Optimization of Economic Dispatch of 150 kV Sulselrabar System using Lagrange Approach

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***Abstract*—In this study, the Lagrange method was used to solve the Economic Dispatch problem in the 150 kV electrical system in South, Southeast and West Sulawesi (Sulselrabar). The South Sulawesi system consists of several thermal and non thermal plants. For this reason, arrangements are needed to regulate the loading of the power plant, so that the amount of electricity generated in accordance with the needs and production costs is to a minimum. This research will propose the Lagrange method to find an economical composition of plants. The case study used was the peak daytime load. In this economic dispatch, the algorithm will work based on the given objective function, the objective function is the cheapest generation cost. From the optimization results of generation for the case of peak daytime load, using the Lagrange method, it was obtaining the total generation cost is IDR. 117,121,631.08/hour to generate power of 339.4 MW with losses of 25.016 MW. While in the real system the total generation cost is IDR. 127, 881, 773.68/hour to generate power of 393.1 MW with losses of 24.956 MW. The Lagrange method can reduce the Sulselrabar system generation costs by IDR. 10,760,142.6/hour or 8.41% in peak daytime loads.**

Keywords—Economic Dispatch, Lagrange, Cost, Real, Losses.

I. INTRODUCTION

The operation of several generating units within a power plant requires good management. Particularly in loading and the amount of power that must be delivered into the system. Economical operation management, especially on the thermal plants, can save power generating costs, especially fuel costs (where it is a basic electricity cost), which from time to time continue to experience a fairly high increase. Meanwhile, the power system load always vary from time to time, therefore the load of the thermal generator unit also vary accordingly in supplying the load of the electric power system. This resulted in the variation on the cost accordingly. In the thermal generation unit, the increase in load will encourage an increase in the amount of fuel per unit time and as a result, it will increase the incremental cost per unit of time, which is commonly called the output-input of a power plant.

The Sulselrabar 150 kV electricity system is a system that consisting of 46 transmission lines and connects to large load centers such as Makassar, Pangkep, Maros, Barru, Pare-Pare, Pinrang, Polmas, Majene, and Mamuju. This system consists of 37 buses with 16 generating units (12 thermal generating units and 4 hydro generating units). For large systems such as Sulselrabar, a comprehensive study is required to achieve optimal generation performance. Some studies that have been carried out on the Sulselrabar electrical system include Power flow studies [1], short circuit [2], stability studies [3-12], load forecasting studies [13-18], and study of optimum capacitor placement [19].

The study of economic generation research in the Sulselrabar system has also been carried out, including using conventional methods, such as merit loading, dynamic programming, and lambda iterations [20-28]. However, in these studies, case studies are still limited to each generating unit only. In this paper, a study on Economic Dispatch using the Lagrange method on the Sulselrabar electrical system is introduced and discussed where all generating units are involved simultaneously.

II. METHOD

A. Basic Theory

Economic Dispatch is the load share on generating units based on the most optimal and economically effective at the certain price of load system. With the application of Economic Dispatch, the minimum generation costs will be obtained for the production of electric power generated, as stated in [29]: "The purpose of economic dispatch is to minimize fuel consumption or the overall operation cost of the power system by determining the output power of each generating unit according to the power demand". The generated output power is always expected to be equal to the load side demands because the changes in the load side will cause fluctuations in fuel costs. The correlation between the two is expressed in the input-output characteristics of a power plant.

The solution to the Economic Dispatch problem with various methods whether to use deterministic or indeterministic has been attracting researchers for a long time. The deterministic approach is based on the branch of mathematical engineering while the indeterministic approach is heuristic using probability techniques.

Examples of deterministic solutions to Economic Dispatch problems such as using the Lagrange method, Regional Iteration and Base Point [29].

An indeterministic solution for the Economic Dispatch problem based on a heuristic approach such as using Particle Swarm Optimization [30, 31], Improved Differential Evolution [32], and Genetic Algorithm [33].

Solving the problem of economical operation of power plants is aimed to determine the generating units to supply load power demand at optimum costs by taking into account the generated power limits. Configuration system consisting of N plants connected by busbars to supply electrical loads (PD) as shown in Figure 1. Input for generating units F_i represents the cost of the unit. The output of each unit P_i is the electrical power generated [29]. Load sharing configuration can be seen in Figure 1.

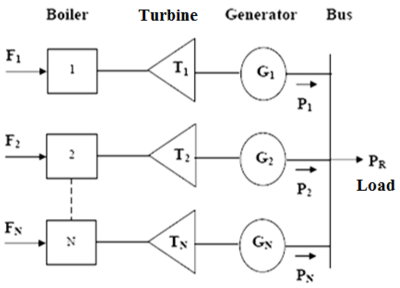

Fig. 1. Load sharing configuration

Economic Dispatch is the sharing of loading on each generating unit to obtain the effective economic value of operational costs on each generating unit by using the limits of equality and inequality constraints [34]. The cost function of each generator can be formulated mathematically as an objective function as given in equation (1) [35]:

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

Where:

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

Characteristics of generator input-output are characteristics that describe the relationship between fuel inputs (liters/hour) and the output produced by a generator (MW). In general, the generator input-output characteristics are approached by the second-order polynomial function, as stated in equation (2) [35].

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

Where:
C_i =Input for generator fuel generator for-i (IDR / hour).
P_i = Generator output (MW)
$\alpha_i \beta_i \gamma_i$ = Constant value for input-output of the i-generator

Determination of the parameters α_i, β_i, and γ_i requires data obtained from experimental results related to C_i fuel input (US dollar/hour) and P_i generator output (MW). The input unit output characteristics of a generator can be stated as follows [36]:

- Input from the generator is stated in: H = Mbtu / hour (heat energy needed), or C = IDR / hour (total fuel cost).
- While the output from the generator is stated in P = MW (power).

The output of each generator unit has an inequality constraint that is [29]:

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

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

At power equilibrium, Equality constraint must be fulfilled, where the total power generated by each generating unit must be equal to the total load requirements on the system. Equality constraint power equilibrium is [29]:

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

Where: P_i is output power for each generator (MW)
P_D is the total power requirement of the system (MW)

To calculate the Economic Dispatch carried out by using the limits of equality and inequality. Limitation of equality reflects a balance between the total power generated by the total load power on the system. Inequality limits reflect the minimum and maximum generation limits that must be met to obtain the optimum total fuel cost.

B. Proposed Method Using Lagrange Method

Lagrange method is a deterministic method that is widely used to solve the problem of cost optimization or economic dispatch, using the objective function equation as follows:

$$L = F_T + \lambda\ (P_R + P_L - \sum_{i=1}^{N} P_i) \qquad (5)$$

Where:
L= *Lagrange* equation
F_T= Total cost of generation (IDR/hour)
λ =Multiplier Lagrange
P_i= Output power for each generator (MW)
P_L= Loses in transmission line (MW)
P_R= Total required loads in the system (MW)
I=i-th generation index (i= 1,2,3,...,n)

Economic operating conditions are obtained by equating with zero all the first partial derivatives of the Lagrange equation against the variable λ.

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_t}{\partial P_i} + \lambda \left(\frac{\partial P_R}{\partial P_i} + \frac{\partial P_L}{\partial P_i} - \frac{\partial P_i}{\partial P_i} \right) = 0\ , i = 1,2, \ldots . n \qquad (6)$$

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_t}{\partial P_i} + \lambda \left(0 + \frac{\partial P_L}{\partial P_i} - 1 \right) = 0 \qquad (7)$$

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_t}{\partial P_i} - \lambda \left(1 + \frac{\partial P_L}{\partial P_i} \right) \qquad (8)$$

$$2C_i P_i + b_i = \lambda \left(1 + \frac{\partial P_L}{\partial P_i} \right) \qquad (9)$$

The flowchart diagram of the Lagrange method for solving economic dispatch problems is shown in Figure 2.

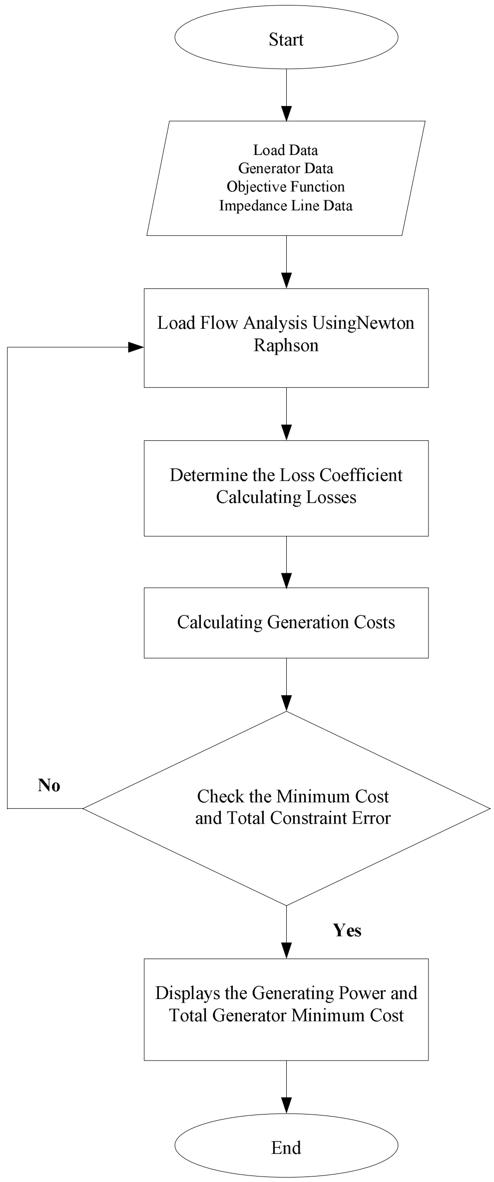

Fig. 2. Flowchart of research stages

III. RESULT AND DISCUSSION

In this study, the Lagrange method will be used to solve the Economic Dispatch problem in the 150 kV electricity system in South, Southeast and West Sulawesi (South Sulawesi). The case studies used is the peak load during the day. In this study, Matlab program is used, to create a Lagrange algorithm, to calculate the cost function of the fuel, by previously calculating the input-output characteristics of each Sulselrabar system thermal generating unit. The Lagrange algorithm will look for an optimal/economical thermic generation combination. 4 Hydro generating units will be maximized because they are the cheapest generation. In this economic dispatch, what is used as an objective function is the lowest generation cost. The function of the total generation cost of the plants connected to the system is as follows:

$$C_t = \sum_{i=1}^{n_g} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \qquad (11)$$

The output power of the generator must not exceed or be less than the rating of each generator to obtain a stable generator operation. Therefore, generators must be limited to the maximum and minimum limits. Constraints are given by the following two equations (eq. 12 and eq. 13), equality constraint is given by equation 16, and the inequality constraint is given by equation 17.

$$\sum_{i=1}^{n_g} P_i = P_D \qquad (12)$$

$$P_{i_{min}} \leq P_i \leq P_{i_{max}} \qquad (13)$$

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

A. Input-Output Characteristic of Thermal Power Plants

To calculate the cost function of each thermal generator, the calculation of the input-output characteristics of each thermal generator is performed first. The actual input-output equation can be obtained with the help of Matlab, and it is displayed in table 1.

TABLE I. INPUT-OUTPUT CHARACTERISTIC OF THERMAL POWER PLANTS IN SULSELRABAR

No	Power Plant Unit	Input-Output Equation (Litre/Hr)
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	$771.975 + 160P + 2.7397P^2$
6	PLTD Sgmnsa	$617.625 + 477.25P - 4.1667P^2$
7	PLTD Arena	$629.475 + 176.3P + 4.8052P^2$
8	PLTD Matekko	$506.25 + 124.9P + 9.4444P^2$
9	PLTD Pajelasang	$432 + 66.2P + 12.5P^2$
10	PLTGU Sengkang	$4418.89 + 38.0952P + 0.021898P^2$
11	PLTD Malea	$165.75 + 409.5P + 5.7692P^2$
12	PLTD Palopo	$103.5 + 112.4P + 50P^2$

B. Cost Function of Thermal Power Plant

The fuel cost equation from each generator is obtained by multiplying the generator input-output equation with the fuel price. Then the complete fuel cost equation is shown in table 2.

TABLE II. EQUATIONS FOR FUEL COST OF THERMAL POWER PLANTS IN SULSELRABAR

No	Power Plant Unit	Input-Output Equation (Liter/Hr)
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	$6716182.5 + 1392000P + 23835.39P^2$
6	PLTD Sgmnsa	$5373337.5 + 4152075P - 36250.29P^2$
7	PLTD Arena	$5476432.5 + 1533810P + 41805.24P^2$
8	PLTD Matekko	$4404375 + 1086630P + 82166.28P^2$
9	PLTD Pajelasang	$3758400 + 575940P + 108750P^2$
10	PLTGU Sengkang	$27839000.000 + 240000.00P + 137.9539P^2$
11	PLTD Malea	$1442025 + 3562650P + 50192.04P^2$
12	PLTD Palopo	$900450 + 977880P + 435000P^2$

C. Case study

For the case study, a load simulation was performed during the daytime peak load on Thursday, April 12, 2012. The total system load at the time of the peak load was

402,100 MW. Table 3 shows the generation of real and costs for the Sulselrabar thermal system unit at peak load during the day before optimization. The results of simulations performed using the Lagrange method is shown in table 4.

TABLE III. REAL GENERATION OF THE THERMAL POWER PLANT AT DAYTIME PEAK LOAD

No	Power Plant Unit	Real System		
		Active Power (MW)	Cost (IDR/hour)	Losses (MW)
1	PLTD Pare-Pare	20.200	9423279.229	
2	PLTD Suppa	52.000	10821756.000	
3	PLTU Barru	37.800	8837173.034	
4	PLTU Tello	44.700	6996479.963	
5	PLTD Agrekko	19.300	4246022.692	
6	PLTD Sgmnsa	12.500	5161016.719	
7	PLTD Arena	9.300	2335660.071	
8	PLTD Matekko	9.100	2109689.765	
9	PLTD Pajelasang	15.000	3686625.000	
10	PLTGU Sengkang	164.500	71052067.022	
11	PLTD Malea	3.600	1491805.384	
12	PLTD Palopo	5.100	1720198.800	
Total		**393.1**	**127881773.68**	**24.956**

From the results of the analysis for the first case, namely the peak load condition during the generation before being optimized, the generation load charged to the thermal unit is 393.1 MW, with a total generation cost of IDR. 127,881,773.68, -. Losses generated before being optimized were 24,956 MW, for a total system load of 402,100 MW. 4 hydro generating units respectively: Bakaru PLTA 126 MW, PLPM Teppo Pinrang 0.3 MW, PLTM Tangka Manipi Sinjai 3.5 MW, PLTM Bili-Bili 7.1 MW. Furthermore, by using the proposed method using the Lagrange method, it is obtained more optimal generation results. More is shown in the following Table 4.

TABLE IV. REAL GENERATION OF THE THERMAL POWER PLANT AT DAYTIME PEAK LOAD

No	Power Plant	Lagrange Method		
		Active Power (MW)	Cost (IDR/hour)	Losses (MW)
1	PLTD Pare-Pare	19.100	9004168.860	
2	PLTD Suppa	30.000	6775560.000	
3	PLTU Barru	30.000	7201807.200	
4	PLTU Tello	28.200	4140583.650	
5	PLTD Agrekko	19.960	4399656.001	
6	PLTD Sgmnsa	11.600	4865956.848	
7	PLTD Arena	11.680	2909450.447	
8	PLTD Matekko	11.700	2836568.807	
9	PLTD Pajelasang	13.520	3142356.480	
10	PLTGU Sengkang	154.260	68144171.366	
11	PLTD Malea	3.160	1320119.663	
12	PLTD Palopo	6.220	2381231.760	
Total		**339.4**	**117121631.08**	**25.016**

Table 4 shows the results of the optimization of economic generation using the Lagrange method, which shows the cost of the generation which has decreased compared to the operation of the plant without being optimized. From the results of the optimization of generation generates a total generation cost of IDR. 117,121,631.08/hour to generate power of 339.4 MW with losses of 25,016 MW. Whereas in the real system the total cost of generation without optimization is IDR. 127,881,773.68/hour to generate power of 393.1MW with losses of 24,956 MW. From the results of this simulation, it can be concluded that the methodology can reduce the cost of generating the South Sulawesi system by IDR.10,760,142.6/hour or 8.41% at peak daytime load. 4 hydro plants are maximized because they are the cheapest generation. The Sengkang power plant unit acts as a slack bus in this system, which generates the most expensive thermal generation cost of IDR. 68,144,171,366/hour, with the generated power of 154.26 MW. While the cheapest thermal generating unit in the Malea Makale PLTD generator is IDR. 1,320,119,663/hour, with the power generated at 3.16 MW.

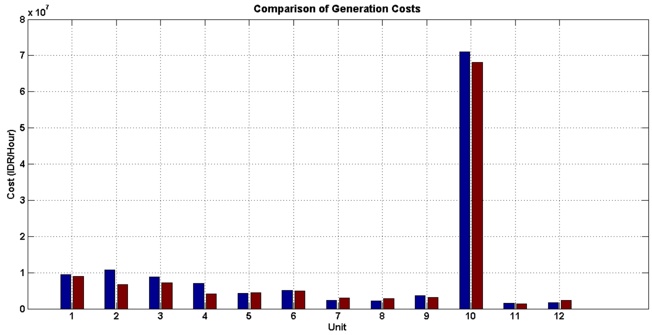

Fig. 3. Comparison of generation cost for mid-day peak load

IV. CONCLUSION

1. From the results of the optimization of generation for the first case of peak day load using the Lagrange method, generating a total generation cost of IDR. 117,121,631.08/hour to generate power of 339.4 MW with losses of 25,016 MW. In the real system, the total generation cost is IDR. 127,881,773.68/hour to generate power of 393.1MW with losses of 24,956 MW.
2. From the results of the optimization of generation for the first case of peak day load, it can be concluded that Lagrange can reduce the cost of generation of the South Sulawesi system by IDR.10,760,142.6/hour or 8.41% in the peak daytime load.

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