Cost analysis of an electricity supply chain using modification of price based dynamic economic dispatch in wheeling transaction scheme

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Abstract. Deregulation of the electricity market requires coordination between parties to synchronize the optimization on the production side (power station) and the transport side (transmission). Electricity supply chain presented in this article is designed to facilitate the coordination between the parties. Generally, the production side is optimized with price based dynamic economic dispatch (PBDED) model, while the transmission side is optimized with Multi-echelon distribution model. Both sides optimization are done separately. This article proposes a joint model of PBDED and multi-echelon distribution for the combined optimization of production and transmission. This combined optimization is important because changes in electricity demand on the customer side will cause changes to the production side that automatically also alter the transmission path. The transmission will cause two cost components. First, the cost of losses. Second, the cost of using the transmission network (wheeling transaction). Costs due to losses are calculated based on ohmic losses, while the cost of using transmission lines using the MW-mile method. As a result, this method is able to provide best allocation analysis for electrical transactions, as well as emission levels in power generation and cost analysis. As for the calculation of transmission costs, the Reverse MW-mile method produces a cheaper cost than the Absolute MW-mile method.

1. Introduction
The restructuring of the electric power market has created a new deregulation. The deregulation transforms the original monopoly power system with vertical integration into a competitive system. Vertical integration, generation, transmission, and distribution are managed by one party [1]. Whereas in deregulation, the system is separate and competitive.

Deregulation divides the electricity market into 3 types: pool system, bilateral contract and hybrid system. Pool system is the most widely applied market systems. In this system, the parties involved are divided into Gencos, Transcos, Discos and managed by an ISO (Independent System Operator). As a producer, Gencos will offer price to market, as well as Discos. Discos are a term for a group of customers. Then ISO will determine the winner of the transaction. The ISO will also arrange the scheduling of each Gencos operation that is tailored to the network load for the security of the system. Bilateral is an electric market between two parties without involving ISO. Two parties, namely Gencos and Discos conduct transactions bilateral. The result of the agreement is the amount of electricity
transacted reported to ISO, then ISO will schedule shipments from producer to consumer tailored to network security [2]-[4].

This study discusses the allocation of electrical load on the bilateral contract. In this type of contract, the price agreement involves only two parties namely Gencos and Discos. Therefore, Gencos should be able to optimize the performance of plants owned so that it can produce low-cost electricity by minimizing fuel consumption. While Discos as the buyer will pay 2 types of costs, which is the cost of each kWh purchased and the cost of transmission. Transmission costs in the bilateral system are also known as wheeling transactions. There are 2 types of wheeling that is, own use and not own use. Wheeling for own use occurs when there are parties/customers who have their own power station in an area, and want to deliver electricity to its production facilities to other distant places. For that must use the network of the other party. Wheeling is not for own use when the party/customer wants to run electricity at his production facility, and for that he must buy electricity from other parties.

The type of wheeling used is not its own use. Deregulation enables all power companies to compete with each other to provide cheaper, quality power supplies. On the other hand, deregulation has also transformed the transmission system into a transportation service provider system. As a service function, the transmission should be able to provide transportation at a low cost, fair and transparent. Cheaper transportation is expected to reduce the total cost of electricity. Transparent transportation means that the fees paid by transportation service users can be clearly illustrated. Equitable transportation means that all transport service users are not subject to discriminatory treatment.

Cheaper power supplies can be achieved by minimizing fuel costs. A load allocation aimed at minimizing fuel costs using economic dispatch is present in [5]–Error! Reference source not found. Economic dispatch is also called static economic dispatch because it does not consider changes in the demand side. Economic dispatch that considers changing demand is called dynamic economic dispatch as in [3]. Error! Reference source not found.-Error! Reference source not found. However, the two types of models are not suited to the deregulation of the electricity market due to differences in purpose structure and function. Therefore, the price based dynamic economic dispatch (PBDED) model emerges. This model fits into market deregulation. In this model as the goal is to maximize profit as in [20]. All of the above models result in the allocation of loads with minimal cost. By reducing fuel costs, it is expected to reduce the final price of electricity so that it is competitive. Once electricity is produced, electricity must be transmitted through the transmission network. To be able to produce competing products then the transmission should also be available at a cheap price.

Transmission cost will be cheap, fair and transparent when the transmission costs can be presented in detail [22]. This can be realized by dividing the transmission operation into several parts according to the conditions. The condition of the transmission operation is that in order to reach the customer, the electricity generated by the generator must pass through several substations first connected by a network. There are many substations and paths, so that electricity will have many combinations of lines before it reaches the customer. This combination of paths and substations raises a new problem of losses on the network.

The loss in the transmission network is the loss of electrical energy due to the nature of the conductor used or known as ohmic losses. This loss is influenced by the magnitude of current and resistance. The losses on the transmission line can be approximated by a model proposed by Bamigbola et al. Error! Reference source not found.. In the model, the greater the distance between the plant and the load, the greater the loss occurs. This network loss causes the plant to produce more. This is a compensation for network losses that occurs so that the amount of energy produced equal to the energy demanded. Thus, the optimization should not only be on the production side, but also on the transmission side to minimize the total cost.

Thus, the total cost of a load allocation actually consists of 3 components. First, the cost of fuel consumption due to the load. Second, the cost of fuel consumption due to transmission losses. Third, the cost of transmission. This research proposes the development of PBDED model called Multi-Echelon PBDED. This model is a combination of 2 types of models that are multi-echelon models as in [24] and PBDED models as in [20]. The model can answer the goal of profit maximization by
minimizing fuel costs, minimizing transmission losses and minimizing transmission costs. The cost of transmission is determined based on the MW-mile method. Proposed models have been tried on systems with artificial data consisting of 3 generators, 3 substations, and 6 load centers. The result is a load allocation with detailed transmission costs and their impact on total costs and emissions.

2. PBDED model and multi-echelon distribution

The PBDED model aims to maximize profit with the following objective functions:

\[
\text{maximize } PF = RV - TC
\]

In this case,

\[
TC = \sum_{t=1}^{T} \sum_{m=1}^{M} C_i (P_{(i,t)} + ST_i)
\]

\[
RV = \sum_{t=1}^{T} \sum_{m=1}^{M} \sigma_g(t) (P_{(i,t)} I_{(i,t)})
\]

\[C_i: \text{production cost of unit } i, P_{(i,t)}: \text{Output of generator } i \text{ at time } t, I_{(i,t)} \text{ commit or not commit at time } t, ST_i \text{ start-up cost at time } t, i: \text{index generator. } N \text{ is the number of generating units.} \]

\[
\sigma_g(t) \text{ load forecasting at time } t, C_i(P_{(i,t)}) \text{ generation cost of unit } i
\]

1. Demand Constraint

\[
\sum_{i=1}^{N} P_{(i,t)} I_{(i,t)} \leq D_t \quad t = 1, ..., Tm
\]

2. Generator Constraint

\[
P_{\text{min}} \leq P_{(i,t)} I_{(i,t)} \leq P_{\text{max}}
\]

\[-DR_i \leq P_i - P_i^0 \leq UR_i
\]

\[
\text{max}\{P_i^0 - DR_i, P_{\text{min}}\} \leq P_i \leq \text{min}\{P_i^0 + UR_i, P_{\text{max}}\}
\]

3. Multi-echelon distribution model

Multi echelon distribution as in[24] as follows:

Minimize \[
\sum_{j} f_j X_j + \sum_{i} \sum_{j} \sum_{m} c_{ijm} Y_{ijm}
\]

Constraints \[
\sum_{i} \sum_{m} \sum_{k} Y_{ijm}^k \leq MX_j
\]

\[
\sum_{j} \sum_{m} Y_{ijm}^k \geq h_i^k
\]

\[
\sum_{i} \sum_{j} Y_{ijm}^k \leq S_m^k
\]

\[
Y_{ijm}^k \geq 0
\]

\[
X_j = 0, 1
\]

\[h_i^k = \text{Demand} \]

\[f_j = \text{fixed cost} \]

\[c_{ijm}^k = \text{production cost of unit } i \text{ at plant } m. \]

\[S_m^k = \text{Plant capacity.} \]

4. Proposed model using multi-echelon PBDED

The PBDED model has managed to maximize profit, but cannot present optimization of the transmission network, whereas the transmission network leads to the emergence of two types of costs. First, the costs which is caused by losses on the network. Second, the cost which is caused by the use of transmission (wheeling transaction). While in multi-echelon distribution model (formula 8 to 13), this model can present optimization on the distribution line, but it is less suitable for electricity. Therefore, to utilize the advantages of both models, this paper proposes a multi-echelon PBDED model. The objective function of this proposed model is the same as the formula (1) - (3) while the additional restrictions include:

\[
F = \sum_{t=1}^{T} \sum_{i=1}^{I} F_{it}(P_{it})
\]

\[
F_w = \sum_{t=1}^{T} \sum_{i=1}^{I} F_{it}(P_{it}) w
\]

\[
C_w = F_w - F + c_{ijt}^f + c_{ijkt}
\]

\[
F_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i
\]
\[ C_{ijt}^y = \frac{p_{ijt}^y}{p_{ijt}} z_{ij} \]  \hspace{1cm} (20)

\[ C_{jkt}^y = \frac{p_{jkt}^y}{p_{jkt}} z_{jk} \]  \hspace{1cm} (21)

\[ E_{it}(P_{it}) = \alpha_i P_{it}^2 + \beta_i P_{it} + \delta_i \]  \hspace{1cm} (22)

The formula (16) is the cost of fuel with a regular load. The formula (17) is the cost of fuel when wheeling occurs. The formula (18) is the transmission cost. The formula (19) is a quadratic function of fuel costs. Formulas (20) and (21) MW-mile method calculations for transmission of 500 KV and 150 KV. While the formula (22) is a quadratic function of the resulting emissions.

5. Numerical experiment
Models are tried on systems with artificial data. The system consists of 3 generators, 3 substations and 6 loads, with the following details:

| Table 1. Distance between Generators and Transmission Stations 500 kV and 150 kV (in km) |
|----------------------------------|------------|------------|------------|----------|----------|----------|----------|----------|----------|
| GT1 | GT2 | GT3 | GD1 | GD2 | GD3 | GD4 | GD5 | GD6 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| P1  | 50  | 300 | 500 | 10  | 5  | 30  | 15  | 20  | 15 |
| P2  | 200 | 50  | 600 | 10  | 5  | 20  | 10  | 20  | 10 |
| P3  | 200 | 600 | 50  | 30  | 20 | 5   | 10  | 20  | 30 |

| Table 2. Generator Data |
|-------------------------|
| a | b | c | α | β | δ | Max (MW) | Min (MW) | UR (MW) | DR (MW) |
|-----|-----|-----|----|----|----|---------|---------|---------|---------|
| P1  | 0.04 | 50 | 15 | 0.0400 | 0.09 | 0.10 | 8.000 | 500 | 1.000 | 1.000 |
| P2  | 0.35 | 22 | 20 | 0.0200 | 0.09 | 0.90 | 5.000 | 500 | 1.000 | 1.000 |
| P3  | 0.25 | 10 | 30 | 0.0100 | 0.01 | 0.05 | 8.000 | 500 | 1.000 | 1.000 |

| Table 3. Load Data |
|-------------------|
| Time (t) | Load GD1 | Load GD2 | Load GD3 | Load GD4 | Load GD5 | Load GD6 | Scenario |
|---------|----------|----------|----------|----------|----------|----------|----------|
| 1       | 1,000   | 2,000   | 2,000   | 1,100   | 1,700   | 2,000   | + 200   |
| 2       | 1,100   | 1,500   | 1,700   | 1,500   | 2,000   | 1,600   | +150    |
| 3       | 1,100   | 1,700   | 1,500   | 1,700   | 1,900   | 2,000   | +100    |

6. Results
At base load, the total profit for 3 periods is Rp 31,836,139 (income Rp 69,650,728 Expenses Rp 37,814,589). Emissions 6,109,994 and losses of 15,153. With the utilization of the plant between 46 and 84%, except in the third period, the utilization of the plant reaches 100% for the 2nd plant. The low utilization will have a bad impact on the return on investment, but on the contrary, up to 100% utilization is at high risk due to electricity demand which fluctuates.

Furthermore, there are two scenarios used for this model. Scenario 1 is a condition when a request occurs on GD1 (retailer1). Scenario 2, is a condition when additional demand occurs on GD4 (Retailer 2). The results of both scenarios are shown in the following table:

| Table 4. Profit, Emission and network loss for wheeling cases on GD1 and GD4 |
|-----------------------------|-----------------------------|-----------------------------|
| t | Scenario 1 (on GD1) | Scenario 2 (on GD4) |
|----|-----------------|-----------------|
| Revenue | Expense | Emission | Losses | Revenue | Expense | Emission | Losses |
| 1 | 21,203,763 | 10,386,790 | 2,222,548 | 4,936 | 21,250,202 | 10,464,871 | 2,226,951 | 4,967 |
| 2 | 27,020,181 | 15,894,890 | 2,900,362 | 6,108 | 27,095,314 | 16,004,907 | 2,915,597 | 6,137 |
| 3 | 26,029,078 | 14,547,499 | 2,335,343 | 5,311 | 26,057,472 | 14,557,974 | 2,343,724 | 5,328 |
Table 5. The cost of transmission with Reverse and Absolute MW mile on GD1 and GD4

| Scenario | Reverse MW mile | Absolute MW mile |
|----------|----------------|-----------------|
|          | The difference between fuel costs | 3,014,590 | 3,213,163 |
|          | wheeling 500 KV | 33,202 | 33,664 |
|          | wheeling 150 KV | -14,733 | -12,591 |
| Total Cost | 3,033,059 | 3,234,236 |
| The difference between fuel costs | 3,014,590 | 3,213,163 |
| wheeling 500 KV | 62,870 | 63,067 |
| wheeling 150 KV | 27,207 | 28,929 |
| Total Cost | 3,104,667 | 3,305,159 |

With the same amount of load, both scenarios produce different profits. Profit on scenario 1 is bigger, that is Rp. 33,423,843. This profit is earned from income for 3 periods of Rp. 74,253,022. And fuel costs are Rp. 40,829,179. With total emissions of 7,458,252 and transmission losses is Rp. 16,355. Although scenario 1 generates a smaller total revenue than scenario 2, it produces a larger total profit. This is because scenario 1 can result in a more efficient allocation of loads with lower total cost (fuel costs) than scenario 2. This can also be seen from the resulting losses. Where losses in scenario 1 are smaller than scenario 2. Losses will increase generation fuel costs. Losses can be reduced by the selection of appropriate transmission routes through optimization. With regard to wheeling transaction, scenario 1 also provides a lower total transmission cost, which is Rp. 3,033,059 and Rp. 3,104,667 using Reverse MW-mile and Absolute MW-mile respectively.

The calculation of wheeling transaction using Reverse MW-mile method will result in lower total transmission cost, which is Rp. 33,202 on the transmission of 500 kV and -Rp. 14.733 on a 150 kV transmission. Negative signals on transmission costs mean a decrease in the amount of electricity that flows on the network. Negative transmission becomes revenue for transmission service users. Thus, additional demand (wheeling transaction) will be more advantageous if done on GD1 (retailer 1) than on GD4 (retailer 2).

7. Conclusions
The Multi Echelon Priced Based Dynamic Economic Dispatch method has successfully been built to maximize profit electrical allocation by presenting a more detailed and fair transmission cost calculation for the parties involved. Maximum profit can be obtained by two ways: first, maximizing revenue; and second, reducing fuel and transmission costs. This paper uses a reverse MW-mile and an absolute MW-mile method, based on 2 scenarios of wheeling transactions performed. The Reverse MW-mile method produced the cheapest transmission cost. In general, it can be concluded that transactions on GD1 (scenario 1) result in greater profit and lower transmission costs. Greater profits on scenario 1 are due to cheaper generation fuel costs and smaller losses.

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