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# Evolutionary algorithm solution for economic dispatch problems

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**ABSTRACT**

A modified firefly algorithm (FA) was presented in this paper for finding a solution to the economic dispatch (ED) problem. ED is considered a difficult topic in the field of power systems due to the complexity of calculating the optimal generation schedule that will satisfy the demand for electric power at the lowest fuel costs while satisfying all the other constraints. Furthermore, the ED problems are associated with objective functions that have both quality and inequality constraints, these include the practical operation constraints of the generators (such as the forbidden working areas, nonlinear limits, and generation limits) that makes the calculation of the global optimal solutions of ED a difficult task. The proposed approach in this study was evaluated in the IEEE 30-Bus test-bed, the evaluation showed that the proposed FA-based approach performed optimally in comparison with the performance of the other existing optimizers, such as the traditional FA and particle swarm optimization. The results show the high performance of the modified firefly algorithm compared to the other methods.



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## NOMENCLATURE

| | |
|---|---|
| FCz | : Fuel cost of plant (z) expressed by $/h. |
| Pz | : Real power generation of plant z. |
| a, b, c | : Cost function constant. |
| N | : Number of power plants. |
| Pz min | : Minimum limit for real power generator (z) expressed by MW. |
| Pz max | : Maximum limit for real power generator (z) expressed by MW. |
| PL | : Total power losses in MW. |
| PD | : Real power load in GfW. |
| B | : B coefficients. |

## 1. INTRODUCTION

It is important that power systems should be of a high grade and economically feasible, meaning that the cost of building the system must be optimized. In the power systems, the economic dispatch (ED) issue portrays the expected level of load that must be partitioned between the generators to ensure minimal operating cost. The concept of optimization demands minimization of the objective functions while maintaining a reasonable and acceptable level of system performance [1], [2]. Typically, ED is considered an important area of the control and operation of power systems as its main objective of the ED plant is to schedule the operations of the generating units to ensure maximum performance at the minimum operation cost; this amounts to low-cost electricity on the side of the customers and possible gain on the side of the service provider in the electricity market. Being that the generated power by the generating units cannot be stored as other types of products, coupled with the need for transmission and distribution networks to get the generated power to the consumers, it is becoming difficult to accurately determine the cost of electric power generation and services [3], [4]. The study by Touma [5] proposed the whale optimization approach of finding a solution to the ED problem. The proposed system was evaluated in a standard IEEE 30-Bus testbed and the performance was compared with those of other optimization algorithms, such as elephant heart optimization (EHO), Garra Rufa optimization (GRO), particle swarm optimization (PSO), and genetic algorithm [6]. Another study by Victoire and Jeyakumar [7] reported the use of PSO to solve different forms of ED, including the two-area ED with tie line limits, ED of generators with forbidden operation zones, and ED with different fuel choices. The study relied on quadratic programming for the modification of the PSO used to determine the optimal solution. In [8], this study use teaching and learning based optimization (TLBO) to analysis the practical non-convex economic demand dispatch objective. The presented method is applied to determine demand dispatch for six units and ten units standard network among other methods. While in [9], Rajesh and Visali presented hybrid method, modified non-dominated sorted genetic algorithm and modified population variant differential evolution for solving and optimization economic demand dispatch ED problems. The cost of electrical power generation, which reduced by sharing load between power generation plant is a main target of the problem.

Genetic algorithm (GA) has been proposed in [10] for solving the ED issue; the study incorporated a novel heuristic mechanism for finding infeasible solutions to the feasible area. The behavior of the algorithm was enhanced using the dynamic relaxation for equality constraints and diversity mechanism. A hybrid system called fuzzy-based hybrid-PSO has been presented by [11], for finding a solution to the ED problem. To make the obtained results more practicable, the study investigated the actual conditions, valve-point action, and containing multi-fuels process during the evaluation of the proposed hybrid system. The study by Daniel and Chaturvedi [12] presented an algorithm for addressing the ED problem; the algorithm was developed for the reduction of the nonlinear behavior of the fuel cost of power generation subject to practical constraints. The evaluation was done on the IEEE standard system testbed and from the results, the presented solution was efficient in finding solutions to the ED problem. A genetic algorithm approach to the ED problem of thermal generators has been presented by [13]; the study applied the proposed method in 3 and 6 generator test systems. The considered system in the system is a lossless system. Another study by Chopra and Kaur [14] presented a modified GA approach to the ED problem with the aim of minimizing costs and overworking constraints. In this approach, the iteration method requires a precise modification of the Lambda even though it does not guarantee the global optimal solution.

A genetic algorithm-based system has been presented by [15] for solving the ED problem; the system is for the determination of the global solution to ED considering the transmission line losses. A fuzzy based GA for solving ED problems has been presented by [16]; the system relies on the control and exploitation capabilities of the heuristic search theory (the basis of the GA) to explore and exploit the solution space more efficiently. In the study in [17], [18], a new stochastic optimization technique was presented for finding a solution to the ED problem; the techniques depend on the hybrid bacterial foraging-differential evolution (BFOM) method. This method combined the chemotaxis calculation of bacterial foraging optimization algorithm (BFOA) BFOA (considered a stochastic gradient search) with the crossover and mutation parameters of GA. In this study, a modified FA was proposed for solving the ED problem; the proposed system was evaluated using a standard IEEE 30-Bus testbed and the performance was compared with that of other existing optimization techniques, such as the traditional FA and PSO.

## 2. ECONOMIC DISPATCH PROBLEM

The ED problem is mainly concerned with the determination of the optimal distribution of power in a manner that minimizes the overall operation cost while considering the equality and inequality constraints. The operation characteristics of a generator with different fuel choices can be described using a second-order function. For instance, the (1) defines an ED problem with a piece-wise quadratic function.

$$FC_z = a_z P_z^2 + b_z P_z + c_z \tag{1}$$

The following are considered constraints to the cost function:

– The inequality conditions in the formularization of the ED problem are described by the generator limits.

$$\text{Pz min} \leq \text{Pz} \leq \text{Pz max}, \text{i} = 1, \ldots\ldots.., \text{n}$$

– The losses from the transmission line have an impact on the optimal flow of power in the power system. These losses can be mathematically written as in (2).

$$P_L = \sum_{z=1}^{n} \sum_{z=1}^{n} P_z B_{zj} P_j + \sum_{j=1}^{n} B_{0j} P_j + B_0 \quad (2)$$

For a variable system demand, the B coefficients are to be determined. The electrical equality conditions for ED are represented in (3).

$$P_D = \sum_{z=1}^{n} P_z - P_L \quad (3)$$

The objective function of the economic dispatch is minimized as in (4).

$$(\text{FC}) = \min \sum_{\text{z}=1}^{\text{n}} \text{FC}_\text{z} \quad (4)$$

## 3. CASE STUDIED

A modified firefly algorithm (M-FA) was proposed in this article; the technique was evaluated on a standard IEEE 30-Bus testbed with six power plants and 41 interconnected lines. The electric power load of the system is 0.3 GW. The simulation study was performed in the MATLAB R2017b platform. Figure 1 showed the grid for the simulation of the proposed system while Tables 1 and 2 described the datasheet of the test system [1].

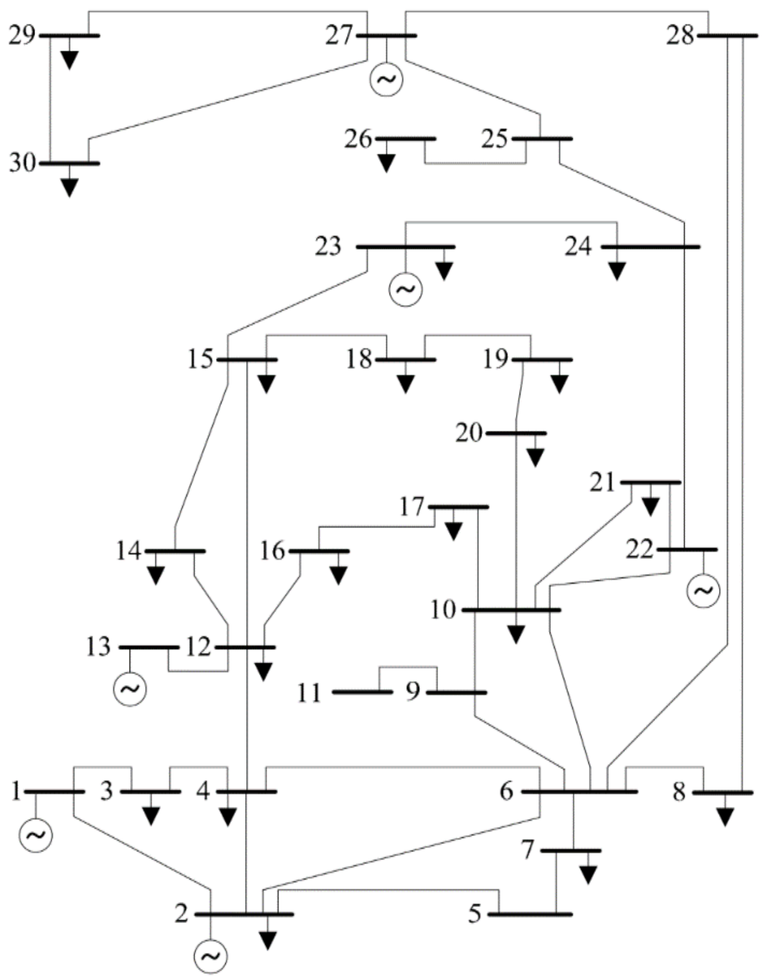


Figure 1. Interconnected grid of IEEE 30-Bus

Table 1. Cost equation factors

| Generator Number | Fuel cost factors | | | Capacity levels (MW) | |
|---|---|---|---|---|---|
| | a($/MWhr) | b($/MWhr) | c($/hr) | Pmin | Pmax |
| 1 | 0.0037 | 2.0000 | 0 | 50 | 200 |
| 2 | 0.0175 | 1.7500 | 0 | 20 | 80 |
| 3 | 0.0625 | 1.0000 | 0 | 15 | 50 |
| 4 | 0.0083 | 3.2500 | 0 | 10 | 35 |
| 5 | 0.0250 | 3.0000 | 0 | 10 | 30 |
| 6 | 0.0250 | 3.0000 | 0 | 12 | 40 |

Table 2. Fuel cost function parameter

| | | | | | | |
|---|---|---|---|---|---|---|
| B= | | | | | | |
| | 0.0002180 | 0.0001030 | 0.0000090 | -0.00010 | 0.0000020 | 0.0000270 |
| | 0.0001030 | 0.0001810 | 0.0000040 | -0.0000150 | 0.0000020 | 0.0000300 |
| | 0.0000090 | 0.0000040 | 0.0004710 | -0.0001310 | -0.0001530 | -0.0001070 |
| | -0.000100 | -0.0000150 | -0.0001310 | 0.0002210 | 0.0000940 | 0.0000500 |
| | 0.0000020 | 0.0000020 | -0.0001530 | 0.0000940 | 0.0002430 | -0.000000 |
| | 0.0000270 | 0.0000300 | -0.0001070 | 0.0000500 | -0.000000 | 0.0003580 |
| B00= | -0.0000030 | 0.0000201 | -0.0000560 | 0.0000340 | 0.0000150 | 0.000078 |
| B0= | 0.0000140 | | | | | |

## 4. MODELLING OF PSO ALGORITHM

PSO was developed in 1995 as a swarm-based heuristic by [19], [20]. In the PSO, each particle is considered a potential solution, and the best particle in the solution space, p, is defined by the character, g. At each iteration step, the speed of the k$^{th}$ particle which is given as vɉ=(vɉ1, vɉ2, . . ., vɉd), is updated over each axis j using the formula:

$$v_{ɉ}(t+1) = \omega v_{ɉ}(t) + c_1 r_1 (Ƥ_{ɉ}(t) - Y_{ɉ}(t)) + c_2 r_2 (G_k(t) - X_k(\mathrm{t})) \quad (5)$$

where, $c_1$ and $c_2$ represent the acceleration coefficients, $Ƥ_{ɉ}$=local solution and Gk is the global solution at each iteration, and ω=the inertia weight. The range of velocity of the particle is fixed and can be updated at iteration:

$$v_{kj} = [-V_{max}, V_{max}] \quad (6)$$

The following function is applied to determine the new location of a particle:

$$Y_{ɉ}(t+1) = Y_{ɉ}(t) + v_{ɉ}(t+1) \quad (7)$$

This new coordinates of the particle are updated by (8):

$$Ƥ_{ɉ}(t+1) = \begin{cases} Ƥ_{ɉ} t f\left(Y_{ɉ}(t+1)\right) < f(Ƥ_{ɉ}(t)) \\ Y_{ɉ}(t+1) f\left(Y_{ɉ}(t+1)\right) < f(Ƥ_{ɉ}(t)) \end{cases} \quad (8)$$

where the global best index is:

$$g = \arg\min f(Y_{ɉ};\ t+1)),\ 1 \le ɉ \le N \quad (9)$$

## 5. FIREFLY ALGORITHM

Abdullah *et al*. [21] introduces the FA for the first time in 2008 as a nature-inspired optimization technique. The FA is inspired by the flashing nature of fireflies which are unisexual insects and hence, they moved to each other with no gender preferences [22]. However, the flash of the firefly is the indication to pull other fireflies. The attractiveness among fireflies is associated with their brightness, and for every two fireflies, the one with less bright flash moves to the shining ones and so on. The brightness decrease as the fireflies are onward from each other. If particles are equal in their flashes' brightness, the movement will be random. Like other evolutionary algorithms, FA was employed for the setting of the control parameters; here, each firefly is considered a potential solution and described based on the position.

The current position of a firefly in the d dimensional vector space is given as $X_k = (x_{k1}, \ldots\ldots, x_{kn}, \ldots\ldots, X_{kd})$. However, the initialization of the random positions of n fireflies is done within a specified range. Hence, the formulation of the changes in position k subject to attraction by a brighter firefly j is given thus:

$$X_k(t+1) = X_k(t) + \beta_0 \exp(-\gamma rkj)\left(x_j - x_k\right) + \alpha(rand - 0.5) \quad (10)$$

where the changes in the position of the brighter firefly are captured thus:

$$xbest(next) = xbest(current) + \alpha(rand - 0.5) \quad (11)$$

In (10) and (11), the first terms are the current positions of the attracted firefly and the brightest firefly, respectively while the second term in (10) represents the attractiveness of the firefly to the brighter light intensity. Assume that β0=the initial attractiveness at r = 0, γ= the absorption parameter (ranging from 0 to 1), and r=the distance between any 2 fireflies (k and j) at positions $x_k$ and $x_j$ respectively, then, the Euclidean distance can be formulated as:

$$r_{kj} = \sqrt{\sum_{n=1}^{d}(x_{k,n} - x_{j,n})^2} \quad (12)$$

where $x_k$ and $x_j$= the location vectors for k and j, respectively, and $x_{k,n}$= the location value of the dimension. To decrease the randomness, the third terms in (10) and (11) are applied; this implies a gradual reduction of the velocity of the fireflies through $\alpha = \alpha_0 \rho_k$, where α0 ranges from 0 to 1, δ is the randomness reduction factor, where (0.0 < $\rho$ < 1.0), and k= the counter of iterations.

## 6. THE PROPOSED ALGORITHM

The FA has been previously applied in the optimization of the application of different power systems. This work strives to decrease the problem of local optima entrapment of FA to improve its search ability via some modification steps on the FA algorithm. The following enhancements were made to the FA to achieve the proposed M-FA [23], for every 2 mutations, 3 crossover processes are considered. The overall generations are to be pushed toward optimal (either local or global) [24], [25]. In each iteration, the modification must be done to complete the following two steps:

$$\mathrm{Y}_{\mu} = \mathrm{Y}_{\mu} + \delta \times (\mathrm{Y}_{\mu+1} - \mathrm{Y}_{\mu+2}) \quad (13)$$

$$\mathrm{Y}_{\mu 2} = \mathrm{Y}_{\mu 1} + \delta \times (\mathrm{Y}_{Best}^{iter} - \mathrm{Y}_{Worst}^{iter}) \quad (14)$$

where, δ is a number between [0, 1], Where ($\mathrm{Y}_1$, $\mathrm{Y}_2$ $and$ $\mathrm{Y}_3$) are random elements of firefly, $\mathrm{Y}_{bett1} = [y_{bett1,} y_{bett2,} \cdots \cdots, y_{bettn}]$

$$\mathrm{Y}_{Best1} = [y_{Best1,} y_{Best2,} \cdots \cdots, y_{Bestn}] \quad (15)$$

$$\mathrm{Y}_{improve1,ɉ} = \begin{Bmatrix} \mathrm{Y}_{\mu 1,ɉ}, if & ɉ_1 \leq ɉ_2 \\ \mathrm{Y}_{Best1,ɉ}\ if & ɉ_1 > ɉ_2 \end{Bmatrix} \quad (16)$$

$$\mathrm{Y}_{improve2,ɉ} = \begin{Bmatrix} \mathrm{Y}_{\mu 1,ɉ}, if & ɉ_2 \leq ɉ_3 \\ \mathrm{Y}_{,ɉ}\ if & ɉ_2 > ɉ_3 \end{Bmatrix} \quad (17)$$

$$\mathrm{Y}_{improve3,ɉ} = \begin{Bmatrix} \mathrm{Y}_{Best1,ɉ}, if & ɉ_3 \leq ɉ_4 \\ \mathrm{Y}_{,ɉ}\ if & ɉ_3 > ɉ_4 \end{Bmatrix} \quad (18)$$

where, $\mathrm{Y}_{bett}^{iter}$ $and$ $\mathrm{Y}_{bad}^{iter}$ are the better and the bad population respectively in each iteration, $ɉ_1 - ɉ_5$ have amount in range [0, 1]. However, fireflies have to locate the objectives in order to meet the best value for their iteration. The flowchart of the proposed algorithm is illustrated in Figure 2.

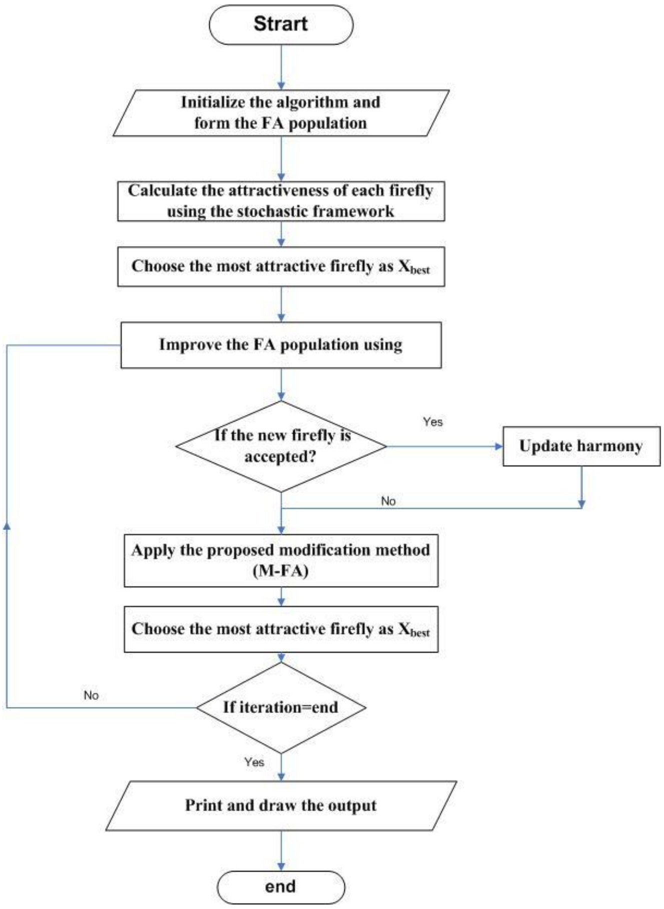


Figure 2. Flowchart of the modified firefly algorithm

## 7. RESULTS AND DISCUSSION

The proposed M-FA algorithm was compared with the traditional FA and PSO algorithms for identifying the impact of the modification proposed in this paper. The evaluation was done on a power system of 6 units using MATLAB 2017b. The actual power generation by each unit based on the three employed optimization methods was presented in Table 3, this is an important aspect of the optimal ED calculation. The overall cost of the system when using each of the considered algorithms is presented in Table 4. The table showed that the proposed MFA performed better cost reduction than PSO (by >0.3%) and original FA (by >0.24%) within 24 h. Hence, the proposed M-FA outperformed PSO and original FA. The calculated overall power losses by the three algorithms were 8.9140 MW (for MFA), 8.9144 MW (for PSO), and 8.9172 MW (for original FA). The error and run time for each algorithm are presented in Table 5. Observably, FA required the shortest time to achieve results but with bigger error margin while M-FA took longer time to achieve results with the least error margin. Hence, the proposed M-FA is more suitable for practical applications.

Table 3. Real generation of six generators in system, (0.3 GW load)

| Algorithm | P1(GW) | P2(GW) | P3(GW) | P4(GW) | P5(GW) | P6(GW) |
|---|---|---|---|---|---|---|
| PSO | 0.177316 | 0.051200 | 0.020318 | 0.019637 | 0.011764 | 0.012000 |
| FA | 0.177919 | 0.05136 0 | 0.020363 | 0.019959 | 0.011878 | 0.012000 |
| M-FA | 0.176959 | 0.05110 0 | 0.020291 | 0.019446 | 0.011697 | 0.012000 |

Table 4. Economic dispatch in (0.3 GW)

| Evolutionary Algorithm | PL(MW) | Total Cost (Fuel Cost) $/hr |
|---|---|---|
| PSO | 8.9144 | 799.7964 |
| FA | 8.9172 | 800.0274 |
| M-FA | 8.9140 | 799.7636 |

Table 5. Error and run time of each algorithm

| Evolutionary Algorithm | Error | Run Time |
|---|---|---|
| PSO | 0.0082 | 0.7970 |
| FA | 0.0653 | 0.0881 |
| M-FA | 0.0079 | 0.1273 |

Figure 3 presents the overall cost input of using each of the evaluated methods. Notably, the proposed M-FA achieved the least cost function compared to PSO and FA within 24 h of operation. This suggests that M-FA can produce better performance in practical terms compared to FA and PSO. The rate of changes in error for each method per iteration is captured in Figure 4. The figure showed that the error is not constant. Despite the error margin in each method, the M-FA exhibited the least and more stable error margin as shown in Figure 4.

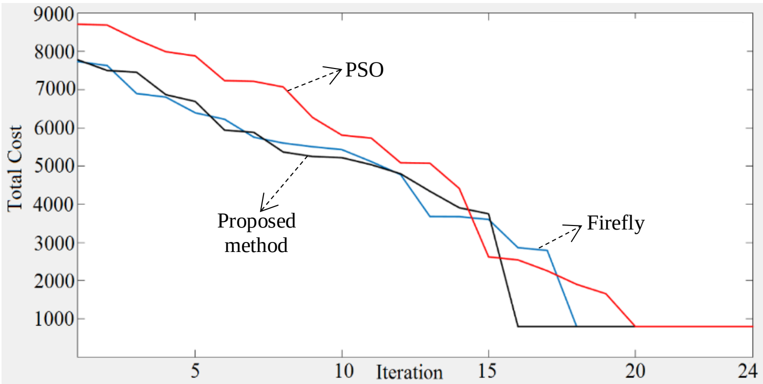


Figure 3. PSO, FA and M-FA algorithms cost

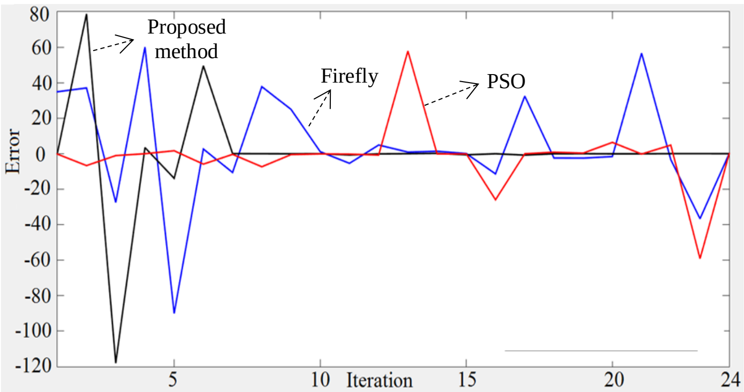


Figure 4. PSO, FA and M-FA algorithms error

## 8. CONCLUSION

This study presented a modified FA for the determination of the optimal solution for ED problems. The evaluation of the proposed system was done on the IEEE 30-Bus testbed with 6 generating units. From the results, it can be concluded that the proposed method achieved optimal performance in providing a solution to ED problems. The performance of the modified FA in comparison to the PSO and FA showed the impact of the modification propose in this study. In the future, efforts can be channelled on other real high complex electric power system, for example the Iraqi power system.

## REFERENCES

[1] P. T. Ha, H. M. Hoang, T. T. Nguyen, and T. T. Nguyen, "Modified moth swarm algorithm for optimal economic load dispatch problem," *TELKOMNIKA (Telecommunication, Computing, Electronics and Control)*, vol. 18, no. 4, pp. 2140–2147, Aug. 2020, doi: 10.12928/telkomnika.v18i4.15032.

[2] K. Chen, L. Han, S. Wang, J. Lu, and L. Shi1, "Modified Antipredatory Particle Swarm Optimization for Dynamic Economic Dispatch with Wind Power," *Mathematical Problems in Engineering*, vol. 2019, pp. 1–17, Oct. 2019, doi.org/10.1155/2019/5831362.pp1–17.

[3] T. M. Phan, P. T. Ha, T. L. Duong, and T. T. Nguyen, "Improved particle swarm optimization algorithms for economic load dispatch considering electric market," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 4, pp. 3918–3926, Aug. 2020, doi: 10.11591/ijece.v10i4.pp3918-3926.

[4] M. Haziq Suhaimi, I. Musirin, M. Hidayab, S. Jelani, and M. Helmi Mansor, "Multiverse optimisation based technique for solving economic dispatch in power system," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 20, no. 1, pp. 485–491, Oct. 2020, doi: 10.11591/ijeecs.v20.i1.pp485-491.

[5] H. J. Touma, "Study of the economic dispatch problem on IEEE 30-bus system using whale optimization algorithm," *International Journal of Engineering Technology and Sciences*, vol. 3, no. 1, pp. 11–18, Jun. 2016, doi: 10.15282/ijets.5.2016.1.2.1041.

[6] A. S. Jaber, H. A. Abdulbari, N. A. Shalash, and A. N. Abdalla, "Garra Rufa-inspired optimization technique," *International Journal of Intelligent Systems*, vol. 35, no. 11, pp. 1831–1856, Nov. 2020, doi: 10.1002/int.22274.

[7] T. A. A. Victoire and A. E. Jeyakumar, "Hybrid PSO–SQP for economic dispatch with valve-point effect," *Electric Power Systems Research*, vol. 71, no. 1, pp. 51–59, Sep. 2004, doi: 10.1016/j.epsr.2003.12.017.

[8] D. Rao and N. Kumar, "Comparisional investigation of load Dispatch solutions with TLBO," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 6, pp. 3246–3253, Dec. 2017, doi: 10.11591/ijece.v7i6.pp3246-3253.

[9] B. Dey, B. Bhattacharyya, and F. P. Marquez, "A hybrid optimization-based approach to solve environment constrained economic dispatch problem on microgrid system," *Journal of Cleaner Production*, vol. 307, pp. 1–14, Jul. 2021, doi: 10.1016/j.jclepro.2021.127196. pp1–14.

[10] M. F. Zaman, S. M. Elsayed, T. Ray, and R. A. Sarker, "Evolutionary algorithms for dynamic economic dispatch problems," *IEEE Transactions on Power Systems*, vol. 31, no. 2, pp. 1486–1495, Mar. 2016, doi: 10.1109/TPWRS.2015.2428714.

[11] S. R. Spea, "Solving practical economic load dispatch problem using crow search algorithm," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 4, pp. 3431–3440, Aug. 2020, doi: 10.11591/ijece.v10i4.pp3431-3440.

[12] L. Daniel and K. T. Chaturvedi, "Economic load dispatch using ant lion optimization," *International Journal of Engineering Trends and Technolog*, vol. 67, no. 4, pp. 81–84, Apr. 2019. doi:10.14445/22315381/IJETT-V67I4P218.

[13] A. Kaur, H. Singh, and A. Bhardwaj, "Analysis of economic load dispatch using genetic algorithm," *International Journal of Application or Innovation in Engineering and Management (IJAIEM)*, vol. 3, no. 3, pp. 240–246, 2014.

[14] L. Chopra and R. Kaur, "Economic load dispatch using simple and refined genetic algorithm," *International Journal of Advances in Engineering and Technology*, vol. 5, no. 1, pp. 584–590, 2012.

[15] D. C. Walters and G. B. Sheble, "Genetic algorithm solution of economic dispatch with valve point loading," *IEEE Transactions on Power Systems*, vol. 8, no. 3, pp. 1325–1332, 1993, doi: 10.1109/59.260861.

[16] H. Nezamabadi-pour, S. Yazdani, M. Farsangi, and M. Nayestani, "A solution to an economic dispatch problem by a fuzzy adaptive genetic algorithm," *Iranian Journal of Fuzzy Systems*, vol. 8, no. 3, pp. 1–21, 2011.

[17] A. Biswas *et al.*, "Economic load dispatch using a chemotactic differential evolution algorithm," in *Lecture Notes in Computer Science*, Springer Berlin Heidelberg, 2009, pp. 252–260.

[18] R. Prabha, V. Bharadwaj, and G. Siddhartha, "Invasive weed optimization for economic dispatch with valve point effects," *Journal of Engineering Science and Technology*, vol. 11, no. 2, pp. 237–251, 2016.

[19] R. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory," in *MHS'95. Proceedings of the Sixth International Symposium on Micro Machine and Human Science*, pp. 39–43, doi: 10.1109/MHS.1995.494215.

[20] B. M. Hussein, "A new scaled fuzzy method using PSO segmentation (SePSO) applied for two area power system," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 2, pp. 815–825, Apr. 2019, doi: 10.11591/ijece.v9i2.pp815-825.

[21] A. Abdullah, K. Haniya, D. Hakim, and T. Simanjuntak, "A hybrid method of ann-bp and lambda iteration for anomalous short-term economic dispatch of hydrothermal power systems," *Journal of Engineering Science and Technology*, vol. 15, no. 6, pp. 4061–4074, 2020.

[22] O. Bendjeghaba, S. I. Boushaki, and N. Zemmour, "Firefly algorithm for optimal tuning of PID controller parameters," in *4th International Conference on Power Engineering, Energy and Electrical Drives*, May 2013, pp. 1293–1296, doi: 10.1109/PowerEng.2013.6635799.

[23] I. Fister, X.-S. Yang, J. Brest, and I. Fister, "Modified firefly algorithm using quaternion representation," *Expert Systems with Applications*, vol. 40, no. 18, pp. 7220–7230, Dec. 2013, doi: 10.1016/j.eswa.2013.06.070.

[24] X. S. Yang, "Firefly algorithm, stochastic test functions and design optimisation," *International Journal of Bio-Inspired Computation*, vol. 2, no. 2, pp. 78–84, 2010, doi: 10.1504/IJBIC.2010.032124.

[25] B. M. Hussein and A. S. Jaber, "Unit commitment based on modified firefly algorithm," *Measurement and Control*, vol. 53, no. 3–4, pp. 320–327, Mar. 2020, doi: 10.1177/0020294019890630.


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