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Analysis of Input-Output Characteristic and Generation Cost Optimization Using Quadratic Least Square Regression and Dynamic Genetic Algorithm Method: Case study PT.PLN PJB UP Gresik

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Abstract. . For optimization of electricity production, especially in the thermal power plant required analysis of input-output characteristics and operated optimally. Input-output characteristics will oversee the curve and detected the plant need for maintenance or not. Input-output characteristics can be calculated by quadratic least squares regression method. Operated load properly, making electricity production corresponding maximum desired load with lowest cost. Load calculations performed by dynamic genetic algorithm method. This method is applied to data from PT. Pembangkit Jawa Bali (PJB) Unit Pembangkit Gresik in July 2015 has saving 3.162,9147 kNm^3 (kilo Normal cubic meters) fuel consumption and \$22,773 fuel costs compared PJB. While applied to data December 2012 has saving 16.532,2189 liters fuel consumption and \$84,654.79 fuel costs compared PT. PJB.

INTRODUCTION

Concomitant use of thermal power plants continuously in the generation of electrical energy, causing its performance to change. To determine changes in a plant's performance, it is used input-output characteristic curve. Input-output curve will show the relationship between the fuel and the power generated by the plant. There are several ways to calculate the input-output characteristics, such as Lagrange method and Gauss Jordan method. Previous research explains that the method of Lagrange, has the disadvantage of the lack of precision accuracy. While, the Gauss Jordan method can only be applied to certain data, because in essence, this method requires that the data be used as the reduced echelon matrix that cannot be applied to all data. From this problem, quadratic least square regression method can be applied to enhance the two previous methods, because this method can provide more precise results and a simple regression operation that can be applied to all data. The least squares method states that "the sum of squared difference of the actual value with the calculated value, multiplied by the number of measurements is the minimum". The least squares method is a system parameter estimation method that minimizes the sum of squares error criterion function prediction [1]. The results of these calculations, would yield curve equation used to be made to see the performance of a plant and curves also can be used as a parameter to determine the repair or maintenance at the plant, both regular repair and overhaul.

In addition, performance of plants must be controlled at all times, the selection of plant operation also requires. This is done in order to obtain a large power generation with the most minimal cost. The setting operation of the plant selection can be done using economic dispatch. Many methods can be used to resolve the economic dispatch problems, one of them is using genetic algorithms method[2-8]. However, in a paper entitled Evolution of Appropriate, Crossover and Mutation in a Genetic Process Operator stated that this method can only do one crossover and mutation to get a new generation. So that the results obtained become less detail. Weakness in the

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genetic algorithm is enhanced by adding the solution matches the number of the ratio calculation every time makes a cross and mutation to get more detail and precision. Refinement of the genetic algorithm method with more than one mutation is called dynamic genetic algorithm method[7]. By using this dynamic genetic algorithm method is expected to provide the best solution for the settlement of economic dispatch.

INPUT-OUTPUT CHARACTERISTICS AND ECONOMIC DISPATCH

The research process on the characteristics of input-output analysis and optimization of generation costs using dynamic genetic algorithm method implemented in PT. PLN PJB UP Gresik. The capacity owned PLTU Gresik are 600MW comprising four units with details are 100 MW Unit 1, Unit 2 of 100 MW, 200 MW of Unit 3 and Unit 4 of 200 MW.

PT. PJB UP Gresik has a thermal generating units at PLTU that is still operating normally today is PLTU 1 with capacity of 100 MW, PLTU 2 with a capacity of 100 MW, PLTU 3 with a capacity of 200 MW and PLTU 4 with a capacity of 200 MW. Each PLTU has a production loading which is different in a day. For PLTU 1 and PLTU 2, minimum production ranges from 45 MW and 85 MW as the highest. While the PLTU 3 and PLTU 4, has minimum production ranges from 108 MW and 185 MW as the highest. The analysis is divided into two groups, analysis generating with gas fuel period and liquid fuel period.

Quadratic Least Square Regression

Quadratic least square regression method is used to perform regression or curve fitting on the problem on input-output characteristics of thermal power plant which is expected to form a specific mathematical equation[1]. Input-output characteristics of the thermal power plant is a second order function of polynomial, so use the following equation:

$$y = ax^2 + bx + c \tag{i}$$

a. Coefficients (a, b, and c)

$$a = \frac{\left\{\left[\sum\left(x^2 y\right).\sum\left(x^2\right) - \sum\left(xy\right).\sum\left(x^3\right)\right]\right\}}{\left[\sum\left(x^2\right).\sum\left(x^4\right) - \left[\sum\left(x^3\right)\right]^2\right]} \tag{ii}$$

$$b = \frac{\left\{\left[\sum\left(xy\right).\sum\left(x^4\right) - \sum\left(x^2 y\right).\sum\left(x^3\right)\right]\right\}}{\left[\sum\left(x^2\right).\sum\left(x^4\right) - \left[\sum\left(x^3\right)\right]^2\right]} \tag{iii}$$

$$c = \left[\frac{\sum\left(y_i\right)}{n}\right] - \left\{b.\left[\frac{\sum\left(x_i\right)}{n}\right]\right\} - \left\{a.\left[\frac{\sum\left(x_i^2\right)}{n}\right]\right\} \tag{iv}$$

b. Squares Regression Statistics Equations

$$\sum x^2 = \sum\left(x_i^2\right) - \left[\frac{\left(\sum x_i\right)^2}{n}\right] \tag{v}$$

$$\sum x^3 = \sum x_i^3 - \left[\frac{\left(\sum x_i . \sum x_i^2\right)}{n}\right] \tag{vi}$$

$$\sum x^2 y = \sum\left(x_i^2 y_i\right) - \left[\frac{\left(\sum x_i^2 . \sum y_i\right)}{n}\right] \tag{vii}$$

$$\sum x^4 = \sum x_i^4 - \left[\frac{\left(\sum x_i^2\right)^2}{n} \right] \quad \text{(viii)}$$

where

yi = the individual scores for each combination of variables
xi = the individual scores for each combination of variables
n = number of data

Dynamic Genetic Algorithm

Dynamic genetic algorithm method (DGA) is used as an approximation method algorithm is applied to solve the problem of economic dispatch optimization or generation costs as a new and better solutions.

This method is operated with data resulting from the calculation and analysis of input-output characteristics were calculated by quadratic least squares regression method. After entering the data of input-output characteristic in a series of dynamic genetic algorithm method, it's expected to generate an output value are power output of each generator, total power, and generation costs are used as a solution to economic problems dispatch or optimal generation cost optimization. The steps of the method of dynamic genetic algorithm, namely:

1. Create a set of initial population of N individuals to evolution by inputting coefficient value of input output characteristics (a, b, c), Pmin and Pmax
2. Evaluate the fitness value. At this steps, the range between the value of Pmin to Pmax will be included in the equation of input and output characteristics. Good fitness values represented in the value of fuel consumption is minimal.
3. Establish the ratio of the initial crossover and mutation. At this steps it will be determined the value of n, Pc and Pm. n is a matrix formed from inputs a, b, c, Pmin and Pmax. Pc value is 0,9 and Pm value is 0.1.
4. Form mating set. Sample bred parents who will be drawn at random from individual fitness evaluation in step 2. Parents are drawn at random from the range Pmin and Pmax.
5. Apply the crossover operator to produce offspring. From parents who have been out of step 4, then this samples randomly crossed to produce new offspring. Crossover do by converting Pmin and Pmax into binary numbers and then be random by the program.
6. Evaluate the fitness value of each individual generated by each operator crossover. This evaluation will also remove values that are not in the set of rules Pmin to Pmax.
7. Adjust the crossover ratio by the average value of the progress obtained. At this steps, there is a ranking program to sort the descent with the best fitness value.
8. Apply the mutation operator to produce offspring. At this steps, the program will insert random binary on the descent that has a value closer to solution.
9. Evaluate the fitness value of each individual is generated by mutation carriers. This evaluation will also remove values that are not in the set of rules Pmin to Pmax.
10. Adjust the crossover ratio by the average value obtained progress. At this steps, there is a ranking program to sort the descent with the best fitness value
11. Obtained a new population (solution). The solution obtained is not necessarily as the best solution. If not good, it will be the return process starting from step 4. Parameters used both when an individual is the best with the fitness value (the value of the lowest fuel consumption).

RESULTS AND ANALYSIS

Input-Output Characteristics Analysis of Gas Period

Periods of fuel gas started from January 2013 until the year 2016. The fuel used is natural gas extracted from drilling directly without any further processing. This fuel has a unit kNm^3 with a price of \$7.2 / kNm^3. Analysis of input-output characteristics in gas period is used sample data in May until July 2015. The data were obtained from PT. PJB UP Gresik is the daily data, so the data is sampled and retrieved some data by load variations. Snapshot data is shown in **TABLE 1**. From the data table 1, these data are used as input to quadratic least square regression method combined with a Graphical User Interface (GUI) to obtain input-output characteristics. From the calculations, the plants constants obtained in **TABLE 2**.

TABLE 1. Correlation of Power and Fuel PJB

PLTU 1		PLTU 2		PLTU 3		PLTU 4	
Power	**Gas Flow**	**Power**	**Gas Flow**	**Power**	**Gas Flow**	**Power**	**Gas Flow**
45	12,23	42	12,10	105	22,62	80	21,20
46	12,65	44	12,25	106	22,79	90	23,00
61	16,21	45	12,32	107	23,01	102	24,90
66	17,31	46	12,67	108	23,20	107	25,20
67	17,46	65	16,61	134	28,05	108	25,40
78	20,33	67	17,09	141	28,58	110	26,50
79	20,56	84	20,84	160	32,98	160	38,00
80	21,07	85	21,64	169	39,08	170	39,33
81	22,41			170	35,68	175	39,90
84	23,34						
85	23,89						

TABLE 2. Constants of Input-Output Characteristics PLTU PT PJB Gresik

Plants	Constants of Plants		
	a	**b**	**c**
PLTU 1	0,0028	-0,0855	106,793
PLTU 2	0,0016	0,0312	78,453
PLTU 3	0,0018	-0,2645	310,498
PLTU 4	0,0004	0,0910	108,872

From the constants obtained from the plants, it will be set up the input-output characteristic curve to determine the relationship of power and fuel in power plants. These curves can be used as an indicator to see the performance of a plant. Figure 1 (a) is an input-output characteristic curve of PLTU 1. In this curve is seen that the greater the fuel is used, the power generated is also getting bigger or relationships of power and fuel directly proportional. it means that PLTU 1 is still in good condition, this is reinforced by reports of PT. PJB UP Gresik stating that PLTU 1 did the last overhaul on April 30, 2016 to May 20, 2016 for 30 days.

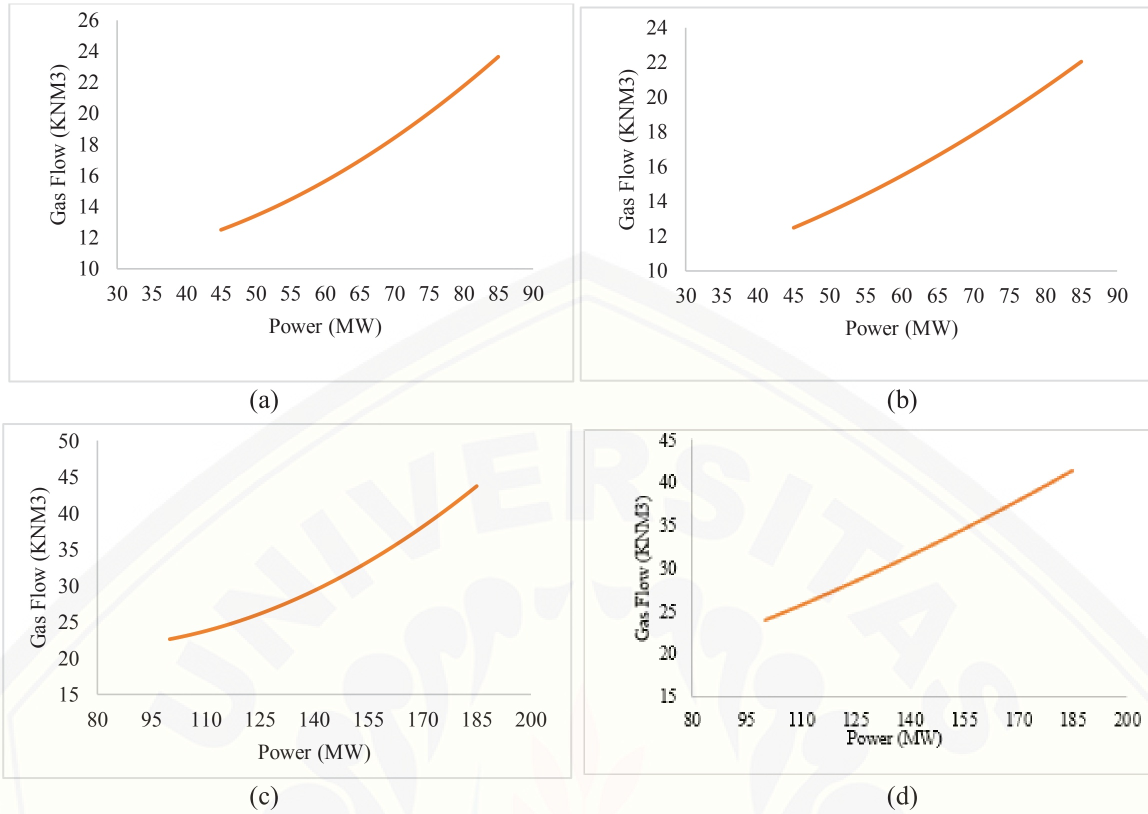

FIGURE 1. Input-Output Characteristics Curve of (a) PLTU 1, (b) PLTU 2, (c) PLTU 3, and (d) PLTU 4

Figure 1(b) is an input-output characteristic curve of the power plant 2. With the same characteristics as the power plant 1, the curve formed by the power plant 2 is not much different. Judging from the curve formed, it can be concluded that PLTU 2 is still operating properly. This is reinforced by the fact that the PLTU 2 did the last overhaul on May 16, 2015 until June 22, 2015 for 45 days. Figure 1(c) is an input-output characteristic curve of PLTU 3. Just as like PLTU 1, the power curve and fuel is directly proportional to the mean that will produce great power with great fuel contribution anyway. The shift experienced by PLTU 3 is not significant and still in reasonable limits because it has just carried out an overhaul on November 22, 2016 to January 5, 2016. Figure 1(d) is an input-output characteristic curve for PLTU 4. Similar to PLTU 3, PLTU 4 is loaded operating expenses charged higher than PLTU 1 and PLTU 2. The minimum loaded that is charged by PLTU 4 around 108 MW with a maximum load of 185 MW. PLTU 4 lasted overhaul on August 27, 2015 to October 9, 2015, and from the curve formed can be analysed that PLTU 4 still operating properly as there was no deviation curve occurred.

Imposition Period Gas

The data used is data loading July 2015. The results of the calculation of the loading method of dynamic genetic algorithm and comparison with PJB UP Gresik shown in **TABLE 3**.

TABLE 3. Imposition Generating Unit

Date	PJB's Imposition				DGA's Imposition				Load
	Plants				Plants				
	#1	#2	#3	#4	#1	#2	#3	#4	
1	45	45	108	107	45	45	115	100	305
2	45	45	108	107	45	45	115	100	305
3	46	85	108	107	48,9	49,2	125,9	122	346
4	45	45	108	107	45	45	115	100	305
5	45	45	108	107	45	45	115	100	305
6	45	45	108	107	45	45	115	100	305
7	85	85	108	107	52,4	55,2	131,2	146,2	385
8	85	85	108	107	52,4	55,2	131,2	146,2	385
9	45	45	108	107	45	45	115	100	305
10	45	45	108	107	45	45	115	100	305
11	45	45	105	102	45	45	107	100	297
12	45	45	170	175	56,8	63	138,1	177,1	435
13	45	45	170	175	56,8	63	138,1	177,1	435
14	45	45	108	90	45	45	108	90	288
15	45	45	108	107	45	45	115	100	305
16	45	45	160	160	54,6	59,1	134,7	161,6	410
17	85	85	108	107	52,4	55,2	131,2	146,2	385
18	45	45	108	175	51,3	53,4	129,6	138,7	373
19	45	45	160	160	54,6	59,1	134,7	161,6	410
20	45	45	108	107	45	45	115	100	305
21	85	85	108	107	52,4	55,2	131,2	146,2	385
22	45	45	108	107	45	45	115	100	305
23	45	45	0	175	45	45	117,2	57,8	265
24	45	46	107	107	45	45	115	100	305
25	45	45	108	107	45	45	115	100	305
26	45	45	160	160	54,6	59,1	134,7	161,6	410
27	45	46	169	160	55,5	60,7	136	167,8	420
28	45	45	170	175	56,8	63	138,1	177,1	435
29	45	45	0	107	45	45	46,3	60,7	197
30	45	45	0	107	45	45	46,3	60,7	197
31	46	85	0	107	45	45	74,8	73,2	238

Analysis of Fuel Consumption

From Figure 2, the loading obtained in previous calculations, calculated fuel consumption used in each plant. From Figure 2, it can be seen that the PLTU 1, PLTU 2, PLTU 3 has cheaper fuel consumption by using dynamic genetic algorithm method while for PLTU 4 is cheaper PJB. However, in overall, dynamic genetic algorithm methods can save 3162.9147 kNm^3 than PT. PJB UP Gresik.

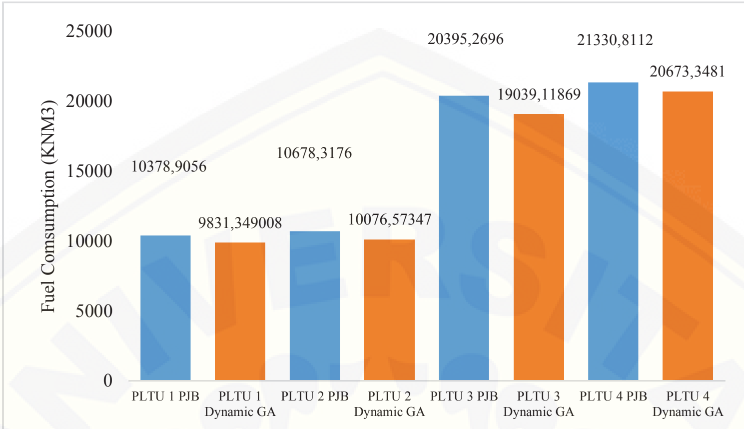

FIGURE 2. Fuel Consumption Comparison between PT PJB and Dynamic GA Method

CONCLUTION

In this paper, a new strategy of input-output characteristics analysis and electricity production optimization recommended. Input-output characteristics of the gas is still a good period, while the period of liquid, one power plant still has a good performance, while the second power plant has undergone a shift. In the period of gas, the fuel consumption savings 3162.9147 kNm^3 and fuel costs saved $22,773 compared to CHD, while in the period liquid, fuel consumption can be saved 16532.2189 liters and fuel costs saved $84,654.79 compared PT. PJB.

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