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Economic Dispatch in 150 KV Sulselrabar Electrical System Using Ant Colony Optimization

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Abstract: *Ant Colony Optimization (ACO) method in this research is used to solve the problem of Economic Dispatch on 150 kV electrical system of South, Southeast, and West Sulawesi (Sulselrabar). As a comparison, Lagrange method is also used. Case studies used include peak loads in both daytime and nighttime. The ACO algorithm looks for an economical thermal generation combination. In this economic dispatch, which serves, as an objective function is the cheapest cost of generation. From the optimization results for the first case of peak of daytime load, ACO generates a total generation cost of IDR 94,670,335.98 per hour to generate power of 270,309 MW with losses of 25,918 MW. Meanwhile, by using the Lagrange method, it provides a total generation cost of IDR 117,121,631.08 per hour to generate power of 339.4 MW with losses of 25,016 MW. In real system, the total generation cost is IDR 127,881,773.68 per hour to generate power of 393.1 MW with losses of 24,956 MW. The ACO is able to reduce the cost of generating the system Sulselrabar IDR 33,211,437.62 per hour or 25.98% at peak of daytime load. Meanwhile, by using Lagrange method it can reduce the cost of generating Sulselrabar system of IDR 10,760,142.6 per hour or 8.41% at peak of daytime load. From the optimization results for the second case of the peak of nighttime load, ACO generates a total generation cost of IDR 131,473,269.39 per hour to generate power of 400,812 MW with losses of 26,219 MW. Whereas by using the Lagrange method can be generated a total generation cost of IDR 134,889,397.56 per hour to generate power of 400.67 MW with losses of 28,352 MW. In real system, the total generation cost is IDR 140,806,274.24 per hour to generate power of 435.3 MW with losses of 26,299 MW. The ACO is able to reduce the cost of generating the system Sulselrabar IDR 9,333,004.9, per hour or 6.62% at night peak load. While using the Lagrange method is able to reduce the cost of generating the system Sulselrabar IDR 5,916,876.7 per hour or 4.2% at peak of nighttime load.*

Keywords: *economic dispatch, ant colony optimization, cost, lagrange, losses.*

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I. Introduction

The operation of some generating units requires good management. Particularly in loading and the amount of power, a generating unit must contribute that or a generating center into the system must be well regulated. The economical operation of operations, especially thermal generation, can save the cost of power production, especially the increasing fuel costs, while the power system load is constantly changing over time so that the load of thermal generating units also changes with time in serving the load of the power system. This resulted in the cost of fuel was also unity of time in rupiah per hour also took change according to time. In the thermal generating unit, the increase in load drives the increase of fuel amount per unit time and ultimately increases the cost increment.

The method of artificial intelligence is a method or algorithm that is inspired from a particular behavior or event. This intelligent algorithm is created and used for a solution to complex computing problems and requires a high degree of accuracy based on the objective function used. Ant Colony Optimization is a computational technique that solves an optimization problem based on the behavior of a group of ants in finding the shortest path from the nest to a food source. The application of ACO as an economic dispatch optimization method has already been done and shown good results [1-9].

The application of intelligent methods to the Sulselrabar electricity system has been done [10-20] and showed good result, and optimum use of ACO method in economic dispatch in some electrical system study, hence in this research will be proposed as "Economic Dispatch Optimization at 150 kV Sulselrabar electrical system using Ant Colony Optimization (ACO)".

II. Economic Dispatch

Economic Dispatch is the division of load on each generating unit so that the operational cost of each generating unit is economical by using equality and inequality constrains. The cost function of each generator can be formulated mathematically as an objective function as given in the equation [21]:

$$C_T = \sum_{i=1}^{n} C_i\ (P_i) \qquad (1)$$

Where:

C_T = The amount of total cost on the generator
$C_i(P_i\ )$ = The input-output cost function of the generator
n = Number of generator units

The input-output characteristic is a characteristic that describes the relationship between the fuel input (liter / hour) and the output generated by the generator (MW). Generally, the input output characteristic of the generator is approximated by a second order polynomial function ie[22]:

$$C_i = \alpha_i + \beta_i . P_i + \gamma_i . P_i^2 \qquad (2)$$

Where:

C_i = Generator fuel input (rupiah / hour).
P_i = Generator output(MW).
$\alpha_i\beta_i\gamma_i$ = The input-output constant of the i-th power plant.

Parameter determinationα_i, β_i, and γ_i requires data obtained from experimental results related to Ci fuel inputs (american dollar / hour) and Pi generating output (MW). The input characteristics of the generating unit output can be expressed as follows:

- The input of the generator is expressed in H = Mbtu / hour (heat energy required), or C = IDR / hour (total fuel cost).
- While the output of the generator is expressed in P = MW (power).

The output of each generator unit has the minimum and maximum limit of inequality constraints, i.e.[22]:

$$P_{i\,min} \le P_i \le P_{i\,max} \qquad (3)$$

Where:

$P_{i\,min}$, $P_{i\,max}$ is the minimum and maximum power output of generator i.

At equilibrium power, Equality constraint must be met ie the total power generated by each generating unit must be equal to the total load requirement in the system. Equality constraint equilibrium power is [22]:

$$\sum_{i=1}^{n_g} P_i = P_D \qquad (4)$$

Where:

P_i = output of each generator (MW).
P_D = total load requirement on the system (MW).

To calculate Economic Dispatch is done by using equality and inequality limitation. The equality boundary reflects a balance between the total powers generated by the total load power of the system. The inequality limit reflects the minimum and maximum limits of generation to be met to obtain the optimum total fuel cost.

III. Implementation Ant Colony Optimization for Economic Dispatch

Determination of Inter-City Distance

The city referred to here is the magnitude of the generation value of each plant. Prior to the trip, the distance between the value of the generation of one power plant and the other is calculated first (initialized). After initialization, the ants are placed in the first city at random. Then the ants will continue their journey from one city to another randomly to the final destination, the last city. Once the journey is over, the location of the cities that the ant has passed through will be used to calculate the solution resulting from the trip.

Ant Tour

Ants choose a path to be traversed from point r to point s in a journey with probability:

$$p(r,s) = \frac{\gamma(r,s)}{\sum_{t} \gamma(r,l)} s, l \in N_r^k \qquad (5)$$

Where:

The matrix γ (r, s) represents the amount of pheromone intensity between r and spoints. Then the pheromones will be updated through the following equation:

$$\gamma(r,s) = \alpha \cdot \gamma(r,s) + \Delta y^k (r,s) \qquad (6)$$

Where:

α is the endurance of a pheromone with interval $0 < \alpha < 1$, then $(1- \alpha)$ represents the evaporation occurring in pheromones and $\Delta\gamma k$ (r, s) is the number of pheromones that ants drop on line (r, s).

Power Flow Analysis

The method used in conducting the power flow analysis here is the Newton Raphson method. The steps used are the same as the power flow analysis used in the Lagrange method.

The power generated by the bus and slack bus generators is obtained from the travels made by the ant colony. The equations used to obtain the generated power of each plant are as follows.

$$P_i = (P_{i_{min}} + (P_{i_{max}} - P_{i_{min}}) \cdot P_{gn_i}) \qquad (7)$$

Where:

P_i = power generated by i-th generator

$P_{i_{min}}$ = minimum power limit generated to the i-th generator

$P_{i_{max}}$ = maximum power limit generated to the i-th generator

P_{gn_i} = value of the ant trip for the i-th generator

Update Local Pheromones

The pheromone trace (r, s) for the best trip the ant has made (the ant that generates the smallest generation cost) will be updated using the following equation.

$$\gamma(r,s) = \alpha \cdot \gamma(r,s) + \frac{Q}{f_{best}} r,s \in J_{best}^{k} \qquad (8)$$

Where:

Q is a very large positive constant.

Update Global Pheromones

To avoid stagnation (a situation where ants will follow the same path, which will produce the same solution), the pheromone trace strength is limited to the following intervals:

$$\gamma(r,s) = \left\{ \begin{array}{l} \tau_{min} \text{ if } \gamma(r,s) \le \tau_{min} \\ \tau_{max} \text{ if } \gamma(r,s) \ge \tau_{max} \end{array} \right\} \qquad (9)$$

The upper and lower limits are as follows:

$$\tau_{max} = \frac{1}{\alpha \cdot f_{best}} \qquad (10)$$

$$\tau_{min} = \frac{\tau_{max}}{M^2} \qquad (11)$$

Where:

M is the number of ants that travel.

Ants Plot Travel

The solution of the ant colony's journey in minimizing the cost of generation is plotted into a graph up to the maximum iteration limit.

Best Tour Plot

Travel with the best solution of the ant colony (minimum generation cost) for each iteration is plotted to the maximum iteration threshold.

Parameters ofAnt Colony Optimization

Some parameters used in Ant Colony Optimization method in this thesis are as follows:

- Number of ants = 10
- Maximum iteration = 100
- Pheromone endurance (alpha) = 0.9

Initialization of Pheromones (Tau Matrix)

The tau matrix has a size of n x m, with the number of buses in the system, whereas the number of generator units generated on a scale of 0 to 1 having a 0.01 interval. The value of this matrix will be updated every time the ant colony travels.

IV. Results and Analysis

In this research, Ant Colony Optimization (ACO) method will be used to solve the problem of Economic Dispatch on 150 kV electrical system of South Sulawesi, Southeast, and West (Sulselrabar). As a comparison, the method used conventional Lagrange optimization. The case studies used are peak day load and night peak load. In this research Matlab program is used, to make ACO algorithm, calculate cost function (Cost Function) of fuel, by previously counting input-output characteristic of each unit of thermal generator of Sulselrabar system. The ACO algorithm will look for optimal / economical thermal generation combination. All of four hydro generator units will be maximized because it is the cheapest generation. In this economic dispatch, the objective function is the cheapest generation cost. The function of the total generation cost of the plants connected to the system is as follows.

$$C_t = \sum_{i=1}^{n_g} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \qquad (12)$$

The output power of the generator should not exceed or less than the rating of each generator to obtain a stable generator operation. Therefore, generator generated power should be limited to the maximum and minimum. Restrictions or constraints are given by the following two equations, equality constraint is given by equation 13, and its inequality constraint is given by equation 14.

$$\sum_{i=1}^{n_g} P_i = P_D \qquad (13)$$

$$P_{i_{min}} \le P_i \le P_{i_{max}} \qquad (14)$$

With Pi_{min} and Pi_{max} and is the minimum and maximum limits of the power generated by the i-th generator.

Input-Output Characteristics of Thermal Generators

To calculate the cost function of each thermal generator, first calculating the input output characteristics of each thermal generator. The input-output equation can actually be obtained with the help of MatLab, and is displayed in the following input-output characteristic table.

Table 1. Characteristics of Input-Output of Sulselrabar thermal plant

No	Units	Input-Output Equation (Liter / Hour)
1	PLTD Pare-Pare	$714.0000 + 567.4000P - 3.2941P^2$
2	PLTD Suppa	$2070 + 178.6P + 0.4P^2$
3	PLTU Barru	$2805.6 + 251.6P - 0.11976P^2$
4	PLTU Tello	$558 + 174.5P + 1.375P^2$
5	PLTD Agrekko/T.Lama	$771.975 + 160P + 2.7397P^2$
6	PLTD Sgmnsa	$617.625 + 477.25P - 4.1667P^2$
7	PLTD Arena/Jeneponto	$629.475 + 176.3P + 4.8052P^2$
8	PLTD Matekko/Bulukumba	$506.25 + 124.9P + 9.4444P^2$
9	PLTD Pajelasang/Soppeng	$432 + 66.2P + 12.5P^2$
10	PLTGU Sengkang	$4418.89 + 38.0952P + 0.021898P^2$
11	PLTD Malea/Makale	$165.75 + 409.5P + 5.7692P^2$
12	PLTD Palopo	$103.5 + 112.4P + 50P^2$

Cost Function Thermal Generator

The fuel cost equation of each plant is obtained by multiplying the generator's input-output equation at its fuel price. Then the full fuel cost equation is shown in the following table.

Table 2. Equal Fuel Cost of Sulselrabar thermal plant

No	Units	Input-Output Equation (Liter / Hour)
1	PLTD Pare-Pare	$6211800 + 4936380P - 28658.67P^2$
2	PLTD Suppa	$18009000 + 1553820P + 3480P^2$
3	PLTU Barru	$17675280 + 1585080P + 754.488P^2$
4	PLTU Tello	$3515400 + 1099350P + 8662.5P^2$
5	PLTD Agrekko/T.Lama	$6716182.5 + 1392000P + 23835.39P^2$
6	PLTD Sgmnsa	$5373337.5 + 4152075P - 36250.29P^2$
7	PLTD Arena/Jeneponto	$5476432.5 + 1533810P + 41805.24P^2$

8	PLTD Matekko/Bulukumba	$4404375 + 1086630P + 82166.28P^2$
9	PLTD Pajelasang/Soppeng	$3758400 + 575940P + 108750P^2$
10	PLTGU Sengkang	$27839000.000 + 240000.00P + 137.9539P^2$
11	PLTD Malea/Makale	$1442025 + 3562650P + 50192.04P^2$
12	PLTD Palopo	$900450 + 977880P + 435000P^2$

Peak Night Load

Table 6 shows the real generation and cost for the Sulselrabar thermal system at night's peak load before being optimized. The simulation results performed using Ant Colony Optimization (ACO) method and Lagrange method are shown in table 3 below. The graph of optimization of the cost of generation and global best tour can be seen in figure 1 and 2.

Table 3. Real Thermal Generation Expenses at night peak loads

No	Units	Real System		
		P (MW)	**Cost (IDR/hour)**	**Losses (MW)**
1	PLTD Pare-Pare	20.1	9385464.873	
2	PLTD Suppa	62.2	12812016.720	
3	PLTU Barru	44.7	10360370.528	
4	PLTU Tello	29.7	4380719.963	
5	PLTD Agrekko/T.Lama	19.3	4246022.692	
6	PLTD Sgmnsa	12.3	5095955.363	
7	PLTD Arena/Jeneponto	19.6	5159900.950	
8	PLTD Matekko/Bulukumba	9.0	2083951.368	
9	PLTD Pajelasang/Soppeng	15.1	3725118.150	
10	PLTGU Sengkang	192.9	79268321.180	
11	PLTD Malea/Makale	3.5	1452615.249	
12	PLTD Palopo	6.9	2835817.200	
Sum		**435.3**	**140806274.24**	**26.299**

From the analysis result for the second case that is the peak of nighttime load condition before optimized, the generating load charged to the thermal unit is 435.3 MW, with total generation cost of IDR 140,806,274.24. Losses generated before optimization amounted to 26,299 MW. The total system load is 532.3 MW. Fourhydro power plants bear respectively: PLTA Bakaru 126 MW, PLTM TeppoPinrang 0.3 MW, PLTA TangkaManipiSinjai 3.5 MW, PLTMBili-Bili 7.1 MW. Furthermore, by using the proposed method is by using the intelligent method based on Ant Colony Optimization (ACO) obtained a more optimal generation results. As a comparison, thetechnique in this study used Lagrange method. More is shown in Table 4 below.

Table 4. Results of thermal power plant optimization for night peak load

No	Units	Lagrange Method			ACO Method		
		P (MW)	**Cost (IDR/hour)**	**Losses (MW)**	**P (MW)**	**Cost (IDR/hour)**	**Losses (MW)**
1	PLTD Pare-Pare	19.40	9119159.496		18.500	8772640.019	
2	PLTD Suppa	31.98	7125923.059		60.030	12382534.573	
3	PLTU Barru	44.00	10202568.768		41.400	9622921.452	
4	PLTU Tello	19.80	2867857.650		17.800	2582845.650	
5	PLTD Agrekko	19.00	4176875.829		21.880	4858396.363	
6	PLTD Sgmnsa	27.60	9235658.659		29.200	9570548.023	
7	PLTD Arena	23.86	6587284.551		13.360	3342993.467	
8	PLTD Matekko	6.30	1451132.365		11.940	2909265.788	
9	PLTD Pajelasang	14.56	3519839.040		11.520	2482548.480	
10	PLTGU Sengkang	184.380	76780078.632		166.102	71509642.449	
11	PLTD Malea/Makale	3.730	1542902.633		3.520	1460445.245	
12	PLTD Palopo	6.060	2280116.880		5.560	1978487.880	
Sum		**400.67**	**134889397.56**	**28.352**	**400.812**	**131473269.39**	**26.219**

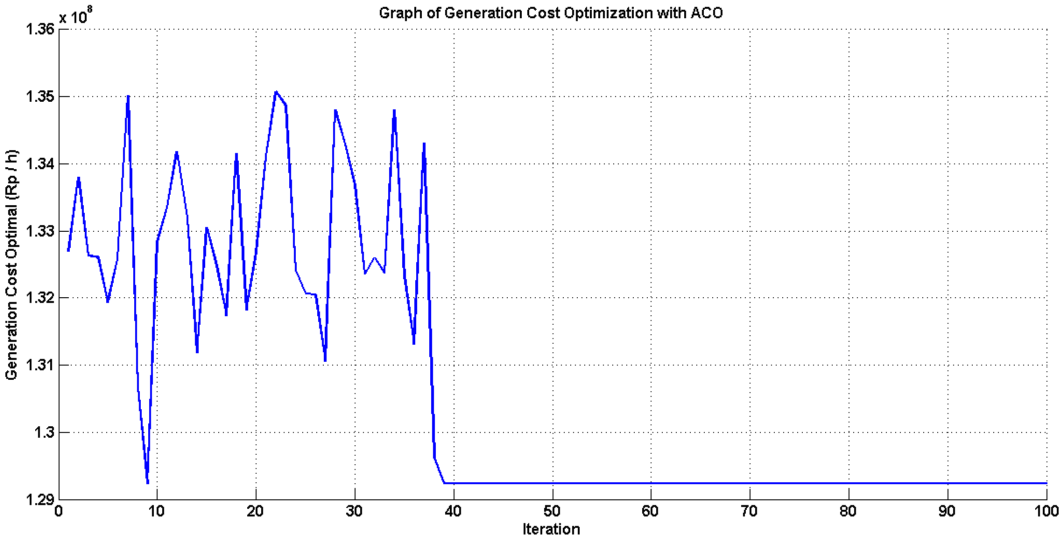

Figure 1. Graph of cost optimization of Sulselrabar system generation at night peak load by using Ant Colony Optimization (ACO)

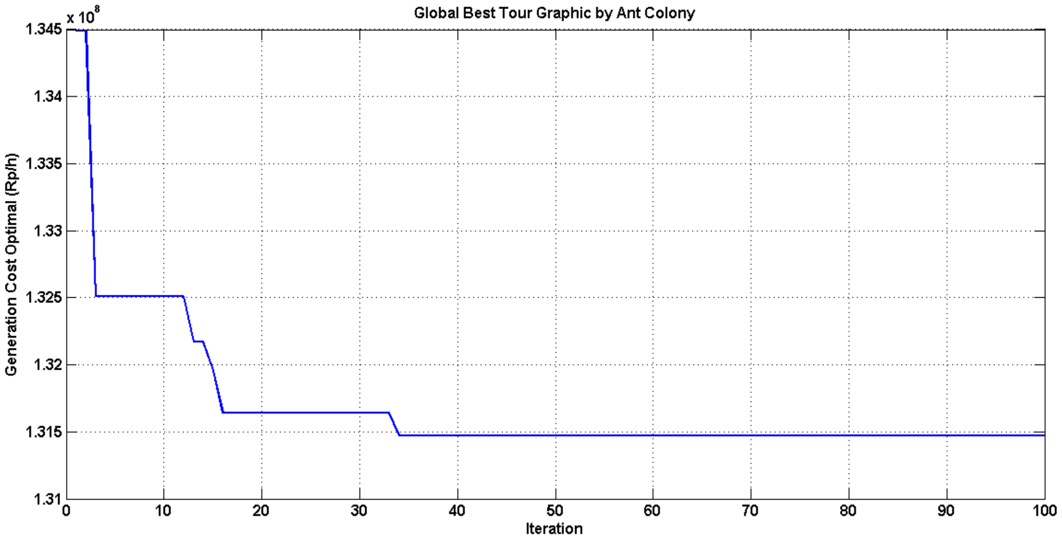

Figure 2. The global chart of the Sulselrabar system tour at night peak loads using Ant Colony Optimization (ACO)

Analysis

The ACO optimization graph shows the decreasing cost of generation on each iteration although on some iterations there is a slight oscillation. Figure 1 shows how ACO performance in reducing generation costs. On the graph, the oscillations occur until about the 34th iteration. This shows from the beginning of iteration to the 34th iteration, ant colonies in each iteration produce optimal journey (optimal solution) which is different. While figure 2 shows the global best tour that ant colony is done. The global best-tour graph shows the best objective function value that can be derived from the initial iteration algorithm to maximum iteration (100). Figure 3 shows the comparison of generation costs at night peak loads for each method.

The optimization result using ACO method resulted in total generation cost of IDR 131,473,269.39 per hour to generate power of 400,812 MW with losses of 26,219 MW, whereas using the Lagrange method, generating a total generation cost of IDR 134,889,397.56 per hour to generate power of 400.67 MW with losses of 28,352 MW. In real system, the total generation cost is IDR 140,806,274.24 per hour to generate power of 435.3 MW with losses of 26,299 MW. From the results of this simulation can be concluded that Ant Colony Optimization (ACO) is able to reduce the cost of generating the system Sulselrabarto IDR 9,333,004.9 per hour or 6.62% at night peak load. While using the Lagrange method is able to reduce the cost of generating the system Sulselrabar IDR 5,916,876.7 per hour or 4.2% at night peak load. All four units of each hydro generator are maximized because those are the cheapest generation. The Sengkang PLTGU power plant unit acts as a slack bus in this system, which generates the most expensive thermal generation cost of IDR 71,509,642.449 per hour, with generated power of 166,102 MW. While the cheapest thermal generator unit at MaleaMakale power plant is IDR 1,460,445.245 per hour, with a raised power of 3,520 MW.

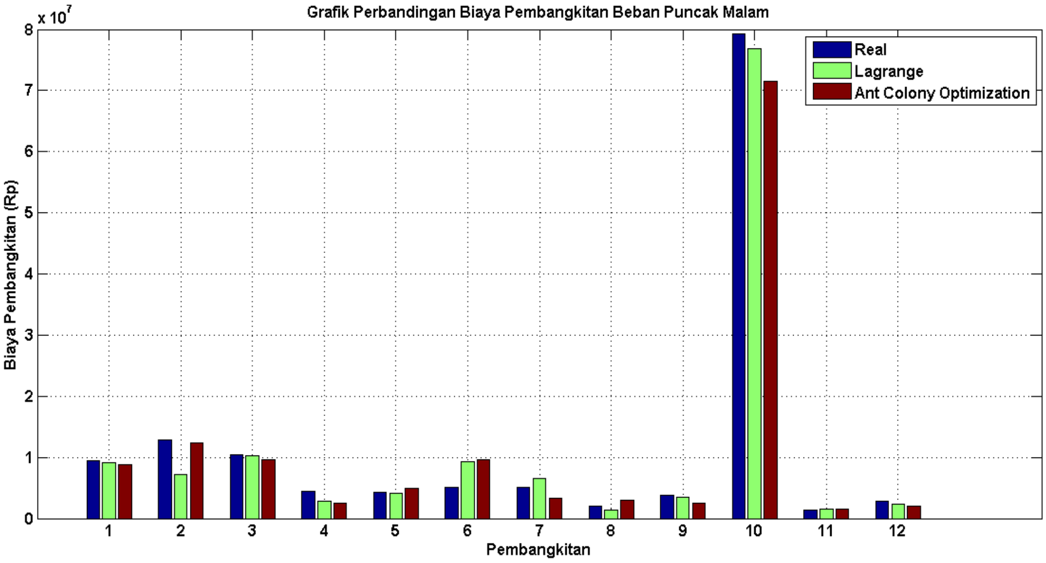

Figure 3. Comparison of the cost of raising the peak of nighttime load

V. Conclusion

Comparing to the current system, implementation of ACO for power generation provides a cost reduction of 25.98% in the peak of daytime load, and 6.62% in the peak of nighttime load. On the other side, implementation of Lagrange optimization method for power generation provides a cost reduction of 8.41% in the peak of daytime load, and 4.2% in the peak of nighttime load, comparing to the real system. It verifies that ACO implementation for optimization has a better effectiveness than Lagrange optimization method.

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