

Development of a Multi Echelon Economic Dispatch Model for Combined Optimization Between The Production and Distribution Side of The Electricity

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Abstract

Combined optimization between the production and distribution side of electricity must be done because electricity produced must be sent directly to the customer. Electricity cannot be saved so it must be produced as much as Demand. For this reason, the production system must consider losses in the network, where there are two types of losses, namely transmission losses and distribution losses. Power plant scheduling using economic dispatch does not present combined optimization. Therefore, this research has produced a Multi Echelon Economic Dispatch (MED) model. This model is able to make a combined optimization between the production and distribution/shipping sides. Not only that, this model has also divided shipments into two parts, transmission and distribution, so that more detailed production scheduling and electricity delivery can be obtained while minimizing fuel costs.

Keywords

Transportation Problem, Multi Echelon Distribution, Economic Dispatch, Simulation, Optimization, Electricity, Power Plant, Supply Chain.

1. Introduction

Electricity production and distribution are two separate systems. Electricity production is carried out in a group of power plants, while electricity distribution is carried out through a transmission and distribution network. Each power plant involved in production has its own characteristics. These characteristics lead to differences in fuel use and the resulting emissions (Gani *et al.* 2019). This is the reason the importance of interconnected generator scheduling is done well, errors in scheduling cause wasteful use of fuel.

Scheduling of interconnected power plants can be with the economic dispatch model (Jadoun *et al.* 2015). This model is capable of scheduling the entire power plant so that the minimum total cost is obtained as in (Meng *et al.* 2016; Arriagada *et al.* 2016; Bhattacharjee and Khan 2018; Mahdi *et al.* 2018). However, this model only optimizes the production side. Optimization on the distribution side has not been done.

The combined optimization of production and distribution is carried out using the Transportation Economic Dispatch model (Wahyuda *et al.* 2019). This model is able to carry out production escort at the power plant while synchronizing with the shipping network to obtain a minimum total cost. However, this model only considers one delivery echelon. So, it is assumed that after production is carried out to the power plant, electricity is directly sent to the final customer (Gani *et al.* 2019). In fact, electricity generated by interconnected plants must go through a transmission and then distribution network, where the two networks have different characters.

Therefore, this study proposes a Multi Echelon Economic Dispatch model. This model is a combination of the economic dispatch model for the production side and the multi echelon distribution model for the distribution side. This model divides electricity delivery into two levels, transmission and distribution networks. This model is able to make better power plant scheduling and more detailed distribution.

2. Literature Study

This section consists of two parts of literature, namely multi echelon distribution and economic dispatch.

2.1 Multi Echelon Distribution

Multi echelon distribution is commonly used in product distribution in the manufacturing industry. In this distribution, a product sent from a production facility does not reach the end customer directly, but rather has to go through several places/levels. Figure 1 is the levels in a multi echelon distribution are described (Guo and Li 2014).

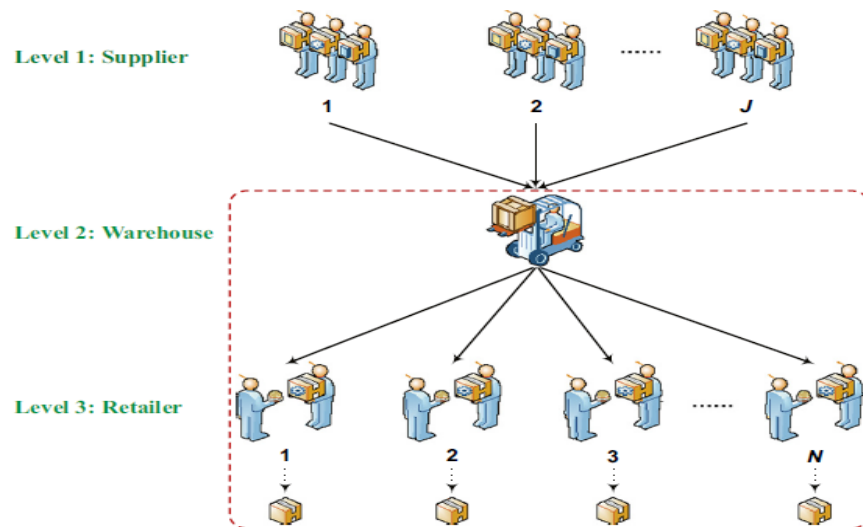


Figure 1. Illustration of multi echelon distribution in supplier selection.

At level 1 is a supplier, level 2 is a warehouse, and level 3 is a retailer. The multi echelon structure in (Guo and Li 2014) has similarities with the structure of electric power systems in (Hunt 2002). The similarities referred to are as follows: level 1 in (Guo and Li 2014) is a supplier whose job is to supply products to the warehouse.

The most important thing in multi echelon is the coordination of ordering goods or supplies at each level. Coordination errors will result in higher total costs and inventory that exceeds what is needed. The main objective of a multi echelon system is to reduce total costs by coordinating orders along the supply chain (Chopra and Meindl 2007).

In (Daskin 1995) multi echelon is used to solve the problem of site selection in order to obtain a minimal total distribution cost. Multi echelon for site selection is described as in Figure 2.

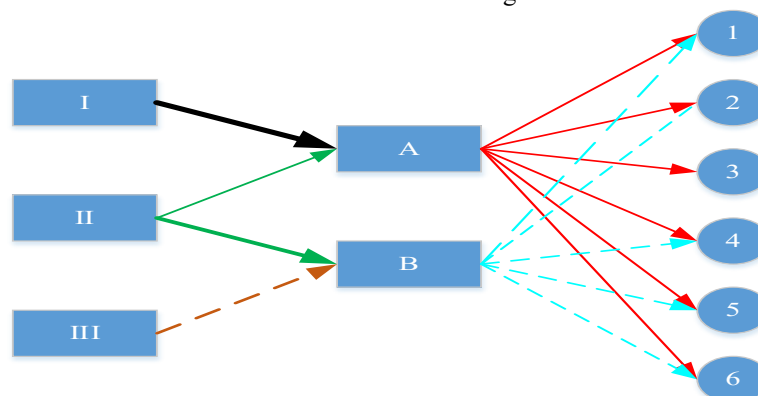


Figure 2. Multi echelon for location selection problems.

In Figure 2, there are three alternative plant locations (I, II, and III), two warehouses (A and B), and 6 marketing areas. The multi-echelon model is used to determine the combination of plant and warehouse that must be chosen to serve the entire marketing area with the aim of minimizing costs

The parameters and variables involved are explained as follows:

h_i^k = Demand for product k in market of i

f_j = Fixed cost at j

c_{ijm}^k = Production cost for production 1-unit k at plant m which deliver to market i via warehouse j

S_m^k = Capacity of plant m to produce k.

M = Big Number

Decision variable:

Y_{ijm}^k = Flow product of k from plant m to market i via warehouse j.

$X_j = \{1, \text{ if warehouse at } j, 0, \text{ if not}\}$

$$\text{Minimize } \sum_j f_j X_j + \sum_i \sum_j \sum_m \sum_k c_{ijm}^k Y_{ijm}^k \quad (1)$$

$$\text{Constraints } \sum_i \sum_m \sum_k Y_{ijm}^k \leq M X_j \quad (2)$$

$$\sum_j \sum_m Y_{ijm}^k \geq h_i^k \quad (3)$$

$$\sum_i \sum_j Y_{ijm}^k \leq S_m^k \quad (4)$$

$$Y_{ijm}^k \geq 0 \quad (5)$$

$$X_j = 0, 1 \quad (6)$$

2.2 Economic Dispatch Model

This model is used to overcome the complexity of the input-output power plant characteristics. The characteristics of this power plant determine the use of fuel for electricity generation. The cost characteristics of each plant can be seen with the input / output curve and the incremental cost curve. The unit for generating fuel consumption functions is the amount of heat input Btu / hour (or MBtu / hour). The output of the power plant is denoted by P_i , which is the number of megawatts produced by the generating unit

An Input-output power plant that is limited to the minimum output power capacity and maximum power plant, namely:

$$P_{i \min} \leq P_i \leq P_{i \max} \quad (7)$$

The input-output characteristic that is widely used for a thermal generating unit is a quadratic function as follows:

$$F = a_i P_i^2 + b_i P_i + c_i \quad (8)$$

Where a, b, and c are coefficients for input-output characteristics. Constance c is equivalent to the fuel consumption of the operation of the generating unit without the power output

2.3 Environmental Dispatch

The IEEE Working Group Report (1981) states that Environmental Dispatch is an allocation or change in the allocation of electrical resources, which are 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 limits. Emissions are measured using the quadratic function approach as follows:

$$E_i = \alpha_i P_i^2 + \beta_i P_i + \delta_i \quad (9)$$

where

$\alpha_i, \beta_i, \delta_i$ = Constance emission of power plant

P_i = Power

3. System Consideration

Electricity is produced at the power plant (P1 to P4). Each power plant has the characteristics of cost $a_i P_i^2 + b_i P_i + c_i$, emission $\alpha_i P_i^2 + \beta_i P_i + \delta_i$, production Limit P_{\min} and P_{\max} . After being produced, electricity is sent to customers through 2 types of networks. First, the transmission network of a number of P_{ij} . In this transmission network electricity experienced transmission losses of a number of L_{ij} . This shipment ends at the Transmission station (TS). Second, distribution network. After reaching TS, electricity is sent to the distribution station through a distribution

network. This shipment amounted to L_t . With distribution losses of L_{jk} . The amount of electricity production at the power plant must be equal to the amount of demand on the DS taking into account losses in the transmission and distribution network. Overview of the production and distribution systems in the electric power system is presented in Figure 3.

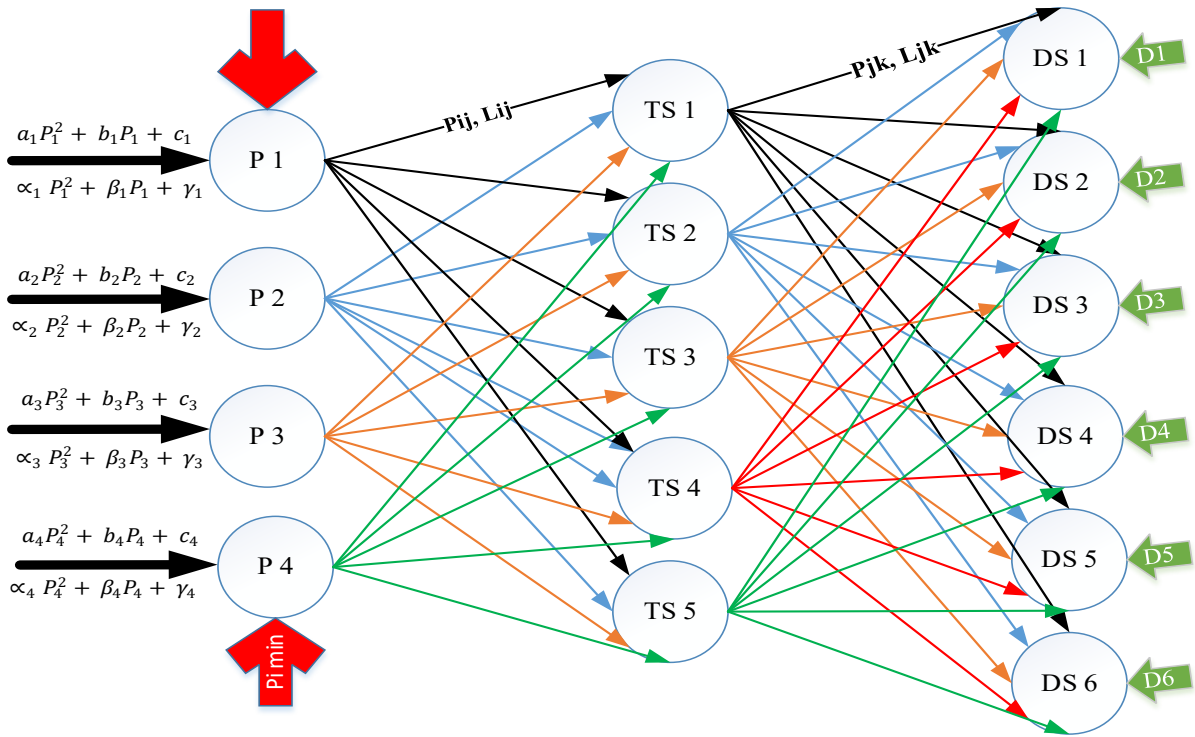


Figure 3. Electricity production and distribution system.

4. Proposed Model

This section consists of two parts, namely conceptual model and proposed model.

4.1A Conceptual Model

The purpose of the Multi Echelon Economic Dispatch (MEED) model is to balance supply with demand in order to obtain minimal costs. The parameters for supply are cost and production limit. Production is carried out at the power plant (P). Delivery of products is done through two lines, namely Transmission line (TL) and distribution line (DL). On the Transmission line there were losses of $Tloss$ and on the distribution line there were losses of $Dloss$. The conceptual model is presented in Figure 4.

Cost function for power plants:

$$F = a_i P_i^2 + b_i P_i + c_i \quad (10)$$

Limit of production for power plants

$$P_{i \min} \leq P_i \leq P_{i \max} \quad (11)$$

Equation for losses:

$$Tlosses = DLosses = I^2 R \quad (12)$$

$$I = \frac{P}{V} \quad (13)$$

$$R = \rho \frac{l}{A} \quad (14)$$

Where:

F = total of cost (Rp)

P_i = Electricity production for power plant i. (MW)

$P_{i \min}$ = Lower limit of production for power plant i. (MW)
 $P_{i \max}$ = Upper limit of production for power plant i. (MW)
 T_{loss} = Losses at Line of Transmission (MW)
 D_{loss} = Losses at line of Distribution (MW)
 R = Conductor resistance (ohm)
 V = voltage (kv)
 l = length of conductor (km)

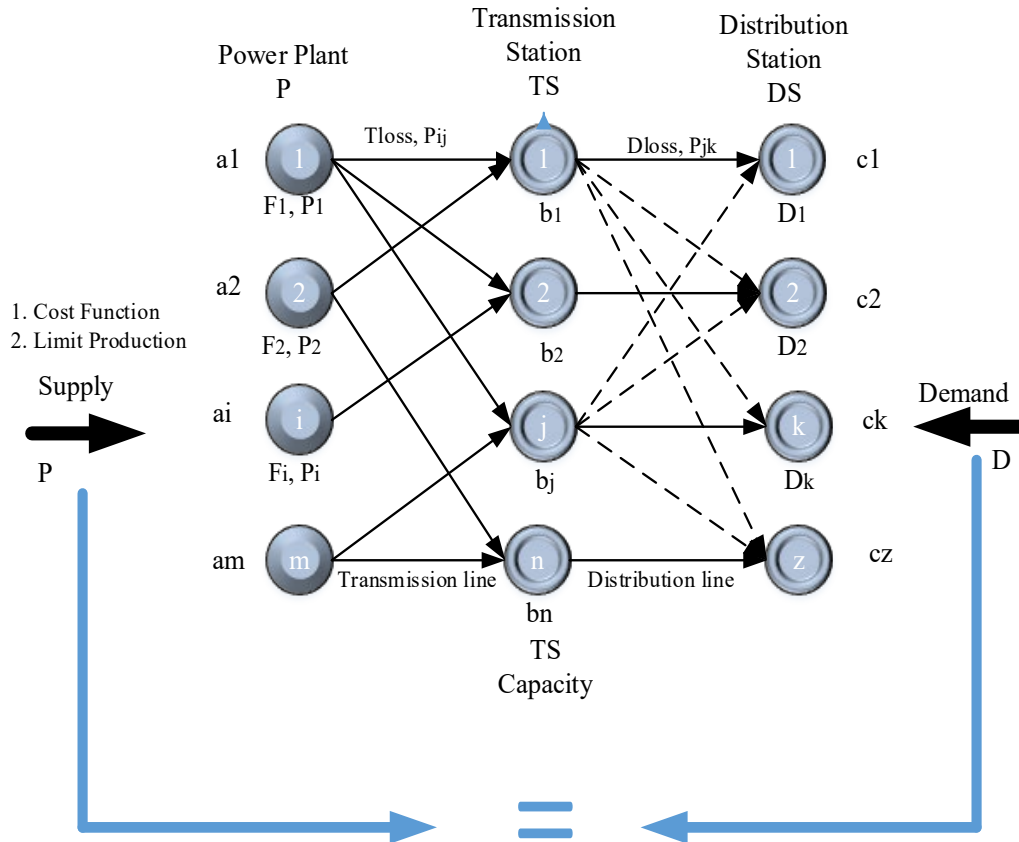


Figure 4. Conceptual model.

4.2 Mathematic Model

4.2.1 Relationship Between Power Plant, Transmission/Distribution Line and Transmission/Distribution Station.

If P_{ij} is the amount of electricity sent from a plant i to Transmission substation j, P_{jk} is the amount of electricity sent from Transmission substation j to distribution substations k, X_{ij} , and X_{jk} respectively, are transmission networks from generator i to substation j and the transmission network from substation j to substation k. Y_i and Y_j are the generating status i and the substation status j, respectively, so they can be modeled:

$$P_{ij} \leq L_{ij} X_{ij} \quad (15)$$

$$P_{jk} \leq L_{jk} X_{jk} \quad (16)$$

$$X_{ij} \leq Y_i \quad (17)$$

$$X_{jk} \leq Y_j \quad (18)$$

4.2.2 Limit of Power Plant and Transmission/Distribution Station

Electric power plants have the lowest and highest limits in their operations so that these plants can run safely and efficiently.

$$P_i \geq P_{i \min} Y_i \quad (19)$$

$$P_i \leq P_{i \max} Y_i \quad (20)$$

$$\sum_i P_{ij} \leq T_{j \max} Y_j \quad (21)$$

4.2.3 Power Balance in Each Echelon

In this study, the amount of electricity produced by the power plant i must equal the amount of electricity flowing from the power plant i to substation j . The relationship between echelons is formulated as follows:

$$P_i = \sum_{j=1}^J \sum_{l=1}^L P_{ij} \quad (22)$$

The amount of electricity entering substation j must be the same as the amount of electricity coming out of substation j

$$\sum_{j=1}^J \sum_{l=1}^L P_{ij} = \sum_{k=1}^K \sum_{j=1}^J P_{jk} \quad (23)$$

The amount of electricity flowing from substation j to substation k must be equal to the amount of demand / load.

$$\sum_{k=1}^K \sum_{j=1}^J P_{jk} = \sum_{k=1}^K D_k \quad (24)$$

5. Numerical Experiment

To prove that the proposed model can be applied, the model is tested on several power plants that are interconnected in the electric power system with dummy data. There are four power plants, five transmission stations, and six distribution stations.

Table 1 is the data characteristic of the power plant which is the input for a MED model. The characteristics included are the cost function, emission function, and production limit (P_{\max} and P_{\min}) for four power plants.

Table 2 is the simulation result of MED model for 3 scenarios as follows:

- Scenario 1 is a combined optimization of production and distribution in order to minimize costs
- Scenario 2 is a combined optimization of production and distribution in order to minimize emissions
- Scenario 3 is a combined optimization of production and distribution sides with the aim of minimizing losses on the network

Table 1. Characteristics of power plant.

Power Plant	Cost Function	Emission Function	Pmax	Pmin
P1	$20000P_1^2 + 256000P_1 + 200000$	$0.0004P_1^2 + 0.1P_1 + 0.45$	100	10
P2	$10000P_2^2 + 264000P_2 + 250000$	$0.00075P_2^2 + 0.7P_2 + 0.48$	80	5
P3	$7000P_3^2 + 50000P_3 + 150000$	$0.0009P_3^2 + 0.8P_3 + 0.5$	100	0
P4	$15000P_4^2 + 256000P_4 + 256000$	$0.0007P_4^2 + 0.2P_4 + 0.7$	200	10

Table 2. Three scenarios of production and distribution.

Scenario	Production (MW)	Fuel Cost (xRp1000)	Emissions (kg)	Losses (MW)
Scenario 1 (Minimize Cost)	P1= 86.6	P1= 172,451.240	P1= 12	TLoss= 30.07
	P2= 80.0	P2= 85,370	P2= 61	DLoss= 23.41
	P3= 100	P3= 75,150	P3= 90	
	P4= 76.9	P4= 108,529.029	P4= 20	
	343.5	441,500.268	183.1	53.5

Scenario 2 (Minimize Emission)	P1= 100 P2= 80 P3= 0 P4= 171.4	P1= 225,800 P2= 85,370 P3= 150 P4= 484,671.251	P1= 14 P2= 61 P3= 1 P4= 56	TLoss= 36.19 DLoss= 25.22
	351.4	795,991.251	131.8	61.4
Scenario 3 (Minimize Losses)	P1= 100 P2= 80 P3= 72.1 P4= 86.9	P1=225,800 P2= 85,370 P3= 40,149.695 P4= 135,840.218	P1= 14 P2= 61 P3= 63 P4= 23	TLoss= 26.49 DLoss= 22.55
	339.0	487,159.914	162	49.0

With demand at six distribution stations of 290 MW (DS1 = 50 MW, DS2 = 80 MW, DS3 = 10 MW, DS4 = 40 MW, DS5 = 50 MW, and DS6 = 60 MW) the results for the scenario:

- Scenario 1: Total production of 343.5 MW, where the excess production of 53.5 MW is produced to cover losses on the transmission network (transmission losses = 30.07 MW, distribution losses = 23.41 MW). The cost of fuel needed is IDR 441,500,268 and the resulting emissions are 183.1 kg.
- Scenario 2: Total production of 351.4 MW, where the excess production of 61.4 MW is produced to cover losses on the transmission network (transmission losses = 36.19 MW, distribution losses = 25.22 MW). The cost of fuel needed is IDR 759,991,251 and the resulting emissions are 131.8 kg.
- Scenario 3: Total production of 339.0 MW, where the excess production of 49.0 MW is produced to cover losses on the transmission network (transmission losses = 26.49 MW, distribution losses = 22.55 MW). The cost of fuel needed is IDR 487,159,194 and the resulting emissions are 162 kg.

There is a cost increase of 80% between scenario 1 versus 2. This cost is compensation for losses that fell from 183.10 kg in scenario 1 to 131.76 kg in scenario 2. Minimizing losses can also reduce emissions as seen in scenario 3. Losses can decrease from 53.48 MW in scenario 1 to 49.04 MW in scenario 3, but scenario 3 results in a cost increase of 10%.

6. Conclusion and Future Research

6.1. Conclusion

The Multi echelon Economic Dispatch (MED) model has succeeded in making a combined optimization between the production and distribution sides of electricity. Optimization on the production side is in the form of scheduling power plants while optimization on the distribution side is minimizing electricity mileage. Not only that, this model is also able to present electricity production and distribution in more detail. Electricity that reaches the customer can be known from the origin of the plant. And also, the losses incurred by each plant to send electricity to the customer can be known with certainty, where this advantage is not shared by the classic economic dispatch model.

Another benefit of this model can be used for incentive programs for environmentally friendly power plants. This is because minimizing costs at power plants will tend to use low-cost, high-emission power plants, low-emission power plants with more expensive costs will not be selected and cannot compete with plants that are not environmentally friendly.

6.2. Future Research

Costs and emissions in this study are nonlinear, causing complexity in modelling and computing. Therefore, the initial MED model was designed for single objective cases, further research is needed to develop the MED model with multi objective cases.

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