Analysis of Cost

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Analysis of Costs and Emissions on The Addition of Production Capacity of The Power Plant Using Multi Echelon Economic Dispatch

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Abstract. Electricity production using fossil fuel and coal may cause adverse effects to the environment. However, regardless the amount of emission produced, these practices are common due their ability to reduce cost, particularly in providing electricity as the basic needs for human being. One way that can be done to minimize the adverse effects is to optimize the power plant collaboration. This paper performs simulations to choose the best location for additional power plants. Simulation is done based on multi-echelon economic dispatch model. The advantage of this model is primarily its high flexibility to be applied in various conditions with two objectives: minimizing costs and emissions. The model is devised on the electricity system in East Kalimantan by using artificial data and computed using Excel Solver as the analytical tool. The result shows that zone A is the best location for additional production capacity in term of cost point of view. Whilst from the emissions perspective, zone C is the best location to increase production capacity.

INTRODUCTION

There are two serious problems related to the global energy demand, namely the declined oil reserves and CO2 gas emissions. Depleted oil reserves lead to the increase in fuel prices, while emission-related problems become one of the causes of global warming. Both of these issues must be taken very seriously due to their potential menace to endanger human life.

In this regard, electricity producers have a significant role in reducing emission by applying certain technology means or methods to minimize emission generated from production activity. Among other, there are two methods that have been commonly conducted. *First*, replace the use of oil with renewable energy, and *second*, save oil usage by collaborating power plants. Collaboration between suppliers can be done with economic dispatch as has been carried out by [1]. Initially, the economic dispatch only considers costs that have a potential negative impact on the environment [2]. Therefore, economic dispatches are developed by involving emissions as performed by [3].

Although the process of electricity production has the potential to trigger adverse effects on humans, the practice is still going on until today because electricity has become a major part of human life. In fact, every year, there is a need to increase the power plant production capacity to meet the needs of community. The use of coal-fired power plants can reduce fuel costs, but it increases emissions. Meanwhile, the use of gas fuel can reduce emissions, but it increases fuel costs [2]. Therefore, the right way to do a combination of the use of these fuels must be examined.

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The present study presents the results of the simulation of two conditions, which are costs and emissions. Each condition consists of 4 (four) scenarios and the simulations are carried out based on the combination of two models in [4] and [5]. The result will provide recommendation for the best location for a power plant that can minimize costs and emissions.

ECONOMIC DISPATCH

History of Economic Dispatch

Economic dispatch was introduced in 1928 by three researchers who extensively introduced this model, namely [6-8]. The initial economic dispatch, also known as the classic Economic dispatch, uses the concept of the base load method and the best point load method. The way it works is by sorting its efficiency. The most efficient power plant will be assigned first. Furthermore, the load allocation will be given to the power plant with the lowest efficiency, and so on until the last power plant.

Load base method is carried out based on load allocation, which is less effective when applied to different power plant characteristics. This new developed technique is known as equal incremental cost that considers the characteristics of each different power plant. After that, one find the meeting point of all power plants, and the optimal allocation is decided based on this meeting point. This equal incremental cost technique is still used until today. This technique is introduced by [9] with its ability to produce cheaper total fuel cost for all power plants involved in the system as one of its advantages [10-12].

Economic dispatch will produce optimal load allocation for all power plants involved, but there is no guarantee that the produced electricity can flow in the transmission network because each network has a maximum capacity in a certain time. For this reason, [13] introduced a new method to solve economic dispatch problems with security constraints in the form of DC load flow. Network security constraints are flow limits on the network. By considering this factor, the electricity load that has been allocated to each power plant can flow in a particular transmission network accordingly, as explained in [14].

Characteristics of Power Plant

The characteristics of the power plant determine the use of fuel for electricity production. Fuel costs for each power plant can be seen from the input/output curve and the incremental cost curve. The unit for the function of power plant fuel consumption is the amount of Btu/hour heat input (or MBtu/hour). The output for the power plant is symbolized by PG, which is the number of megawatts generated by the power plant.

The input-output characteristics for the power plant system can be determined by a combination of boiler input-output characteristics and input-output characteristics of the turbine-generator unit as in the following Fig. 1.

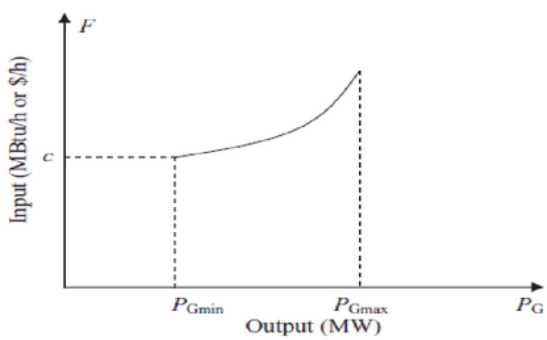

FIGURE 1. The input-output characteristics of power plant.

The figure explains that the characteristics of input-output power plant, which is the power output, is limited by the minimum and maximum capacity of the power plant as shown in the equation below:

$$P_{i\,min} \le P_i \le P_{i\,max} \quad (1)$$

If the input-output characteristics of all power plants are identical, the entire power plant can be assigned to the same task. However, the power plant generally has different input-output characteristics. It means that by entering the same amount of fuel, each power plant does not necessarily produce the same amount of power (Pi). This fact causes the importance of allocating electricity loads to be managed in such a way that the total cost becomes minimal.

Generally, the power plant cost function is nonlinear. The input-output characteristics used for a power plant unit are the following functions:

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

Where a, b, and c are coefficients for input-output characteristics. The constant c is equivalent to the use of fuel without power output as shown in Fig. 1.

Environmental Dispatch

The IEEE Working Group Report states that Environmental dispatch is the allocation or change in the allocation of electrical resources, which is connected to the system at a certain time, to meet the system load at that time which can minimize costs and environmental impacts, or still within the acceptable limit.

Minimum emission dispatch (MED) is in the form of a simple single criteria optimization problem. The emission problem of the dispatch is explained in [15]. Based on the types of pollutants and the available data, the emission curve for thermal units is described in three types, namely: linear function, quadratic function, and combination of a straight line forming polynomial or exponential.

Emission dispatch is also introduced by [16]. In this concept, it is assumed that the goal is cost. Emission limits can be applied to total system emissions or group or unit emissions. The solution that is obtained from this concept is often at the limit of the system, so that it can cause boundary violations if there is an error in forecasting or the availability of a power plant. A new problem arises in the form of how to expand the concept of costs and simultaneously develop conversions from generating units, which are in line with environmental objectives into one monetary unit. The idea raised by [16] is to calculate costs without emissions in advance as initial costs, and then include emission factors into the allocation of expenses. Furthermore, the difference is the cost of emissions.

Economic Dispatch does not only minimize fuel costs but also minimize emissions as found in [17-20]. Emissions are measured using the quadratic function approach that is expressed as follows:

$$E_i = \alpha_i P_i^2 + \beta_i P_i + \delta_i \quad (3)$$

Where:

$\alpha_i, \beta_i, \delta_i$ = Emission constants for power plant i,

P_i = Electrical power generated by the power plant i.

MODEL DEVELOPMENT

Model

The simulation carried out in the present study is based on a combination of two models. The models are the load allocation power plant model [4] and the multi echelon economic dispatch model as in [21]. Both of these models have advantages because they are potential to optimize the combination of production and distribution. This combination makes this model is very flexible to be used in a variety of application, including planning for additional production capacity.

Scenario

The simulation is done under two main conditions. *First*, simulation focused on minimizing costs as the objective, and *second*, simulation with the aim of minimizing emissions. Each simulation consists of 4 (four) scenarios as follows:

1) Existing condition.
2) Additional production capacity of 500 MW in zone A.
3) Additional production capacity of 500 MW in zone B.
4) Additional production capacity of 500 MW in zone C.

All simulations are completed with Solver Excel and compared to each other to determine the best solution for the establishment of planning power plant by using cost and emission parameters.

RESULTS

Existing condition

TABLE 1. The results of the simulation of existing conditions

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distr. Losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	1,250,015	1,250,015	1,250,015	1,000,450	1,000,450	1,000,450	200	200	200	798	926	883
Zone B	2,216,549	2,806,706	3,438,327	123,759	157,114	192,854	99	112	124	358	363	416
Zone C	3,103,555	3,659,170	4,294,001	122,768	144,874	170,142	140	152	165	393	454	540
Sub Total	6,570,118	7,715,890	8,982,342	1,246,977	1,302,438	1,363,446	440	464	489	1,549	1,742	1,838
								1,393			5,130	
Total		23,268,351			3,912,861				6,523			

In existing conditions as detailed in Table 1, the fuel needed to provide electricity demand is Rp. 23,268,351. The total emissions produced by all power plants in all three zones are 3,912,861 grams, losses on the transmission network are 1,393 MW while losses in the distribution network are 5,130 MW. In overall, the total system losses are 6,523 MW.

Additional Production Capacity with Cost Parameters

a. Zone A

TABLE 2. The results of the simulation of additional capacity in zone A with cost parameters

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distr. losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	1,485,015	1,485,015	1,485,015	1,210,495	1,210,495	1,210,495	220	220	220	894	998	982
Zone B	1,884,572	2,324,587	2,993,016	105,018	129,862	167,653	92	102	116	330	349	395
Zone C	2,638,787	3,254,808	3,737,911	104,285	128,785	148,007	129	144	154	354	422	473
Sub Total	6,008,373	7,064,410	8,215,942	1,419,797	1,469,142	1,526,155	441	465	490	1,577	1,769	1,850
								1,396			5,196	
Total		21,288,726			4,415,094				6,592			

If the power plant production capacity in zone A is increased by 500 MW, the fuel needed to provide electricity demand is Rp. 21,288,726. The total emissions produced by all power plants in three zones are 4,415,094 grams. Losses on the transmission network are 1,396 MW, and losses in the distribution network are 5,196 MW. This simulation found that the total system losses are 6,592 MW as specified in Table 2.

b. Zone B

TABLE 3. The results of the simulation of additional capacity in zone B with cost parameters

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distr. losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	1,250,015	1,250,015	1,250,015	1,000,450	1,000,450	1,000,450	200	200	200	798	926	895
Zone B	2,216,549	2,806,706	3,701,001	123,759	157,114	207,727	99	112	129	358	363	427
Zone C	3,103,554	3,659,170	4,040,030	122,768	144,874	160,032	140	152	160	393	454	510
Sub Total	6,570,118	7,715,890	8,991,046	1,246,977	1,302,438	1,368,209	440	464	489	1,549	1,742	1,832
								1,393			5,123	
Total		23,277,055			3,917,624				6,516			

If the power plant production capacity in zone B is increased by 500 MW, the fuel needed to provide electricity demand is Rp. 23,277,055. Total emissions produced by all power plants in all zones are 3,917,624 grams. Losses on the transmission network are 1,393 MW, and losses in the distribution network are 5,123. In overall, total loss in the system is approximately 6,516 MW as clarified in Table 3.

c. Zone C

TABLE 4. The results of the simulation of additional capacity in zone C with cost parameters

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distr. losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	1,250,015	1,250,015	1,250,015	1,000,450	1,000,450	1,000,450	200	200	200	798	926	883
Zone B	2,216,549	2,806,706	3,438,327	123,759	157,114	192,854	99	112	124	358	363	416
Zone C	3,103,554	3,659,170	4,294,001	122,768	144,874	170,142	140	152	165	393	454	540
Sub Total	6,570,118	7,715,890	8,982,342	1,246,977	1,302,438	1,363,446	440	464	489	1,549	1,742	1,838
								1,393			5,130	
Total		23,268,351			3,912,861				6,523			

If the power plant production capacity in C zone is increased by 500 MW, the amount of fuel needed to cover electricity demand is Rp. 23,268,351. Total emissions produced by all power plants in three simulation zones are 3,912,861 grams. Losses on the transmission network are 1,393 MW while losses in the distribution network are 5,130 MW, thus the total system losses are 6,523 MW as detailed in Table 4.

Additional Production Capacity with emission parameters

a. Zone A

TABLE 5. The results of the simulation of additional capacity in zone A with emission parameters

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distri. Losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	561,892	723,879	905,866	403,429	540,461	697,493	127	147	167	491	699	776
Zone B	4,973,127	5,351,608	5,688,020	279,815	301,279	320,361	150	155	160	477	482	502
Zone C	4,040,030	4,040,030	4,040,030	160,032	160,032	160,032	160	160	160	509	510	510
Sub Total	9,575,048	10,115,517	10,633,916	843,276	1,001,771	1,177,886	437	462	487	1,476	1,692	1,788
								1,386			4,956	
Total		30,324,481			3,022,933				6,341			

If the power plant production capacity in zone A is increased by 500 MW, the fuel needed to cover the electricity demand is Rp. 30,324,481. Total emissions produced by all power plants in the zones are 3,022,933 grams. Losses on the transmission network are 1,386 MW, and losses in the distribution network are 4,956 MW. The losses of the total system are 6,341 MW as detailed in Table 5.

b. Zone B

TABLE 6. The results of the simulation of additional capacity in zone B with emission parameters

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distr. Losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	413,429	554,431	715,434	281,150	397,197	533,245	106	126	146	415	573	693
Zone B	6,366,473	6,883,976	7,186,520	358,857	388,230	405,406	169	176	180	524	579	554
Zone C	4,040,030	4,040,030	4,040,030	160,032	160,032	160,032	160	160	160	509	539	518
Sub Total	10,819,932	11,478,437	11,941,984	800,039	945,460	1,098,682	435	462	486	1,448	1,692	1,764
								1,383			4,904	
Total		34,240,353			2,844,181				6,287			

If the power plant production capacity in zone B is increased by 500 MW, the amount of fuel needed is Rp. 34,240,353. Total emissions produced by all power plants in all zones are 2,844,181 grams. Losses on the transmission network are 1,383 MW while losses in the distribution network are 4,904 MW. Thus, the total system losses are 6,287 MW as clarified in Table 6.

c. Zone C

TABLE 7. The results of the simulation of additional capacity in zone C with emission parameters

Power Plant	Fuel Cost (Rp)			Emission (gram)			Transm. Losses (MW)			Distr. Losses (MW)		
	1	2	3	1	2	3	1	2	3	1	2	3
Zone A	419,905	561,892	723,879	286,397	403,429	540,461	107	127	147	371	579	656
Zone B	4,973,127	5,351,608	5,688,020	279,815	301,279	320,361	150	155	160	477	482	502
Zone C	5,107,530	5,107,530	5,107,530	202,536	202,536	202,536	180	180	180	629	630	630
Sub Total	10,500,561	11,021,030	11,519,429	768,748	907,243	1,063,358	437	462	487	1,476	1,692	1,788
								1,386			4,956	
Total		33,041,019			2,739,349					6,341		

If the power plant production capacity in zone B is increased by 500 MW, the fuel needed to cover electricity demand is Rp. 33,041,019. Total emissions produced by all power plants in three zones are 2,739,349 grams, while losses on the transmission network are 1,386 MW, and losses in the distribution network are 4,956 MW. Hence, the total system losses are 6,341 MW as presented in Table 7.

ANALYSIS

Based on the results of four simulations on three scenarios of power plant allocation, i.e. the existing conditions, capacity additions in Zone A, capacity addition in Zone B, and capacity additions in Zone C with cost parameters, the results showed that the addition of production capacity in Zone A is the best way to reduce costs. The simulation revealed a decrease in costs by 9.3%, but at the same time, the result showed negative impact on emissions as well as losses on transmission and distribution networks. Furthermore, it found that there was an increase in emissions by 11.8% and losses by 1.05%.

TABLE 8. Comparison of scenario based on two parameters

Simulation	Cost Parameter			Emission Parameter		
	Fuel Cost (Rp)	Emission (Rp)	Losses (MW)	Fuel Cost (Rp)	Emission (Rp)	Losses (MW)
Existing condition	23,268,351	3,912,861	6,523	23,268,351	3,912,861	6,523
Additional production capacity in zone A	21,288,726	4,415,094	6,592	30,324,481	3,022,933	6,341
Additional production capacity in zone B	23,277,055	3,917,624	6,516	34,240,353	2,844,181	6,287
Additional production capacity in zone C	23,268,351	3,912,861	6,523	33,041,019	2,739,349	6,341

Based on the same simulation using emission parameter, it is known that by adding a production capacity of 500 MW in zone C, it can decrease emissions by 42.84% and losses by 2.86%. This is the lowest emission compared to other scenarios. however, this decision will cause an increase in cost of production by 29.58% as depicted in Table 8.

As can be observed in Fig. 2, large losses do not necessarily produce the greatest total cost. This result is caused by a unique relationship that occurs between power plants, where costs are not only affected by the amount of production, but also by the characteristics of the power plant of each supplier as well as losses in each network.

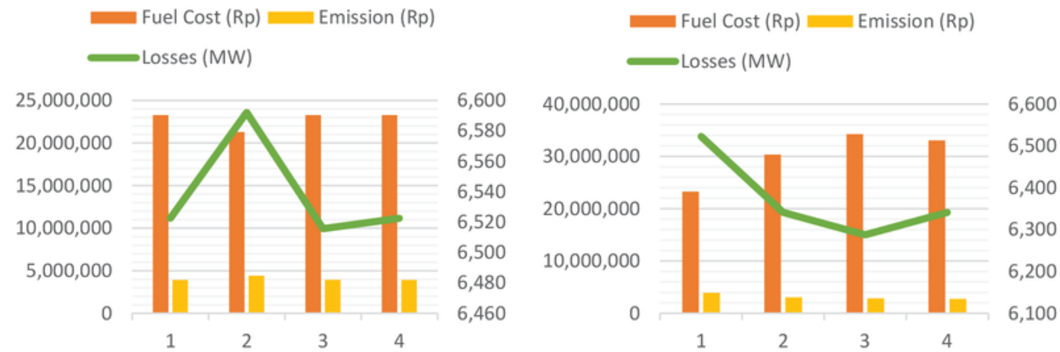

FIGURE 2. Comparison of each scenario with cost and emission parameters.

CONCLUSION

The addition of a production capacity of 500 MW in zone A is the best way to reduce the cost of production using fossil fuel-based oil. However, this decision has a negative impact on the environment and losses on the transmission network. The addition of a 500 MW power plant in zone C has a good impact for the environment because it reduces emissions by almost half. However, this decision has a negative impact on production in term of the increase in fuel costs.

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