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# Optimal Power Flow For A Non-Smooth Cost Function Using Particle Swarm Optimization On A 150 KV System

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***Abstract* – optimal power flow by considering the non-smooth cost curve using the meta-heuristic algorithm method, namely particle swarm optimization (PSO), in the 150 kV Sulselrabar electrical system. In this study, the PSO algorithm was used to optimize optimal power flow so that the cheapest generation price was obtained with a non-smooth cost curve while still considering the limitations of similarity and inequality. In this study, the PSO algorithm was used to optimize optimal power flow so that the cheapest generation price was obtained with a non-smooth cost curve while still considering the limitations of similarity and inequality. From the results of generation optimization using the particle swarm method, it produces the lowest generation costs compared to other methods, namely Rp. 93,498,916.10/hour to generate power of 270.14 MW with losses of 25.73 MW. The Particle Swarm Optimization (PSO) method is able to reduce the cost of generating the Sulselrabar system by Rp. 34,382,857.58 per hour, or 26.89%. From the results of generation optimization using the ant colony method, it resulted in a total generation cost of Rp. 94670335.98 per hour to generate power of 270,309 MW with losses of 25,91 MW. The ant colony method is able to reduce the cost of generating the Sulselrabar system by Rp. 33,211,437.70 per hour, or 25.98%. From the results of generation optimization using the Lagrange method, it resulted in a total generation cost of Rp. 117,121,631.08 per hour to generate power of 339.4 MW with losses of 25,016 MW. The Lagrange method is able to reduce the cost of generating the Sulselrabar system by Rp. 10,760,142.60 per hour, or 8.41%. The artificial intelligence method based on Particle Swarm Optimization (PSO) can well perform optimization of optimal power flow, based on the results of the analysis, which obtained the cheapest generation cost compared to the comparison methods, the Lagrange Method and the Ant Colony Artificial Intelligence Method.**

***Keywords: Optimal Power Flow, Valve Point Effect, Non-Smooth Cost Curve, Particle Swarm Optimization.***



## I. Introduction

In the analysis of an optimal power flow, there are two important issues to pay attention to, namely the analysis of power flow and the price of generation. In an economic dispatch, we have one restriction, which is that the total generation must be equal to the total load and power lost. Each plant has its own cost curve. In a plant, sometimes a non-smooth cost curve is found. This non-smooth cost curve can be caused by valve point effects. Because of the influence of this non-smooth cost curve, conventional methods of calculation produce difficult results.By using the Particle Swarm Optimization method, this non-smooth problem can be solved.

For power flow analysis, there are several constraints that must be considered, namely equality and inequality constraints. These limitations are in the form of limiting line power and limiting the minimum and maximum voltage on each bus. The voltage on a bus must be in a certain range of values so that undervoltage and overvoltage do not occur. The flow of power passing through a line must comply with the maximum requirements because the cable has a certain capacity to flow power. The voltage on the bus is also worth paying attention to.

The development of technology in a plant makes the problem of finding the value of generation costs more complex. This is complicated by the existence of equality and inequality constraints in an optimal power flow. Inequality constraints certainly cannot be solved by conventional methods such as power flow with the Lagrange or Newton-Raphson methods. The non-smooth cost curve is also a major problem in determining the cheapest generation cost. This non-smooth characteristic is obtained due to the effect of valve opening and the use of variegated fuel.

This research will discuss the creation of a method for solving optimal power flow problems based on a non-smooth cost curve. The limitations in making this program are carried out with Matlab software and data used by the Sulselrabar transmission system, non-smooth cost curves due to the influence of valve effects, and using PLBUS voltage limit standards.

After an analysis of the creation of an OPF program, a PSO is planned that makes it easier to find and determine objective functions by looking at the limitations that have been given.

Research on optimal power flow in several electrical systems has been widely carried out, both based on conventional methods and artificial intelligence methods, including the following. Rajaei et al [1-3] discusses Power Flow Analysis Using Newton Raphson's Method, [4] discusses Power Flow Analysis Using the Flower Pollination Method, [5] discusses Power Flow Analysis Using Bisection Method, [6] discusses Power Flow Analysis Using Gravitational Search Method. Meanwhile, Power Flow research on the Sulselrabar electrical system, previously there has also been carried out, [7] discusses Power Flow Analysis and Transmission Disturbances (Using Newton Raphson's Method), and [8] discusses Power Flow and Short Circuit Analysis (Using Newton Raphson's Method). From this research, it shows the road map of research that has been carried out in the Sulselrabar electrical system. From the review, the research that has been carried out is still within the scope of the study or reviewing the power flow profile in the system.

Previously, the authors had tested the effectiveness of the PSO algorithm for case studies on the IEEE 14 bus electrical system and showed optimal results compared to using conventional methods. In addition, the effectiveness of the PSO algorithm also provides optimal results in its application in the Sulselrabar electrical system, such as [9] which discusses the implementation of PSO for optimization of power system stabilizer parameters in generators in the Sulselrabar electrical system. In some other systems the use of the PSO algorithm for optimization of the electric power system shows optimal results, such as in the Java Bali system. [10] which discusses optimal power flow.

Based on the description of the research conducted above, this research proposes an optimal power flow analysis (optimal power flow) in the Sulselrabar electrical system, with the proposed method using an artificial intelligence method based on Particle Swarm Optimization (PSO).

## II. METHOD AND DESIGN

The OPF problem has a lot to do with optimizing power performance under steady-state conditions with regard to objective functions when subjected to many restrictions. For optimal active power dispatch, the objective function f is the total generation cost, which can be expressed as follows.

$$F = \sum_{i=1}^{N} C_i\,(P_{Gi}) = \sum_{i=1}^{N} ai + bi\,P_{Gi} + ci\,{P_{Gi}}^2 \quad (1)$$

Where

N : number of generating units

Ai, bi, ci : cost coefficient of the generating unit

Pgi : Real power generation of the I-th unit. i = 1.2 ... N

Limitations of similarity :

$$F = \sum_{i=1}^{N} P_i = P_D + P_L \quad (2)$$

Where:

$P_i$ = Power generated unit i

$P_D$ = total power required

$P_L$ = power and line losses on transmission

Limitations of inequality include

- Branch flow limits :

$$|Si| \le S_i^{max} \quad i = 1,2 \dots nl \quad (3)$$

Where nl : number of channels

- Voltage on the bus :

$$|E_D|^{min} \le E_i \le |E_D|^{max} \quad i = 1,2 \dots nd \quad (4)$$

Where nd : number of load buses

- Generator MVAR

$$Q_{Gi}{}^{min} \le Q_{Gi} \le Q_{Gi}{}^{max} \quad (5)$$

Slack bus MW

$$P_G{}^{min} \le P_G \le P_G{}^{max} \quad (6)$$

The fuel cost functions of generating units with steam turbine valves are diverse. This valve opening effect produces the ripples shown in figure 1, the cost function being a non-linear function of high order. Therefore, equation (1) must be replaced with equation (7) to consider the effect of the valve. On this cost curve, a sinusoidal function is added to the quadratic function of that cost curve. The increase in the cost function of the generating unit with the valve effect is represented as follows.

$$F_i\,(P_{GI}) = a_i + b_i\,P_{Gi} + c_{Gi}{P_{Gi}}^2 + |e_i \times \sin\,(f_i \times (P_{Gi\,min} - P_{Gi}) \quad (7)$$

Where e i and f i are the coefficients of the generator i that reflect the valve effect .

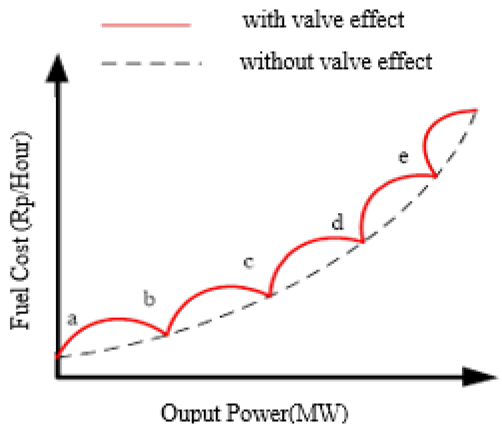


Figure 1. Fuel cost vs output power curve for a 6-valve steam turbine

Particle Swarm Optimization (PSO) is a population-based optimization method first developed by Kennedy and Eberhart in 1995 and inspired by the social behavior of a group of birds and fish. The PSO has optimization tools that provide a population-based search procedure where each individual is called a particle. The particle changes its position every time. The collection of particles that are potential solutions is called a swarm. In PSO systems, particles hover around a multidimensional search space.

During the flight process, each particle determines its own position based on its own experience (this value is called the Pbest) and on the experience of its neighboring particles (this value is called the Gbest). The process of searching for Pbest and Gbest can be illustrated in the following image

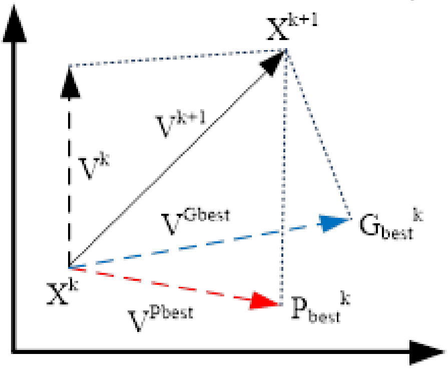


Figure 2. Pbest and Gbest search concepts from PSO

This modification can be represented as a concept of speed. The speed of each agent can be derived from the following equation.

$$v_{k+1} = w.v_k + c_1 rand \times (P_{best} - x^k) + c_2 rand \times (G_{best} - x^k) \quad (8)$$

Using the above equation, certain velocities that will gradually get closer to Pbest and Gbest can be calculated. The current position (search in solution space) can be obtained from the following equation.

$$x^{k+1} = x^k + v_{k+1} \quad . \quad k = 1,2 \dots n \quad (9)$$

Where

| | |
|---|---|
| $X^k$ | : current search point |
| $X^{k+1}$ | : modified search position |
| $V^k$ | : current speed |
| $V^{k+1}$ | : modified agent speed |
| Vpbest | : pbest-based speed |
| Vgbest | : speed based on gbest |
| n | : number of particles in the group |
| m | : number of members in the particle |
| $pbest_i$ | : pbest dari agen k |
| $gbest_i$ | : gbest dari kelompok |
| w | : Heavy Function of K Agent Speed |
| $c_i$ | : weight coefficient |

For the following terms: c1 and c2 are 2 positive constants, r1 and r2 are random numbers ranging from 0 to 1, and w is the inertial weight, which is defined as an iteration function of k as follows:

$$w(k) = w_{max} - \left(\frac{w_{max} - w_{min}}{max.iter}\right) \times k \quad (10)$$

To ensure uniform speed of all dimensions, the maximum speed is as follows.

$$v^{max} = \frac{(x^{max} - x^{min})}{N} \quad (11)$$

Where N is the specified maximum number of iterations

## III. Results and Discussion

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. Input-Output Characteristics of Sulselrabar thermal plant

| Generating Unit | Input-Output Equation (liters/hour) |
|---|---|
| PLTD Pare-Pare | $714.0000 + 567.4000P - 3.2941P^2$ |
| PLTD Suppa | $2070 + 178.6P + 0.4P^2$ |
| PLTU Barru | $2805.6 + 251.6P - 0.11976P^2$ |
| PLTU Tello | $558 + 174.5P + 1.375P^2$ |
| PLTD Agrekko/T.Lama | $771.975 + 160P + 2.7397P^2$ |
| PLTD Sgmnsa | $617.625 + 477.25P - 4.1667P^2$ |
| PLTD Arena/Jeneponto | $629.475 + 176.3P + 4.8052P^2$ |
| PLTD Matekko/Bulukumba | $506.25 + 124.9P + 9.4444P^2$ |
| PLTD Pajelasang/Soppeng | $432 + 66.2P + 12.5P^2$ |
| PLTGU Sengkang | $4418.89 + 38.0952P + 0.021898P^2$ |
| PLTD Malea/Makale | $165.75 + 409.5P + 5.7692P^2$ |
| PLTD Palopo | $103.5 + 112.4P + 50P^2$ |

All of PLTD and PLTG use HSD (High Speed Diesel) with a per-liter price of Rp. 8,700, while PLTU uses MFO (Marine Fuel Oil) fuel with a per-liter price of Rp. 6,300. The fuel cost equation of each such plant is obtained by multiplying the input-output equation of the plant by the price of its fuel. For example, if the input-output equation is 714.0000 + 567.4000P - 3.2941P2 (liters/hour) and the fuel price is Rp. 8700, the fuel cost equation is obtained:

$$(714.0000 + 567.4000P - 3.2941P^2) \times Rp.\ 8700$$
$$= 6211800 + 4936380P - 28658.67P^2$$

Using the same formula, the full fuel cost equation is shown in the following table.

Table 2. Thermal plant fuel cost equation Sulselrabar

| Generating Unit | Input-Output Equation (liters/hour) |
|---|---|
| PLTD Pare-Pare | $6211800 + 4936380P - 28658.67P^2$ |
| PLTD Suppa | $18009000 + 1553820P + 3480P^2$ |
| PLTU Barru | $17675280 + 1585080P + 754.488P^2$ |
| PLTU Tello | $3515400 + 1099350P + 8662.5P^2$ |

| | |
|---|---|
| PLTD Agrekko/T.Lama | $6716182.5 + 1392000P + 23835.39P^2$ |
| PLTD Sgmnsa | $5373337.5 + 4152075P - 36250.29P^2$ |
| PLTD Arena/Jeneponto | $5476432.5 + 1533810P + 41805.24P^2$ |
| PLTD Matekko/Bulukumba | $4404375 + 1086630P + 82166.28P^2$ |
| PLTD Pajelasang/Soppeng | $3758400 + 575940P + 108750P^2$ |
| PLTGU Sengkang | $27839000.000 + 240000.00P + 137.9539P^2$ |
| PLTD Malea/Makale | $1442025 + 3562650P + 50192.04P^2$ |
| PLTD Palopo | $900450 + 977880P + 435000P^2$ |

The data used in this study was when there was a peak load during the day on. The total system load at the time of this peak load was 402.1 MW. The loading and generation data on each bus can be seen in the following table.

Table 3. Sulselrabar system bus data at peak daylight load

| Bus Name | Types of Buses | Load | | Generation | |
|---|---|---|---|---|---|
| | | P (MW) | Q (Mvar) | P (MW) | Q (Mvar) |
| Bakaru | Generator | 2.1 | 0.2 | 126 | -5.2 |
| Pinrang | Generator | 11.3 | -2.3 | 0.3 | 0.0 |
| Pare-Pare | Generator | 8.3 | -1.0 | 20.2 | 5.4 |
| Suppa | Generator | - | - | 52.0 | 18.9 |
| Barru | Generator | 4.6 | 1.5 | 37.8 | 0.0 |
| Tello | Generator | 38.5 | 16.0 | 44.7 | 19.9 |
| Tello Lama | Generator | 11.6 | 10.7 | 19.3 | 0.0 |
| Sgmnsa | Generator | 2.8 | 2.5 | 12.5 | 3.4 |
| Jnpnto | Generator | 1.9 | 3.6 | 9.3 | 0.0 |
| Blkmba | Generator | 3.5 | 2.7 | 9.1 | 0.0 |
| Sinjai | Generator | 6.4 | 4.4 | 3.5 | -0.5 |
| Soppeng | Generator | 7.5 | 9.3 | 15.0 | 7.5 |
| Sengkang | Slack | 12.4 | 6.0 | 164.5 | -2.8 |
| Makale | Generator | 3.9 | 1.7 | 3.6 | 0.0 |
| Palopo | Generator | 22.5 | 6.9 | 5.1 | 0.0 |
| Borongloe | Generator | 3.5 | 0.0 | 7.1 | 1.0 |
| Polmas | Beban | 6.9 | 2.3 | - | - |
| Majene | Beban | 5.1 | 1.9 | - | - |
| Mamuju | Beban | 8.3 | 1.0 | - | - |
| Pangkep | Beban | 14.9 | 7.7 | - | - |
| Bosowa | Beban | 19.7 | 3.5 | - | - |
| Tel. Lama | Beban | - | - | - | - |
| Panakukkang | Beban | 28.1 | 8.4 | - | - |
| Tanjung Bunga | Beban | 30.5 | 12.4 | - | - |
| Talasa | Beban | 7.9 | 3 | - | - |
| TIP | Beban | - | - | - | - |
| Bone | Beban | 15.1 | 6.3 | - | - |
| Sidrap | Beban | 13.2 | 6.0 | - | - |
| Maros | Beban | 4.7 | 2.2 | - | - |
| Pangkep D | Beban | - | - | - | - |
| Tonasa | Beban | 39.4 | 22.8 | - | - |
| Mandai | Beban | 19.7 | 2.1 | - | - |
| Daya | Beban | 24.1 | 1.6 | - | - |
| TelloA | Beban | - | - | - | - |
| TelloB | Beban | - | - | - | - |
| Barawaja | Beban | 5.2 | 0.0 | - | - |
| Bontoala | Beban | 18.5 | 0.0 | - | - |

In this study, the simulation results used a comparison method of the Lagrange and Ant Colony Optimization (ACO) methods to test the optimization of the Particle Swarm Optimization (PSO) method. Table 4 shows the real generation and cost for the Sulselrabar thermal system unit at peak load during the day before being optimized.

*Table 4. Real Thermal Generation Load at peak load day*

| Generation | Real System | | |
|---|---|---|---|
| | Active Power (MW) | Cost (Rp/jam) | Losses (MW) |
| PLTD Pare-Pare | 20.200 | 9423279.229 | |
| PLTD Suppa | 52.000 | 10821756.000 | |
| PLTU Barru | 37.800 | 8837173.034 | |
| PLTU Tello | 44.700 | 6996479.963 | |
| PLTD Agrekko/T.Lama | 19.300 | 4246022.692 | |
| PLTD Sgmnsa | 12.500 | 5161016.719 | |
| PLTD Arena/Jeneponto | 9.300 | 2335660.071 | |
| PLTD Matekko/Bulukumba | 9.100 | 2109689.765 | |
| PLTD Pajelasang/Soppeng | 15.000 | 3686625.000 | |
| PLTGU Sengkang | 164.500 | 71052067.022 | |
| PLTD Malea/Makale | 3.600 | 1491805.384 | |
| PLTD Palopo | 5.100 | 1720198.800 | |
| | 393.1 | 127881773.68 | 24.956 |

The generation load charged to the thermal unit was 393.1 MW, with a total generation cost of Rp. 127,881,773.68, according to the results of the analysis in the case study of the peak load during the daytime generation before being optimized.The losses generated before optimization were 24,956 MW. The total system load amounted to 402 MW. 4 hydro generation units each: PLTA Bakaru (126 MW), PLTM Teppo Pinrang (0.3 MW), PLTA Tangka Manipi Sinjai (3.5 MW), and PLTM Bili-Bili (7.1

MW). Furthermore, by using the proposed method, namely, a smart method based on Particle Swarm Optimization (PSO), more optimal generation results are obtained. As a comparison method in this study, the Lagrange and ant colony methods were used. More is shown in Table 5.

Figures 4 and 5 show graphic optimization of generation costs and the global best tour using the Ant Colony Method.The graph of Ant Colony's optimization results shows that generation costs decrease with each iteration, even though in some iterations there are slight oscillations. Figure 4 shows how an ant colony performs in lowering generation costs. In the graph, oscillations occur until around the 41st iteration. This shows that from the beginning of the iteration to the 41st iteration, the ant colonies in each iteration produced different optimal journeys (optimal solutions). Figure 5 depicts the world's best ant colony tour.The best tour global graph shows the best objective function values that the algorithm can achieve from the beginning of the iteration to the maximum iteration (100).

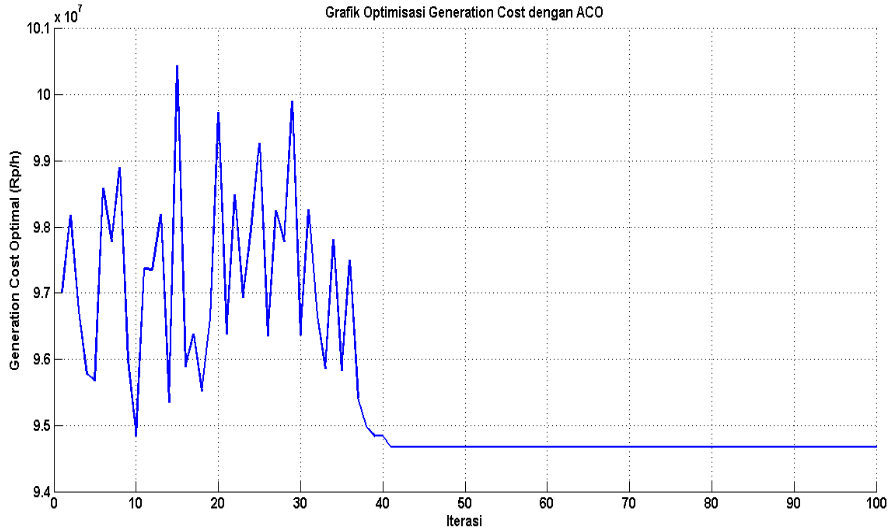


Figure 4. Graph of optimization of Sulselrabar system generation costs at peak daylight loads using *Ant Colony Optimization (ACO)*

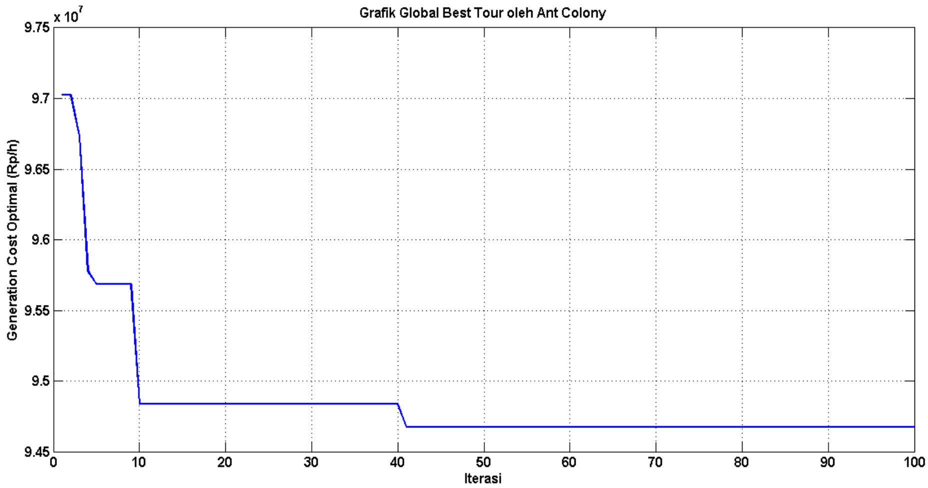


Figure 5. Global chart of Sulselrabar system tour at peak daylight loads using *Ant Colony Optimization (ACO)*

Optimization of generation costs can be seen in figure 6. The Particle Swarm Optimization optimization result graph shows the minimum generation cost compared to the Lagrange and Ant Colony methods. Figure 6 shows how Particle Swarm performs in optimizing the cheapest generation costs. The computational process is carried out for 50 iterations. From the convergence graph, the performance of Particle Swarm was obtained, which found the generation cost on iteration 19 with a fitness function value of 9.349779e+07.

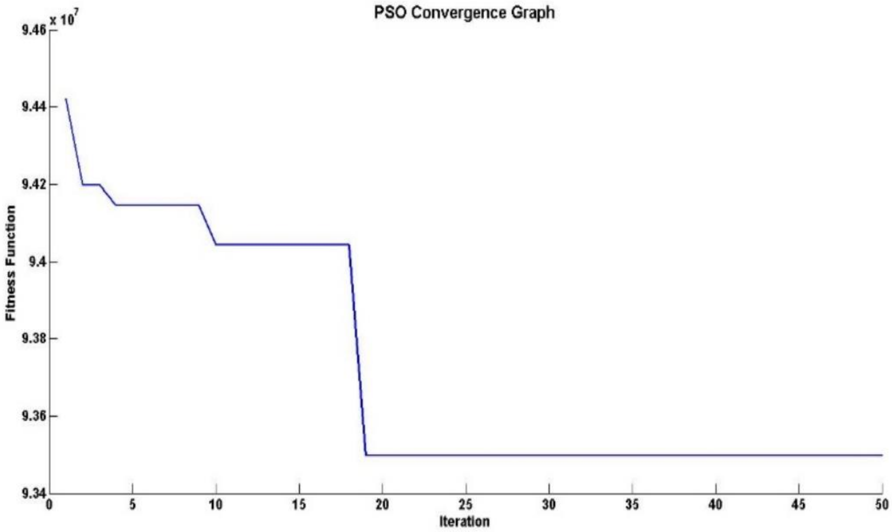


Figure 6. Particle *Swarm Optimization (PSO)* convergence graph

From the results of generation optimization using the particle swarm method, it resulted in a total generation cost of Rp. 93,498,916.10/hour to generate power of 270.14 MW with losses of 25.73 MW. Meanwhile, using the Ant Colony method resulted in a total generation cost of Rp. 94,670,335.98,-/hour to generate power of 270,309 MW with losses of 25,918 MW, while using the Lagrange method resulted in a total generation cost of Rp. 117,121,631.08,-/hour to generate power of 339.4 MW with losses of 25,016 MW. The total generation cost in the real system is Rp. 127,881,773.68, +/-/hour to generate 393.1 MW of power with losses of 24,956 MW. From the results of this simulation, it can be concluded that the Particle Swarm Optimization (PSO) method is able to reduce the cost of generating the Sulselrabar system by Rp. 34,382,857.58 per hour, or 26.89% at peak loads during the day. Meanwhile, by using Ant Colony, it is able to reduce the cost of generating the Sulselrabar system by Rp. 33,211,437.7/hour, or 25.98% at peak night loads. Meanwhile, the lagrange method allows it to reduce the cost of generating the Sulselrabar system by Rp. 10,760,142.60/hour, or 8.41% at peak load during the day. 4 hydro generating units each are maximized because it is the cheapest generation. The Sengkang PLTGU generating unit acts as a slack bus in this system, which produces the most expensive thermal generation cost of Rp. 54,117,894.45/hour with a generated power of 103.36 MW. While the cheapest thermal generation unit at the Palopo PLTD plant is Rp. 456,941.03 (US$ 0.93), with a generated power of 1.99 MW, For more results shown in table 5 and figure 7 below.

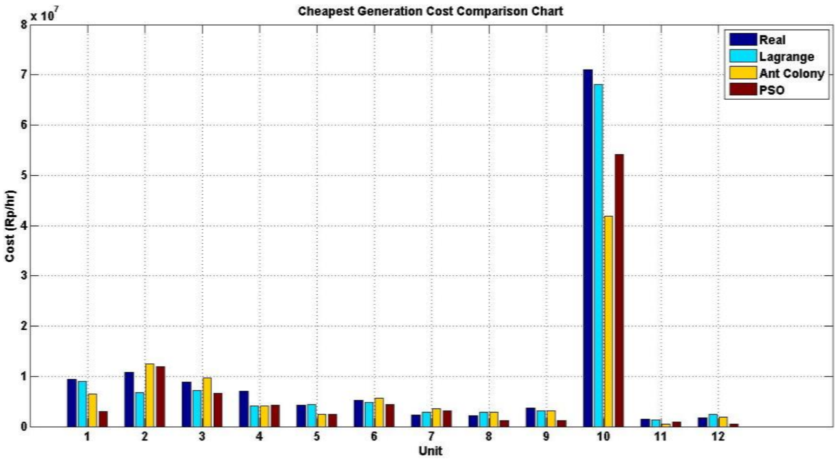


Figure 7. Daytime peak load generation cost comparison

## IV. CONCLUSION

From the results of generation optimization using the Particle Swarm method, it produces the cheapest generation costs from other methods, namely Rp. 93,498,916.1,-/hour to generate power of 270.14 MW with losses of 25.73 MW. The Particle Swarm Optimization (PSO) method is able to reduce the cost of generating the Sulselrabar system by Rp. 34,382,857.58,-/hour or 26.89%. From the results of generation optimization using the Ant Colony method, it resulted in a total generation cost of Rp. 94670335.98,-/hour to generate power of 270,309 MW with losses of 25.91 MW. The Ant Colony method is able to reduce the cost of generating the Sulselrabar system by Rp. 33,211,437.70,-/hour or 25.98%. From the results of generation optimization using the lagrange method, it resulted in a total generation cost of Rp. 117,121,631.08,-/hour to generate power of 339.4 MW with losses of 25,016 MW. The lagrange method is able to reduce the cost of generating the Sulselrabar system by Rp. 10,760,142.60,-/hour or 8.41%.

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