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Optimal Allocation of Thermal Generating Sources in Solving Clean Energies – Economic Load Dispatch Problem Using Hippopotamus Optimizer

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Abstract– *This study presents the application of a novel meta-heuristic algorithm called Hippopotamus optimizer (HO) to solve the problem of clean energies – economic load dispatch (CE-ELD). The application of HO is focused on optimizing the power output of all thermal generating sources in the given system so that the value of total electricity generation cost (TEGC) is minimal. In the process of solving the considered problem, solar and wind energy are also connected to the given system to evaluate their contribution and reduce the environmental damages caused by ThS's operation. Moreover, the value of power loss and the prohibited operating zones are also employed while applying HO to the CE-ELD problem to assess its actual performance. Finally, the results achieved by HO are compared to another meta-heuristic algorithm, Frilled Lizard Optimization, using different criteria, including Lst. TEGC, Aver. TEGC, and Hst. TEGC. The comparison results indicated that HO saves $0.29 on Lst. TEGC, $6.282 on Aver. TEGC, and $21.792 on Max corresponding to 0.002%, 0.04%, and 0.161% on each criterion, respectively. Based on these results, HO is proved to be a power search method and is highly recommended for use to solve this CE-ELD problem.*

Keywords: *Clean energies – economic load dispatch problem; thermal generating sources; total electricity generation cost; prohibited operating zones; Hippopotamus optimizer; Frilled Lizard Optimization.*

I. INTRODUCTION

In the modern power system, solving the economic load dispatch problem (ELD) still remains one of the first priorities [1]. The main work of solving the ELD problem is to optimize the allocation of power outputs supplied by all thermal generating sources (ThSs) to achieve the minimum value of the main objective function, which is total electricity generation cost (TEGC) for most cases [2-3]. In the past, ThSs were the only type of generating source in power systems, and the operation of these sources caused environmental damage. Recently, clean energies, which are mainly solar and wind-generating sources, have also been connected to the power system to reduce the negative effects on the environment partly. Hence, the ELD problem is modified and becomes the CE-ELD problem [4-5].

By understanding the important role of solving both ELD and CE-ELD problems, a huge number of studies have been published to solve these two problems with different considerations and applied methods. Regarding the applied methods, meta-heuristic algorithms are mostly selected to solve ELD and CE-ELD problems. The application of meta-heuristic algorithms is such as coyote optimization algorithm (COA) [6], modified equilibrium algorithms (MEA) [7], ameliorated dragonfly algorithm (ADA) [8], harmonic search algorithm (HSA) [9], improved firefly algorithm (IFA) [10], Whale optimization algorithm (WOA) [11], Grasshopper optimization algorithm (GOA) [12], Marine predator optimization algorithm (MPA) [13], astute black widow optimization (ABWO) [14], the multi-objective multi-verse optimization (MOMVO) [15], Firework algorithm (FWA) [16], Biogeography-based optimization (BBO) [17], Modified moth swarm algorithm (MMSA) [18], Modified Jaya algorithm (MJA) [19], Ameliorated dragonfly algorithm (ADA) [20], Social optimization algorithm (SOA) [21], search and rescue optimization algorithm (SARO) [22], Krill Herd Algorithm (MKHA) [23], …

In this study, novel meta-heuristic algorithms recently proposed called The Hippopotamus Optimizer (HO) [24] will be applied to solve the CE-ELD problem with the consideration of both photovoltaic generating source (PGS) and wind generating source (WGS). The application of HO to the CE-ELD problem is aimed at optimal the allocations of ThSs in the considered power system to reach the optimal value of the TEGC. Power loss and the prohibited operating zones of ThSs are also evaluated. Regarding HO, the algorithm is inspired by the natural behaviors of hippopotamuses; the HO metaheuristic algorithm introduces a novel approach. It employs a trinary-phase model, incorporating riverine movement, defensive tactics, and evasion strategies, all mathematically formalized. For assessing the actual performance of HO while solving the ED-ELD problem, the results of HO will be compared to another meta-heuristic algorithm, which was also proposed in 2024, the Frilled Lizard Optimization (FLO) [25].

The main novelties and striking contributions of the study can be summary as follows:

- Successfully apply two novel meta-heuristic algorithms, including Hippopotamus optimizer and Frilled Lizard Optimization to optimize the allocation of ThS's power output while solving the CE-ELD problem.
- Discuss and prove the actual performance of HO over FLO using particular criteria and indicate the better method.

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- Evaluate the amount of power loss and successfully handle the prohibited constraint of ThS's while solving the considered problem.
- Considering the presence of both solar and wind generating sources in solving the most important problem in power system operation.

II. Problem formulation

2.1. The main objective function

As mentioned earlier, this study focuses on minimizing the total electricity generation cost (TEGC) of all thermal generating sources (ThSs) using the following mathematical expressions:

$$Minimize\ TEGC = \sum_{i=1}^{N_{ThSs}} \alpha_i P_{ThS,i}^2 + \beta_i P_{ThS,i} + \varepsilon_i \quad (1)$$
$$with\ i = 1, \dots, N_{ThSs}$$

Where $TEGC$ is the total electricity generation cost of all ThSs in the considered power system; α_i, β_i, and ε_i are, the fuel coefficient of ThSs i; $P_{ThS,i}$ is power generated by ThS i with i = 1, 2, … N_{ThSs} and N_{ThSs} is the quantity of ThSs in the considered system.

2.2 The constraints

- *The prohibited operating zone constraints*

This study will consider the prohibited operating zones (POZs) of ThSs, which are formulated by the following expression:

$$P_{ThS,i} \in \begin{cases} P_{ThS,i}^{min} \le P_{ThS,i} \le P_{ThS,i1}^{i} \\ P_{ThS,m-1}^{m} \le P_{ThS,i} \le P_{ThS,nm}^{i}; m = 2, \dots, M; \forall i \\ P_{ThS,iM}^{k} \le P_{ThS,i} \le P_{ThS,i}^{max} \end{cases} \in \Omega \quad (2)$$

Where M is the number of prohibited operating zones of ThS i in the system.

- *The power balance constraints:*

The power balance constraint is utilized to maintain the balance between the total power supplied by all generating sources and the amount of power needed by load plus the amount of loss, as shown below:

$$\sum_{i=1}^{N_{ThS}} P_{ThS,i} + \sum_{p=1}^{N_{PGS}} P_{PS,p} + \sum_{q=1}^{N_{WGS}} P_{WG,q} = PD + P_{loss} \quad (3)$$

Where, $\sum_{i=1}^{N_{ThS}} P_{ThS,i}$ is the total power supplied by all ThSs ; $\sum_{p=1}^{N_{PGS}} P_{PS,p}$ and $\sum_{q=1}^{N_{WGS}} P_{WG,q}$ are the total power supplied by all photovoltaic generating sources (PGSs) and all wind generating sources (WGSs) in the system; N_{PGS} and N_{WGS} are the number of PGSs and WGSs; PD and P_{loss} are the amount of power needed by load and the power loss, respectively.

In Eq. (3), the value of P_{loss} is calculated using the following expression:

$$P_{loss} = \sum_{i=1}^{N_{ThS}} \sum_{k=1, i\neq k}^{N_{ThS}} P_{ThS,i} LF_{ik} P_{ThS,k} + \sum_{i=1}^{N_{ThS}} LF_{0i} P_{ThS,i} + LF_{00} \quad (4)$$

Where, LF_{ik}, LF_{0i}, and LF_{00} are the loss factors.

- *The ThS's operational constraint*

This constraint is applied to ensure the ThS is operated within its physical limitation for safety reason:

$$P_{ThS,i}^{Min} \le P_{ThS,i} \le P_{ThS,i}^{Max} \quad (5)$$

Where, $P_{ThS,i}^{Min}$ and $P_{ThS,i}^{Max}$ are the minimum and maximum amount of power supplied by ThS i.

- *The operational constraint of PGS and WGS*

Similar to ThSs, the power supplied by PGSs and WGSs must be varied between the minimum and maximum value as follows:

$$P_{PS,p}^{Min} \le P_{PS,p} \le P_{PS,p}^{Max} \quad (6)$$

$$P_{WG,q}^{Min} \le P_{WG,q} \le P_{WG,q}^{Max} \quad (7)$$

Where, $P_{PS,p}^{Min}$ and $P_{PS,p}^{Max}$ are minimum and maximum power supplied by PGS p; $P_{WG,q}^{Min}$ and $P_{WG,q}^{Max}$ are the minimum and maximum power supplied by WGS q; $P_{PS,p}$ and $P_{WG,q}$ are the power supplied by PGS p and WGS q, respectively.

III. The Hippopotamus optimizer

This section will briefly describe the update mechanism, which is the main difference between HO and another meta-heuristic algorithm. Similar to another state-of-the-art meta-heuristic algorithm, the update mechanism of HO also includes two phases: the exploration phase and the exploitation phase:

1.1. The exploration phase

The exploration phase is employed using the following mathematical models:

$$X_n^{new1,P1} = X_n + \theta_1 \times (X_{Best} - \varepsilon_1 \times X_n) \text{ with } n = 1, 2, \dots, \frac{N_{pop}}{2} \quad (8)$$

$$X_n^{new2,P1} = \begin{cases} X_n + Rn \times (X_{Best} - \varepsilon_2 \times X_A), if\ Rf > 0.6 \\ \gamma, \text{else} \end{cases} \quad (9)$$

With

$$\gamma = \begin{cases} X_n + Rn \times (RX - X_{Best}), & \text{if } Rf_1 > 0.5 \\ X_{min} + Rn \times (X_{max} - X_{min}), & else \end{cases} \quad (10)$$

In the Eqs (8) – (10) above, $X_n^{new1,P1}$ and $X_n^{new2,P1}$ are the two new solutions created on the exploration phase; X_n is the current solution n with n = 1, 2, …, to $\frac{N_{pop}}{2}$ and N_{pop} is the population number; θ_1 is the amplifying factor; X_{Best} is the best solution at current iteration; ε_1 and ε_2 are the random values between 0 and 1; X_A is the average solution around the considered solution; Rf and Rf_1 are the reference factors; X_{min} and X_{max} are the minimum and maximum solution.

1.2. The exploitation phase

In this all the solution with be updated using the following expressions:

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$$X_n^{new1,P2} = \begin{cases} LV \cap X_R + \theta_2 \times \frac{1}{D} \text{ if } F_{X_R} < F_{X_n} \\ LV \cap X_R + \theta_2 \times \frac{1}{2 \times D + \varepsilon_2} \text{ if } F_{X_R} \geq F_{X_n} \end{cases} \text{ with } n = \frac{N_{pop}}{2}, \ldots, N_{pop} \quad (11)$$

$$X_n^{new2,P2} = X_{min,lc} + Rn \times \left(X_{max,lc} - X_{min,lc}\right) \text{ with } n = 1, 2, \ldots, N_{pop} \quad (12)$$

In the Eqs (11) and (12), $X_n^{new1,P2}$ and $X_n^{new2,P2}$ are the two new solutions updated in the exploitation phase; LV is the value of the Levy's flight distribution; X_R is the random solution; θ_2 is the amplifying factors; D is the distance from the random solution X_R to the considered solution X_n; F_{X_R} and F_{X_n} are the fitness value of the random solution and the considered solution; $X_{min,lc}$ and $X_{max,lc}$ are the local minimum and local maximum solution.

IV. Results and Evaluations

In this section, HO is applied to solve the CE-ELD problem with the main objective function of minimizing the TEGC value of all ThSs in the power system with 6 ThSs and 1263 MW of load demand. Besides, 50MWp PGS and 100 MWp WGS are connected to the mentioned system to partly reduce the emission from ThSs, mitigating the environmental damage overall. Additionally, the amount of power loss and POZ constraint are considered while solving the problem. The results achieved by HO are compared to another meta-heuristic algorithm to evaluate its actual performance. For a fair assessment, HO and FLO use a similar preset in terms of population size (N_{pop}) and the highest number of iterations (*HI*), which are 20 and 50, respectively. Moreover, HO and FLO executed 50 trial tests for the best solution before comparison.

All the work is performed on a personal computer with a 2.25 GHz clock speed of the central processing unit (CPU) along with 8GB of random access memory (RAM). MATLAB programming language version R2019a is the main digital environment used to carry out all the related work.

Figure 1 presents the results achieved by the two meta-heuristic algorithms among 50 trial tests. In the figure, HO can achieve a more optimal value of the main objective function than FLO. Moreover, the fluctuation of the fitness values among the trial tests of HO is completely smaller than FLO. That means that HO provides higher stability while solving the considered problem.

The provided passage discusses the performance comparison between HO and FLO algorithms, as depicted in Figures 2a, 2b, and 2c. In terms of minimum convergence, HO outperforms FLO by reaching the optimal value faster. Additionally, HO exhibits better performance in both average and maximum convergence, solidifying its superiority over FLO.

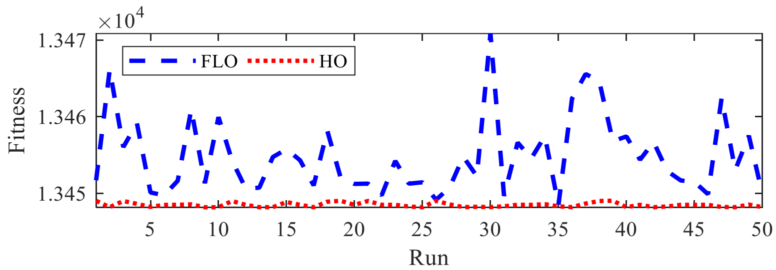

Figure 1. The fitness value achieved by HO and FLO among 50 trial test.

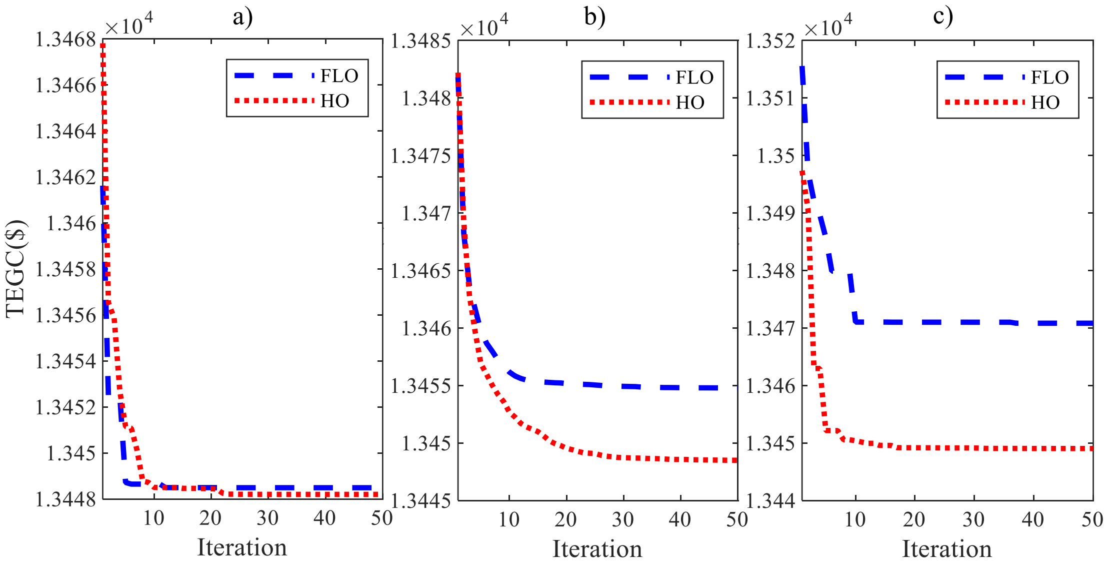

Figure 2. The minimum, average, and maximum convergence curves achieved by HO and FLO for their best run.

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In Figure 3, the results achieved by HO and FLO are compared using different criteria, including the lowest TEGC (Lst. TEGC), average TEGC (Aver. TEGC), and highest TEGC (Hst. TEGC). HO always achieved better values than FLO in all three criteria. HO can save $0.29 on the first criterion, $6.282 on the second criterion, and $21.792 on the third criterion compared to FLO. By converting to percentage, HO is 0.002%, 0.04%, and 0.161% better than FLO at all three criteria.

Figures 4 and 5 show the power output and electricity generation cost (EGC) for each ThS. Thanks to the better allocation of the power output among all the ThSs, HO can achieve a better TEGC overall, as shown earlier.

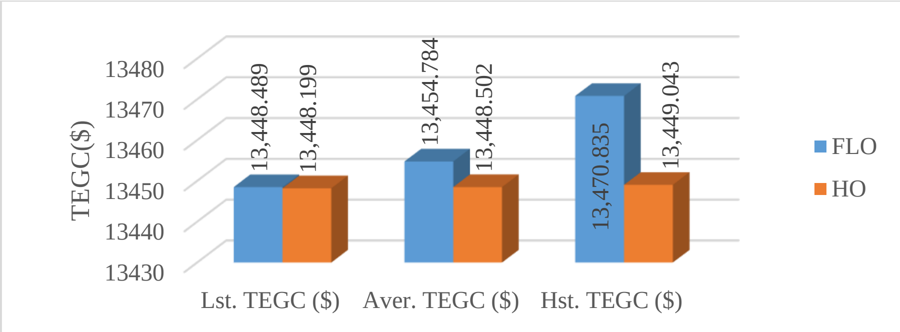

Figure 3. The comparison between HO and FLO on different criteria

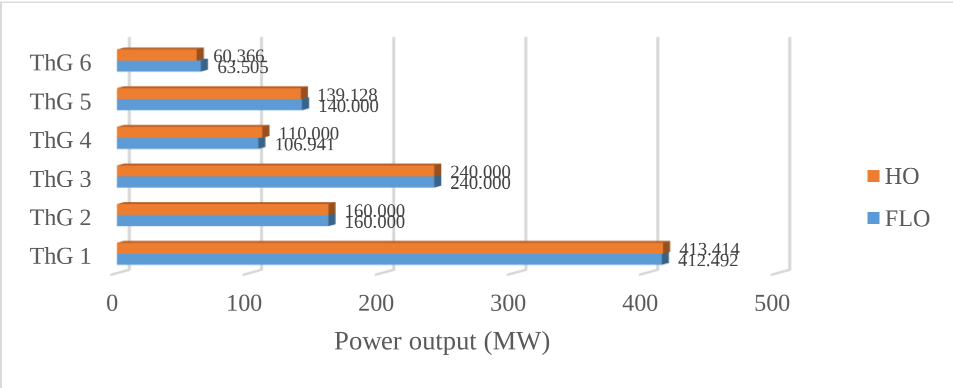

Figure 4. The power output of all ThSs in the considered power system achieved by HO and FLO

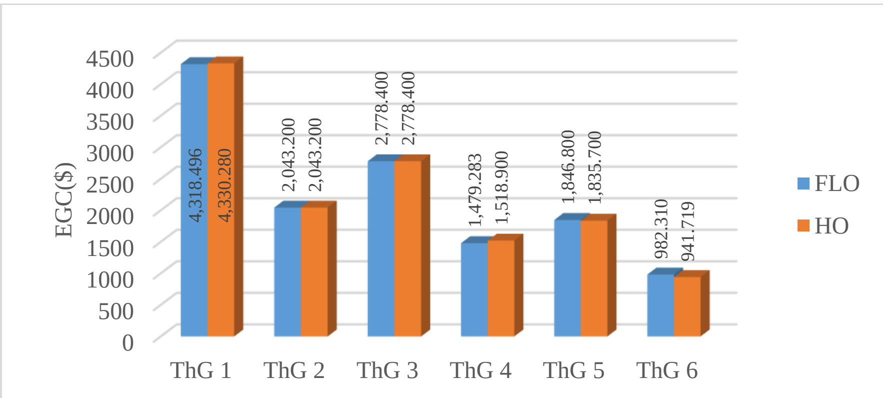

Figure 5. The EGC value of all ThSs in the considered system corresponding to their power outputs in Figure 4

V. CONCLUSIONS

In this study, a novel meta-heuristic algorithm proposed in mid-2024, Hippopotamus optimizer (HO), is successfully applied to solve the clean energies – economic load dispatch problem (CE-ELD) with the main objective function to minimize the total electricity generation cost (TEGC). Besides, the study evaluated the presence of both photovoltaic and wind-generating sources while solving the considered problem. Moreover, the amount of power loss and the prohibited operating constraints of ThS are also taken into account. HO has proven itself very effective compared to Frilled Lizard Optimization (FLO) – another new meta-heuristic algorithm also proposed in 2024. Mainly, HO can save $0.29 on Lst.

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TEGC, $6.282 on Aver. TEGC, and $21.792 on Max. TEGC compared to FLO corresponding to 0.002%, 0.04%, and 0.161%, respectively. Additionally, HO offers higher stability while solving the considered problem than FLO. Based on all these proofs, HO is acknowledged to be a powerful search method, and the authors strongly suggest applying HO to solve such CE-ELD problems.

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