

Scheduling Economical Thermal Power Plant 500 KV Java-Bali System Using Lagrange Multiplier

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Abstract. The highest cost of electricity generation operation is fuel cost. Therefore, it is necessary to optimize the thermal generator scheduling. The present study aimed at obtaining the schedule and load sharing of the electric power generation, in order to gain the minimum fuel cost, with regard to inequality and equality constraints. The data tested was the thermal generation system of 500 kV Java-Bali using daily loads. This study employed a lagrange multiplier method to perform the economic scheduling. This method is one of mathematical techniques commonly used to solve economic dispatch problems. The results of the optimization of lagrange multiplier were compared with the real condition in the field. Based on the optimization results, it was found that the lagrange multiplier method is more economical than the real condition of system.

1. Introduction

In the planning, operation and control of electric power systems appear various technical and economic problems. One is the rise and fall of the power consumption by the consumer so that the system load becomes dynamic. Because the electrical energy generated can not be stored on a large scale, the energy must be provided when required. In addition, the generator output is generated always strived to match the requirements on the load side. The result appears the issue of how an electric power system must be operated in order to meet the power demand that change at any time, with good quality and low prices. The highest cost of electricity generation operation is fuel cost [1]. Therefore, the output of each generating unit need scheduled to be economically to get a minimum fuel costs.

In solving problems economical operation of generation in the electric power system, there are two main problems, namely setting the generating unit (unit commitment) and scheduling economical (economic dispatch). Unit commitment determine the generator unit which on and off within a certain time period to meet the load demand economically [2]. From generating units that "on" then determined economic loading on each unit is called the economic dispatch. The main objective of the



economic dispatch is to schedule generating units that "on" so as to meet the demand of the load required at minimum cost [3].

Many methods both deterministic and nondeterministic that can be used to solve scheduling problems economically. Deterministic approach based on technical mathematic while undeterministic is heuristic approach using probability techniques. Deterministic solutions include lambda Iteration Method [4], Lagrange Relaxation [5], Dynamic Programming [6] and Priority List Method. While nondeterministic are Partical Swarm Optimization [7-8], Tabu Search [9], Evolutionary Programming [10], Genetic Algorithm [11-12] and Ant Colony Optimization [13-14].

In the previous study, with the same data of system, scheduling of thermal power plant is done by hybrid neuro fuzzy without transmission losses [15]. But in this case, the losses will be involve into the calculation. This study aims to determine the optimal scheduling of thermal power plant and minimize the total generation cost among the committed units satisfying all unit and system equality and inequality constraints. Equality constraint reflects a balance between the total powers generated with the total power load on the system. And the inequality constraint reflects the minimum and maximum limit of the generation that must be met in order to obtain the optimum of total fuel cost.

2. Method

In this study, the method to be used for economic scheduling is lagrange multiplier method. Here is a flow chart of economical scheduling using lagrange multiplier:

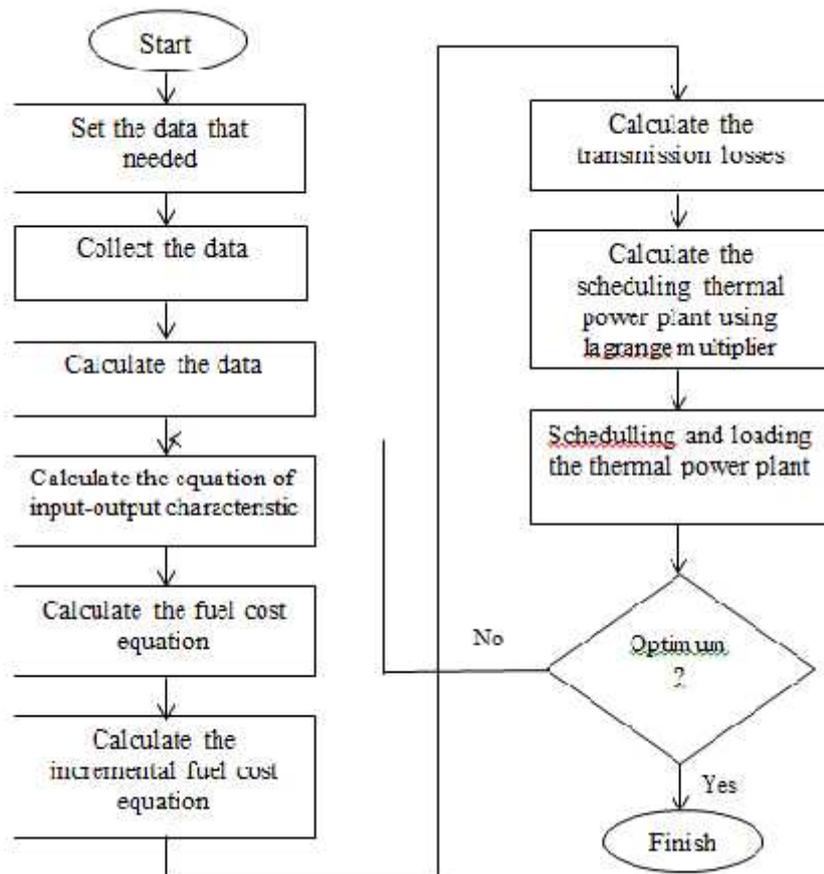


Figure 1. Flowchart of scheduling economical using *lagrange multiplier*

The first is looking for primary data in the form of spending per-hour electric load issued by Indonesia Electrical Company. The primary data is data loading on each bus on Tuesday, May 7 2013

[16], heat rate thermal power plant, the maximum and minimum operation of thermal power plants, the daily load thermal power plants and fuel costs. Equation of input-output characteristics of plants that express the relationship between the amount of the fuel cost needed to generate a given power at thermal power plants are approximated by polynomial functions, namely [17]:

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

where,

F_i = cost function of generator i (Btu/h atau \$/h),

P_i = power of generator i (MW),

a_i, b_i, c_i = cost coefficients of generator i ,

Total production costs in n generating units are as follows,

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

Incremental cost value for some plants that serve a load can be found using the formula below,

$$\lambda = \frac{\partial F}{\partial P} = b_i + 2c_i P_i \quad (3)$$

Operating constraints economical power plant is the power balance, an equality constraints should be satisfied. The total power generated by the centers of power plants must be the same total load demand plus the total line loss, according to equality:

$$\sum_{i=1}^n P_i = P_D + P_L \quad (4)$$

where P_D is the total system demand and P_L is the total line loss.

Other constraint is the limits of minimum and maximum of power plants are represented as follows:

$$P_{i_{\min}} \leq P_i \leq P_{i_{\max}} \quad (5)$$

To accommodate the transmission loss when determining the loading generation, then the transmission loss should be expressed as a function of linear equations and constant equation known as losses Kron formula [18]:

$$PL = \sum_{i=1}^n \sum_{j=1}^n P_{gi} B_{ij} P_{gj} + \sum B_{i0} P_{gi} + B_{00} \quad (6)$$

where B_{0i} , B_{0j} and B_{00} are the transmission network power loss B-coefficients, which are assumed to be constant, and reasonable accuracy can be achieved when the actual operating conditions are close to the base case where the B-coefficients were derived.

The typical approach to the method of Lagrange to be added in the objective function is called the Lagrange multiplier factor (lagrange multipliers). Lagrange multiplier equation is [19]:

$$\mathcal{L} = F + \lambda (P + P - \sum_{i=1}^n P_i) \quad (7)$$

where \mathcal{L} is the lagrange equation and λ is the lagrange multiplier.

Economical operating conditions obtained by equating to zero all the first partial derivatives of the lagrange equation to variable λ . Lagrange equation is a function of the plant output, optimum state can be obtained from lagrange equation equal to zero [19].

$$\frac{\partial \mathcal{L}}{\partial P} = \frac{d}{dP} + \lambda \left(\frac{\partial}{\partial P} + \frac{\partial}{\partial P} - \frac{\partial}{\partial P} \right) = 0 \quad (8)$$

with P_R does not depend on changes of P_i so:

$$2C + b = \lambda \left(1 - \frac{\partial}{\partial P} \right) \quad (9)$$

The steps in resolving scheduling plants using lagrange multiplier is as follows [18]: Set the starting value for P_1 , P_2 , P_3 , P_4 , P_5 and P_6 according to the amount of the load; Calculating incremental losses $\partial P_L / (\partial P_i)$ and total losses P_L . Incremental losses and total losses will be kept

constant so that it can return to step 2; Calculating the value of λ that causes P1, P2, P3, P4, P5 and P6 can be added up to a total loss and total load; Comparing P1, P2, P3, P4, P5 and P6 from step 3 to the values used for the start at step 2. If not significantly change the value, proceed to step 5 in another way if it does not go back to step 2.

Next is calculating the number of combinations on and off thermal power plants as many 2^n-1 for each period, where n is the number of thermal generating units and test combinations that may occur with the calculation of economic dispatch.

The final step is scheduling the generating unit for one day, the chosen combination is the combination with the cheapest fuel costs.

In this study used data of 500 kV interconnection system of Java-Bali consisting of 25 buses with eight plants. Power plants that are used only thermal power plants like Suralaya, Muara Tawar, Tanjung Jati, Gresik, Paiton and Grati, whereas hydro power as Saguling and Cirata not included in this study. Single line diagram of the 500 kV interconnection system of Java-Bali which has been modeled can be seen in the figure below:

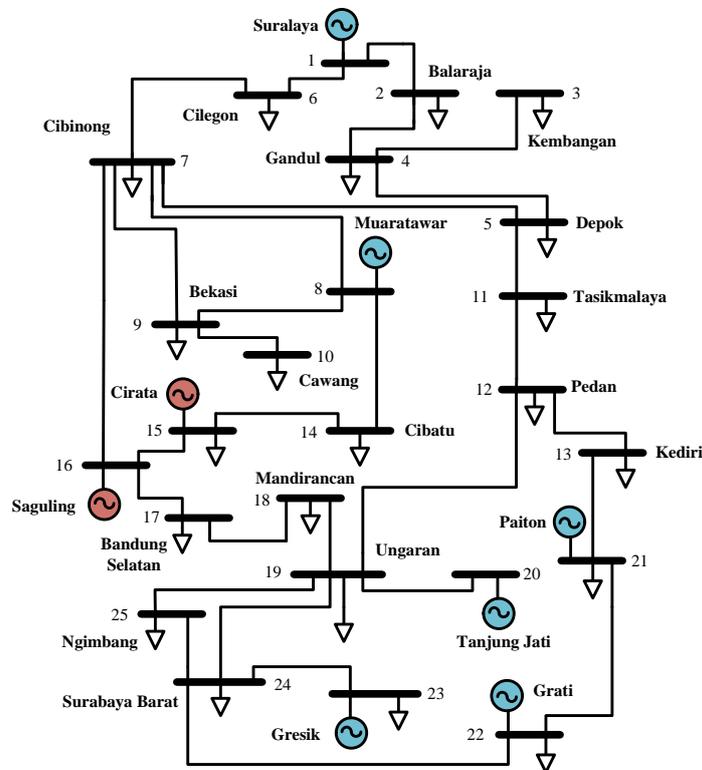


Figure 2. Modeling of 500 kV Interconnection System of Java-Bali.

Daily load thermal power plant of 500 kV Java-Bali system consists of 24 hours then the researchers made the eight periods, with each period is the average load for 3 hours. From the graph shows that the daily load peak on Tuesday, 7 May 2013 occurred at 19.00-21.00, where the load reached 11959 MW. While the lowest load occurs at 04:00-06:00, where the load is 10854 MW.

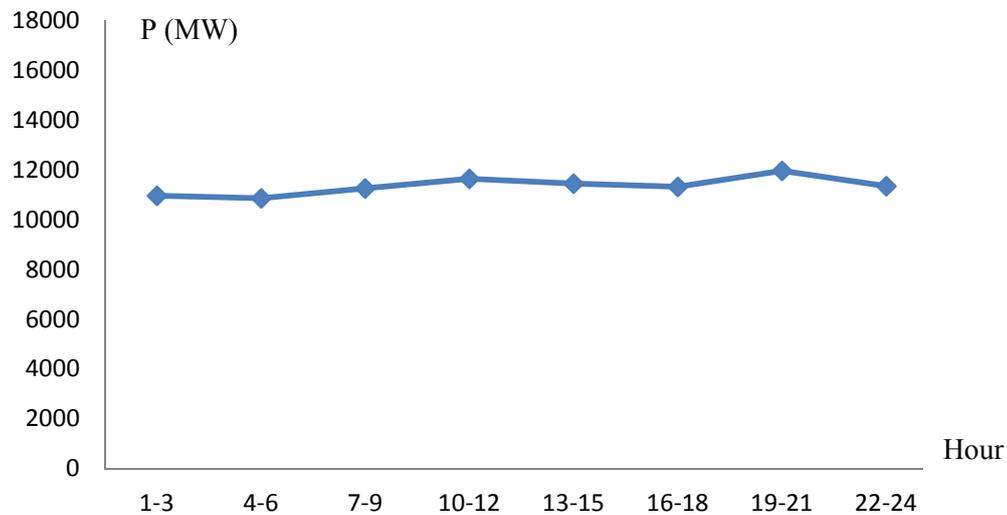


Figure 3. Graph of daily load thermal power plant of 500 kV Java-Bali system (Tuesday, May 7 2013) [16].

To search for a function of the cost of generating electrical energy generation, before we need the heat rate data of each power plant consisting of at least 4 (four) point of heat-rate that is obtained from the results of experiments as well as from the manufacturer's specification to design a power plant.

Table 1. Heat-rate cost of generating the 500 kV Java-Bali system.

Unit	Generating Power (MW)				Heat-Rate (Btu/kWh)			
	1	2	3	4	1	2	3	4
Suralaya	1703	2221	2561	3247	76492.24	74493.38	73454.29	71796.5
Muaratawar	666	826	993	1140	112582.84	112253.66	100783.99	98182.3
Tanjung Jati	1227	1525	1812.8	1982.8	28800.93	28483.89	28186.52	27978.62
Gresik	1141	1382	1649	1973	191161.2	189915.88	189237.69	188630.89
Paiton	2071.5	2792.5	3358.75	4005	76161.72	73013.27	70840.3	68897.35
Grati	320	400	560	795.6	124583.96	111932.42	108890.5	106665.57

Table 1 represents heat rate data of thermal power plant of 500 kV Java-Bali system. Each unit consists of four-point of plant heat rate obtained from the experiments. If the data is approximated by a polynomial function will be obtained heat rate equation of thermal generation in MBtu/h. Multiplication heat rate equation with the fuel cost will produce a new equation that describes the characteristics of a thermal power plant fuel costs. The fuel cost of each plant is \$ 0.41 per MBtu for Suralaya, \$ 1.25 per MBtu for Muaratawar, \$ 0.85 per MBtu to Tanjung Jati, \$ 0.26 per MBtu for Gresik, \$ 1.74 per MBtu for Paiton, and \$ 0.38 per MBtu for Grati. Other data needed are limit of plant scheduling system as well as real data of generating units that will be compared with the results of calculations of researchers that can be seen in Table 2 and Table 3.

Table 2. Limit Power Operation of 500 KV Java-Bali System.

Unit	P min (MW)	P max (MW)
Suralaya	1600	3400
Muaratawar	600	1400
Tanjung Jati	1200	2100
Gresik	900	2100
Paiton	1800	4300
Grati	290	800

Table 3. Imposition generator of 500 kV system Per-3 hours, Tuesday, May 7 2013.

Hour	Suralaya	Muara Tawar	T. Jati	Gresik	Paiton	Grati
1-3	2985	926	2416	1327	2915	392
4-6	2996	992	2216	1393	2863	394
7-9	2978	1214	2225	1422	3009	406
10-12	2974	1338	2358	1584	2980	403
13-15	2866	1307	2370	1493	3008	401
16-18	2903	1075	2544	1335	3055	402
19-21	3005	1317	2631	1536	3056	414
22-24	2950	956	2550	1420	3060	407

3. Result and Discussion

Scheduling of generating unit aims to optimize the loading of generating units operated by pressing the cost of materials economically or known by the term economical operation. The optimal state obtained when operated with the same incremental cost by taking into limit of the maximum and minimum operation of generating units.

To be able to calculate the economical operation first sought a function of fuel cost 500 kV of Java-Bali system by processing the heat rate data using polynomial function approach, which is then multiplied by the function of the fuel cost in order to obtain the data as shown in Table 4.

Table 4. Characteristics of generation costs (\$/h)

Unit	Characteristics of generation costs (\$/h)
Suralaya	$F(P) = 275.1741 + 34.2155P - 0.0015P^2$
Muaratawar	$F(P) = 624.9346 + 178.8621P - 0.0512P^2$
Tanjung Jati	$F(P) = 348.5491 + 27.2541P - 0.0019P^2$
Gresik	$F(P) = 538.3751 + 52.8313P - 0.0003P^2$
Paiton	$F(P) = -212.5033 + 151.7804P - 0.0083P^2$
Grati	$F(P) = -119.3939 + 45.6393P - 0.0061P^2$

Table 4 is an input-output characteristics of the thermal power plant that is a function F (\$/h) to P (MW). If $F(P)$ each unit differentiate once to the P , then the value of incremental cost of each plant will be obtain.

The combination of scheduling and loading on each plant for a certain period a combination that may be applied to the scheduling system of thermal power plant of 500 kV Java-Bali system, but in these combinations are the best combination that can provide fuel cost is minimum. In order to achieve the economical operation of 500 kV the Java-Bali system that have the best scheduling are shown in Table 5.

Tabel 5. Best Combination for Scheduling

Hour	Suralaya	Muara Tawar	T. Jati	Gresik	Paiton	Grati
1-3	1600	-	1400	2100	3200	-
4-6	1600	-	1400	2100	3200	-
7-9	1600	-	1400	2100	3200	150
10-12	1600	-	1400	2100	3200	150
13-15	1600	-	1400	2100	3200	150
16-18	1600	-	1400	2100	3200	150
19-21	1600	1280.1909	1400	2100	3200	-
22-24	1600	-	1400	2100	3200	150

Comparison of fuel costs to be incurred by thermal power plants can be seen as follows:

Table 6. Comparison of generation costs based on real data of system with lagrange calculation

Hour	PLN (\$/h)	Lagrange multiplier (\$/h)
1-3	725.147,1084	597.119,6857
4-6	725.173,6286	597.119,6857
7-9	756.562,4788	603.828,3307
10-12	770.235,1493	603.828,3307
13-15	764.411,749	603.828,3307
16-18	751.869,4749	603.828,3307
19-21	780.652,972	742.186,215
22-24	749.389,3663	603.828,3307
TOTAL	6.023.441,927	4.955.567,24

Based on the table 6, the authors describe the scheduling of every 3 hours into the every hour, in order to get the scheduling pattern for 24 hours on Tuesday, May 7 2013. This was done because the increase or decrease of the load is very small for every hour.

Comparison charts generation scheduling optimization of 500 kV Java-Bali system with Lagrange multiplier on Tuesday, May 7 2013 per one hour to the real conditions can be seen on Figure 4.

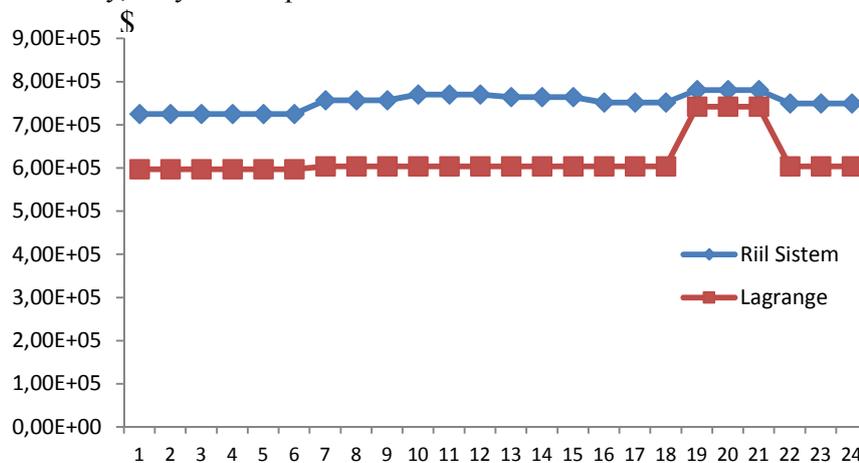


Figure 4. Comparison graph of the cost of real conditions with optimization multiplier

4. Conclusion

After conducting empirical studies, it can be said that to obtain a cost function of plant can use the heat rate data for each plant; optimization of scheduling power plants can use lagrange multiplier; operating costs of power thermal plant by using lagrange multiplier is more economical compared with real data of the system (Indonesia Electrical Company).

The results of the optimization using lagrange multiplier with the data loading on Tuesday, May 7 2013 acquired a total cost of \$ 4,955,567.24, while the total cost of the real data for \$ 6,023,441.927 system. So by using lagrange multiplier method can reduce the operation cost up to \$ 1,067,874.69 which is 17.73% more economical

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