Economic Dispatch Analysis Using Equal Incremental Cost Method with Linear Regression Approach

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Abstract

The use of fuel is one thing that needs special attention, because most of the operating costs of a plant are fuel costs.One of the efforts to minimize the cost of generating fuel is called Economic dispatch.In this study, an Equal Incremental Cost method with a Linear Regression approach will be presented to obtain a minimum generation cost.The case taken is the Pangkalan Susu PLTU which operates two generating units. Based on the results of calculations using the Equal Incremental Cost method with the Linear Regression approach, the cost is -0.033% or an average of -13,111 $/hour.

Keywords : Economic Dispatch; Equal Incremental Cost Method; Linier Regression

Introduction

The use of fuel is one of the things that needs special attention in the operation of power plants, because about 60% of the total operational costs incurred are fuel costs (Marsudi, 2006). Changes in the demand for electrical energy on the load side will cause fluctuations in fuel costs. These fluctuations are very difficult to predict and are always changing, therefore we need a very fast system to cope with and respond to them (Syah *et al.*, 2012). The analysis to produce the minimum cost at the generator is usually referred to as economic dispatch. Economic Dispatch is the distribution of loading on generating units in the system optimally and economically at a certain system load price. With the application of economic dispatch to the electricity generating unit, the minimum generation cost for electricity production will be obtained (Syah *et al.*, 2012)(Pramudia, Hardiansyah and Junaidi, no date).

There are two methods of approach taken to solve the economic dispatch problem, namely the numerical method and the meta-heuristic method (Takeang and Aurasopon, 2019). Examples of numerical method solutions in economic dispatch problems include using the Lagrange method (Syah *et al.*, 2012), Lambda Iteration (Dike, Adinfono and Ogu, 2013), Dynamic Programming Techniques (Nabila, 2017), Equal Incremental Cost (Hasibuan, no date) while the meta-heuristic method solution, for example using the Particle Swarm Optimization method (Dewangan, Jain and Huddar, 2015), Cuckoo Optimization Algorithm (Iskandar, 2016), Artificial Bee Colony Algorithm (Pramudia, Hardiansyah and Junaidi, no date), Taguchi (Rusilawati, Penangsang and Soeprijanto, no date). Previous research conducted by Arnawan Hasibuan examined the Economical Operation of a Steam Power Plant Using the Equal Incremental Cost Method with a Linear Regression (Least Square) Approach, obtained savings are when compared with an even distribution of the total power output to the generating units (Hasibuan, no date). This research was conducted using the Equal Incremental Cost method with the Linear Regression (Least Square) approach to obtain the minimum power plant operating costs. The calculation of the Equal Incremental Cost method to calculate economic dispatch is carried out by using constrain equality and inequality constrain (Syah *et al.*, 2012). Equality constraint is a power balance limitation, which requires that the total power generated by each generator must be equal to the total required load and transmission losses(Syah *et al.*, 2012)(Nabila, 2017).Inequality constraint is a cost function that is not influenced by reactive power but on the real power balance in the system(Suman *et al.*, 2016).

Literature Review

Electric Power System operation

Operation of the power system is an operating process to produce electric power from a generation, transmission distribution, distribution to consumer loads. The main objective of operating the electric power system is to meet needs

efficiently, namely to meet the load at an optimal and economical cost by paying attention to reliability that meets environmental safety standards and can serve demand continuously from time to time(Pertiwi, Syahrizal and Siregar, 2018). The operation of the electric power system at a fixed frequency is said to be in a balanced power state if the total real power generated is equal to the total system load. In the form of an equation written as follows (Kristianto, Suyono and Wijono, 2014).

$$P_G = P_R + P_L \tag{1}$$

$$P_G = \sum_{i=1}^{n} P_i \tag{2}$$

Where:

P_G = The total power generated by the generator (MW)

P_R = total system load (MW)

P_L = Total loss - actual loss of power from the transmission line (MW)

P_i = The power generated by the ith generator (MW)

n = Number of generators in the system

Power Plant Economical Operation Considerations

Economic operation is the process of dividing or rationing the total load for each generating unit, all generating units are controlled continuously at certain time intervals so that optimal operation is achieved, so that the generator can be run in the most economical manner (Hakimah, 2016). The considerations taken to achieve the economic operation of the power system can be divided into two parts, namely the economic dispatch and the unit commitment (Mariang, no date).

Economic Dispatch

Economic Dispatch is a method used to divide the power generated by the generating unit to meet load requirements. This power plant aims to get the cheapest generation costs (Nabila, 2017). In the Economic Dispatch, there are two certain constraints that must be met, namely the Equality constraint and the Inequality constraint (Syah *et al.*, 2012)(Suman *et al.*, 2016). Equality constraint can be expressed by equations 1 and 2.The inequality constraint is stated in the following equation :
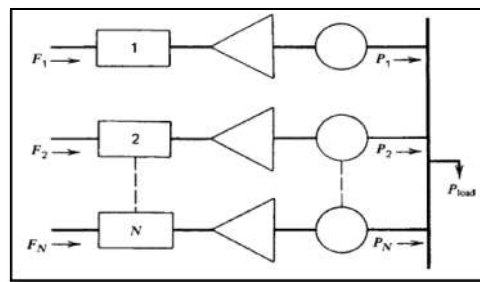
$$P_{i,min} \leq P \leq P_{i,max} \tag{3}$$

Figure 1. N$_{gen}$ thermal units committed to serve a load of P$_{load}$ (Wood and Wollenberg, 1996)

Figure 1 shows the configuration of multiple load serving generators. This system consists of N thermal generator units connected to one bus bar to serve the received electrical load P$_{load}$.The input for each unit is shown as F_i representing the cost of fuel from the units whose total quantity is :

$$F_{total} = F_1 + F_2 + F_3 + \ldots + F_N = \sum_{i=1}^{N} F_i\,(P_i) \tag{4}$$

$$P_{total} = P_1 + P_2 + P_3 + \ldots + P_N = \sum_{i=1}^{N} F_i\,(P_i) \tag{5}$$

$$\emptyset = 0 = P_{load} - \sum_{i=1}^{N} P_i \tag{6}$$

Generator Input-Output Characteristics

Each generator has its own characteristics in operation. The input-output characteristics of a thermal generator are characteristics that describe the relationship between the input in the form of heat energy demand (MBtu/hour) or fuel (liters/hour) and the output produced by the generator (MW)(Pertiwi, Syahrizal and Siregar, 2018)(Syafii and Monice, no date).
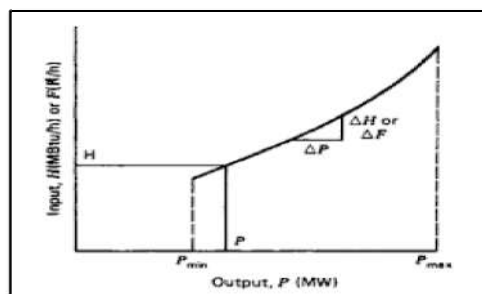

Figure 2. Characteristic curves of the generator input-output

Linear Regression (Least Square)

The linear regression equation is an equation model describes the relationship between one independent variable/predictor (X) and one non variable free/response (Y), which is usually represented by a straight line. Below is a straight line equation namely (Yuliara, 2016).

$$\lambda = aP + b \tag{7}$$

The magnitude of the constants a and b can be determined using equations:

$$a = \frac{n \sum(PF) - \sum P \sum F}{n \sum P^2 - (\sum P)^2} \tag{8}$$

$$b = \frac{(\sum P)^2 \cdot \sum(F) - \sum P \cdot \sum(PF)}{\sum P^2 \cdot n - (\sum P)^2} \tag{9}$$

The above formula can be converted into a 2 × 2 matrix as below:

$$\begin{bmatrix} N & \sum P_i \\ \sum P_i & \sum P_i^2 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum F_i \\ \sum P_i F_i \end{bmatrix}$$

Where:

F = Put in fuel ($/h)
P = Power output (MW)
a, b = linear line constants
n = The amount of data

Equal Incremental Cost Method

The unit cost of additional fuel (Equal Incremental Cost) of a unit for each output is the limit on the ratio of the increase in fuel input cost in dollars per hour to the corresponding increase in power output in MW as the increase in power output approaches zero. Mathematically, Equal Incremental Cost can be calculated using the following equation:

$$EqualIncrementalCost = \frac{dF_i}{dP_i} \tag{10}$$

Where:

F_i = Input to unit i ($/h)
P_i = Unit output i (MW)

Research Methods

The stages carried out in this research are literature study or literature review, study guidance, data collection and processing, and calculation simulation with Matlab and Microsoft Excel. Below is a picture of a flow chart for calculating the Equal Incremental Cost method with the Linear Regression approach to obtain the minimum generation cost.
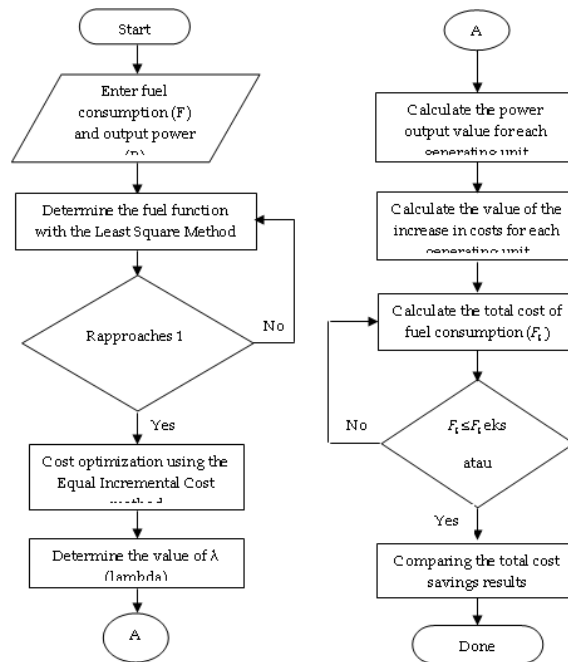

Figure 3. Flowchart of Calculation of the Equal Incremental Cost Method

Results and Discussion

Operational Data of Pangkalan Susu PLTU

Table 1. Unit Calculation Data 1

Power (MW)	Fuel Flow (ton/hour)	Cost (Rp)	Cost ($)
45.00	39.10	42,658,100	3,047.01
70.70	49.80	54,331,800	3,880.84
91.50	64.70	70,587,700	5,041.98
134.00	77.00	84,007,000	6,000.50
116.90	86.80	94,698,800	6,764.20

Table 2. Unit Calculation Data 2

Power (MW)	Fuel Flow (ton/hour)	Cost (Rp)	Cost ($)
45.20	40.70	44,403,700	3,171.69
63.90	45.20	49,313,200	3,522.37
91.80	62.70	68,405,700	4,886.12
124.00	80.00	87,280,000	6,234.29
165.00	100.00	109,100,000	7,792.86

Table 3. Electricity load data for the Pangkalan Susu PLTU

Hour	Unit 1	Unit 2	Cost ($/h)
00 : 00	126	151	13,676.616
01 : 00	127	142	13,348.237
02 : 00	127	140	13,265.617
03 : 00	127	147	13,555.347
04 : 00	127	150	13,679.997
05 : 00	127	149	13,638.415
06 : 00	128	148	13,641.928
07 : 00	129	146	13,604.055
08 : 00	129	148	13,687.059
09 : 00	130	148	13,732.258
10 : 00	116	148	13,105.660
11 : 00	127	147	13,555.347
12 : 00	121	146	13,244.911
13 : 00	122	144	13,206.690
14 : 00	119	146	13,155.805
15 : 00	117	146	13,066.971
16 : 00	123	147	13,375.775
17 : 00	124	148	13,462.084
18 : 00	124	146	13,379.080
19 : 00	123	146	13,334.289
20 : 00	120	145	13,158.870
21 : 00	120	144	13,117.448
22 : 00	120	145	13,158.870
23 : 00	122	147	13,331.052

Modeling Generating Units with Linear Regression (Least Square)

This generating unit modeling aims to determine the input-output characteristic equation of a generating unit. Calculate the equation of the input-output characteristics of each generating unit with simulation matlab. The equation of the input-output characteristics of the unit one generator is obtained.

$$\frac{dF_1}{dP_1} = 42.5P_1 + 1,052.1$$

And the equation for the input-output characteristic of the unit two generator is:

$$\frac{dF_2}{dP_2} = 40.1P_2 + 1,194.9$$

Optimization Using Equal Incremental Cost Method

Optimization of costs when the load is 277 MW

$$\lambda = \frac{(P_T a_1 a_2) + (a_2 b_1) + (a_1 b_2)}{a_2 + a_1}$$

$$= \frac{(277 \times 42.5 \times 40.1) + (40.1 \times 1,052.1) + (42.5 \times 1.194,9)}{40.1 + 42.5}$$

$$= \frac{472077.25 + 42189.21 + 50783.25}{82.6}$$

= 6,840.795

The power in each generating unit is:

$P_1 = \dfrac{\lambda - b_1}{a_1}$

$= \dfrac{6840.795 - 1{,}052.1}{42.5}$

= 136.205 MW

$P_2 = \dfrac{\lambda - b_2}{a_2}$

$= \dfrac{6840.795 - 1194.9}{40.1}$

= 140.795 MW

Obtained per unit cost viz:

$F_1 = a_1 P_1 + b_1$

= 42.5(136.205) + 1,052.1

= $ 6,840.812

$F_2 = a_2 P_2 + b_2$

= 40.1(140.795) + 1,194.9

= $ 6,840.779

$F_t = F_1 + F_2 =$ 6,840.812 + 6,840.779 = $ 13,681.591

For the next load optimization is done with the same calculation. The results of optimization calculations using the Equal Incremental Cost method using the Linear Regression approach can be seen in Table 4.

Table 4. Optimization Results with Equal Incremental Cost Method

Hour	P_1(MW)	P_2(MW)	$P_T = P_1 + P_2$	Cost ($/h)
00 : 00	136.205	140.795	277	13,681.591
01 : 00	132.321	136.679	269	13,351.469
02 : 00	131.350	135.650	267	13,268.94
03 : 00	134.749	139.251	274	13,557.797
04 : 00	136.205	140.795	277	13,681.591
05 : 00	135.720	140.280	276	13,640.328
06 : 00	135.720	140.280	276	13,640.328
07 : 00	135.234	139.766	275	13,599.061
08 : 00	136.205	140.795	277	13,681.591
09 : 00	136.691	141.309	278	13,722.857
10 : 00	129.894	134.106	264	13,145.145
11 : 00	134.749	139.251	274	13,557.797
12 : 00	131.350	135.650	267	13,268.94
13 : 00	130.865	135.135	266	13,227.675
14 : 00	130.379	134.621	265	13,186.409
15 : 00	129.408	133,592	263	13,103.879
16 : 00	132.807	137.193	270	13,392.736
17 : 00	133.778	138.222	272	13,475.267
18 : 00	132.807	137.193	270	13,392.736
19 : 00	132.321	136.679	269	13,351.469
20 : 00	130.379	134.621	265	13,186.409
21 : 00	129.894	134.106	264	13,145.145
22 : 00	130.379	134.621	265	13,186.409
23 : 00	132.321	136.679	269	13,351.469

Comparison of Optimization Results and Discussion

Table 5. Comparison of the cost of optimization results between the Equal Incremental Cost method and the actual costs in the field

Hour	$P_T = P_1 + P_2$	True Cost ($/h)	IEC Method ($/h)	Saving ($/h)
00 : 00	277	13,676.616	13,681.591	-4.975
01 : 00	269	13,348.237	13,351.469	-3.232
02 : 00	267	13,265.617	13,268.94	-3.323
03 : 00	274	13,555.347	13,557.797	-2.450
04 : 00	277	13,679.997	13,681.591	-1.594
05 : 00	276	13,638.415	13,640.328	-1.913
06 : 00	276	13,641.928	13,640.328	1.600
07 : 00	275	13,604.055	13,599.061	4.994
08 : 00	277	13,687.059	13,681.591	5.468
09 : 00	278	13,732.258	13,722.857	9.401
10 : 00	264	13,105.660	13,145.145	-39.485

11 : 00	274	13,555.347	13,557.797	-2.450
12 : 00	267	13,244.911	13,268.94	-24.029
13 : 00	266	13,206.690	13,227.675	-20.985
14 : 00	265	13,155.805	13,186.409	-30.604
15 : 00	263	13,066.971	13,103.879	-36.908
16 : 00	270	13,375.775	13,392.736	-16.961
17 : 00	272	13,462.084	13,475.267	-13.183
18 : 00	270	13,379.080	13,392.736	-13.656
19 : 00	269	13,334.289	13,351.469	-17.180
20 : 00	265	13,158.870	13,186.409	-27.539
21 : 00	264	13,117.448	13,145.145	-27.697
22 : 00	265	13,158.870	13,186.409	-27.539
23 : 00	269	13,331.052	13,351.469	-20.417
Total	6489	321,482.381	321,797.038	-314.657
Average	270.375	13,395.099	13,408.209	-13.111

The following is a graphic image of the comparison of the input cost of fuel ($ / h) and the output of power produced by the generator (MW).
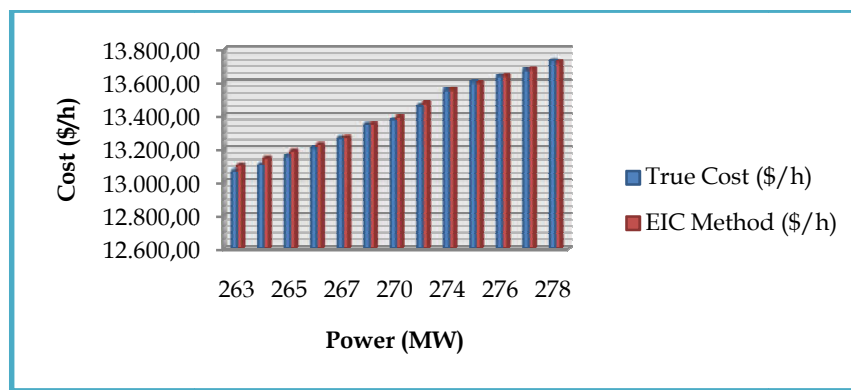

Figure 3. Graph of comparison of fuel costs and generation load before and after optimization

Figure 3 above is a graph of the comparison of the input fuel costs ($ / h) and the power output generated by the generator (MW) between the actual costs in the field. This figure shows that the fuel costs from the optimization using the Equal Incremental cost method are greater than the actual costs incurred by generators in the field. Comparison of fuel costs ($ / h) between actual costs in the field and optimization costs using the Equal Incremental cost method for more details, can be seen in the following Figure 4.
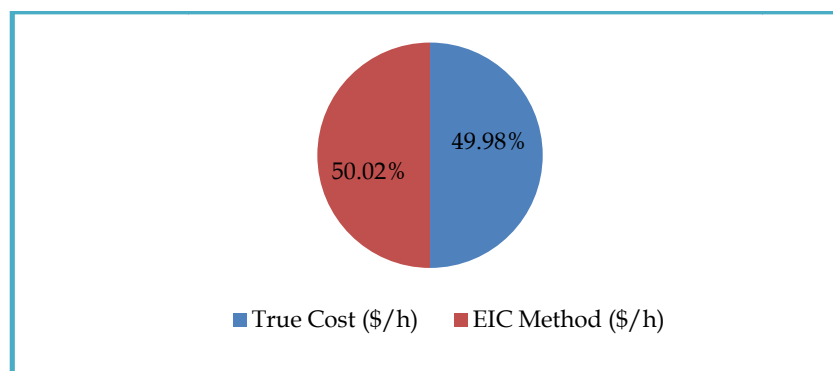

Figure 4. Graph of comparison of fuel costs in percent

The percentage of this fuel cost is obtained from the quotient between the total cost of the incremental cost method and the actual cost in the field with the total cost of the incremental cost method and the actual cost in the field and then multiplied by 100%.The savings obtained using the Equal Incremental Cost method is -0.033% ($ / h). This minus value is obtained from the reduction in actual fuel costs in the field, which is cheaper than the optimization result of the Equal Incremental Cost method.

Conclusions

From the results of the analysis and discussion carried out, the following conclusions can be drawn:

1. The equation for the input output characteristics of PLTU Pangkalan Susu with the Linear Regression equation approach at generator unit 1, namely $\frac{dF_1}{dP_1}$ = 42.5P_1 + 1,052.1and on generating units 2, namely $\frac{dF_2}{dP_2}$ = 40.1P_2 + 1,194.9

2. The results of calculations using the Equal Incremental Cost method with the Linear Regression approach when the maximum load is 278 MW is 13,722.857 \$/h and when the minimum load is 263 MW is 13,103.879 \$/h.

3. The results of calculations using the Equal Incremental Cost method using the Linear Regression (Least Square) approach obtained a cost of -0.033% or an average of -13.111 \$ / h when compared to the value of existence in the field.

4. The optimization calculation using the Equal Incremental Cost method with the Linear Regression approach is not feasible to be applied at PLTU Pangkalan Susu because the actual costs in the field are cheaper when compared to the results of optimization calculations.

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