

Multi-objective dynamic economic dispatch using Fruit Fly Optimization method

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Abstract: An essential task of the interconnected power system is about how to optimize power plants during operation time which is known as economic dispatch. In this study, the Fruit Fly Optimization method is proposed to solve problems of dynamic economic dispatch in an electrical power system. To measure the performance of the method, a simulation was conducted for two different electric systems of the existing Sulselbar 150 kV thermal power plant system in Indonesia with two objective functions, namely fuel costs and active power transmission losses, as well as the 30-bus IEEE standard system with five objective functions namely fuel costs, transmission losses (active and reactive power), a reactive power reserve margin, and an emission index by considering a power generation limit and ramp rates as the constraints. Under tested cases, the simulation results have shown that the Fruit Fly Optimization method can solve the problems of dynamic economic dispatch better than other existing optimization methods. It is indicated by all values of the objective functions that are lowest for the Fruit Fly Optimization method. Moreover, the obtained computational time is sufficiently fast to get the best solution.

Key words: dynamic economic dispatch, Fruit Fly Optimization method, multi-objective

1. Introduction

Thermal plants that use fossil fuels are still used in many power systems including in Indonesia. As the use of fossil fuels in power plants is costly, it is necessary to properly manage them to minimize operational costs and this is known as economic dispatch (ED). According to [1], the ED problem is how to organize the output of generator units to fulfill electricity demand with the



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lowest fuel costs and meet system limits. However [2], ED is about how to reduce the operating costs of power plants to get the optimal condition of power plants at a specified load.

Several optimization methods have been used to deal with various ED problems such as differential evolution [3], particle swarm optimization (PSO) [4], backtracking search [5], improved bacterial foraging [6], knee point driven evolutionary [7], an artificial bee colony [8], firefly [9], enhanced moth-flame optimization [10][10], the fuzzy cardinal method, multi-objective load dispatch for 3 and 10 generator units with two objective functions [11][11], enhanced quantum-behaved PSO [1], quadratic programming [12], gravitational search [13], parallel and distributed computation [14], hybrid big bang-big crunch [2], a hybrid of PSO and teaching-learning based optimization (TLBO), multi-objective power dispatch with convex and non-convex for 3 and 6 generators with two objective functions [15], and the Fruit Fly Optimization (FOA) method as in [16–19], and [20].

Particularly for the FOA method above, it has been utilized to solve certain ED problems. For example, in [16] the FOA method is applied by the authors to solve the environmental ED based on the enhanced non-dominated sorting with two objective functions for case testing of the IEEE 30-bus. Next in [17], the improved FOA method is used to solve ED with a single objective function for three different cases namely the IEEE 40 system, IEEE 10 system, and IEEE 6 system. In [18], the FOA method is used to solve ED in an electrical power system by allocating the optimal value of real power with a single objective function for IEEE 26 bus case. In [19], an advanced FOA uses the PSO method by considering the variety of electrical power system operation modes with a single objective function for a modified New England 39 bus system. While [20], the multi-objective FOA method is used for a non-convex problem with two objective functions for case testing of the IEEE 30 system. Meanwhile, research related to economic dispatch with multi-objective dynamic economic dispatch (MDED), among others is carried out. The researcher in [21], stated that multi-objective economic load dispatch (MELD) using a fuzzy hybrid algorithm, and the bacterial foraging-Nelder-Mead Algorithm can solve emission, reserve and load economy scheduling (ERELD) problems where the simulation shows a reduction in the total cost of the system. The research conducted by [22] proposes an optimization with a multi-objective economic emission dispatch (MEED) and with two objective functions called the Pareto concavity elimination transformation (PaCcET) algorithms. The PaCcET algorithm is implemented on a microgrid with various scattered energy sources (DERs) to find different operating conditions most economical not only to minimize the total cost of fuel but also to find the best environmentally friendly solution. The researcher in [23] states that the optimization method of multi-objective economic emission load dispatch (MEELD) for two objective functions with load limitations and operating limits is calculated with the assumption of individual objective functions, the multi-objective problem is converted into a unique objective optimization with a goal attainment method (GAM) which then is completed with the simulated annealing technique (SAT) by minimizing generation costs.

The availability of fossil fuels in the world is decreasing day by day and the price is increasing. Therefore, thermal power plants that use fossil fuels as fuel input need to do economic dispatch of the generator so that the cost of generating it is as minimum as possible with the most optimal power generated. The problem of dynamic economic dispatch (DED) is a complex optimization problem with multiple objectives, which is difficult to solve using traditional methods. Besides, in many studies related to the problem of DED, the objective function is the study of only two or

three objective functions. Moreover, a multi-objective function is very important to be studied in solving DED problems because most real problems need to be optimized in a group of objectives simultaneously.

As a system of electrical power is getting complex and to approach the real operation of a power system, this work presents a more complicated ED study. Here, the FOA method is proposed to DED problems by reviewing five objective functions, namely generation fuel costs, transmission losses (active and reactive power), the emission index of pollutants caused by thermal plants, the margin of reactive power reserve considering only power limits of the generator and ramp rate of the generator as constraints. The tested fuel cost function uses only the quadratic cost function which is included in the non-linear optimization complexity problem. The test data for the real electricity system of Sulselbar 150 kV is carried out by using the peak load data, the power generation limit, and the coefficient of the cost of generation from each generator. Besides, this paper does not discuss the unit commitment (UC), which is the scheduling of the switching time and connection of the generating unit in a power system planned in a time that varies from a few hours to several days, the main objective of which is meeting load demands.

The effectiveness of the used method in solving DED is firstly tested on the standard system of the IEEE 30-bus with five objective functions. Next, it is tested on a real electric system placed in Indonesia, namely the Sulselbar thermal system with two objective functions. The obtained optimization results for each tested system mentioned above are analyzed and compared with other optimization techniques.

2. Objective function and constraint

The objective function will be optimized at a minimum or maximum level. Whereas the constraint is a condition of the optimization problem that the solution must meet. Constraints can be in the form of obstacles to equality or inequality.

2.1. Objective function

The multi-objective functions are applied to analyze the optimal power flow of the system. In this case, optimization is performed by reviewing several objective functions. The objective functions include fuel costs of the generator, transmission losses (active and reactive power), an emission index or environmental index, and a reactive power reserve margin.

2.1.1. Active power transmission line losses

The 1st objective function to be minimized is active power transmission line loss which is generally formulated in Equation (1).

$$\text{minimize } \sum P_i = \sum P_{Gi} - \sum P_{Di} = V_i \sum_{j=1}^n Y_{ij} \cdot V_j \cdot \cos(\delta_i - \delta_j - \theta_{ij}), \quad (1)$$

where: i is the bus i , P_i is the active power at the bus i , P_G is the generated power of the generator at the bus i and P_D is the load demand at the bus i , V_i and V_j represent the voltage at the bus i

and j , Y_{ij} is the admittance at the bus ij , δ_i , δ_j and θ_{ij} represent a magnitude of the angle at the bus i and j .

2.1.2. Fuel costs

The generator fuel cost variable is a function of an economic perspective to minimize the cost of fuel for each thermal power plant unit. In general, the cost of fuel is expressed as the output of the quadratic function for a related generator as shown in Equation (2).

$$\text{minimize } (F_T) = \sum_{i=1}^{N_G} F_i(P_i),$$

$$F_i(P_i) = a_i + b_i P_{Gi} + c_i P_{Gi}^2, \quad (2)$$

where: N_G is the number of generators, a_i , b_i , c_i are the coefficients of generator fuel costs, P_{Gi} is the output of the actual power of the i -th generator and F_T is the total fuel cost.

2.1.3. Reactive power transmission line losses

The 3-rd objective function to be minimized is reactive power losses for the transmission line. The voltage stability margins associated with static network systems depend on the reactive power availability to support real power delivery. The total minimized var loss is shown in Equation (3).

$$\text{minimize } \sum Q_i = \sum Q_{Gi} - \sum Q_{Di} = V_i \sum_{j=1}^n Y_{ij} \cdot V_j \cdot \sin(\delta_i - \delta_j - \theta_{ij}), \quad (3)$$

where: i is the bus i , Q_i is the reactive power at the bus i , Q_{Gi} is the reactive power of the generator at the bus i and Q_{Di} is the reactive power of demand at the bus i . V_i and V_j represent the voltage at the bus i and j , Y_{ij} is the admittance at the bus ij , δ_i , δ_j and θ_{ij} represent the magnitude of the angle at the bus i and j .

2.1.4. Reactive power reserve margin

The 4-th objective function to be maximized is the margin of reactive power reserves and distribution reserves between the generator and SVC proportionally. The objective function can be obtained by minimizing Equation (4).

$$\text{minimize } F = \sum_{i=1}^{N_G} \left[\frac{Q_i^2}{Q_{i-\max}} \right], \quad (4)$$

where: F is the symbol of the reactive power reserve margin, N_G is the generators number, Q_i is the reactive power at the bus i and $Q_{i-\max}$ is the maximum reactive power at bus i .

2.1.5. Emission index

An emission index (environmental) is an index from an environmental perspective. Pollutants resulting from the use of thermal elements such as nitrogen oxide (NOx) and sulfur oxide (SOx) could be modeled separately. The formulation to minimize the emission is by an exponential function and quadratic function as shown generally in Equation (5).

$$\begin{aligned} & \text{minimize } (F_T) = \sum E_i(P_{Gi}), \quad \text{for } i = 1, 2, \dots, N_G, \\ E_i(P_{Gi}) &= \sum 10^{-2}(\alpha_i + \beta_i \cdot P_{Gi} + \gamma_i \cdot P_{Gi}^2) + \zeta_i \exp(\lambda_i \cdot P_{Gi}), \end{aligned} \quad (5)$$

where: E_i is the emission index, P_{Gi} is the power of the generator, α_i , β_i , γ_i , ζ_i , and λ_i are the emission characteristic coefficients for the involved generator.

2.2. The constraints of the system

In this case, variables of control for optimal power flow (OPF) include the actual power from generator units, bus voltage of the generator, tap position of the transformer, and the reactor of the shunt. The analyzed constraints of OPF are the power limits of the generator and the ramp rate of the generator. The system constraints referred to in this paper are constraints on the generating capacity and the ramp rate generator.

2.2.1. Generating capacity

The power output for generator units in a network is restricted by the maximum limit and minimum limit of the power plant as formulated in Equation (6).

$$P_{Gi(\min)} \leq P_{Gi} \leq P_{Gi(\max)} \quad \text{for } i = 1, 2, \dots, N_G \quad (6)$$

where: P_{Gi} is the generated power by the i -th generator, $P_{Gi(\min)}$ is the limit of minimum and $P_{Gi(\max)}$ is the limit of maximum for the i -th generator.

2.2.2. Ramp rate generator

A ramp rate generator is the generator that has ability to respond to the rate of change in load over time [8]. The ramp rate generator constraint is used to stave off undesired outcomes owing to rapid dynamics alterations that exceeds the ability of the generator to withstand them. This restriction is significant if scheduling generators working within a specific period will influence the power limits of the generator for the subsequent time, as shown in Equation (7).

$$P_{\min,i}^t = \max(P_{\min,i}, P_i^{t-1} - DR_i)$$

and

$$P_{\max,i}^t = \min(P_{\max,i}, P_i^{t-1} + UR_i), \quad (7)$$

where $P_{\min,i}^t$ is the limit of minimum at the time t of the i -th generator and $P_{\max,i}^t$ is the limit of the maximum at the time t of the i -th generator. However, $P_{\min,i}$ represents the minimum limit and $P_{\max,i}$ represents the maximum limit of the i -th generator, and P_i^{t-1} is the i -th generator output at the time $t-1$. Whereas DR_i is the descending rate and UR_i is the ascending rate value of the i -th generator.

3. Fruit Fly Optimization method

The FOA method is introduced by Wen-Tsao Pan in 2012 [24], it is a new solving global optimization method based on the foraging behavior of the fruit fly that states that the sense of smell and sight of fruit flies help scent aromas and help allocate food sources from the air even

though the distance of food sources is up to 40 km. The FOA method is one of the heuristic methods used to solve optimization problems, which is a search method based on intuition or empirical rules to obtain a better solution than previously achieved solutions. The Fruit Fly Optimization method has advantages in terms of a simple computational process and the ease of transforming concepts into program codes. The FOA optimization method is represented in the following steps:

1. Determine the initial position of the swarm of fruit flies X_{axis} ; Y_{axis} .
2. Find the direction and distance of food sources by using a smell sense of fruit flies.

$$X_i = X_{axis} + \text{random value}, \quad (8)$$

$$Y_i = Y_{axis} + \text{random value}. \quad (9)$$

3. Estimate the distance of origin (Dist.) of fruit flies, due to the location of unknown food by calculating the smell concentration value (S).

$$\text{Dist}_i = \sqrt{X_i^2 + Y_i^2}, \quad (10)$$

$$S_i = \frac{1}{\text{Dist}_i}. \quad (11)$$

4. Substitute the value of smell concentration (S) into the function of smell concentration.

$$\text{Smell}_i = \text{function}(S_i). \quad (12)$$

5. Determine the maximum smell concentration among swarms of fruit flies.

$$[\text{bestSmell}, \text{bestIndex}] = \max(\text{Smell}). \quad (13)$$

6. Maintain the value of the best smell concentration and coordinates X , Y .

$$\text{Smellbest} = \text{bestSmell}, \quad (14)$$

$$X_{axis} = X(\text{bestIndex}), \quad (15)$$

$$Y_{axis} = Y(\text{bestIndex}). \quad (16)$$

7. Do optimization, and repeat steps 2 to 5 and see if the current smell concentration is better than the concentration of previous Smell, if true, run step 6.

Meanwhile, the procedure for applying the FOA method in solving the multi-objective DED is described as follows:

Step 1: Enter parameters from the FOA, bus data, line data, generator power limits, ramp rate, cost, and emission functions.

Step 2: Find the initial position of the FOA.

Step 3: Enter the Y_{bus} matrix, run Newton Rapson's load flow to calculate the cost function (fitness function).

Step 4: Find the minimum cost and index function.

Step 5: Enter into iterative of the optimization.

Step 6: Next, repeat step 2 until step 4, if the current objective function is better than the previous objective function, then the function of the current objective becomes the minimum and the best.

The problems of the multi-objective dynamic economic dispatch (MODED) studied by researchers using the Fruit Fly Optimization method in the last 6–7 years include the number, type of objective, and several constraints, which are summarized in Table 1.

Table 1. ED problems with quadratic cost functions using the FOA method

| Year | Researcher | Title | n | Objective Function | Number of Constraints |
|------------|------------------------------------|--|-----|--------------------|-----------------------|
| 2019, IEEE | Jiaxiang Liang <i>et al.</i> | Economic Dispatch of Power System Based on Improved Fruit Fly Optimization Algorithm | 1 | FC | 3 |
| 2018, IEEE | Mridula Tiwari and Achala Jain | Multi-Objective Based Economic Emission Dispatch Problem in Thermal-Wind System Using IFOA Technique | 2 | FC, E | 3 |
| 2018, IEEE | Adel Ali Abou El-Ela <i>et al.</i> | Solving Multi-Objective Economical Power Dispatch Problem Using MO-FOA | 2 | FC, E | 5 |
| 2018, IEEE | Chen Guang | Optimal Siting and Parameter Selection for Fault Current Limiters considering Optimal Economic Dispatch of Generators | 1 | FC | 5 |
| 2017, IEEE | Harold Anak Geruna <i>et al.</i> | Fruit Fly Optimization (FFO) for Solving Economic Dispatch Problem in Power System | 1 | FC | 1 |
| 2014, IEEE | Xiaolong Zheng <i>et al.</i> | An Enhanced Non-Dominated Sorting Based Fruit Fly Optimization Algorithm for Solving Environmental Economic Dispatch Problem | 2 | FC, E | 2 |

FC – represents the fuel cost, E – represents the emission

n – represents the number of objectives

4. Results and discussion

As stated before, two different electricity systems are used to observe the effectiveness of the FOA method of the case under study. Initially, the testing was conducted on the system of IEEE 30 and the results were compared with the optimization method in [25], where the power limits of the generator and the ramp rate of the generator were constraints. Next, testing was carried out on the existing system in Indonesia, the Sulselbar thermal power plant, and the results were compared with other techniques of optimization as in [26, 27]. For the IEEE 30 electrical system, the test was carried out in two cases, in case 1 using three objective functions and in case 2 using five objective functions.

4.1. IEEE-30 system

Data for the IEEE 30 system is taken from [25] and performed with five objective functions. Data of this system (control variable constraints, the function of fuel cost, and coefficient of emission) are shown in Tables 2 and 3.

Table 2. Control variable for the IEEE 30 system

| | Variable | Minimum limit | Maximum limit |
|-------------------|----------|---------------|---------------|
| Active power (MW) | P_{G1} | 50 | 200 |
| | P_{G2} | 20 | 80 |
| | P_{G3} | 15 | 50 |
| | P_{G4} | 10 | 35 |
| | P_{G5} | 10 | 30 |
| | P_{G6} | 12 | 40 |

Table 3. Fuel costs and emission coefficients for each unit generator (UG)

| | | UG ₁ | UG ₂ | UG ₃ | UG ₄ | UG ₅ | UG ₆ |
|----------|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Cost | a | 0 | 0 | 0 | 0 | 0 | 0 |
| | b | 2.00 | 1.75 | 1 | 3.25 | 3.00 | 3.00 |
| | c | 0.00375 | 0.0175 | 0.0625 | 0.00834 | 0.025 | 0.025 |
| Emission | α | 0.04091 | 0.02543 | 0.04258 | 0.05426 | 0.04258 | 0.06131 |
| | β | -0.05554 | -0.05094 | -0.05094 | -0.03550 | -0.05094 | -0.05555 |
| | γ | 0.0006460 | 0.0004586 | 0.0004586 | 0.0003380 | 0.0004586 | 0.0005151 |
| | ζ | 2.0e-6 | 1.0e-8 | 1.0e-8 | 2.0e-5 | 1.0e-8 | 1.0e-7 |
| | λ | 0.02857 | 0.08000 | 0.08000 | 0.02000 | 0.08000 | 0.06667 |

Case studies are carried out with two tests, namely:

CASE 1: minimize active power transmission line losses, reactive power transmission line losses, and emission.

CASE 2: minimize active power transmission line losses, reactive power transmission line losses, emission, fuel cost, and a reactive power reserve margin.

The simulation results of the FOA method in solving the DED problem with case 1 are shown in Table 4. Figure 1 shows the convergence graph of the emission with a required computational time of 193.810314 s. The results of case 2 are shown in Table 5 and the convergence graph of total fuel costs is shown in Figure 2 with a required computational time of 282.976823 s. The required computing time is the amount of time required to run the FOA algorithm or method to get the solution of the proposed method by running the power flow using the Newton Raphson method. Runtime or execution time is the time during which the proposed method takes effect

until the process of the method stops when convergence is achieved. In other words, “runtime” is the running phase of a program on the computer’s central processing unit by using the proposed method.

Table 4. Optimization results using the FOA method of case 1

| Objective function | Optimal value |
|------------------------------------|---------------|
| Active power transmission losses | 7.348 MW |
| Reactive power transmission losses | -4.989 Mvar |
| Emission index | 0.05959 t/h |

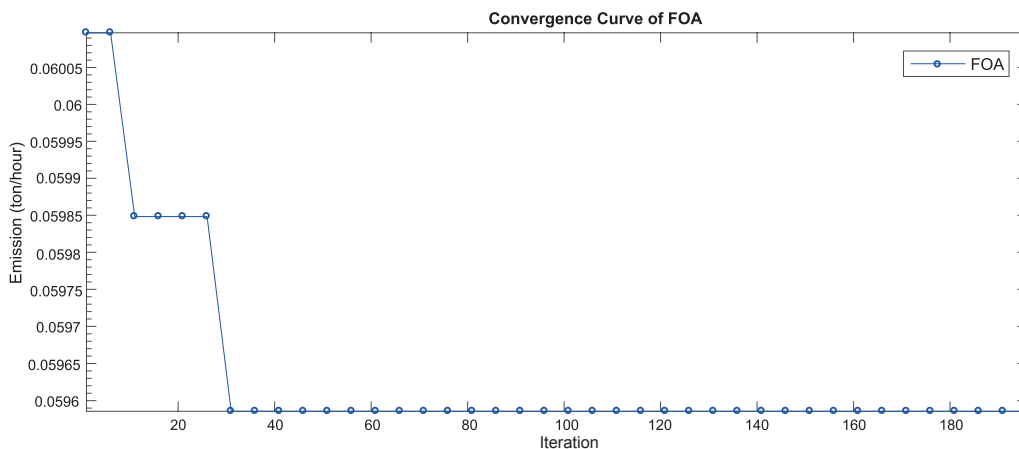


Fig. 1. Convergence graph of emission

Table 5. Optimization results using the FOA method of case 2

| Objective function | Optimal value |
|--|---------------|
| Transmission line losses of the active power | 7.366 MW |
| Generation fuel costs | 795.327 \$/h |
| Transmission line losses of the reactive power | -4.934 Mvar |
| Index of emission | 0.068 t/h |
| The margin of reactive power reserve | 0.211 |

Table 4 shows that the values for the three objective functions tested in case 1 of the IEEE 30 system by using the FOA optimization method are, respectively, 7.348 MW for active power transmission loss, -4.989 Mvar for reactive power transmission loss, and 0.05959 t/h for an emission index. The above test results in case 1 were obtained by minimizing the objective

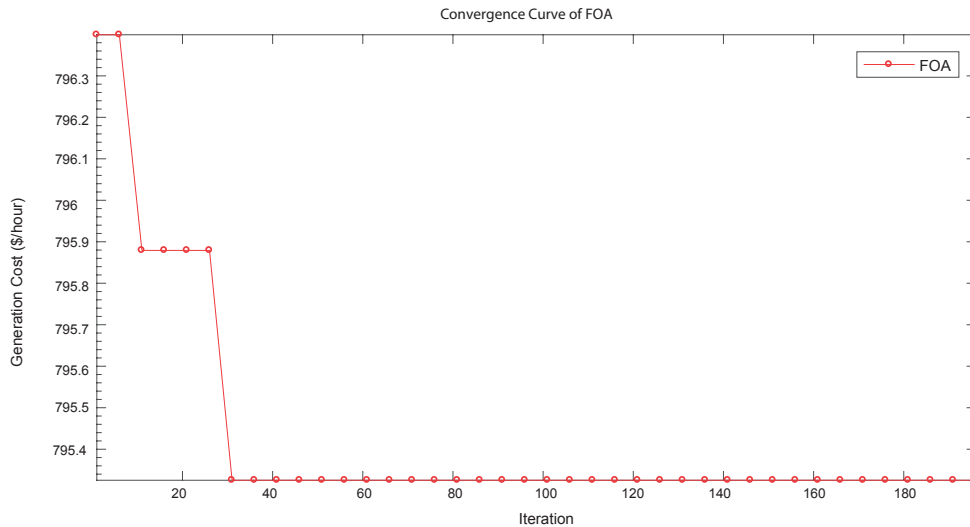


Fig. 2. Convergence graph of total fuel costs

function of active power transmission line losses, reactive power transmission line losses, as well as emissions with the minimum and maximum control variable limits of generating capacity. All objective function tests were carried out at once by entering data and its parameters into the proposed FOA method.

Table 5 shows that the values for the five objective functions tested in case 2 of the IEEE 30 system are respectively 7.366 MW for active power transmission losses, -4.934 Mvar for reactive power transmission losses, and 0.068 t/h for an emission index, generation fuel costs of 795.327 \$/h, and 0.211 for a reactive power reserve margin. Tables 4 and 5 show that the optimization value for active power transmission losses, reactive power transmission losses, and the emission index for test case 2 is greater than the value in test case 1. This is due to test case 2 involving 5 objective functions where the cost of generating fuel is affected by the amount of transmission line losses in the system. So, when the losses in the transmission line in the system go down, the generation fuel costs also decrease. The above test results in case 2 were obtained by minimizing the objective function of active power transmission line losses, reactive power transmission line losses, generating fuel costs, emissions, and the margin of reactive power reserves with the minimum and maximum control variable limits of generating capacity. All objective function tests were carried out at once by entering data and its parameters into the proposed FOA method.

4.2. Sulselbar thermal system

To learn more about the ability of the FOA method in solving DED, testing of the existing system of the Sulselbar thermal power plant was carried out with two objective functions (due to the limitation of data). Here, they were used to generate data for a peak load of the Sulselbar thermal plant system at 7.30 p.m., December 4, 2017, where the fuel cost functions and generator

power constraints are shown in Table 6 [26]. A single line diagram for the system of the Sulselbar thermal plant is shown in Figure 3.

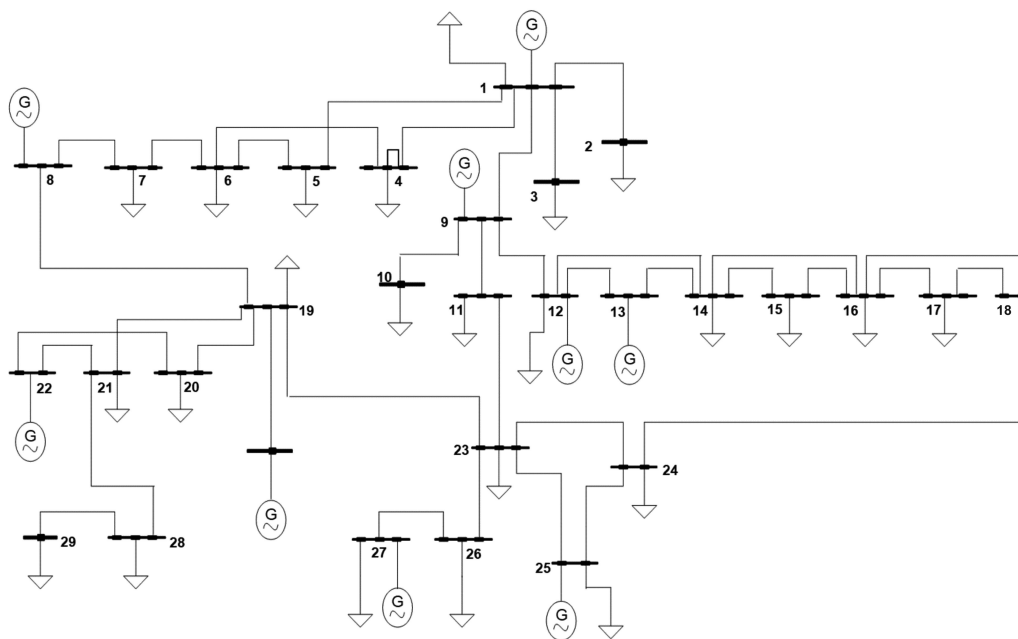


Fig. 3. Single line diagram for a tested real system

Table 6. Fuel cost functions and power constraints for each generator unit

| Generator | Fuel cost functions (IDR/h) | P_{\min} (MW) | P_{\max} (MW) |
|-----------|---|-----------------|-----------------|
| 1 | $1.3736e-9 + 2.2409e6P_1 + 7.1332e-8(P_1)^2$ | 2 | 8 |
| 2 | $-2.4144e-11 + 0.4274e6P_2 - 1.1182e-8(P_2)^2$ | 9.68 | 38.73 |
| 3 | $-3.6365e-11 + 1.9178e6P_3 - 4.5984e-8(P_3)^2$ | 5 | 8 |
| 4 | $6.346e-12 + 0.43275e6P_4 + 1.9212e-7(P_4)^2$ | 55.59 | 222.35 |
| 5 | $-2.5302e-11 + 1.90844e6P_5 + 1.8497e-8(P_5)^2$ | 15 | 60 |
| 6 | $-4.7539e-12 + 0.42778e6P_6 - 1.0608e-7(P_6)^2$ | 54.88 | 219.5 |
| 7 | $1.587e-10 + 2.6343e6P_7 + 1.3227e-8(P_7)^2$ | 1.25 | 5 |

The results of the FOA optimization method for the Sulselbar thermal system (real system) are shown in Table 7, and the convergence graph of total generator fuel costs is shown in Figure 4 with the required computing time of 127.814 s.

Table 7 shows that the real system optimization value of the Sulselbar 150 kV thermal power plant is 20.303 MW for the number of the active power transmission line losses and 364.787

Table 7. Optimization results in two objective functions for the real system

| Objective function | Optimal value |
|---------------------------------------|-------------------------|
| Active power transmission line losses | 20.303 MW |
| Generation fuel costs | 364.787 million (IDR/h) |

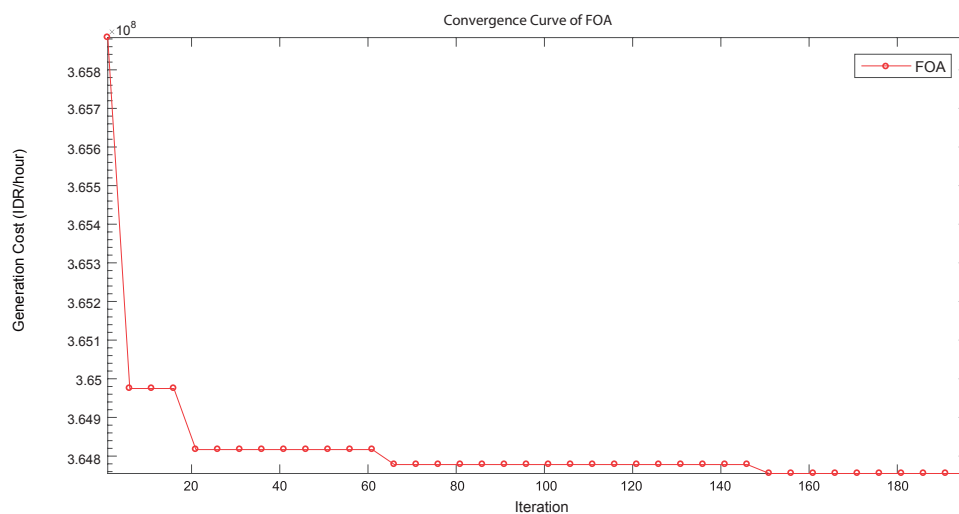


Fig. 4. Convergence graph of the total fuel costs of Suselbar thermal system

million (IDR/h) for the total generation fuel costs. The above test results of Suselbar 150 kV thermal systems above were obtained by minimizing the objective function of active power transmission line losses and generating fuel costs with the minimum and maximum control variable limits of generating capacity. All objective function tests were carried out at once by entering data and its parameters into the FOA method proposed.

5. Comparison of results

To measure the effectiveness of the used method, the results of obtained optimization are compared with other methods in the references, as shown in Table 8 for the IEEE system, and Table 9 for the existing system of the Suselbar 150 kV thermal system.

As shown in Table 8, the results of optimization for the FOA give smaller values compared to the PSO method which means that the proposed method is more powerful in solving the DED problem for the case of the IEEE 30-bus. The obtained value for active power transmission line losses is 7.366 MW while for the PSO method, it is 9.071 MW. The difference loss is 1.705 MW with a decrease of around 18.8%. The value for reactive power transmission loss is lower (−4.934 Mvar) than with the use of the PSO method (1.370 Mvar). For the emission index, the obtained value is 0.068 t/h for the FOA while for the PSO, it is 0.431 t/h with a decrease of

Table 8. Comparison of DED optimization results for the IEEE 30-bus system

| Objective function | Method | |
|---|--------------|--------------|
| | FOA | PSO [25] |
| Active power transmission line losses | 7.366 MW | 9.071 MW |
| Generation fuel costs | 795.327 \$/h | 799.986 \$/h |
| Reactive power transmission line losses | -4.934 Mvar | 1.370 Mvar |
| Emission index | 0.068 t/h | 0.431 t/h |
| Margin of reactive power reserve | 0.211 | 0.319 |

Table 9. Comparison of optimal values obtained based on the objective function for the Sulselbar 150 kV thermal system

| Objective function | Method | | |
|----------------------------------|-------------------------|-------------------------|-------------------------|
| | FOA | ABC [26] | Lagrange [27] |
| Active power transmission losses | 20.303 MW | 23.269 MW | 23.471 MW |
| Generation fuel costs | 364.787 million (IDR/h) | 366.071 million (IDR/h) | 366.158 million (IDR/h) |
| Computational time | 127.814 s | 216.09 s | NI |

NI – stands for no information

84.2%. As with a reactive power reserve margin, it is also lower (0.211) than the value obtained with the use of the PSO method (0.319) when a decrease of 33.86% occurred. The cost of generating fuel when using the FOA method is 795.327 \$/h while the cost of generating fuel using the PSO method is 799.986 \$/h. Thus, there is a difference in the generation fuel cost of 4659 \$/h for the proposed FOA method with a reduction in the generation fuel cost of 0.58%, compared to when using the PSO method for the same case. This shows that the effectiveness of the FOA method in decreasing active power transmission losses, reactive power transmission losses, total cost of generating fuel, an emission index, and reactive power reserve margin is better than when using the PSO method.

For the case of the Sulselbar thermal system, optimization results for the FOA method are also found better than for other methods (ABC and Lagrange methods). The optimization value for active power transmission loss is 20.303 MW, for the ABC method and Lagrange's method is 23.269 MW and 23.471 MW, respectively. The decrease in power losses is around 12.75 to 13.5%. Next, for the fuel cost of the generator, the cost of the generating fuel obtained for the FOA method is 364.787 million (IDR/h). Whereas the cost of fuel for generation using the ABC method is 366.071 million (IDR/h) and the Lagrange method is 366.158million (IDR/h). Thus, a difference in the cost of generating fuel is 1.28 million (IDR/h) when compared to the ABC method or, expressed in percentage, a decrease in the use of fuel costs equals 0.351% and a difference in the use of fuel costs equals 1.371 million (IDR/h) using the Lagrange method or, expressed in percentage, a decrease in the use of costs equals 0.374%, as seen in Table 9.

Based on the test results and comparison of the FOA method with the other methods shown in Tables 4, 8, and 9 above, it can be seen that the value of the test results obtained from the FOA method is lower than from the comparative methods, and the computational time of the FOA method is sufficiently fast even when analyzing the Y_{bus} matrix and calculating Newton Raphson's power flow as well as with quite a lot of objective functions for the IEEE 30 system. In addition, based on the example of the Sulselbar thermal system, the computational time for the FOA method (127.814 s) is faster than for the ABC method. The procedure for determining the above optimal MDED solution using the FOA method is sought based on the random value given by the fruit fly swarm during the initialization process. Initialization is the process of reading initial data related to the data bus, data line, generator power limits, generator increase rate, fuel cost coefficient, and emissions. The given random values are the direction and distance traveled by fruit flies to calculate the objective function of the MDED solution. The direction and distance traveled by the FOA swarm are obtained from the position of bus data parameters, line data, generator power limits, generator ramp rates, fuel cost coefficients, and emissions. At this stage, the calculation of the power flow is carried out to determine the amount of voltage on each bus, and the optimal power generation of each generator. The results of the power flow calculation are used as input to calculate the fitness function or the objective function of the proposed fruit fly swarm method to obtain an effective solution to solving the MDED problem. The calculation stage for the objective function is the most decisive step for the process of determining the optimization value obtained. At this stage, it is also necessary to find the minimum value of the obtained objective function, namely the total cost of fuel, active power transmission losses, reactive power transmission losses, an emission index, and reactive power service margin. At the optimal stage, the looping process is carried out by updating the bus data, channel data, generator power limits, generator ramp levels, fuel cost coefficients, and emissions according to population size, several fitness functions, test limits. Next, re-update the direction and distance traveled by the FOA flock obtained from the bus data parameters, line data, generator power limits, generator ramp rates, fuel cost coefficients, and emissions. Finally, recalculate the new fitness function. If the final fitness function is smaller than the fitness function before the optimization has been fulfilled and the iteration has reached its maximum iteration, it will display the minimum fitness function value or its objective.

6. Conclusions

In this study, the FOA method is proposed to solve the DED problem in electricity systems with the multi-objective function. Two different cases were used to test the performance of the method namely the IEEE 30 system and the Sulselbar thermal power plant system. Next, the FOA method was compared with PSO, ABC, and Lagrange methods for two cases. Results show that the FOA method has better performances than PSO, ABC, and Lagrange methods in providing the best solution. It is indicated by values of five objective functions which are optimized for the IEEE 30 system, and by values of two objective functions for the Sulselbar thermal system which are lower when the use of comparative methods. Besides, the FOA method has sufficiently fast computational time. Therefore, it is promising to use the FOA method as an alternative technique in solving complicated DED problems in power systems. Future research will consider other objective functions in the tested cases by using a new optimization technique.

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