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Optimal operation scheme for diesel power plant units of PT. PLN-Manokwari Branch using Lagrange Multiplier Method

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Abstract

Economic dispatch has been used in many power plants to optimize the plants operation. As one of method in economic dispatch, Lagrange multiplier method was utilized for calculating the economic operation in power system of PT. PLN-Manokwari branch which is the electrical company working in area of Manokwari. This power system includes nine units and the other rental units of diesel power plant. Based on some schemes which had been designed and calculated with Lagrange multiplier method, the most economic unit refers to diesel power plant unit P_1 with prime mover DEUTZ BV8M 628 while diesel power plant unit P_6 with prime mover MITSUBISHI S12 R-PTA is indicated as the least economic unit at the system. The system shows existence of good efficiency when working for schemes 3500 to 6000 kW and for schemes above 6000 kW, the operating expenses are increasing significantly in the consequence of operating of the low efficient units. Result of calculation using average daily generating power shows that this power system will be very optimal using economic dispatch.

Keywords: Economic dispatch; Lagrange; diesel power plant;

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1. Introduction

Development of energy sources to obtain the other activity is the important key to increase the continual life level for people, anywhere they reside in. The biggest challenges, which are faced by the world today, are how to provide energy wherever it is needed, how to alter the energy to the other form and how to use it without producing any pollution.

Diesel power plant (DPP) is a type of power plant that converts fossil fuel to be electrical energy. The best efficiency of a conversion machine is about 80% but mostly it will be laid in between 40-60% [12]; therefore the conversion process in DPP may not over 80% of the efficiency and it will deliver some pollutants as the effect of the process. According to high mobility and simple to be installed, the DPP is somewhat the best chosen to be used in remote area. The disadvantage of the DPP is high operation cost for both fuel and maintenance. By operating the DPP in economic operation, the DPP will become optimal in producing energy and then the pollutants can be reduced.

The factors influencing power-generation at minimum cost are operating efficiencies of generators, fuel cost, and transmission losses. The most efficient generator in the system does not guarantee minimum cost as it may be located in an area where cost to get the fuel is high. In the same way, transmission losses may be considerable higher and then the plant may be overly un-economical, if the plant is located far from the load center. Hence, the problem is to determine the generation of different plants such that the total operating cost is minimum [10].

PT. PLN-Manokwari branch is an Indonesian government company that handles electrical energy productions in the area of Manokwari, which is the capital city of West Papua Province, Indonesia. In the effort to increase efficiency and to reduce the generation cost, the company will operate high efficient machine and continue to middle and to low efficient machines together with increasing of the load. Even without taking the power transmission loss into account, this effort is failed to reduce production cost [9].

Many researches had been done to optimize power generation units in different way [1-8], but most of the researches refer to the basic economic dispatch formulation. This paper will explain and simulate economic dispatch for all machines of PT. PLN- Manokwari branch in some schemes by ignoring transmission losses.

Nomenclature

i	number of unit
a,b	the coefficient of the cost input of the i-th generator
c	equivalent to fuel consumption of the generating unit operation without power output
n	total number of units in the system
F_i	fuel cost function of the units
P_i	generation of unit i
P_R	total system load
$Pmin,_i$	lower limit of the unit i
$Pmax,_i$	upper limit of the unit i
L	Lagrange function
λ	the Lagrange multiplier.

2. Economic Dispatch

The definition of economic dispatch (ED) is given by Kumar *et. al* (2008) as the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities. In traditional economic dispatch, the operating cost is reduced by proper allocation of the amount of power to be generated by different generating units. However, the optimum economic dispatch may not be the best interms of the environmental criteria. Recently many countries throughout the world have concentrated on the reduction of the amount of pollutants from fossil fuel power generating units [8].

The ED problem is how to minimize a total generation cost of power system for a given demand load with satisfy various constraints including power balance constraint and generation power limits of each unit. While the load has been variated, the output of generators has to balance the load variation. The fundamental of the ED problem is the set of input-output characteristic of the power generating unit and the ED problem can be expressed as [1-10]:

Minimize

$$F_T = \sum_{i=1}^{n} F_i P_i \tag{1}$$

$$F_i(P_i) = (a_i P_i^2 + b_i P_i + c) \tag{2}$$

Subject to :

$$\sum_{i=1}^{n} P_i = P_R \tag{3}$$

$$P\min_i \le P_i \le P\max_i \tag{4}$$

3. Lagrange Multiplier Method

The fundamental components in ED are planning for future dispatch and dispatching the power system today. Generally target function of ED can be investigated by Lagrange multiplier method, first or second order gradient method, and lambda iteration but these methods may encounter some difficulties for complex generation cost functions [3]. Lagrange formulation can be rewritten as [9-11]:

$$L = F_T + \lambda\phi = \sum_{i=1}^{n} F_i P_i + \lambda(P_R - \sum_{i=1}^{n} P_i) \tag{5}$$

The function of output generating power is assumed that optimal condition is reached if gradient operation equal to zero. In other word, the first derivative of the Lagrange function L with respect to each of the independent variables has to be set equal to zero as follows.

$$\nabla L = \nabla F_T + \nabla \lambda \phi = 0 \tag{6}$$

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_T}{\partial P_i} + \lambda \left(\frac{\partial P_R}{\partial P_i} - \frac{\partial P_i}{\partial P_i} \right) = 0 \tag{7}$$

By solving 7th equation, we get :

$$\frac{\partial F_i}{\partial P_i} + \lambda(0-1) = 0 \Rightarrow \frac{\partial F_i}{\partial P_i} = \lambda \tag{8}$$

Eq. 8 shows that optimum condition can be reached if the incremental of each power generation connected to the system is equal. This condition should respect to the constraint defined in eq. 4

4. Discussion

4.1. Defining fuel cost function

PT. PLN-Manokwari branch has operated nine diesel power plant units to produce maximum electrical energy about 7610 kW. The power plant units of are operated in same location and directly connected to the grid system. The specification of each machine is provided in table 1.

Table 1. Machine specifications

Machine number	Type of machine	Serie	Output power, kW	
			maximum	minimum
P_1	DEUTZ	BV8M 628	950	180
P_2	DEUTZ	BV8M 628	1100	180
P_3	MAN	6L 26/32 H	900	150
P_4	MAN	6L 26/32 H	900	150
P_5	DAIHATSU	6DL - 28	1000	180
P_6	MITSUBISHI	S12 R -PTA	800	150
P_7	MITSUBISHI	S12 H -PTA	600	120
P_8	MITSUBISHI	S16 R -PTA	900	150
P_9	KOMATSU	SAA 6D 170-P800	460	75

Data of power output in kWh and fuel cost for every machine unit had been used for defining the fuel cost characteristic of the machines using second polinomial function as shown in figure 1.

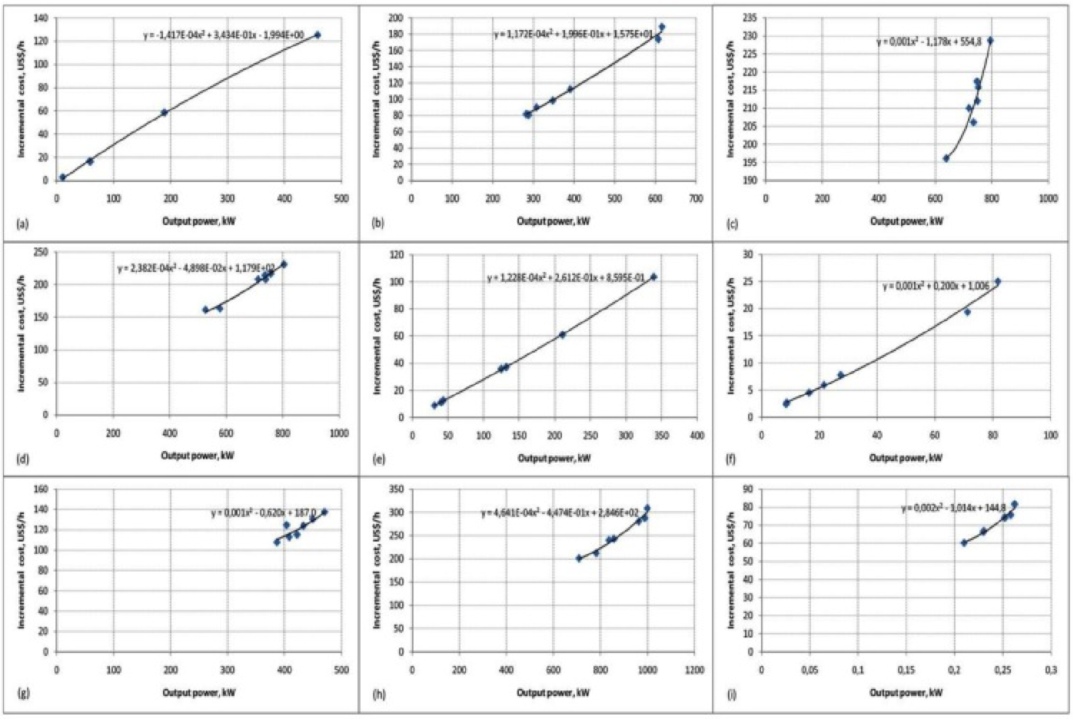

Fig. 1.(a) to (i) Curve of machine unit P_1 to P_9

The lines in fig. 1 (a) to (i) are given by quadratic polinomial function to connect each data point of machine unit P_1 to P_9. All of the fuel cost curves on the figure are non linear curves but the curve for machine 5 (fig. 1.e) seems to be linear curve. The fuel cost functions for each machine unit appear on the figure as *Y* and *X* variables. The functions can be rewritten by substituting both variables with F_i and P_i as shown in eq. 9.

$$
\begin{aligned}
&F_1 = -1.42e^{-4}P_1^2+0.343P_1-1.994; && for\ 180 \le P_1 \le 950\\
&F_2 = 1.17e^{-4}P_2^2+0.200P_2+15.800; && for\ 180 \le P_2 \le 1100\\
&F_3 = 0.001P_3^2-1.178P_3+554.8; && for\ 150 \le P_3 \le 900\\
&F_4 = 2.38e^{-4}P_4^2-4.90e^{-2}P_4+118; && for\ 150 \le P_4 \le 900\\
&F_5 = 1.23e^{-4}P_5^2+0.261P_5+0.860; && for\ 180 \le P_5 \le 1000\\
&F_6 = 0.001P_6^2+0.2P_6+1.006; && for\ 150 \le P_6 \le 800\\
&F_7 = 0.001P_7^2-0.62P_7+187; && for\ 120 \le P_7 \le 600\\
&F_8 = 4.64e^{-4}P_8^2-0.447P_8+285; && for\ 150 \le P_8 \le 900\\
&F_9 = 0.002P_9^2-1.014P_9+144.8; && for\ \ 75 \le P_9 \le 460
\end{aligned}
\qquad (9)
$$

4.2. Applying economic dispatch

Lambda λ for each generation unit can be defined by solving derivative function of the machine fuel cost equations in eq. 9 as follows.

$$
\begin{aligned}
\lambda &= -0.000283P_1 + 0.3434 &\Rightarrow\quad P_1 &= -3528.58\lambda + 1211.72\\
\lambda &= 0.0002344P_2 + 0.1996 &\Rightarrow\quad P_2 &= 4266.21\lambda - 851.54\\
\lambda &= 0.002P_3 + 1.178 &\Rightarrow\quad P_3 &= 500\lambda + 58\\
\lambda &= 0.0004764P_4 - 0.04898 &\Rightarrow\quad P_4 &= 2099.08\lambda + 102.81\\
\lambda &= 0.0002456P_5 + 0.2612 &\Rightarrow\quad P_5 &= 4071.66\lambda - 1063.52\\
\lambda &= 0.002P_6 + 0.2 &\Rightarrow\quad P_6 &= 500\lambda - 100\\
\lambda &= 0.002P_7 - 0.62 &\Rightarrow\quad P_7 &= 500\lambda + 310\\
\lambda &= 0.0009282P_8 - 0.4474 &\Rightarrow\quad P_8 &= 1077.35\lambda + 482.01\\
\lambda &= 0.004P_9 - 1.014 &\Rightarrow\quad P_9 &= 250\lambda + 253.5
\end{aligned}
\tag{10}
$$

The first derivative equation of each unit in eq. 10 can now be used to determine total lambda by refering to eq. 3 as follows.

$$P_R = \sum_{i=1}^{9} P_i = 9735.72\lambda + 933.98 \tag{11}$$

By solving lambda for P_R about 3500 kW, lambda λ in eq. 11 is found about 0.2636. For the other generating schemes, lambda can be solve in same way as rewriten in table 2 and 3.

Table 2. Generating power for fulfilling demand power

Demand power, kW	λ	Output power of diesel power plant units, kW								
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
3500	0.2636	950.00	180.00	623.19	246.35	180.00	150.00	344.19	555.68	270.59
3750	0.2892	308.06	241.03	717.05	640.38	180.00	150.00	438.05	757.92	317.52
4000	0.3149	180.00	426.57	738.79	731.67	180.00	150.00	459.79	804.77	328.40
4250	0.3406	180.00	518.05	749.52	776.68	243.61	150.00	470.52	827.87	333.76
4500	0.3663	180.00	601.61	759.31	817.79	323.36	150.00	480.31	848.97	338.65
4750	0.3920	180.00	685.16	769.10	858.91	403.10	150.00	490.10	870.07	343.55
5000	0.4176	180.00	768.73	778.89	900.00	482.86	150.00	499.89	891.18	348.45
5250	0.4433	180.00	876.04	791.47	900.00	585.28	150.00	512.47	900.00	354.74
5500	0.4690	180.00	987.28	804.51	900.00	691.44	150.00	525.51	900.00	361.25
5750	0.4947	180.00	1,098.52	817.55	900.00	797.61	150.00	538.55	900.00	367.77
6000	0.5204	180.00	1,100.00	840.90	900.00	987.76	150.00	561.90	900.00	379.45
6250	0.5460	180.00	1,100.00	900.00	900.00	1,000.00	244.33	600.00	900.00	425.67
6500	0.5717	180.00	1,100.00	900.00	900.00	1,000.00	460.00	600.00	900.00	460.00

Machine unit P_1 is very efficient while it is used in operation schemes that are less than 4000 kW and for schemes more than 4000 kW, this unit tends to work in its lower limit. On the other hand, unit P_6 is started for schemes more than 6000 kW. The other units which are unit P_2, P_3, P_4, P_5, P_7, P_8 and P_9 are occepied from earlier schemes and by increasing the schemes power, then these units will produce more power until each upper limit.

Table 3 shows that unit P_6 is hardly not efficient which is marked with the cost of lambda value. This unit works with cost about 0.5 US$/h at minimum power. This unit is maybe better to be operated at high demand power although the cost of system will increase as its consequence. The other possibility is to deactivate this machine for lower demand power; therefore its load will be generated by the other unit which is more efficient.

Table 3. Fuel cost for increasing demand power

Demand power, kW	λ	Fuel cost of diesel power plant units, US$/h									Total Cost, US$/h
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	
3500	0.2636	0.0742	0.2418	0.0684	0.0684	0.3054	0.5000	0.0684	0.0684	0.0684	1.4633
3750	0.2892	0.2561	0.2561	0.2561	0.2561	0.3054	0.5000	0.2561	0.2561	0.2561	2.5981
4000	0.3149	0.2924	0.2996	0.2996	0.2996	0.3054	0.5000	0.2996	0.2996	0.2996	2.8953
4250	0.3406	0.2924	0.3210	0.3210	0.3210	0.3210	0.5000	0.3210	0.3210	0.3210	3.0396
4500	0.3663	0.2924	0.3406	0.3406	0.3406	0.3406	0.5000	0.3406	0.3406	0.3406	3.1767
4750	0.3920	0.2924	0.3602	0.3602	0.3602	0.3602	0.5000	0.3602	0.3602	0.3602	3.3138
5000	0.4176	0.2924	0.3798	0.3798	0.3798	0.3798	0.5000	0.3798	0.3798	0.3798	3.4509
5250	0.4433	0.2924	0.4049	0.4049	0.3798	0.4049	0.5000	0.4049	0.3880	0.4049	3.5849
5500	0.4690	0.2924	0.4310	0.4310	0.3798	0.4310	0.5000	0.4310	0.3880	0.4310	3.7152
5750	0.4947	0.2924	0.4571	0.4571	0.3798	0.4571	0.5000	0.4571	0.3880	0.4571	3.8456
6000	0.5204	0.2924	0.4574	0.5038	0.3798	0.5038	0.5000	0.5038	0.3880	0.5038	4.0328
6250	0.5460	0.2924	0.4574	0.6220	0.3798	0.5068	0.6887	0.5800	0.3880	0.6887	4.6037
6500	0.5717	0.2924	0.4574	0.6220	0.3798	0.5068	1.1200	0.5800	0.3880	0.8260	5.1724

Compared to the other units in the system of PT. PLN-Manokwari branch, unit P_1 shows high economic function. By working to generate 950 kW, this unit only uses cost 0.0742 US$/h. On the contrary, production cost will increase if the unit is operated to generate low power. In the schemes, it uses 0.2924 US$/h to produce 180 kW. This unit differs with the other system units which tend to apply high fuel cost along with the increasing of power generated.

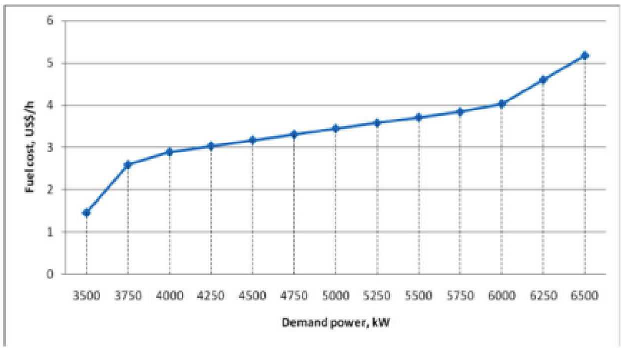

Fig. 2.Fuel cost vs demand power

Based on fig. 2, it can be seen from the designed schemes that there is a proportional relationship between demand power and fuel cost. Together with the growing of demand power, fuel cost will increase. Steep slopes in the begining and ending of the curve show spacing transitions that influence the linearity of the curve. The relationship seems to be linear in between 4000 and 6000 kW of schemes. On the other hand, in lower and upper demand power of the schemes, the curve tends to be non linear.

Fig. 2 also shows that as a whole system would more efficient if it is working for demand power in between 3500 and 6000 kW. While demand power is more than 6000 kW, unit P_6 which is the least efficient unit would perforce to be worked; therefore it will make production cost larger. For demand power under 3500 kW, it is better to deactivate the least economic unit(s) to force unit P_1 as the most economic unit to work in its maximum limit.

4.3. Case study

As the case study, the real of total generating power of the nine DPP machines for May 2012 is given about 1100175 kWh with cost US$ 307167.12. The average daily generation will be 35489.52 kWh with cost US$ 9908.62 and so total system generation for every hour will be 1478.73 kW.

By applying the amount of total system generation about 1478.73 kW and solve the lambda of the system equation in eq. 11, it will give lambda about 0.05595 and total cost 0.5036 US$/h. It means that after working for 24 hours, the machines will produce 35489.52 kWh with cost US$ 12.086. This cost is only 0.122% of the average daily cost and it was significantly reduced from manual operation without ED.

The data for calculation in this case is average data and so the result is not always true. Output power is not always constant and so lambda will increase for peak load and it will increase daily cost. In general, the calculation shows that by using ED, total cost can be reduced and the system will be optimal in operation.

5. Summary

Diesel power plant unit P_1, which is one of the nine diesel power plant units operated by PT. PLN-Manokwari branch, is the most efficient unit. Using prime mover DEUTZ BV8M 628, this unit can produce up to 950 kW with production cost about 0.0742 US$/h. In this unit, production cost tends to increase along with lowering of power production. On the other hand, unit P_6 with prime mover MITSUBISHI S12 R-PTA is unit with high production cost; therefore with economic dispatch, this unit will be forced to work in lower limit. This unit will start to work in effective way for high demand power.

Result of calculation in a case study using average daily generating power of power system of PT. PLN-Manokwari branch in May 2012 shows that by applying economic dispatch for the system, it will produce 35489.52 kWh with cost US$ 12.086. The cost is only 0.122% of US$ 9908.62 which is the cost of daily average operation.

Economic dispatch is not applicable to turn on or off machines in a power system, so that a combination with unit commitment needs to be done in other schemes. By applying the unit commitment, the low efficient generator will be turn on and off in such a way to reduce the production cost.

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