Economic Dispatch of 500 kV Java-Bali Power System using Hybrid Particle Swarm-Ant Colony Optimization Method

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d Abstract—The rapid growth of population and economic development of a country requires an adequate support of electrical power supply management. The interconnected system of generation plants with appropriate economic dispatch is purposed to achieve certain goal. This paper describes the use of a hybrid method between the Particle Swarm Optimization (PSO) method and Ant Colony Optimization (ACO) method to be implemented for economic dispatch of the 500kV Java-Bali power system. It aims to divide the generation loading among the whole thermal power plants in the system and to look for the best combination which gives the most economical generation cost. The search for solutions using this hybrid method is determined by the Gbest's particle distribution and the ability of ants to find the best solution, which is called BestAnt. In this study, the evaluation process was carried out using 60 iterations for the 30-bus network and the 500kV Java-Bali power network based on the available data. The optimization results show that the generation cost being optimized using the hybrid method is lower than when using the PSO method, even if it is still higher than when using the ACO method. However, the hybrid method offers the best achievement in terms of computation speed being compared to both the PSO and ACO methods.

Keywords—Ant Colony Optimization, economic dispatch, Particle Swarm Optimization

I. INTRODUCTION

To meet the electricity needs of a country, in general the electric power system is built from the interconnection of thermal power plants. The more the number of power plants involved, the greater the total generation costs. One important factor to consider in planning, operating, and controlling an electric power system is the cost of fuel. Fuel costs are the most expensive component in a thermal generator plant [1]. The savings in the fuel cost of generating system can reduce the cost of electricity production.

There are 2 problems to solve in obtaining an economical generation cost, namely economic dispatch or unit load management and unit commitment or economic scheduling. Unit commitment aims to determine the most optimum generating unit to be operated to meet certain load needs with minimum fuel cost, while economic dispatch is used to share the load among the operating thermal units in order to achieve the minimum fuel cost [2].

Many computation techniques have been developed to solve the optimization problem of economic dispatch, for example the Particle Swarm Optimization (PSO) by Kennedy and Eberhart in 1995 [3], the Artificial Bee Colony (ABC) optimization [4], Ant Colony Optimization (ACO) [5], Genetic Algorithm (GA) [6], Gravitational Search Algorithm (GSA) [7]. The computation techniques have been proven to successfully solve the optimization problems in economic dispatch and to offer a better solution than the conventional methods. The development of those methods in a form of Hybrid Soft Computing Techniques like GA-PSO, ABC-PSO, PSO-GSA, and others has also proven the better improvement in economic dispatch problems.

Among those all methods, the PSO method has been known effective to find the global best in economic dispatch problem. However, it has a quite famous limitation in dealing with local optima, especially in a high-dimensional space problem, besides the low convergence rate during iteration. To overcome the problem, the PSO method has been combined with other methods (GA, ABC, GSA, etc.) to form a hybrid optimization method for economic dispatch problem [8]. The ACO method is famous for its convergence robustness and flexibility when being combined with other methods for solving the economic dispatch problem [9].

In this study the conventional PSO method [10] is combined with the ACO method, to form the hybrid PSO-ACO method, and to be applied to economic dispatch problems in the 500kV Java-Bali power system. This method is expected to produce a more accurate combination of output power from each plant involved so that lower production costs and faster calculation execution are obtained.

II. RESEARCH METHOD

A. Power System Modeling

Two system models have been used in this paper. One was the 30-Bus IEEE system, whereas the other was the 500kV Java-Bali power system. The 30-Bus IEEE system comprises 6 generators, being used to validate the method, is presented in Fig. 1. The detail steady state data and single line diagram are provided in reference [11], while the generating cost data is given in reference [12].
quadratic polynomials can be formulated as follows:

\[ HR(P) = c + bP_i + aP_i^2 \]  

(1)

where \( P_i \) is the active power output of the generating unit \( i \) (in MW or per unit) with the following limit:

\[ P_{\text{min}} \leq P_i \leq P_{\text{max}} \]  

(2)

where \( P_{\text{min}} \) : the minimum active power output; \( P_{\text{max}} \): maximum active power output; and \( a, b, c \): the coefficient constants of the output-input function of the generating unit \( i \).

The main constraints of the power system operation is the balancing active power between the generating power output and the load power. Mathematically, the input (cost) and output (power) functions are represented as an objective function, \( F_i \), which shows the total operating costs to meet certain load requirements, that given as follows:

\[ F_i = \sum_{i=1}^{N} F_i(P_i) \]  

(3)

where \( P_i \): active power output of the generating unit \( i \) (MW); \( F_i(P_i) \): operational cost of the generating unit \( i \) (Rp/hour); and \( N \) : total number of the generating unit.

Some constraints can be considered in the calculation such as the power balance between generation and load powers, spinning reserve requirement, start-up and shutdown time, start-up and shutdown cost, and etc.

C. Hybrid PSO-ACO Optimization Method Algorithm

The steps to implement the Hybrid PSO-ACO optimization method in the economic dispatch problem of the 500kV Java-Bali Power System is elaborated below.

1) Determining the data of generators and loads: The required data includes the input-output characteristics of the thermal generators, maximum and minimum loading of each unit, and generating capacity data. The required load data are the demand data during 24 hours.

2) Initialization of PSO and ACO parameters [8]:
   a) The particles number: It was taken to be 30.
   b) The maximum iteration number: It was determined to be 60, where 30 was for PSO, 30 was for ACO.
   c) The coefficient acceleration \( c_1 \) and \( c_2 \): It was determined to be 2.05 for each.
   d) Determination of initial weight \( (w_i) \) to be 0.9 and final weight \( (w_f) \) to be 0.3.
   e) The ants number: It was 5.
   f) The pheromone evaporation coefficient \( \rho \) to be 0.02.
   g) The pheromone intensity gain \( \alpha \) to be 1.
   h) The pheromone intensity \( Q \) to be 100.

3) Determination of PSO initial particle: The initialization is done by considering the inequality limits, \( P_{\text{min}} \leq P_i \leq P_{\text{max}} \), which is the generating limits of each generator. Each particle represents the generated power of each unit. The power value corresponding to the initial position of particle is determined by the difference of \( P_{\text{max}} \) and \( P_{\text{min}} \) (\( P_{\text{max}} - P_{\text{min}} \)) being multiplied with a random number, which is the being added to \( P_{\text{min}} \).

4) The execution of PSO method: The implementation of the PSO method comprises the evaluation of the particle velocity, the related position, and the \( P_{\text{best}} \) value. It is done...
by evaluating the velocity of each particle and renewing the position of each particle using (4) and (5).

\[ V_{i+1} = wV_i + c_1r \text{rand}_1(G_{\text{best}} - X_i) + c_2r \text{rand}_2(P_{\text{best}} - X_i) \quad (4) \]

\[ X_{i+1} = X_i + V_{i+1} \quad (i = 1 \ldots N) \quad (5) \]

where \( V_{i+1} \) represents the renewed velocity, whereas \( X_{i+1} \) represents the renewed position of particle. The variable \( w \) represents the weight of the particle velocity, which is expressed using (6).

\[ w = w_i - \frac{(w_i-w_f)}{t} x t \quad (6) \]

where \( w_i \) represents the initial weight, \( w_f \) the final weight, \( t \) is the maximum iteration, \( it \) is the current iteration. This step is repeated until the determined maximum iteration is achieved.

5) Storing the \( G_{\text{best}} \) result: After reaching the last iteration step, the \( G_{\text{best}} \) value from the PSO method implementation is stored. This value is to be stored in the ant’s memory to be used as the global best ant.

6) Initialization of the ant’s path: It is done by randomly creating the ant’s path. Using a software tool, some matrices are constructed to represent the position, cost, initial pheromone and visibility. The initial pheromone \( \tau(t) \) is found using (7).

\[ \tau(t)_k^{rs} = \begin{cases} \frac{Q}{L} & \text{if } r \in N_k^r \\ 0 & \text{if } r \notin N_k^r \end{cases} \quad (7) \]

where; \( Q \): the constant value; \( L \): the shortest path of the ant \( k \); and \( N_k^r \): the set of routes that will be visited by ant \( k \) at point \( r \) (to make sure the solution is close to optimal value). After obtaining the matrix of ant’s path, it is required to compute the probability of each path to be passed through by the ant using the random proportional rule as given by (8).

\[ p_{rs}^k = \frac{\tau_{rs}^k(t)}{\sum_{rs} \tau_{rs}^k} \quad (8) \]

where \( \alpha \) is a parameter that controls the relative weight of the pheromone.

7) The execution of ACO method: In this step the ants are distributed over paths using the roulette wheel selection principle. The selection is carried out by comparing the random value to the cumulative sum of probability of all ants’ paths. After the finding of the path by the ant, the resulted path is stored into the memory, and then being compared to the global best ant value. If it is less than the global best ant value, the found path value is stored in the memory of the global best ant. If a convergence has not been achieved, it is repeated until the determined maximum iteration is reached.

III. RESULTS AND ANALYSIS

The hybrid PSO-ACO method has been implemented on the 30-bus IEEE system and on the 500kV Java-Bali system. The IEEE system has been used to validate the method, before being implemented on the 500kV Java-Bali system.

A. Results of Implementation on the IEEE System

The 30-Bus IEEE system consists of 6 generators with the total load of 283.4 MW, as shown in Table I. The iteration process is depicted using the curve shown in Fig. 3. As can be observed in Table I and Fig. 3, the optimized total generation cost in the IEEE system being computed using the hybrid PSO-ACO method was $770.12 and it reached the convergence on the 50th iteration.

Results comparison of some hybrid method implementation on the IEEE system have been given in [14], and in Table II it is added with the results of hybrid PSO-ACO method in this study.

<table>
<thead>
<tr>
<th>No.</th>
<th>Hybrid Method</th>
<th>Resulted Cost ($/hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>FFA-ACO</td>
<td>800.79</td>
</tr>
<tr>
<td>P2</td>
<td>FABC</td>
<td>938.75</td>
</tr>
<tr>
<td>P3</td>
<td>GA-APO</td>
<td>984.94</td>
</tr>
<tr>
<td>P4</td>
<td>PSO-ACO</td>
<td>770.09</td>
</tr>
</tbody>
</table>

Table I shows the optimum generation cost when the IEEE 30 bus data is loaded 283.4 MW. The proposed hybrid PSO-ACO has found the optimal generation cost was 770.12 $/hours, better than the other hybrid method given in [14]. As seen in Table II, the hybrid PSO-ACO method offers the optimization results which promise the more economical generation cost than the other hybrid optimization methods [14]. The power load profile of the 30-Bus IEEE system during 24 hours is given in Fig. 4 [8].
The results of the hybrid PSO-ACO method implementation on the 30-Bus IEEE system are shown in Table III. Table III indicates the results of scheduling on the 30-Bus IEEE system during 24 hours and the optimum generation cost for each hour.

### TABLE III. RESULTS OF SCHEDULING AND TOTAL GENERATION COST ON THE 30-BUS IEEE SYSTEM USING THE HYBRID PSO-ACO METHOD

<table>
<thead>
<tr>
<th>Time</th>
<th>Generated Power (MW)</th>
<th>$P_{total}$ (MW)</th>
<th>Generation Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>126 34.4 0 0 0</td>
<td>161</td>
<td>397.7</td>
</tr>
<tr>
<td>2</td>
<td>128 20.3 15.2 10.1 10.1</td>
<td>196</td>
<td>496.98</td>
</tr>
<tr>
<td>3</td>
<td>152 39.9 0 0 0</td>
<td>192</td>
<td>486.16</td>
</tr>
<tr>
<td>4</td>
<td>126 34.4 0 0 0</td>
<td>161</td>
<td>398.17</td>
</tr>
<tr>
<td>5</td>
<td>115 31.8 0 0 0</td>
<td>147</td>
<td>369.34</td>
</tr>
<tr>
<td>6</td>
<td>126 34.2 0 0 0</td>
<td>160</td>
<td>395.01</td>
</tr>
<tr>
<td>7</td>
<td>134 35.9 0 0 0</td>
<td>170</td>
<td>436.44</td>
</tr>
<tr>
<td>8</td>
<td>118 20 15 10 10</td>
<td>185</td>
<td>464.79</td>
</tr>
<tr>
<td>9</td>
<td>138 21.1 15.6 10.4 10.4</td>
<td>208</td>
<td>533.05</td>
</tr>
<tr>
<td>10</td>
<td>153 24.3 17.5 11.4 14</td>
<td>232</td>
<td>605.8</td>
</tr>
<tr>
<td>11</td>
<td>1200 27.8 0 0 0</td>
<td>227.82</td>
<td>651.8</td>
</tr>
<tr>
<td>12</td>
<td>174 29.1 20.3 13.8 13</td>
<td>267</td>
<td>716.5</td>
</tr>
<tr>
<td>13</td>
<td>178 44.3 17.9 15 10.6</td>
<td>283.4</td>
<td>773.2</td>
</tr>
<tr>
<td>14</td>
<td>200 27.8 0 0 0</td>
<td>227.82</td>
<td>651.8</td>
</tr>
<tr>
<td>15</td>
<td>133 21.4 15.8 10.6 10.7</td>
<td>209</td>
<td>520.92</td>
</tr>
<tr>
<td>16</td>
<td>174 29.1 20.3 13.8 13</td>
<td>267</td>
<td>716.5</td>
</tr>
<tr>
<td>17</td>
<td>178 44.3 17.9 15 10.6</td>
<td>283.4</td>
<td>773.2</td>
</tr>
<tr>
<td>18</td>
<td>177 29.7 20.7 14 13.2</td>
<td>272</td>
<td>730.27</td>
</tr>
<tr>
<td>19</td>
<td>165 24.7 17.8 12 11.6</td>
<td>246.08</td>
<td>658.08</td>
</tr>
<tr>
<td>20</td>
<td>115 20 15 10 10</td>
<td>182</td>
<td>464.6</td>
</tr>
<tr>
<td>21</td>
<td>130 31.7 0 0 0</td>
<td>161</td>
<td>403.14</td>
</tr>
<tr>
<td>22</td>
<td>101 30.3 0 0 0</td>
<td>131</td>
<td>320.7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>4825.58</td>
</tr>
</tbody>
</table>

It can be known from Table III that the generation cost changes hourly with the total generation cost during 24 hours was $12803.22/hour.

The iteration process during the execution of the hybrid PSO-ACO method on the IEEE system is presented in Fig. 5. As seen, the convergence has been reached on the 32nd iteration.

**Fig. 5. Iteration process of the hybrid PSO-ACO method implementation on the 30-Bus IEEE system.**

### B. Results of Implementation on the Java-Bali System

Implementation has been done on the data of the 500kV Java-Bali power system which covered 38 units of thermal generator. The considered loading data were taken from three different days during 4-7 December 2011 [13]. Thursday, Saturday, and Sunday have been chosen to represent different load characteristic of curves, where Thursday represents the working day, Saturday represents the half-day working condition, while Sunday represents the full-day off work condition.

Comparison of the resulted total generation cost of the three considered days using the three methods is presented in Table V.

### TABLE V. COMPARISON OF THE RESULTED TOTAL GENERATION COST OF THE THREE DIFFERENT DAYS USING THREE METHODS

<table>
<thead>
<tr>
<th>Day</th>
<th>Total Generation Cost (IDR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSO Method</td>
<td>ACO Method</td>
</tr>
<tr>
<td>Thursday</td>
<td>18,237,630,416</td>
</tr>
<tr>
<td>Saturday</td>
<td>16,292,222,242</td>
</tr>
<tr>
<td>Sunday</td>
<td>15,456,744,847</td>
</tr>
</tbody>
</table>

As shown in Table V, it is the ACO method which resulted in the smallest total generation cost on the three different days under consideration, being followed with the hybrid method, and the PSO method. It can be observed that the hybrid PSO-ACO method resulted in more economical generation cost than the PSO method, however, it did not offer the same advantage with respect to the ACO method.

The improvement of the ACO method compared to the PSO method was 12.15%, 8.27%, and 11.61% for the three cases tested. Hybrid PSO-ACO did not provide a better value than the results obtained by the ACO method. The optimal
value obtained by the ACO method is better than the hybrid PSO-ACO method that is equal to 4.76%, 4.34%, and 5.05% for the cases tested.

Initially, the optimum value obtained by the PSO method have very closed to the optimal solution ($G_{best}$) and the ACO method could not find the more other final optimum solutions.

The iteration process during the execution of the optimization method to find the most economical generation cost of the plant units in the 500kV Java-Bali system is shown using the curves in Fig. 6 – Fig. 8, for the three considered days respectively, using the hybrid PSO-ACO method. As can be observed in Fig. 6 – Fig. 8, the convergence has been reached on the 32nd iteration. Observation on the duration of computation of the three considered methods resulted in the execution time of 50.220 seconds using the PSO method, 112.967 seconds using the ACO method, and 31.171 seconds using the hybrid PSO-ACO method, as also shown in Fig. 9.

The execution time of the hybrid optimization method was the shortest among the three methods. In addition, the ACO method is initially designed for combinatorial optimization problems and then adapted to solve continuous optimization problems [15]. Therefore the ACO methods could provide the alternative solutions in more details, thus the optimum solution also could be determined. As consequences, the epoch number, floating point operations per second (FLOPS) and the execution time required for ACO method to find the optimal solution was more consuming time comparing with the PSO and hybrid PSO-ACO. However, the results obtained by the hybrid PSO-ACO were not significantly difference compared with the ACO method.

The implementation of the hybrid method of Particle Swarm Optimization and Ant Colony Optimization (PSO-ACO) on the economic dispatch problem of the 500 kV Java-Bali power system has been performed to find the combination of all generators giving the least operation cost. The process has been carried out by alternately evaluating using each of the PSO and ACO methods within a limited number of iterations. The evaluation process stopped when the best cost of sharing between generators had been converging or the value has not been changing much anymore. In this study, the evaluation process stopped after 32 iterations. It can be observed that the hybrid PSO-ACO method resulted in more economical generation cost than the PSO method, however, it did not offer the same advantage with respect to the ACO method.

Comparison of execution time shows that the calculation using the hybrid method of PSO-ACO method is faster than each of the PSO and ACO methods.
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