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Power plant allocation in East Kalimantan considering total cost and emissions

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Abstract. The fulfillment of electricity need in East Kalimantan is the responsibility of State Electricity Company/Perusahaan Listrik Negara (PLN). But PLN faces constraints in the lack of generating capacity it has. So the allocation of power loads in East Kalimantan has its own challenges. Additional power supplies from other parties are required. In this study, there are four scenarios tested to meet the electricity needs in East Kalimantan with the goal of minimizing costs and emissions. The first scenario is only by using PLN power plant. The second scenario is by combining PLN + Independent Power Producer (IPP) power plants. The third scenario is by using PLN + Rented power plants. The fourth scenario is by using PLN + Excess capacity generation. Numerical experiment using nonlinear programming is conducted with the help of the solver. The result shows that in the peak load condition, the best combination is scenario 2 (PLN + IPP). While at the lowest load condition, the cheapest scenario is PLN + IPP while the lowest emission is PLN + Rent.

1. Introduction
Related to power energy, two major issues in the world which have always been a topic of discussion is the decrease in fossil-fueled fuel and increased emissions. Reduced fuel sources will result in all human activities, whether production, construction, transportation, etc. Furthermore, uncontrolled emissions will trigger an increase in earth temperature and harmful gas for humans.

The main emissions from energy combustion are CO$_2$ and SO$_2$. It is estimated that 70% of total CO$_2$ emissions comes from coal combustion, while the rest comes from burning fossil fuels such as oil and natural gas. Furthermore, 90% of total SO$_2$ emissions come from coal combustion while the rest are oil burning [1].

Electrical energy has become a major need for human beings to support their daily activities. However, not all people have access to electricity. More than 1.6 billion people worldwide have no access to electricity and about 80% are in Asia and Africa especially in rural areas [2].

Electrical system consists of three subsystems namely: generating subsystem, transmission subsystem and distribution subsystem. Each subsystem has a specific problem. In the case of Indonesia, the main problem in the power plant system is the determination of the type and number of power plants that need to be involved in meeting the fluctuating electricity demand with multi power plants. Multi generators will be a problem when viewed from an emissions standpoint. Generators with low cost not necessarily produce low emissions as well [3]. The current problem of electricity
generation is the determination of the optimal load allocation at the plant to obtain the cheapest cost with low emissions.

As an illustration is the case of Indonesia. In 2014, the use of fuel oil for electricity generation is 12.35% of total fuel used, and then coal fuel is 51.35% while gas is 23.41%. These data suggest that the choice of cheap fuels does not necessarily provide a single solution for the procurement of electrical energy to meet demand. The main reason is emissions; all countries including Indonesia are committed to lower emission levels in their respective countries.

2. **Economic Dispatch Model**

Initially the main objective of economic dispatch is to simply minimize the total cost [3]–[9]. Furthermore, economic dispatch is required to also consider environmental factors by including emissions [10]–[18]. The purpose of this electrical load allocation model is to minimize the operational costs of a plant while minimizing the impact on the environment through reducing emissions. Generally, between cost minimization and emission minimization are two contradictory things. Reduce costs easily by using the cheapest fuel such as coal. However, the move will result in an increase in emissions.

The model in this paper is based on 4 scenarios. First, the load allocation model using only power plant owned by State Electricity Company/Perusahaan Listrik Negara (PLN). Second, the load allocation model using PLN + Independent Power Producer (IPP) combined power plant. Third, the model of load allocation by using a combination of PLN + rented power plant. Fourth, the load allocation model using PLN + excess power plant.

3. **Load Allocation Model with PLN Power Plant.**

The general form of allocation of generation loads by economic dispatch model is as follows:

\[
\text{Minimize } \sum_{i=1}^{N} F_i (P_i) = a_i P_i^2 + b_i P_i + c_i
\]  

Constraints
\[
\sum_{i=1}^{N} P_i = PD
\]
\[
P_{min} \leq P_i \leq P_{max}
\]

The above model aims to minimize fuel costs. The first limitation indicates that the amount of energy generated must be equal to the demand for electricity, this limitation is called the power balance constraints. The second limitation describes the limits of the generator. The power released by each generator has a maximum value depending on the type of plant used. The plant also has a minimum limit in order to operate with a stable

4. **Load allocation model with PLN + IPP power plant**

Minimize \( \sum_{i=1}^{N} F_i (P_i) + \sum_{i=1}^{N} F_{iPP} (P_{iPP}) = a_i P_i^2 + b_i P_i + c_i + a_{iPP} P_{iPP}^2 + b_{iPP} P_{iPP} + c_{iPP} \)  

Constraints
\[
\sum_{i=1}^{N} P_i + \sum_{i=1}^{N} P_{iPP} = PD
\]
\[
P_{min} \leq P_i \leq P_{max}
\]
\[
P_{iPPmin} \leq P_{iPP} \leq P_{iPPmax}
\]

5. **Load allocation model with PLN + Rent power plant**

Minimize \( \sum_{i=1}^{N} F_i (P_i) + \sum_{i=1}^{N} F_{iR} (P_{iR}) = a_i P_i^2 + b_i P_i + c_i + a_{iR} P_{iR}^2 + b_{iR} P_{iR} + c_{iR} \)  

Constraints
\[
\sum_{i=1}^{N} P_i + \sum_{i=1}^{N} P_{iR} = PD
\]
\[
P_{min} \leq P_i \leq P_{max}
\]
\[
P_{iRmin} \leq P_{iR} \leq P_{iRmax}
\]
6. Load allocation model with PLN + Excess power plant

Minimize \( \sum_{i=1}^{N} F_i (P_i) + \sum_{i=1}^{N} F_{IE} (P_{IE}) = a_i P_i^2 + b_i P_i + c_i + a_{IE} P_{IE}^2 + b_{IE} P_{IE} + c_{IE} \)  

Constraints

\( \sum_{i=1}^{N} P_i + \sum_{i=1}^{N} P_{IE} = PD \) 

\( P_{imin} \leq P_i \leq P_{imax} \)  

\( P_{IEimin} \leq P_{IE} \leq P_{IEimax} \)  

7. Results

The experiment was conducted using 4 scenarios and 2 conditions. The four scenarios used are: (1) using PLN’s power plant, (2) using PLN + IPP power plant, (3) using PLN + Rental power plant, and (4) using PLN + Excess power plant. While the two conditions considered are peak load conditions and low load conditions.

Scenario 1 with peak load conditions yields the largest total cost of 1,159,917.51 and the largest emission of 173.7. While under low load conditions, this scenario yields a total cost of 209,487.94 and emission of 93.9.

Scenario 2 with peak load conditions resulted in the lowest total cost of 273,136.5 and the lowest emission of 142.0. For low load conditions, this scenario is also capable of producing the lowest cost of 118,133.1 but the resulting emissions of 95.5.

Scenario 3 with peak load conditions resulted in total cost of 634,620.08 and emissions of 155.9. While at low load this scenario generates a total cost of 227,274.53 and emissions of 86.5.

Scenario 4 with peak load conditions resulted in total cost of 753,529.92 and emissions of 166.7. While under low load conditions, this scenario generates a total cost of 332,655.37 with a total emission of 98.5

| Table 1: Result of numerical experiment |
|----------------------------------------|
| Scenarios | Conditions | Total Cost | Emission |
| 1         | Peak       | 1,159,917.51 | 173.7    |
|           | Low        | 209,487.94   | 93.9     |
| 2         | Peak       | 273,136.5    | 142.0    |
|           | Low        | 118,133.1    | 95.5     |
| 3         | Peak       | 634,620.08   | 155.9    |
|           | Low        | 227,274.53   | 86.5     |
| 4         | Peak       | 753,529.92   | 166.7    |
|           | Low        | 332,655.37   | 98.5     |

8. Discussion and Further Research

The maximum load on the plant system in East Kalimantan is 343.4 kW. While the minimum load of 194.86 kW. This load can be met from interconnected power plants. Based on the ownership of the plant, the power plant is divided into 4. First, the power plant owned by PLN. Secondly, the plant is owned by Independent Power Producer (IPP). Third, the plant is owned by another party but is leased by PLN. Fourth, the plant has the other party and the excess of its production can be bought by PLN.

Based on the ownership of the power plant, there are 4 scenarios to fulfill the electrical load. Scenario 1: using PLN’s power plant. Scenario 2: using PLN and IPP power plants. Scenario 3: using PLN’s power plant and rental generator. Scenario 4: Own generator + excess capacity. There are 2 conditions of electrical load that is peak load conditions and minimal load conditions. When the system is in peak load condition, the PLN + IPP scenario will produce two advantages at a minimum value, i.e., price and emissions. Conversely, scenario 1 in the form of use of PLN’s power plant alone will result in the highest cost and emission.

While the system is in the lowest load condition, the lowest fuel cost is the combination of PLN + IPP generator, while the most expensive is the combined generator between PLN + Excess. While the lowest emission is when using a combination of power plants owned by PLN + Rent.
Based on the 4 scenarios above, it is found that the result of load allocation for peak load condition is not the same as low load condition. This raises two types of problems which lead to further research. The first one is static economic dispatch to dynamic economic dispatch. The above load allocation uses load allocation assuming that the electrical load does not change, so load allocation is made based on 1 type of load. The allocation of these loads does not match the real conditions. Seen from 4 plant scenarios for 2 types of time, they do not present the same results. Peak load time is more appropriate using the second scenario, which is a combination of PLN + IPP. While the low load time is more appropriate using the scenario, PLN + IPP while the lowest emissions from the scenario PLN + Rent.

Second issue is reliability. Reliability system is defined as the ability of the electric power system to supply additional electrical power caused by damage to one of the generators. In the Mahakam system, the largest power plant is P11 with a maximum power of 200 MW. Based on the total power owned by all power plants, then when there is disruption at the largest power plant, the power system will not be able to supply the required power, so from the point of view of reliability still need to be added new generator to do the allocation of the load.

![Figure 1. Peak and Load Condition](image)

9. Conclusion

The allocation of load in East Kalimantan would be better if it combines PLN + IPP power plant. The combination of both propellers will result in an allocation of electrical loads with a minimum total cost and the smallest emissions for peak load conditions. As for the low load, the combination of PLN + IPP power plant will still provide the smallest total cost but the smallest emission is generated from the combined PLN + Rent power plant. All of the above scenarios assume that there is no disruption to the entire plant. Further research needs to be conducted to find proper allocation of the load if one of the generators is damaged.

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