan motors, pump motors, sudden pressure relay, and inert gas equipment. Inspect regularly for oil leaks and gasket leaks.

4.13 Bushing Power Factor and Capacitance Tests

Testing schedules should call for initial power factor and capacitance tests and rechecks at least every second year thereafter. External damage, or collection of dirt on insulating surfaces may make more frequent inspections and tests necessary.

The normal power factor of capacitor type bushings is so low that measurements may be greatly distorted by dirt or moisture on the porcelain surfaces. Incorrect readings can also result if tests are made near wet or grounded surfaces. External parts connected to the bushings such as the interrupter or leads will greatly increase power factor test results.

Before making a power factor test on a bushing, wipe it clean of all foreign matter using cloths wrung out of 1, 1, 1, trichloroethane or other non-explosive cleaning fluid, then polish with a dry cloth.

Make certain that power connections do not create a strain on the bushing. Use flexible connectors.

4.14 Moisture

Transformers may become contaminated with moisture in many ways:

Failure to use filter presses and vacuum equipment when filling the transformer with insulating oil.

Opening the Transformer under unfavorable weather conditions.

A leak in the transformer tank that will allow entrance of moisture laden air.

Moisture may enter during the filling process if the oil lines are not sealed and the filter press not closely coupled to the transformer.

Warning: Always treat transformer oil as a flammable liquid. Closed transformers and tap changer tanks may accumulate explosive gases and oil handling procedures may generate static electricity. Safety precautions include purging all gas spaces with nitrogen before oil filling or filtering. Ground the transformer, its bushings, and all oil handling equipment. Failure to follow these precautions can cause severe personal injury or death, and damage to property.

If the Transformer is to be filled with insulating oil in temperatures below freezing, pre-heat the oil before admitting to the transformer. If the oil is not heated the filter press will not remove the moisture from the oil, and the vacuum in the transformer tank will not operate efficiently to remove trapped air, gasses, and moisture.

4.15 Oil Heater

Any time the ambient air is warmer than the transformer condensation will cause the accumulation of moisture inside the transformer tank. This is especially true in cold weather, conditions of high humidity, or anytime the transformer tank has been open. If a transformer is to be filled under these circumstances, the temperature of the core and coils must be raised and maintained during the filling process. This is accomplished by heating the oil. There is, therefore, a need for an on-site oil heater.

Figure 5 is a plan for a portable oil heater developed for the purpose of heating oil on-site. This device is compact, portable, easy to construct, and can be built at a reasonable cost. The oil temperature can be controlled by cutting in or out of the circuit as needed.

Heating should be regulated to maintain an oil temperature not to exceed 24C except when dry-out procedures are being followed. For dry-out the maximum temperature should not exceed 75C.

4.16 Field Dry-Out of Transformers

Warning: Do not energize a wet transformer. If there is reason to believe that the transformer contains moisture, from any cause, it must be thoroughly dried before energizing. Failure to do so can cause severe personal injury or death, and damage to property.

A. Hot-Oil, Vacuum Dry-Out

Once a power transformer becomes wet it must be dried out before it can be energized. Hot-oil heating and vacuum dry-out is effective; provided the transformer is braced for full vacuum.

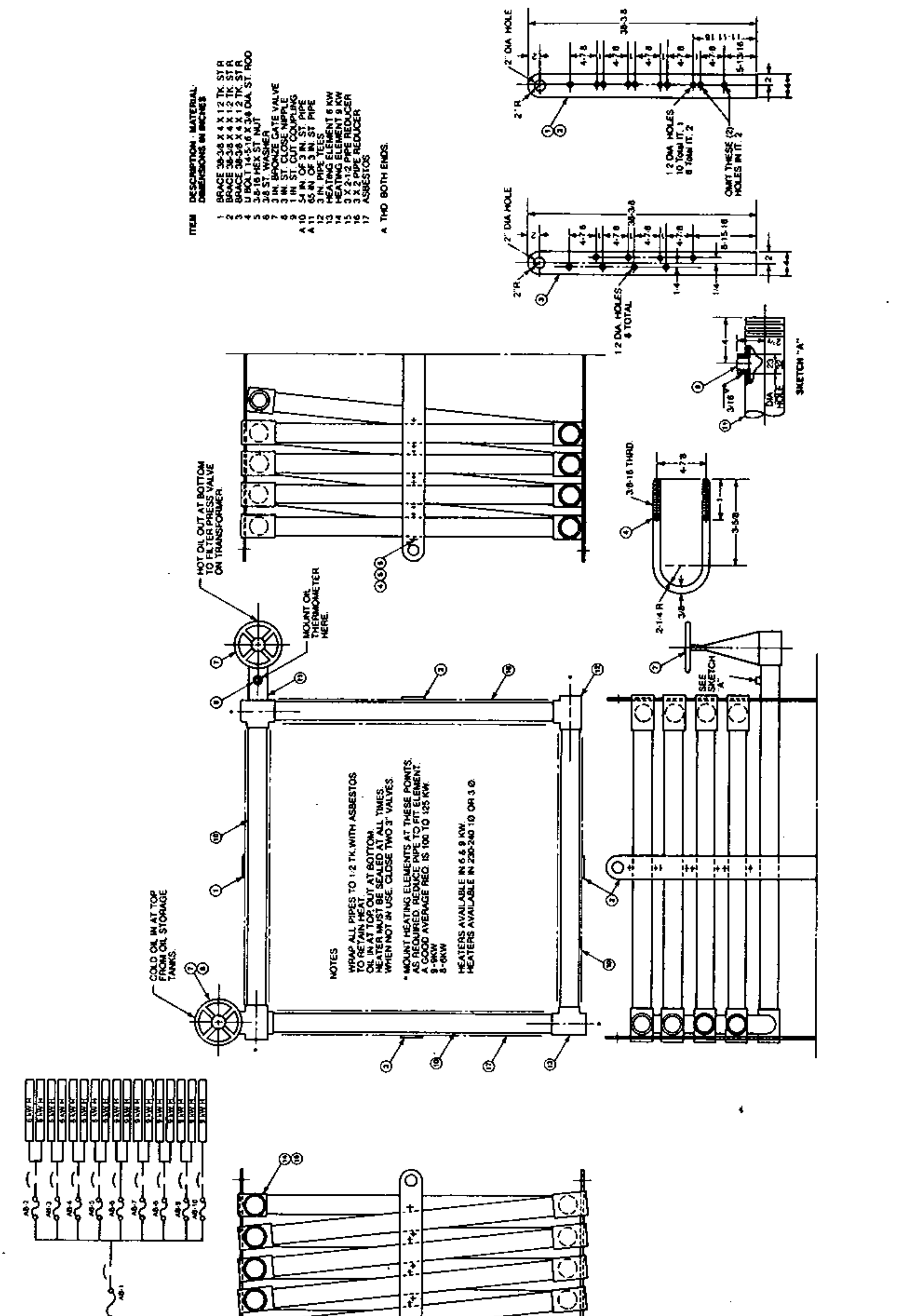


Fig. 5 – A Design for a Portable Oil Heater for On-Site Heating of Insulating Oil

The following equipment is necessary for field dry-out procedure:

30 gallon per minute filter press, blotters, oven.

2 hot oil thermometers or thermocouples.

Oil storage for the full capacity of the transformer.

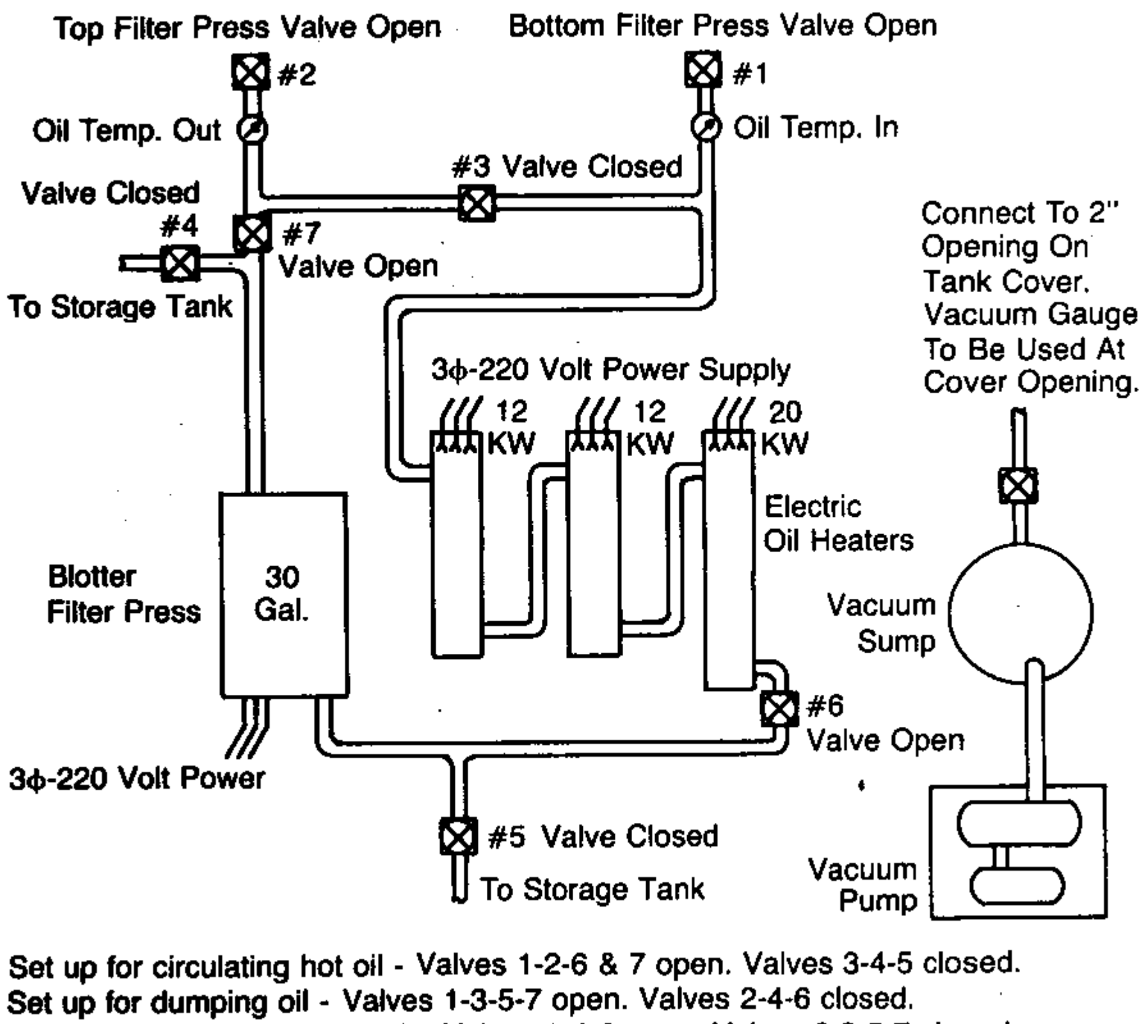
Immersion oil heaters, 44 kW heating element for transformers to 10,000 gallon oil capacity, 125 kW heating elements should be used for larger volumes of oil.

(See Figures 5 and 6 for piping and heater arrangements.) Vacuum pump capable of 200 microns vacuum during drying and 4-10 mm during the oil filling process.

Pipe, 1¼ to 2 inch diameter, clean, with appropriate fittings to close the oil system.

Oil test set, 40 kV.

Megohmmeter, 1000 volt motor driven.



Set up for circulating hot oil - Valves 1-2-6 & 7 open. Valves 3-4-5 closed.
Set up for dumping oil - Valves 1-3-5-7 open. Valves 2-4-6 closed.
Set up for refilling with hot oil - Valves 1-4-6 open. Valves 2-3-5-7 closed.
Set up for refilling with hot oil under full vacuum - Valves 1-5-7 closed. Valves 3-4-6 open and regulate oil flow with #2 valve.
Use clean 1-1/4" iron pipe, valves and unions.

Fig. 6 – Filtered Hot Oil and Vacuum Piping System

The hot oil enters at the bottom of the transformer tank and returns from the top, just below the surface. The thermometer or thermocouples are placed to measure the temperature at the points of entrance and exit from the transformer. The temperature of the entering oil should not exceed 75C and that input temperature should be maintained until the return oil temperature and the megohmmeter readings become constant.

Oil temperatures should be closely observed and recorded hourly. Megohmmeter readings should be taken at one hour intervals throughout the oil heating cycle and should be of one minute duration. Readings should be made at:

High voltage to low voltage and ground.

Low voltage to high voltage and ground.

High and low voltage to ground.

Dielectric strength tests should be made and recorded every hour. The oil test data will indicate progress in the drying procedure.

When the return oil temperature and the megohmmeter readings have stabilized for eight hours the transformer is as warm as it will get. It should be sealed off for vacuum treatment as quickly as the oil can be drained into the storage tank. The time element is important because the transformer should not be allowed to cool below 50C.

B. Alternate Transformer Heating Procedure

An alternate transformer heating procedure can be used where practical. It may bring the equipment to the desired temperature in a shorter time.

1. *Pull a vacuum of approximately 10 millimeters for at least 4 hours.*

Following this, spray hot oil through the upper filter press valve of the transformer. The oil should be sprayed so the stream is broken up into droplets for more efficient heating of the core and coils. Maintain a vacuum of at least 10 millimeters on the transformer during the spraying operation to prevent oxidation of the oil and to aid in the removal of gas from the insulation.

It will probably be necessary to maintain some oil in the bottom of the unit to feed the output pump. Usually 12 to 14 inches of oil in the bottom will be sufficient. Do not allow the level of the oil in the tank to rise above 36 inches. A clear plastic hose can be used as an oil-level indicator.

2. *Pump the oil from the bottom of the transformer,* through filters, through the heater, and back to the top inlet of the transformer.

The oil temperature entering the transformer should be as hot as possible but not to exceed 75C. Continue spraying the hot oil under vacuum until the temperature of the core and coils is well above 10C. The temperature of the core and coils will be at equilibrium conditions when the output oil temperature becomes constant, and approximates the input temperature.

The heating rate can be accelerated by closing the bottom valves to the coolers or radiators and by blanketing the outside of the tank to restrict heat loss.

3. *After the temperature of the core and coils has been elevated* drain all oil from the tank and coolers or radiators. It will be necessary to break the vacuum to drain the oil. The vacuum must be broken with dry gas to prevent condensation in the tank.

4. *When the oil is drained from the tank* immediately start the vacuum treatment.

While the heating process is underway prepare for the vacuum drying cycle by connecting the vacuum pump to the top of the transformer tank. Use the shortest pipes with the greatest diameter possible. Bolt the access hole cover down with a new gasket. This preparation will permit starting the vacuum pump immediately after the oil has been drained, thus minimizing heat loss.

Maintain the vacuum as specified in the manufacturer's instructions and fill the transformer with oil using the procedures given in the manufacturer's instructions.

4.17 Solid Insulation

Little can be done in the way of maintenance of the solid insulation of oil-insulated transformers and regulators, but correct load and temperature control can do much to keep insulation aging within normal limits. Aging of insulation is affected by the operating temperature of the windings and the condition of the oil in which it is submerged. Oil of high acidity will accelerate aging of the solid insulation. The aging rate of organic insulation doubles for approximately each 8 C increase in its temperature. The lower the operating temperature, the longer the insulation life.

Since aging is so much more rapid at the high range of temperature, avoid excessively high temperatures as much as possible. On the other hand, little is gained by having insulation life exceed the obsolescence life of the apparatus. Maximum life is assured only under uniform, normal loading. Therefore, loading should be controlled as much as possible to obtain that objective.

4.18 Repairing Tank Leaks

The following general instructions are procedures for repairing weld leaks in power transformer tanks or auxiliary compartments. Variations on these instructions may be required for special repair tasks.

A. Transformer Cases and Fittings

Transformer cases and their fittings are fabricated from $\frac{3}{16}$ inch to $\frac{1}{2}$ inch thick welding quality low carbon steel, which is joined by manual, semi-automatic, and automatic welding, using manual shielded arc, submerged arc, and inert gas arc process.

To repair a weld leak in a case seam or around one of the fittings, the following procedure is recommended:

1. *De-energize the transformer.* Check the liquid level in relation to the area to be welded. It should be 4 inches or more above the area to be welded.

2. *If the liquid has not been removed,* pull a vacuum of one inch for each foot of oil above the leak to stop the oil seepage. This may be done either with a vacuum pump or by sealing all fittings on the case and draining sufficient oil to obtain the necessary vacuum. Vacuum is not always required, especially when a sweating leak is to be repaired and the case wall is relatively thick.

3. *Peen the weld leak closed,* if possible, with a ball-peen hammer or with a blunt or round-nosed chisel.

4. *Grind or scrape the paint* from the area to be welded and prepare a suitable point for attaching the ground lead from the arc welding machine.

5. *Select a $\frac{1}{8}$ inch diameter all purpose, coated electrode,* American Welding Society Type E-6012. Either alternating- or direct-current welding current may be used. When direct current is used, straight polarity is preferred. The electrode should be negative polarity.

Adjust the welding machine to supply the desired welding current. Some value between 115 to 125 amperes should be used, depending upon the individual task at hand.

6. *Apply a weld bead,* welding over the defect in a single quick pass. This weld may be made horizontally or vertically. If the weld is deposited vertically, it is recommended that it be made downward to drive any liquid seepage ahead of the weld.

Successive welds are then made adjacent to and overlapping the first bond, or a single pass may be woven across it to complete the weld. If no liquid seepage is present, upward passes may be made if preferred. Remove the slag from each pass before depositing the next weld.

Oil interferes with the welding operation and the quality of the deposited metal. It should be wiped clean with a dry cloth.

7. *Clean the repaired area and* check with a suitable leak detector to be sure the leak has been stopped.

8. *After testing for leaks,* re-clean the area and apply touch-up paint.

B. Alternate Method Using a Patch
A patch may be welded to the transformer case to repair a large leak as an alternate to the method above. The recommended procedure is as follows:

1. *De-energize the transformer and pull a vacuum,* peen the weld, clean the weld area, check the liquid level, use ⅛ inch Type E-6012 electrodes and adjust the welding machine.

2. *Fit a patch of 3/16 inch to ¼ inch thick steel* over the area to be sealed. Tack this patch in place, then weld it to the transformer case by welding the sides first, top to bottom. Then, weld horizontally across the top of the patch and finally, horizontally across the bottom. This welding sequence is required to prevent any liquid interfering with or contaminating the weld.

3. *Clean the repaired area* and check with a suitable leak detector to be sure the leak has been stopped.

4. *After testing for leaks,* re-clean the area and apply touch-up paint.

C. Tubular Coolers

To repair a weld leak in a tube cooler assembly or in the weld attaching the headers to the case the following procedure is recommended:

1. *De-energize the transformer and pull a vacuum* above the liquid to stop the fluid leak. This is essential when repairing swaged tube coolers.

2. *Peen the weld leak closed if possible* with blunt or round nosed chisels.

3. *Scrape the paint from the area to be welded* and prepare a suitable point for attaching the ground lead to the arc welding machine. Remove any liquid from the surface to be welded.

4. *If a leak occurs in the weld at the swaged end* or where a brace is welded to a header use a 3/32 inch diameter coated electrode with low penetration characteristics, AWS type E-6013. Either direct current (straight polarity preferred) or alternating current may be used. The recommended welding current is 50 to 60 amperes.

5. *Seal the leak with a single, quick pass.* Apply the bead horizontally, vertically or overhead as the occasion demands. If vertically, weld downward. When sealing a weld joining the header to the case, start at the top of the header and weld downward around its periphery to the bottom of the header. Always weld so any oil seepage will flow away from the weld rather than into it.

Weld beads must be small and made quickly to prevent burning through the tube walls. An arrangement of mirrors may aid in repairing a weld that can be reached, but is not in the welding operator's direct line of vision.

6. *Clean the repaired area* and check with a suitable leak detector to be sure the leak has been stopped.

7. *After testing for leaks,* re-clean the area and apply touch-up paint.

8. *If a leak occurs in the tube* (usually a flash weld seam) or where a brace is welded to the riser tube, drain the liquid and blanket with nitrogen. Then the repair can be made by gas welding. After repair has been made, repeat steps 6 and 7.

Approximate metal thicknesses used in tubular coolers are 2 inch 18 gauge (approximately .05 inches) wall thickness riser tubes, 2 3/8 inch .093 inch wall thickness header tubes. Wall thickness of the riser tube at the swaged end at the point of weld is approximately .070 inches.

Tube cooler assemblies without swaged riser tubes are made from much heavier metal, riser tubes approximately 1½ inch pipe with 9/64 to 5/16 inch wall thickness, and 2 inch header tubes of extra heavy duty pipe.

D. Fin-Type Radiators
Fin-type radiators consist of varying numbers of fin elements welded together and to a formed header. The fin elements are made from two sheets of mild steel (approximately .06 inches thick) continuously welded along their outer edges and with intermediate seams between the individual lobes. Field repair of a seam between lobes or replacement of an element is not recommended. The radiator should be returned to the manufacturer for repair.

E. Header Flanges
To repair weld leaks around the header flange, along the outer edge of the elements or in the weld where the elements join the header or each other, the following procedure is recommended:

1. *Close the radiator valves* between the radiator and the transformer case. Drain the liquid from the radiator and remove the radiator from the transformer.

2. *Grind or scrape the paint from the area to be repaired.* Also remove any liquid, dirt, or foreign matter.

3. *If the weld to be repaired is around the header flange,* use ⅛ inch diameter Type E-6012 electrodes with current settings between 115 to 125 amperes. Weld horizontally around the flange.

4. *A short, hot oxygen-acetylene welding flame is recommended* for repairing a weld along the edge of an element, a weld joining the elements to each other, or a weld joining the elements to the header. The procedure for repairing a leak along the edge of an element is outlined below:

a. Heat the full length of the seam with the torch to drive out all trapped oil.

b. Find the exact location of the leak by means of a suitable leak detector.

c. When the location of the leak has been determined, notch the edge of the element at points two to three inches on either side of the leak. These notches may be cut with a hack saw, a file, or a small grinder.

d. Start by brazing one of the notches. Then braze the second notch. Finally fuse the edges of the element between the notches moving forward with slightly weaving motion of the torch. Be sure to tie this seam into both repaired notches. Use 1/16 inch soft iron gas welding rod as filler material.

5. *Clean the repaired area* and check to be sure the leak has been stopped.

6. *After testing for leaks,* reclean the area and apply touch-up paint.

7. *Reinstall the radiator.*

F. Yukon Coolers

Yukon Coolers are formed by corrugating sections of the tank wall and are integral with the tank wall. The thickness of these coolers is usually 5/16 inch which corresponds to the wall thickness of network transformers on which they are primarily used. Since they are the same thickness as the tank wall and consist mostly of flat surfaces, the procedure for repairing weld leaks is the same as that used for repairing tank leaks.

4.19 Forced Oil Circulating Pumps and Coolers

Forced oil circulating pumps and coolers may not be shipped mounted on the transformer. The transformer manufacturer's instructions will contain procedures for mounting.

A. Oil Circulating Pumps

All gasket grooves and surfaces to be bolted together must be carefully cleaned. Joints are usually designed to provide proper gasket pressure when metal to metal contact is made in bolting. Only enough gasket cement is needed to hold the gasket in place during assembly.

When the cooling system mounting is complete the pump may be filled with transformer liquid by opening the tank and cooler valves and permitting liquid from the transformer tank to fill the pump. Entrapped air must be released through the topmost vent plug. When liquid appears at the vent tighten the plug.

It is important that no air be trapped in the pump. The manufacturer's instructions for clearing the trapped air from the pump must be executed before the transformer is energized.

Before energizing the pump, check the nameplate to make sure the proper power supply, voltage, and phase are connected. The supply voltage may vary a maximum of ± 10 percent from the specified voltage.

Normal operation of the pump is indicated by the *ON* operation of the flow gauge. It is possible for the pump flow gauge to indicate it is on when the pump is running backward. This condition is identified by a very noisy rattle in the pump.

These units require little maintenance. Periodic inspections should be made to detect evidences of distress such as heat, noise, and vibration.

B. Oil Circulating Coolers

Joints are usually designed with recessed gasket grooves which will produce the correct gasket compression when drawn into metal-to-metal contact. The gasket grooves and the surfaces that are bolted together must be thoroughly cleaned before assembly. Only enough gasket cement to hold the gaskets in place during assembly should be used.

To fill the cooler with oil, open the bottom tank valve and allow the oil from the transformer to flow into the cooler. Open the top cooler vent plug to permit venting of any trapped air. Oil must be added to the transformer tank during this operation to maintain the proper oil level.

It is important that no air be trapped in the pump. Entrapped air must be released by loosening the topmost vent plug on the pump. When oil begins to seep out the vent, the plug should be replaced and tightened. See Figure 7 for cooler venting instructions.

After the control and alarm contacts circuits have been completed the cooler is ready for operation.

4.20 Accessories

A. Maintenance of Circulating Pumps

The oil circulating pump and motor are rotating equipment subject to bearing wear and failure. Periodic checks will give assurance of bearing condition. Any departure from the usual sound of the pump and motor indicates need for investigation.

Some oil circulating pumps are a completely enclosed close coupled pump and motor designed as an integral unit. These should never be operated dry as wiping of the bearings will occur.

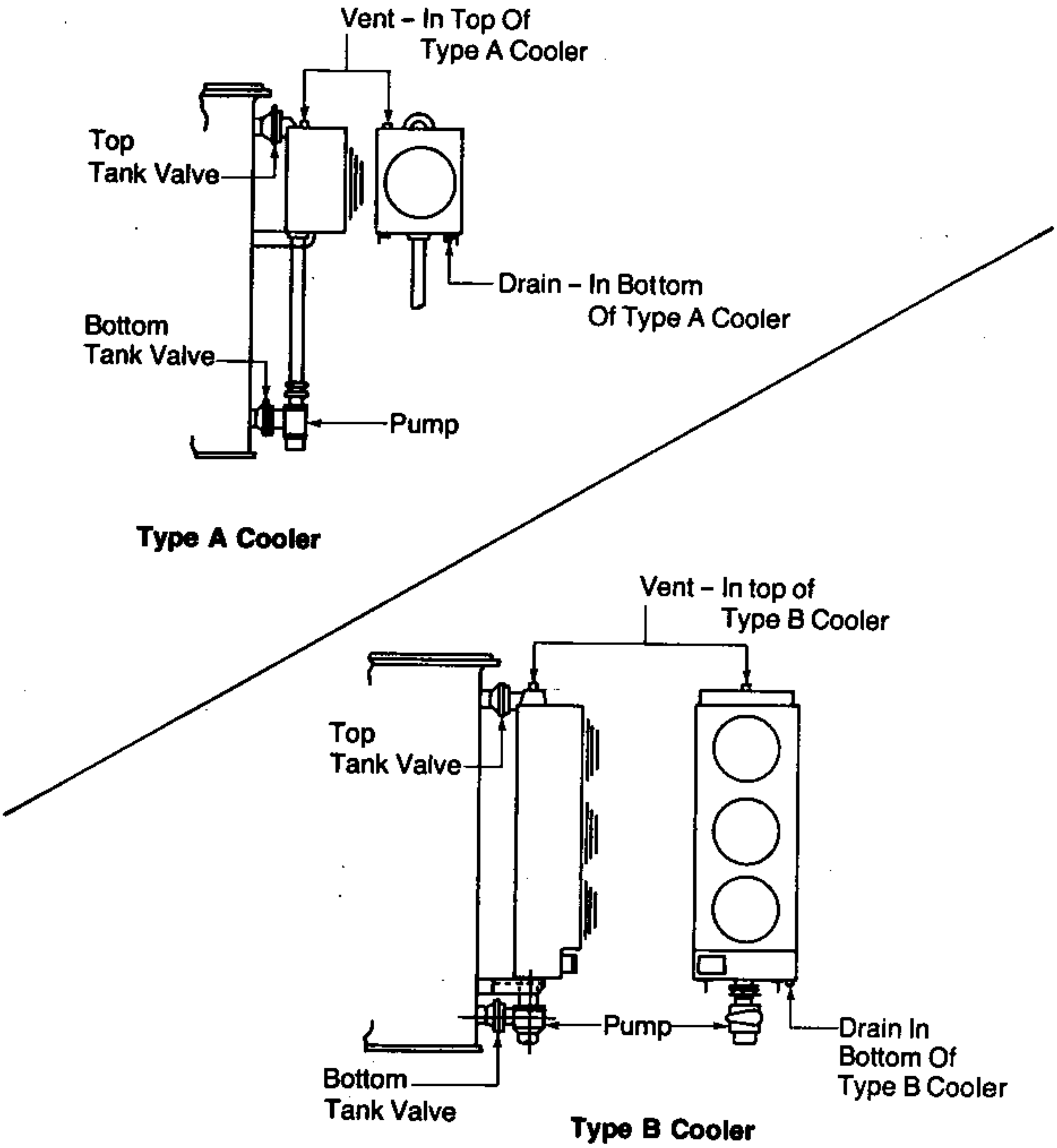


Fig. 7 – Type A and B Coolers

B. Maintenance of Radiators

The only maintenance required for radiators consists of periodic repainting or touch up to keep the surface free of rust. Since the radiator tubing walls are thin for cooling efficiency, it is critical to keep them rust free to prevent possible rupture or perforation.

C. Maintenance of Coolers

Very little maintenance is required for coolers. Fan motors are usually permanently lubricated. Liquid pump motors are usually lubricated by the coolant they are pumping. Most fluid-to-air cooler tubing is copper

Volume 3
Chapter 5

Outdoor Condenser Bushings

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury, death, and substantial damage to property.

Chapter 5

Outdoor Condenser Bushings

Descriptions and procedures given here are based on current and recent Westinghouse designs. Bushings manufactured at other times or by other manufacturers may vary in detail. When installing, testing, or maintaining bushings, the manufacturer's instructions for the specific bushing must be consulted.

Warning: Do not attempt test or maintenance work on a bushing before it has been de-energized and isolated from the circuit. Failure to heed this precaution could result in severe injury or death from electric shock, and damage to property.

5.1 Receiving, Handling, and Storage

A. Receiving

Depending on the voltage ratings, bushings may be shipped in three different ways:

Smaller Bushings 242 kV and below: shipped installed in the breaker.

Large Bushings, 345 kV: shipped individually, horizontal in a crate.

Transformer Bushings: boxed.

General instructions for unpacking and handling are usually included in the shipment.

Inspection should be made for any evidence of damage, and if found, reported to the delivering carrier, and the manufacturer.

B. Handling

Use a double hoist when lifting a bushing from the blocking in a horizontal packing case. One lift must be around the flange, below the porcelain, and one looped around the top under the lifting lugs. Lifting in a vertical position or raising to a vertical position can be done with a single cable or rope looped around the top nut under the lifting lugs. Refer to Figure 1.

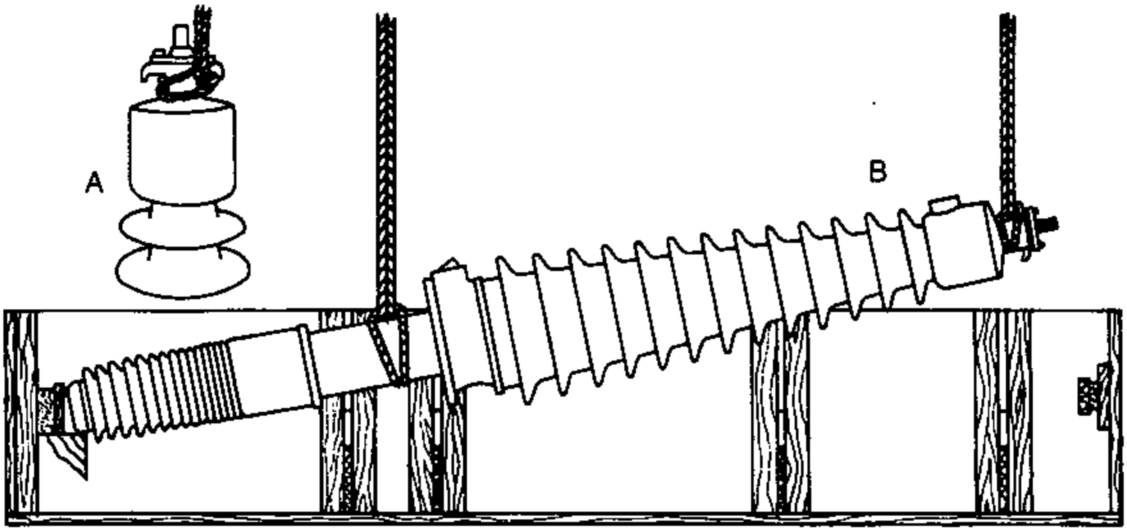


Fig. 1 – Lifting a Bushing
A. From a Vertical Position
B. From a Horizontal Position

When up-ending the bushing, rest the lower end on a felt or wood pad, braced to protect the threads and prevent slipping, and keep the porcelain out of contact with the floor.

C. Storage

Outdoor condenser bushings, when installed, are not sensitive to weather. The upper end is sealed and the lower end is immersed in oil.

In storage, a means must be employed to protect the lower end of the bushing, unless it is of the weather-proofed-all-over type. Bushings with unsealed lower ends, when not installed, must have the lower end covered with a polyethylene bag containing silica gel crystals, or similar air tight cover and moisture absorbing agent. This protection should not be removed until the bushing is installed in the apparatus or the lower end placed under oil for storage.

An advantage in using a plastic bag to cover the lower end of the bushing is that it is transparent so moisture condensation, if it occurs, can be seen. If condensation is seen, remove the bag and both the bushing and the bag dried. Recharge the bag with silica gel and replace it over the lower end of the bushing.

Notice: This protective cover must be removed before making power factor tests.

The storage area must be clean, very dry, ventilated, several degrees warmer than the outside temperature, and not subject to wide variations in temperature. Cellars, outdoor sheds, and similar places are not suitable.

Compound-filled bushings must be stored in an upright position for at least 24 hours before they are placed in service or tested.

The condition of the stored bushing can be determined by the power factor test. Periodic tests showing a high or increasing power factor indicate improper storage conditions. Such bushings must be moved to more suitable storage. A power factor test measurement must be made before putting a stored bushing in a circuit breaker or transformer to give additional assurance that the bushing is suitable for service.

5.2 Installation
Before installing a bushing in a transformer or circuit breaker, it must be wiped clean of all dust, grease, or particles of packing material, using clean cloths wrung out of 111 trichloroethane, or transformer insulating oil, and dried with a clean dry cloth.

Figure 2 shows a method of suspending a bushing for installation.

A. Installing Transformer Bushings
Transformer bushings are provided with static shields to cover the threads and sharp corners of bottom terminals. These must be in place on the bushing before it is put into the transformer if possible.

Transformer cover bosses, Figure 3, are flat with a recess to retain the gasket and limit its compression. The side of the gasket in the recess must be covered with gasket cement before it is installed. The bushing must be correctly rotated and carefully centered as it is lowered against the boss so clearances from internal parts of the transformer are adequate.

Spare bushings furnished for a transformer are supplied without cable leads if they are duplicates of the bushings to be replaced. The cable inside the transformer will fit the new bushing. If replacement bushings require new cables they will be furnished by the bushing manufacturer as a length of cable attached to a stud terminal. To install such a bushing it is necessary to cut off the old cable and splice the new cable to the old one. The splice should be brazed or crimped. The splice joint should be within the condenser tube if there is sufficient clearance. The location of the splice can be determined by measuring the length of the bushing above the bushing cover boss and the length of the cable to the surface of the cover boss. Add two inches to this measurement to give proper slack.

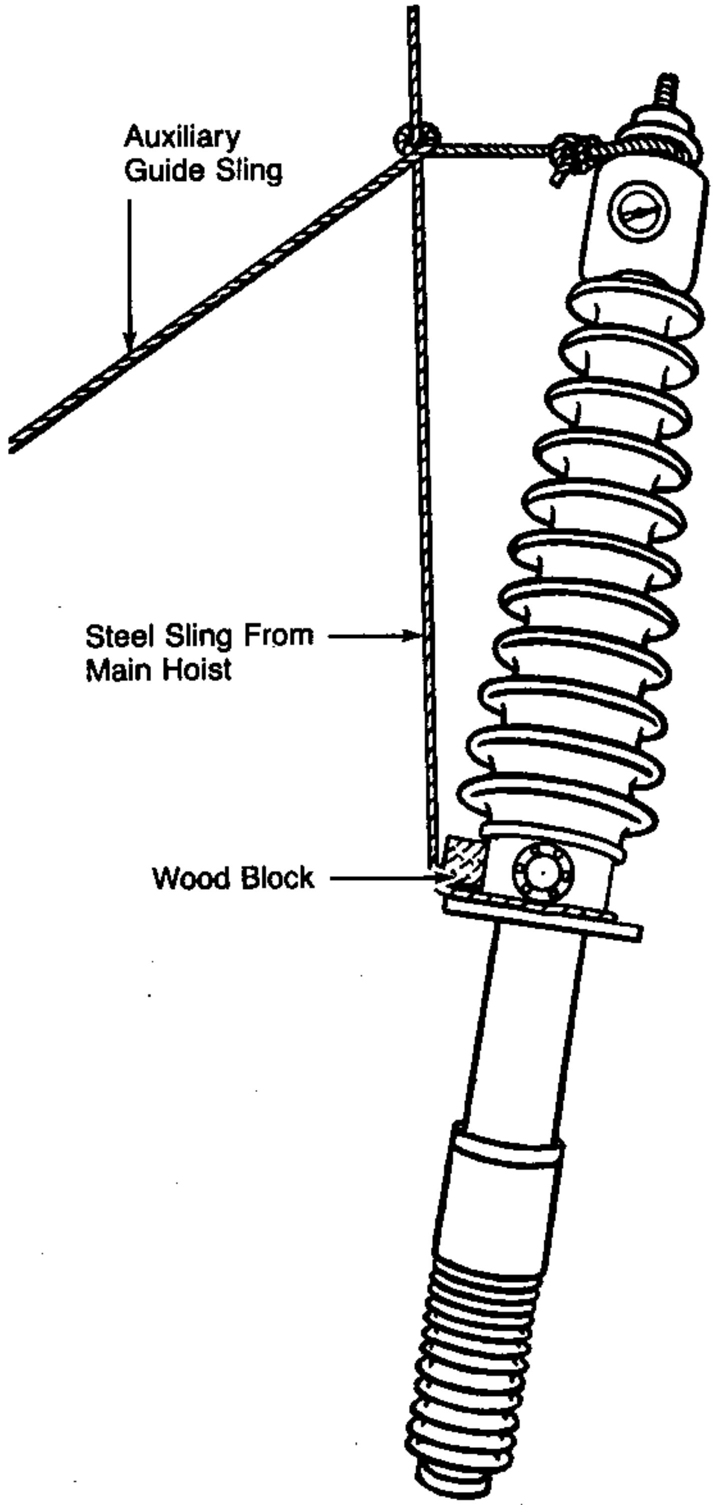


Fig. 2 – Suspending a Bushing at the Angle for Installation

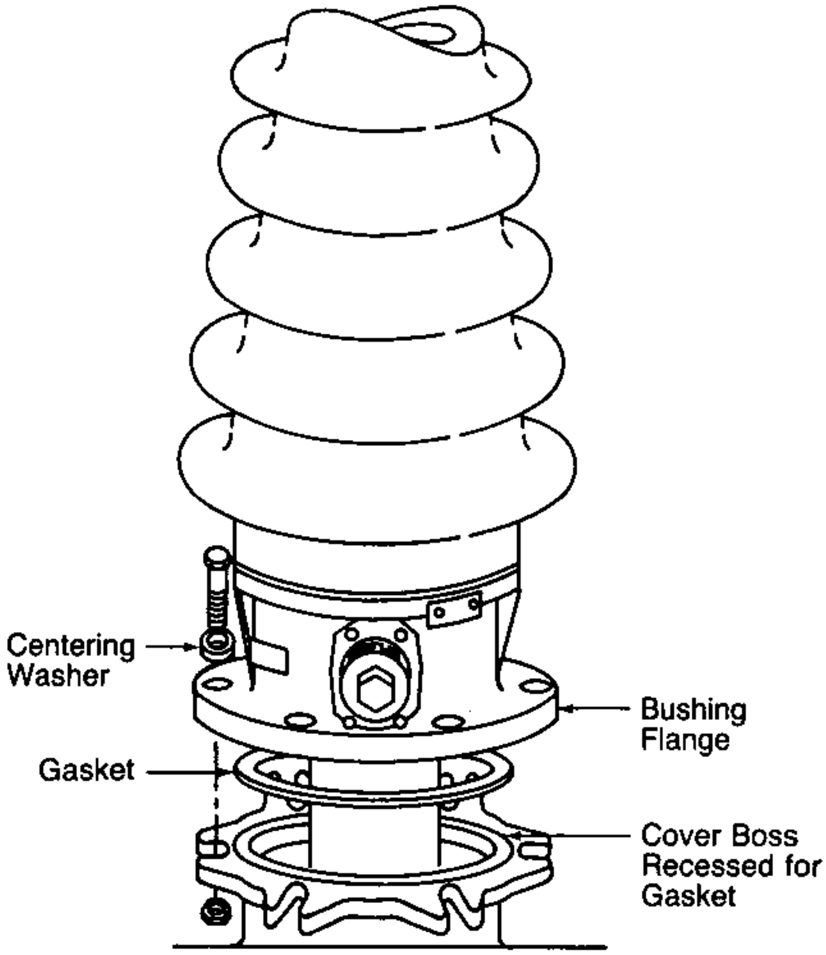


Fig. 3 – Installation of a Bushing on a Transformer

Bushings on transformers are supplied with draw-through leads unless the current exceeds the value set by safe thermal considerations, in which case the transformer leads are connected to the lower end of the bushing and the current is carried in the central tube. When transformer bushings are removed for shipment the draw-through leads are coiled and secured to the underside of the blind flange on the bushing boss or to a loop on the underside of the transformer cover, so the bushing can be installed without lowering the oil level in the transformer.

A stout cord or a wire must be fished through the bushing tube and attached to a 3/8 inch bolt screwed into the threaded hole in the terminal on the end of the draw-through lead. Draw the lead taut so it is free of twists and kinks, and the bushing slipped over it. If the lead appears to be too short it is an indication that something is preventing its free passage through the tube, and the condition must be cleared.

After the bushing is bolted down, place a drift pin or screw driver through the lower hole in the terminal to hold the lead while the draw cord or wire is removed. The locking nut and the terminal cap with gasket cemented in place, must be turned on the lead terminal, locking the cap in place. The drift pin holding the lead can then be removed, and the terminal cap bolted to the cap nut on the bushing.

B. Installing Circuit Breaker Bushings

Notice: Make sure that outside connections do not throw strains on the bushing in excess of those specified by standards.

Circuit breaker cover bosses for bushings are typically flat with a machined groove in the flat surface to retain the bushing gasket, see Figure 4. Cement the gasket in the groove and apply petroleum jelly between the gasket and the bushing. This will permit shifting the bushing without damaging the gasket. Eccentric bushings are used on the flange bolts to shift bushings for contact adjustment. All bolts must be tight at final assembly.

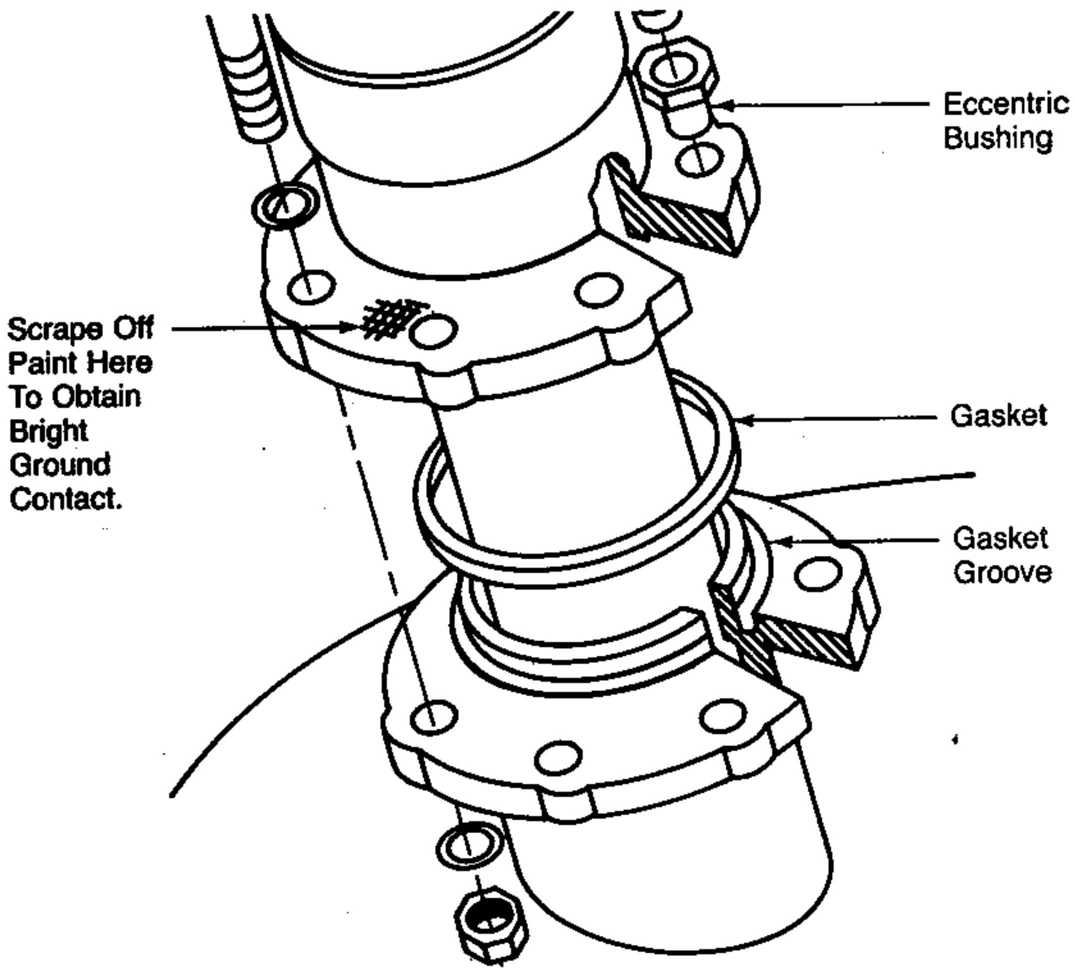


Fig. 4 – Installation of a Bushing on a Circuit Breaker

C. Voltage Tap

Most bushings rated 115 kV and above are furnished with a voltage tap located at the flange. This voltage tap may be one of two configurations:

Type A normally grounded. This tap is grounded by its cap unless it is connected to a potential device. See Figure 5.

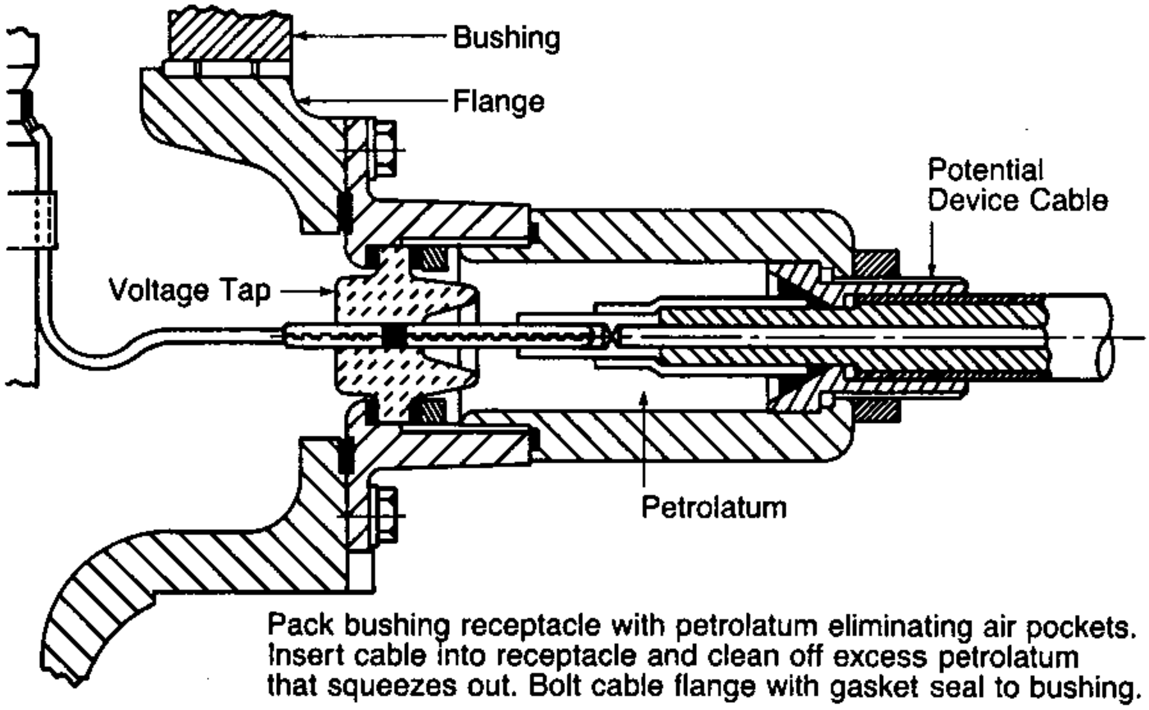


Fig. 5 – Type A Voltage Tap Receptacle with Potential Cable Connected

Type B normally ungrounded. This tap is never grounded and the receptacle is filled with insulating oil when a potential device is not connected.

To connect the potential device cable, the voltage tap receptacle cap must be removed and the cable connected as shown in Figure 6.

For Type A taps the retaining nut on the cable should be loosened until the sleeve turns freely. The cavity of the sleeve should be packed full with petrolatum, eliminating all air pockets. With the O-ring gasket in place on the sleeve, the cable should be carefully engaged with the receptacle, the sleeve screwed into the threads, the excess petrolatum cleaned off and the retaining nut tightened.

For Type B taps, the voltage tap receptacle should be packed with petrolatum, eliminating air pockets. The cable should then be connected to the tap tightening the bolts only enough to produce a slight bulge all around the edge of the gasket. Excess petrolatum squeezed out by the tightening should be cleaned off.

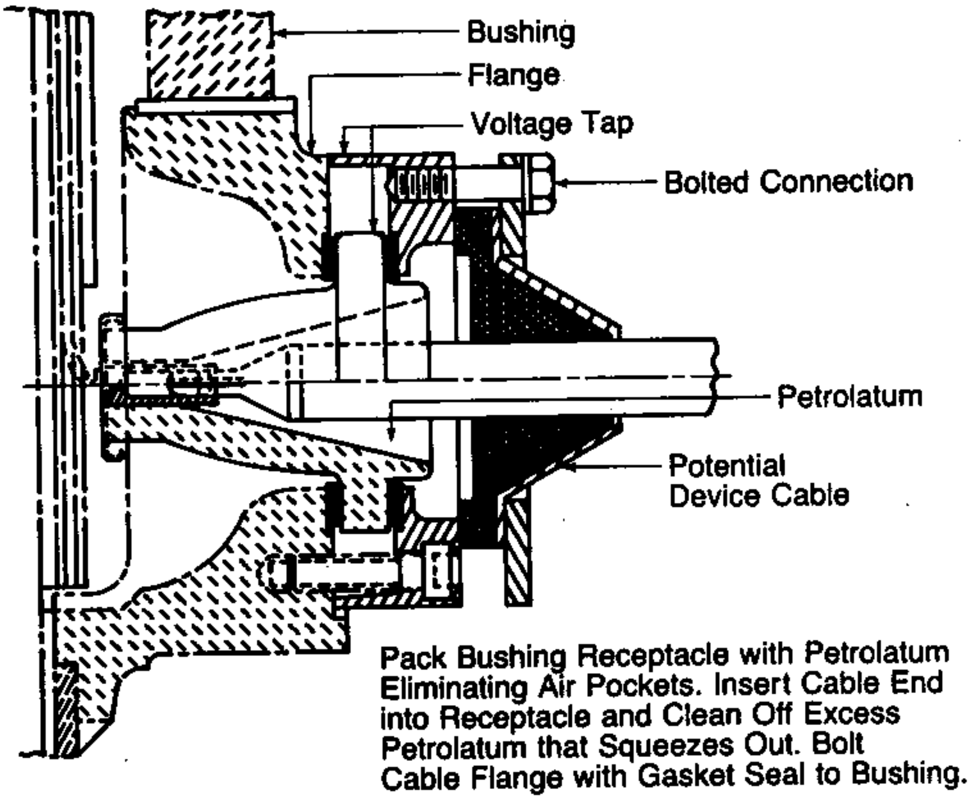


Fig. 6 – Type B Voltage Tap Receptacle with Potential Device Cable Connected

5.3 Power Factor Tests

Notice: The normal power factor of bushings is so low that the correct values of the bushing power factor may be greatly distorted if either of the porcelain surfaces is dirty or wet, if tests are made with the bushings near wet or grounded surfaces, or if external parts are connected to the bushings, such as the interrupter.

It is recommended that power factor and capacitance tests be made at the time of installation, at the end of the first year of operation, and every second year thereafter.

A. Ungrounded Specimen Test Method

This method is used for making power factor and capacitance measurements of a bushing without disconnecting it from the apparatus.

A 10 kV test voltage can be applied to the bushing conductor for bushings rated 23 kV and above, 5 kV or less must be used for bushings rated below 23 kV. Not more than 500 volts must be applied to the power factor test terminal, Figure 7, or 2500 volts to the test prong, Figure 8. This will avoid damage to the test terminal or corona in the test prong.

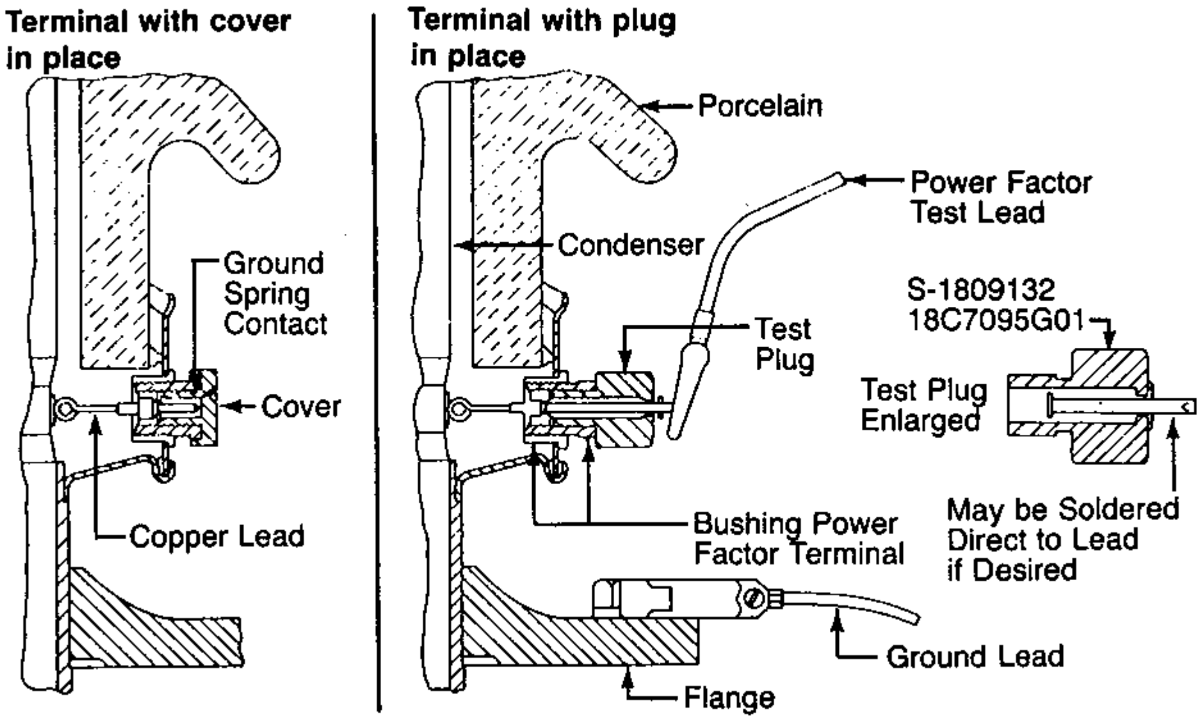


Fig. 7 – Power Factor Testing Terminal for Making Ungrounded Power Factor Tests on Condenser Bushings 69 kV and Below.

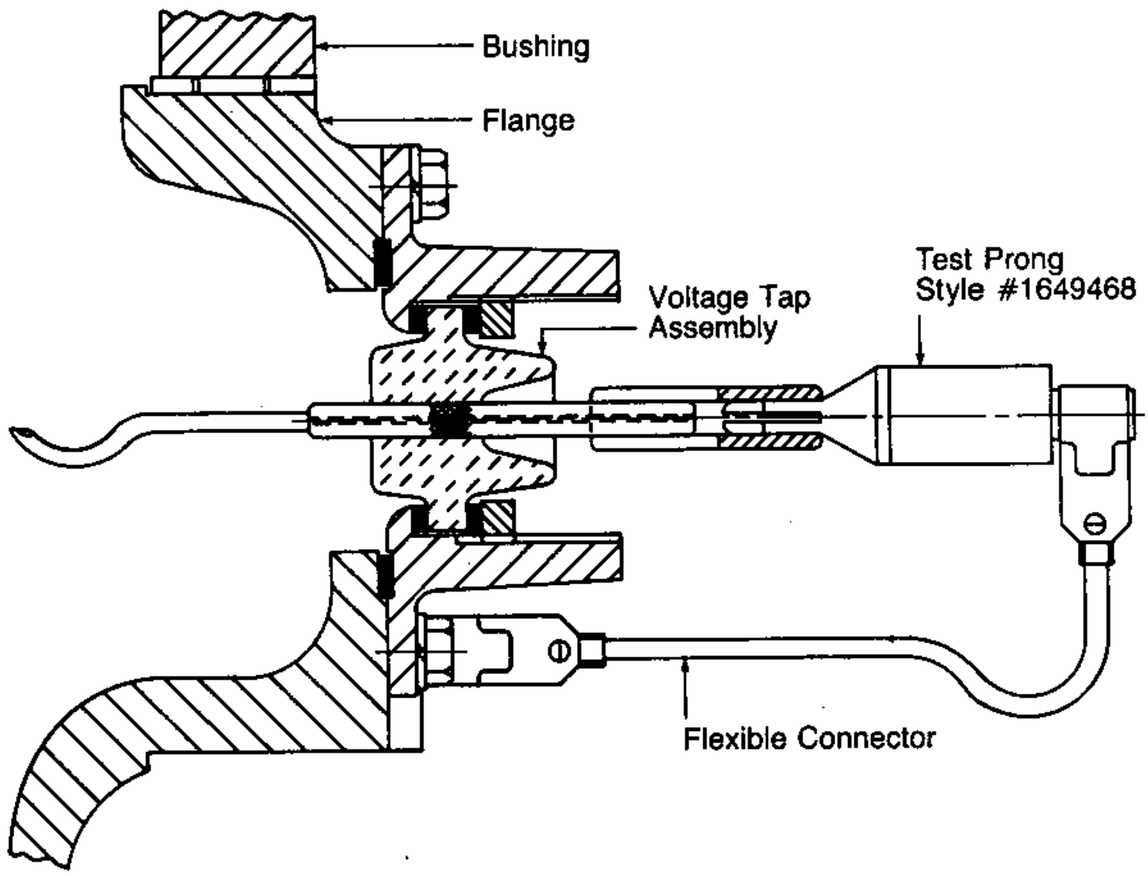


Fig. 8 – Test Prong for Making Ungrounded Power Factor Tests Through the Voltage Tap on Bushings Above 69 kV with a Type A Tap

B. Condenser Bushings 69 kV and Below with Power Factor Testing Terminal

Warning: Do not remove the testing terminal cover until the bushing has been de-energized and will remain so during the test. Failure to take this precaution could result in severe personal injury or death, and substantial damage to property.

After the bushing has been de-energized, the terminal cover may be removed, but the power factor testing terminal must not be turned or removed.

With the test lead connected to the test terminal, the insulation resistance to the grounded flange must be measured with a 500 volt megohmmeter. The resistance should read 5000 megohms or more. After verifying the insulation resistance to the flange the power factor test maybe made as outlined in **5.4** below. When the test is completed, replace the terminal cover finger tight, do not wrench.

Warning: Make sure the test terminal cover is re-assembled on the testing terminal before the bushing is re-energized; failure to do so can result in severe personal injury or death from electric shock, and substantial damage to property.

C. Condenser Bushings Above 69 kV with a Voltage Tap

Warning: Do not expose the voltage tap until the bushing has been de-energized by disconnecting it from the high voltage line and grounding it, failure to de-energize could result in severe injury or death by electric shock, and damage to property.

When the bushing has been de-energized the ungrounded-specimen test procedure is:

Remove the pipe plug in the voltage tap cover.

Connect the terminal end of the test prong to ground with a flexible connector so any electrostatic charge left in the bushing after it was disconnected will be discharged to ground when the test prong is inserted into the voltage tap.

Insert the prong through the hole in the voltage tap cover to reach the contact in the rear of the assembly.

Disconnect the test prong from ground and connect it to the proper power factor test lead.

Measure the insulation resistance from the test prong to ground with a 500 volt megohmmeter. Resistance should read at least 5000 megohms.

Make power factor tests as outlined in **5.4** below.

Remove test prong after completing test.

Add new oils to bring level up to even with the bottom of the cover hole, if necessary.

Replace the pipe plug using Teflon ribbon or similar material to assure weathertight enclosure.

Warning: Do not re-energize the bushing until the pipe plug has been re-assembled in the voltage tap cover. Failure to take this precaution could cause severe personal injury, and substantial damage to property.

5.4 General Procedure for Power Factor Tests

It is possible for a high power factor reading to be caused by conducting surfaces near the bushing being tested. This is especially true of spare bushings being tested in their crates. It is possible for the crate, particularly if it has a high moisture content, or the testing personnel, to cause a high power factor reading. For this reason it is recommended that the bushings be removed from their crates for testing and that all conducting surfaces be eliminated from the immediate vacinity of the tested bushing.

If high losses are detected, it is best to determine their location before removing the bushing from the apparatus. Losses can often be eliminated by cleaning some surfaces on the bushings.

Power Factors of bushings vary with temperature. It is therefore desirable to make the tests in warm, dry weather, with the apparatus not cooler than 15C (59F). A record of the test should include the temperature of the bushing as well as the ambient temperature.

The approximate temperature of the bushing can be determined by one of the following methods, provided the apparatus has just been taken out of service.

1. Use the mean of the air and top oil temperatures as measured by thermometers; the oil measured at the top inside the tank, the air measured in the shade within four feet of the tank.

2. With a thermometer measure the temperature on the outside of the tank at the level of the top of the oil in the tank, and add 9C (5F) to allow for the difference in temperature between that of the bushing and the outside of the tank.

3. If the apparatus has been out of service long enough to allow all parts to cool to atmospheric temperature, then the atmospheric temperature measured in the shade, may be used.

The power factor level at which apparatus should be withdrawn from service depends upon how critical an interruption in the circuit would be.

Allowable power factor limits vary with different bushings. The bushing manufacturer must be consulted for the limits which will assure dielectric strength necessary to pass the standardized one-minute acceptance test. Refer to Figures 7, 8, and 9.

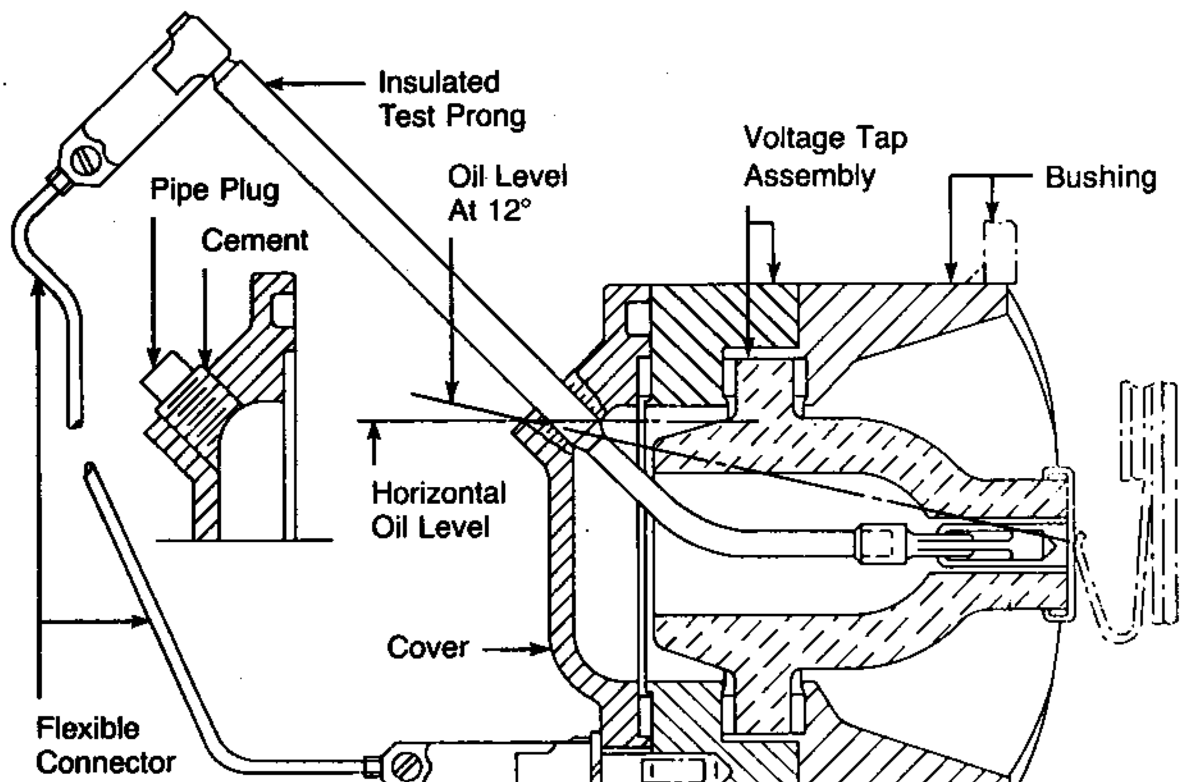


Fig. 9 – Test Prong for Making Ungrounded Power Factor Tests Through the Voltage Tap on Bushings Above 69 kV with a Type B Tap

A. **Procedure for Circuit Breaker Power Factor Tests.**

Warning: Before undertaking power factor tests, de-energize the circuit breaker and isolate it from the circuit; failure to do so could result in severe personal injury, and substantial damage to property.

Clean and thoroughly dry all porcelain, including the bottom porcelain when the bushing is first installed.

Disconnect bus at bushing. Parallel insulators or a length of bus will cause erroneous readings.

Conduct outdoor tests on a clear day when humidity is less than 80 percent.

Measure temperature by one of two methods given above (**5.4, 1, 2**).

The general method used to test bushings 23 kV and above when installed in a circuit breaker:

Test 1. Grounded Specimen Test. Test with lead at high voltage, flange at ground, on each bushing, with the breaker open. Make six readings.

Test 2. General Specimen Test. Test with lead at high voltage, flange at ground, on each phase, with breaker closed. Make three readings.

Test 3. Ungrounded Specimen Test. Test with lead at high voltage, tap at low voltage, flange at guard, on each bushing, with the breaker open. Make six readings. This test can be made only on bushings with power factor or voltage tap.

Test 4. Tap Insulation Test.
A. For power factor taps a 500 volt megohmmeter should read 5000 megohms or more.

B. For voltage taps make ungrounded specimen test with tap at high voltage, flange at ground.

Tests 1, 2, and 3 can be conducted at 2.5 to 10 kilovolts, 10 kV is recommended. Test 4A should not be made at more than 500 volts. Test 4B can be made at 500 volts to 2.5 kilovolts, 2.5 kV is recommended.

Tests 1 and 2 are made to determine the Tank Loss Index. This index is found by totalling the watts lost on the two bushings of any one phase

(Test 1) and subtracting that value from the losses measured on that phase in Test 2. If the sum of the losses when measured with the breaker in the open position is less than in the closed position, the net losses are attributable to the breaker lift rod. If the sum of the loss with the breaker in the open position is greater than the loss in the closed position, the difference can be attributed to leakage in the breaker interrupting grid plates.

The reason for differences in the open and closed positions is that the different members have different applied voltage stresses. This difference is the Tank Loss Index and it varies between breakers. Usually this index is of less value than the findings of Test 3.

In a large breaker 10 kV will not show any significant losses in a breaker lift rod. Breakers with resistor grids or grids that have absorbed moisture will produce high Tank Loss Index values, although moisture in the grids is not harmful if the plates are not warped to the point they interfere with movement of the contacts, because the grids are not primary insulation members. Resistor grids will naturally add to the watts loss.

B. Procedure for Power Factor Tests of Transformer Bushings

Warning: Before undertaking power factor tests, de-energize the transformer and isolate it from the circuit; failure to do so could result in severe personal injury, and substantial damage to property.

The line terminals of three-phase wye connected transformers, and of autotransformers, should be connected together before making power factor tests. This eliminates unsymmetrical losses in the magnetic circuit in the transformer which may otherwise affect the measurements. The transformer winding must be ungrounded when the tests are made.

Bushings with power factor test terminals or voltage taps may be tested in transformers without disconnecting the winding. Where ungrounded power factor methods are not available, the bushings may be tested by other methods.

Bushings without power factor test terminals or potential taps may be tested without removal from the transformer provided the following conditions are met:

Draw-through lead with top cable connection is used.

The transformer winding is disconnected from ground.

The test set is equipped to bring the tube and lead to the same potential and phase relationship.

If there is a layer of tape on the lead, used in current designs and most older designs, then there is sufficient insulation to permit testing without bushing removal.

A thin-wall insulating tube slipped over the lead provides sufficient insulation for the top end of the lead.

If the transformer bushings have an insulating head and the test set is equipped to bring the test circuit and the shielding circuit to the same potential and phase relationship, then it is not necessary to disconnect the internal bushing lead or the small length of outside line, but the transformer winding must be disconnected from ground.

C. Power Factor Limits

The best way to determine the condition of a bushing using power factor measurements is to compare several readings taken at regular biennial scheduled tests, at approximately the same temperature. These readings should remain nearly constant. Any continual rise in the readings indicates that the bushing is deteriorating and must be removed from service and checked to determine the cause. Where previous records are not available, test measurements may be compared between similar bushings.

Bushings operated at very high temperatures, whether due to heavy loads or high ambients, will have relatively high losses. For this reason the manufacturer's limit data must be used in determining the safe power factor of the bushings. When field tests with a power factor test set indicate that the condition of the bushing is questionable, the results must be referred to bushing engineers for analysis and recommendation.

There are some differences in the safe power factor limits of bushings of different manufacturers and different times, and different designs. It is recommended that the manufacturer be consulted if there is any doubt in the interpretation of test results.

With normal capacitance the power factor is directly indicative of the watts loss in the insulation. The power factor shows the quality of the insulation. The watts loss is a composite indication of the quality and quantity of the insulation tested. Power factor can be used for direct comparison between small and large bushings.

Capacitance measurements of bushings are valuable for analyzing the quality of bushings if the measurement can be compared with previous measurements of the same bushing or bushings of the same design. A bushing with increasing capacitance measurements, or one measuring 15 percent or higher than the average of similar bushings, must be removed from service for complete investigation. The power factor of such a bushing could still be acceptable, but the increase in capacitance could indicate a shorted layer.

The most likely cause of a high power factor reading is that moisture has found its way inside the procelain weather casing or that the lower end has been exposed to moisture in storage, or the lower end has been exposed to moisture or carbon in the insulating oil.

When it has been determined that the cause of the high power factor reading is in the bushing, it must be removed from service.

5.5 Potential Device Connection

All modern bushings are capable of providing input to a potential device. Connection can usually be made without a cable adapter. If not, the bushing manufacturer can supply an adapter.

5.6 Maintenance

A. Visual Inspection

General maintenance includes periodic visual inspections for physical damage, leaks, poor connections, dirty porcelain. Clean the bushings at intervals to keep the surfaces free from contamination. Paint exposed metal parts to protect them from weather and atmospheric damage. Some manufacturers can provide devices which will permit adding oil without removing the bushing from the apparatus, if it is necessary to add small amounts of oil.

B. Service

Measure power factor and capacitance at intervals recommended by the manufacturer.

A damaged or defective bushing must not be allowed to remain in service.

C. Factory Repair

Bushings should be returned to the manufacturer for repair accompanied by all available information regarding cause of failure. Field repair of bushings is generally not recommended. Factory repair can provide these advantages:

Proper processes, gasket materials, filling compounds, cements, etc., are used.

Whenever possible bushings are modernized and all gaskets renewed.

Pressure tests are made to assure tightness of condenser and weather case assembly.

Power factor tests and 60 hertz routine tests are made. Any bushing that cannot be processed to have a power factor equal to a new bushing is completely rebuilt. A repaired bushing must meet the same test limits and withstand the same 60 hertz voltage as a new bushing of the same design.

Experienced personnel and special facilities are applied.

A factory repaired bushing may carry new bushing warranty.

Replace bushings manufactured prior to 1960 by bushings of modern design when their condition, as indicated by visual inspection or power factor and capacitance tests, shows them to be in need of servicing. When circuit breakers or transformers are undergoing major rehabilitation, replacement of bushings of modern design should be part of the program if the bushings were manufactured prior to 1960.

Standard bushings should be used when replacing old bushings. Space limitations may make it impossible to provide standard bushings which are impulse coordinated. Adapters are required in some instances to fit standard bushings to old apparatus.

D. Field Repair

Some condenser bushings can be rebuilt successfully in the field if proper facilities and capable, experienced personnel are available. The equipment required includes a 60 hertz test set, power factor testing equipment, and ovens of a suitable size with temperature control up to 110C, and a ventilating system. For larger bushings crane service may also be required. The best results are obtained by having repair and rebuilding work done by the original manufacturer.

5.7 Permanently Sealed Condenser Bushings

In 1982 a condenser bushing of a new design concept was introduced by Westinghouse (designated "Type O plus"). It differs from previous designs significantly and is therefore treated separately here.

These bushings are designed for oil filled transformer and circuit breaker applications. They meet all applicable dimension requirements of the ANSI C76.1-1977 Standard and meet or exceed all applicable electrical and mechanical requirements of the ANSI 76.1-1976 Standard and IEC Publication 137-1973 Standard.

The bushing consists of an oil-impregnated, multi-layered paper condenser wound on a central tube. The condenser is housed in a sealed cavity formed by the upper and lower porcelain insulators, the one piece aluminum flange, and the aluminum expansion bowl. This cavity and the condenser are evacuated then filled with highly processed insulating oil providing very low moisture content and low bushing power factor. The low moisture and low power factor are maintained throughout the life of the bushing because the cavity is sealed by welding the expansion bowl and gasketing all threaded connections and metal to porcelain joints. Once the bushing cavity is sealed during manufacture the tight integrity is never broken.

Notice: It is imperative for continued high performance of this bushing that no attempt be made to perform any type of maintenance or repair action other than listed here or in the manufacturer's instruction literature.

Oil level indication is provided by a clear sight glass and floating ball arrangement shown in Figure 10. A proper oil level is indicated by the oil visible in the sight glass.

The bushing has a potential tap receptacle so a potential device can be connected or periodic power factor and capacitance measurements of the bushing can be made without disconnecting the bushing from the transformer winding. Refer to **D** below *Capacitance and Power Factor Measurement*. For details on the potential device connection refer to *Potential Device Connection,* **E** below.

A. Safety Precautions

Among potential unsafe conditions are:

- High pressures
- Lethal voltages
- Moving machinery
- Heavy components

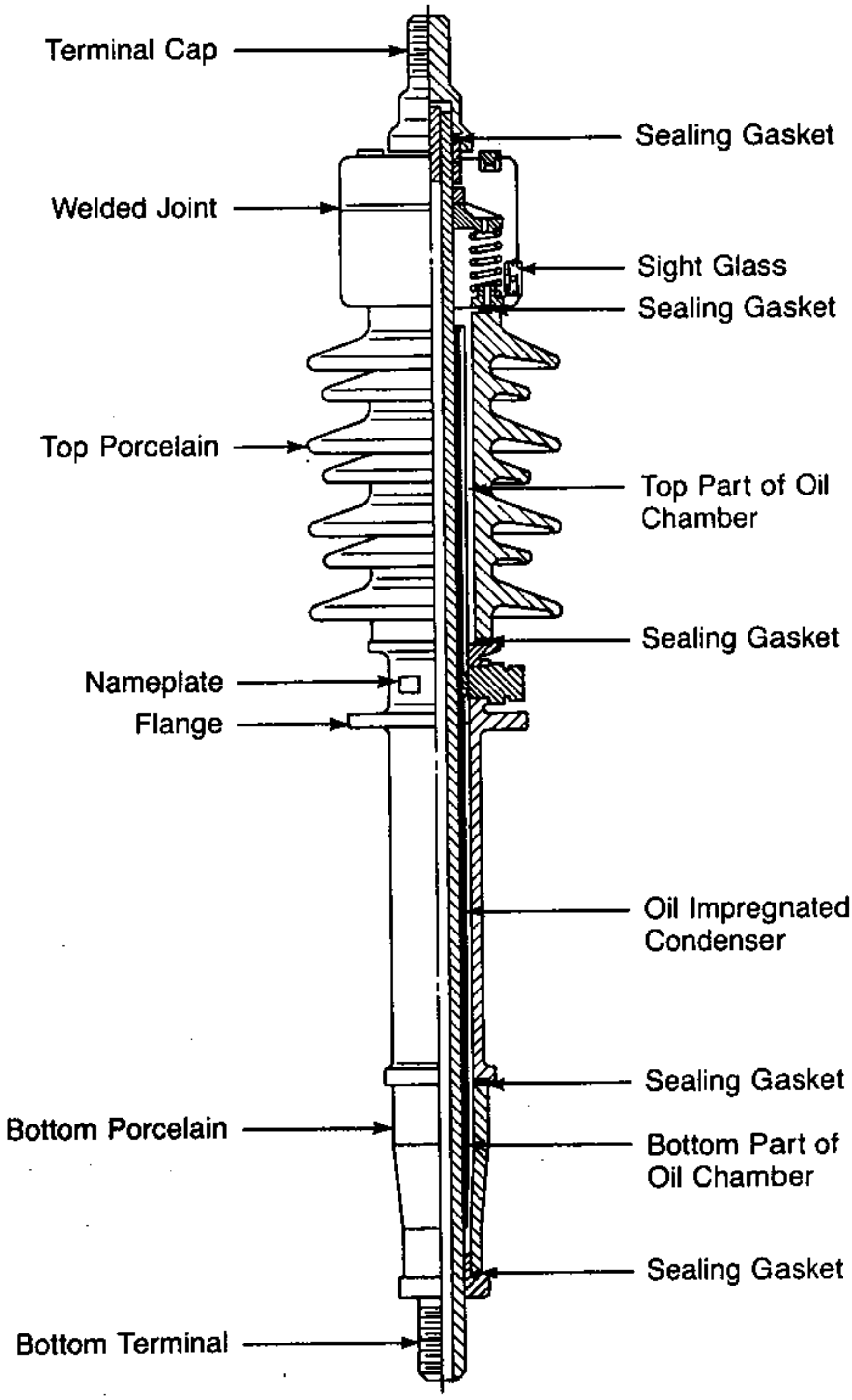


Fig. 10 – Type "O Plus" Condenser Bushing

Specialized knowledge and procedures are required and the manufacturer's instructions must be followed exactly when working with this apparatus. Failure to follow these instructions can result in severe personal injury or death, and damage to property.

Work on this apparatus must be done only by experienced personnel and in compliance with all applicable OSHA requirements, regional and local safety regulations. Safe working practices, and good judgment must be used at all times.

B. Receiving, Handling, and Storage
A receiving inspection should be performed on the bushing upon receipt. The inspection should include the following:

1. Visual inspection for evidence of breakage or mishandling.

2. Inspection for oil leaks and assurance that oil is visible in the sight glass.

3. Perform capacitance and power factor measurement and compare result with nameplate data.

4. Assure that all nameplate data agrees with order and shipping information.

The bushing shipping crate is designed to assure that the bushing is maintained at the proper angle during shipment and to protect it against damage. The bushing should be stored in this crate or in a vertical position if it is not immediately installed.

The bushing should be removed from the shipping crate as shown in Figure 11. It may be lifted into an upright position by hoisting from both flange lifting lugs and supporting the bushing with a line run between the uppermost porcelain sheds. See Figure 12. The lifting and support lines must be of non-metallic material to prevent damage to the porcelain.

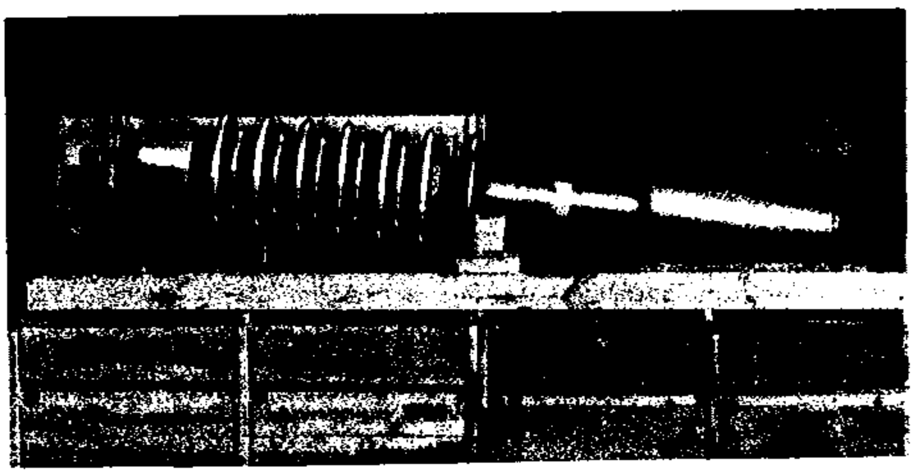


Fig. 11 – Removing a Permanently Sealed Condenser Bushing from Its Shipping Crate.

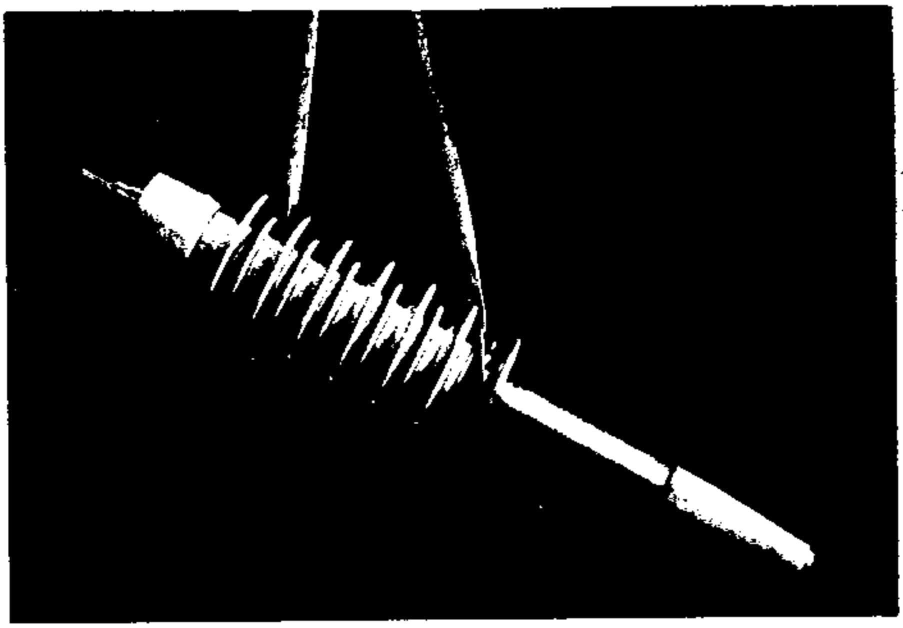


Fig. 12 – Lifting a Permanently Sealed Condenser Bushing

C. Installation

Before installation the bushing should be wiped clean of all dust, grease, or packing materials, using a dry, clean, lint-free cloth. Conduct a capacitance and power factor measurement before energizing.

After the bushing has been placed in an upright position check that the internal bushing oil is visible in the sight glass and check for any indications of oil leakage.

Always allow the bushing temperature to equalize with the apparatus on which it is installed prior to putting it into service.

These parts are normally supplied as part of the bushing:
- Potential tap cover and gasket
- Terminal cap
- Lead tube sealing gasket.

Draw lead bushings are supplied with these additional parts:
- Draw lead connector
- Large locking nut
- Bottom corona ring

The top terminal cap for the draw lead bushing application is shown in Figure 13. This connection is used on bushings suitable for transformer application. The assembly procedure is as follows:

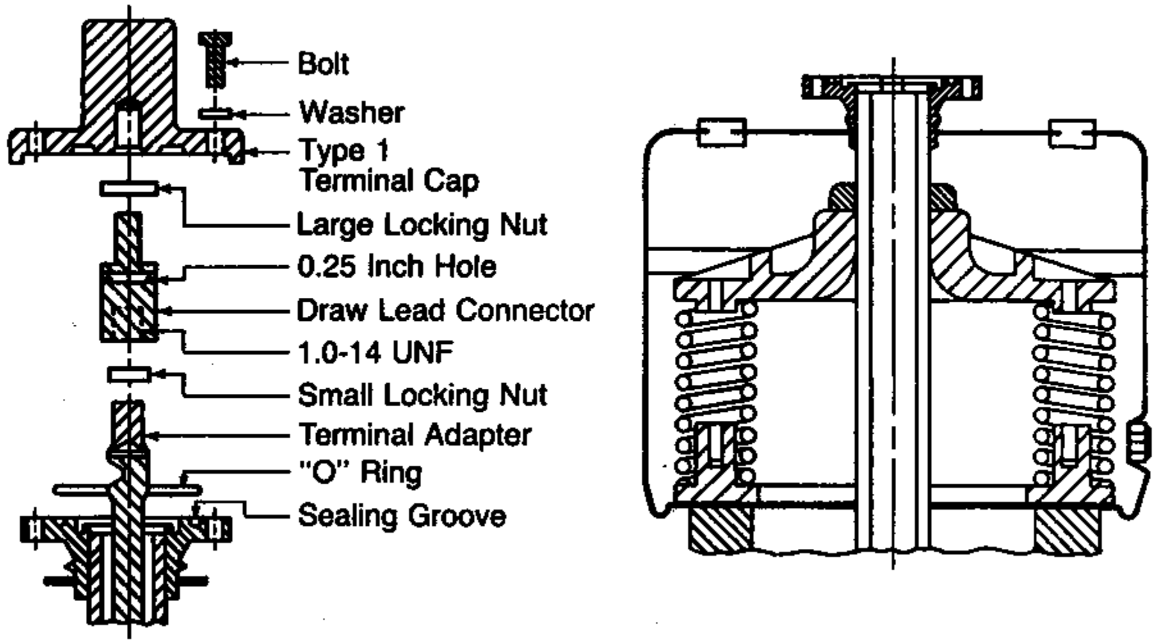


Fig. 13 – Top Terminal Cap for a Draw Lead Bushing

1. Pull draw lead throught bushing tube.

2. Screw small locking nut completely down on terminal (nut not normally supplied).

3. Screw draw lead connector on terminal adapter until tight.

4. Tighten small locking nut (not provided) against draw lead connector to lock connection.

5. Support the parts assembled (1-4 above) by inserting a steel rod through the 0.25-inch hole in the draw lead connector.

6. Screw large locking nut completely down on draw lead connector.

7. Place sealing gasket in machined gasket groove on cap nut.

8. Screw terminal cap onto the draw lead connector.

9. Lock connection by tightening large locking nut against terminal cap.

10. Remove steel support rod and lower terminal cap, then draw lead assembly onto gasketed surface.

11. Tighten terminal bolts using washers provided.

The upper terminal cap provided for non-draw lead bushings is shown in Figure 14. To assemble, place the sealing gasket in the machined gasket groove on the cap nut and screw the terminal cap down on the lead tube to assure a tight connection (tighten to 40 ft/lbs torque).

Notice: The bushing upper terminal cap shown in Figures 13 and 14 must be tight to provide a vacuum seal for the apparatus on which the bushing is installed.

Notice: If the bushings are installed on apparatus which is not filled under vacuum, the bushings de-aerated prior to each test and prior to putting into service. De-aeration is done by loosening the terminal cap. *The terminal cap must then be retightened.*

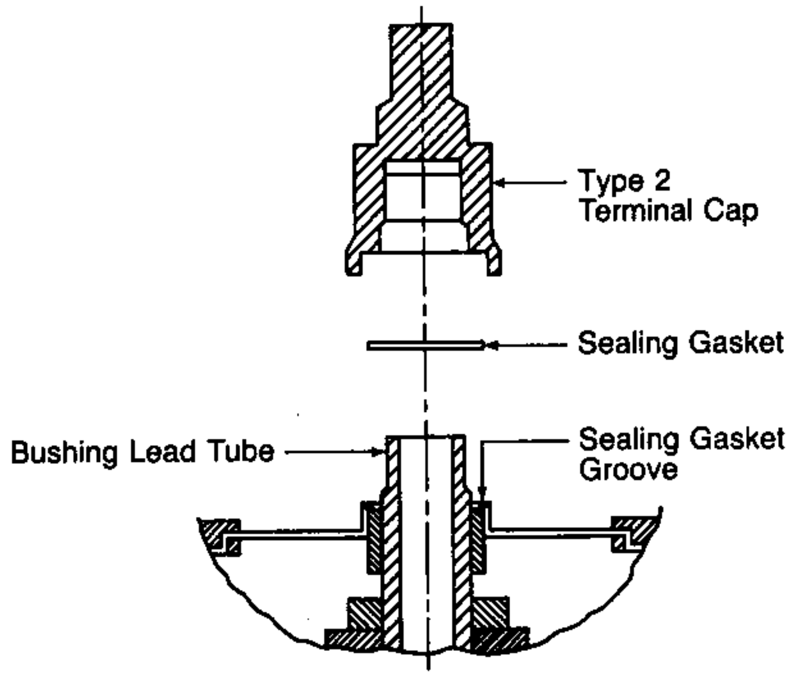


Fig. 14 – A Non-Draw Lead Terminal

D. Capacitance and Power Factor Measurement

A capacitance and power factor measurement tap is combined in the potential tap. Details are shown in Figure 15. This device provides access to the bushing condenser through the normally grounded flange.

Danger: De-energize the bushing, test equipment, and/or potential device before making or breaking any connections to the bushing, the test equipment, or potential device. Failure to de-energize will result in severe personal injury or death, and damage to property.

Danger: De-energize the bushing before removing potential tap cover. After testing assure that the potential device is connected to

the tap or that the tap cover is replaced before putting the bushing back in service. Failure to replace the tap cover or connect a potential device will cause severe personal injury or death, and damage to property.

The following test procedure applies to the Westinghouse Type "O plus" bushing and is only typical of the procedure for other bushings of this general design (Refer to Figure 15):

1. Remove potential tap cover from tap receptacle, after de-energizing bushing.

2. Connect one end of a flexible lead (not furnished) to the grounded bushing flange and the opposite end to the potential tap terminal. This will discharge to ground any electrostatic charge left in the bushing after it has been disconnected from service.

3. Remove the lead from the potential tap terminal and connect to the power factor test equipment ground.

4. Proceed to make power factor test in the conventional manner used for testing ungrounded specimens, see **5.3, A** above.

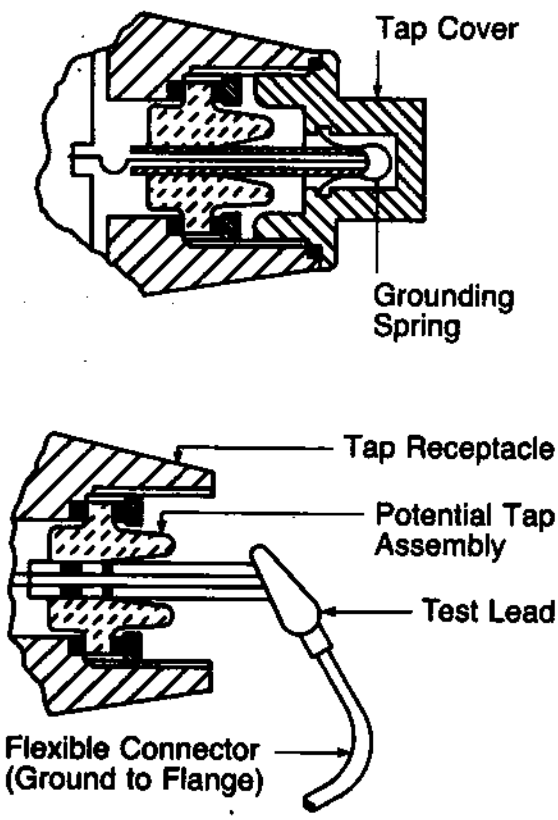
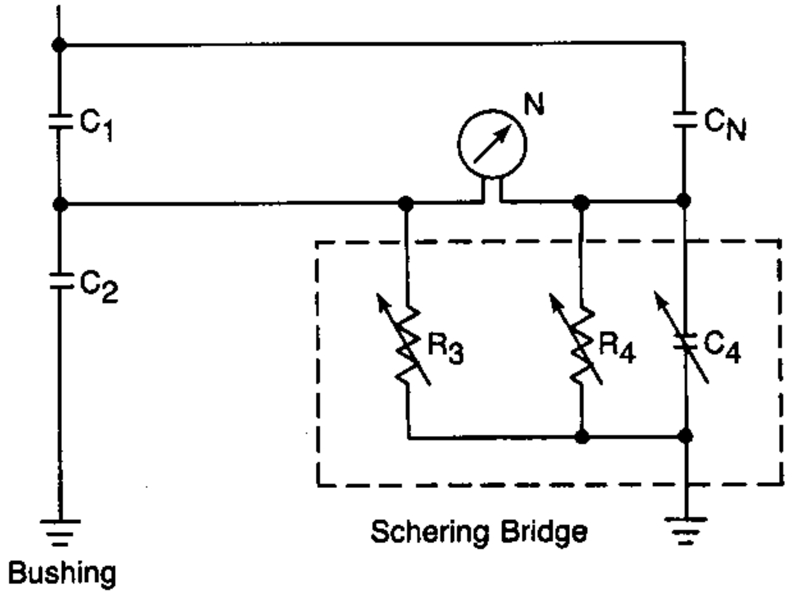


Fig. 15 – Capacitance and Power Factor Tap

5. After completing the power factor test, remove the flexible lead from the grounded bushing flange. Replace the potential tap cover snugly to provide a weatherproof closure.

This self grounding feature may be defeated by removal of the tap cover as shown in Figure 15.

The bushing power factor or capacitance may be measured with the flange grounded by the use of a Schering bridge connected to the bushing as shown in Figure 16.



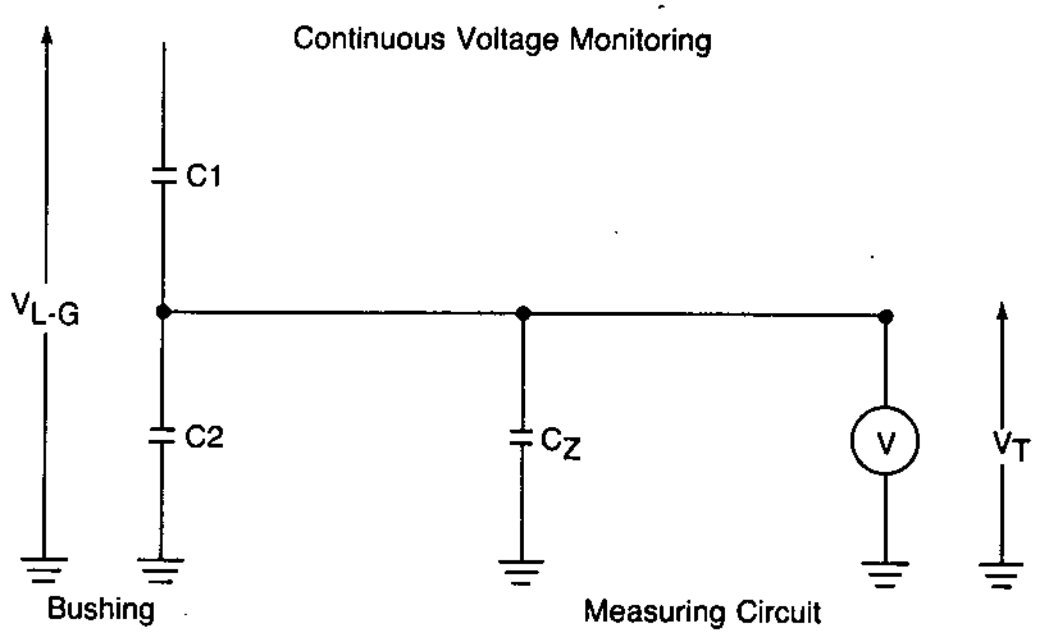
$$C_1 = C_N \frac{R_4}{R_3}$$

$$R_4 = 2\pi f - C_4$$

C_1	Capacitance between metal tube (high voltage potential) and measuring layer
C_2	Capacitance between measuring layer and flange
C_N	Standard capacitance
R_3, R_4, C_4	Balance elements in the bridge-arms of the Schering bridge
N	Zero indicator
f	Frequency

Fig. 16 – Measuring Circuit For Measuring Capacitance and Power Factor of Condenser Bushings

The total capacitance of the bushing, from the lead tube (at high voltage potential) to the flange, is divided by the condenser tapped layer into partial capacitances C1 and C2, Figure 17. As a result of the ratio between these two capacitances an excessive voltage across C2 will occur if the potential tap is left ungrounded (i.e., without the tap cover in place), with full line to ground voltage applied to the bushing. Therefore **it is imperative that the potential tap always be grounded.** For this reason the tap cover has a self-contained spring type grounding feature that grounds the condenser to the tap receptacle and bushing flange when the tap cover is in place.



P	Available Tap Layer Output Power
C1	Capacitance Between Metal Tube (High Voltage Potential) and Tap Layer
C2	Capacitance Between Tap Layer and Flange
C_Z	Supplemental Capacitance Including Cable Capacitance
V_{L-G}	Maximum Line to Ground Service Voltage for Bushing
V_T	Tapping Voltage
f	Frequency

$^{\bullet}C_Z = C1\,[(V_{L-G}/V_T) - 1] - C2$

$^{\bullet}P = 2\pi f V_T C1\,(V_{L-G} - V_T)$

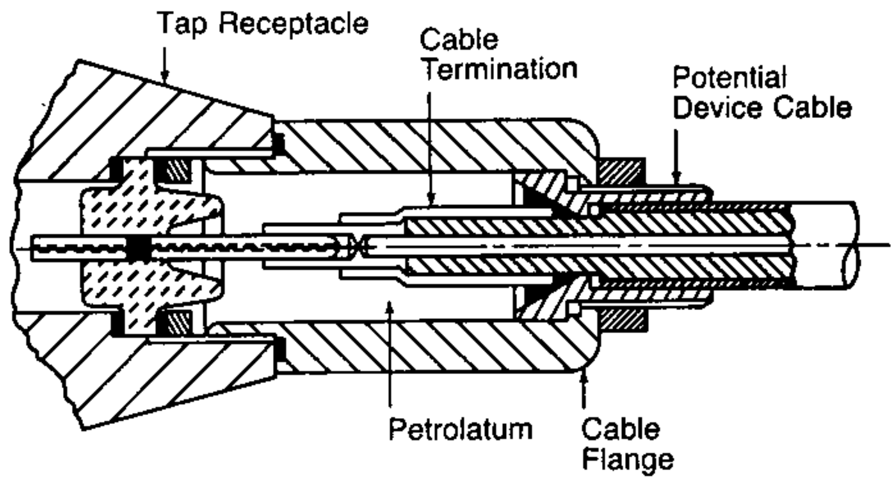
$^{\bullet}V_T$ Must be $\leq$ 10kV When Bushing has Maximum Line to Ground Voltage Applied

Fig. 17 – Potential Measurement

E. Potential Tap

For bushings with a potential tap, it is located on the flange, it is ANSI type A, and is grounded to the bushing flange by the potential tap cover when in place. To connect the potential device cable, remove the potential tap cover from the tap receptacle, pack the tap receptacle with petrolatum and screw the cable termination in place. See Figure 18.

The potential tap capacitance (C2 Figure 17) is less than 5000 picofarads for all Type "O plus" bushings rated 115 kV and above. The measured value of C2 (Figure 17) is given on the bushing nameplate. Maximum tap voltage must be limited to 10 kV or less by the potential device circuit. See Figure 17.



Pack Tap Receptacle and Cable Flange with Petrolatum Eliminating Air Pockets. Insert Cable Termination into Tap Receptacle and Clean Off Excess Petrolatum that Squeezes Out. Fasten Cable Flange with Gasket Seal to Tap Receptacle.

Fig. 18 – Potential Tap Connection

F. Maintenance and Repair

Warning: Make sure the bushing is de-energized before undertaking any maintenance or repair work and assure that it will remain de-energized until the work is completed. Failure to heed this warning can cause severe personal injury or death, and damage to property.

The only maintenance required for these bushings is a periodic cleaning of the exposed porcelain insulator surface, periodic checks to assure that internal bushing oil is visible in the sight glass, and regular testing by measuring the bushing power factor and capacitance on the following schedule:

When received
Prior to putting into service if stored for 6 months or longer.
On a regular basis after placing in service.

The power factor and capacitance should be measured using the ungrounded specimen method. These measurements are good initial values to compare with the values measured at future times. Nameplate data are the result of tests performed in the controlled conditions in the factory and may not directly compare with the results of field tests. When the bushing is placed in service the power factor should not vary more than 10 percent from nameplate value.

G. Oil Replacement

If the sight glass indicates a low oil level and any emergency exists, a small amount of oil (2 quarts or less) can be added by following the procedure outlined below. If more than 2 quarts of oil are required, the bushing should be returned to the manufacturer for service.

1. Obtain the proper oil from the bushing manufacturer.

2. Remove both oil fill plugs (the oil fill plug center recess is filled with sealing compound at the factory).

3. Purge, using low pressure (less than 5 psig) nitrogen, through one hole for approximately 30 seconds.

4. Replace and tighten one fill plug.

5. Fill bushing with special oil obtained from manufacturer, to a level just above the sight glass top (full sight glass with red ball at top).

6. Replace and tighten second fill plug.

7. Refill plug center recesses with silastic compound.

Volume 3
Chapter 6

Dry-Type Power Center Transformers

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Chapter 6

Dry-Type Power Center Transformers

Dry-type transformers are air-cooled, air-insulated transformers developed for use indoors, close to the load. They require no liquid and little or no organic material for insulation, and no liquid for cooling. They are explosion resistant and the material used for insulation in class H transformers, while it will burn over flame, is self-extinguishing. See Figure 1.

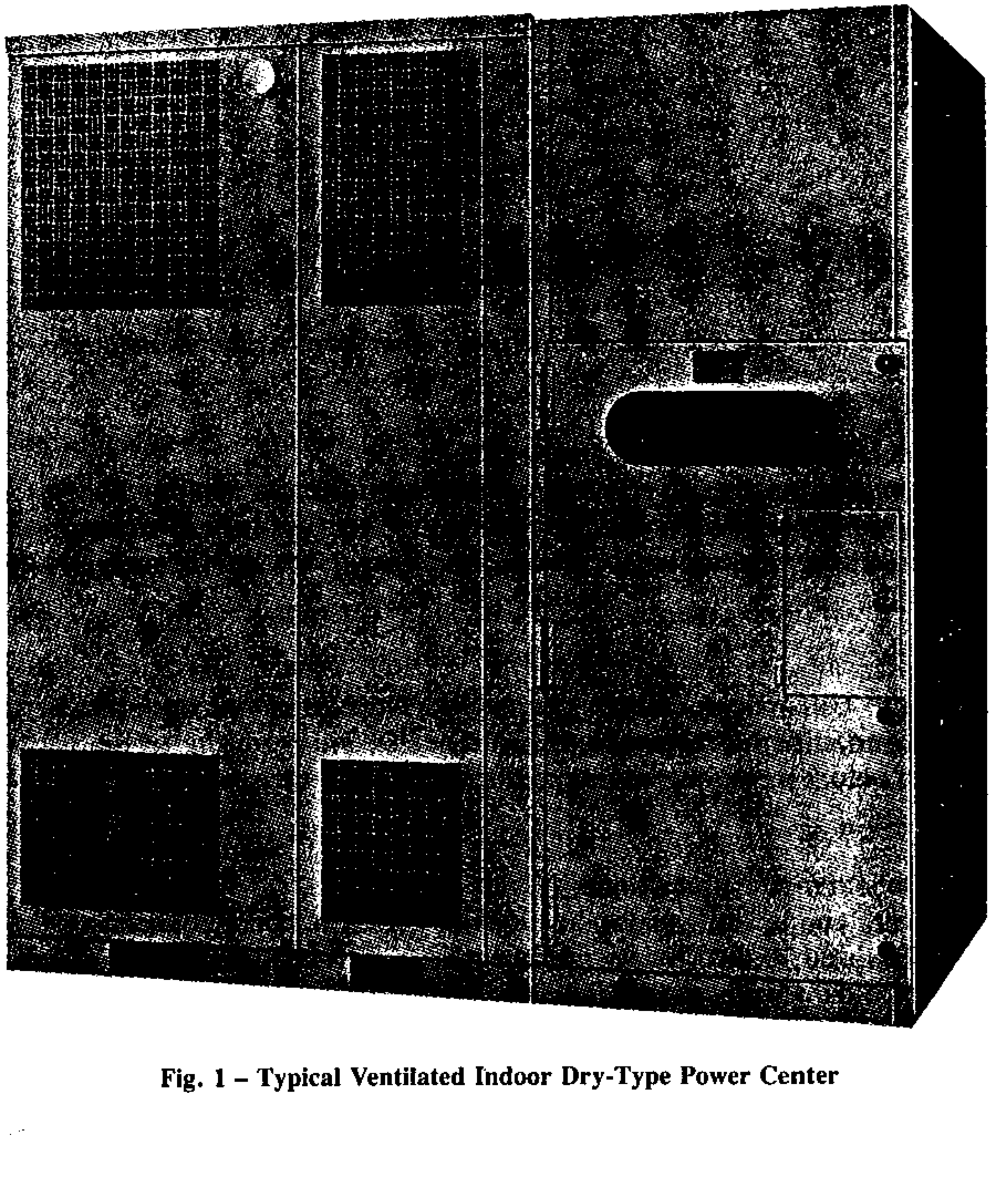


Fig. 1 – Typical Ventilated Indoor Dry-Type Power Center

Some dry-type transformers are designed for outdoor installation. These units are equipped with space heaters, special grille work, and extra varnish treatments. See Figure 2.

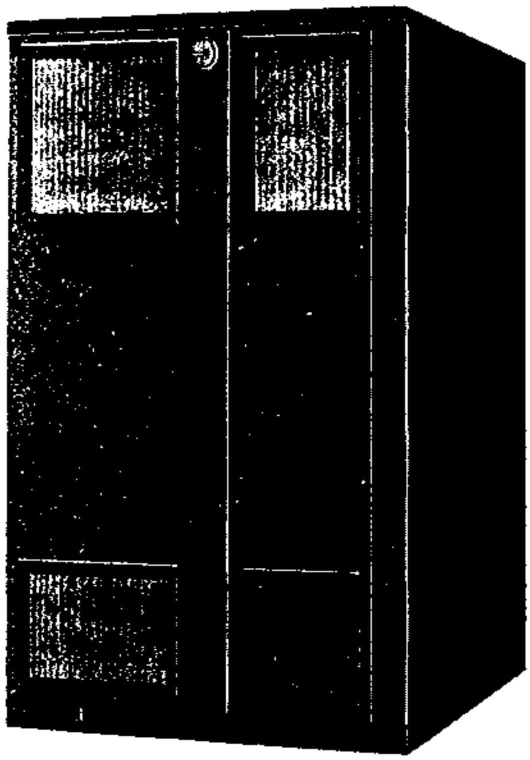


Fig. 2 – Typical Outdoor Dry-Type Power Center Transformer

6.1 Selection, Application, Inspection

Warning: Do not remove transformer case panels or change transformer taps while the transformer is energized. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Hazardous voltage can cause severe personal injury or death, and substantial property damage. De-energize the transformer before removing the transformer case panels or changing taps.

A. Transformer Connections

Aluminum connections may be welded or bolted. Copper connections may be brazed, bolted, or crimped. Aluminum-to-copper connections will be bolted. Surfaces will be silver plated, tin plated, or aluminum grease (joint compound) will be used.

B. Sound Levels
Avoid locations where sound level is critical such as offices, conference rooms, and hospital areas.

Keep sound levels within OSHA limits in non-critical areas such as shops, near generators or motors, or other operating equipment.

Sound is transmitted directly through walls, through structural members, or through conduit. Reflecting surfaces can cause objectionable sound levels by amplifying sound①.

The normal sound warranty is 64 decibels for 1000kVA in conformity with NEMA standard TR27.509. This sound level is comparable to the noise level inside a jet airplane at take-off.

Most sound level problems result from mechanical vibration of transformer parts.

C. Preparation
Make certain that all shipping braces and shims are removed. These items will be painted a distinctive color (yellow) for easy identification.

Make certain that all enclosure parts are tight.

D. Temperature Requirements
The maximum ambient temperature limit is 40C (104F). Average ambient temperature for a 24 hour period should not exceed 30C (86F).

E. Altitude
At altitudes above 3300 feet the transformer design should be altered for higher dielectric strength and temperature rise.

F. Auxiliary Equipment Temperature Limits
Ambient temperatures for meters, auxiliary transformers and other instrumentation, and wiring compartments should not exceed 90C (194F).

① Refer to *Minimizing Transformer Noise*, an article which appeared in *Electrical Construction and Maintenance* and is available from Westinghouse as Reprint 6116.

G. Unusual Service Conditions

Caution: Unusual environmental conditions, such as the following can pose a threat to the life or operation of the transformer and should be avoided.

adverse atmospheric conditions such as corrosive fumes, salt spray, dust, moisture.

locations where there is a potential for severe physical shocks, vibration, or tilting

ambient temperatures that exceed the established limits.

transportation and storage involving moisture, temperature, and shock hazard.

Locations where the transformer is less than two feet from other equipment or structures.

H. Control Wiring

The control wiring is in the bottom of the transformer case in the main compartment and in special compartments. This wiring is insulated for the temperature in which it is installed. It must always be securely clamped or tied, there should be no slack or dangling wires.

I. Insulation

Classifications	Hot Spot Limit (Coils)	Limiting Temperature
80C	110C	150C
115C	145C	185C
150C	180C	220C

J. Clearances

Dimensions for field connections.

Insulation Class	BIL	Clearance-Inches
1.2	10	1
2.5	20	2
5.0	30	2.5
8.7	45	3.5
15.0	60	5
15.0	95	7

Dimensional clearances inside the case are considered design dimensions and are not individually subject to NEMA standards or the National Electrical Code.

K. Field Testing of Insulation

Insulation tests should be made when the transformer is ready for service. These tests will help to assure that the unit is in satisfactory operating condition. Future test results should be compared with the initial test readings to reveal any trend in insulation condition.

Warning: Do not install arresters, remove transformer case panels, perform any maintenance or repair work, or conduct any tests on a transformer that is energized; to do so can cause severe personal injury or death, and damage to property.

Warning: Hazardous voltage can cause severe personal injury or death and substantial property damage. Disconnect the transformer leads and de-energize the transformer before removing the transformer case panels, installing arresters, peforming maintenance or repair work, or any tests.

1. *Insulation Resistance*

The following minimum values may be used:②

Winding kV class	Insulation Resistance—Megohms
1.2	600
2.5	1000
5.0	1500
8.7	2000
15.0	3000

Megohmmeters should operate at 500 volts or above.

2. *Low Frequency High-potential Test*

Test voltages are for one-minute intervals

Insulation Class—kV	A-C Test Voltage—kV
1.2	4
5.0	12
8.66	19
15.00	31

Note: For ratings above 15kV consult the manufacturer.

② Dried transformers may be expected to have readings 5 to 10 times these minimum values.

Warning: Do not energize a dry-type transformer unless the case has been solidly grounded. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Danger: Hazardous voltage can cause severe personal injury or death, and substantial property damage. Solidly ground the transformer case before energizing the dry-type transformer.

L. Field Cleaning

Circulating air carries dust, chemicals, other airborne matter into the case through the open grille work. These particles can reduce the dielectric strength of the insulation, clog cooling ducts, and create a fire hazard.

1. *Preparation for Cleaning*

Warning: Do not remove transformer case panels while the transformer is energized; to do so could cause severe personal injury or death, and damage to property.

Warning: Hazardous voltage can cause severe personal injury or death, and substantial damage to property. Disconnect transformer leads and de-energize the transformer before removing the transformer case panels.

a. De-energize the transformer.

b. Ground terminals.

c. Remove appropriate side panels.

d. Inspect for dirt, especially on insulating surfaces.

e. Check for signs of over-heating, voltage creep, and corona.

f. Check for rust and corrosion.

g. Check connections.

2. *Cleaning*

a. Vacuum inside of case and floor.

b. Vacuum core and coils.

c. Blow out horizontal and vertical ducts with dry compressed air or dry nitrogen. Maximum air pressure 25 psi.

d. Loosen adhering particles with soft brush and blow away.

e. Wipe all porcelains with clean, dry, lint-free cloth.

f. Clean grooves with strips of cloth. Check for any loose pieces of cloth left after cleaning.

g. Re-vacuum inside surfaces of unit.

3. *Final Check*
a. Re-inspect for signs of deterioration of varnish and insulations. The varnish should darken very little when wiped with bare hands or fingers.

b. Re-check that all cleaning materials are removed.

c. Re-install case panels.

d. Remove grounds.

e. Make megohmmeter readings.

Warning: The following testing and drying procedures must be performed by qualified experienced personnel, and in conformance with normal industry safety practice. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Testing and drying procedures can result in severe personal injury or death, and substantial property damage if performed by inexperienced or otherwise unqualified people. Only qualified experienced personnel can perform, in compliance with industry practice, the following testing and drying procedures.

M. Drying

Moisture is not a problem in dry-type transformers continually in service unless they have suffered from flood damage or some other circumstance under which they have become wet. Normally, heat generated by the unit evaporates any moisture which might collect.

Stored transformers or transformers de-energized for extended periods that have been subjected to high humidity should be dried before being put into service.

1. *External Heat*
a. Space heaters installed by the manufacturer.

b. Space heaters temporarily installed by the user. These should be 1000kW per side. See section **6.2** for details or refer to the manufacturer's instruction literature.

2. *Internal Heat*
This is accomplished by energizing the unit.

3. *Combination External and Internal Heat*
Apply external heat to partially dry the unit, then energize to provide internal heat to completely dry. This is the quickest method.

Warning: Transformers being dried must be constantly attended and appropriate fire extinguishing equipment must be conveniently available. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Fire can cause severe personal injury or death, and substantial damage to property. Transformers must be constantly attended and appropriate fire extinguishing equipment must be conveniently available throughout the drying process.

4. *Drying Time*
Drying time depends on the condition of the transformer, size, voltage, moisture content, and drying method.

6.2 Procedures for Installation, Operation, Inspection, and Maintenance③

Warning: Failure to observe the following procedures for installation, operation, inspection, and maintenance can cause severe personal injury or death, and substantial property damage.

A. Location
Major considerations in locating dry-type transformers are: accessibility, ventilation, and atmospheric conditions.

B. Moisture
Ventilated dry-type transformers are normallly designed for installation indoors in dry locations. They will operate where humidity is high but if they are de-energized for any prolonged period it is necessary to take precautions to keep them dry. (This is discussed more fully under **6.20** *Storage* and 6.2. R,5-*Effect of Humidity*.)

③ Based on USA standard ANSI/IEEE Appendix C57.94 and Westinghouse Instruction Leaflet 47-060-93.

Location where there is a possibility of water dripping on the transformer, or of water being sprayed or splashed on the transformer should be avoided.

C. Ventilation

Adequate ventilation is essential for the proper cooling of transformers. Clean, dry air is desirable. Filtered air may reduce maintenance if the atmosphere in the location presents particular problems.

When transformers are installed in vaults or other restricted spaces, sufficient ventilation should be provided to hold the air temperature within established limits when measured near the transformer inlets. This will normally require 100 cubic feet of air per minute per kilowatt of transformer loss. The area of ventilating openings required depends on the height of the vault, the location of the openings, and the maximum load to be carried by the transformers. For self-cooled transformers, the required effective area should be at least one square foot each of both inlet and outlet per 100 kVA of rated transformer capacity, net after deduction of the area occupied by screens, gratings, or louvers.

Ventilated dry-type transformers should be installed in locations free from unusual dust producing activities or activities producing chemical fumes.

Transformers should be located at least 24 inches away from walls or other obstructions to accommodate free circulation of air through and around each unit. The free space around each transformer should not be less than 24 inches. Figure 3 illustrates a typical fan arrangement for cooling a large dry-type transformer.

D. Accessibility

For maintenance purposes adequate space must be provided around each transformer.

E. Fire Hazard

If the transformer is to be located in the vicinity of combustible materials, the minimum separations set by current National Electrical Code and applicable fire laws must be maintained.

F. Intrusion

The transformer case is designed to prevent the entrance of most small animals and foreign objects, but in some locations, it may be necessary to give consideration to added protection.

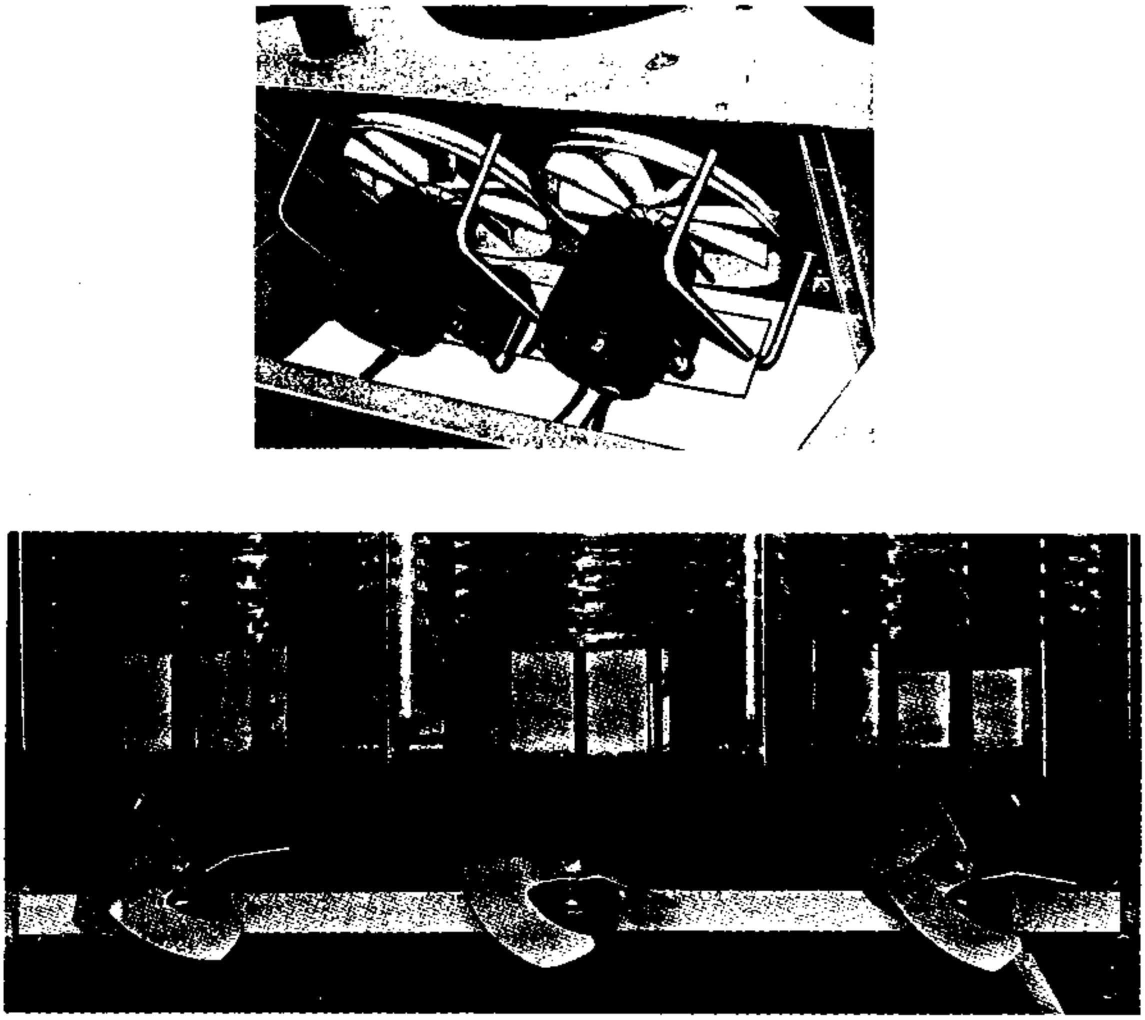


Fig. 3 – Typical Fan Assemblies for Forced-Air Ventilation

G. Transformer Noise

If noise is a factor in the location and operation of a transformer, special consideration should be given to the installation.

The most effective way to reduce the noise level of a transformer is for the manufacturer to design for low sound level. This is done by designing the most compact core and coil possible, and to dampen vibrations as much as possible within the unit.

There are two approaches:

1. *To reduce the magnitude of the generated vibrations* by using high density, grain-oriented steel and high-temperature insulation. This allows a minimum size core loop with a minimum core cross sectional area. Minimum vibration magnitude is accomplished together with the smallest, lowest weight core possible.

2. *Attenuation of Structure-borne Noise* is essential for noise reduction. The vibrations from driven machinery and other sound sources can be transmitted through the building structure to the transformer where they are radiated and function to amplify the sound level of the transformer. These structure-borne vibrations can be isolated by use of damping devices such as springs between the core and coil assembly and the transformer mounting base and case.

These are steps taken by the transformer manufacturer that allow shipment of a transformer that meets the sound level requirements set by the specifying engineer. The tests are made under ideal conditions that virtually eliminate any increase in sound level due to structure-borne vibration.

In the field where the transformer will be installed structure-borne vibrations become a major consideration in controlling noise levels. Improper installation will greatly increase sound levels.

3. *Use of Dampening Devices in Mounting.*
Flexible coupling of conduit, and auxiliary dampeners can greatly reduce sound level build-up, but vibrations can still be transmitted through the case and conduit throughout the building. Even with flexible conduit connections, the transformer case remains a major contributory source to audible sound levels.

4. *Audibility*④
The audibility of sound is affected by: frequency, ambient sound level, nature of surroundings, and distance from the source. Frequency is not a great problem since most are at levels that are not bothersome. The ambient sound level and its masking effect is of prime importance and should be given consideration.

5. *Masking*
Masking takes place when a sound is made inaudible by a louder sound. The first sound becomes audible again if the second (louder) sound is removed. In reality, the first sound remains at the same level, its audibility changed by the second sound. This phenomenon should be considered in locating a transformer. As an approximate guide, if the sound level of the transformer is 10 decibels lower than the background noise, the transformer is inaudible.

6. *Proximity*
Proximity to reflecting surfaces and the nature of the surfaces have a great effect on both the perceived and actual sound levels. In a room

④ Refer to *Minimizing Transformer Noise*-article in *Electrical Construction and Maintenance*-available from Westinghouse as *Reprint 6116.*

with low sound-absorption walls, the sound from the transformer will reflect back and forth between the walls resulting in an increase in the sound level. The proximity of the wall to the transformer will also affect the sound level.

Example:
Assume a transformer with a surface area of 21 square feet, and walls with an absorption coefficient of .01 (concrete or masonry).

Room size sq. ft.	Room volume cu. ft.	Surface area sq. ft.	Sound build-up db
10 × 10 × 6	600	440	13.0
10 × 10 × 12	1200	680	11.2
10 × 10 × 24	2400	1160	9.1
10 × 20 × 24	4800	1840	7.4

The statistics in the example demonstrate the effects of confining the sound in a restricted space.

Another consideration is how close the transformer is mounted to a reflecting surface. If the transformer is mounted in the geometric center of the floor the radiating space for the transformer sound is in the shape of a hemisphere, moving the transformer to a wall reduces the radiating space to a quarter of a sphere, and if the transformer is moved to a corner,the radiating space is reduced to one-eighth of a sphere. The sound level build-up as a result of these reductions approximates a ratio of 1.5 to 3 to 4.5.

7. *Audible Sound Level Tests*
(from TR 27-5.09)
Transformers shall be so designed that the average sound level will not exceed the values given in the following tables when measured as follows:

a. Test Conditions - Measurements shall be made in an ambient having a sound level at least 4 decibels, and preferably 7 decibels or more, lower than the transformer and ambient combined. The ambient sound level shall be the average of the measurements taken immediately before and immediately after the transformer is tested at each location as indicated in this standard. Corrections shall be applied in accordance with Table 1.

The transformer shall be so located that there is no acoustically reflecting surface, other than floor or ground, within 10 feet of the transformer.

Table 1 - Decibel corrections for Ambient Sound

Difference in Decibels Between Sound Level of Transformer and Ambient Combined and Sound Level of Ambient	Corrections in Decibels to be Applied to Sound Level of Transformer and Ambient Combined to Obtain Sound Level of Transformer
4	−2.2
5	−1.7
6	−1.3
7	−1.0
8	−0.8
9	−0.6
10	−0.4
over 10	−0.0

Table 2 - Average Sound Levels

Equivalent Two-Winding kVA	Average Sound Level Self-Cooled Ventilated (1)	Average Sound Level Self-Cooled Sealed (2)	Equivalent Two-Winding kVA	Average Sound Level-Decibels Ventilated Forced-Air-Cooled (3)
0-9	45	45	0-1167	67
10-50	50	50	1168-2000	68
51-150	55	55	1668-2000	69
151-300	58	57	2001-3333	71
301-500	60	59	3334-5000	73
501-700	62	61	5001-6667	74
701-1000	64	63	6668-8333	75
1001-1500	65	64	8334-10000	76
1501-2000	66	65		
2001-3000	68	66		
3001-4000	70	68		
4001-5000	71	69		
5001-6000	72	70		
6001-7500	73	71		

Columns (1) and (2) - Class AA rating.
Column (3) - Class FA and AFA rating.
Column (3) does not apply to sealed dry-type transformers.

The transformer shall be energized at rated voltage and frequency with no load.

b. Measurements
(1) Sound levels shall be measured with an instrument which is in accordance with the American Standard Specification for General-Purpose Sound Level Meters. S1.4-1961.

Response Curve A (for 40 decibel sound level) shall be used.

(2) The average sound level is defined as the arithmetic means of the sound level readings, taken in accordance with par. (4) and (5) below.

(3) The major sound producing surface of a transformer is a vertical surface which follows the contour traced by a string stretched around the horizontal projection of the transformer outline. This outline is to include primary and secondary switchgear compartments.

(4) For transformers having an overall tank height of less than 8 feet, measurements shall be made at approximately half height. For transformers having an overall tank height of 8 feet and above, measurements shall be made at approximately ⅓ and ⅔ height.

(5) Starting at a point opposite the front center of the transformer enclosure and proceeding clockwise around the transformer as viewed from above, mark off reference points at 3-foot intervals measured in a horizontal direction along the major sound producing surface. There should be no fewer than four reference points, which may result in intervals of less than 3 feet for small transformers.

One sound measurement shall be taken opposite each reference point. The microphone shall be located on a straight line which is perpendicular to the major sound producing surface at a reference point. The microphone shall be 1 foot from the major sound producing surface.

(6) Procedure for Investigation
Warning: Hazardous voltages can cause severe personal injury or death, and substantial damage to property. Disconnect transformer leads and de-energize the transformer before removing the transformer case panels.

(a) Shipping braces which brace the case to the core and coils must be removed. These braces are located at the end of the case.

Shipping shims and bolts, under core and coil feet, should be removed so the core and coil assembly floats free on isomode vibration dampers.

Notice: Sound absorbing devices will not function and the transformer will be noisy if the shims and shipping braces placed between the core and coil frame and the base of the transformer case are not removed after the transformer is in place.

For installations with special seismic requirements, the bolts between the core and coil frame and the case may be loosened but not removed.

Shipping braces, bolts, and shims are usually painted a distinctive color for identification.

(b) Connections to the low voltage bus should be flexible cable or bus.

(c) Inspection should be made for loose panels, bolts, and parts.

8. *Methods of Reducing Sound Level*
a. Fiberglass sound panels may be installed. Materials and instructions should be obtained from the transformer manufacturer.⑤

b. The amount of surface area in contact with the isomodes may be increased. Requires jacking the core and coil assembly, increasing the length of the feet, and installing more isomode material.

c. Entire case may be set on isomodes.

d. Core bolts may be adjusted.

e. Cerafelt material may be installed between the end frames and the top yoke to reduce lamination buzz.

Additional transformers in the same room increase the sound level on a rapidly ascending curve.

9. *General Guidelines for Indoor Installation*
a. The transformer should be installed where noise will be least objectionable.

b. Nearby reflecting objects or enclosures which will resonate or echo should be avoided as well as areas such as halls and stairwells which tend to amplify sound.

c. Tile, brick, concrete, or metal walls, floors, and ceilings are poor sound absorbers and should be avoided when possible. Acoustic material may be required to reduce excessive sound build-up.

⑤ Covered in Westinghouse Instruction Leaflet 47-069-11.

d. Mounting transformers on structures having light mass should be avoided. The heavier the floor structure the less likely the transformer sound will be transmitted or amplified.

e. Specially designed low sound level transformers are available for use where noise requirements justify the additional cost.

H. Protection

Warning: Do not install dry-type transformers on unprotected circuits. These transformers are designed for use on protected circuits only. Failure to heed this warning can cause severe personal injury or death, and damage to property

Warning: Hazardous voltage can cause severe personal injury or death, and substantial property damage. Install dry-type transformers on protected circuits only. Do not install dry-type transformers on unprotected circuits.

The impulse strength of these transformers may be less than that of some liquid-immersed units of the same voltage class. If there is any likelihood that the dry-type transformer will be exposed to lightning or severe switching surges, adequate protective equipment should be provided. Arresters applied to dry-type transformers should have the RM characteristics.

I. Altitude

For de-rating factors which apply to installations at high altitudes, refer to ANSI C57.12.01.

J. Inspection

New transformers should be inspected for damage in shipment when received. Examination should be made before removing from cars or trucks and if any injury is evident or any indication of rough handling is visible, a claim should be filed with the carrier at once and the manufacturer notified.

Subsequently, covers or panels should be removed and internal inspection made for injury or displacement of parts, loose or broken connections, cracked porcelain, dirt or other foreign material, and for the presence of free water or indications of moisture. Corrective measures should be taken where indicated. Shipping braces and shims should be removed. (These shipping braces are painted yellow for identification.)

Notice: sound absorbing devices will not function and the transformer will be noisy if the shims, bolts, and shipping braces placed between the core and coil frame and the base of the transformer case are not removed after the transformer is in place. Remove these shims, bolts, and braces after the transformer is in place.

Notice: for installations with special seismic requirements, loosen but do not remove the bolts between the core and coil frame and the base of the transformer case.

After the transformer is removed from the car or truck, or if it is stopped before installation, this inspection should be repeated before placing the unit in service.

Before placing in service the operation of fans, motors, thermal relays, and other auxiliary equipment should be verified.

K. Handling

Warning: Consult the transformer manufacturer's lifting instructions before attempting to move a dry-transformer. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Improper lifting of dry-type transformers can cause severe personal injury or death, and substantial property damage. Consult the transformer manufacturer's lifting instructions before attempting to move a dry-type transformer.

Ventilated dry-type transformers may be handled in much the same way as liquid-immersed transformers except that somewhat greater care is required because of the lighter cases. In most instances, large transformers can only be lifted from end frame lugs accessible through the roof of the case. If it is necessary to handle ventilated dry-type transformers outdoors during inclement weather, they should be thoroughly protected against the entry of snow or rain.

L. Grounding

The case and core assembly of these transformers should be permanently and solidly grounded.

M. Connections

All electrical connections should be checked for tightness. Taps should be checked for correct connection and tightness.

N. Testing

It is recommended that tests be made before placing the transformer in service to determine that it is in satisfactory operating condition and to obtain data for future comparison. The minimum recommended testing includes insulation resistance and low frequency high-potential tests.

Warning: Do not remove case panels, install arresters, or attempt any maintenance or repair work, or conduct tests on a transformer that is energized. Failure to heed this warning can cause severe injury or death, and damage to property.

Warning: Hazardous voltage can cause severe personal injury or death, and substantial property damage. Disconnect transformer leads and de-energize the transformer before attempting to remove the transformer case panels, install arresters, or undertaking any maintenance or repair work.

1. *Insulation Resistance Test*

The insulation resistance test is of value for future comparison purposes and for determining the suitability of the transformer for the application of the high-potential test. The values given in **6.1, K,1** may be used as minimum values.

Note: Arresters should be disconnected before making insulation resistance tests.

2. *Low Frequency High-Potential Test*

If a transformer is known to be wet or if it has been subject to unusually damp conditions, it should be dried out before application of the high-potential test or before placing in service, regardless of insulation resistance.

The values given in **6.1, K,2** may be used in making low frequency high-potential tests.

Dielectric test in the field are to be made in accordance with ANSI C57.12.01.

3. *Additional Tests-optional*

Ratio tests for the full windings and for all tap positions.

Resistance measurement of windings.

Polarity or phase relation.

Power factor of insulation.

The power factor test is of value for future comparison in periodic checks of the transformer condition.

If any of these tests are made it is preferable that they be made before applying the dielectric tests.

O. Storage

Ventilated dry-type transformers should be stored in a warm, dry location with uniform temperature. Ventilating openings should be curved. If it is necessary to store a transformer outdoors it should be thoroughly protected to prevent moisture and extraneous material from entering. Condensation and absorption of moisture can be prevented or greatly reduced by installation of space heaters (or small portable electric heaters).⑥

P. Periodic Inspection and Maintenance

Warning: Hazardous voltage can cause severe personal injury or death, and substantial property damage. De-energize the transformer before conducting inspections or performing any maintenance or repair.

Inspection should be made at regular intervals and corrective or preventive measures taken when necessary to assure optimum service from the equipment.

The frequency of inspections depends on operating conditions. In a clean, dry location an annual inspection or an even longer interval may be sufficient. In less ideal conditions, where the air is contaminated with dust or chemical fumes, inspection at three to six month intervals may be needed. Usually after the first few inspection periods a definite schedule can be established based on conditions.

In making inspections the transformer should first be de-energized and covers over openings in the case removed. Inspection should be made for dirt, especially accumulations on insulating surfaces or surfaces where accumulations might tend to restrict air flow. Inspection should also be made for loose connections, loose tape, the condition of tap changers and terminal boards, and for the general condition of the transformer.

⑥ This subject is covered in greater detail in Westinghouse Instruction Leaflet 47-060-93.

Observation should be made for signs of overheating and of voltage creepage over insulating surfaces as evidenced by tracking or carbonization.

Evidence of rusting, corrosion, and deterioration of paint should be checked and corrective and preventive action taken where necessary.

Fans, motors, and other auxiliary devices should be inspected and serviced during regular scheduled inspections.

Q. Cleaning

If excessive accumulations of dirt are found on the transformer windings or insulators, the dirt should be removed to permit free circulation of air and to guard against possible insulation breakdown. Particular attention should be given to cleaning top and bottom ends of the winding assemblies, and to cleaning ventilating ducts.

The preferred cleaning method is to use a vacuum cleaner, secondly a blower or compressed air or nitrogen. The compressed air or nitrogen, used after first cleaning with a vacuum cleaner, should be clean and dry and applied at a low pressure (not over 25 psi). Lead supports, tap changers and terminal boards, bushings, and other major insulating surfaces should be brushed or wiped with a soft bristle brush or a soft dry cloth. The use of liquid cleaners is not recommended for these transformers in routine cleaning because some of the cleaners have a solvent or deteriorating effect on many insulating materials.

R. Drying of Core Coil Assembly

Warning: The following tests and drying procedures must be performed by qualified experienced personnel, and in conformance with normal industry safety practice. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Testing and drying procedures can result in severe personal injury or death, and substantial property damage if performed by inexperienced or otherwise unqualified people. Only qualified experienced personnel can perform, in compliance with industry practice, the following testing and drying procedures.

When it is necessary to dry out a transformer before installation or after an extended shutdown under humid conditions, one of these methods can be employed: application of external heat, application of internal heat, or application of internal and external heat simultaneously or serially. Before employing any of these methods free moisture should be blown or wiped off the windings to reduce the length of the drying time.

1. *Drying by External Heat*

Warning: Transformers being dried must be constantly attended and appropriate fire extinguishing equipment must be conveniently available. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Do not energize a dry-type ventilated transformer unless case is solidly grounded. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Fire can cause severe personal injury or death, and substantial property damage. Transformers must be constantly attended and appropriate fire extinguishing equipment must be conveniently available throughout the drying process.

Warning: Hazardous voltages can cause severe personal injury or death, and substantial property damage. Solidly ground a ventilated dry-type transformer before energizing it.

External heat may be applied to the transformer by one of these methods: directing heat into the bottom air inlets of the transformer case, or placing the core and coil assembly in a suitable ventilated oven. It is important that most of the heated air pass through the winding ducts and not around the sides. Good ventilation is essential to assure that condensation will not take place in the transformer or the case. A sufficient quantity of circulating air should be present to provide approximately equal inlet and outlet temperatures.

In directing the heat into the transformer case inlets, or using externally heated oven, resistance grids or space heaters may be used. The heaters may be placed inside the transformer case or the oven box, or outside and the heat blown in at the bottom. The core and coil should be carefully protected from direct radiation from the heaters.

It is recommeded that the air temperature not exceed 110C.

Auxiliary transformer equipment will not withstand temperatures above 90C.

Applying external heat by using a self-heating oven is the most efficient method, if such an oven is available.

2. *Drying by Internal Heat*
This method is relatively slow and should not be used if application of external heat is practical.

The transformer should be located to allow free circulation of air through the coils from bottom to top. One winding should be short-circuited and sufficient voltage at normal frequency should be applied to the other winding to circulate approximately normal current.

It is recommended that the winding temperature not be allowed to exceed 100C as measured by resistance or by thermometers placed in the ducts between the windings. The thermometers used should be of the spirit type because mercury thermometers give erroneous readings due to the generation of heat in mercury as a result of eddy currents.

Warning: Do not use metallic thermometers. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Warning: Hazardous voltages can cause severe personal injury or death, and substantial property damage. Use spirit type thermometers, do not use metallic thermometers.

The end terminals of the windings (not the taps) must be used to circulate current through the entire winding.

Proper precaution must be taken to protect the operator from dangerous voltages.

3. *Drying by External and Internal Heat*
This is by far the quickest drying method. The transformer core and coil assembly should be put into an oven (or a nonflammable box to function as an oven), or kept in its case, and external heat applied as described above. Simultaneously current should be circulated as described under *Internal Heating*. The current required will be considerably less than when no external heat is applied, but must be sufficient to produce the desired temperature in the windings. The temperatures attained should not exceed those indicated above.

4. *Use of Insulation Resistance to Determine Drying Time*
Drying time depends on the condition of the transformer; its size, voltage, moisture content, and drying method.

The measurement of insulation resistance is of value in determining the status of drying.

Warning: Hazardous voltages can cause severe personal injury, or death, and substantial property damage. De-energize the transformer and disconnect arresters before removing case panels or making resistance measurements.

Measurements should be taken before the drying process is started and at two-hour intervals during drying. The initial value, if taken at moderate temperature, may be high even though the insulation may not be dry. Because insulation resistance varies inversely with temperature, the transformer should be kept at an approximately constant temperature to obtain valid readings for comparison. As the transformer is heated, the presence of moisture will be evident by the rapid drop in resistance measure. Following this initial period the insulation resistance will slowly increase until near the end of the drying period when the rate of resistance increase will accelerate. Sometimes the resistance will rise and fall through a short range before steadying because moisture in the interior of the insulation is working out through the initially dried portions. A curve with time as the abscissa and resistance as the ordinate should be plotted and the run should be continued until the resistance levels off and remains constant for three or four hours.

Insulation resistance measurements should be taken for each winding to ground with all windings being grounded except the one being measured. Before taking insulation resistance measurements the current should be interrupted and the windings short circuited and grounded for at least one minute to drain off any static charge. All readings should be for the same interval of test voltage, preferably one minute.

Warning: Hazardous voltages can cause severe personal injury or death and substantial property damage. De-energize the transformer and disconnect arresters before removing case panels or making resistance measurements.

5. *Effect of Humidity*

As long as the transformer is energized, humidity conditions are unimportant. When a dry-type transformer is de-energized and allowed to cool to ambient temperature, consideration must be given to the possible effects of humidity.

If a shutdown occurs for a period exceeding 24 hours during a period of high humidity, particularly if atmospheric conditions are such as to encourage condensation within the transformer case, precautions should be taken.

Small strip heaters may be placed in the bottom of the case before the transformer has cooled to ambient temperature. The temperature of the unit should be maintained a few degrees above ambient with the heaters. If such a precaution has not been taken, the unit should be inspected for evidence of moisture and insulation resistance should be measured. If there is evidence of moisture or if the insulation resistance is low, the transformer should be dried out using one of the methods described.

6.3 Sealed Dry-Type Transformers

Note: Refer to 6.1 and 6.2 for general information on installation, operation, and maintenance of dry-type transformers. The following information applies specifically to sealed dry-type transformers.

Warning: Hazardous voltages can cause severe personal injury or death, and substantial damage to property. Be sure the transformer is not energized before removing case panels, installing, inspecting, performing any maintenance, or corrective work, or storing the transformer.

A. Installation

Transformers should be located at least 24 inches away from walls or other obstructions.

B. Inspection

Before placing in service the transformer should be tested for pressure tightness.

C. Handling

When lifting a sealed dry-type transformer, the lifting cables must be held apart by a spreader to avoid bending the lifting studs or other parts of the structure.

When a transformer cannot be handled by a crane, it may be skidded or moved on rollers, but care must be taken not to damage the base or tip the transformer over. When rollers are used under large transformers, skids must be used to distribute the stress over the whole base.

The case of these transformers must be adequately, solidly, and permanently grounded.

D. Storage

If the transformer is filled with inert gas, the gas pressure should be maintained and periodically tested.

Auxiliary devices should be periodically inspected and serviced.

The transformer manufacturer or the manufacturer's instruction literature should be consulted if there are specific questions relating to sealed dry-type units.⑦

Warning: Hazardous voltages can cause severe personal injury, or death and substantial damage to property. Do not energize any dry-type transformer unless the case has been solidly grounded.

E. Application

The dry-type transformer is suited to indoor application. The high-rise building requires that power be continuously available for the operation of elevators, the prime access to the building, and to avoid hazard of panic or serious inconvenience due to water or heat shortage in the event of a power outage. Dry-type transformers in high-rise buildings are an essential part of regular and stand-by electrical systems.

Dry-type transformers have been specifically designed for use in high-rise buildings. They require minimum checking and are nearly maintenance free. No vaults and no special vents, no domes, or other protection are needed, they can be installed in any convenient location.

6.4 Pad Mounted Dry-Type Transformers

The dry-type pad mounted transformer was designed for underground power distribution to shopping centers, apartment and office buildings, schools, industrial parks, and the like. There is no need for unsightly fences or other external protection. Since these transformers have no accessible external bolts, hinges, screws, or fasteners, they are to the extent possible a self-contained unit secure from intrusion by unauthorized personnel. These units are usually completely factory assembled and shipped as a single piece. Refer to Figure 5.

6.5 Most Frequent Field Troubles

Warning: Treating field troubles can result in severe personal injury or death, and substantial damage to property if performed by inexperienced or otherwise unqualified people. Only qualified experienced personnel can perform, in compliance with industry practice, the following procedures.

A. Coordination

1. *High Voltage:* cable connections, cable not properly spaced; flash-over occurs.

⑦ Westinghouse Instruction Leaflet 47-060-92 provides more detailed information.

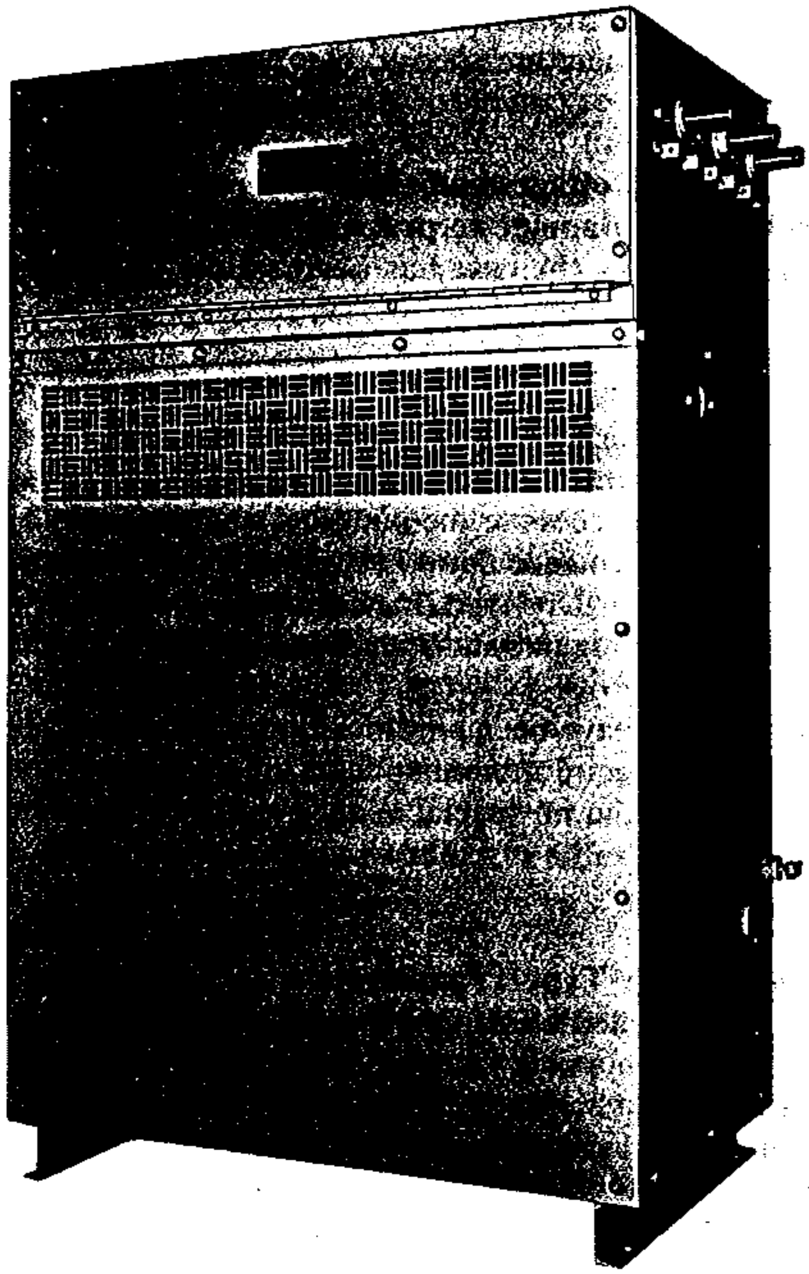


Fig. 4 – Typical Dry-Type Transformer for High Rise Building Application

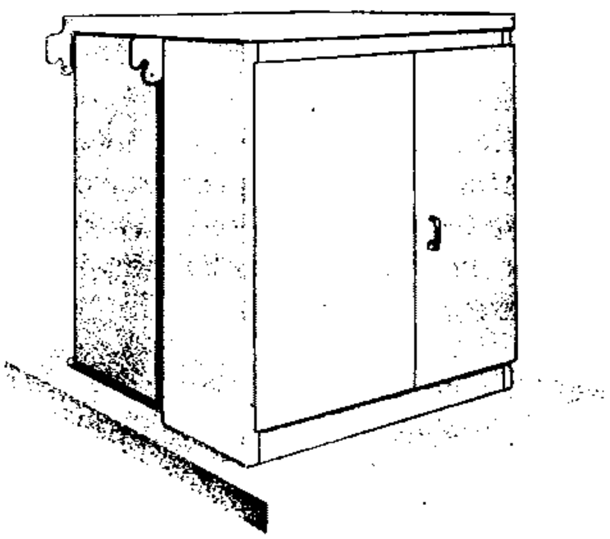


Fig. 5 – Typical Pad Mounted Dry-Type Power Center Transformer

2. *Low Voltage:* Bus work does not match: Correct with longer flexible connectors (Make flexible connectors from cable or purchase.) Move transformer core and coil slightly to obtain coordination.

B. Transformer Hot Spot Measurement Devices
Several types of hot spot devices are currently in use:

1. *Bourdon Tube Device*⑧
Warning: Hazardous voltages can cause severe personal injury or death, and substantial damage to property. De-energize the transformer before performing any maintenance on the hot spot indicator, as the thermometer bulb is in direct electrical contact with the low voltage leads.

Caution: Maintenance may be performed on the forced-air control circuit panel with the circuits energized, provided adequate safety precautions are followed.

Warning: Maintenance can be performed on the hot spot indicator and the hinged forced-air control panel only after they have been removed from the transformer case.

This device, refer to Figure 6, uses a bourdon tube inserted in a metal tube which is welded to the low voltage lead a few inches from the edge of the low voltage coil. This tube measures the actual temperature of the low voltage lead and the dial is calibrated to read the hottest spot temperature of the transformer coils. The temperature of the low voltage lead is proportional to the load current in the lead.

Most problems involve lack of any indication on the dial. It is normal to have little or no indication on the dial until the transformer has reached up to half load, due to the wide range of temperature to be covered. Half loaded transformers will give no indication above minimum scale reading because the temperature is proportional to I^2R losses, and 50% load will cause only 25% of the temperature experienced at full load.

Additional questions on device calibration should be referred to the transformer manufacturer.

Warning: Do not remove the temperature indicator when the transformer is energized. The thermometer bulb is in direct electrical contact with the low voltage leads. Failure to heed this warning can cause severe personal injury or death, and damage to property.

⑧ Covered in detail in Westinghouse Instruction Leaflets 47-062-11B and 47-062-3C.

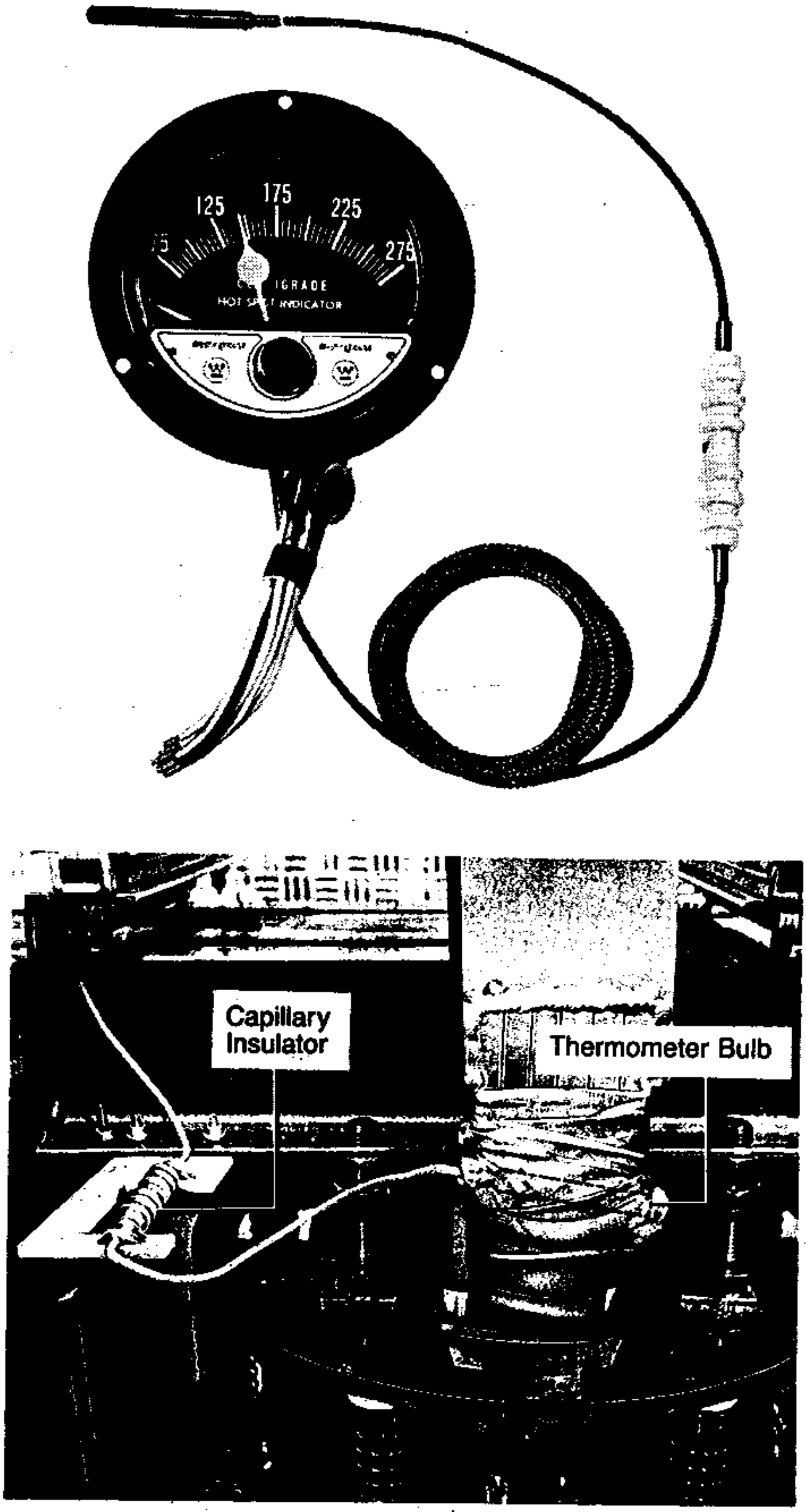


Fig. 6 – A Bourdon Tube, Isolated Bulb Temperature Indicator

2. *Thermocouple Devices*⑨

These devices, refer to Figures 7A and 7B, use a thermocouple which is embedded in the low voltage winding.

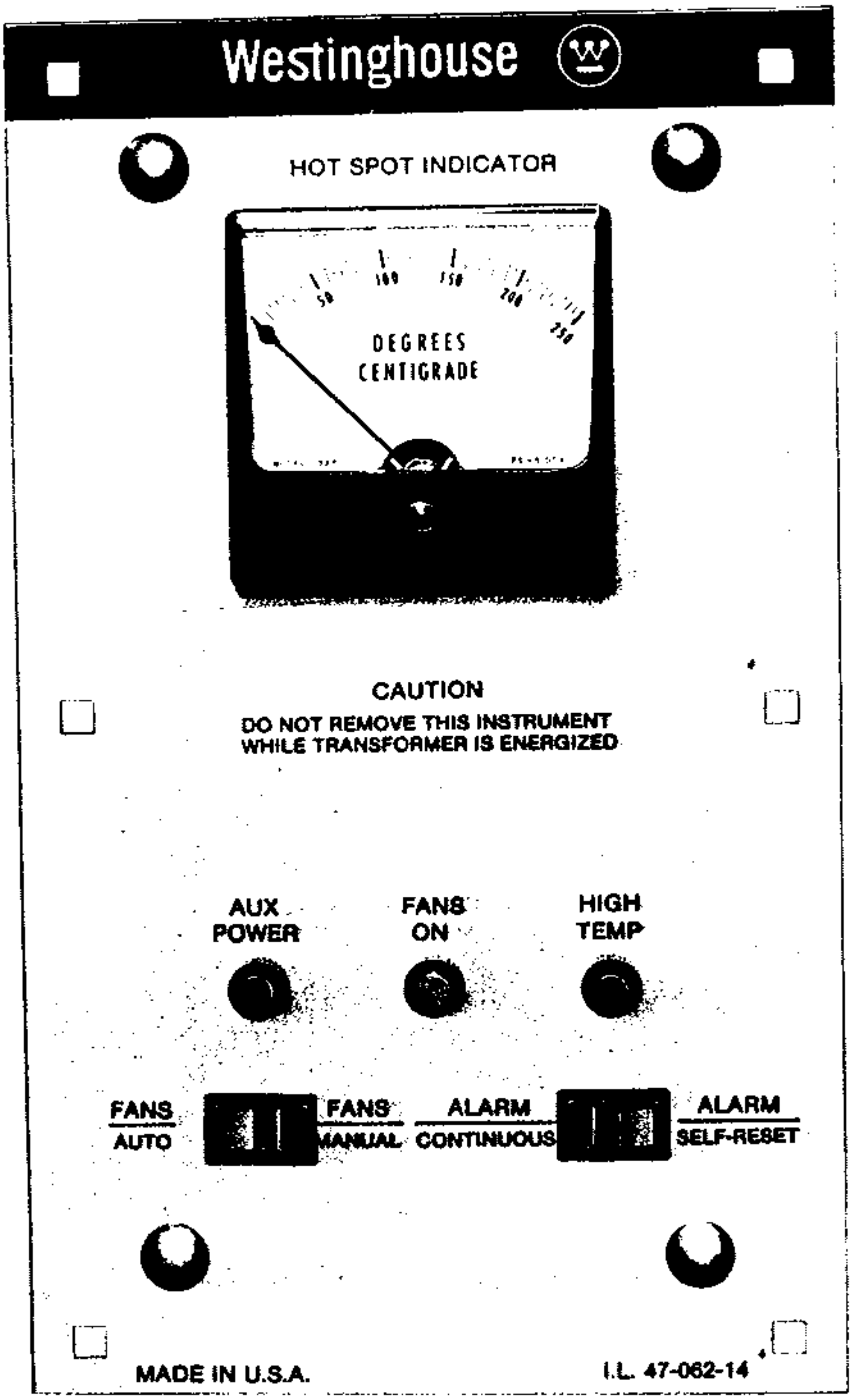


Fig. 7A – Thermocouple Actuated Temperature Indicator and Control – Front View

⑨ Covered in detail in Westinghouse Instruction Leaflets 47-062-12 and 47-062-14.

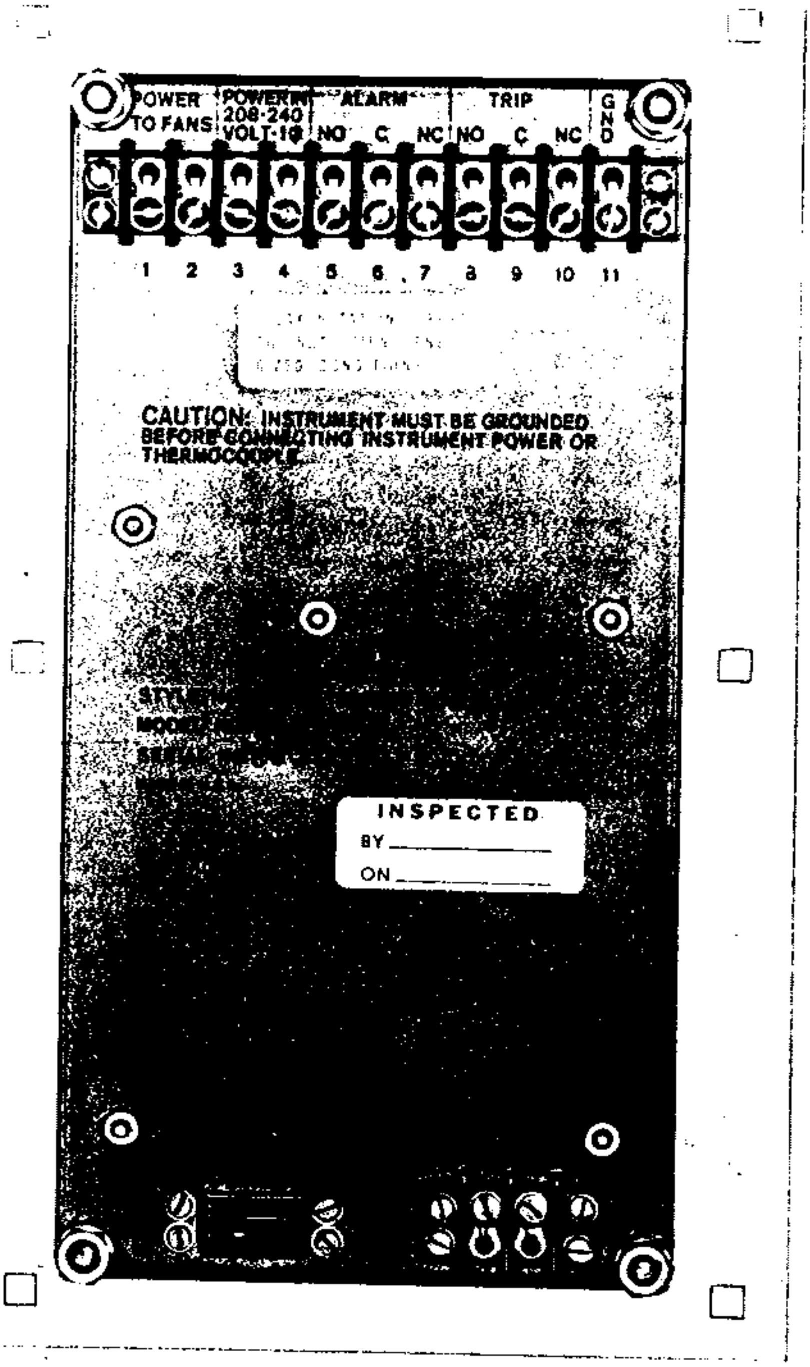


Fig. 7B – Thermocouple Actuated Temperature Indicator and Control – Rear View

Warning: Hazardous voltages can cause severe personal injury or death, and substantial damage to property. De-energize the transformer before removing the thermocouple connection or replacing any wiring, or cracked or broken glass front of the hot spot indicator.

Electrical isolation is maintained between the thermocouple input and the fan control circuits. These thermocouple actuated devices are not field serviceable if internal components fail. The manufacturer's instruction literature should be consulted to verify that the instrument is actually malfunctioning, that all switches are properly set and circuits properly energized.

The most common problem is the continuous burning of the alarm light under normal temperature conditions.

The alarm light is designed to come on in the event of the failure of any component of the instrument, in addition to providing a signal that the maximum transformer temperature has been reached. Defective instrument components are not field replaceable. The transformer manufacturer should be consulted for replacement procedures.

C. Sound Level

Typical problems:

1. *High Sound Level*
Sound level standards are fairly loud. Transformers meet guaranteed sound levels when shipped. Refer to 6.2, G for more complete noise information.

2. The guaranteed sound level is too high for the location. Refer to 6.2, G for more complete noise information.

3. When the guaranteed sound level is 64 db many complaints of noise are the result of not realizing how loud 64 db is. This level is approximately the same as the interior of a jet airplane at take-off. See 6.2, G.

Installation can have a critical effect on sound levels. Installations of power centers have been found where the installed sound level was as much as 10 db higher than the laboratory measurement at the factory.

4. Loose transformer enclosures contribute to high sound levels. See 6.2, G.

5. All shipping shims must be removed and the bolts between the transformer base and the core and coil assembly must be completely removed (except where required by seismic restrictions).

6. The enclosure must be on a level surface.

7. Overvoltage will overexcite the transformer and produce high sound levels.

D. Handling Damage and Loose Parts

Warning: Improper lifting of dry-type transformers can cause severe personal injury, or death, and substantial damage to property. Consult the transformer manufacturer's lifting instructions before attempting to move a dry-type transformer.

Undetected handling damage can affect electrical performance. All coils and conductors and cores should be visually inspected prior to energizing.

1. *Pressure Blocks Loosened:*
These blocks are located at top and bottom of the H.V. coil between the coil and the pressure ring. To tighten:

a. Loosen jack bolts which hold the pressure ring at the top of the coil.

b. Place silastic rubber RTV (731, 892, 893) on both ends of the loose blocks. Tubes of RTV are available at most hardware stores. RTV acts as an adhesive and a cushion.

c. Tighten the pressure ring to a uniform clamping force at the four jack bolts. Too tight will displace the RTV rubber and too loose will not secure the blocks.

d. Exposed hardware should be covered with class H varnish to provide locking and prevent oxidation.

The loosened pressure block problem is frequently caused by lifting the unit at two points instead of four.

2. *Loose Nuts and Bolts*
Tighten all detected loose nuts and bolts. Specifically: End frame bolts located at each end, top and bottom, should be as tight as possible without bending the end frames. If the end frame is bent, it will tend to strain the core steel and increase the sound level.

3. Forced-Air Housing is a frequent cause of rattles, it should be carefully checked.

4. Radial spacers and miscellaneous parts should be checked.

These parts can be anchored in place with RTV rubber or class H varnish.

E. Trouble Shooting

Indications and causes of Transformer failure

Warning: Trouble shooting procedures can result in severe personal injury or death, and substantial damage to property if performed by inexperienced or otherwise unqualified personnel. Troubleshooting can be done only by qualified experienced people after consultation with the manufacturer or the manufacturer's instructions.

Electric Circuit

Symptoms:	Cause:
Overheating	Continuous overload, wrong external connections, poor ventilation - high ambient temperature.
Reduced or zero voltage	Shorted turns, loose connections to transformer terminal board.
Excess secondary voltage	High input voltage, dirt accumulations on primary terminal board.
High copper loss	Overload, terminal boards not on identical tap positions.
Coil distortion	Short circuit, lightning surge.
Insulation failure	Continuous overload, dirt accumulation on coils, mechanical damage in handling, water exposure.
Breakers or fuses opening	Short circuit, overload, reversed polarity when paralleling transformers.
Smoke	Terminal boards, tap connections, or tap changers not on identical tap positions.

Magnetic Circuit

Vibration and noise	Low frequency, high input voltage, core clamps loosened in shipping or handling.
Overheating	High input voltage.
High exciting current	Low frequency, high input voltage.
High core loss	Low frequency, high input voltage.
Insulation failure	Very high core temperatures due to high input voltage or low frequency.

Dielectric Circuit

Smoke	Insulation failure.
Burned insulation	Lightning surge, switching or line disturbance, broken terminals, taps, or arresters, excess dirt on coils.
Overheating	Clogged air ducts.
Breakers or fuse open	Insulation failure.

6.6 Definitions of Transformer Terms

AA - An ANSI (American National Standards Institute) designation indicating open, natural-draft ventilated construction (found in ANSI Standard C57.12 pg 9).

AIEE - American Institute of Electrical Engineers, now part of IEEE.

Ambient Noise Level - The noise level of the surrounding area measured in decibels.

Ambient Temperature - Ambient temperature is temperature of surrounding atmosphere into which the heat of the transformer is dissipated.

Ampere - Unit of current flow.

ANSI (American National Standards Institute) - an organization which provides written standards on dry-type transformers, 600v and below (ANSI C89.1) and on distribution transformers, 601v and above (ANSI C57.12)

ANSI 61 - An ANSI designation for color of paint, usually written in specifications as "must be ANSI-61 light gray paint," but often referred to verbally as "ANSI-61."

ASTM - American Society for Testing Materials.

Autotransformer - An autotransformer is a transformer in which part of the winding is common to both the primary and the secondary circuits.

BIL - Basic Impulse Level, (see Impulse Tests).

Buck-Boost Application - The name of a standard, stock two-winding, one-phase transformer with low-voltage secondary windings which can be connected as an autotransformer for boosting and bucking single and three-phase supply voltages in small amounts.

Cast-coil Transformer - Transformer with high-voltage coils cast in an epoxy resin. Usually used with 5 and 15 kV transformers.

Certified Tests - Actual values taken during production tests and certified as applying to a given unit shipped on a specific order.

Class A, B, F, & H - Refers to the class of insulation system in a transformer.

Concentric Knockout - Dual-purpose knockouts designed for accepting two sizes of conduit.

Continuous Rating - Continuous rating defines the constant load which a transformer can carry at rated primary voltage and frequency without exceeding the specified temperature rise.

Copper Losses - See Load Losses.

Corrosion Resistant - (Also see Rust Resistant and Rust Inhibiting); specifically prepared or treated to resist corrosion and rusting.

Current Transformer - A transformer generally used in instrumentation circuits for measuring or controlling current.

Decibel (DB) - A term used in sound measurement. A change of one db in sound level is the smallest change the human ear can detect. A busy office might measure from 60-75 db. DB is a measure of sound intensity.

Delta (Δ) - A standard three-phase connection with the ends of each phase winding connected in series to form a closed loop with each phase 120 degrees from the other. Sometimes referred to as 3-wire.
Delta Wye (Δ-Y) - A term or symbol indicating the primary connected in delta and the secondary in wye when pertaining to a three-phase transformer or transformer bank.
Dielectric Tests - Dielectric tests are tests which consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdowns of insulating materials and spacings under normal conditions.
Distribution Transformers - Those rated 120 to 5 kV on the high-voltage side and normally used in secondary distribution systems. An applicable standard is ANSI C-57.12.
Dripproof - Constructed or protected so that successful operation is not interferred with when subjected to falling moisture or dirt.
Dry-Type - A dry-type transformer is one in which the transformer core and coils are not immersed in liquid.
Impedance - Retarding forces of current flow in a-c circuits.
Indoor Transformer - An indoor transformer is one which, because of its construction, is not suitable for outdoor service.
Induced Test - A standard high-frequency test of transformer insulation.
Insulating Materials - Those materials used to electrically insulate the transformer windings from each other and ground. Usually Class A, B, F, and H.
Insulating Transformer - An insulating transformer is one which insulates the primary from the secondary winding.
Insulation System - Balancing of insulation materials to properly insulate a given product.
Iron Losses - (See No-load Losses).
Isolating Transformer - (See Insulating Transformer); isolating primary circuit from secondary circuit.
IR% - (See Percent IR).
IX% - (See Percent IX).
IZ% - (See Percent IZ).
Knockout - Easily removed circle of metal which eliminates the need for drilling holes for conduits.
KVA or Volt-ampere Output Rating - The kVA or volt-ampere output rating designates the output which a transformer can deliver for a specified time at rated secondary voltage and rated frequency without exceeding the specified temperature rise (1 kVA = 1000 Va).
Liquid-immersed Transformer - A liquid-immersed transformer is one with core and coils immersed in liquid (as opposed to a dry-type transformer).
Load - The load of a transformer is the power in kVA or volt-amperes - supplied by the transformer.

Load Losses - Load losses are those losses in a transformer which are incident to load carrying. Load losses include I^2R loss in the windings due to load current, stray loss due to stray fluxes in the winding, core clamps, etc., and to circulating currents (if any), in parallel windings.
Mid-tap - A reduced-capacity tap mid-way in a winding - usually the secondary.
Moisture-resistant - Moisture-resistant apparatus is one which is constructed or treated so that it will not be harmed readily by exposure to a moist atmosphere.
Multiple Winding - (See Parallel and Series/Multiple).
Natural-draft or Natural-draft Ventilated - An open transformer cooled by the draft created by the chimney effect in heating the air in its enclosure.
NEC - National Electrical Code.
NEMA - National Electrical Manufacturers Association.
NEMA Enclosures - Specifications of various enclosures:

NEMA 1 General purpose (protection only).
NEMA 2 Drip-tight (cover protects transformer).
NEMA 3 Weather resistant (can be installed outside).
NEMA 4 Watertight (applicable for spray, hose, etc).
NEMA 5 Dust-tight (gasketed to keep out dust, dirt).
NEMA 6 Submersible (operates under water).
NEMA 7 Hazardous locations (Class I, air break).
NEMA 8 Hazardous locations (oil immersed).
NEMA 9 Hazardous locations (meets NEC).
NEMA 10 Bureau of Mines (explosion- proof).
NEMA 11 Acid and fume resistant (oil immersed).
NEMA 12 Industrial use (non-ventilated - protected from flying dirt, dust, etc.)

NEMA Standard - Standards recommended by NEMA, NEMA ST-1 applies to specialty transformers 600 v and below while NEMA TR-1 applies to distribution transformers; (NEMA ST-1 is same as ANSI-C89.1)
Electrostatic Shield - Copper or other conducting sheet placed between primary and secondary and grounded to prevent electrical interference and to provide additional protection.
Encapsulated Winding - Transformer having coils either dipped or cast in an epoxy resin.
Enclosed - In contrast to open or core-and-coil construction.
Enclosures - (Also see NEMA Enclosures). The metal case parts surrounding the core-and-coil and (usually) wiring compartment.
Exciting Current (No-load Current) - Exciting current is current which flows in any winding used to excite the transformer when all other windings are open-circuited and is usually expressed in percent of the rated current of a winding in which it is measured.

Extended Winding - A winding made longer than necessary so that it can perform some of the duties normally expected of another winding or windings. The best example is an extended primary transformer. Its primary winding is continued on up the core beyond the point where it will do its rated job. In this additional section of the winding, taps can be added for the purpose of regulating the secondary voltage.
Note: The taps in the extended section make it possible to change the voltage ratio.
FCBN - "Full capacity below normal" taps. An abbreviation which, when pertaining to transformers, designates that they are suitable for full-rated power at voltages below rated level.
FCAN - Like FCBN taps, except full capacity above normal nameplate voltage.
Fan Cooled - Cooled mechanically to stay within rated temperature rise by addition of fans internally and/or externally. Normally used on large transformers only.
Flexible Connection - A non-rigid connection designed to eliminate transmission of noise, in contrast to rigid conduits, etc.
Frequency - On ac circuits, designates number of times that polarity alternates from positive to negative and back again . . . such as 60 hertz.
Full-capacity Tap - A full-capacity tap is one through which the transformer can deliver its rated kVA output without exceeding the specified temperature rise.
Grounding Transformer - A special 3-phase autotransformer for establishing a neutral on a 3-wire delta secondary.
Grounds or Grounding - Connecting one side of a circuit to the earth through low-resistance or low-impedance paths. This helps prevent transmitting electrical shock to personnel.
Group II and Group III Insulation - NEMA designations for insulation systems which are commonly classified as B and H.
Hazardous Location - Area contaminated with gases or dust which could explode or ignite.
High-voltage and Low-voltage Windings - Terms used to distinguish the winding having the greater voltage rating from that having the lesser in two-winding transformers. The termination on the high-voltage windings are identified by H1, H2, etc., and on the low-voltage by X1, X2, etc.
Hi Pot - A standard test on dry-type transformers consisting of extra-high potentials (high voltages) impressed on the windings, (see Transformer Tests).
IEEE - Institute of Electrical and Electronic Engineers.
Impulse Tests - Impulse tests are dielectric tests consisting of the application of a high-frequency steep-wave-front voltage between windings and between windings and ground.
Noise Level - The relative intensity of sound, measured in db.

No-load Losses (Excitation Losses) - Loss in a transformer which is excited at rated voltage and frequency but which is not supplying load. No-load losses include core loss, dielectric loss, and copper loss in the winding due to exciting current.

Parallel Operation - Single and three-phase transformers having appropriate terminals may be operated in parallel by connecting similarly-marked terminals, provided their ratios, voltages, resistances, reactances, and ground connections are designed to permit paralled operation and provided their angular displacements are the same in the case of three-phase transformers.

Per Cent IR - (Per cent resistance) - Voltage drop due to resistance at rated current in per cent of rated voltage.

Per Cent IX - (Per cent reactance) - Voltage drop due to reactance at rated current in per cent of rated voltage.

Per Cent IZ - (Per cent impedance) - Voltage drop due to impedance at rated current in per cent of rated voltage.

Phase - Type of ac electrical circuit, usually single-phase, 2-wire or 3-wire, or three-phase, 3- or 4-wire.

Polarity Tests - A standard test on transformers to determine instantaneous direction of the voltages in the primary compared to the secondary, (see Transformer Tests).

Poly-phase - More than one phase.

Potential (Voltage) Transformer - A transformer generally used in instrumentation circuits for measuring or controlling voltage.

Power Factor - The relation of watts to volt amps in a circuit.

Primary Taps - Taps added in the primary winding, (see Tap).

Primary Voltage Rating - Designates the input circuit voltage for which the primary winding is designed.

Primary Winding - The primary winding is the winding on the energy input (supply) side.

Rating - The rating of a transformer or other induction apparatus consists of the output or input and any other characteristic, such as primary and secondary voltage, current, frequency, power factor and temperature rise assigned to the transformer by the manufacturer.

Ratio Test - A standard test of transformers to determine the ratio of the primary to the secondary voltage, (see Transformer Tests).

Reactance - The effect of inductive and capacitive components of the circuit producing other than unity power factor.

Reactor - A device for introducing inductive reactance into a circuit for motor starting, operating transformers in parallel, and controlling current.

Reduced Capacity Taps - Taps which will carry full-rated winding current only, thus reducing available power because of lower output voltage.

Regulation - Usually expressed as the percent change in output voltage when the load goes from full load to no load.

Rust Inhibiting - Material added as a protective cover thus making the covered surface rust resistant.
Rust-proof - Will not rust during normal life.
Rust Resistant - Can successfully resist rust much better than a non-treated material but is not rust-proof.
Scott Connection - Connection for polyphase transformers. Usually used to change from two-phase to three-phase or three-phase to two-phase.
Secondary Voltage Rating - Designates the load-circuit voltage for which the secondary winding (winding on the output side) is designed.
Secondary Taps - Taps located in the secondary winding, (see Tap).
Sealed Transformer - Completely sealed from outside atmosphere and usually contains an inert gas which is slightly pressurized.
Series/Multiple - A winding of two similar coils that can be connected for series operation or multiple (Parallel) operation.
Shell-type Construction - A type of transformer construction where the core completely surrounds the coil.
Specialty Transformer - A specialty transformer is generally intended to transform electric power for low-voltage, general-purpose control, machine-tools, Class 2 signaling, ignition, luminous-tube, cold-cathode lighting, series street-lighting, and similar applications.
Standard - See NEMA, IEEE, and ANSI.
Star Connection - Same as wye connection.
Step-down Transformer - A step-down transformer is one in which the energy transfer is from the high-voltage winding to the low-voltage winding or windings.
Step-up Transformer - A step-up transformer is one in which the energy transfer is from the low-voltage winding to a high-voltage winding or windings.
Submersible - Submersible apparatus is constructed so that it will operate successfully when submerged in water under predetermined conditions of pressure and time.
Surface Temperature - Actual temperature of the surface (much lower than the allowed temperature rise stamped on the nameplate).
T-Connection - Use of Scott connection for three-phase operation.
Tap - A tap is a connection brought out of a winding at some point between its extremities, usually to permit changing the voltage or current ratio. (See FCBN, FCAN, and Universal Taps).
Temperature Rise - The increase over ambient temperature of the winding due to energizing and loading the transformer.
Test Reports - See Certified Tests.
Total Losses - Total losses are the losses represented by the sum of the no-load and the load losses.
Transformer - A transformer is an electrical device, without continuously moving parts, which, by electro-magnetic induction, transforms energy from one or more circuits to other circuits at the same frequency, usually with changed values of voltage and current.

Transformer Tests - Normal production tests include: A. Core loss (no-load); B. Load losses (winding loss); C. Impedance; D. Hi-pot (high voltage between windings and ground); and, E. Induced (two times normal voltage between turns and layers). Special tests: A. Heat run, and B. Noise test.

Turns Ratio - The turns ratio of a transformer is the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding.

Typical Test Data - Tests on similar units which have already been produced and tested.

Universal Taps - A combination of six primary voltage taps consisting of 4-2½% FCBN and 2-2½% FCAN, covering a 15% voltage range.

Volt-amperes - Circuit volts multiplied by circuit amperes.

Voltages:

A. 240/480 - suitable for series or multiple or 3-wire operation.

B. 240 x 480 - suitable for series or multiple (but normally for 3-wire operation).

C. 240/120, 3-wire only - suitable for reduced kVA output at 120.

D. 220/210/200 - reduced capacity taps with full capacity at 220 only and reduced capacity at 210 and 200 volts.

E. 200/210/220 - full capacity taps with full capacity at either 200, 210 or 220 volts.

Voltage Ratio - The voltage ratio of a transformer is the ratio of the RMS primary terminal voltage to the RMS secondary terminal voltage under specified conditions of load.

Voltage Regulation - Voltage regulation of a transformer is the change in secondary voltage which occurs when the load is reduced from rated value to zero, with the values of all other quantities remaining unchanged. The regulation may be expressed in percent (or per unit) on the basis of the rated secondary voltage at full load.

Weatherproof - Constructed so that exposure to weather will not interfere with successful operation.

Winding Losses - See Load Losses.

Winding Voltage Rating - The winding voltage rating designates the voltage for which the winding is designed.

Wye Connection (Y) - A standard 3-wire transformer connection with similar ends of the single-phase coils connected. This common point forms the electrical neutral point and may be grounded.

Zig-Zag Connection - Special transformer connection commonly used in grounding transformers.

6.7 Bibliography

Information on Dry-Type Transformers available from Westinghouse.

Instruction Leaflet 47-060-93 Receiving, installing, operating, and maintaining ventilated Dry-type transformers.
Instruction Leaflet 47-069-7 Lightning Arresters.
Instruction Leaflet 47-069-11 Sound Absorbing Material.
Instruction Leaflet 47-062-11B Bourdon Tube Hot Spot Instrument (TRM) and Forced Air Control for ventilated Dry-type Transformers.
Instruction Leaflet 47-062-12 OPT-I-Therm I (TRC)
Instruction Leaflet 47-062-14 OPT-I-Therm II
Instruction Leaflet 47-060-92 Receiving, Installing, Operating and Maintaining Sealed Gas filled Transformers.
Instruction Leaflet 47-061-2A Welded Bushing Type RFW
Instruction Leaflet 48-062-28 Bourdon Tube Hot Spot Instrument for Gas filled Transformers.

Distribution Transformers

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Distribution Transformers

7.1 Distribution Transformers - General

Oil-immersed distribution transformers have a primary voltage rating of 2400 volts or above and a secondary rating of 600 volts or below, with a kVA between 10 and 500. Applicable industry standards for distribution transformers are given in the ANSI C-57 series.

These transformers are generally used for stepping utility voltages (ranging from 2400 volts to 34,500 volts) down to lower utilization voltages. They are sometimes used for stepping down to commercial and industrial voltages of 277, 240/480, and even 2400 and 4800 volts. Most applications are for stepping down to 120/240 volts. They are also occasionally used for small substations and miscellaneous applications including stepping up voltages.

7.2 OSHA Compliance①

Perform periodic inspection during installation and during service to insure OSHA compliance for overcurrent devices and transformers. These inspections should include documented proof of intent to comply and assure the reliability of the equipment.

A. Important checkpoints for Overcurrent Devices

All electrical systems require overcurrent protection by fuses or circuit breakers and, on new construction, ground fault devices. Since these devices have a primary effect on worker safety they should be given special attention.

1. *The interrupting capacity* of all devices should be checked to assure it is adequate for the highest current to which it might be subjected.

2. *Consider ambient temperature* when installation is in an area subject to high temperatures such as near an oven, in a foundry, or in the hot sun. Assure that there is adequate ventilation, high temperatures distort calibration. If normal ventilation facilities are inadequate, consult the equipment manufacturer for guidance.

① This information on OSHA requirements for Transformers and Overcurrent Devices is extracted from data originally compiled by the editors of *Maintenance Engineering*.

3. *Make certain the overcurrent devices are free* to open in the event of an overload. One way this can be done is with a trip-free or multiple breaker with an operating handle for each pole. There must be provision for hand operation as well as automatic operation. There must be a clear visible indication of whether the device is open or closed.

B. Location of Overcurrent Devices

1. *Overcurrent devices must be mounted* so they are easily accessible. This is a maintenance safety precaution as well as good emergency procedure. The device must be mounted so it is easily reached without use of a ladder. Mounting should be high enough to keep workers away from suddenly moving parts such as a circuit breaker lever.

2. *Live parts of the device* must be kept away from combustible materials.

3. *The device must be mounted* so that it is not exposed to physical damage such as dripping water, damaging gases in the air, or too near an aisle.

4. *Overcurrent devices should be located* where the conductor to be protected receives its supply, except as follows:

a. When service overcurrent devices must be an integral part of the service disconnecting means, immediately adjacent, or at the outer edge of the entrance.

b. When an overcurrent device protecting the larger conductors also protects smaller conductors in accordance with OSHA tables 310-12 to 310-15.

c. Taps to individual outlets and circuit conductors supplying an electric range are considered protected if in accord with OSHA sections 210-19 and 210-20.

d. Conductors tapped from a feeder are considered properly protected, when installed in accord with OSHA sections 364-8 and 430-59.

e. Conductors tapped to a feeder, where:
length of conductor is less than 10 feet,

ampacity of tap conductor is less than the combined total loads of the circuits supplied by the tap conductors, and not less than the ampere ratings of the switchboard or panelboard supplied by the tap conductors,

protrusion of tap conductor is not beyond the switchboard.

f. Feeder taps not over 25 feet long. Where the conductor has ampacity at least one-third that of the conductor from which it is applied and provided the set of fuses which limit the load on tap (refer to OSHA Tables 310-12 - 310-15). Beyond this point conductors may supply any number of circuit breakers or set of fuses.

g. The transformer feeder taps with primary plus secondary not over 25 feet long. All the following requirements must be met:

Conductors supplying the primary of a transformer have a capacity of at least one-third that of the conductors or overcurrent protection from which the primaries are tapped.

Ampacity of the conductors supplied by the secondary transformer, multiplied by the ratio of secondary-to-primary voltage, is at least one-third the ampacity of the conductors or overcurrent protection from which the primary conductors are tapped.

Length of the primary plus secondary conductor (excluding any portion of the primary conductor that is protected at its ampacity) is not over 25 feet.

Termination of secondary conductors in a single circuit breaker or set of fuses which limit the load allowed (see OSHA Tables 310-12 - 312-15).

C. Enclosures for Overcurrent Devices

Overcurrent devices should be enclosed in NEMA approved boxes or cabinets or in a specially NEMA approved assembly which affords equal protection. OSHA approves mounting overcurrent devices in switchboards or panelboards, or controllers if the room is free from ignitable materials and dampness. There should be at least ¼ inch air space between enclosures and wall surfaces.

1. *Damp or wet locations* require weatherproof enclosures.

2. *The box should be mounted vertically* if possible.

3. *Rosettes must not be used* to mount fuses.

4. *When overcurrent devices are enclosed* their capacity rating must be restricted to 80 percent of the rating for continuous load, except for devices installed on services operating at 600 volts.

5. *When a vault of* metal-enclosed switchgear is not used, OSHA requires the following:

Use of air load interrupter switches (or other OSHA approved switches capable of interrupting the load) with manufacturer specified fuses on a pole or elevated structure outside the building. The device must be operable from inside the building.

Use of an automatic trip circuit breaker (on circuits of any voltage) with an overcurrent device on each ungrounded conductor. The circuit breaker may be located on a pole, roof, foundation, or other structure outside the building. It must be located as near as possible to the point where the service conductors enter the building.

In some circumstances as in the instance of bus bars at the rear of a panel or switchboard, the only way to provide adequate protection for the overcurrent device is to install a permanent guard or fence.

Use of locking enclosures discourages tampering by unauthorized personnel. It also discourages temporary overload hook-ups since the electrician knows the box will be locked.

6. *Normal maintenance procedures* should never expose personnel to shock hazard. Not only must the maintenance technician be trained in the use of safety equipment, such as blankets, gloves, hot sticks, etc., but the area must be safe. For example guards must be placed around fuse blocks, space heaters must be used to control humidity and condensation, and two-hole lugs must be used on cables 350 MCM and larger.

7. *Preventive maintenance* is required to prevent malfunctions due to such causes as, but not limited to, lack of proper coordination, of devices and loads, improper calibration, and inadequate testing. Frequent testing is required to assure relay and instrument calibration and circuit breaker timing.

D. Fuses and Fuseholder Maintenance
In replacing a blown fuse the first check should be for evidence of tampering or overfusing. The rating of the device will usually be clearly stated on the case or an attached label, but sometimes a trim or shield must be removed to find the rating. The replacement fuse should be of the specified type and rating. Care must be taken not to leave any live part of the fuse or the holder exposed.

In replacing fuses:
An Edison-base type of plug fuse or a type S fuse must never be used in circuits rated over 125 volts, 30 amperes.

1. *If it is easy to interchange fuse types,* investigation into possible tampering should be made and corrective action taken.

2. *Cartridge fuses have no 250 volt ratings* over 600 amperes, but 600 volt fuses may be used for lower ratings.

3. *All fuses must be clearly marked* with the manufacturer's name or trademark, interrupting rating, (if other than 10,000 amperes), ampere rating, voltage rating, and if current limiting or non-current limiting. Interrupting ratings may be omitted on fuses used for supplementary circuit protection.

4. *Disconnecting means must be provided* on the supply side of all fuses or thermal cutouts in circuits of more than 150 volts to ground and for cartridge fuses of any voltage where they are exposed to unauthorized persons.

5. *Except as described in Section 230-73,* each fused circuit must have provision to be disconnected from the power supply.

6. *A disconnecting means must be provided* whenever a cartridge fuse is used in a panel. This is a common violation in older installations.

Warning: Re-energize a circuit with all due precaution after replacing a blown fuse. A blown fuse may represent a permanent fault condition. Failure to heed this warning can cause severe injury or death by electric shock.

E. Supplementary overcurrent protection used in connection with appliances and other utilization equipment to provide protection to specific components or internal circuits need not be as accessible as the overcurrent devices protecting the branch circuits. However, branch circuit overcurrent devices must be accessible.

F. OSHA Check List – Overcurrent Devices
This check list is not a substitute for the complete OSHA regulation. It is a check of the more frequently encountered problem areas based on OSHA regulations at the time of writing.

1. *Are there fuses or circuit breakers* located where personnel can accidentally contact a live or suddenly moving part?

2. *Is the working space around the front* of the apparatus at least 30 inches? Working space is the distance between exposed live parts or enclosure opening and the nearest grounded surface.

3. *Is any overcurrent device in the vicinity* of any easily-ignitable material?

4. *Are there more than 42* overcurrent devices, other than those provided in the mains, in any one cabinet for a lighting and appliance branch circuit panelboard? A two-pole circuit breaker counts as two devices and a three-pole breaker as three devices, etc.

5. *Does the load on any overcurrent device* located in an enclosure exceed 80% of its rating where the operational load continues for three hours or more?

6. *Are all overcurrent devices provided* with appropriate enclosures for the hazards to which they may be subjected?

7. *Is it clearly indicated* on each overcurrent device whether it is open or closed?

8. *Are any ratings of fuses or circuit breakers* not clearly shown? It is possible that a trim or shield has to be removed to read the rating.

9. *Is the interrupting capacity* of the circuit breakers shown on the breaker or on an attached label? This applies to breakers rated 240 volts or less and 100 amperes or less with an interrupting capacity of 5000 amperes.

10. *Is the ampere rating of all circuit breakers* rated 100 amperes or less and 600 volts or less molded, stamped, or etched on the handle or shield of the device?

11. *Does each circuit breaker rated more* than 240 volts or more than 100 amperes, with an interrupting capacity other than 10,000 amperes, show its rating on the breaker or on an attached label? Interrupting ratings may be omitted on circuit breakers used only for supplementary overcurrent protection.

G. OSHA Check List – Transformers

This check list is not intended to assure complete compliance with all OSHA rules. It is a list of the more frequently encountered problem areas based on OSHA regulations at the time of writing.

1. *Are there transformers located* where they are exposed to physical damage?

2. *Are there transformer installations* which do not conform to the guarding provisions for live parts in Section 1910-310(j)?

3. *Are there transformer installations* which do not offer protection against accidental insertion of foreign objects?

4. *Are there transformers* which do not have their exposed live parts indicated by markings on the equipment or structures?

5. *Is there any transformer* that develops operating surface temperatures high enough to cause extensive dehydration of any organic dust deposits that may occur? Maximum surface temperatures under operating conditions must not exceed 120C for equipment subject to overloading.

6. *Are any transformers installed* where dusts from magnesium, aluminum, aluminum-bronze, or other volitile metals are present?

7. *Are there transformer installations* which have exposed non-current-carrying parts, including fences and guards, which are not grounded where required in the manner prescribed for metal parts in Section 1910-314?

8. *Do all transformers have a manufacturer's*
a. nameplate that shows the manufacturer's name?
b. rated kVA?
c. frequency?
d. primary and secondary voltages?
e. type of insulating liquid (mineral oil, etc.)

7.3 Application Restrictions for Distribution Transformers

Do not use distribution transformers for applications such as;

a. When the kVA required by the load exceeds 500 kVA per phase on a continuous basis.

b. When fire rules or other regulations prohibit use of oil in the location.

c. When the application requires more than a two-winding transformer.

d. When the application requires that the transformer be externally reconnected to be used as an autotransformer.

e. When the application is to supply loads that have a continuous transient voltage imposed on the transformer windings, such as an arc furnace.

f. When the application would require that the distribution transformer be used as a rectifier transformer without special modification.

g. When the application requires that they be exposed to repetitive short circuits. For such short-circuit duty a special design may be necessary.

h. When there are restrictions on the use of oil-filled distribution transformers, or any oil-filled transformer, such as:

- **(1)** An oil-filled transformer must not be used in any application where the National Electrical Code prohibits use of oil-filled apparatus.
- **(2)** The ambient temperature exceeds 65C (149F).
- **(3)** The transformer tank is placed in a confined, tightly sealed enclosure. Submersible distribution transformers should be used. They are enclosed in stainless steel tanks and covers and meet the applicable ANSI temperature rise standards.

i. When the application is marine duty, these transformers should not be installed on ships, boats, or any water craft.

j. When the application is for use as a substitute for an electric arc welder.

7.4 Service Requirements for Distribution Transformers

The service requirements for distribution transformers are exacting and difficult.

a. The load varies widely.

b. Large numbers of transformers are remotely located and pole mounted.

c. The cost of supplying transformer losses is at its highest point at the distribution transformer. Even the cost of supplying reactive volt-amperes may be appreciable. A low exciting (no-load) current is desirable.

d. Voltage regulation is important, and most commonly accomplished by separate voltage regulation equipment.

e. It is often impractical to design distribution circuits to avoid excessive voltages.

f. Because of their relatively small size, widespread use, and pole mounting, many distribution transformers are subjected to mechanical damage.

g. Distribution transformers must have a low cost of installation and replacement since a distribution system requires so many of them.

7.5 Pole Type Distribution Transformers

The pole-mounted, oil-filled distribution transformer is the most commonly encountered. This transformer steps voltage down from the distribution line for use in residential, commercial, and light industrial applications. See Figure 1.

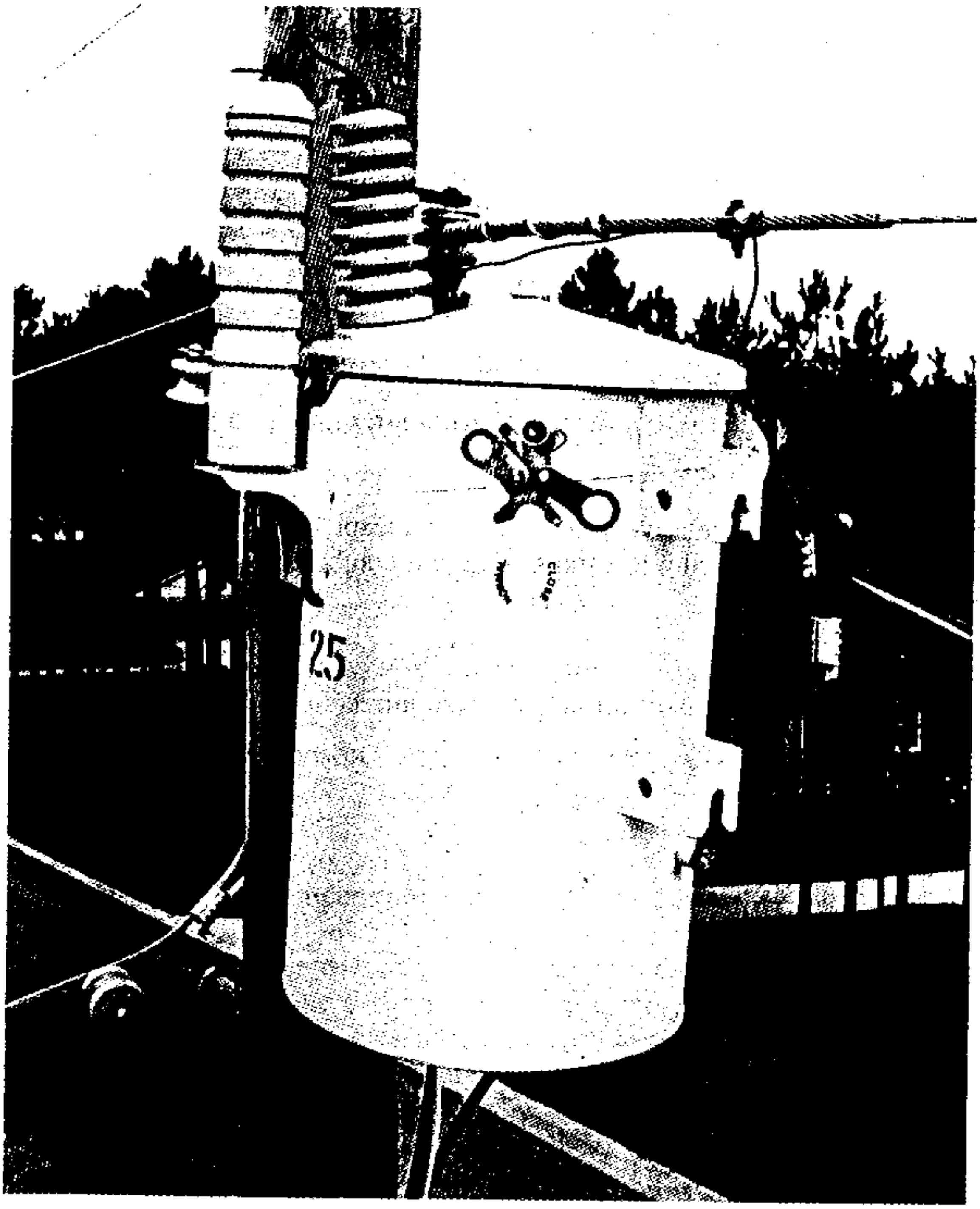


Fig. 1 – Typical Oil-Filled, Pole-Mounted Distribution Transformer

7.6 Underground and Pad-Mounted Distribution Transformers

These transformers may be buried in vaults underground, they are totally submersible. They may be mounted on a pad at ground level. In either case they make it possible to put the outgoing power lines underground, and the incoming distribution lines may also be buried.

These transformers allow the elimination of the overhead wiring for distribution systems. The application of these transformers is growing, especially in new construction and major renewals in urban areas. See Figures 2, 3, and 4.

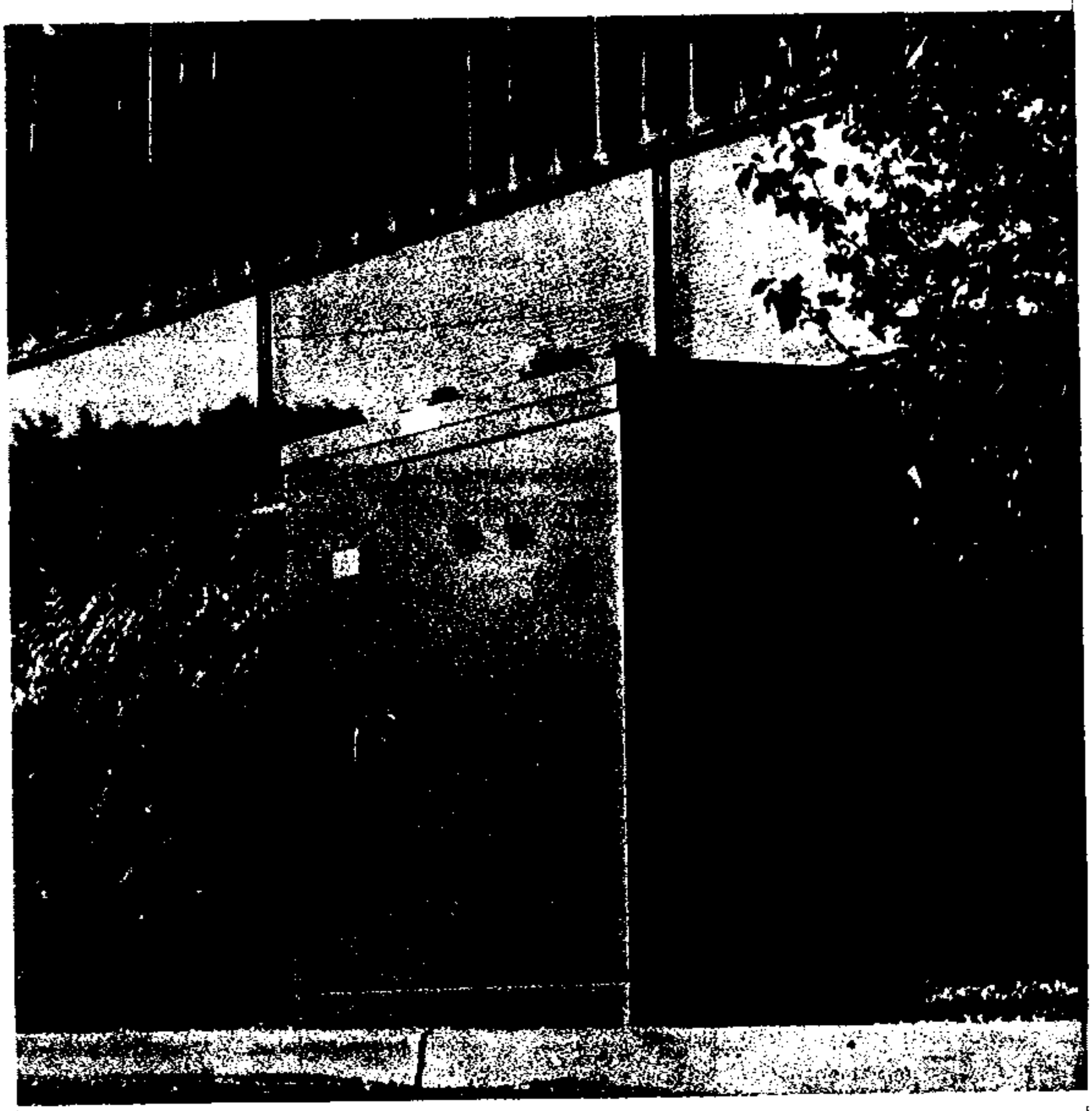


Fig. 2 – Typical Pad-Mounted, Oil-Filled Distribution Transformer

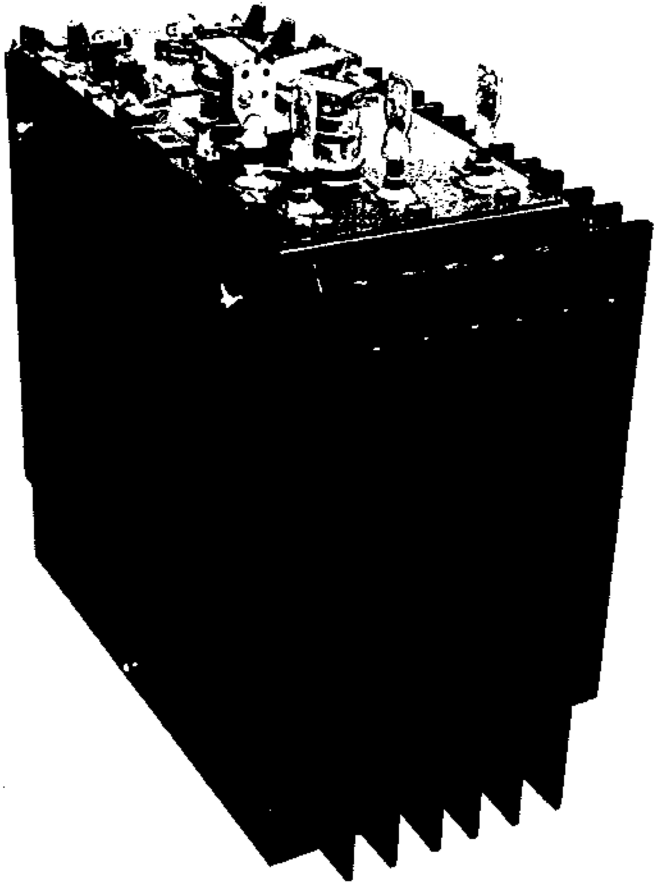


Fig. 3 – Typical Underground, Oil-Filled Distribution Transformer

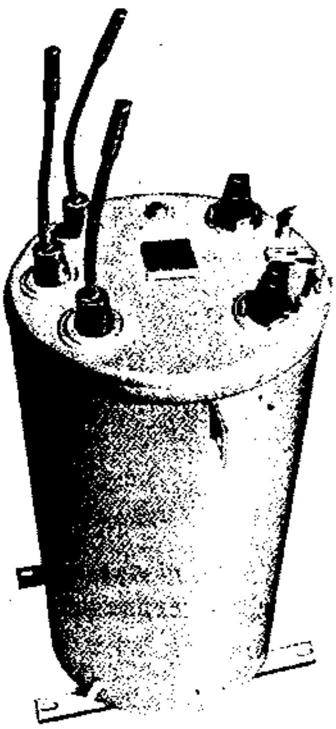


Fig. 4 – A Submersible Oil-Filled Distribution Transformer

7.7 Basic Function and Construction

The transformer is a device by which the energy of an alternating-current circuit is received at one voltage or current and delivered at another voltage or current. It transforms voltage or current and can perform this transformation from high to low or from low to high, and do it economically.

It is not practical to transmit alternating current long distances at low voltages because the corresponding heavy current would require wire too heavy to use. To transmit energy the voltage is stepped up at the generator, thereby reducing the current so smaller wire can be used. The voltage is then stepped down in stages until it reaches the low levels required by the ultimate user. The transformer is required for all these stepping processes. The present widespread use of electrical power would be impossible without the transformer.

A. The Fundamentals of a Transformer

Consist of three parts:

Primary winding. The coil of electrical wire which receives energy from the supply source or circuit.

Secondary Winding. The coil of electrical wire which receives energy from the primary winding and delivers it to the secondary circuit.

Core. An iron or steel structure between, but not electrically connected to the two windings. See Figure 5.

B. Transformer Voltage

The core and coils operate as a unit. When a voltage is applied to the primary winding, the input, the resulting current magnetizes the core. The magnetic field of the core induces a voltage in the secondary coil, the output.

Figures 5 and 6 show a typical example: If both coils have the same number of turns around the core (Figure 5), the voltage induced in the secondary will be equal to the voltage applied to the first coil. If the input is 120 volts the output is 120 volts.

If the output (secondary) coil has fewer turns than the input (primary) coil, as shown in Figure 6, the voltage induced in the output coil will be reduced in the same ratio as the number of turns of wire in the two coils. If the input is 2400 volts with 200 turns and the output coil has 10 turns, the output voltage will be 120 volts.

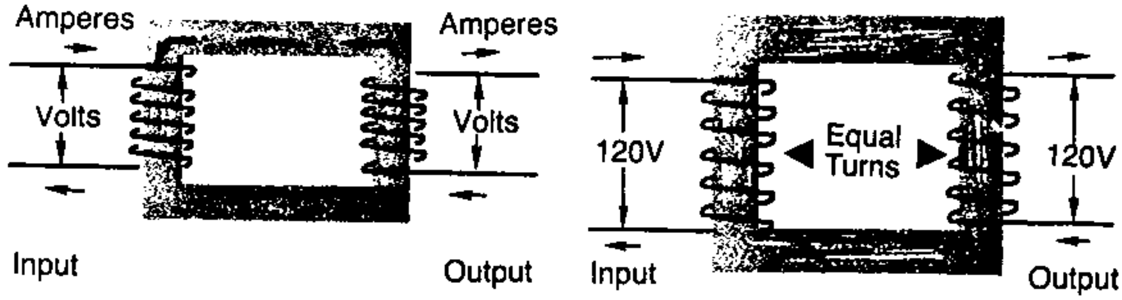


Fig. 5 – Transformer Construction
Equal Turns Means Input Equals Output

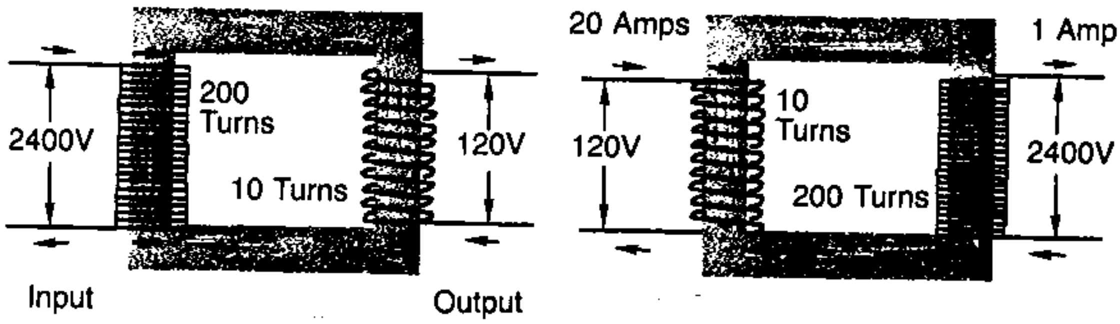


Fig. 6 – Transformer Construction
Ratio of Turns Equals Ratio of Voltages

The reverse is also true. An increase in the number of turns on the output will cause a proportionate increase in the voltage. If the input voltage is 120 volts with 10 turns on the primary coil and the secondary coil has 200 turns, the output voltage will be 2400 volts. This direct relationship of input-output voltages to turns on the primary and secondary coils is expressed as:

$$\frac{N_P \text{ (turns on primary)}}{N_S \text{ (turns on secondary)}} = \frac{E_P \text{ (voltage on primary)}}{E_S \text{ (voltage on secondary)}}$$

Thus, if:
$N_P = 10$, $N_S = 5$, $E_S = 60$ to find the value of E_P

$$\frac{N_P}{N_S} = \frac{E_P}{E_S} \text{ or } E_P = \frac{N_P \times E_S}{N_S}$$

so:

$$E_P = \frac{10 \times 60}{5} = \frac{600}{5} = 120 \text{ volts}$$

The voltage ratio is 2 to 1. The turns ratio is 2 to 1.

If a transformer is connected to a 2400 volt a-c supply, and both input and output coils have 200 turns, the output will be 2400 volts, the same as the input.

If the output coil of the above example has 10 turns instead of 200, the output voltage will be 120 volts, one twentieth of the input. If the number of turns on the output coil were increased to 400, the output voltage would be 4800 volts, twice the input voltage. The voltage is transformed in direct ratio to the number of turns on the two coils. This is the *Turns Ratio.*

C. Transformer Currents

In transforming electrical energy current must also be considered. Current is transformed in inverse ratio to the number of turns. When the voltage goes up with an increase in turns, the current goes down. This is called *Ampere Turns.*

The current times the turns on the input equals the current times the turns on the output. The volts times the amperes on input equals the volts times the amperes on output. The current is inversely proportional to the voltage as well as to the turns.

Therefore:

$$\frac{N_P \text{ (turns on primary)}}{N_S \text{ (turns on secondary)}} = \frac{I_S \text{ (amperes in secondary)}}{I_P \text{ (amperes in primary)}}$$

or:

$$\frac{E_P \text{ (volts primary)}}{E_S \text{ (volts secondary)}} = \frac{I_S \text{ (amperes secondary)}}{I_P \text{ (amperes primary)}}$$

so:

$E_P = 120$ volts, $E_S = 2400$ volts
$I_P = 20$ amps, $I_S = ?$

$$I_S = \frac{E_P \times I_P}{E_S} = \frac{120 \times 20}{2400} = \frac{2400}{2400} = 1 \text{ amp}$$

D. Transformer Rating

Transformers are rated in kVA, thousands of volt-amps. The output voltage is multiplied by the output current to obtain volt-amps. The k designates thousands.

From the above Example:

$$\text{kVA} = \frac{2400 \times 1}{1000} = \frac{2400}{1000} = 2.4$$

E. Losses

When the input voltage is multiplied by the input current the product is almost the same as the output voltage multiplied by the output current. Theoretically these two products should be exactly equal if the transformer operated at 100 percent efficiency.

In reality there are small energy losses in the iron core and in the conducting wire turns of the coils. These are shown by the differences in the product of input and output volt-amperes. See Figure 7.

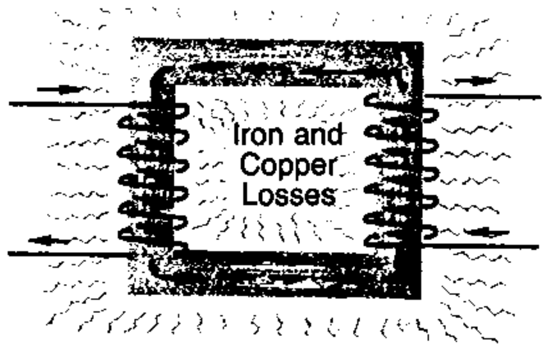


Fig. 7 – Iron and Copper Losses in a Transformer

There are three types of losses which must be considered.

1. *Iron Losses.* The energy used to magnetize the core.

2. *Eddy current stray losses.* They are caused by the magnetic fields.

Both 1 and 2 are evidenced as heat in the core.

3. *Load losses.* These are caused by resistance when a load current is drawn by a load consuming device and along with resistance in the coils are evidenced as heat.

F. No-Load Losses

The no-load loss is the loss measured by a wattmeter when rated voltage at rated frequency is applied to either winding, the other winding being open circuited. It includes core loss, due to magnetizing the core; loss in the windings due to exciting current, I^2R loss; and dielectric loss in the insulation. This no-load loss is independent of load and practically independent of temperature.

G. Exciting Current and Flux

The current that flows under no-load conditions is the exciting current. It is made up of two components. One component supplies the losses in the core caused by hysteresis and eddy currents, and the other produces the magnetizing force in the core. The alternating-current voltage in the primary winding of a transformer produces a magnetic induction or magnetic *flux* in the core. This oscillating flux is what causes the voltage to be produced in the secondary winding.

H. Load Losses

The load losses are the losses measured by a wattmeter when sufficient voltages is applied to one winding to produce full-load current in the other winding, which is short-circuited. The load loss consists of the I^2R loss in the winding due to full-load passing through and a stray loss produced by stray flux inducing currents in the winding.

I. Efficiency

Transformer efficiency is expressed as a relation of output to input, as a ratio or as a percentage:

$$\left(\text{Percent efficiency} = \frac{\text{output x 100}}{\text{input}} = \frac{\text{output x 100}}{\text{output + losses}}\right)$$

7.8 Selection and Application

A. Selecting Transformer kVA Rating

If load requirements in kVA are not known, they can be calculated by multiplying the maximum load current by the load voltage which gives volt-amp capacity. The transformer must have at least this minimum nameplate capacity in volt-amps (or kVA if volt-amps have been divided by 1000). Usually some future load increase should be provided for.

For example, if the maximum load current is 500 amps and load voltage is 120 volts, single-phase, the requirement is 60,000 volt-amps or 60 kVA. The next larger standard single-phase transformer rating is 75 kVA. Selection of a unit of this size provides room for load growth.

If load requirements are given in watts, the power factor of the load must be considered. Watts divided by power factor will give volt-amp capacity:

$$\text{V-A capacity} = \frac{\text{watts}}{\text{power factor}}$$

When motors are installed in the circuit, allowance of 1 kVA for each horsepower of total connected motor load should be made. This rule applies to motors of 1hp and above provided the largest motor horsepower does not exceed half the transformer kVA. For single motors with horsepower rating greater than half the transformer kVA. The starting duty must be considered.

B. Selecting Voltage Rating

After kVA rating requirements have been determined, proper line and load voltages must be selected. In single phase circuits the transformer primary rating must include the line voltage. If the line voltage is single phase, 60 hertz, 480 volts, a transformer rated 480 volts primary, 240 x 440 volts primary, or 480 volts primary with taps, can be used. The same applies to the load voltage. If the load is rated 115 volts, a transformer with a 120/240 volt secondary can be used.

A transformer voltage is in proportion to its winding turns. A transformer having a 480 volt primary and a 120 volt secondary is a 4-to-1 transformer. It will deliver 120 volts when connected to a 480 volt supply, it will also deliver 115 volts if connected to a 460 volt supply, and 110 volts when connected to a 440 volt supply.

Transformer taps compensate for line voltage problems.

Warning: Do not attempt to make changes in transformer function or performance other than those provided for in the wiring compartment and for which complete instructions are available. To do so can create a danger of severe injury or death from electric shock, and damage to property.

Frequently the transformer is selected by the user with anticipation of a future change in source voltage. The user may anticipate a change from 120 volts source to 240 volts source. It also may anticipate a need to accommodate both a 120 volt source and a 240 volt source.

At the time of manufacture, the secondary winding of the transformer can be divided into two equal lengths and four leads can be brought out instead of two. Each winding is rated 120 volts. The result is a series-multiple winding. Each of the new coils will be half the original.

By connecting the two windings in series, the winding will be for 240 volts, see Figure 8. By connecting the two windings in parallel or multiple, the windings will deliver 120 volts, see Figure 9. The number of applications the transformer can handle has been doubled.

The same can be done with the primary windings, thus doubling again the applications of the transformer which would then have a rating of 240 x 480 volts primary and 120/240 volts secondary.

When the secondary is connected for 240 volts, as shown in Figure 8, the mid-point is available for 240/120 volt, three wire operation. 120 volts can be obtained from connecting ½ of the winding X4 and X3 or X2 and X1 in Figure 9, and the kVA is reduced by half. By supplying loads in this way,the transformer load can be balanced on the halves of the winding.

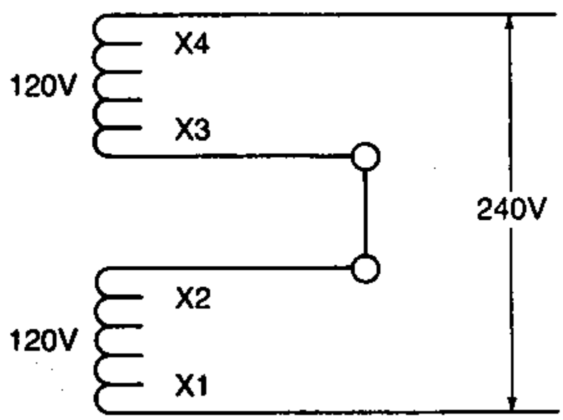


Fig. 8 – Secondary Windings Connected for 240-Volt Output

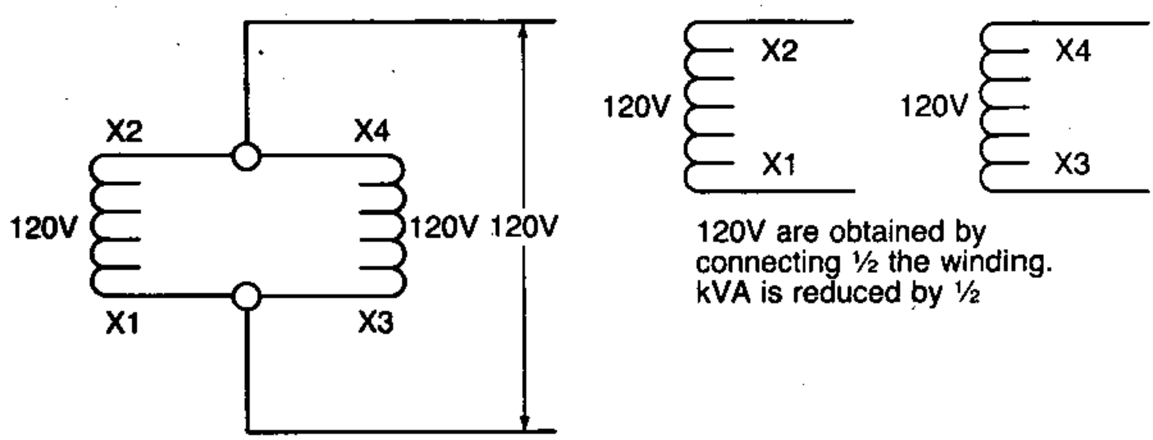


Fig. 9 – Secondary Windings Connected for 120-Volt Output

C. Transformer Taps

A transformer tap is an auxiliary lead connected to a transformer coil at some point above or below the point at which the normal lead is connected. A number of taps may be provided on one winding, above and below normal.

The provision of taps could allow for adjustment of the transformer to meet changes in the voltage of the power supply.

A transformer with a primary rated at 480 volts could have taps provided at 12 volt increments (2½% of 480). This is illustrated in Figure 10. The maximum spread is 10%.

No one transformer would have all eight taps shown in Figure 10. The maximum spread for transformer A, Figure 10, is 480-528 volts, and for Transformer B, 456-504 volts, for transformer C it is 432-480 volts.

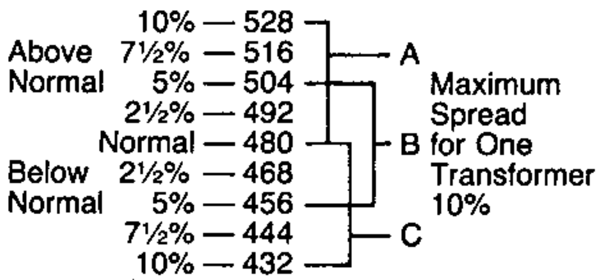


Fig. 10 – 2½% Tap, Above and Below Normal

The high voltage (primary) and low voltage (secondary) windings are terminated in the transformer wiring compartment. High voltage terminations are identified in accordance with NEMA standards as H1, H2, H3, etc., and low voltage leads as X1, X2, X3, X0, etc. The connection diagram on the transformer nameplate shows the proper connections for series or multiple connections and tap settings.

D. Phase

In a single-phase circuit, the power delivered is pulsating. When the current and voltage are in phase, the power is zero twice in each cycle. When the power factor is less than unity, not only is the power zero four times in each cycle, it is negative twice in each cycle (the circuit returns power to the source part of the time). This pulsating nature of power in single-phase circuits is objectionable for many applications.

Practically steady power can be obtained by use of a three-phase circuit. The total power is constant, especially in loads which are balanced.

Carefully follow the manufacturer's connection instructions.

If the load is three-phase, both the supply and the transformer must be three-phase. If the load is single-phase, the supply can be either single- or three-phase, but the transformer must be single phase.

The single-phase-three-phase power delivery is covered more fully under *Transformer Connections* below.

E. Frequency
A transformer cannot change the frequency of the supply. If the load is 60 hertz, the supply must be 60 hertz, and the transformer must be rated 60 hertz. Transformers rated at 60 hertz should not be used on lower frequencies without adjusting the kVA and voltage. A 60 hertz transformer applied to a 50 hertz system requires a 17% reduction in both voltage and kVA. There are transformers rated 50/60 hertz that operate on either frequency.

Transformers rated for 50 hertz can be used for either 50 or 60 hertz at the rated kVA.

If higher than rated frequencies are used on transformers the efficiency, performance, and regulation will drop, the impedance will increase, varying directly as the frequency. Transformers should be applied to handle only the frequency for which they are rated.

F. Insulation
There are four insulation systems commonly used in distribution transformers. Each class of insulation is made of materials that will withstand certain temperatures without shortening the transformer life.

G. Temperature Rise
The rated kVA of a transformer is the output which can be obtained continuously at rated voltage and frequency without exceeding the specified temperature rise. Temperature rise is used for rating purposes rather than a measurement of actual temperature because the ambient varies so greatly under operating conditions.

Temperature rise is the average temperature rise of the conductor inside the coil winding. The temperature rise is established by the design and is compatible with the limits of the insulation system.

The temperature rise depends upon the losses which in turn depend upon the load. The core loss remains constant with the load and the load loss varies as the square of the load.

H. Performance

Performance data and certified test reports are available from the transformer manufacturer. These test values, such as load losses, impedance, regulation, and efficiency are based on NEMA reference temperatures. The reference temperature will always appear on the nameplate of the transformer.

7.9 Transformer Connections

Warning: Transformer connections must be made only by qualified, experienced personnel. Improper transformer connections can cause severe injury or death by electric shock, and major damage to property.

Warning: Make transformer connections in accordance with the manufacturer's instructions only. Connections not specified by the manufacturer can cause severe injury or death by electric shock and major damage to equipment.

Transformer connections are critical and must be carefully made in accordance with the connection instructions shown on the transformer nameplate. Any incorrect connection will change the input or output and the capacity of the transformer which can result in severe personal injury or death, or damage to the transformer and the system and other connected apparatus.

Connection diagrams show terminations identified by NEMA standard symbols on single- and three-phase transformers. High voltage leads are designated H1, H2, H3, etc., and low voltage leads as X1, X2, X3, etc.

A. Basic Single-Phase Connections

A single-phase transformer has a primary winding and a secondary winding. Each winding is designed for the voltage and the kVA specified for the application. Figure 11 is a diagram of the basic single-phase transformer connections showing the terminals identified by NEMA standards. Most single-phase transformers are designed with a primary voltage, with taps, and dual secondary.

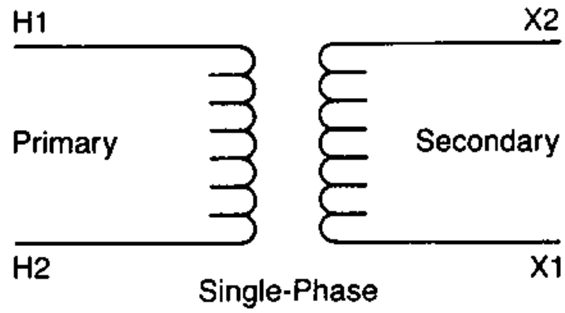


Fig. 11 – Single-Phase Transformer Connection Schematic

If the secondary windings are connected as shown in Figure 12, it is a series connected winding. If the windings are connected as shown in Figure 13, it is a parallel connected winding.

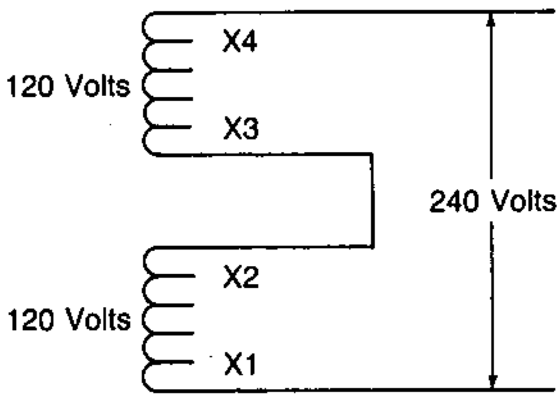


Fig. 12 – Series Connected Secondary Windings of a Single-Phase Transformer with Dual Secondary

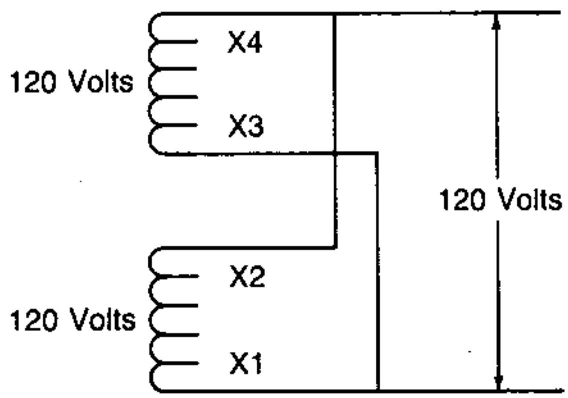


Fig. 13 – Parallel Connected Secondary Windings of a Single-Phase Transformer Having a Dual Secondary

The single phase transformer is a straight forward device with a fixed kVA capacity, an input and an output voltage.

The kVA of a single phase transformer can be determined if the load and voltage are known. The equation is:

$$kVA = \frac{E\ I}{(1000)}\ pf \text{ (where pf is mostly unity)}$$

E is voltage, I is load, pf is power factor

B. Basic Three-Phase Connections

Three-phase transformers are essentially three single-phase units connected together or a three-phase unit in which three single phase coils are mounted on a single core. The most common three-phase connections are delta (for the Greek letter Δ) or wye (for the letter Y) so named because of their shape.

1. *Delta System*

The simplest three-phase alternating-current distribution system is the three wire delta system. In the delta system, see Figure 14, each side of the triangle represents the voltage carried in the lines. In the example shown in Figure 14, the voltage across each leg of the triangle is 2400 volts. To make this a system, a line representing a wire is extended from each point of the triangle, see Figure 15.

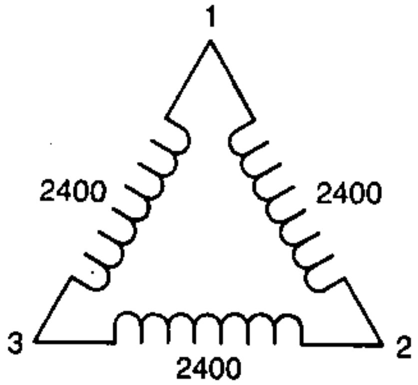


Fig. 14 – Three-Wire Delta Schematic

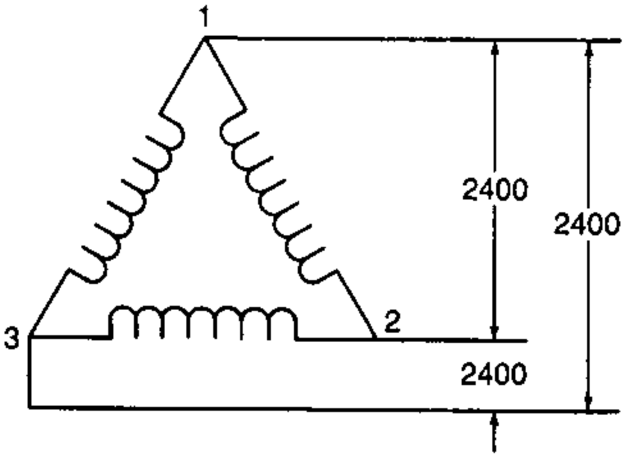


Fig. 15 – Three-Wire Delta System

In the system shown in Figure 15, the voltage between any two wires is the equivalent of one side of the triangle. Between any two wires the voltage is the same as that fed into the system. In Figure 15, there is a voltage of 2400 volts, single-phase, between wires 1 and 2; 2400 volts between wires 1 and 3; and 2400 volts between wires 2 and 3. There are three separate single-phase voltages, each measuring 2400 volts. In practice any two wires may be tapped anywhere along the line to get 2400 volts, single-phase. By tapping all three wires, 2400 volts three-phase three wire is obtained. The delta system is usually used for distribution relatively near the generator or substation. It is a good, simple short distance system but, only one voltage is available between any two wires.

Line and Phase Voltage and Current

There is a relationship between the line voltage and line current and the transformer winding. In a three-phase delta system, this is referred to as phase voltage and phase current. The line voltage is the same as the winding voltage of the transformer but the line current is equal to the phase current multiplied by the square root of 3 or 1.73; or the phase current equals the line current divided by the square root of three. The kVA capacity or power required can be calculated:

$$\text{kVA} = \frac{1.73 \times \text{E line} \times \text{I line}}{1000}$$

where
E is line voltage, I is line current (system Ø-Ø)
e is phase voltage, i is phase current

Either equation produces the same result.

2. *Wye System*
The wye system can provide two different voltages. This system is shown in Figure 16. (It is sometimes referred to as the star system.) The end points, 1, 2, and 3 in Figure 16, form the line leads and the common point at the center, the neutral. The neutral, being symmetrical to the lines, may be grounded without creating an unsymmetrical condition.

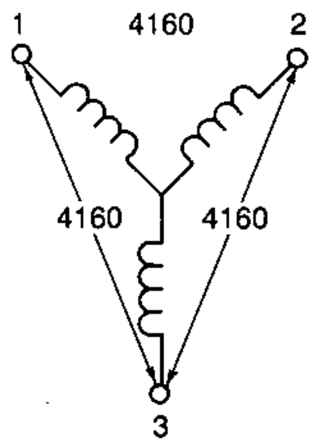


Fig. 16 – Three-Wire Wye Schematic

If the system is 4160 volts, then 4160 volts are available between any two of the three end points, as shown in Figure 17. As in the delta system the same voltage is available between any two wires, but in the wye system it is possible to have an additional wire, the neutral wire.

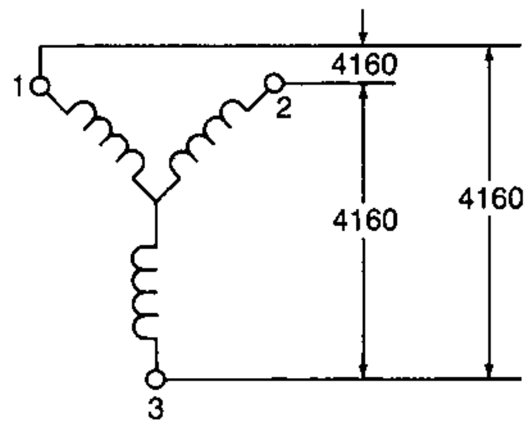


Fig. 17 – Three-Wire Wye System

When a neutral wire is added by extending a line from the midpoint of the wye, a second voltage is obtained. The voltage between any one of the three power lines and the neutral will be considerably less than the voltage between any two power lines. In Figure 18 an input voltage of 4160 volts can supply 4160 volts between power lines and 2400 volts between any power line and the neutral. In a wye system the voltage between any two power lines will always be 1.73 times the voltage between the neutral and any power line.

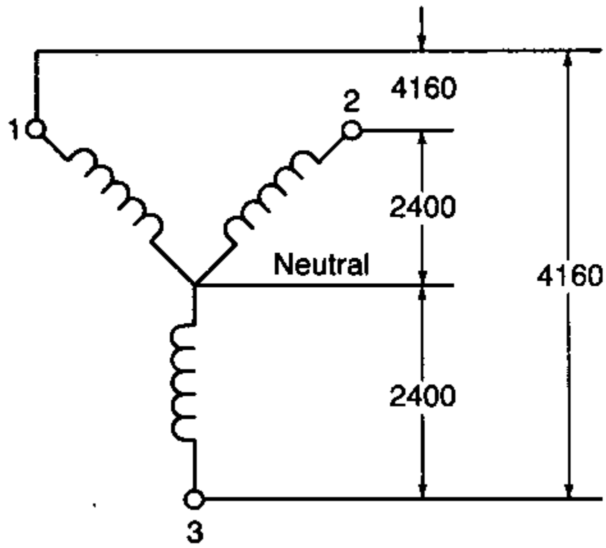


Fig. 18 – A Three-Wire Wye System Can Supply Two Different Voltages

Warning: Extreme care must be taken in connecting a transformer in a wye system. Connecting a 2400 volt transformer to two power lines instead of a power line and neutral would put 4160 volts into the transformer and burn it out, and may cause severe personal injury or death.

The wye system permits power to be transmitted at 4160 volts and still have 2400 volt service available at the distribution transformer. Another advantage is that 2400 volt transformers can be used, they are smaller and less expensive than 4160 volt transformers. The higher 4160 volt service is still available if needed.

a. Grounded and Ungrounded Wye Systems

The neutral wire of a solidly grounded wye system is always grounded at the distribution transformer, and frequently also at numerous points along the line. Frequent grounding helps to complete the circuit back to the source. The weakness of the system is that it is subject to frequent ground faults.

The ungrounded wye system is not usually grounded at the distribution transformer, and may be grounded as infrequently as only at the substation and once or twice along the line. This system is less susceptable to ground faults.

b. Line and Phase Voltage and Current
A definite relationship exists between the line voltage and line current and the winding or phase voltage and phase current in a three-phase wye circuit. The line voltage is equal to the phase voltage times the square root of 3; the line current in a wye connection is equal to the phase current. The kVA capacity or power required can be calculated.

$$\text{kVA} = \frac{1.73 \times \text{E line} \times \text{I line}}{1000}$$

where
E is line voltage, I is line current (system Ø-Ø)
e is phase voltage, i is phase current

Either equation produces the same result.

The transformer can be connected in either delta or wye if the line currents and line voltages are kept in proper relationship.

3. *Single-Phase and Three-Phase*
The voltage of an alternating current is usually symbolized by a wave line. The continuous changing of polarity or direction, is symbolized by a plus sign at the peaks and a minus sign at the valleys. See Figure 19. A single-phase alternating current is continuously changing from plus to minus to plus, etc. This is the type of voltage found between any two wires of an a-c distribution system. It deals with one voltage and can have only one phase. Only single-phase transformers can be used on such a circuit.

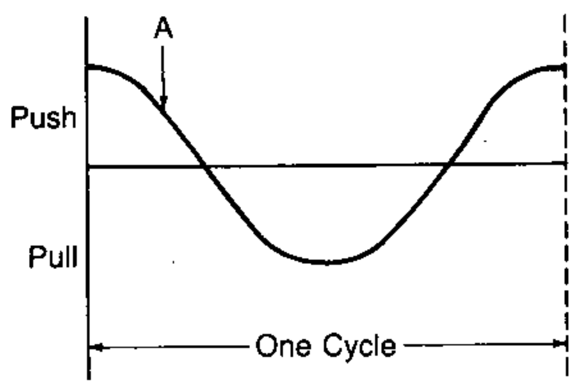


Fig. 19 – One Cycle of a Single-Phase Alternating-Current

The single-phase circuit can be compared to a single cylinder steam engine, see Figure 20. For each revolution of the flywheel the cylinder pushes on the crank shaft for one half of the revolution and pulls on it for the other half. There are two positions where the energy delivered to the shaft is zero, at either end of the stroke of the piston. When the engine is running at 3600 revolutions per minute this mechanical system is equivalent to a 60 hertz alternating-current system.

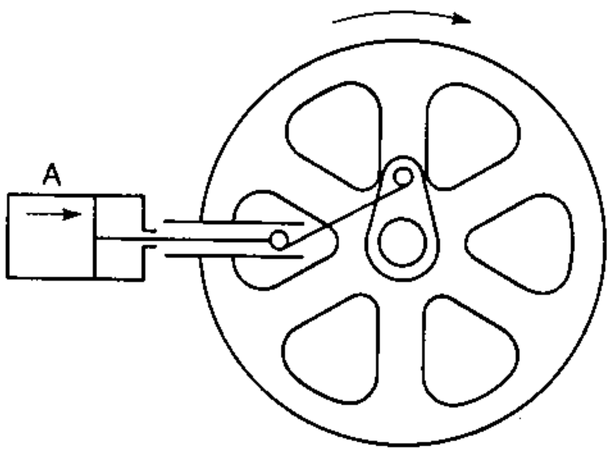


Fig. 20 – A Single-Phase Circuit is Comparable to a Single-Cylinder Steam Engine

A three-phase voltage is the connection of all three power wires of the system. The voltage between wires 1 and 2 is single-phase, between wires 1 and 3 is another single-phase voltage, and between wires 2 and 3 is a third single-phase voltage. These three sets of voltages do not change polarity at exactly the same time. The wave for these three single-phase voltages would be as shown in Figure 21. A three-phase circuit is created.

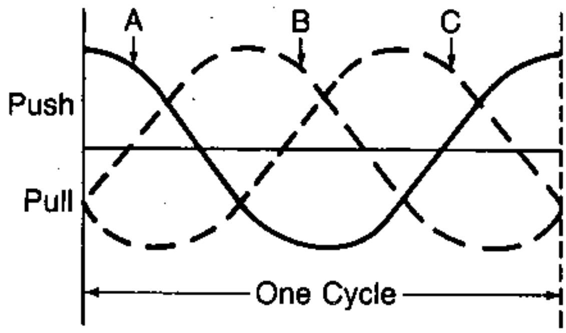


Fig. 21 – One Cycle of a Three-Phase Alternating-Current

To continue the analogy of the steam engine, see Figure 22, the engine has now become a three cylinder machine. In this machine the cylinders are one-third of a revolution apart so the force transmitted to the shaft never passes through zero. The starting position, see Figure 21, indicates that cylinder A is delivering maximum force pushing on the crank, cylinders B and C are each pulling on the crank at half the force of cylinder A. The total energy of the three cylinders is equivalent to two cylinders, but a constant force is exerted on the shaft.

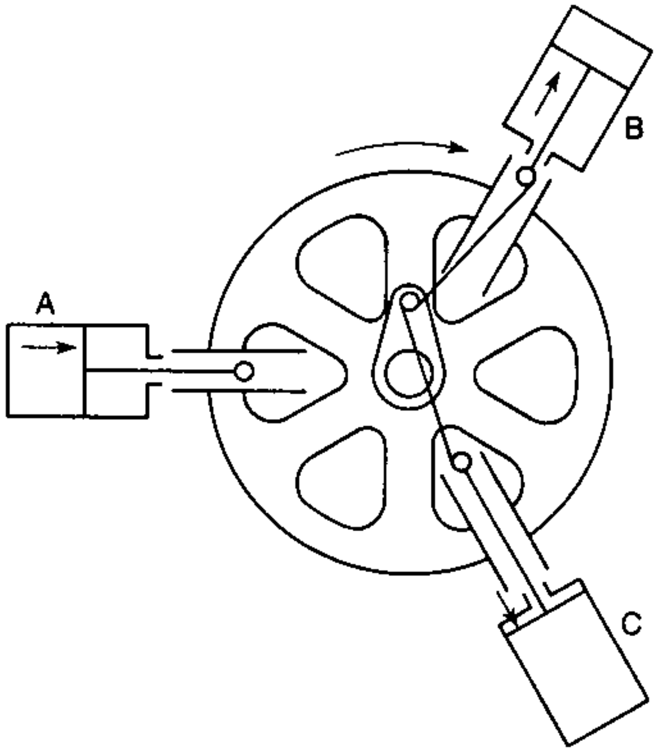


Fig. 22 – A Three-Phase Circuit is Comparable to a Three-Cylinder Steam Engine

The wave lines of the three voltages show that each changes polarity at a different time. They are not in phase so there are three different phases. Only three-phase apparatus can be supplied from a three-phase source.

4. *Polarity*

There is no fixed positive or negative pole in an alternating current. Transformers therefore cannot have fixed poles. They do have relative polarities. Transformer polarity may be either additive or subtractive. It will always be identified on the nameplate.

Transformers polarity refers to the relative direction of induced voltages between the high voltage terminals and the low voltage terminals. In a transformer with standard markings the voltage from terminal H1 to H2 is always in the same direction or in phase with the flow, from X1 to X2. In a transformer where H1 and X1 are adjacent, Figure 23, the unit has subtractive polarity. When H1 and X1 are diagonal, Figure 24, the transformer has additive polarity.

Polarity can be determined by connecting terminal H1 with the adjacent X terminal and applying voltage to the high voltage winding. If the voltage between the unconnected H and X terminals is greater than the voltage applied to the high voltage winding the transformer has additive polarity, if lower it has subtractive polarity.

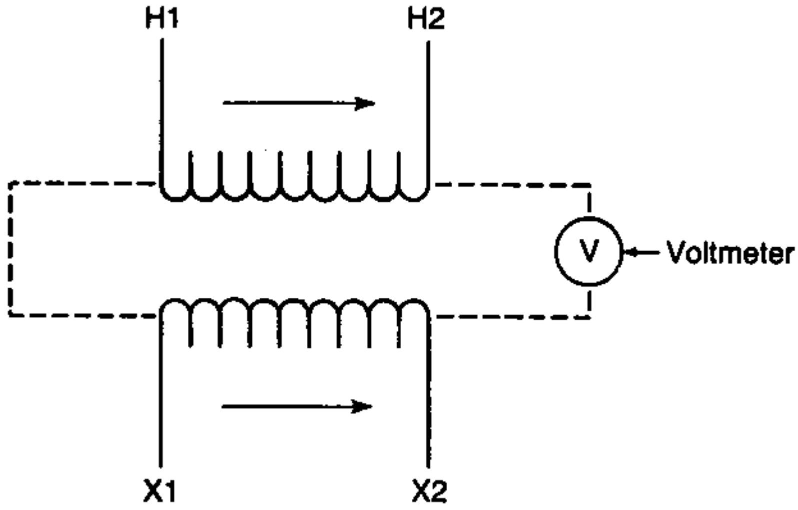


Fig. 23 – Subtractive Polarity

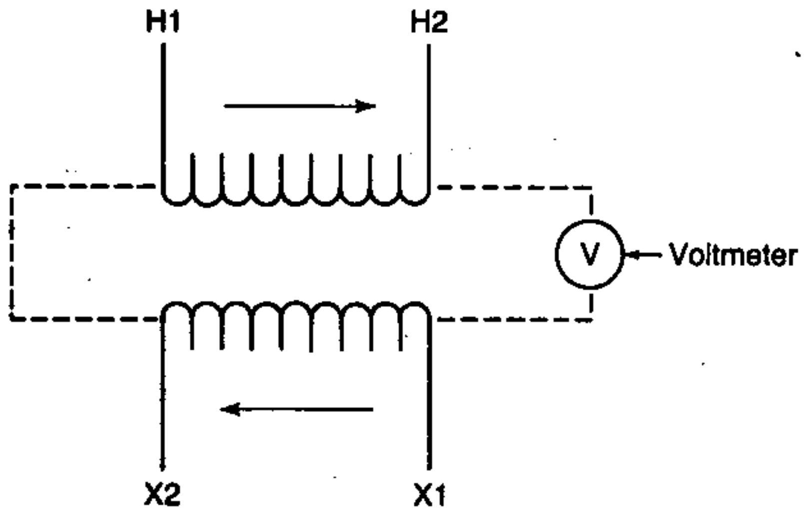


Fig. 24 – Additive Polarity

Two or more transformers connected together must have the same polarity. This is a connection that must be made with great care. If improperly connected the transformers would cancel each other out, create a circulating current that would result in a short circuit on both units.

Warning: Make sure transformers to be connected together have the same polarity. Transformers with different polarity connected together can cause severe injury or death from electric shock and destructive damage to property.

C. Standard and Special Connections

1. *Single-Phase Connections*

Most of the following diagrams show a two-wire per phase secondary, however many of these connections can be used to supply a single-phase three-wire system by using the midpoint of the secondary winding. In many of the connections shown in the following diagrams it is also possible to supply combined two- or three-phase and single-phase 2 or 3 wire loads. In such instances it may be desirable to use unequal kVA ratings for different transformers so all the transformers carry the same percentage of rated load.

a. *The single-phase three-wire secondary,* series connection shown in Figure 25 is the most commonly used connection for small distribution transformers where the three-wire secondary is supplied at 120/240 volts. A similar connection may be used for 240/480 volts. The primary may be supplied from a single-phase line, two wires of a three-phase line, or one line wire and a neutral of a three-phase line.

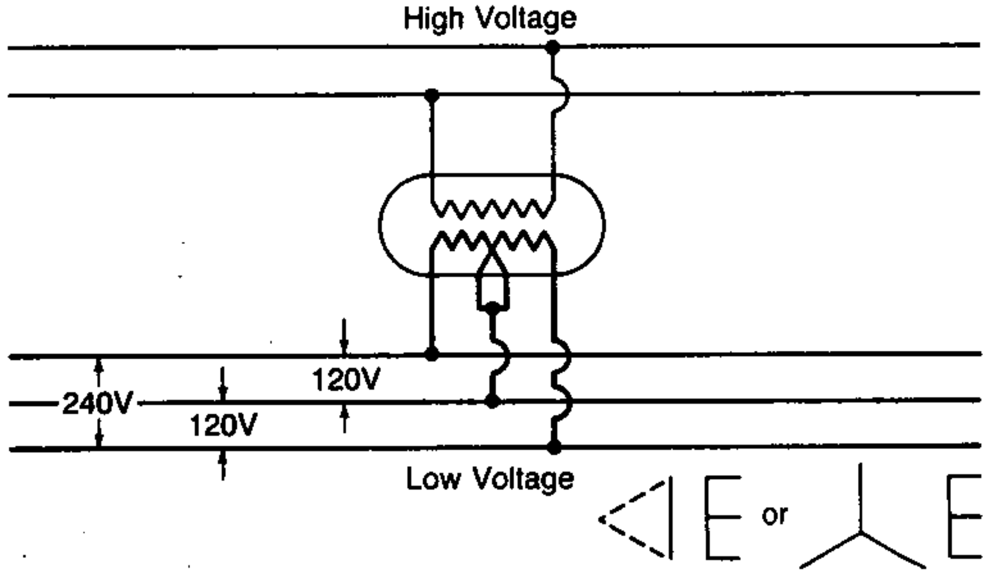


Fig. 25 – Three-Wire Secondary-Series Connected

The 120-volt loads should be balanced so both halves of the low voltage winding will be equally loaded. If more than half of the transformer rated load were drawn from either half of the low voltage winding, that half would be overloaded.

b. *Single-phase parallel operation* of two single-phase units is shown in Figure 26. Parallel operation of transformers having the same high voltage and low voltage ratings can be used when it is necessary to increase the total bank capacity and a single unit of the proper size is not available. It is not economically efficient to use two transformers in parallel if a single unit can be used. The losses of two units in parallel are greater than the losses of a single unit of the same capacity.

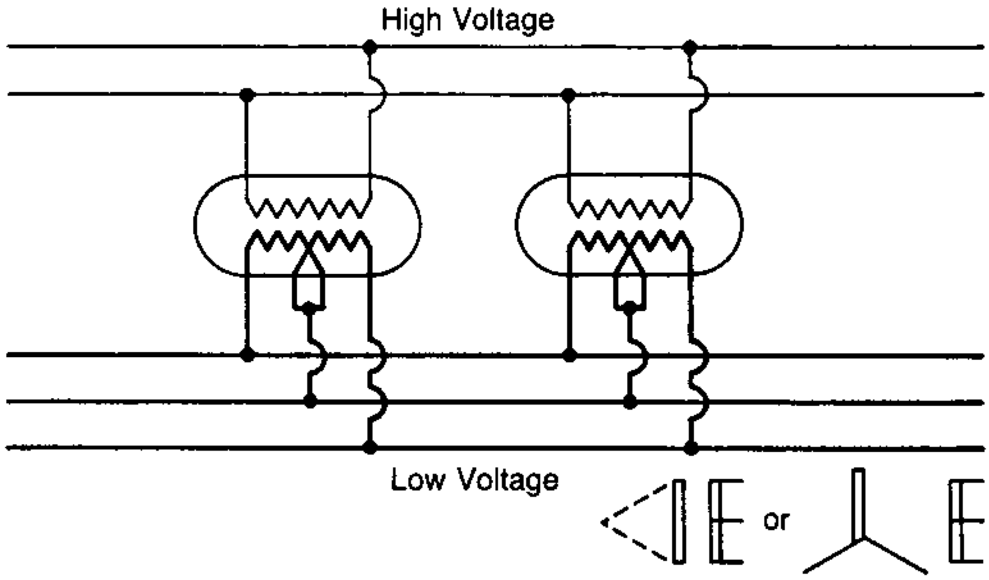


Fig. 26 – Parallel Operation of Two Single-Phase Transformers

Safe bank capacity can be determined. When the ratio of reactance to resistance is about the same for both transformers, the safe capacity is the smaller of the values obtained from the following equations:

Bank capacity based on not overloading transformer 1.

$$\text{Bank capacity} = \frac{C_1Z_2 + C_2Z_1}{Z_2}$$

Bank capacity based on not overloading transformer 2.

$$\text{Bank capacity} = \frac{C_1Z_2 + C_2Z_1}{Z_1}$$

where C_1 and C_2 are nameplate kVA ratings of transformers 1 and 2 respectively.

Z_1 and Z_2 are nameplate percentage impedances for transformers 1 and 2 respectively.

c. *Buck or Boost Transformer Applications*

A standard transformer connected to function as a booster is shown in Figure 27. The purpose of a booster transformer is to raise the voltage of the circuit from which the transformer is excited. The primary winding is connected in multiple and the secondary winding in series with the line. By reversing the secondary winding its action can be changed from boosting to bucking. In this connection the low-voltage winding is subjected to the overvoltages of the high-voltage circuit. Transformers for booster operation are insulated to withstand high voltages.

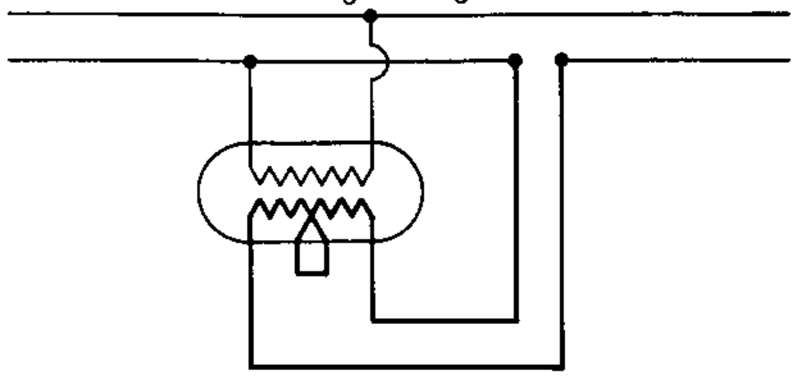


Fig. 27 – A Standard Transformer Connected as a Booster

Warning: Ground the secondary windings of two-winding transformers used as boosters if they have secondary windings in the 1.2 kV class. Failure to do so can cause severe injury or death, and damage to property.

The reduction in effective transformer impedance when connected as a booster must be considered. This reduction may require the addition of series impedance to limit short circuit currents to permissible values.

Figure 28 illustrates a number of buck or boost autotransformer connections for the output values shown in Table 1 below:

Table 1 – Buck and Boost Output Values

Nominal Circuit Voltage①	Transformer Function	Change of Circuit Voltage %	Dia.	kVA Output in Terms of Nameplate Rating
120	boost	10	a	10 times
	boost	20	b	5 times
	buck	10	c	10 times
	buck	20	d	5 times
240	boost	5	e	20 times
	boost	10	f	10 times
	buck	5	g	20 times
	buck	10	h	10 times

① If actual voltage varies from nominal voltage, multiply kVA output by ratio of actual voltage to nominal voltage.

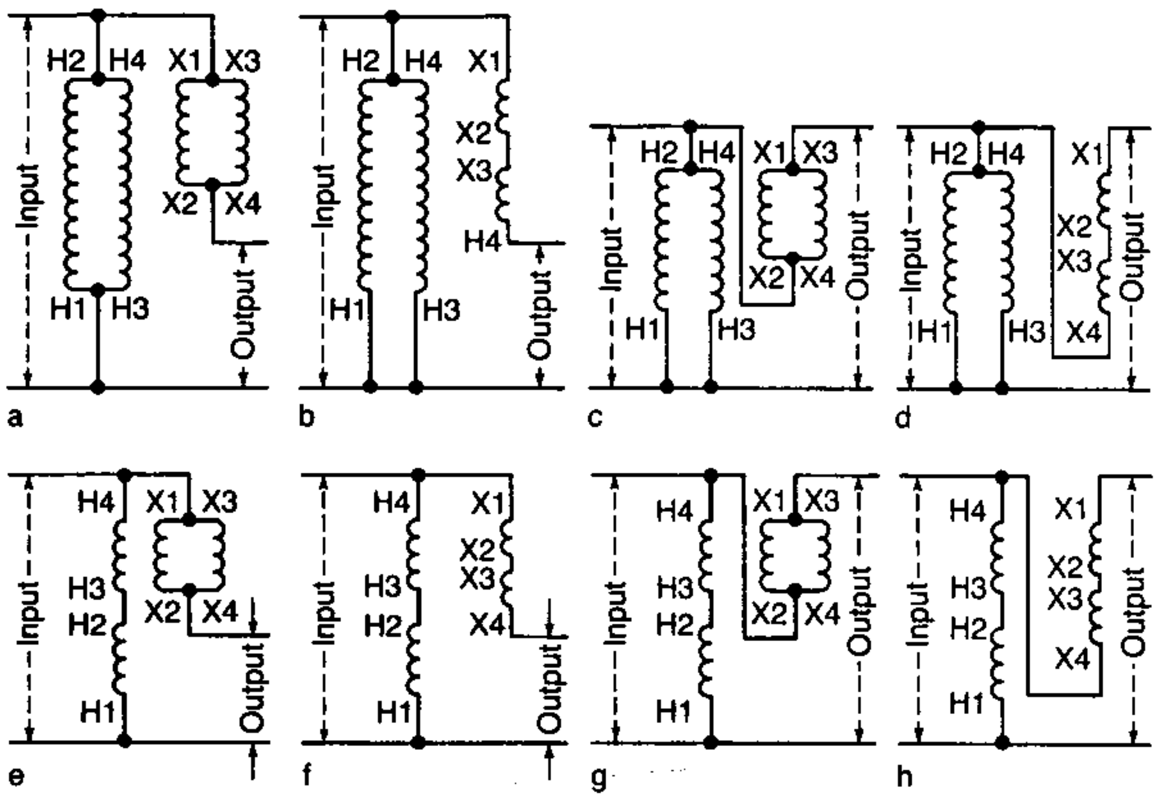


Fig. 28 – Buck or Boost Transformer Connections

2. *60 Hertz Transformers on 25 Hertz Circuits*
When using a 60 hertz transformer on a 25 hertz circuit, a transformer rated at approximately double the voltage of the circuit is required to prevent magnetic saturation of the iron core. The same result can be obtained by connecting two transformers of the same voltage as the circuit in series.

3. *Two-phase connections*
a. *Two-phase, four-wire connections* Transform four-wire to two-phase, four-wire of a different voltage without connection between the phases. See Figure 29.

b. *Two-phase, four-wire to two-phase, three-wire* Connection is shown in Figure 30. The two phases on the low-voltage side are electrically connected. The common third wire is sometimes grounded. With balanced load, the current in the common wire is the value of the square root of two times the current in the outside wires.

c. *Two-phase, three-wire interconnected transformer* connection is shown in Figure 31. In this connection two phases are electrically tied together by the common third wire. This connection is permissible in some circumstances and not in others. The common wire is sometimes grounded. With a balanced load, the current in the common wire has a value of the square root of two times the current in the outside wires.

Warning: Get qualified technical advice before attempting to make this connection. If improperly applied it can cause severe personal injury, death, or damage to equipment.

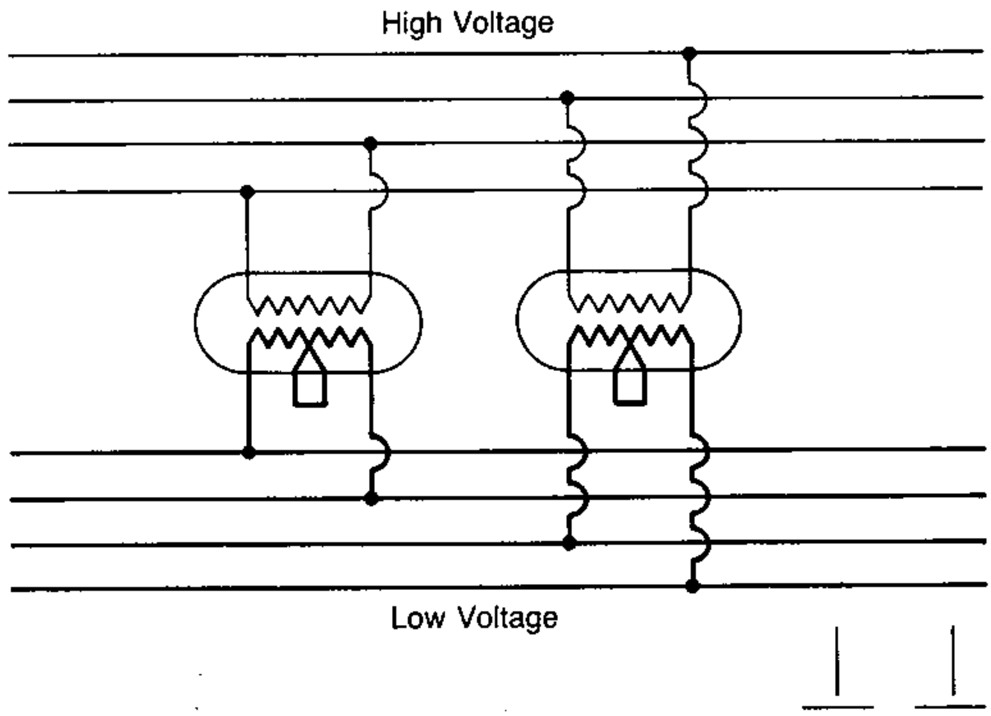


Fig. 29 – Two-Phase, Four-Wire Connection

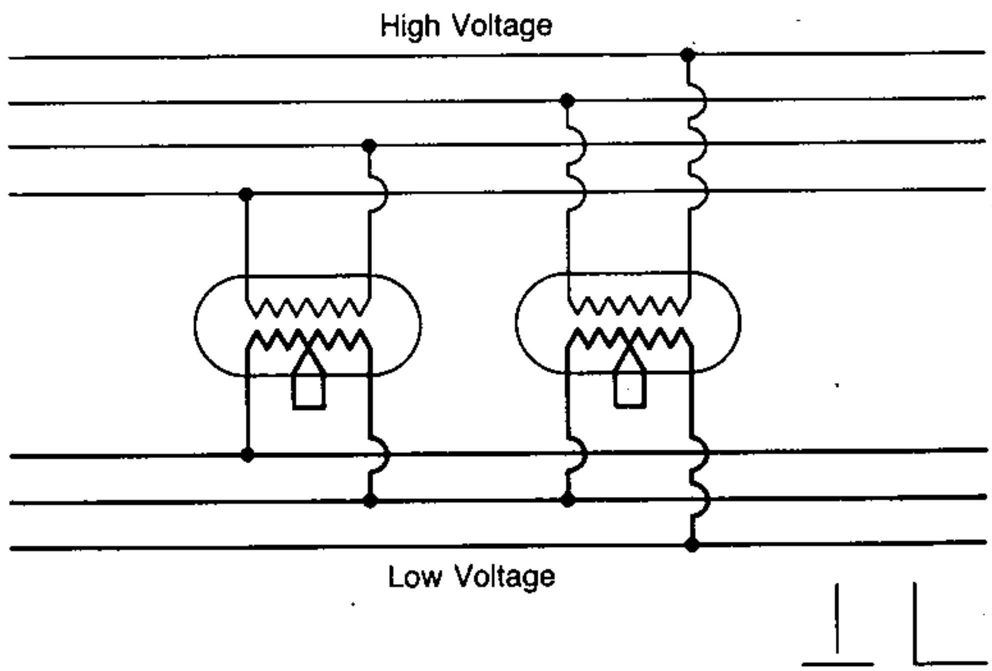


Fig. 30 – Two-Phase, Four-Wire to Two-Phase, Three-Wire

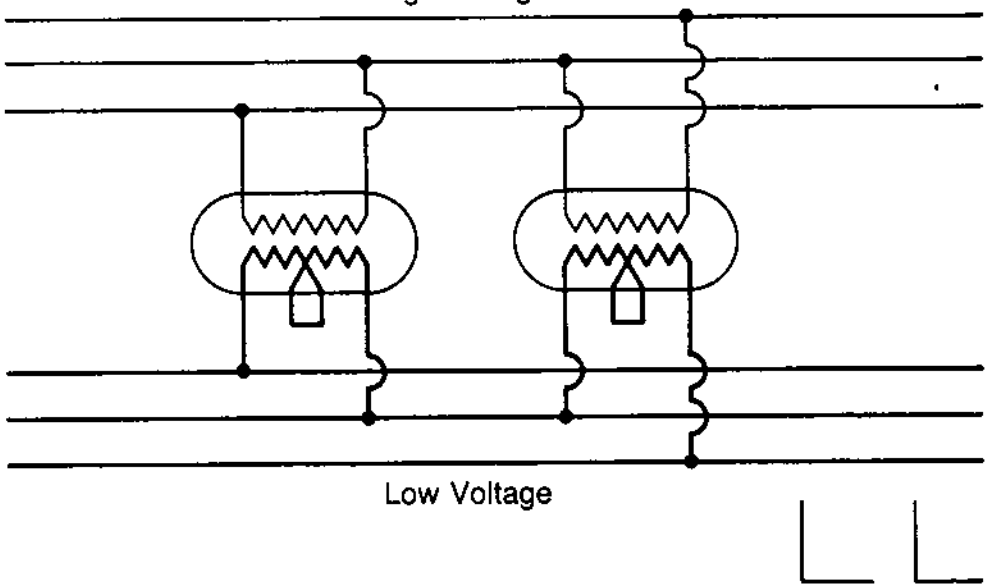


Fig. 31 – Two-Phase, Three-Wire Interconnected

4. *Three-Phase Connections*

a. *Three-phase, closed-delta connection* is shown in Figure 32. When three transformers are operated in a closed delta bank, the impedances must be nominally equal. Transformers having impedances that differ by more than ten percent should not be operated together in a closed delta bank, unless a reactor is used to raise the impedance of the lowest unit equality with the other two transformers.

If the voltage ratio of all three transformers is not the same, there will be a voltage tending to circulate a current inside the delta. This current will be limited by the impedance of the three transformers considered as a series circuit.

Before connecting three transformers in a closed delta, to insert a fuse wire between the terminals of the two transformers closing the delta. The fuse wire should be of sufficient size to carry the exciting current of the transformers. Use of this fuse wire is a very simple means of making certain the transformers have the proper polarity.

b. *Three-phase, open-delta connection* is shown in Figure 33. Three-phase to three-phase may be transformed by the use of two similar transformers in open delta. In the connection the two units will transform 86 percent of their rating, i.e., two 100 kVA units in open delta, transforming three-phase, 2300 volts to three-phase 230-115 volts will have a bank capacity of 172 kVA.

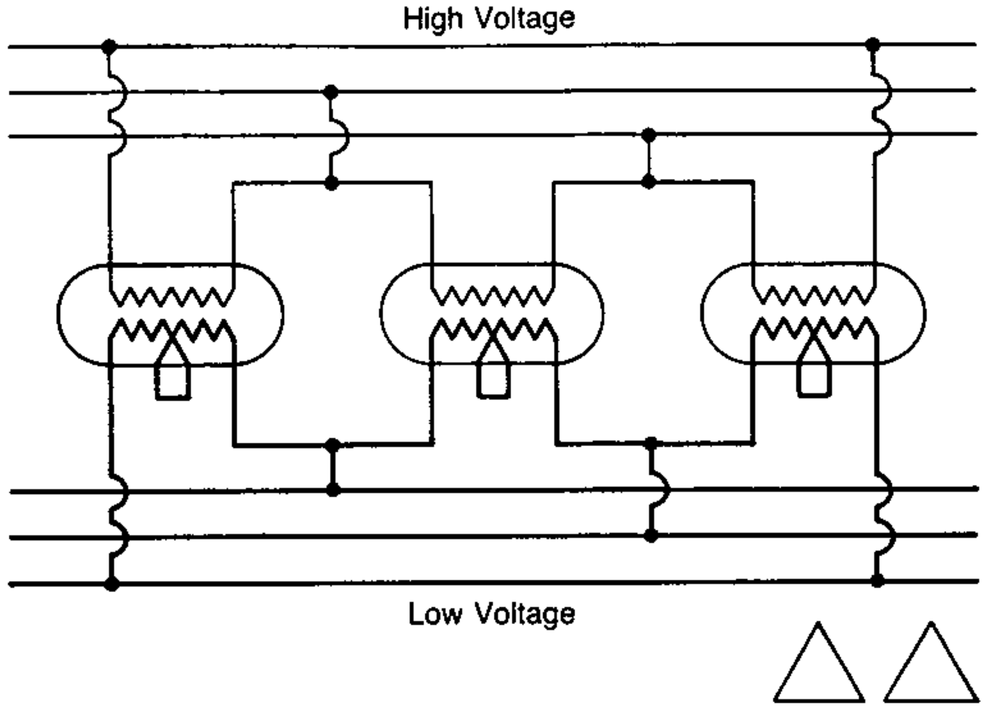


Fig. 32 – Three-Phase, Closed Delta Connection

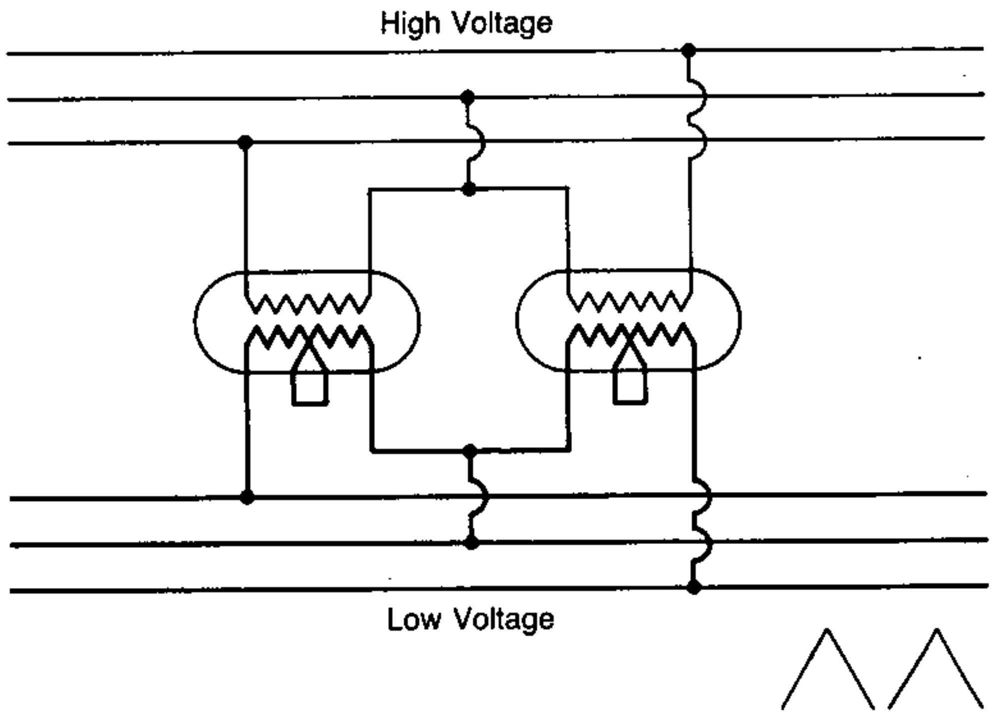


Fig. 33 – Three-Phase, Open Delta Connection

In the open delta connection it is not required that the transformer impedances be the same. It is preferable that the impedances be the same when it becomes necessary to close the delta with a third transformer. Then all three units must have the same impedance.

The open delta connection is often used as a temporary expedient pending anticipated increase of load.

By adding a third 100 kVA unit in the example cited the resultant bank capacity will increase to 300 kVA.

The regulation of an open bank is not as good as that of a closed bank. The drop across the open delta is greater than across each of the separate transformers.

c. *Three-phase, wye, three-wire, high voltage; delta three-wire, low voltage* connections are shown in Figure 34. When three transformers are operated with their high-voltage windings in wye, the incoming line voltage is the value of the square root of three, 1.732, times the transformer winding voltage. This connection is frequently used because it presents a convenient way of boosting the transmission voltage without requiring additional transformers.

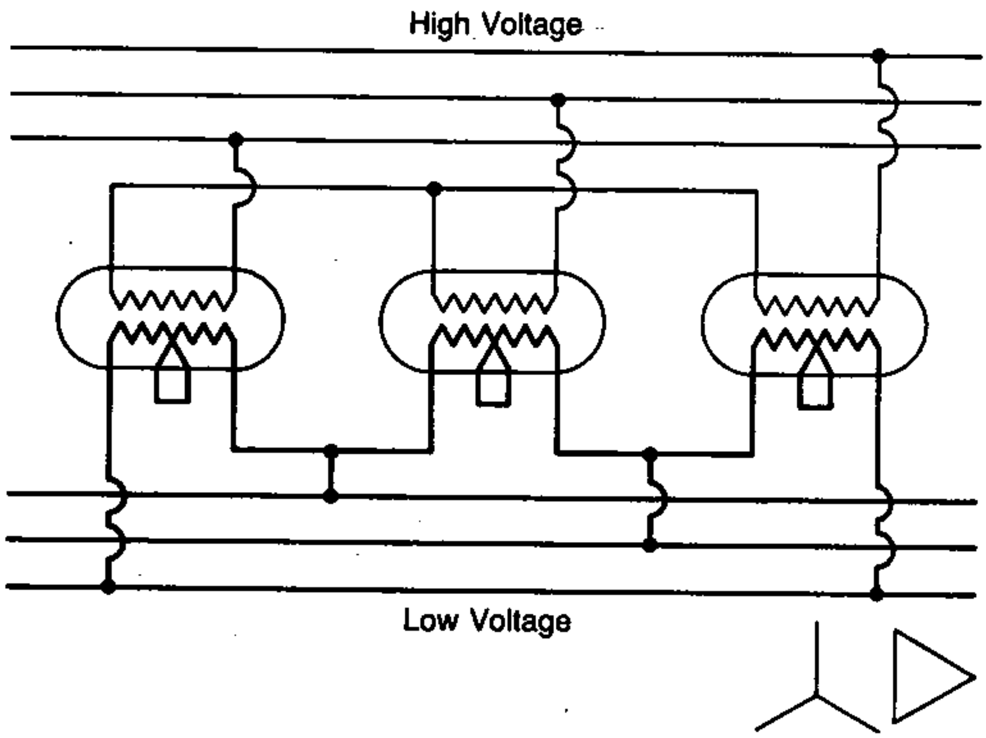


Fig. 34 – Three-Phase, Star, Three-Wire, HV Delta, Three-Wire, LV Connection

d. *Three-phase, wye, four-wire, HV; delta, three-wire LV* connections, see Figure 35. This connection permits three-phase power to be transmitted at wye voltage. At the same time single-phase power may be taken from the mains by connecting the transformer between the neutral and any of the three-phase wires.

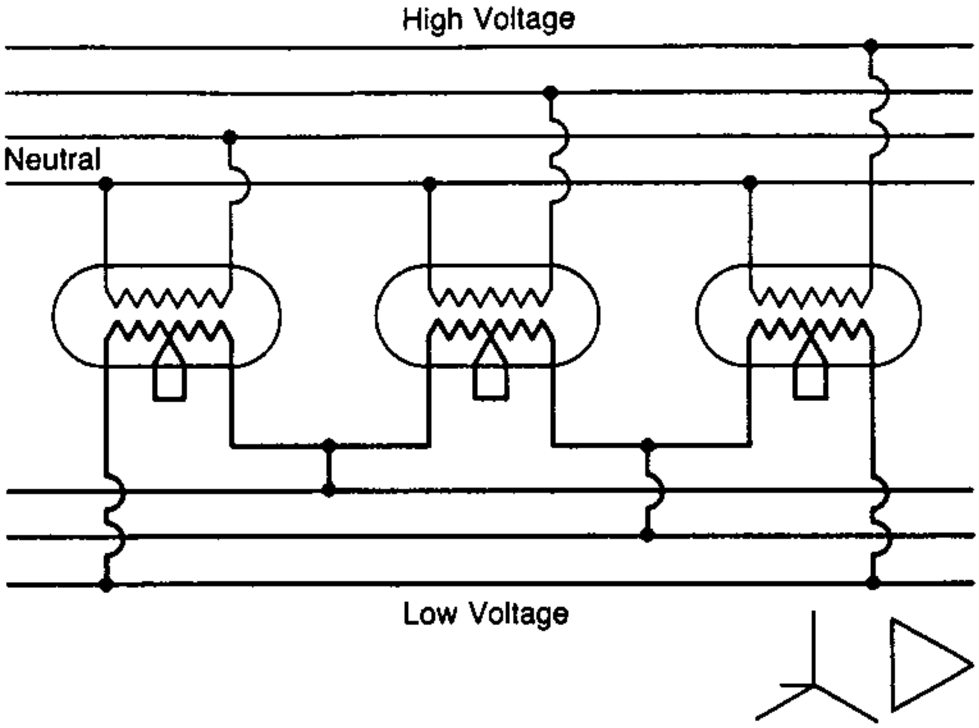


Fig. 35 – Three-Phase, Star, Four-Wire HV Delta, Three-Wire, LV Connection

In this connection the impedances of the transformers need not be the same. The high voltage neutral is usually ungrounded.

5 Special Purpose Connections

a. *Three-Phase, Wye, Four-Wire, One Leg Out, HV Open-Delta, Three-Wire, LV.* See Figure 36. This connection is similar to the wye connection. The primary of each transformer is connected between the neutral and one of the three-phase wires. The secondaries are connected to the secondary mains, the same as for a delta connection except that the third transformer is not used. The secondaries are in open-delta.

The two transformers connected this way will provide 86.6 percent of their combined rated capacity.

b. *Three-Phase, Secondary Wye Interconnected.* See Figure 37. The primary side of this group may be connected in either wye or delta. Each half of the secondary winding of each transformer has a voltage of 57.7 percent of the interconnected wye voltage. A bank of transformers designed for connection in this manner must have a capacity 7½ percent greater than the kVA to be transformed.

The interconnected wye winding permits the unbalanced direct current from the third wire of the three-wire circuit of a rotary converter to get

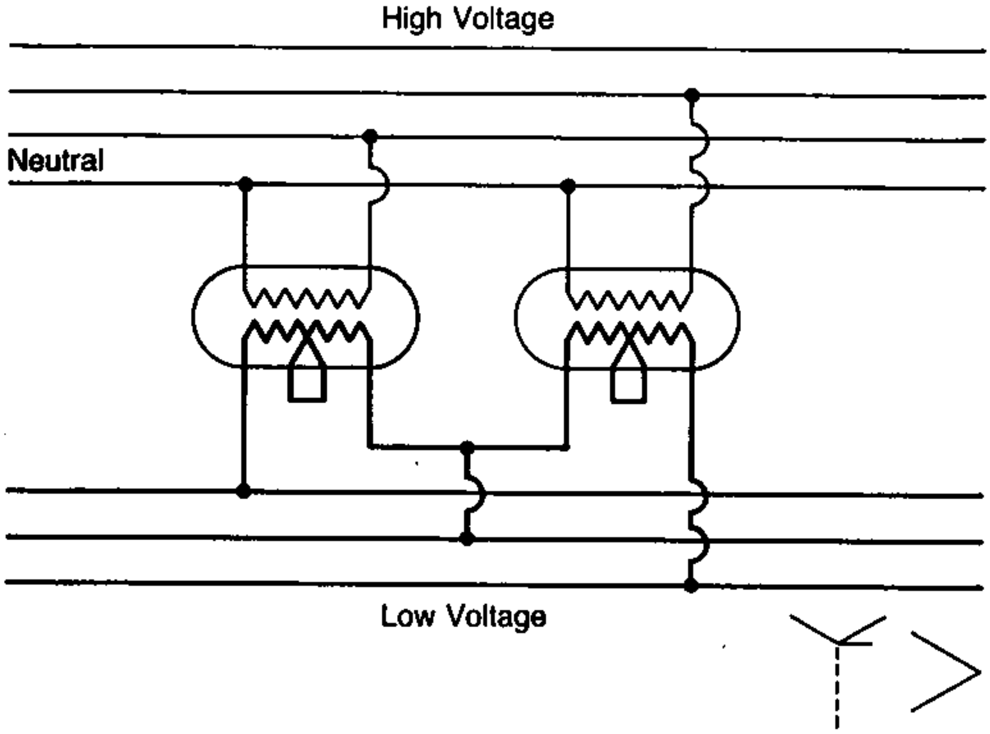


Fig. 36 – Three-Phase, Star, Four-Wire, One Leg Out, HV

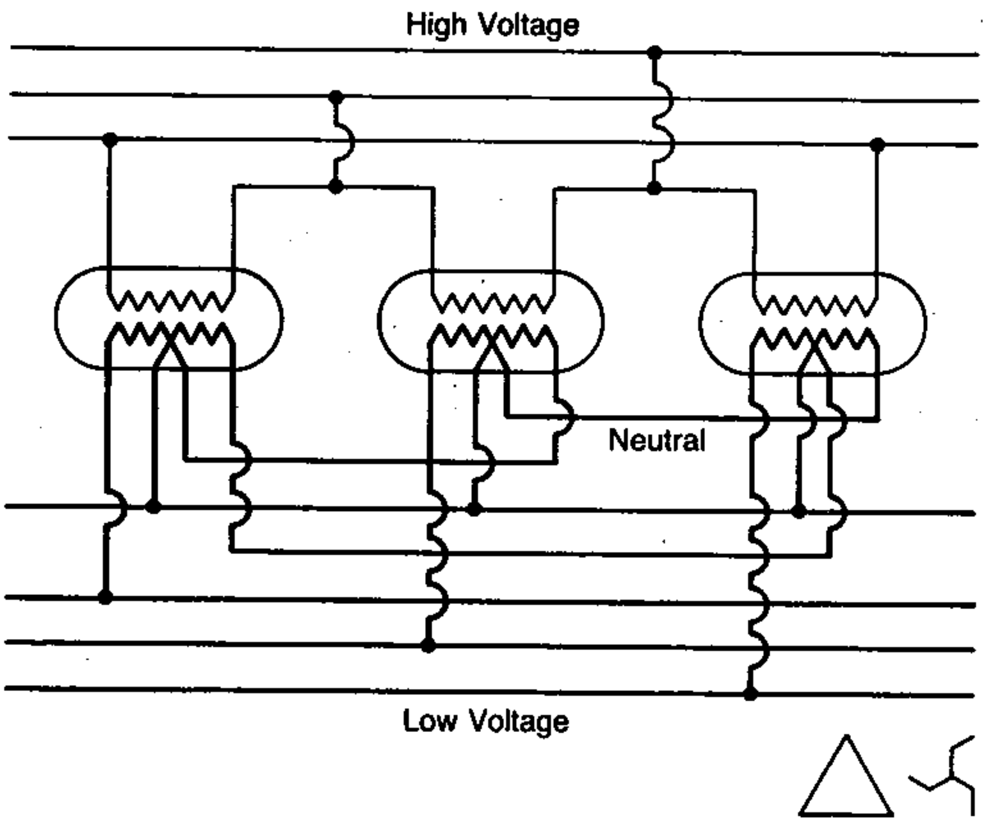


Fig. 37 – Three-Phase Secondary Star, Interconnected

back into the a-c system feeding the converter. Since this direct current divides into two equal parts in each transformer, and since these parts flow in opposite directions magnetically, the direct current does not magnetize the transformer core. If this current were to flow in one direction through the winding, the d-c magnetic flux would add to the a-c flux and perhaps saturate the core.

c. *Three-Phase, Three- or Four Wire, Wye-Wye with Autotransformers.* See Figure 38. In this connection the high and low voltage windings are electrically connected together. For this reason the low-voltage side and connected apparatus will, under fault conditions, be subjected to the voltage of the high-voltage circuit.

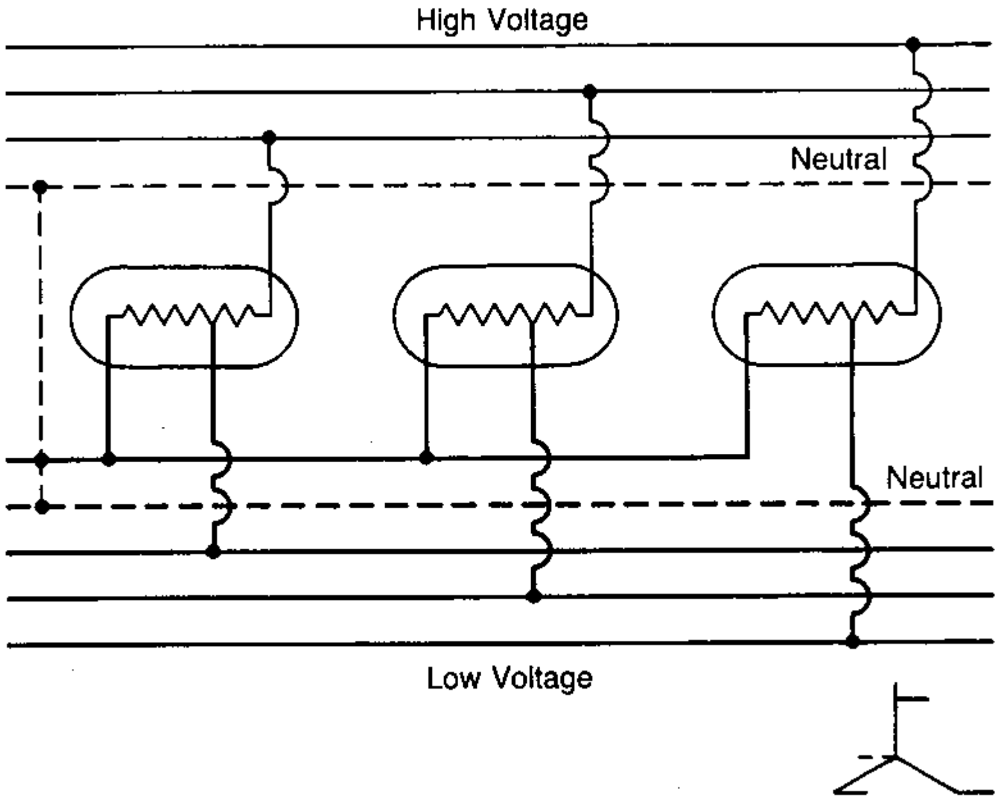


Fig. 38 – Three-Phase, Three- or Four-Wire, Star-Star with Autotransformers

The material in the autotransformer is less than that in a two-winding transformer which is transforming the same power. The saving in material is large when there is a small difference in the primary and secondary voltages, and becomes less as the difference in voltages increases.

d. *Three-Phase, Three-Wire, Open-Delta with Autotransformers.* See Figure 39. The high and low voltages are electrically connected together. For this reason, the low side and connected apparatus will be subjected to high side voltage under fault conditions.

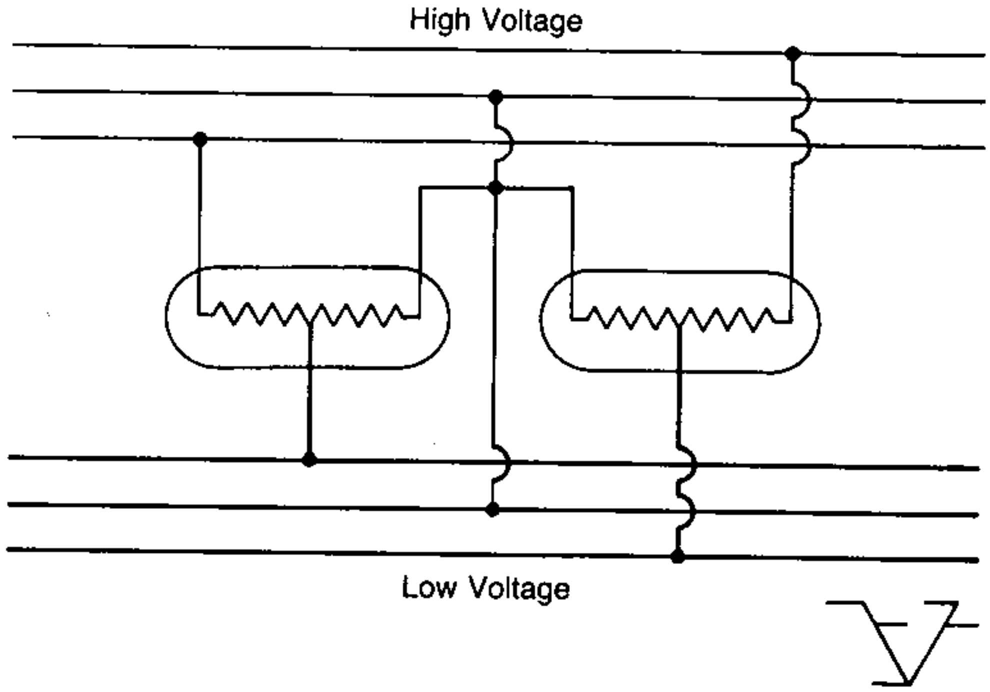


Fig. 39 – Three-Phase, Three-Wire, Open Delta with Autotransformers

The material in the autotransformer is less than that in a two-winding transformer which is transforming the same power. The saving in material is large when the difference in the primary and secondary voltages is small, and becomes less as the voltage difference increases.

This connection requires 17 percent larger transformer capacity than the wye-wye autotransformer connection.

e. *Autotransformers for Phase Transformation.* Three-phase to two-phase, four-wire, interconnected. Refer to Figure 40. When a phase transformation is desired without major stepping up or down of voltage, the autotransformer is the least expensive and the simplest equipment to use. The connection shown has the windings on the two-phase side electrically connected together at their middle point.

f. *Phase Transformation, Scott;*
Two-phase, three-wire to three-phase, three-wire or Scott; three-phase, three-wire, or two-phase, three-wire. Refer to Figure 41. This is a phase transformation from three to two or from two to three. Either the primary or the secondary side may be made three-phase. The three-phase side must have special taps to make this transformation. One unit must have an 86.6 percent tap, and the other unit a 50 percent tap. A three-wire circuit is used on the two-phase side. This is formed by joining together two of the wires forming the two phases. In this manner the two phases are electrically joined.

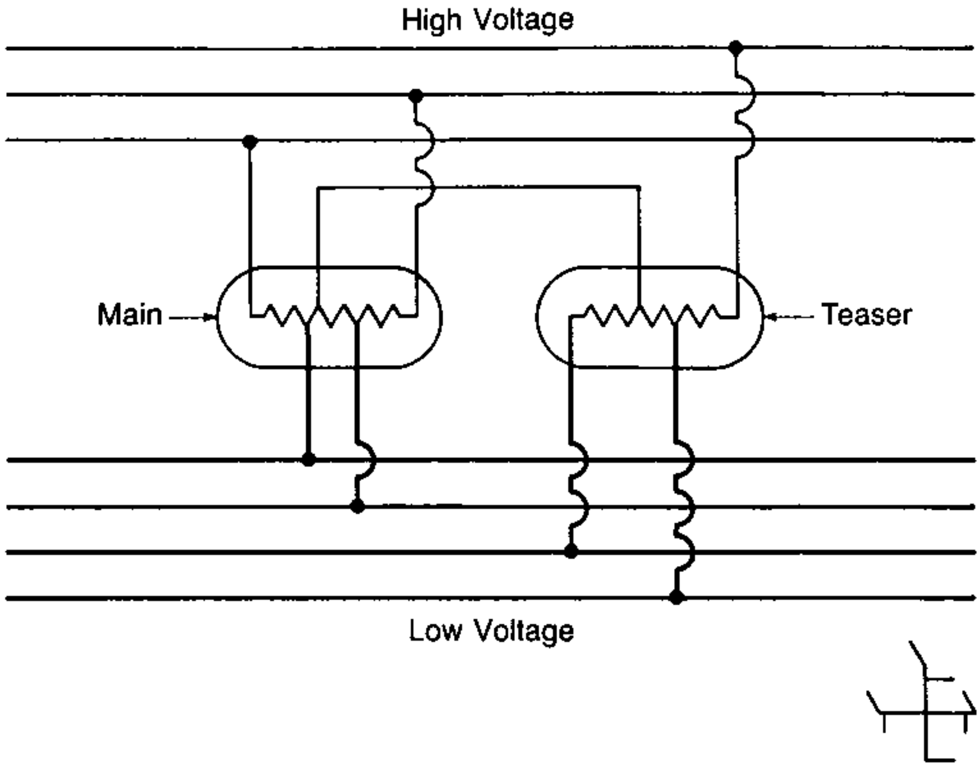


Fig. 40 – Three-Phase to Two-Phase, Interconnected by Autotransformers

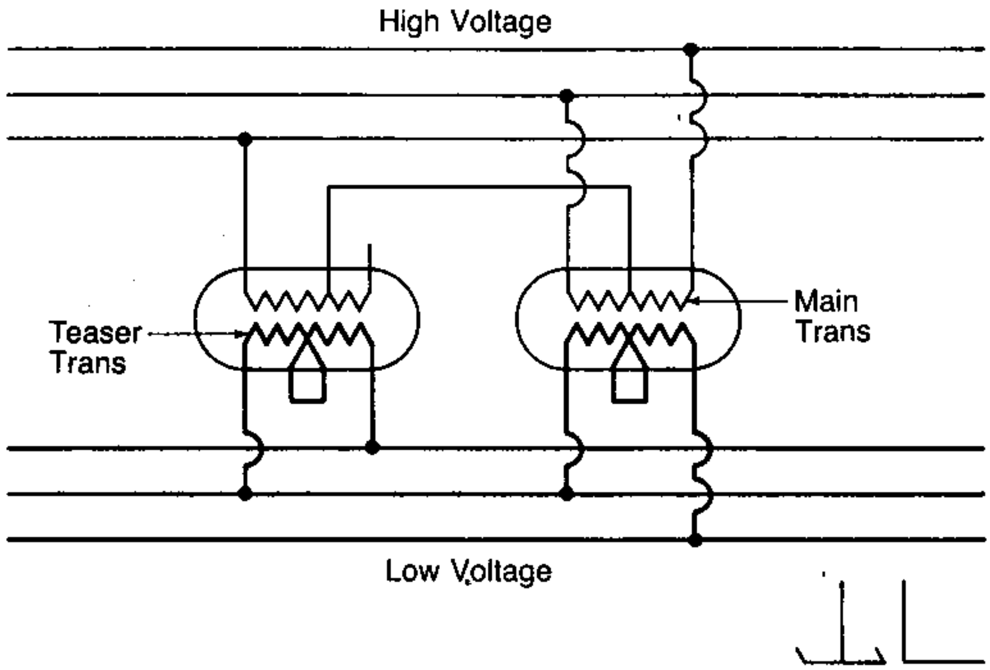


Fig. 41 – Phase Transformation –
Two-Phase, Three-Wire to Three-Phase, Three-Wire or Scott Three-Phase to Two-Phase

If the transformers are to be used with motors interconnected at mid-points, the connection shown in Figure 42 is recommended.

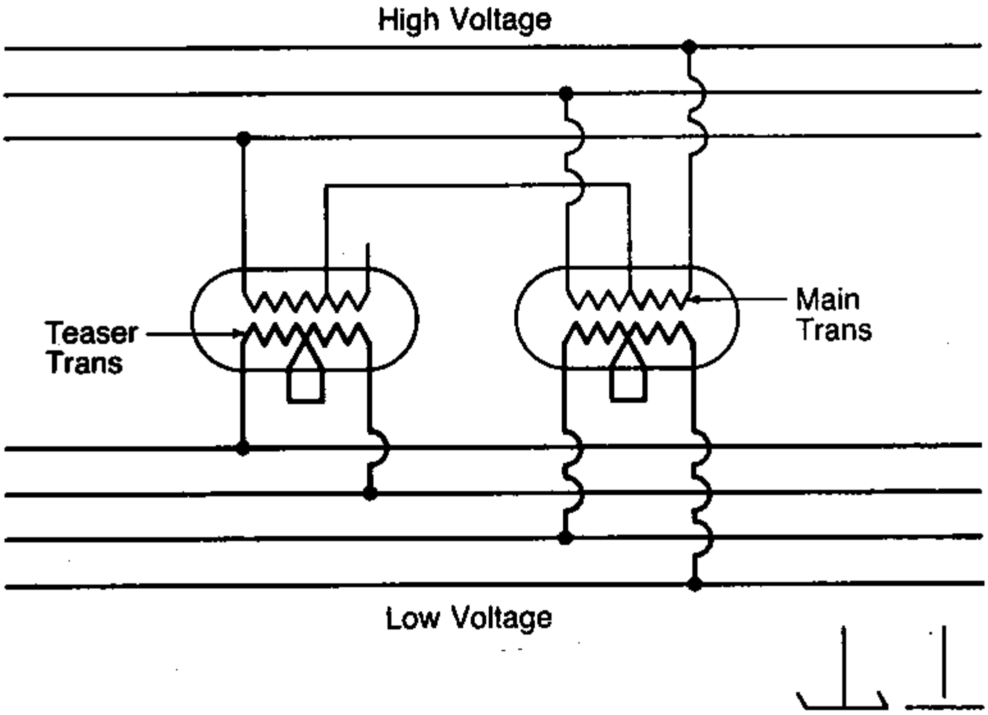


Fig. 42 – Phase Transformation, Scott

g. *Phase Transformation, Scott;*
Three-phase, three-wire to two-phase, four-wire or Scott; two-phase, four-wire to three-phase, three-wire. See Figure 42. This connection is exactly the same as the previous one except the two-phase side is made four-wire, thus electrically separating the two-phase circuits.

h. *Scott Transformation*
Standard 10-1 (high to low voltage) ratio used. Refer to Figure 43. If a Scott transformation is desired, and a transformer having an 86.6 percent tap is not available, a unit having a 10 percent tap or two 5 percent taps may be used to give approximate results. With this arrangement the two-phase voltages will be unbalanced by about 4 percent.

i. *Phase Transformation, Fortesque Connection*
Refer to Figure 44. This is a transformation from three-phase to two-phase by the use of three transformers, one standard and two with special taps on the low-voltage side. One advantage of this connection is that both two- and three-phase current may be delivered at the same time.

The sum of the power delivered at two-phase and three-phase must be somewhat less than the rating of the transformers to assure against overloading.

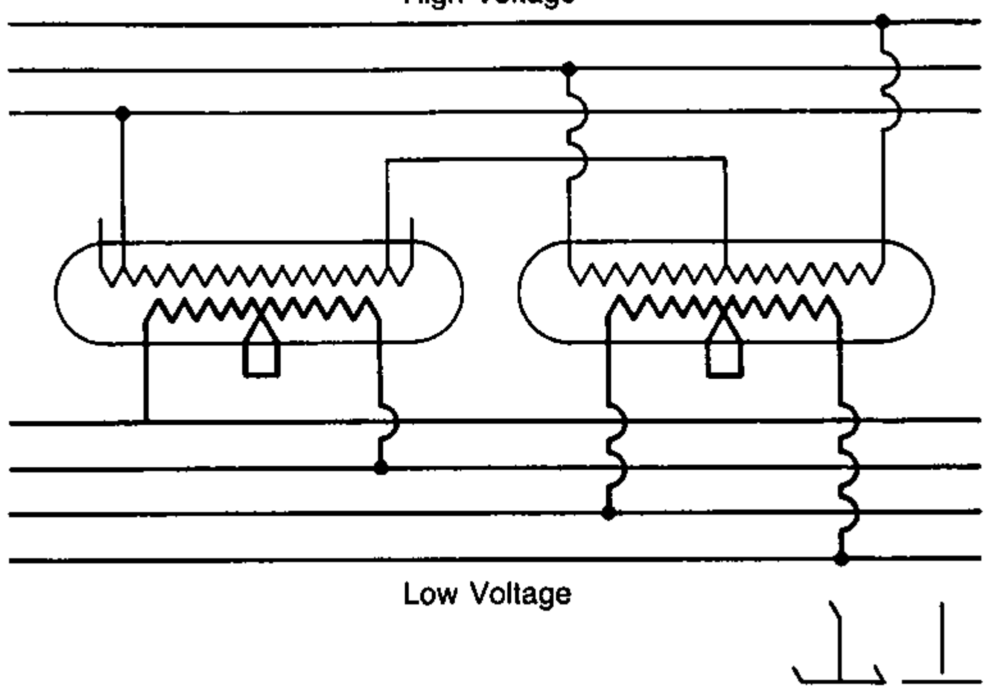


Fig. 43 – Scott Transformation, Standard 10 to 1 Ratio

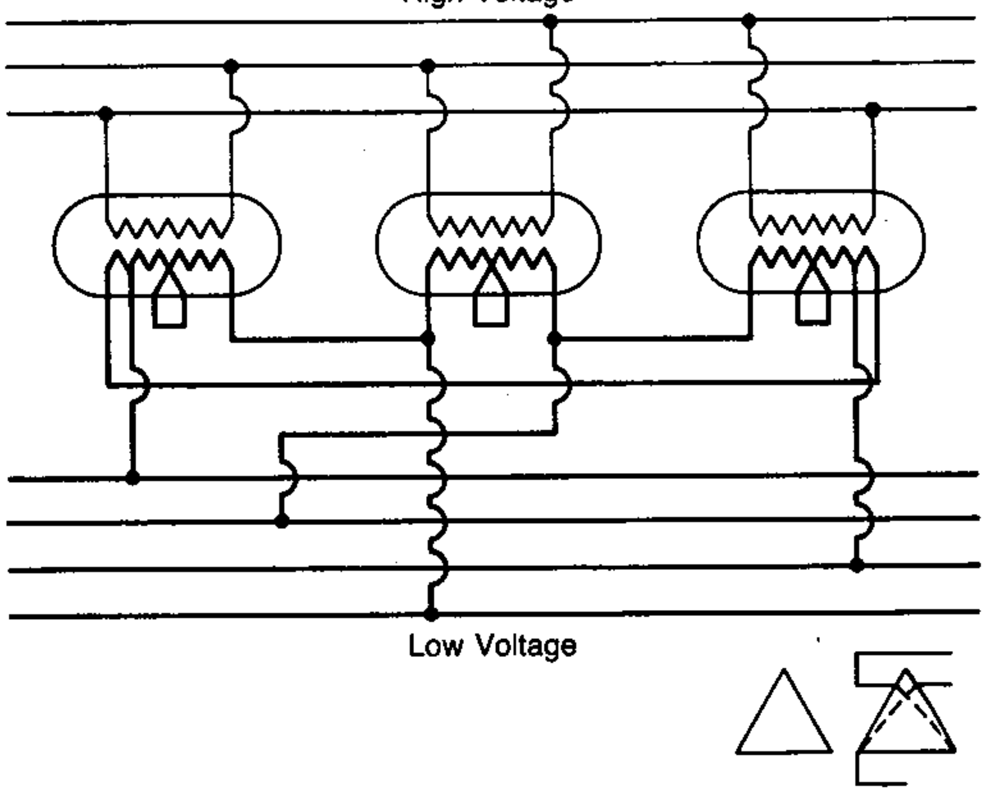


Fig. 44 – Phase Transformation, Fortesque Connection

j. *Autotransformers for Phase Transformation,* three-phase to two-phase, four-wire. See Figure 45. This connection is the same as the one shown in Figure 44 except that the winding on the two-phase side are not connected together at their mid-point.

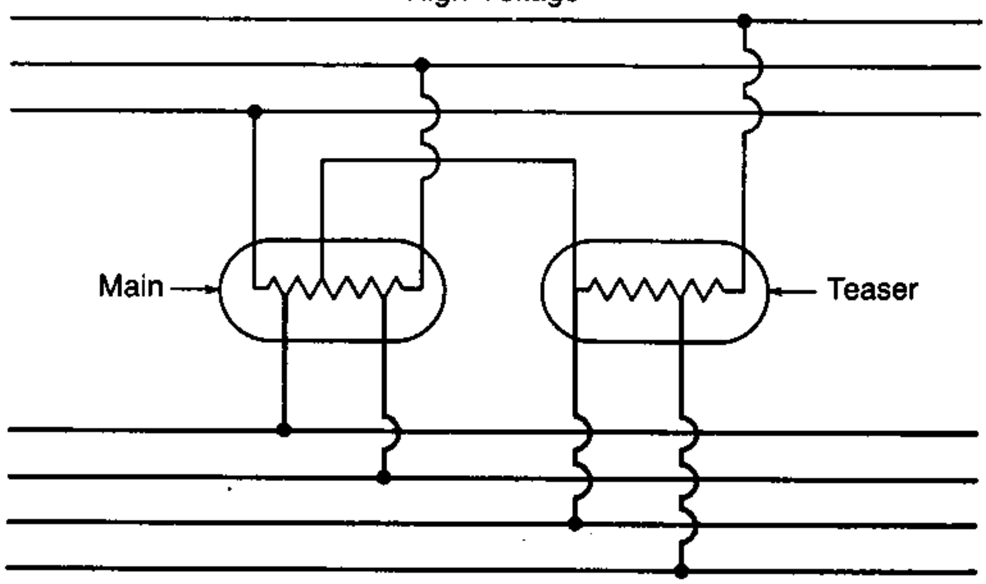


Fig. 45 – Three-Phase to Two-Phase, Four-Wire by Autotransformers

k. *Autotransformers, Three-Phase to Three-Phase, Three-Wire.* Refer to Figure 46. Where the voltage change from primary to secondary is small the use of an autotransformer for voltage transformation is less expensive than use of a two-winding transformer, the primary and secondary windings are joined electrically, which may be objectionable in some installations.

l. *Phase Transformation, Three-Phase to Two-Phase Using an Autotransformer.* See Figure 47. This is the method for taking two-phase voltages from a delta bank by the application of an autotransformer. The autotransformer is connected between the apex of the delta and the mid-point of the opposite side. This connection gives a one-to-one ratio which means that the two-phase and three-phase voltages on the low-voltage side are equal. The high voltage winding of the bank may be connected either star or delta. The two-phase and three-phase loads may be taken off simultaneously. If no load is drawn off at three-phase, approximately 75 percent of the bank rating may be taken off at two-phase.

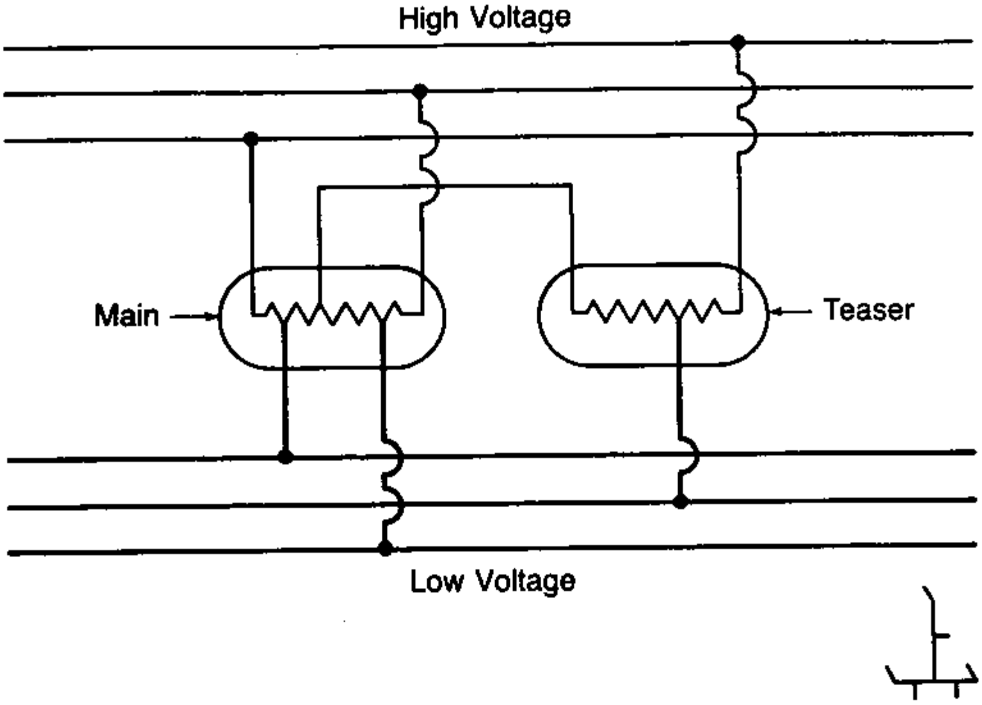


Fig. 46 – Three-Phase to Three-Phase, Three-Wire by Autotransformers

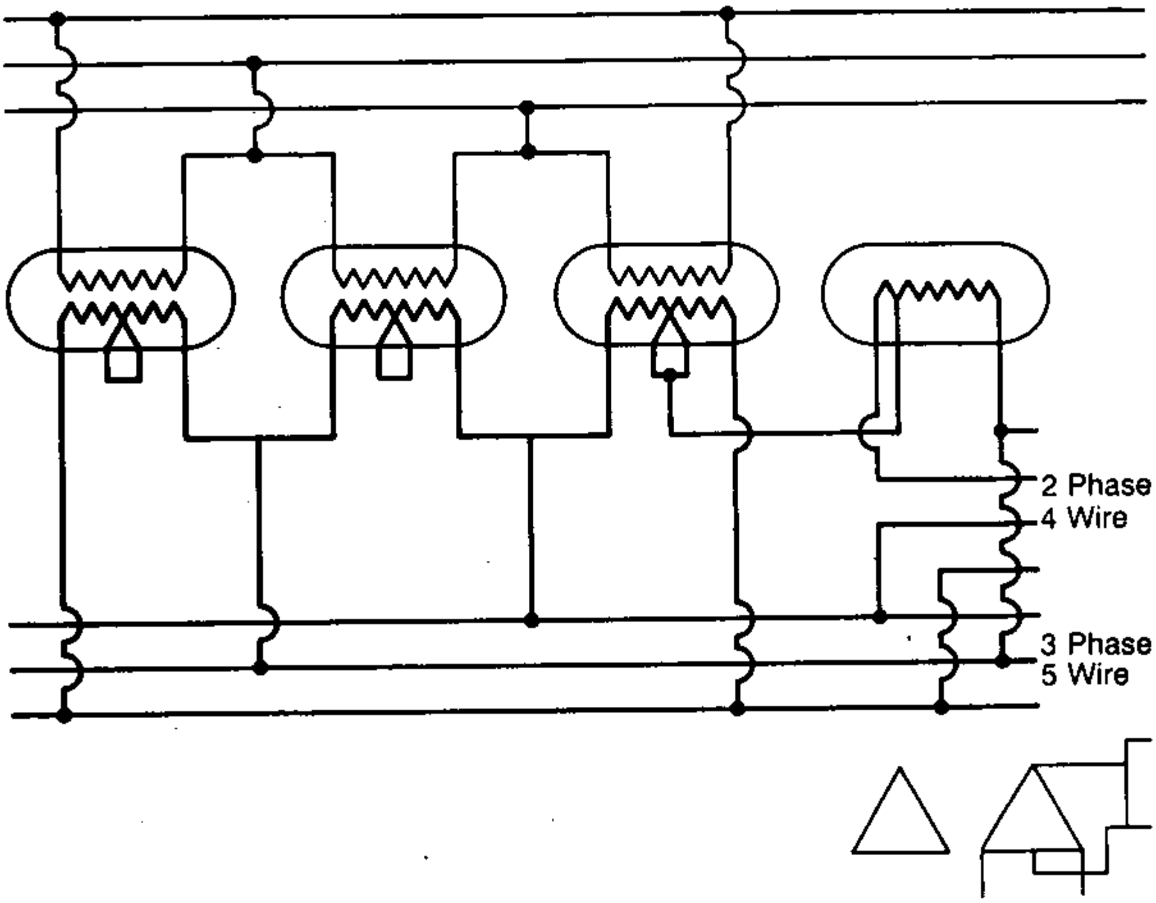


Fig. 47 – Three-Phase to Two-Phase from Delta Bank by Autotransformer

m. *Phase Transformation Using Standard Transformers of Different Voltage Rating.* Refer to Figure 48. In this connection, if transformer 1 is rated at 4160 volts to 240/120, and transformer 2 is rated 2400 volts to 240/120, each transformer will have a rating equal to one-half the two-phase load.

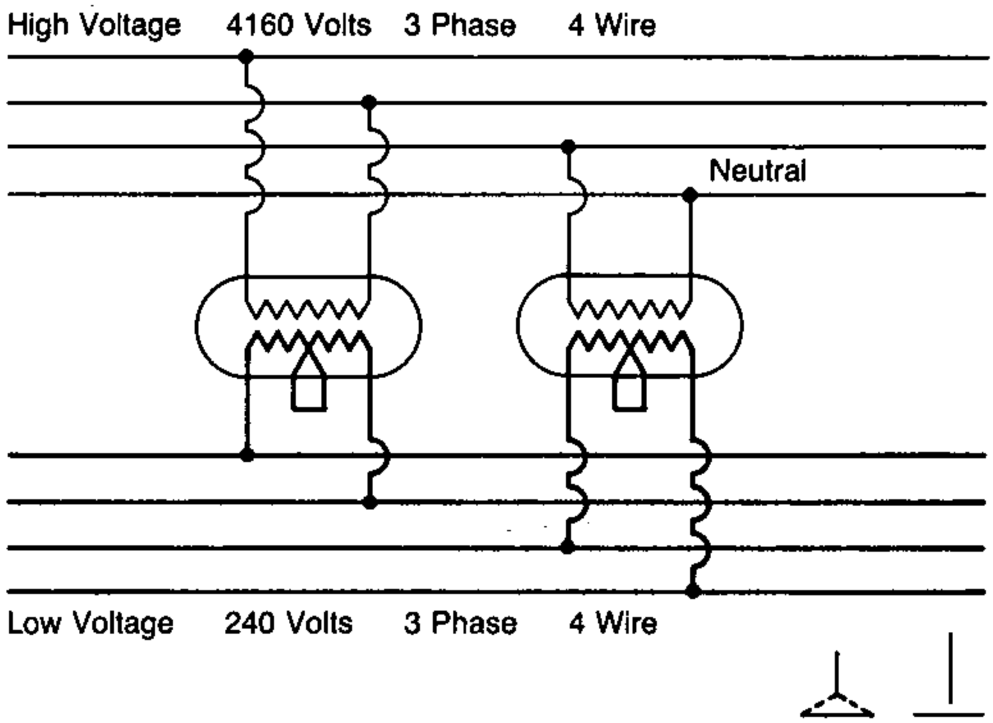


Fig. 48 – Phase Transformation Using Standard Transformers of Different Voltage Ratings

7.10 Accessory Devices②

Warning: Operation of a primary protective device may indicate a faulted transformer. Do not re-energize if any sign of failure is observed. Re-energizing should be performed from a remote location unless the cause of the protective device operation is positively identified and corrected. To do otherwise presents a hazard of violent transformer failure resulting in danger to life and property.

A. Surge Arresters

Surge arresters are mounted on the outside of the transformer tank. Their function is to intercept and divert to ground various overvoltage transients, such as lightning surges, which originate on the distribution system.

B. Protective Links

Many transformers have protective links (expulsion type fuses) mounted inside the tank. They may be mounted in the bottom of the high-voltage bushing or in a terminal block between the high-voltage coil and the high-voltage bushing. These protective links must be under oil for proper operation.

The transformer manufacturer can supply curves giving the characteristics of these protective links so they can be coordinated with the protective devices on the primary side of the transformer.

Protective links are oil-immersed high-voltage, expulsion fuses designed to isolate the transformer from the primary distribution system in the event of a transformer fault inside the tank on the load side of the link. The purpose is to prevent a line lockout when a transformer fails. It is not to provide overload or fault current protection to the transformer.

Warning: Improper coordination of the protective link with the primary protective devices separate from the transformer can prevent the link from operating properly for both load current and fault current characteristics. This can result in a lack of protection for the transformer and a line lockout in the event of transformer failure. It can cause severe personal injury, death, or property damage.

② The descriptions of transformer accessories given here are based on current Westinghouse designs. Equipment manufactured at other times or by other manufacturers may vary in detail. Always consult the manufacturer's instructions for specific information.

C. Current-Limiting Fuses

High-voltage current limiting fuses limit the flow of current (and energy) to a low impedance fault. Refer to Figure 49, a cut-away drawing of a typical current-limiting fuse. Like protective links, their purpose is to isolate the transformer from the distribution system in the event of an internal transformer fault.

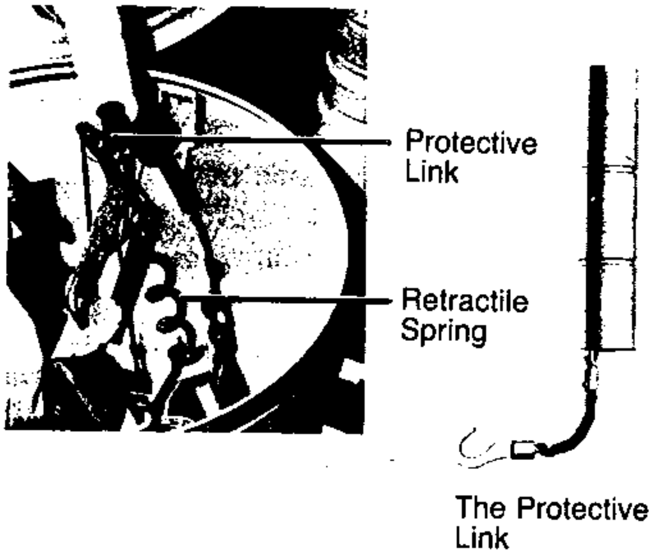


Fig. 49 – A High Voltage Bushing Mounted Current Limiting Fuse in Series with a Protective Link

Current-limiting fuses usually are applied when the system available fault current exceeds the interrupting capacity of the protective link. Because partial range current-limiting fuses are normally applied on overhead distribution transformers, a series protective link is normally applied with each current-limiting fuse.

D. Low-Voltage Circuit Breaker

Some oil-filled distribution transformers have circuit breakers mounted in the tank, under oil and connected between the low-voltage coil winding leads and the low voltage bushing. These breakers protect the transformer from severe overloads and short circuits originating external to the transformer. The low-voltage breaker is not intended to protect the secondary (low-voltage) circuits or connected apparatus such as meters, meter sockets, connectors, service entrance equipment, etc., from thermal and magnetic effects due to short circuits and overloads.

The breaker is calibrated to trip when its bimetal reaches a predetermined temperature. Some breakers also have a magnetic trip element to enable the breaker to respond more quickly to high fault currents.

The breaker is designed for only occasional switching operations. It is not intended for frequent, daily or even weekly, switching duty.

The bimetal element of the breaker is connected in series with the secondary windings of the transformer and the thermal element responds to the current flow of the transformer load and to the oil temperature.

The circuit breaker is always used in conjunction with a protective link. The breaker coordinates with the link so it opens first on overloads and faults on the load side of the breaker.

A typical secondary breaker operating handle and overload signal and emergency overload reset handle is shown in Figure 50. This operating handle assembly is mounted on the side of the transformer tank.

Fig. 50 – Low-Voltage Circuit Breaker Operating Handles and Signal Light

Warning: Do not touch the low voltage terminals, even when the low-voltage circuit breaker is open. There may be enough capacitance coupling between the high-voltage and low voltage winding to cause severe personal injury or death.

1. *Circuit Breaker Emergency Control*
The emergency control handle is provided to recalibrate the breaker to a higher trip temperature and a larger kVA load. This trip setting device should be used only when absolutely necessary and for as short duration as possible. Overuse may result in a reduction of the transformer life.

The breaker is recalibrated to the emergency position by removing the meter seal and rotating the emergency control handle approximately a quarter turn down and away from the breaker operating handle. It is recommended that a new seal be affixed to the handle when it is returned to the normal position after an emergency operation. This will avoid inadvertent operation of the emergency control.

In a short-time emergency situation the circuit breaker calibration can be changed to allow additional overload capacity, as shown in Figure 49.

After the emergency situation has passed, the emergency control handle should be returned to the normal position.

Caution: Do not use the emergency trip setting of the circuit breaker extensively. Frequent use will result in higher winding temperatures before the breaker can trip. Higher winding temperatures cause a reduction in transformer life. When the emergency control setting is made it increases the load at which the signal light will come on and at which the breaker will trip by 20 percent.

2. *Signal Lights*
Some transformers can be supplied with overload signal lights. A burning signal light indicates the transformer is heavily overloaded. The signal light remains on until turned off by moving the breaker reset handle to just short of the top position. It can also be turned off by operating the breaker handle to the maximum upward position and then back to the closed position. The light can be turned on by manually opening the circuit breaker.

If the light remains on after the handle is operated to the reset position, it is an indication that the transformer is still too hot to energize.

E. Arrester-Fuse Combination

There is a protective device which consists of a flip-open type of fuse holder and a surge arrester. It has been named the Protecto-Combo by Westinghouse. It requires field assembly and is used only on transformers 50 kVA and below, class B-2 or B-3 units with one cover mounted high-voltage bushing.

This assembly provides over-voltage and over-current protection without the installation of a pole or cross-arm, separately-mounted arrester or fuse cutout. Both the arrester, either 9/10 kV or 18 kV, and fuse link are mounted externally on the transformer. The arrester protects the transformer from lightning or high-voltage switching surges. The protective link (fuse) provides system protection from internal transformer faults. Illustrated in Figure 51.

F. Tap Changers

Warning: Do not operate the tap changer when the transformer is energized. To do so could cause severe injury, death, and property damage.

Tap changers are connected into the high-voltage coil. The transformer output can be increased or decreased by changing the tap changer setting.

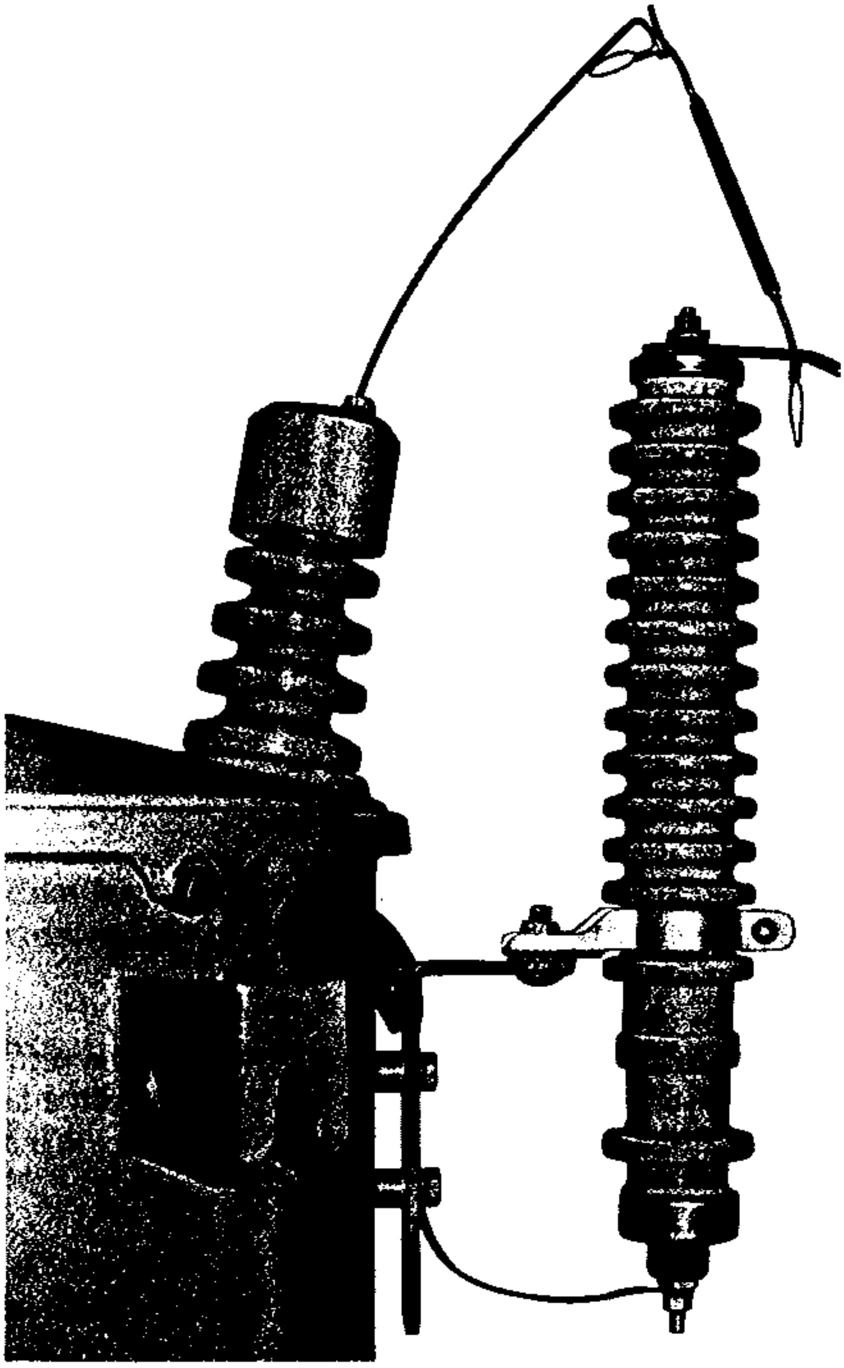


Fig. 51 – Arrester-Fuse Combination Protective Device

The internal tap changer is operated by removing the transformer handhole cover, or the transformer cover, and turning the tap changer handle to the desired position. The tap changer numbers on the position indicator match the ones on the transformer nameplate.

The taps are changed with an externally operated tap changer by loosening the handle locking screw, turning the handle to the desired position, and tightening the locking screw.

After the emergency situ vn in Figure 52.
should be returned to t

Caution: Do not
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com

Internally Operated
Tap Changer

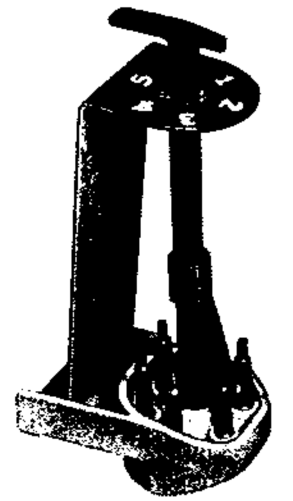

Fig. 52 – Externally and Internally Set Tap Changers

G. Dual Voltage Switch

Warning: Do not operate a transformer dual voltage switch when the transformer is energized. To do so can cause severe injury, death, and damage to property.

Dual voltage switches permit the use of transformers on different primary-voltage systems. They are externally operated with a handle on the side of the tank. Voltage ratings are given at the switch handle and on the transformer nameplate.

The switch handle is held in place by a locking screw. It should be loosened to turn the handle and tightened when the handle has been repositioned. Refer to Figure 53.

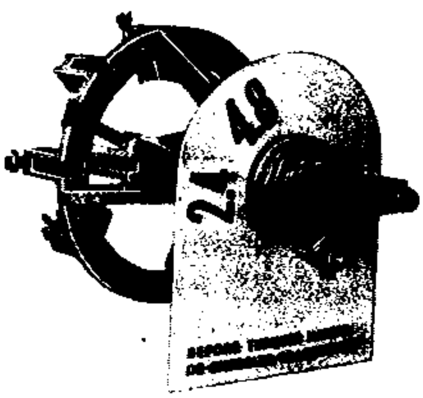

Fig. 53 – Dual-Voltage Switch – Externally Operated

7.11 Receiving, Inspection, Handling, Storage, Installation

A. Shipping Damage

All transformers should be inspected for shipping damage immediately upon receipt. If damage or evidence of possible damage is found, the delivering carrier should be notified. This can be done by making a notation on the way bill when it is signed.

Inspection should give specific attention to porcelain bushings or arresters, oil leaks, tank or enclosure damage, and damage to switch handles, instruments, and accessories.

The transformer manufacturer should also be notified of shipping damage.

B. Storing

No special precautions are required for storing because distribution transformers are built for outdoor service. They should be moved and stored on their shipping skids or pallets, and protected from physical damage.

C. Opening Oil-Filled Transformers

Warning: Relieve pressure in the transformer tank before removing the cover. Static pressure may build up in the transformer tank which must be relieved before the cover is removed or it may be blown off with great force. Failure to heed this caution can cause severe personal injury or death, and damage to property.

It should not be necessary to open a distribution transformer prior to placing it in service. The transformer should not be opened unless it is necessary to repair damage, change taps, or change connections.

Warning: Use great care when a transformer is opened to prevent entrance of moisture or foreign objects. When the transformer is reclosed it must be sealed to prevent either leaking or breathing. Moisture, dirt, or other foreign material in a transformer will weaken the insulation and greatly shorten the transformer life.

D. Lifting

Pole type transformers should be lifted by means of a sling with a spreader bar that is at least as wide as the transformer. The sling should be attached to the lifting lugs and no other part of the transformer. The transformer should never be lifted, or moved, or guided while being lifted by the bushings, arresters, accessory handles, or any part except the lifting lugs.

Pad mounted, submersible, and underground transformers should be skidded on their shipping skids, or if lifted, only with their lifting lugs and with spreader bars on slings to assure that the slings do not damage any parts or rub off any paint.

E. Bushing and Terminal Support Limits

Transformers must be installed so the bushings and terminals are not supporting the weight of heavy cables or bus bars. Spans of unsupported conductor must be avoided. All cables and bus bars must be properly bent and positioned to fasten to bushings and terminals so the force of bending and positioning is not transmitted to any part of the transformer.

F. Tank Grounding

Transformers are provided with tank grounding pads, in some a grounding terminal is included. Many transformers can be operated grounded or ungrounded. Consult the manufacturer's instructions for the specific transformer.

On transformers with surge arresters, the arresters discharge lightning surges through the tank. When tanks are to be operated ungrounded, a tank discharge gap must be used. The gap, normally insulated from ground, sparks over to form a discharge path for dissipating the lightning surge. Transformers are not supplied with a tank discharge gap as standard. Gaps must be specifically ordered.

When installing a transformer, make the ground connection first, the connection to the low-voltage line next, and the high-voltage connection last.

When a transformer is removed from service, all high-voltage connections, including those to protective devices, should be opened before removing the ground connections.

G. Transformer Finish

Transformer tanks and enclosures are finished to provide protection for the service to which they will be applied. Shipping, handling, and installation present considerable hazard to the integrity of these finishes. Care should be exercised in handling and any scratches or abrasions should be repaired immediately. The manufacturer should be consulted for the proper touch-up material.

H. Transformer Oil

Transformers are thoroughly dried at the factory and then filled with dry, de-gassed, inhibited insulating oil. The oil is introduced after the transformer has been assembled, and under vacuum.

Transformers should not be operated with the oil level below the cold oil (25C or 77F) level. Oil of normal dryness and cleanliness will test at 26 kV or higher in the standard test cup, per ASTM test 877.

The user should take the necessary precautions to assure that contamination is not introduced during field filling or maintenance.

I. Mounting

1. *Pole type* transformers are provided with mounting brackets (hanger lugs) depending on their weight. Figure 54 illustrates the three different kinds of support lugs required by ANSI Standards C57.12.20 for different kVA ratings.

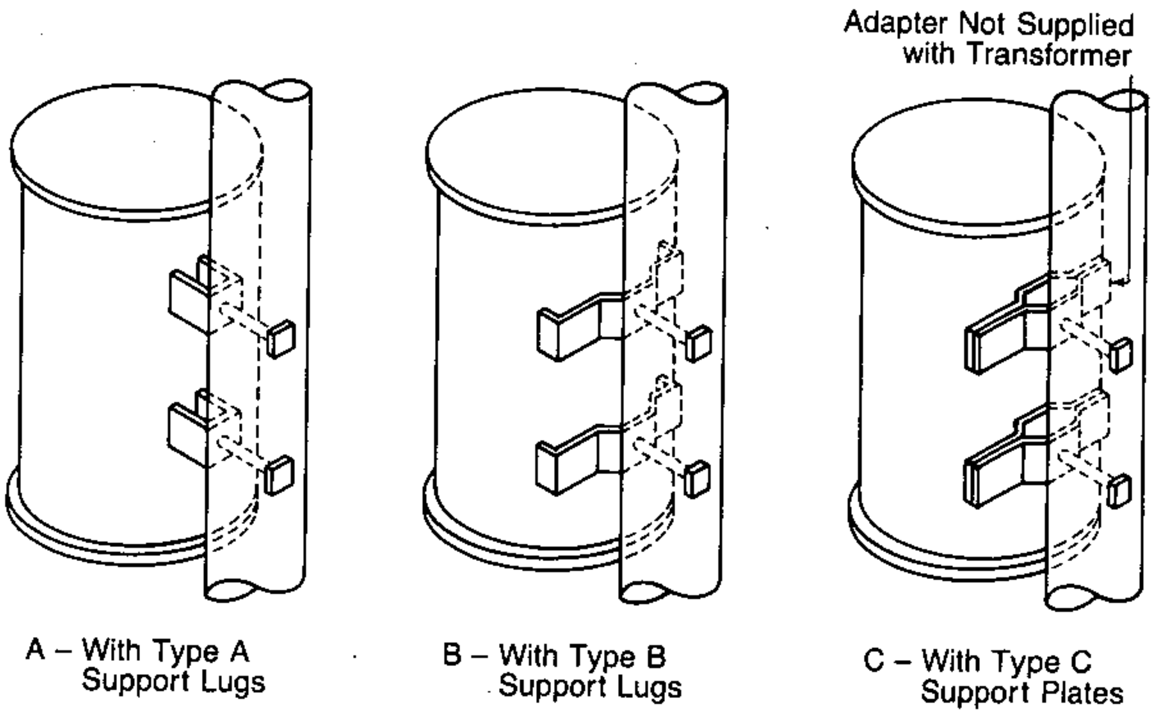

Fig. 54 – Pole-Type Transformer Mounting

It is not recommended that these overhead transformers be mounted to the pole while the pole is on the ground and the transformer is horizontal. These transformers should never be placed in a horizontal position; not while mounting, not during transportation, not in storage. To do so can trap air in the coil and oil and may cause insulation failure when the transformer is energized.

Overhead transformers with tanks 24 inches in diameter or larger should not be installed more than 5 degrees from vertical. Transformers in smaller tanks should not be mounted more than 10 degrees from vertical.

2. *Pad mounted transformers* should be mounted on a level pad strong enough to support the transformer on a stable foundation free from danger of settling, subsidence, or land slippage. The unit should not be tilted in any direction greater than 1.5 degrees.

Hold down cleats or brackets are supplied for attaching the transformer firmly to the pad. See Figure 55 for typical hardware.

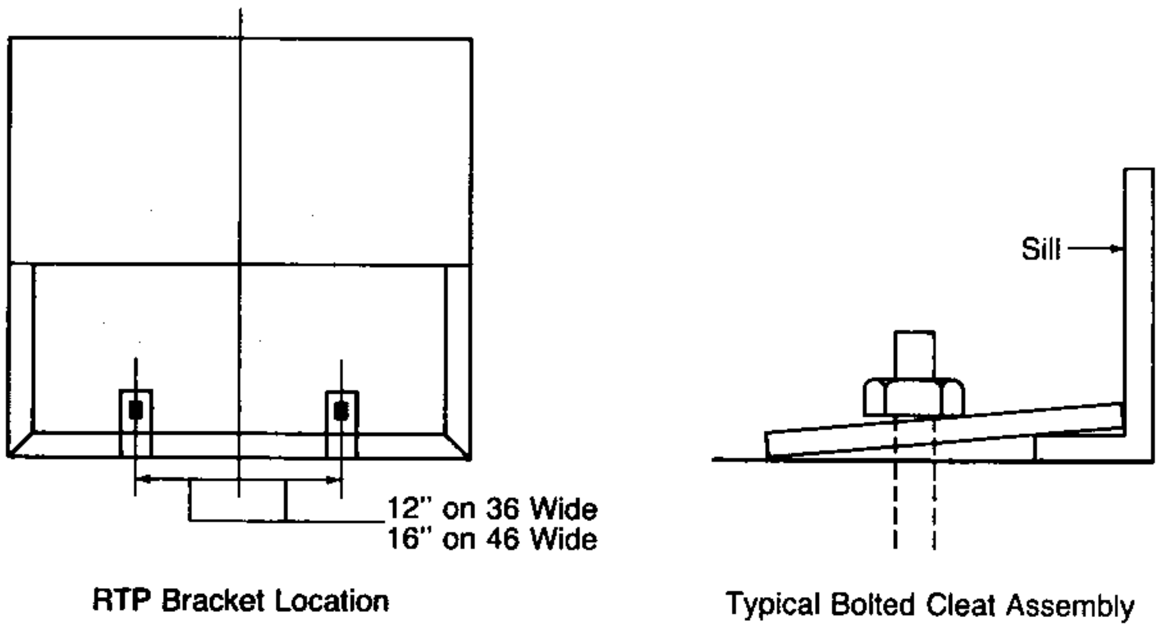

Fig. 55 – Typical Pad-Mounted Transformer Mounting Hardware

c. Elevation at installation should not exceed 3300 feet above sea level (1000 meters) unless the transformer is designed for higher elevation.

d. Ambient temperatures should not exceed 40C (104F) and the average temperature for any 24 hour period should not exceed 30C (86F) unless the transformer is specifically designed for higher temperatures.

e. Continuous kVA should not exceed rating. Short-time overloads do little damage to the transformer when loadings recommended in ANSI Standard C57.91 are not exceeded.

Some transformers are equipped with an internal circuit breaker which permits loading up to full thermal capacity of the transformer. This is considerably above nameplate rating for short-time overloads. The breaker protects the transformer coil from dangerously high short-time overloads and fault currents and also from excessive heat caused by long-time heavy overloads.

f. For transformers not equipped with surge arresters, circuit breakers, and protective links, suitable protection external to the transformer should be provided.

7.12 Operating Limits

Standard transformers are designed to use under the *usual service conditions* described in ANSI C57-12.00 (General requirements for Liquid-Immersed Distribution, Power and Regulating Transformers). All other conditions are considered unusual service and should be avoided unless specific factory approval is obtained. Specific considerations are:

a. Frequency should not be appreciably lower than rating.

b. Voltage applied to the transformer should not exceed its rating by more than 5 percent under full kVA rating or by more than 10 percent at no-load.

1. *Surge Arresters*

Some transformers are supplied with surge arresters mounted on the tank or in the compartment. Their function is to intercept and divert to ground the various overvoltages (such as lightning surges) that occur on distribution systems. The specific manufacturer's instructions should be consulted for proper connection and adjustment.

Transformers with arresters mounted on them must have the arresters grounded to the tank. These connections must be tight when the transformer is installed. Ground connections from the tank or from separately mounted arresters should be completed before any high voltage line connections are made to the transformer.

Transformers with low voltage ratings above 600 volts should have arresters installed on both the high and low voltage side of the transformer.

2. *Protective Links*

Protective links are oil-immersed high voltage expulsion fuses designed to isolate the transformer from the distribution system in the event of a transformer fault inside the tank on the load side of the link. It does not provide overload or secondary fault current protection for the transformer.

Procedure for inspection and replacement of internal links varies with the transformer type and design. The manufacturer's instructions for the specific transformer should be consulted.

7.13. Safety Precautions

Warning: Follow these safety precautions. Failure to do so can cause fire, severe personal injury or death, and damage to property.

a. When a transformer is to be worked on while installed, the primary fuse cutout must be open. The high-voltage and low-voltage bushing terminals must be grounded before the leads are disconnected from the high-voltage bushings.

b. Warning: Relieve pressure in the transformer tank before removing the cover. Static pressure may build up in the transformer tank which must be relieved before the cover is removed or it may be blown off with great force. Failure to heed this warning can cause severe personal injury or death, and damage to property. If a transformer is opened for any reason, care must be taken to prevent any loose articles or foreign material from entering the tank. It must be kept free of moisture and resealed to prevent breathing.

c. For electrical equipment fires use only approved fire extinguishers such as those containing carbon dioxide (CO_2).

d. Never operate tap changers, voltage switches, or make changes on terminal blocks or arrester gaps when transformers are energized.

e. Never apply voltage to a transformer if the oil level is below the proper level. For cover mounted high-voltage bushings, make sure the bottom of the bushing is at least one inch under oil.

f. Overhead transformers with tank diameters over 24 inches must not be installed more than 5 degrees from vertical. Tank sizes 22 inches in diameter and smaller should not be installed more than 10 degrees from verticle.

g. When transformers are not equipped with surge arresters, circuit breakers, and protective links, external protection must be provided.

h. Unless surge arresters are direct connected, make sure the external gap settings are correct before the transformer is energized.

i. The sum of the lengths of line lead to the arrester and the ground lead from the arrester to the transformer should be as short as required to maintain adequate protection. On a pole type transformer this is usually less than 5 feet.

j. Check the transformer nameplate for rating and connections that can be made to it.

k. Never lift a transformer by anything except the lifting lugs.

l. Except where prohibited by codes or laws, transformer tanks must be grounded before the transformer is energized.

m. Avoid contact with an energized transformer tank if it is equipped with a tank discharge gap.

n. Measure the secondary voltage of transformers to be sure the output voltage is correct before connecting a load to the transformer.

o. When three-phase transformers are used in a delta-delta bank, make sure the voltage ratios of all the transformers are the same.

Before the transformer bank is energized on the primary side, the primary delta must be closed, and the secondary delta must be broken or opened at one corner with a small fuse or voltmeter used to close the secondary delta.

If the fuse blows upon energizing of the primary windings, or if voltage appears across the broken delta secondary windings, check for and correct faults such as wrong connections, transformer polarity, etc.

An impedance difference between transformers in the delta-delta bank can cause a small circulating current which makes it necessary to derate the bank.

For units of equal capacity but with a transformer having an impedance different from the other two, the bank derating for balanced loading is approximately as shown below:

Ratio of odd unit impedance to impedance of other two units	Derating Factor
1.6	0.91
1.5	0.93
1.4	0.94
1.3	0.95
1.2	0.97
1.1	0.98
1.0	1.00
.9	0.97
.8	0.93
.7	0.90

p. When transformers are equipped with pressure venting covers, when covers are to be removed, loosen the cover bolt and allow the tank pressure to vent before removing the cover. If not so equipped, operate the relief device.

q. If a fuse in a cutout on the primary side of a transformer, or a protective link inside a protected transformer, is blown, there is the possibility of an internal fault in the transformer. The cutout should not be re-fused unless

It can be re-fused from a location remote from the transformer.

The transformer is replaced then tested to make sure it has not failed.

r. Permitting high overloads on transformers or creating high overloads by using oversized fuses without other protection can cause severe overheating, internal arcing, tank rupture and fire, severe personal injury or death, and property damage.

s. Locate all transformers in accordance with the provisions of ANSI C2 National Electrical Safety Code. Transformers usually contain flammable fluid.

t. Keep transformers upright. Tilting or laying a transformer on its side can cause air to be trapped under the coil when the transformer is righted. Air trapped in the insulation layers can cause coil failure.

u. Remove or dispose of insulating oil or transformers only in accordance with Environmental Protection Agency regulations.

7.14 Maintenance

Warning: Improper or inadequate maintenance can result in reduced transformer life, cause severe personal injury or death, and damage to property.

Refer to 7.13 for safety precautions.

Distribution transformers can be stored for as long as two years when not in service. For longer storage it is recommended that the procedures of ANSI C57.93 be followed.

The following inspections and consequent indicated repairs are recommended for any distribution transformer taken out of service:

a. Inspect porcelain bushings for cracks and leaks.

b. Inspect surge arresters for cracked porcelain. Check gap setting if there is a gap between the arrester top terminal and the HV bushing terminal. Make sure all connections are tight.

c. Remove all rust from tank, prime and paint all spots.

d. Inspect all gasket seals for leaks.

e. Check oil level. It must be within ½ inch of the oil level line inside the tank.

f. Check for signs of moisture entering the tank at gasketed joints.

g. If electrical tests are made, the values given in ANSI Standard C57.12.00 must not be exceeded.

Volume 3
Chapter 8

Protection Devices

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Chapter 8

Protective Devices

8.1 Surge (Lightning) Arresters

Surge arresters do not, under normal conditions, require any maintenance. In very dirty or dusty locations it is sometimes necessary to clean the porcelain weather casing. Wetted contamination on the casing surface affects the operation of the internal gaps by upsetting the voltage distribution of the series gap assembly. The gaps may spark over at a reduced voltage or fail to interrupt the system power current that was initiated by the surge. Failure to interrupt the power current results in the destruction of the arrester. Occasionally the arrester fails violently, destroying the porcelain weather casing which surrounds it.

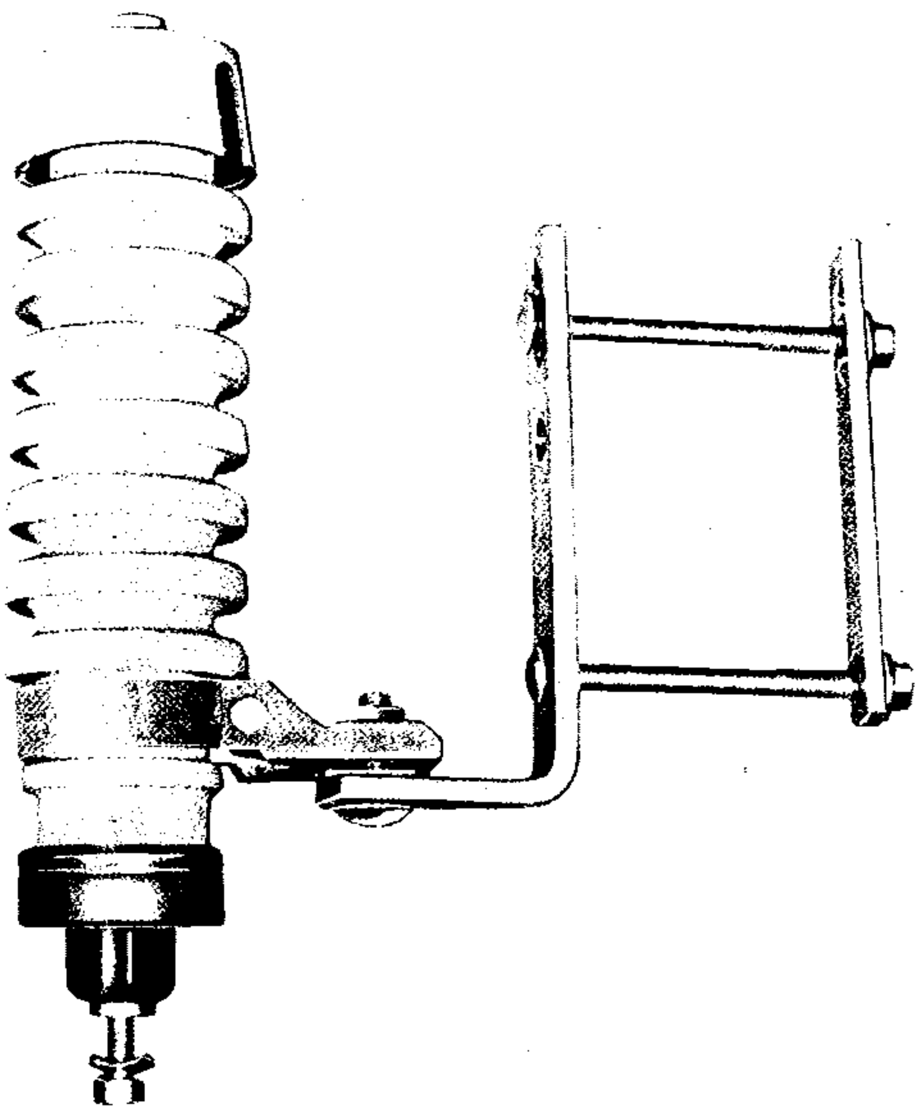

Fig. 1 – Typical Surge Arrester

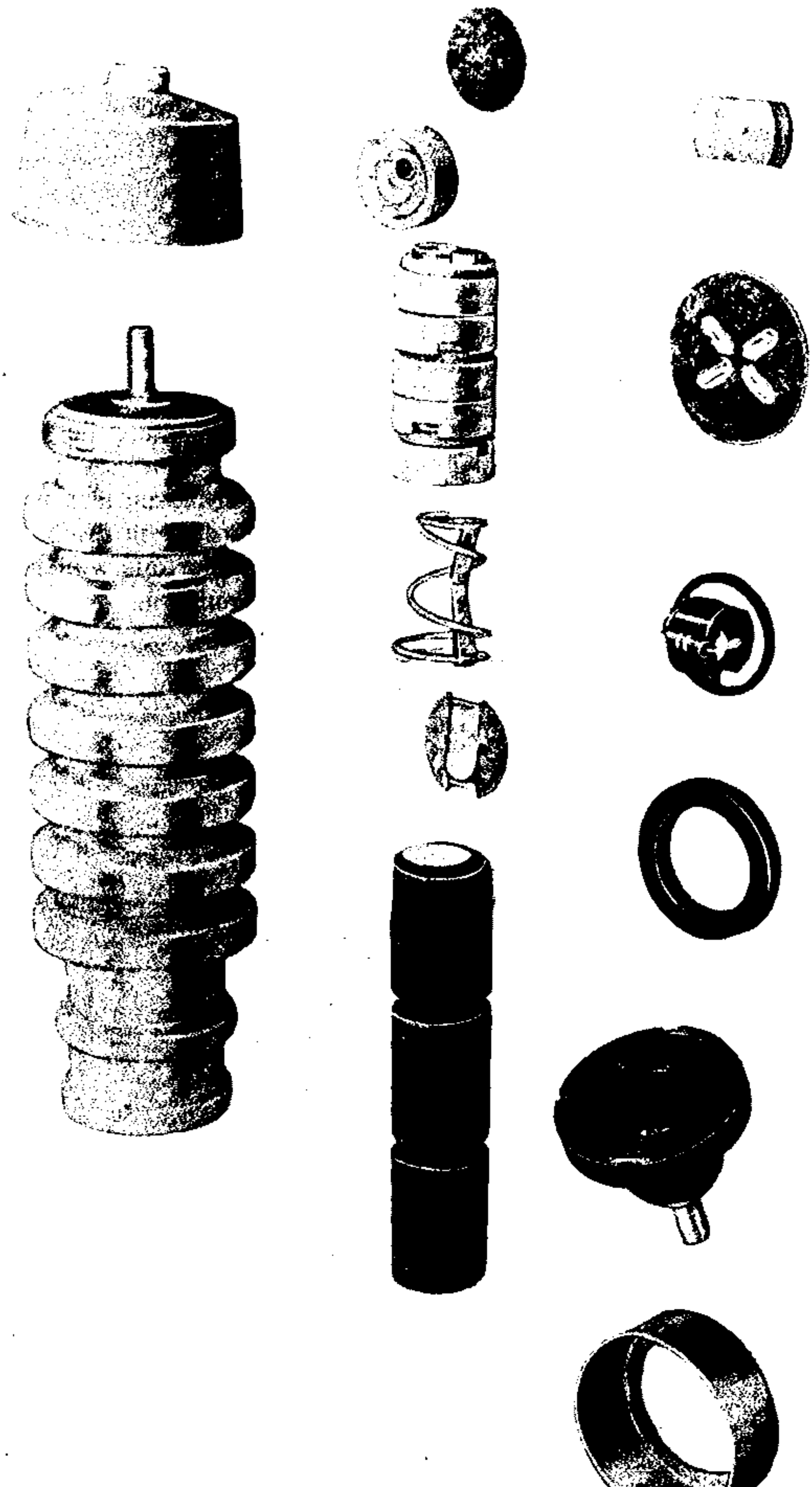

Fig. 2 – Disassembled Surge Arrester

All electrical apparatus has insulation which should be strong enough to prevent any normal voltage from causing short circuits by either puncture through the insulation or by flashover around it. In addition, there should be a margin of insulating strength which will prevent insulation failure at voltages above normal system voltage. It is economically impossible to build enough insulation into power system apparatus to protect it against the high surge voltage caused by lightning.

Lightning is an electrical discharge that occurs in the atmosphere between clouds or between clouds and earth. Very high voltages are built up within a cloud by a process not yet fully understood. When this voltage becomes high enough, the insulating air between clouds or between clouds and earth is broken down and a charge of electricity passes from cloud to cloud or between cloud and earth. The flash of light is an after-effect of the insulation breakdown of the air. Thunder is an after-effect of the sudden heating of the air as the lightning current passes through the stroke channel. The forces capable of causing a voltage high enough to break down hundreds and thousands of cubic feet of air are also capable of breaking down any man-made apparatus insulation.

When lightning strikes any part of a power system, it is certain that the insulation will break down somewhere. If the insulation failure is in the air, such as over the insulators on a transmission line, the failure may be self-restoring. Air quickly regains its insulation strength as it cools after the electric arc has been interrupted. If the insulation failure is inside a transformer, through fiberboard and oil, it will be permanent. Once a break-down path is established by the high lightning voltage, the normal system voltage will cause a short circuit current to flow along the breakdown path.

Lightning does not always cause an insulation failure at the point where it strikes the power system. The process of insulation breakdown has a time lag and the high current injected into the power system by the lightning stroke propagates very rapidly to other parts of the system. The transient voltage caused by the lightning stroke can be increased by reflections so the voltage remote from the stroke point may be higher than at the stroke point. Insulation some distance away from the stroke point may fail before the insulation at the stroke point.

These time delay and reflection effects can be calculated with fair accuracy. The results of the calculations and actual experience have led to a method of protecting apparatus against lightning. Each piece of apparatus in the power system has a rated voltage which is its normal operating voltage. Corresponding to each voltage class is an impulse insulation level which is much higher than the rated voltage. Most apparatus is tested to determine that it withstands its impulse voltage. Not all apparatus with the same operating voltage will have the same impulse voltage strengths.

Transformers and motors designed for the same operating voltage usually have different impulse voltage strengths. Transformers are connected directly to the overhead lines and have a good chance of being subjected to high lightning surges. Motors are usually somewhat protected by having other equipment between them and possible lightning surges. As a result motors have a type of insulation which is satisfactory for the voltages that motors normally meet whereas transformer insulation is designed to withstand high impulse voltages.

The impulse insulation strength for apparatus such as transformers is called the Basic Impulse Level or BIL. Dry-type air insulated transformers usually have a lower BIL than liquid filled transformers.

Since the insulation strength of all electrical equipment is limited and voltages caused by lightning almost unlimited, it is necessary to find some means of protecting electrical equipment from high lightning surges. This is accomplished by use of surge arresters.

A surge arrester is an insulator under normal conditions and has no effect on regular operation of the power system. When a transient voltage high enough to damage other equipment is impressed on the power system, the arrester becomes a low impedance path from the phase wire to ground discharging the transient surge current. After discharging the surge current the arrester again becomes an insulator. Arresters act as safety valves which protect the insulation of electrical equipment from being damaged by lightning surges.

The high voltage caused by lightning lasts a very short time. It does not exist at all parts of the system at exactly the same time but is propagated through the system very rapidly, so the protection afforded by an arrester covers only a limited portion of the system. If the transformer is located too far from the arrester, the transient voltage caused by lightning striking the power system will rise faster than the arrester can drain it off and the transformer insulation will fail. The safest practice is to locate the arresters as close to the transformers as possible.

There are two types of protection for transformers to prevent insulation damage by lightning surges: spark gaps and valve arresters. The latter is the most commonly used. The spark gap design is used in locations where there are very few thunderstorm days.

8.2 Spark Gap

A spark gap is an open gap which flashes over when a high enough voltage is impressed on it. It causes a short circuit to ground which continues even after the lightning surge has passed. The short circuit must be interrupted by a overcurrent device such as a recloser or fuse.

8.3 Valve Surge Arrester

Valve type arresters consist of a series of small air gaps and a power current limiting resistive element. The small gaps are able to interrupt small currents but not high currents like the system fault current. The valve element is a non-linear resistor which offers high resistance to power system currents and low resistance to lightning surge currents. In effect, the non-linear resistor holds fairly constant voltage across the arrester over a wide range of surge currents. In operation the high voltage is caused by lightning sparking over the gap and for a short time a high lightning surge current flows to ground through the arrester. The valve element resistor limits the system power current to a low value so the gaps can interrupt the current at the next voltage zero after sparkover. Valve arresters can be applied at any point on a system without taking the short circuit current into account.

Application of Valve Type Distribution Arresters

Maximum System Phase-to-Phase Voltage

Arrester Rating kV	Multi-Grounded Neutral Service	Effectively Grounded Neutral Service	Ungrounded Neutral Service
3	4,500	3,750	3,000
6	9,000	7,500	6,000
9/10	14,500	12,500	10,000
	17,100	15,000	12,000
12			
15	21,400	18,000	15,000
18	25,000	22,500	18,000

Surge arresters are almost always applied between the phase wires and ground because the lightning currents must be diverted to ground. Occasionally, arresters are connected around a series coil or reactor as protection for that one element. Distribution valve arresters are sensitive to the applied voltage; they will not interrupt the system power current if the system voltage exceeds the rating of the arrester and the arrester will fail. It is important that arresters be applied so the maximum system voltage that can appear across their terminals under any conditions is not higher than their rated voltage. On some systems, the normal voltage between phase and ground can be substantially exceeded during fault conditions.

Where the neutral is not grounded, a fault to ground on one phase may raise the voltage between the other two phases and ground higher than the normal phase-to-phase voltage. Arresters on this type of system must be rated above the normal voltage. Where the neutral is multi-grounded the highest phase-to-ground voltage under the worst condition may be slightly higher than the normal phase to ground voltage. For other types of system grounding, the maximum voltage between an unfaulted phase and ground may range between the two extremes. The selection of the arrester rating should be made on the basis of past experience or reference to industry tables. If there is doubt as to the proper rating to be applied an arrester manufacturer must be consulted.

8.4 Fuse Cutouts

Primary fuse cutouts serve to protect the transmission lines, transformers, and loads of a distribution system from burnout due to heavy instantaneous fault currents or continuous overcurrents.

The principle of the fuse cutout is essentially the same as that of the simple fuses found in many homes. A small piece of soft conducting metal (usually an alloy) which melts at a relatively low temperature, is placed in series with the line current so an overload will heat the link. This causes it to break and form an open circuit.

However, on a primary distribution circuit, the voltage and current are of such a magnitude that a more elaborate device is needed to prevent violent and continuous arcing across the open contacts.

A. Construction and Operation

To prevent continuous arcing, a construction is used in which the arc generated when the link melts is extinguished and the distance between the contacts is greatly increased to prevent restrike. The fuse link itself, supported at both ends by a flexible pigtail conductor, is placed inside a tough fiberlined tube. The lower end of the pigtail is then used to set a dual purpose flipper latch spring and is wound around a bolt and secured by a nut. During a fault, the fuse link melts and a momentary high temperature arc results. A portion of the fiber lining then vaporizes forming a de-ionizing gas which dilutes and cools the conducting path of the arc with small nonconducting particles. The arc is then extinguished at the first current-zero.

When the arc is disposed of, the flipper latch first prevents restriking by pulling the lower half of the broken pigtail out the bottom of the fuse tube. It is helped in this process by the exhaust blast of gases which tend to carry the link along. Second, the latch releases a toggle mechanism which drops the fuseholder straight down, freeing it from the upper contact. This allows the fuseholder to swing to a full open position, providing easy identification of a fault interruption and also providing an added safety measure against restriking. Do not allow fuseholders to hang in the open position for long periods of time; moisture collected may cause damage by swelling of the fibre tube.

B. Application

Fuse cutouts are used extensively in primary feeders as a fuse for clearing faulted circuits and as a disconnect device for isolating parts of a de-energized circuit for maintenance. A third and often convenient function is breaking the circuit under load. This will be explained later. Cutouts are used mainly where faults and overloads are rare since after each interruption a lineman must be sent to change the fuse. Although the first cost of a cutout is very low, a circuit breaker, recloser or sectionalizer may be more economical in the long run if faults are frequent.

Cutouts are rated according to the voltage of the circuit, the continuous current carrying capacity and the maximum short-circuit current interrupting capacity. For any individual case, the continuous current is of course limited by the fuse link installed. Voltage ratings range from 2.6 kV to special cutouts made for 34.5 kV. Continuous current capacity is usually 100 amps. Interrupting capacities range from 2000 amps at high voltages to 20,000 amps at lower voltages. These interrupting capacities are limited by fuse tube construction. For standard duty, paper base tubes are used; for extra-heavy duty, glass epoxy tubes are necessary.

C. Types of Fuse Cutouts

1. *Open Type*

Two basic types of cutouts are in common use, open and enclosed. A typical open type cutout is shown in Figure 3.

A safe, economical, dependable and self-sufficient loadbreak cutout is shown in Figure 4. The loadbreak cutout operates by the use of a plastic arc-chute in which are placed a set of contacts and a snap-action stainless steel blade. These contacts are in parallel with the main contacts. When loadbreaking is desired, the cutout is pulled open with a hookstick – this is the only action necessary by the lineman. The main contacts are first pulled open; but current is still carried by the parallel contacts and the steel blade. When the main contacts are far enough apart to prevent restriking, the blade snaps away from the contacts within the arc-chute, drawing a short, hot arc. The heat of the arc causes the plastic to generate a de-ionizing gas which extinguishes the

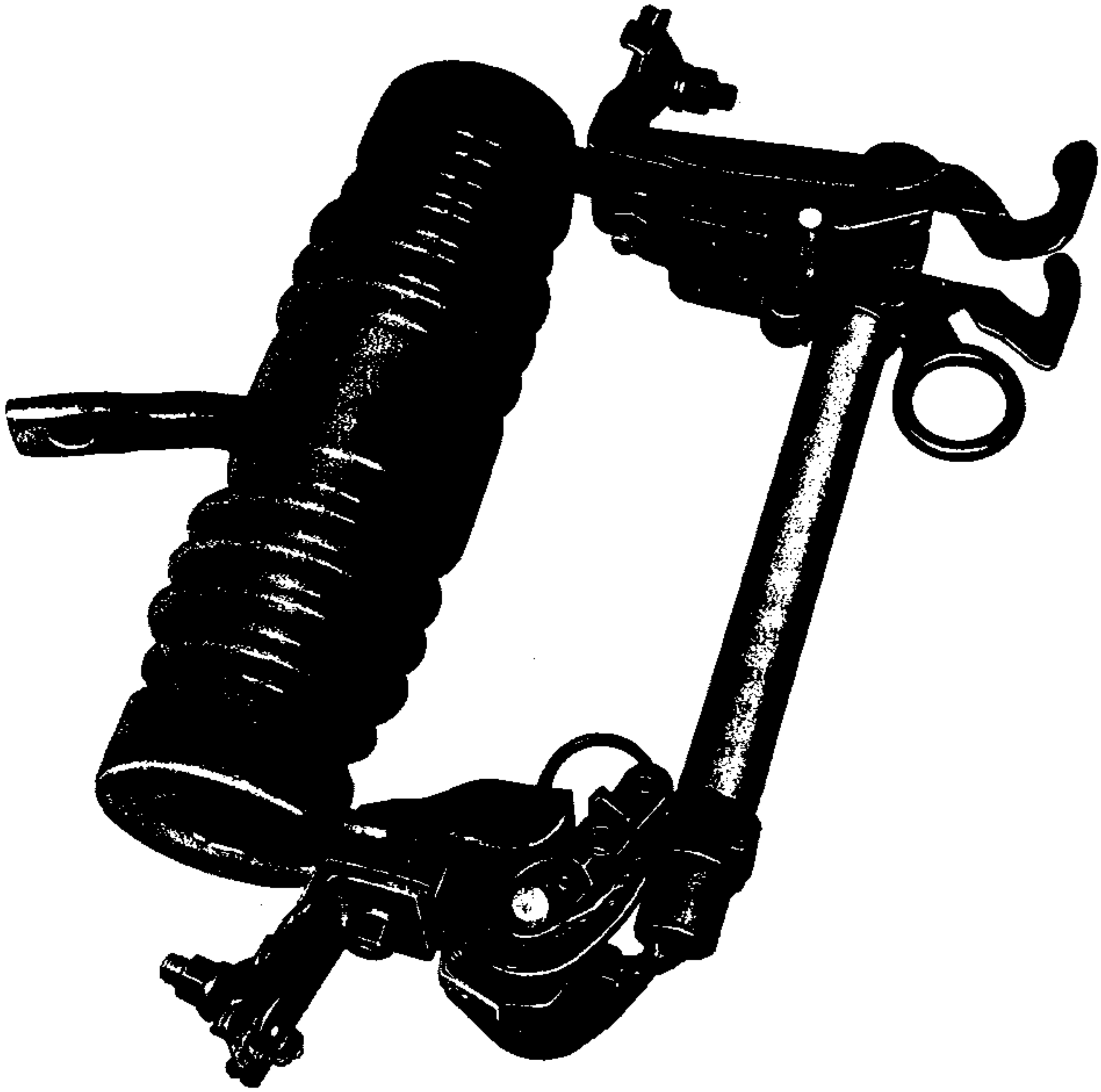

Fig. 3 – An Open Fuse Cutout

arc. This device is capable of interrupting 200 amps over 200 times with no damage to the cutout.

This type of loadbreak cutout has one big advantage over older conventional methods – no maintenance. In the oldest loadbreak device, a long lever was provided which, when pulled with the hookstick, broke the link inside the tube thus interrupting the arc. Obviously, the link had to be replaced after each operation. Also, this method was not very reliable or even safe since the link sometimes pulled away from the clamp at the bottom of the tube instead of breaking. This causes an arc which could result in injury to the lineman.

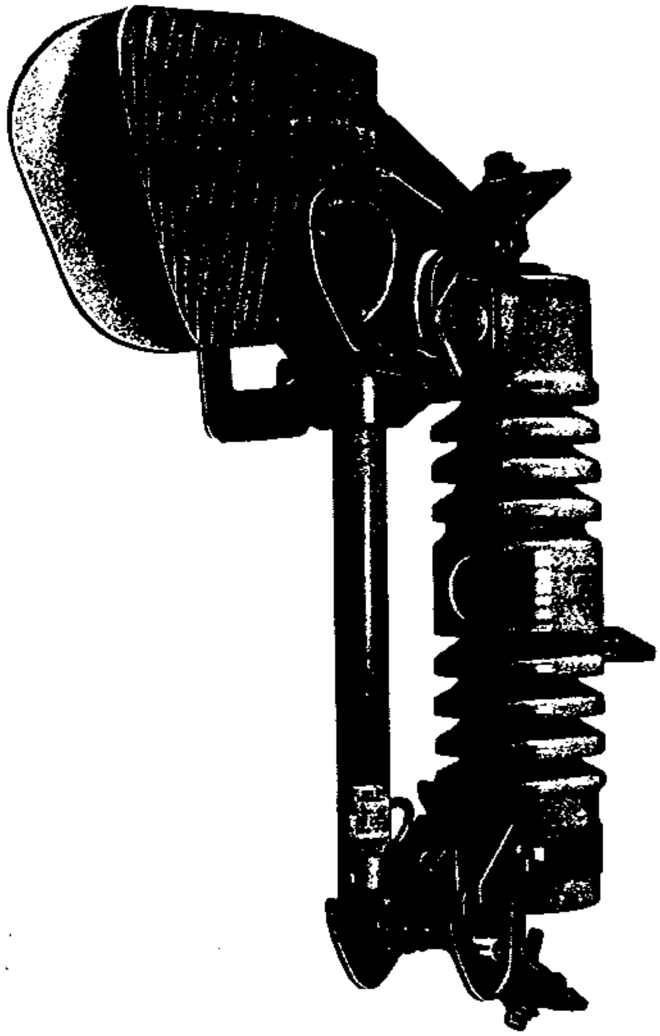

Fig. 4 – An Open Loadbreak Fuse Cutout

A second method consisted of using a gas capsule which ruptured during a loadbreak operation and sprayed a gas through the path of the arc, blowing it out. However, high winds could prevent the gas from reaching the arc; also, the capsule had to be replaced which cost about as much as a fuse link.

A third method employed the use of a separate loadbreak tool which was placed in parallel with the fuseholder of the cutout. The arc was then interrupted within the parallel tube when the cutout was pulled open. However, the first cost of this device was very high and it also required maintenance.

2. *Enclosed Type*
A typical enclosed type fuse cutout is shown in Figure 5. The enclosed type cutout operates on essentially the same principle as the open type,

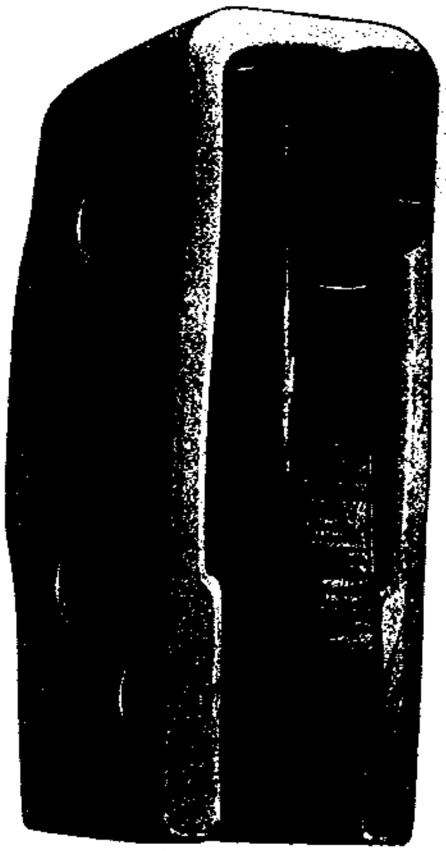

Fig. 5 – An Enclosed Fuse Cutout

but the operating mechanism is completely surrounded in a porcelain box, with the fuse tube supported in a molded plastic door. They are generally available in low and high voltage ratings. The low voltage version is used in low voltage systems and where fault current capabilities of the line are limited. They can also often be used on single phase legs of three phase systems when the systems are solidly grounded. For example 7.8 kV cutouts, either open or enclosed, can be used on single phase legs of 15 kV line-to-line three phase, multi-grounded wye systems. The 7.8 kV enclosed cutouts are much less expensive than the 15 kV open cutouts.

D. Fuse, Recloser, and Sectionalizer Coordination

The main problem in the use of fuses is coordination. Coordination means clearing the short circuit or overload by blowing only the correct fuse. The selection of the size and type of link to be used depends on many considerations. For instance, when using a fuse for transformer protection, voltage and kVA rating, magnitude of secondary shorts and overloads possible, length of the secondary, and the degree to which the transformer can be overloaded, all play a part in determining the size of the link. Tables are available to determine fuse link sizes approximately. Refer to the manufacturer for specific information.

When using a fuse for sectionalizing, three main factors must be considered. First, the fuse must not blow on temporary faults. For example, when a fuse is backed up by an automatic recloser placed nearer the source, it must withstand the instantaneous surge of short circuit current before the recloser opens and closes back in. Then if the fault is off the line, there is no interruption.

Second, if this same fault were permanent, the fuse must blow to protect the line from burndown. So the fuse must be chosen to blow between maximum and minimum permanent fault current values as determined by line parameters.

Third, if two fuses are in series or if fuses are contained in different branches of the network, only the fuse nearest the fault should blow, thus putting a minimum of the system out of service.

Fuse link curves are available on which are plotted time-current melting characteristics of the links. These are used to determine proper sizes for coordination. For example, when two fuses are in series, the one farthest from the source is usually designated the protecting link; the other is the protected link. The curves of these must be compared to insure that total clearing time of the protecting fuse is less than the melting time of the protected fuse. Consult the manufacturer.

When coordinating fuse links with reclosers, on the first instantaneous opening of the recloser, the recloser should protect the fuse; on subsequent time delay openings of the recloser, the fuse should protect the recloser. However, this arrangement is often difficult to achieve. For this reason, oil-filled sectionalizers are frequently used for coordination with reclosers or reclosing circuit breakers. This is usually the practice when frequent faults are expected or when user service is critical, such as hospitals, and industrial plants.

8.5 Power Fuses

Power fuses are used in places where the short circuit current is higher than the interrupting rating of fuse cutouts. The principle of operation is the same, to lengthen the arc path and to get rid of the hot conducting gases.

The wide variety of electrical and operational requirements in distribution and transmission circuits has resulted in the development of a number of types of power fuses. Some designs are derived directly from the

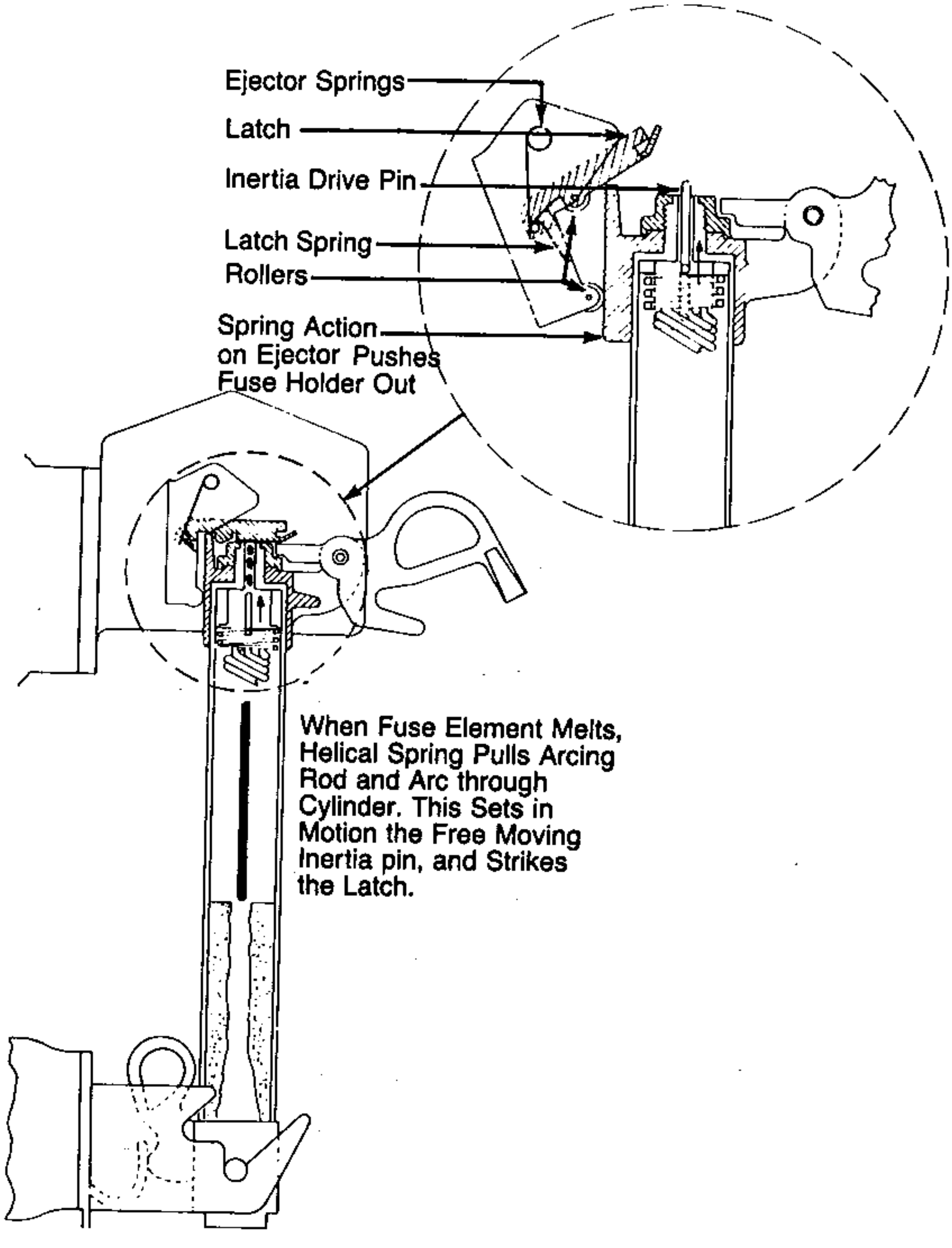

Fig. 6 – Dropout Power Fuse Construction

distribution fuse cutout and except for being designed for higher voltages and interrupting currents retain their essential features.

With larger currents and higher voltages the amount of expelled incandescent gases becomes a problem which affects the required clearances, particularly if the fuses are allowed to vent at both ends. Design variations are directed mainly toward a better solution of this problem, the ideal being a fully enclosed, non-venting fuse.

Range of Ratings
Standard power fuse voltage ratings range from 2.4 kV to 69.0 kV and continuous currents (E ratings) from 1/2 ampere to 400 amperes. Some current-limiting fuses operate on circuits where the available fault current is as high as 80,000 amperes symmetrical. In general, the higher the voltage rating, the lower is the continuous current as well as the interrupting current for which fuses can be produced.

The letter E in connection with continuous current ratings of power fuses designates a characteristic defined by the national (NEMA and ASA) fuse standards. It means that a fuse of an E rating of 100 amperes or less has a melting time of 300 seconds at a current between 200% and 240% of its rating, while fuses with a current rating above 100 amperes must melt in 600 seconds at a current between 220% and 264% of their rating. At higher currents, fuses will melt in shorter time. The relation between current and melting time of any fuse is given by its melting time-current characteristic. According to standard rules, the curves are drawn through the minimum test points obtained at 25C. ambient temperature without preloading of the fuse. If the fuse is loaded or if it is exposed to higher ambient temperature, it will melt in a shorter time or at a lower current than indicated by the melting time-current curve.

For application and coordination, it is necessary to establish a margin of safety with respect to the melting curve. This margin takes into account the ordinary operating variables of load and ambient temperature. Adding this safety zone at the left side of the melting curves results in Short Time Loading time-current characteristics. They are published for most power fuses and can be used for the purpose of application and coordination under all normal service conditions. For these same purposes, it is necessary to also know the maximum time it will take a fuse to clear a fault at a given current. These limits are given by the Total Clearing time-current characteristic. This curve is plotted for fuses without preloading and takes into account maximum manufacturing tolerances. The Standards consider that these tolerances are covered by the 20% range allowed for the melting currents as specified in the definition of E ratings. The fact that actual manufacturing tolerances usually are smaller, combined with the effect of preloading, results in clearing times normally being shorter than the values indicated by the characteristic.

Good fuse coordination results in the faulty circuit being cleared in such a way that service is interrupted to the smallest number of users. The matter is dealt with in terms of protecting and protected devices. The protecting fuse must clear the circuit before the protected fuse is in danger of melting. The easiest way to make sure of this is to superimpose the short-time loading characteristic of the protected fuse on the total clearing curve of the protecting unit. The two curves must cross at a current higher than the maximum fault current possible in the given section of line. When more than two fuses are in series, the coordination should be checked for each pair of adjacent fuses.