

DATA ARTIKEL ILMIAH

Judul	: Optimal Operation Scheme for Diesel Power Plant Units of PT. PLN-Manokwari Branch using Lagrange Multiplier Method
Penulis	: Adelhard BeniRehiara; SabarSetiawidayat; Elias KondoruraBawan
Abstrak	: 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 P1 with prime mover DEUTZ BV8 M 628 while diesel power plant unit P6 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.
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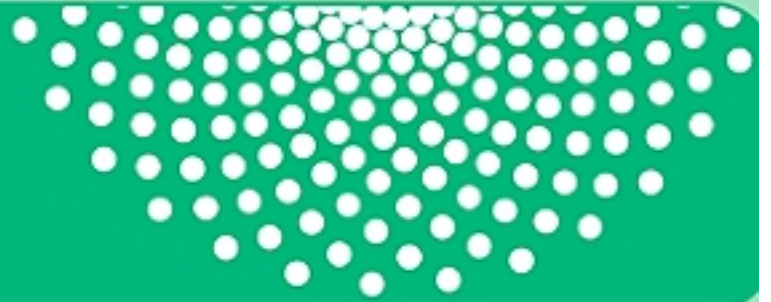


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The 3rd International Conference on Sustainable Future for Human Security, SUSTAIN 2012, 3-5 November 2012, Clock Tower Centennial Hall, Kyoto University, JAPAN

Guest Editor

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Hagus Tarno, Hagus Tarno, Suharman Hamzah,
Arif Bramantoro, Apip, Agus Trihartono**

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The 3rd International Conference on Sustainable Future for Human Security
SUSTAIN 2012

Editorial

The 3rd International Conference on a Sustainable Future for Human Security (SUSTAIN 2012) was held at Kyoto University (Japan) on 3-5 November, 2012. The conference was organized by the Indonesian Students Associations of Kyoto and Kansai, with the support of the Organization for the Promotion of International Relations (OPIR) Kyoto University, Graduate School Energy Science (ES), Global Center for Education and Research on Human Security Engineering (HSE), Center for Southeast Asian Studies (CSEAS), Research Institute for Sustainable Humanosphere (RISH), Global COE Program for Sustainability/Survivability Science for a Resilient Society Adaptable to Extreme Weather Conditions (GCOE-ARS) and the Inter-Graduate School Program for Sustainable Development and Survivable Societies(GSS).

The conference is originated from the need to provide an inter-disciplinary forum where the most serious problems affecting a sustainable future for human security can be discussed, in recognition of the fact that many future problems cannot be solved by a *siloed* approach. The emphasis on sustainable futures is in response to the general awareness of the need to solve numerous human-related problems resulting from the rapid growth of modern society.

The topic of sustainable futures for human security needs to be discussed in an integrated way, in accordance with the principles of sustainability, considering energy and materials supply, economies and trade, technology, cities, agriculture, social and environmental aspects. To continue providing adequate technology to cope with the thirst of human comfort requires intensive research and development with multidisciplinary perspective. The research development in solving the future human security should be done by using the sustainability perspectives, where the development will negatively impact the environment and inefficient use of natural reserves, which result in natural damages, increasing unnecessary emissions, releasing the untreated hazardous substances and eventually-jeopardizing human health and sometimes causing death.

The conference covered a wide range of issues with the aim of highlighting potential issues and paths towards a sustainable future. The conference attracted a high level of attendance from countries of the global North and South, with a wide geographical coverage. Overall, 160 participants were involved, with 120 presentations over the course of the conference. The quality of papers received was a testament to the reputation that the conference has been building over the past 3 years.

Papers presented at SUSTAIN 2012 were divided into six thematic areas: (1) Energy and Environment (EnE); (2) Sustainable Agriculture (A); (3) Sustainable Built Environment in Tropical Hemisphere Countries (BE); (4) Environmentally Friendly and Efficient Technology (FT); (5) Hydrology and Disaster Prevention (HnD); (6) Social Science (S). Under these broad areas, a wide-ranging series of presentations

was given, which elaborated on current research across Asia and the world. Being held in Kyoto, a city of great cultural heritage, the participants also took part in a tour of some of the main sights and experiences that link modern and ancient Japan. Furthermore, due to the strong involvement of the Indonesian Students Associations, a mixture of broader Asian cultural performances was also a highlight.

The two programmed days of the conference each commenced with keynote presentations which, like the conference itself, were wide-ranging. In the first session, Professor Jun Honna (Ritsumeikan University) introduced the historical origins and development of the concept of Human Security – a key concept of the conference. He was followed by Professor Yohannes Surya (Surya Institute), who covered a variety of aspects of renewable energy as well as a discussion of science education in Indonesia. Professor Kaoru Takara (Kyoto University) then discussed the prevalence and impact of extreme weather events and strategies for decreasing the risks associated with them, in the development of “survivable societies”. The second day’s plenaries were presented by Professor Josse De Baerdemaeker (University of Leven), Professor Tsuyoshi Yoshimura (RISH) and Mr Muhammad Lutfi (Ambassador of the Republic of Indonesia for Japan and Micronesia). They covered the topics of sustainable agricultural practices, pest management and Indonesia as the next world’s economy respectively.

Later in the conference a workshop for early career researcher was also run, introducing tips and troubles in the academic writing process. This capacity building exercise attracted 25 young researchers and engaged them in an intensive workshop process to develop their skills and understanding.

The organizers appreciate the support and assistance of the co-operating organizations, the participants, presenters and staff. The next SUSTAIN conference is highly anticipated by all the attendees of SUSTAIN 2012 and the committee expect to further build on the success of this year’s event.

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The 3rd International Conference on Sustainable Future for Human Security
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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.

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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
$P_{min,i}$	lower limit of the unit i
$P_{max,i}$	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

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

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

Subject to :

$$\sum_{i=1}^n P_i = P_R \quad (3)$$

$$P \min_i \leq P_i \leq P \max_i \quad (4)$$

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]:

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

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.

$$\nabla L = \nabla F_T + \nabla \lambda \phi = 0 \quad (6)$$

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

By solving 7th equation, we get :

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

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.

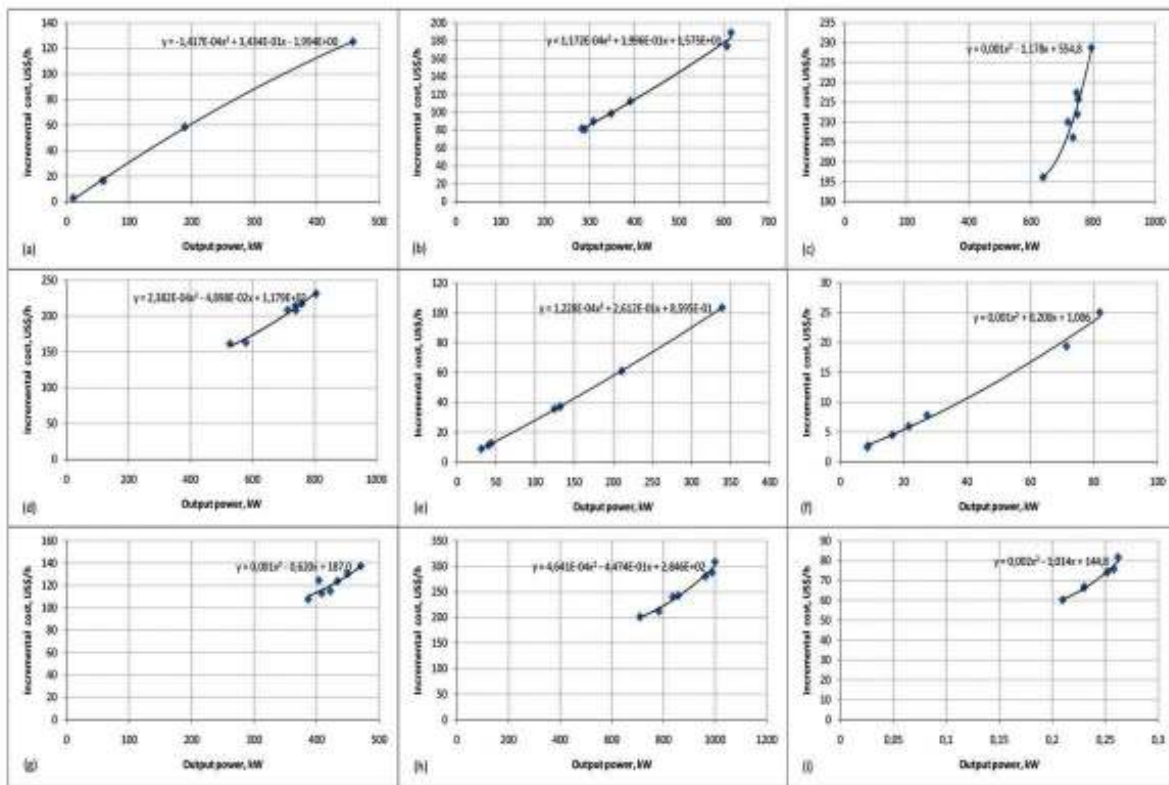


Fig. 1.(a) to (i) Curve of machine unit P₁ to P₉

The lines in fig. 1 (a) to (i) are given by quadratic polinomial function to connect each data point of machine unit P₁ to P₉. 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.

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

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.

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

The first derivative equation of each unit in eq. 10 can now be used to determine total lambda by referring 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 rewritten 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 λ 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

occupied 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 P₆ 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 P₁ 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.

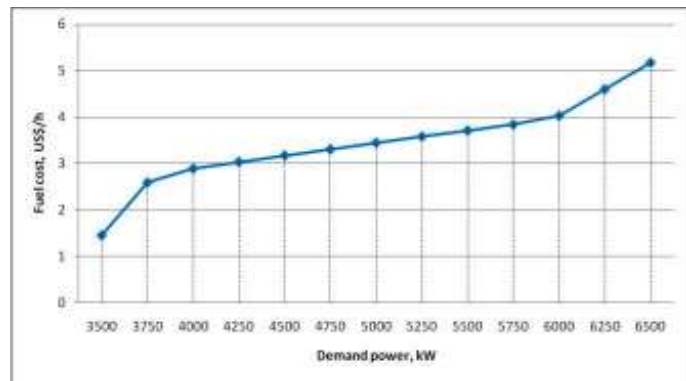


Fig. 2. Fuel cost vs demand power

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 beginning 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 perform 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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