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# Optimal Generation Scheduling Considering Distributed Generator for Cost Minimization based on Adaptive Modified Firefly Algorithm

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**Abstract** The increasing load and the decreasing availability of non-renewable energy sources have encouraged the development of renewable energy utilization. This condition increases the complexity of the power system. Distributed generator (DG) connection causes a significant change in power flow. On the other hand, the load on the power system is dynamic, so it is necessary to adjust the power generation. Proper scheduling of generating units to improve the reliability of the power system is crucial. Scheduling optimization is the key in power system operation planning and control to achieve optimal power system operation, with minimal cost and power loss. This paper presents the optimization of generating unit scheduling by applying the Adaptive Modified Firefly Algorithm (AMFA). The performance of AMFA in optimizing generator scheduling for minimal generation costs and power losses is tested by using a modified IEEE 30-bus system. The simulation results show that AMFA has a better performance than the firefly algorithm (FA), with a convergence speed of 4 times faster. Additionally, optimization by applying a distributed generator shows an improvement in the condition of the bus voltage in the system, lower costs, and power losses. In a system without DG which is loaded with 130% baseload, the optimization results indicate that 67% of the buses are under voltage, the generation cost is 1458.702 \$/hour and the power loss is 23.345 MW. The integration of DG into the system is able to improve the system where only 3% of the buses are under voltage, the cost of generating 1143.111 \$/hour, and power loss 1333.521 MW.

**Keywords**—modified firefly, scheduling, distributed generation, optimization, power flow

## I. INTRODUCTION

A good electric power system must meet several requirements including reliability, quality, stability, and resilient. Monitoring, controlling, and planning are needed to meet the power operation requirement. Moreover, it is necessary to adjust the generator side in providing power supply to the system in order to obtain efficiency in its operation with considering dynamic load. Scheduling generating units is a key issue on the power system operation [1] and needed to realize optimal power system operational conditions in terms of resources and costs [2].

An increasing load on the electric power system and decreasing non-renewable energy reserves have led to a growth in the use of renewable energy sources [3]. The potential for renewable energy is generally not too large and spread over a wide area. These conditions encourage the development of a distributed generation (DG) system to meet load requirements and increase system reliability [4]. The connection of DG tends to make the power system more complex in its operation and control. Inappropriate generation unit scheduling causes higher power losses [5]. Scheduling problems can be modeled in mathematical programming to get the most appropriate generation settings from each generating unit [6].

In reference [7], the firefly algorithm (FA) sets the ON/OFF status and the lambda iterations determine the power generated by each generating unit. The firefly algorithm has better performance than the Integer Coded Genetic Algorithm (ICGA) [8], Shuffled Frog Leaping Algorithm (SFLA) [9], and Extended Priority List (EPL) [10]. This is indicated by the minimum cost when implemented in optimization of 10, 20, and 40 generating units. The hybrid method of priority list (PL) and modified firefly (M-FA) has been applied to solve the unit commitment problem. The first step is to determine the active generating unit based on PL. The second step, M-FA calculates the power of each active generator unit [11].

The firefly algorithm (FA) can be explained that the position of the individual firefly consists of the current position, movement towards a brighter firefly, and random movement. The random movement component has the potential to slow down the achievement of the final position according to the objective functions in the optimization.

This paper discusses the optimization of generating unit scheduling using the Adaptive Modified Firefly Algorithm (AMFA). This modification is an adjustment of the random movement components along with the iteration process to reduce the optimization process and calculation time simultaneously. AMFA's performance is tested by optimizing the generating unit scheduling of the modified IEEE 30-bus system. Load variations are 100%, 120%, and

130% of the baseload 242.55 MW. The performance parameter is the speed of convergence, generating cost, and power loss. In addition, how the DG installation affects the performance.

## II. MATHEMATICAL MODEL

### A. Thermal Generator Input-Output Equivalence

In meeting the power requirements of the load, a power system has  $n$  generators is required to determine the amount of generation for each generator. The power generation affects the fuel costs of each generating unit in the form of the input-output equivalence equation. An  $i$ -th generating unit has the fuel cost ( $F_i$ ) as a function of the power generation ( $P_i$ ) [12].

$$F_i(P_i) = a_i + b_i P_i + c_i (P_i)^2 \quad (1)$$

Where  $a_i, b_i, c_i$  are  $i$ -th input-output coefficients.

The total fuel cost ( $F_t$ ) for the  $n$  generating units in the power system is the sum of the fuel costs for each generator in the system.

$$F_t = \sum_{i=1}^n F_i \quad (2)$$

### B. Thermal Generator Constraint

There are several constraints in determining the power generation for a generating unit. The power requirements ( $P_D$ ) in the system must be agreed with total power generation. This is the first constraint.

$$\sum_{i=1}^n P_i = P_D \quad (3)$$

As shown in Fig. 1, the generation of power determines the fuel costs and efficiency of the generating unit [3]. High efficiency occurs when the generation ranges between  $P_{min}$  and  $P_{max}$  which in that range has a low heat rate, as the second constraint. It can be formulated as below,

$$P_{min} \leq P_i \leq P_{max} \quad (4)$$

## III. OPTIMIZATION ALGORITHM

The firefly algorithm is a metaheuristic method developed by Xin Zhe Yang which is inspired by the behavior of fireflies based on 3 things [13]. First, fireflies are unisex. Second, the individual attraction is proportional to the brightness level. Fireflies have a higher brightness attract the less bright ones to move closer. When there is no difference in brightness, the movement is random. And thirdly, the value of the objective function affects the brightness.

### A. AMFA

The AMFA algorithm is carried out by adapting the random movement components and applied to each iteration [14]. The attractiveness of firefly  $i$  to other firefly  $j$  depends on the brightness ( $\beta_0$ ), the distance ( $r$ ) and the light absorption coefficient ( $\gamma$ ) between fireflies which is expressed by equation (5).

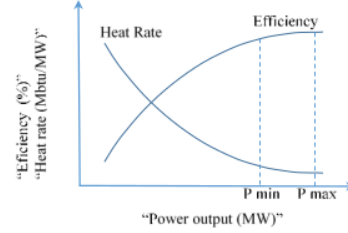


Fig. 1. Heat rate and Efficiency of Thermal Power Generation Unit

$$\beta = \beta_0(X_{ij}) \cdot e^{(-\gamma r^m)}, \quad m \geq 1 \quad (5)$$

The Cartesian distance ( $r_{ij}$ ) between fireflies  $i$  at positions  $X_i$  and  $j$  at  $X_j$  is expressed in equation (6).

$$r_{ij} = \|X_i - X_j\| = \sqrt{\sum_{m=1}^k (X_{j,m} - X_{i,m})^2} \quad (6)$$

Where  $X_{i,m}$  is the  $k$ -th component of the spatial coordinate  $X_i$  of the  $i$ -th firefly. For the 2-dimensional case, the distance equation can be written as below,

$$r_{ij} = \|X_i - X_j\| = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \quad (7)$$

The movement of the less bright firefly ( $X_i$ ) towards the lighter firefly ( $X_j$ ) is expressed as following equation,

$$X_i = X_i + \beta_0 \cdot e^{(-\gamma r^m)} \cdot (X_j - X_i) + \alpha \cdot \varepsilon_i \quad (8)$$

where  $\varepsilon$  is a random value in a Gaussian distribution.

Based on equation (6), the movement of firefly has three components, namely the current position of the firefly ( $X_i$ ), the movement towards a brighter firefly, and the random movement of a firefly with a range of (0,1).

The random movement component can cause the movement of the fireflies to be disorganized and make a slowdown in convergence. Moreover, it can be trapped in the local optima. Based on the previous statement, modifying the firefly algorithm is necessary to reduce the random movement component. The attenuation of the random movement is done by adjusting the value of the parameter  $\alpha$  along with the iteration ( $k$ ). Adaptive random movement can be expressed as following equation [14],

$$\alpha^{k+1} = \alpha^k \left( \frac{1}{2} k_{max} \right)^{\frac{1}{k_{max}+1}} \quad (9)$$

### B. Optimization of Generating Unit Scheduling

The electric power system must be able to adjust the power generation when load changes occur. It is done by adjusting the scheduling of the generating unit. Optimization of generating unit scheduling is to obtain optimal operation in the term of lowest generation cost. AMFA steps are shown in the pseudo-code of Fig. 2.

```

Read system data
Objective function  $f(p)$ ,  $p=(p_1, p_2, \dots, p_n)$ 
Create an initial population of fireflies  $p_i$ , ( $i=1, 2, \dots, n$ )
The light intensity  $I_i$  on  $p_i$  determine by  $f(p_i)$ 
Setting a light absorption coefficient  $\gamma$ 
Setting a randomize movement coefficient  $\alpha$ 
While ( $t < \text{maximum iteration}$ )
  For  $i=1:n$  all  $n$  fireflies
    For  $j=1:n$  all  $n$  fireflies
      If ( $I_j > I_i$ ), firefly  $i$  to  $j$  in  $d$  dimension; end if
      Variation appeal to the distance  $r$  through  $\exp[-\gamma r]$ 
      Update value of  $\alpha$  through reduction with  $U$  of each iteration
      Evaluation of new solutions and update light intensity
    End for  $j$ 
  End for  $i$ 
Run power flow analysis using Newton Raphson
Calculate generation cost and power loss
Arrange fireflies and find the best currently
End while
Display the result of the process

```

Fig. 2. Pseudo Code

#### IV. MODIFIED IEEE 30-BUS POWER SYSTEM

To evaluate AMFA performance, a modified IEEE 30-bus system was used as the test system [15]. The system consists of 6 generating units as shown in Fig. 3. Units 1, 2, 5, and 6 are thermal, while units 3 and 4 are non-thermal generating units as DG. Table I describes the details of the load distribution at each bus. The system load data is 242.55 MW as the baseload. Table II describes the data of each generating unit in the system.

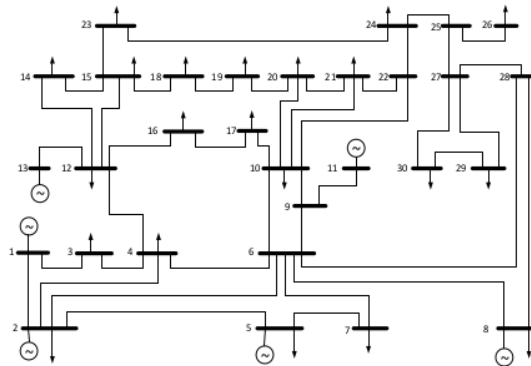


Fig. 3. IEEE 6 generator 30 bus systems

TABLE I. DISTRIBUTION OF LOAD ON EACH BUS FOR BASELOAD (242.55 MW AND 59.85 MVAR)

| Bus | $P_{Load}$ (MW) | $Q_{Load}$ (MVAR) | Bus | $P_{Load}$ (MW) | $Q_{Load}$ (MVAR) |
|-----|-----------------|-------------------|-----|-----------------|-------------------|
| 1   | 0.00            | 0.00              | 16  | 16.65           | 1.62              |
| 2   | 4.50            | 0.90              | 17  | 12.60           | 5.22              |
| 3   | 18.36           | 1.08              | 18  | 15.48           | 0.81              |
| 4   | 14.04           | 1.44              | 19  | 13.05           | 3.06              |
| 5   | 4.50            | 0.90              | 20  | 12.78           | 0.63              |
| 6   | 0.00            | 0.00              | 21  | 21.15           | 10.08             |
| 7   | 25.02           | 9.81              | 22  | 0.00            | 0.00              |
| 8   | 0.00            | 0.00              | 23  | 8.28            | 1.44              |
| 9   | 0.00            | 0.00              | 24  | 9.63            | 6.03              |
| 10  | 18.72           | 1.80              | 25  | 0.00            | 0.00              |
| 11  | 0.00            | 0.00              | 26  | 7.65            | 2.07              |
| 12  | 14.58           | 6.75              | 27  | 0.00            | 0.00              |
| 13  | 0.00            | 0.00              | 28  | 0.00            | 0.00              |
| 14  | 5.58            | 1.44              | 29  | 6.66            | 0.81              |
| 15  | 7.38            | 2.25              | 30  | 5.94            | 1.71              |

TABLE II. GENERATING UNIT DATA ON IEEE 30 BUS SYSTEM

| Generating Unit | Bus | $P_{min}$ (MW) | $P_{max}$ (MW) | Input output coefficient |      |         |
|-----------------|-----|----------------|----------------|--------------------------|------|---------|
|                 |     |                |                | $a$                      | $b$  | $c$     |
| 1               | 1   | 50             | 200            | 0                        | 3.25 | 0.01834 |
| 2               | 2   | 50             | 150            | 0                        | 3.00 | 0.03750 |
| 3               | 5   | 75             | 100            | 0                        | 1.75 | 0.00000 |
| 4               | 8   | 10             | 35             | 0                        | 1.75 | 0.00000 |
| 5               | 11  | 10             | 30             | 0                        | 3.15 | 0.02500 |
| 6               | 13  | 50             | 100            | 0                        | 3.10 | 0.02500 |

#### V. RESULT AND DISCUSSION

Optimization of generating units scheduling is performed with several loading conditions. Loading varieties include 100%, 120%, and 130% of the baseload. Optimization is carried out using the FA and AMFA methods and compared. Furthermore, the results are used as the value of power generation for each generating unit in power flow analysis using the Newton Raphson method.

##### A. Case-1: Optimization of 4 Generating Units

Case-1, the system load is 100%, 120%, and 130% of the baseload. The optimization process is limited to 2000 iterations. The number of a scheduled generating units is 4 units, where DG are not included. This simulation is intended to determine the performance of the FA and AMFA.

The optimization convergence of both methods is shown in Fig. 4. The simulation result provides that AMFA is faster than FA, and a number of iterations is 137 and 861, respectively. Moreover, time calculations are 13.08 and 84.59 seconds, respectively.

For the 3 types of loading, the performance comparison both of methods is presented in Table III. There was an improvement in the optimization process with AMFA compared to FA. Iteration and computation time are reduced significantly and simultaneously. The percentage of iteration reduction and calculation time reduction is obtained by comparing the reduction that occurs when using AMFA against FA.

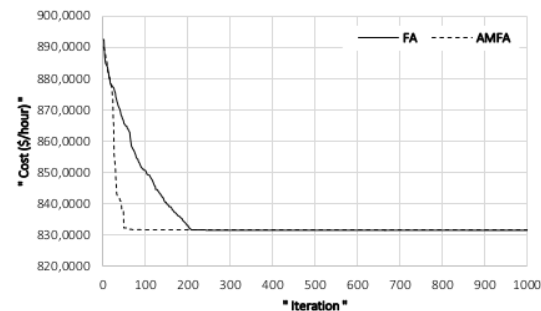


Fig. 4. Convergence of optimization process on scheduling for 4 generating units of IEEE 30-bus standard system with 100% baseload

TABLE III. PERFORMANCE COMPARISON OF FA AND AMFA FOR CASE-1

| Load  | Number of Iteration |      | % Iteration reduction | Calculation time (seconds) |       | % time reduction |
|-------|---------------------|------|-----------------------|----------------------------|-------|------------------|
|       | FA                  | AMFA |                       | FA                         | AMFA  |                  |
| 100 % | 861                 | 137  | 84.09                 | 84.59                      | 13.08 | 84.54            |
| 120 % | 177                 | 79   | 55.37                 | 17.11                      | 7.62  | 55.46            |
| 130 % | 229                 | 126  | 44.98                 | 22.27                      | 12.22 | 45.13            |

TABLE IV. RESULT OF GENERATING UNITS SCHEDULING ON CASE-1, LOADING AT 100%, 120%, AND 130% OF BASELOAD.

| Load               | Para-meters        | Methods         |           |          |
|--------------------|--------------------|-----------------|-----------|----------|
|                    |                    | FA              | AMFA      |          |
| 100% baseload      | Total Load (MW)    | 242.5500        | 242.5500  |          |
|                    | Total Gen (MW)     | 253.2195        | 253.2162  |          |
|                    | Total Loss (MW)    | 10.6695         | 10.6662   |          |
|                    | Gen 1 (MW)         | 60.6695         | 60.6662   |          |
|                    | Gen 2 (MW)         | 50.0001         | 50.0000   |          |
|                    | Gen 3 (MW)         | 92.5499         | 92.4963   |          |
|                    | Gen 4 (MW)         | -               | -         |          |
|                    | Gen 5 (MW)         | -               | -         |          |
|                    | Gen 6 (MW)         | 50.0000         | 50.0537   |          |
|                    | Tot Cost (\$/hour) | 887.8944        | 888.0830  |          |
|                    | Gen 1 (\$/hour)    | 264.6814        | 264.6635  |          |
|                    | Gen 2 (\$/hour)    | 243.7506        | 243.7500  |          |
|                    | Gen 3 (\$/hour)    | 161.9623        | 161.8685  |          |
|                    | Gen 4 (\$/hour)    | -               | -         |          |
|                    | Gen 5 (\$/hour)    | -               | -         |          |
|                    | Gen 6 (\$/hour)    | 217.5000        | 217.8010  |          |
|                    | 120% baseload      | Total Load (MW) | 296.4500  | 296.4500 |
|                    |                    | Total Gen (MW)  | 314.3318  | 314.3218 |
| Total Loss (MW)    |                    | 17.8818         | 17.8718   |          |
| Gen 1 (MW)         |                    | 100.6279        | 100.4466  |          |
| Gen 2 (MW)         |                    | 50.0000         | 50.0006   |          |
| Gen 3 (MW)         |                    | 100.0000        | 100.0000  |          |
| Gen 4 (MW)         |                    | -               | -         |          |
| Gen 5 (MW)         |                    | -               | -         |          |
| Gen 6 (MW)         |                    | 63.7039         | 63.8747   |          |
| Tot Cost (\$/hour) |                    | 1230.4378       | 1230.2578 |          |
| Gen 1 (\$/hour)    |                    | 512.7512        | 511.4930  |          |
| Gen 2 (\$/hour)    |                    | 243.7500        | 243.7540  |          |
| Gen 3 (\$/hour)    |                    | 175.0000        | 175.0000  |          |
| Gen 4 (\$/hour)    |                    | -               | -         |          |
| Gen 5 (\$/hour)    |                    | -               | -         |          |
| Gen 6 (\$/hour)    |                    | 298.9366        | 300.0107  |          |
| 130% baseload      |                    | Total Load (MW) | 323.4000  | 323.4000 |
|                    |                    | Total Gen (MW)  | 346.7438  | 346.7450 |
|                    | Total Loss (MW)    | 23.3438         | 23.3450   |          |
|                    | Gen 1 (MW)         | 121.0041        | 121.0221  |          |
|                    | Gen 2 (MW)         | 51.0954         | 51.0981   |          |
|                    | Gen 3 (MW)         | 100.0000        | 100.0000  |          |
|                    | Gen 4 (MW)         | -               | -         |          |
|                    | Gen 5 (MW)         | -               | -         |          |
|                    | Gen 6 (MW)         | 74.6443         | 74.6249   |          |
|                    | Tot Cost (\$/hour) | 1458.6780       | 1458.7020 |          |
|                    | Gen 1 (\$/hour)    | 661.7974        | 661.9359  |          |
|                    | Gen 2 (\$/hour)    | 251.1888        | 251.2071  |          |
|                    | Gen 3 (\$/hour)    | 175.0000        | 175.0000  |          |
|                    | Gen 4 (\$/hour)    | -               | -         |          |
|                    | Gen 5 (\$/hour)    | -               | -         |          |
|                    | Gen 6 (\$/hour)    | 370.6917        | 370.5590  |          |

The generation scheduling for case-1 is presented in Table IV. It is observed that AMFA is more optimal than FA with very small differences. Improvements to the optimization of the objective function, which consists of total generation, total cost, and total loss, were not significant.

The results of the power flow analysis are listed in Table V. It shows that the bus voltage profile is the same for both FA and AMFA algorithms. This proves that the modifications made have been able to improve performance while maintaining accuracy. It is observed that bus voltage less than IEEE standard 141-1986 using both methods are 1, 18, and 20 buses for 100%, 120%, and 130% of based load, respectively. The voltage profile tends to be worse when the load increased. This condition is improved by DG in case-2.

TABLE V. RESULTS OF POWER FLOW ANALYSIS ON CASE-1 USING FA AND AMFA, LOADING AT 100%, 120%, AND 130% OF THE BASELOAD

| Bus | VI  (p.u)      |        |                |        |                |        |
|-----|----------------|--------|----------------|--------|----------------|--------|
|     | 100 % baseload |        | 120 % baseload |        | 130 % baseload |        |
|     | FA             | AMFA   | FA             | AMFA   | FA             | AMFA   |
| 1   | 1.0500         | 1.0500 | 1.0500         | 1.0500 | 1.0500         | 1.0500 |
| 2   | 1.0450         | 1.0450 | 1.0329         | 1.0329 | 1.0254         | 1.0254 |
| 3   | 1.0029         | 1.0029 | 0.9747         | 0.9747 | 0.9571         | 0.9571 |
| 4   | 0.9945         | 0.9946 | 0.9610         | 0.9611 | 0.9402         | 0.9402 |
| 5   | 1.0173         | 1.0173 | 1.0100         | 1.0100 | 1.0100         | 1.0100 |
| 6   | 0.9828         | 0.9829 | 0.9456         | 0.9456 | 0.9226         | 0.9226 |
| 7   | 0.9850         | 0.9850 | 0.9572         | 0.9573 | 0.9424         | 0.9424 |
| 8   | 0.9821         | 0.9821 | 0.9441         | 0.9442 | 0.9206         | 0.9206 |
| 9   | 0.9488         | 0.9488 | 0.8892         | 0.8892 | 0.8492         | 0.8492 |
| 10  | 0.9345         | 0.9345 | 0.8660         | 0.8661 | 0.8193         | 0.8193 |
| 11  | 0.9488         | 0.9488 | 0.8892         | 0.8892 | 0.8492         | 0.8492 |
| 12  | 0.9901         | 0.9902 | 0.9303         | 0.9304 | 0.8888         | 0.8888 |
| 13  | 1.0365         | 1.0365 | 0.9774         | 0.9775 | 0.9357         | 0.9357 |
| 14  | 0.9675         | 0.9675 | 0.9009         | 0.9009 | 0.8548         | 0.8548 |
| 15  | 0.9501         | 0.9502 | 0.8785         | 0.8786 | 0.8289         | 0.8288 |
| 16  | 0.9503         | 0.9503 | 0.8811         | 0.8811 | 0.8334         | 0.8334 |
| 17  | 0.9328         | 0.9328 | 0.8619         | 0.8619 | 0.8134         | 0.8134 |
| 18  | 0.9154         | 0.9154 | 0.8340         | 0.8341 | 0.7778         | 0.7778 |
| 19  | 0.9075         | 0.9075 | 0.8252         | 0.8252 | 0.7686         | 0.7686 |
| 20  | 0.9105         | 0.9105 | 0.8302         | 0.8303 | 0.7751         | 0.7751 |
| 21  | 0.9212         | 0.9213 | 0.8481         | 0.8481 | 0.7983         | 0.7983 |
| 22  | 0.9222         | 0.9222 | 0.8493         | 0.8493 | 0.7997         | 0.7997 |
| 23  | 0.9276         | 0.9276 | 0.8514         | 0.8515 | 0.7991         | 0.7990 |
| 24  | 0.9139         | 0.9139 | 0.8373         | 0.8373 | 0.7851         | 0.7851 |
| 25  | 0.9236         | 0.9236 | 0.8535         | 0.8535 | 0.8060         | 0.8060 |
| 26  | 0.8926         | 0.8926 | 0.8116         | 0.8116 | 0.7568         | 0.7568 |
| 27  | 0.9443         | 0.9443 | 0.8837         | 0.8838 | 0.8430         | 0.8430 |
| 28  | 0.9755         | 0.9755 | 0.9343         | 0.9343 | 0.9084         | 0.9084 |
| 29  | 0.9208         | 0.9208 | 0.8524         | 0.8524 | 0.8066         | 0.8066 |
| 30  | 0.9169         | 0.9170 | 0.8473         | 0.8473 | 0.8007         | 0.8007 |

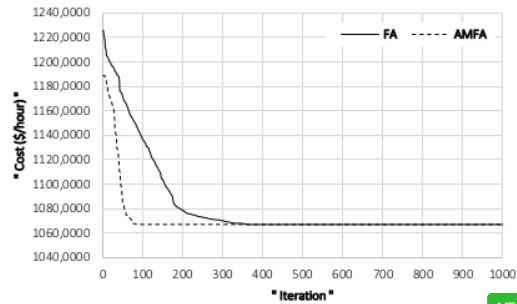


Fig. 5. Convergence of optimization process on scheduling for 6 generating units of IEEE 30-bus standard system with 130% baseload

### B. Case-2: Optimization of 6 Generating Units

Case-2, the number of a scheduled generating units is 6 units, where DG are included. The system load is 100%, 120%, and 130% of baseload. The optimization process is limited to 1000 iterations. This simulation is to examine the performance of the proposed AMFA method for optimizing the scheduling of 6 generating units. In addition, DG's ability to improve the results of generating unit scheduling and bus voltages against increased loads is also analyzed.

Based on the results shown in Fig. 5, AMFA is faster than FA, and the number of iterations is 501 and 1685, respectively for 100% based load, while the calculation time is 93.0789 and 318.8468 seconds, respectively.

TABLE VI. PERFORMANCE COMPARISON OF FA AND AMFA FOR CASE-2

| Load  | Number of Iteration |      | % Iteration reduction | Calculation time (seconds) |       | % time reduction |
|-------|---------------------|------|-----------------------|----------------------------|-------|------------------|
|       | FA                  | AMFA |                       | FA                         | AMFA  |                  |
| 100 % | 1685                | 501  | 70.27                 | 318.85                     | 93.08 | 70.81            |
| 120 % | 531                 | 107  | 79.85                 | 56.18                      | 11.04 | 80.35            |
| 130 % | 524                 | 89   | 83.02                 | 58.63                      | 9.31  | 84.13            |

For the 3 types of loading, the performance comparison both of methods is presented in Table VI. With AMFA, the iteration decreases between 70.27% - 83.02%, while the calculation time decreases by 70.81% - 84.13%.

Table VII presents a comparison of the optimization results for case-1 and case-2. In case-2, the optimization involves 6 generating units consisting of 4 thermal units and 2 DG units as previously described.

TABLE VII. GENERATING UNITS SCHEDULING ON CASE-1 AND CASE-2, LOADING AT 100%, 120%, AND 130% OF BASELOAD

| Load          | Para-meters        | AMFA Methode |           |
|---------------|--------------------|--------------|-----------|
|               |                    | Case-1       | Case-2    |
| 100% baseload | Total Load (MW)    | 242.5500     | 242.5500  |
|               | Total Gen (MW)     | 253.2162     | 250.6112  |
|               | Total Loss (MW)    | 10.6662      | 8.0612    |
|               | Gen 1 (MW)         | 60.6662      | 55.6112   |
|               | Gen 2 (MW)         | 50.0000      | 50.0000   |
|               | Gen 3 (MW)         | 92.4963      | 75.0000   |
|               | Gen 4 (MW)         | -            | 10.0000   |
|               | Gen 5 (MW)         | -            | 10.0000   |
|               | Gen 6 (MW)         | 50.0537      | 50.0000   |
|               | Tot Cost (\$/hour) | 888.0830     | 881.4549  |
|               | Gen 1 (\$/hour)    | 264.6635     | 237.4549  |
|               | Gen 2 (\$/hour)    | 243.7500     | 243.7500  |
|               | Gen 3 (\$/hour)    | 161.8685     | 131.2500  |
|               | Gen 4 (\$/hour)    | -            | 17.5000   |
|               | Gen 5 (\$/hour)    | -            | 34.0000   |
|               | Gen 6 (\$/hour)    | 217.8010     | 217.5000  |
| 120% baseload | Total Load (MW)    | 296.4500     | 296.4500  |
|               | Total Gen (MW)     | 314.3218     | 308.3770  |
|               | Total Loss (MW)    | 17.8718      | 11.9270   |
|               | Gen 1 (MW)         | 100.4466     | 61.9270   |
|               | Gen 2 (MW)         | 50.0006      | 50.0000   |
|               | Gen 3 (MW)         | 100.0000     | 100.0000  |
|               | Gen 4 (MW)         | -            | 35.0000   |
|               | Gen 5 (MW)         | -            | 11.4500   |
|               | Gen 6 (MW)         | 63.8747      | 50.0000   |
|               | Tot Cost (\$/hour) | 1230.2578    | 1008.4390 |
|               | Gen 1 (\$/hour)    | 511.4930     | 271.5940  |
|               | Gen 2 (\$/hour)    | 243.7540     | 243.7500  |
|               | Gen 3 (\$/hour)    | 175.0000     | 175.0000  |
|               | Gen 4 (\$/hour)    | -            | 61.2500   |
|               | Gen 5 (\$/hour)    | -            | 39.3450   |
|               | Gen 6 (\$/hour)    | 300.0107     | 217.5000  |
| 130% baseload | Total Load (MW)    | 323.4000     | 323.4000  |
|               | Total Gen (MW)     | 346.7450     | 336.9210  |
|               | Total Loss (MW)    | 23.3450      | 13.5210   |
|               | Gen 1 (MW)         | 121.0221     | 71.9210   |
|               | Gen 2 (MW)         | 51.0981      | 50.0000   |
|               | Gen 3 (MW)         | 100.0000     | 100.0000  |
|               | Gen 4 (MW)         | -            | 35.0000   |
|               | Gen 5 (MW)         | -            | 30.0000   |
|               | Gen 6 (MW)         | 74.6249      | 50.0000   |
|               | Tot Cost (\$/hour) | 1458.7020    | 1143.1110 |
|               | Gen 1 (\$/hour)    | 661.9359     | 328.6110  |
|               | Gen 2 (\$/hour)    | 251.2071     | 243.7500  |
|               | Gen 3 (\$/hour)    | 175.0000     | 175.0000  |
|               | Gen 4 (\$/hour)    | -            | 61.2500   |
|               | Gen 5 (\$/hour)    | -            | 117.0000  |
|               | Gen 6 (\$/hour)    | 370.5590     | 217.5000  |

TABLE VIII. RESULTS OF POWER FLOW ANALYSIS ON CASE-1 AND CASE-2 USING AMFA, LOADING AT 100%, 120%, AND 130 % OF THE BASELOAD

| Bus | VI  (p.u.)     |        |                |        |                |        |
|-----|----------------|--------|----------------|--------|----------------|--------|
|     | 100 % baseload |        | 120 % baseload |        | 130 % baseload |        |
|     | Case-1         | Case-2 | Case-1         | Case-2 | Case-1         | Case-2 |
| 1   | 1.0500         | 1.0500 | 1.0500         | 1.0500 | 1.0500         | 1.0500 |
| 2   | 1.0450         | 1.0450 | 1.0329         | 1.0450 | 1.0254         | 1.0450 |
| 3   | 1.0029         | 1.0178 | 0.9747         | 1.0108 | 0.9571         | 1.0067 |
| 4   | 0.9946         | 1.0125 | 0.9611         | 1.0046 | 0.9402         | 1.0000 |
| 5   | 1.0173         | 1.0254 | 1.0100         | 1.0256 | 1.0100         | 1.0230 |
| 6   | 0.9829         | 1.0067 | 0.9456         | 1.0002 | 0.9226         | 0.9968 |
| 7   | 0.9850         | 1.0033 | 0.9573         | 0.9965 | 0.9424         | 0.9924 |
| 8   | 0.9821         | 1.0100 | 0.9442         | 1.0100 | 0.9206         | 1.0100 |
| 9   | 0.9488         | 1.0022 | 0.8892         | 0.9898 | 0.8492         | 0.9775 |
| 10  | 0.9345         | 0.9777 | 0.8661         | 0.9585 | 0.8193         | 0.9436 |
| 11  | 0.9488         | 1.0500 | 0.8892         | 1.0491 | 0.8492         | 1.0359 |
| 12  | 0.9902         | 1.0128 | 0.9304         | 0.9987 | 0.8888         | 0.9837 |
| 13  | 1.0365         | 1.0500 | 0.9775         | 1.0447 | 0.9357         | 1.0302 |
| 14  | 0.9675         | 0.9929 | 0.9009         | 0.9739 | 0.8548         | 0.9564 |
| 15  | 0.9502         | 0.9784 | 0.8786         | 0.9564 | 0.8288         | 0.9378 |
| 16  | 0.9503         | 0.9822 | 0.8811         | 0.9622 | 0.8334         | 0.9453 |
| 17  | 0.9328         | 0.9728 | 0.8619         | 0.9519 | 0.8134         | 0.9355 |
| 18  | 0.9154         | 0.9502 | 0.8341         | 0.9216 | 0.7778         | 0.8999 |
| 19  | 0.9075         | 0.9455 | 0.8252         | 0.9163 | 0.7686         | 0.8947 |
| 20  | 0.9105         | 0.9500 | 0.8303         | 0.9222 | 0.7751         | 0.9016 |
| 21  | 0.9213         | 0.9638 | 0.8481         | 0.9410 | 0.7983         | 0.9240 |
| 22  | 0.9222         | 0.9643 | 0.8493         | 0.9417 | 0.7997         | 0.9247 |
| 23  | 0.9276         | 0.9600 | 0.8515         | 0.9344 | 0.7990         | 0.9145 |
| 24  | 0.9139         | 0.9513 | 0.8373         | 0.9248 | 0.7851         | 0.9054 |
| 25  | 0.9236         | 0.9570 | 0.8535         | 0.9334 | 0.8060         | 0.9167 |
| 26  | 0.8926         | 0.9271 | 0.8116         | 0.8956 | 0.7568         | 0.8743 |
| 27  | 0.9443         | 0.9746 | 0.8838         | 0.9569 | 0.8430         | 0.9441 |
| 28  | 0.9755         | 1.0011 | 0.9343         | 0.9936 | 0.9084         | 0.9894 |
| 29  | 0.9208         | 0.9518 | 0.8524         | 0.9283 | 0.8066         | 0.9122 |
| 30  | 0.9170         | 0.9481 | 0.8473         | 0.9236 | 0.8007         | 0.9070 |

TABLE IX. THE NUMBER OF BUSES EXPERIENCING LOW VOLTAGE (<0.9 P.U.) ON CASE-1 AND CASE-2, LOADING AT 100%, 120%, AND 130 % OF THE BASELOAD

| Loading         | Number of Low Voltage Bus |        |
|-----------------|---------------------------|--------|
|                 | Case-1                    | Case-2 |
| 100% Based Load | 1 bus                     | 0 bus  |
| 120% Based Load | 18 bus                    | 1 bus  |
| 130% Based Load | 21 bus                    | 3 bus  |

The optimization results show a smaller of total generation, total cost and total power loss. Thus the operation of the system is more optimal. This proves DG's ability to improve the optimization results.

The power flow analysis based on the scheduling results in Table VII has provided a bus voltage profile. Table VIII presents a comparison of the bus voltage profiles in case-1 and case-2 for 3 types of loading. In case-2, the bus voltage profile is much better than in case-1. The number of buses experiencing low voltage is significantly reduced. Table IX summarizes the number of bus voltages below 0.9 p.u for both test cases.

## VI. CONCLUSION

The adaptive modified firefly (AMFA) algorithm by reducing the random movement components of firefly has improved its performance. There is an improvement in the speed of convergence significantly. Increasing the speed of the optimization process opens up opportunities for online optimization implementation when the power system is operating. The involvement of DG able to improve profile bus voltage. Moreover, DG can also improve optimal

conditions in terms of total generation, generation cost, and power losses. This will be advantageous in the planning of short-term power system operations against daily load changes. In future work, it is necessary to study the application of the AMFA algorithm for optimization of unit commitments in real power systems where the generating unit has more complicated input-output characteristics.

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