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The Application of the Jellyfish Search Algorithm for Solving Modified Economic Load Dispatch Considering Prohibited Operation Zones, Varied Load Demand, and Solar Photovoltaic Plant

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Abstract

In this research, an expanded version of the original economic load dispatch problem (EELD) is concerned to optimize operation of power plants in power systems. While solving the problem, the power supplied from solar energy is considered in addition to the conventional thermal power plants. The main objective function of the research is to minimize the entire electricity generating cost (EEGC) of all thermal power plants in the systems. On top of that, the unactive operating areas belonging to thermal generators and the fluctuating load demand throughout 24 hours are also validated. Moreover, the power supplied by the unique solar power plant is also varied within 24 hours. Two meta-heuristic algorithms, including the artificial hummingbird algorithm (AHA) and the jellyfish swarm algorithm (JFSA) are applied to solve the EELD problem. Both AHA and JFSA are tested for finding the raw performance on the power system with six thermal power plants and one solar power plant. The results obtained by the two applied algorithms indicate that JSFA is completely superior to AHA in all comparing criteria. Hence, JFSA is acknowledged as an effective computing method, and it is highly recommended to be used for the EELD.

Keywords: Expanded economic load dispatch, solar energy, thermal power plant, artificial hummingbird algorithm (AHA), jellyfish swarm algorithm (JFSA).

INTRODUCTION

Solving the economic load dispatch problem (ELD) plays a vital role in power system operation [1–2]. An optimal solution to the ELD problem can benefit both the economic and environmental perspectives. Most of the previous studies on the original ELD problem focused on solving the problem with fixed load demand, and thermal power plants were the only generating sources. But lately, the original ELD has been expanded to different versions that consider the presence of renewable generating sources (RESs) and fluctuating load demand within 24 hours [3–4]. The new versions under research in these studies are named the expanded economic load dispatch problems (EELD). Minimizing the entire electricity generating cost (EEGC) of thermal power plants is mostly considered in both the ELD and EELD problems. Nowadays, the global warming phenomenon is becoming more severe in all aspects of human life. In these circumstances, the use of

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RESs such as wind and solar energy is considered more important than ever. In solving ELD and EELD problems, the presence of RESs can partly minimize the EEGC by serving the load demand at rush hours [5–6]. By acknowledging the advantages of utilizing RESs, many papers are published about solving the EELD problems by incorporating different levels of power supplied from wind and solar energy.

In the past two decades ago, meta-heuristic methods have proved itself to be the most effective computing method for dealing with high-degree complicated optimization problems. ELD and EELD are also acknowledged the typical optimization problems. The application of meta-heuristic algorithms for solving ELD problem can be found in previous research such as Genetic algorithm (GA) [7], Nondominated sorting genetic algorithm II (NSGA) [8], Particle swarm optimization (PSO)[9], Genetic algorithm (GA), Pattern search (PS) and Sequential quadratic programing in [10], the Improved bacterial foraging algorithm (IBFA) [11], Grey wolf optimal (GWO) [12], the Artificial algae algorithm (AAA) in [13], Double-weighed particle swarm optimization (DW-PSO) [14], PSO with jumping time-varying acceleration coefficient (PSO-JTVAC) [15], Differential evolution (DE) in [16], hurricane optimization (HO) and sine-cosine optimization (SCO) in [17], Quantum particle optimization (QPSO) [18], The improved Manta ray optimization (IMRO) [19], The particle swarm optimization with simplex search method (SSM-PSO) [20], The improved bird swarm optimization (IBSA) [21], Distributed roust optimization (DRO) [22], Hybrid grey wolf optimizer [23], Salp swarm optimization [24], The improved firework algorithm (IFA) [25].

In this research we applied two novel meta-heuristic algorithms, including Artificial hummingbird algorithm (AHA) [26] and Jellyfish swarm algorithm (JFSA) [27] to solve the EELD problem. Moreover, the unactive operating areas (UOAs) of thermal generators, the presence of solar power plant, and the fluctuating load demand within a day are also evaluated.

The main contributions of the research can be listed as follows:

- Apply two novel meta-heuristic algorithms to solve the EELD problem successfully.
- The unactive operating areas (UOAs) of the thermal generators, the power supplied from solar energy, and the fluctuating load demand throughout a day are fully considered while solving EELD problem.
- Prove the superior performance of JFSA over AHA while solving the EELD problem by using numbers and graphs.
- Indicate the positive effect of using solar power plant to minimize the EEGC of all thermal power plants.

Besides the introduction, other sections of the research are ordered as follows: The problem formulation is presented in Section 2, the computing method is introduced briefly in Section 3, the results and discussions are shown in Section 4, and the final conclusions are revealed in Section 5.

PROBLEM FORMULATION

The Main Objective Function

As mentioned earlier, the main objective function of the paper is to minimize the entire electricity generation cost (EEGC). The objective function is shown below:

$$Minimize\ EEGC = \sum_{n=1}^{N_G} \alpha_n + \beta_n G_n + \gamma_n G_n^2 \ with\ i = 1, \dots, N_G \quad (1)$$

Where, α_n, β_n and γ_n are coefficients of consuming fuel of thermal power plant, G_n is the amount of power generated by thermal power plant *n*.

The Constraints

- *The constraint of power balance between generating side and consuming side:* The constraint is very important to keep the frequency of power system within a predetermined allowable range. Generation power and consuming power must follow the model below:

$$\sum_{n=1}^{N_G} G_n + PSL - (DM + PL) = 0 \quad (2)$$

Where, $\sum_{n=1}^{N_G} G_n$ is the entire power generated by all thermal power plant in the power system, PSL is the power supplied by solar power plant, DM and PL are, respectively, the power demand and the power loss in transmission lines. The value of PL is determined by using the Equation (3):

$$PL = \sum_{n=1}^{N_G} \sum_{m=1}^{N_G} G_n A_{nm} G_m + \sum_{n=1}^{N_G} A_{0n} G_n + A_{00} \quad (3)$$

Where, A_{nm}, A_{0n}, and A_{00} are the loss coefficients, G_n and G_m are, respectively the power generated by thermal power plant *n* and *m*.

- *The constraint of generators in their operation:*

$$G_n^{min} \le G_n \le G_n^{max} \quad (4)$$

Where, G_n^{min} and G_n^{max} are the minimum and maximum power generated by the thermal power plant *n*.

- *The unactive operating areas of generators:*

$$G_n \in \begin{cases} G_n^{min} \le G_n \le G_{n1}^{p} \\ G_{nw-1}^{q} \le G_n \le G_{nw}^{p}; w = 2, \dots, o; \forall n \in \Omega \\ G_{no}^{q} \le G_n \le G_n^{max} \end{cases} \quad (5)$$

Where, o is the number of the unactive operation areas of the thermal power plant *n*.

THE COMPUTING METHOD

Jellyfish swarm algorithm (JFSA) is nature-inspired meta-heuristic algorithm proposed by J.S. Chou and D.N. Truong at early 2021 [27]. The update mechanism for new solutions of JFSA is lean on the simulation of the Jellyfish movement in the ocean. The mathematical model of the update mechanism is presented below:

$$J_x^{new} = \begin{cases} J_x + \varepsilon \times RD(ub_x - lb_x) \\ J_x + JD \end{cases} with\ x = 1 \dots Pz \quad (6)$$

Where, J_x^{new} and J_x are the new and current location of Jellyfish *x* with *x* = 1, … Pz and Pz is the population size; ε is the motion coefficient and ε is set by 0.1 for the best performance; RD is the random number between 0 and 1; ub_x and lb_x are the upper and lower limitation of the search space. JD is the jump distance and its value is calculated by using the equations below:

$$JD = RD \times NF \quad (7)$$

with

$$NF = \begin{cases} J_{RS} - J_x & \text{if} \quad Fi_{RS} - Fi_x \\ J_x - J_{RS} & \text{if} \quad Fi_x - F_{RS} \end{cases} \quad (8)$$

In Equations (7) and (8), NF is the navigating factor; J_{RS1} and F_{RS} are, respectively, Jellyfish randomly selected in the population and its fitness value.

RESULTS AND DISCUSSIONS

In this section, two meta-heuristic algorithms, including the Artificial Hummingbird Algorithm (AHA) [26] and the Jellyfish swarm algorithm (JFSA) [27], are applied to solve the expanded economic load dispatch (EELD) in 24 hours per day. The power system utilized in the research consists of six thermal power plants and one solar power plant. The power system must fulfill a fluctuating load demand throughout 24 hours so that the EEGC of each hour is a minimum. The description of the fluctuation load demand and the power output supplied by the solar power plant is shown in Figure 1.

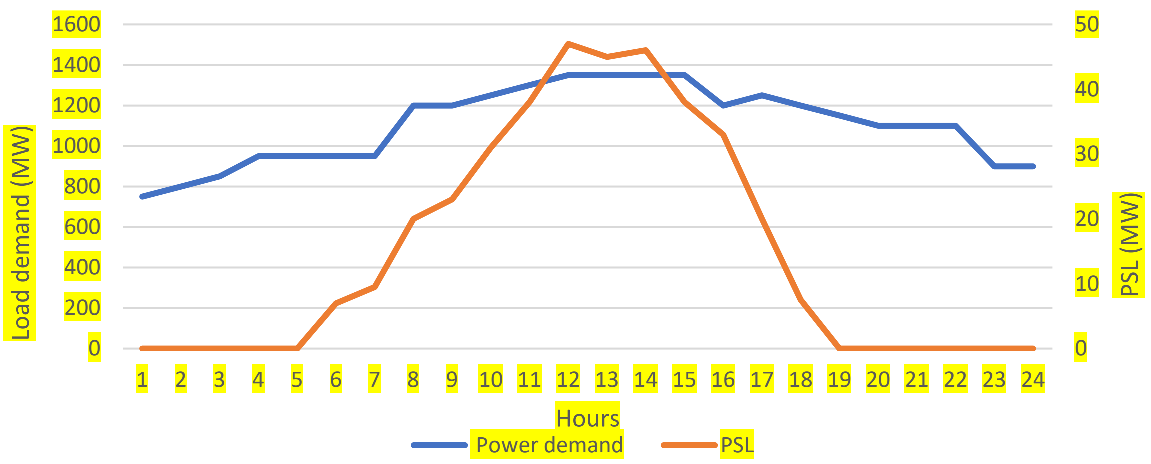

Figure 1. The fluctuation load demand and power supplied by solar power plant throughout 24 hours.

AHA is also a new meta-heuristic algorithm recently proposed by Weiguo Zhao et al [26]. The implementation of AHA is aimed at showing a clear comparison in real performance with JFSA. To have a fair comparison, the initial parameters of the two applied methods, the population size, maximum number of iterations, and number of independent runs, are set to 15, 50, and 100 respectively.

All related work is done on a personal computer with a central processing unit (CPU) clock speed of 2.3 GHz and 8 GB of random-access memory (RAM). The MATLAB software version 2019a is used to run the entire coding script and simulation.

In Figure 2, the fitness values after 100 independent runs at the lowest load demand are shown. The red line illustrates the values obtained by JFSA, while the blue one shows the values reported by AHA. Throughout 100 independent runs, JFSA can reach more minimum values of the main objective function, while AHA cannot reach even one. Moreover, the fluctuations in fitness values between independent runs of AHA are much greater than those of JFSA. That means JFSA is completely more stable than AHA while dealing with the EELD.

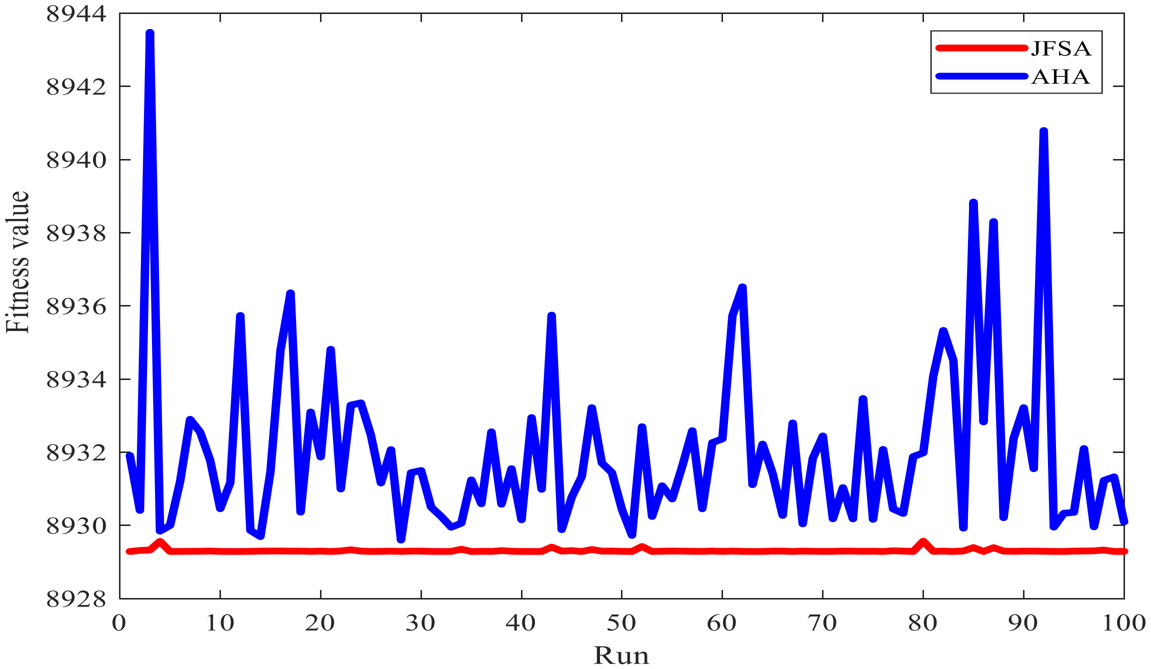

Figure 2. Results after 100 runs at the lowest load demand–hour 1.

The best convergences given by both AHA and JFSA are shown in Figure 3. The figure also uses the same legends as Figure 2. By observing, JFSA only requires approximately 30 iterations to reach the optimal values of EEGC, while AHA cannot reach any even if the last iteration is used. That means, JFSA provides a faster response capability with better efficiency than AHA. The claim is enhanced in Figure 4. Specifically, there are four comparing criteria in the figure, including Minimum EEGC (Min EEGC), Average EEGC (Aver EEGC), Maximum EEGC (Max EEGC) and Standard deviation (Std EEGC). The evaluation of these criteria indicates that JFSA is completely superior to AHA in all aspects.

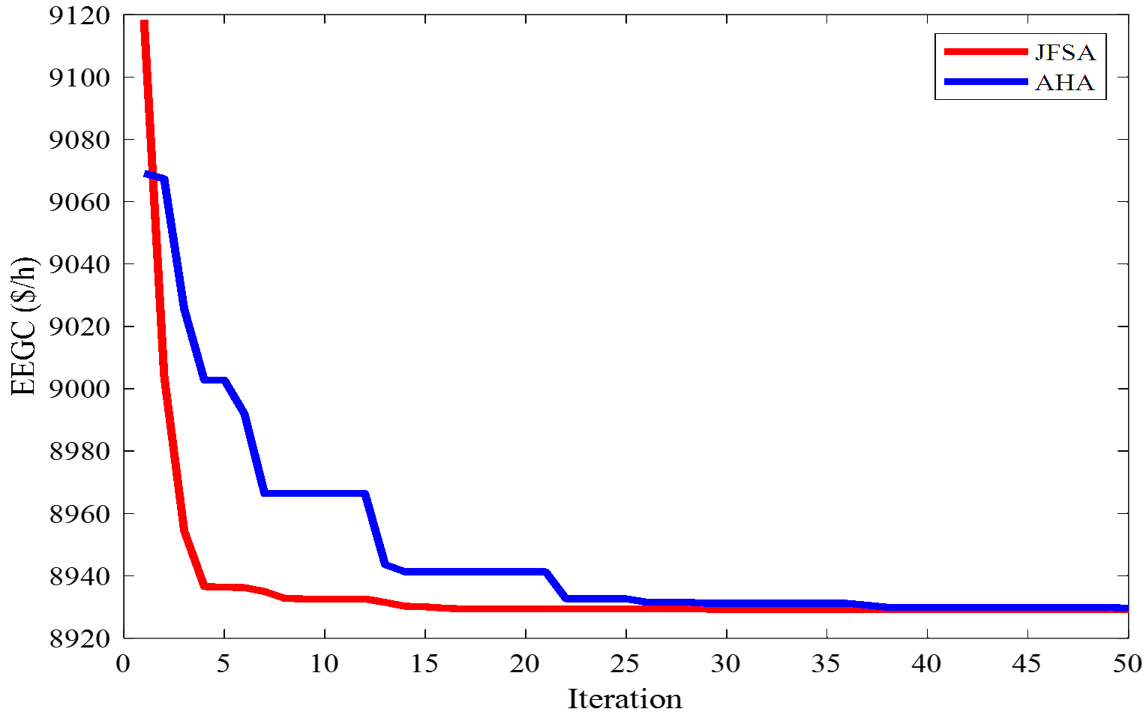

Figure 3. The best convergences given by the two applied methods at lowest load demand hour–hour 1.

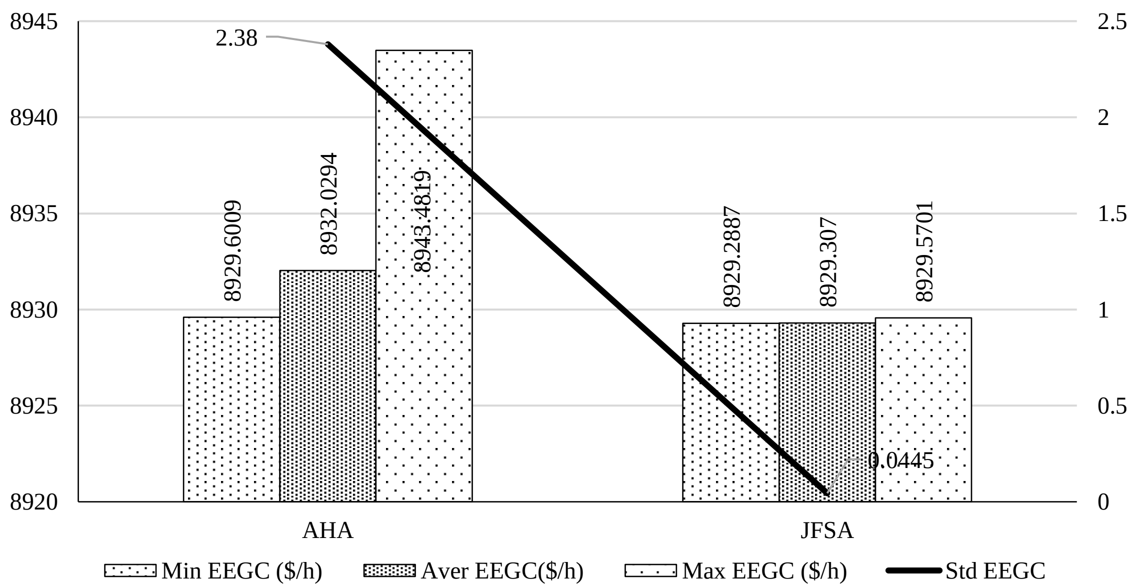

Figure 4. The comparison of AHA and JFSA on different criteria at the lowest load demand hour – Hour 1.

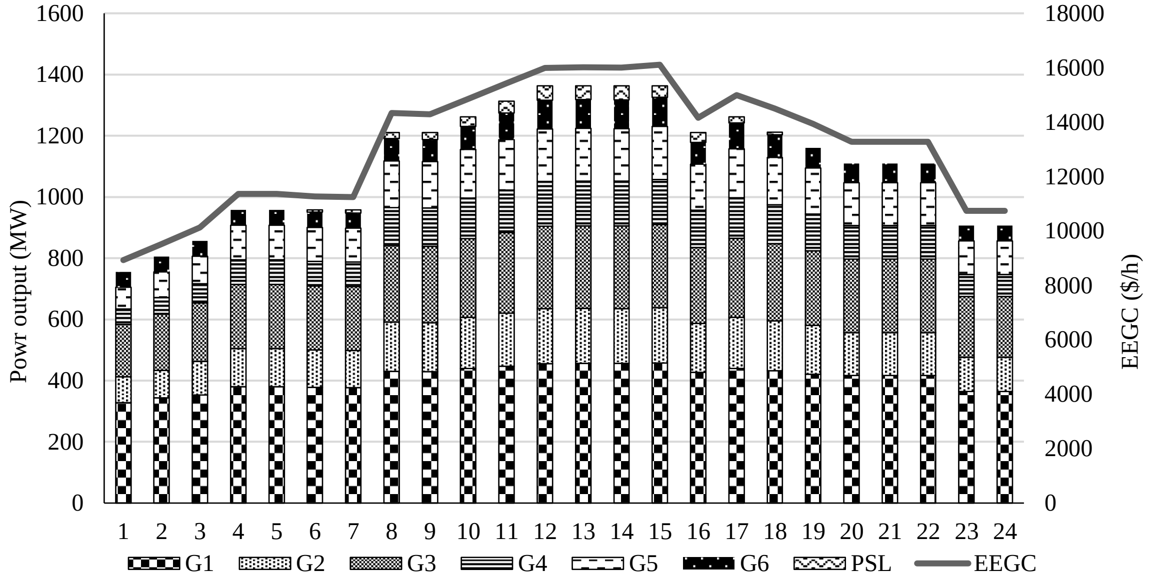

Figure 5. Power output of the six thermal power plants and EEGC value obtained by JFSA throughout 24 hours.

In Figure 5, the power output of the six thermal power plants, the power supplied by the unique solar power plant, and the EEGC in each hour are shown.

CONCLUSION

In this research, the artificial hummingbird algorithm and the jellyfish swarm algorithm were successfully applied to solve the expanded economic load dispatch problem (EELD). In addition, the unactive operating areas of thermal generators, the power supplied by solar power plants, and the fluctuating load demand within 24 hours are all evaluated in the research. JFSA shows the outstanding performance over AHA throughout the test conducted in the power system with six thermal power plants and one solar power plant. Specifically, JFSA not only reaches more optimal values after 100 independent runs but also provides a quick response capability. Furthermore, JFSA consistently outperforms AHA in various comparison criteria such as Min EEGC, Average EEGC, Maximum EEGC, and Std. Therefore, JFSA is considered the most effective computing method for dealing with EELD problems. In the future, JSFA should be improved more to achieve higher efficiency while dealing with large-scale optimization problems with a huge number of control variables.

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