Advances in Intelligent Systems Research, volume 173
1st International Conference on Engineering and Management in Industrial System (ICOEMIS 2019)

Development of Transportation Models for Scheduling Power Plants and Electricity Distribution

Wahyuda[1,a], Muslimin[2,b], and Samdito Unggul Widodo[3,c]

[1]Department of Industrial Engineering, Universitas Mulawarman, Samarinda, Indonesia
[2]Department of Electrical Engineering, Universitas Mulawarman, Samarinda, Indonesia
[3]PT. PLN Samarinda, Indonesia

[a]wahyuda@gmail.com, [b]muscullli@gmail.com, [c]samdito@gmail.com

Keyword Transportation Model; Electricity Supply Chain; Economic Dispatch; Single Echelon Economic Dispatch; Distribution;Optimization

Abstract. Transportation models are often used to solve problems of allocation and distribution of goods. This model is very simple and easy to use so that this model is widely applied to various allocation and distribution problems such as the problem of shipping goods, the selection of transport fleets, the selection of production sites, and others. However, this model has never been applied to electricity allocation and distribution. This is due to differences in the nature of goods and electricity. The loading allocation for each power plant usually uses an economic dispatch model. The Economic dispatch model is able to make allocations for generating plants that minimize fuel costs but are not able to do distribution optimization. Therefore, this study proposes the Single Echelon Economic Dispatch (SEED) models. The SEED model is the development of the transportation model. This model is formed from a combination of transportation models with economic dispatch models. Verification of the model using the Mahakam interconnection system in East Kalimantan. As a result, the SEED model is able to carry out a combined optimization between the production and distribution sides with minimum fuel cost parameters. The SEED model is also able to make a more detailed distribution than the Economic Dispatch model.

1. Introduction

The transportation model has been applied to many actual problems. This is because this model is simple and easy to use. Various problems are solved by the transportation model, including the allocation of labor, the selection of factory locations, the selection of supplier locations, the distribution of goods, and others. This model is simple because it only requires data on production capacity in a source, demand capacity in a destination, and transportation costs from source to destination [1].

However, the transportation model cannot be applied in the case of electricity allocation and distribution. This is due to differences in the nature of electricity and manufactured goods [2]. There are 2 main differences between electricity and manufactured goods. First, electricity cannot be stored. Second, the amount of electricity production must be the same as the number of demand [3]. All this time, the allocation of loading power plants uses economic dispatch models. This model is capable of making generator scheduling with a minimum total fuel cost. However, this model only optimizes the production side without considering the distribution side. In fact, the electricity that has been produced must be immediately distributed to customers [4]. Because customers are in different locations, losses occur in this distribution process. The farther the distance between the generator and the customer, the higher the losses that occur. These losses affect the total cost of production [5]. Therefore, this study proposes a new model called the Single Echelon Economic Dispatch (SEED). This model combines the advantages of the transportation model and the economic dispatch model so that the combined optimization between the production side and the distribution side is obtained. This model is able to make a detailed allocation of power plant scheduling and distribution with minimal costs.

2. Literature Review

This chapter consists of 3 parts, namely the transportation model, the economic dispatch model, and the characteristics of the power plant.

2.1. Transportation Model

The first transportation model was discussed in [6]. In the article, a commodity can be sent from various sources to various destinations. This can be seen through the following Figure:

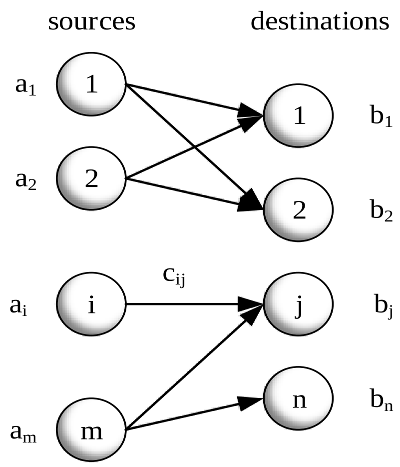


Figure 2.1. The basic concept of the transportation model: m source and n destination

Figure 2.1 provides an illustration of how the transportation model works. In general, the transportation model divides the problem into 2 groups, namely the source group and the destination group. Sources can consist of one or more members, as well as goals. The transportation model used to calculate transmission costs can be seen in [7] described in [8] as follows:

$$Minimize \quad \sum_i \sum_j C_{ij} X_{ij} \tag{2.1}$$

Constraints

$$\sum_j X_{ij} \leq S_i \quad \forall i \tag{2.2}$$

$$\sum_i X_{ij} \geq D_j \quad \forall j \tag{2.3}$$

$$X_{ij} \geq 0 \quad \forall i, j \tag{2.4}$$

where

S_i= Supply capacity at source i

D_j = The number of demand at point j.

C_{ij} = Product shipping costs from source i to destination j.

X_{ij}= Number of items sent from source i to destination j.

The main difference between transportation for goods and transportation for electricity is the balance between supply and demand. In the transportation model for goods, suppliers are allowed to send goods larger than the demand (Equation 2.3), but in transportation for electricity, suppliers must send the goods as large as to demand or called equilibrium. This point of equilibrium is called the Balanced Transportation Problem (BTP). Variations in BTP can be seen in figure 2.2 [9].

Model BTP-1:	Model BTP-2:	Model BTP-3:
$\boldsymbol{Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\,.\,x_{ij}}$ **Subject to** $\boldsymbol{\sum_{j=1}^{n} x_{ij} \geq s_i, (i = 1 \ldots m)}$ $\boldsymbol{\sum_{i=1}^{m} x_{ij} \leq d_j, (j = 1 \ldots n)}$ $\boldsymbol{x_{ij} \geq 0}$	$Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\,.\,x_{ij}$ Subject to $\sum_{j=1}^{n} x_{ij} \leq s_i, (i = 1 \ldots m)$ $\sum_{i=1}^{m} x_{ij} \geq d_j, (j = 1 \ldots n)$ $x_{ij} \geq 0$	$Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\,.\,x_{ij}$ Subject to $\sum_{j=1}^{n} x_{ij} = s_i, (i = 1 \ldots m)$ $\sum_{i=1}^{m} x_{ij} = d_j, (j = 1 \ldots n)$ $x_{ij} \geq 0$

Figure 2.2. Three variations of the Balanced Transportation Problem (BTP)

where
$\boldsymbol{c_{ij}}$: shipping costs from source i to destination j
$\boldsymbol{x_{ij}}$: the amount sent from source i to destination j
s_i : amount of supply from source i
d_j : amount of demand at destination j

2.2. Economic Dispatch Model

Initially, this method was used to plan the allocation of power plants with the aim of minimizing fuel costs. In addition, the output from Economic dispatch must also fulfill all demand on the customer side. At present, the initial Economic dispatch is also known as static/classic economic dispatch. In a classic economic dispatch, network security is still ignored. So the basis of the loading allocation is a set of input-output characteristics of the generating unit involved. Input-output characteristics are explained in section 2.3

Economic dispatch was introduced since 1928. There were 3 people who introduced this model, namely [10] – [12]. The initial economic dispatch is called the classic Economic dispatch model. This model uses the concept of the base load method and the best point load method. How it works, sort generator units based on the highest efficiency level. Furthermore, generator generation is given to the generating unit with the highest level of efficiency, and so on until the most recent generating unit.

When there are differences in the characteristics of each plant, the base load technique becomes less effective. Therefore, a new technique emerged known as equal incremental cost. The main concern of this technique is the characteristics of each different generator. The way it works, the meeting point of all generators is searched, and the optimal allocation is made based on this meeting point. This equal incremental cost technique is still used today. This technique was introduced by [13]. The advantage, this technique can present a lower total cost for all the plants involved in the system. However, this initial model still has shortcomings, namely the lack of consideration of losses in the transmission network. One of the causes of losses in transmission networks is the length of the transmission network. The longer the transmission distance, the greater losses will occur. These losses will ultimately affect the total cost of fuel because the plant must produce more electricity than the demand for compensation losses.

2.3. Characteristics of the power plant

The power plant can consist of several thermal plants with different characteristics. The characteristics of this plant greatly determine the use of fuel for electricity generation. The cost characteristics of each generator can be seen by input/output curves and incremental cost curves. The unit for generator fuel consumption function is the amount of Btu / hour heat input (or MBtu / hour). The output for the generating unit is denoted by Pi, namely the number of megawatts produced by the generating unit i.

The thermal generator input-output curve is formed from the system on the thermal unit. The thermal generator system generally consists of boilers, steam turbines, and generators. The relationship between input and output can be described as a convex curve. Input-output characteristics for generating unit systems can be determined by a combination of boiler input-output characteristics and turbine-generator unit input-output characteristics. As in the following Figure:

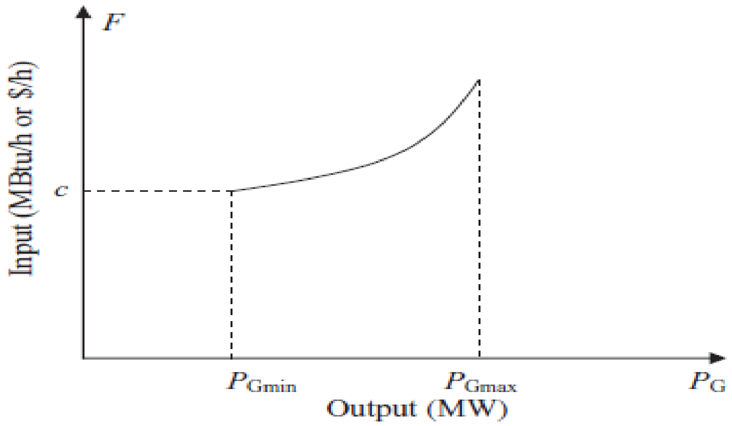


Figure 2.1. Input-output characteristics of the generating unit

The Figure explains that the input-output characteristics of a generator. Output in the form of power has a minimum and maximum limit that must be generated, namely:

$$P_{i\,min} \leq P_i \leq P_{i\,max} \tag{2.5}$$

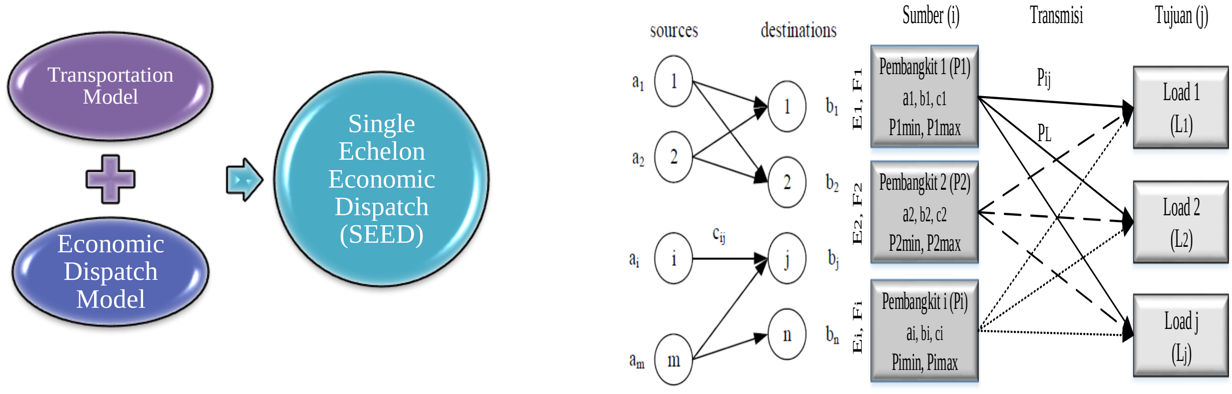
If the input-output characteristics of all plants are identical, the generator can be assigned the same load. But in fact, generators generally have different input-output characteristics. This means that by entering the same amount of fuel, each generator does not necessarily produce the same amount of power (Pi). This fact causes, the importance of managing the allocation of electricity expenses so that the total cost of generation can be minimal [14].

Generally, the characteristics of a thermal generator are nonlinear. Input-output characteristics that are widely used for a thermal generator unit are quadratic functions as follows:

$$F = a_i P_i^2 + b_i P_i + c_i \tag{2.6}$$

3. Development of Single Echelon Economic Dispatch (SEED) Model

The Transportation Model has advantages in the field of distribution which causes shipping costs to be minimal, whereas the Economic Dispatch model has an advantage in the field of generator loading allocation or generator scheduling. The use of economic dispatch models is able to create a power plant scheduling that results in minimal fuel costs. Combining the advantages of these two models provides several advantages. First, the development of a new transportation model called the Single Echelon Economic Dispatch (SEED). Second, the combined optimization between the generator side and the distribution side. Conceptually, the development of the SEED model can be seen in the following figure:



(a) (b) (c)

Figure 3.1. Conceptual Model for the Development of the Single Echelon Economic Dispatch (SEED) model

Figure 3.1.a. conceptually illustrates that the SEED model is formed from two models, namely the transportation model and the economic dispatch model. Figure 3.1.b. is a conceptual model of the transportation model. while Figure 3.1.c is an economic dispatch conceptual model. In the same way, both models are used for resource allocation. While the difference is in the object faced, where transportation is commonly used in people or goods while ED is used in electricity. The nature of the two objects is different. The main requirement for electricity is in the form of an equation between the supply side and the demand side. Therefore, another approach used is the Balanced Transportation Problem as shown in Figure 2.2.

The characteristics of the three variations of BTP are used as a reference for the development of the SEED model. Development is carried out by combining several limitations. Combining these models raises new variations of BTP. Furthermore, a merger with the Economic Dispatch model was obtained to obtain the SEED model. The result of merging BTP with economic dispatch as in figure 3.2.

***Single Echelon Transportation Problem* (Modification BTP)**		***Economic Dispatch* (Equations 2.1 – 2.3)**		**Proposed Model (*Single Echelon Economic Dispatch*, SEED)**
$\boldsymbol{Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\,.\,x_{ij}}$ Subject to $\boldsymbol{\sum_{j=1}^{n} x_{ij} \geq s_{imin}, (i = 1 \dots m)}$ $\boldsymbol{\sum_{j=1}^{n} x_{ij} \leq s_{imax}, (i = 1 \dots m)}$ $\boldsymbol{\sum_{i=1}^{m} x_{ij} = d_j, (i = 1 \dots n)}$ $\boldsymbol{x_{ij} \geq 0}$	+	$F_i = a_i P_i^2 + b_i P_i + c_i$ $P_{i\,min} \leq P_i \leq P_{i\,max}$ $P_i = D_i$	=	$Minimize\ Fi = \sum_{i=1}^{I}\sum_{j=1}^{J} a_i\,P_{ij}^2 + b_i P_{ij} + c_i$ $\sum_j P_{ij} \geq P_{i\,min}$ $\sum_j P_{ij} \leq P_{i\,max}$ $\sum_i P_{ij} = L_j + P_{Lij}\ (j = 1 \dots J)$ $P_{ij} \geq 0$

Figure 3.2. Scheme of formation of the SEED model

The SEED model has the objective function of minimizing fuel costs as in the economic dispatch model. While the difference between the two models lies in the scope of the model. This can be seen from the notation used. The basic model of economic dispatch uses Pi notation, which means the amount of electricity produced at the generator i. Whereas the SEED model uses Pij notation which means the amount of electricity production generator i sent to destination j. If this scope is included in the objective function, this model is prepared to be able to complete 2 tasks, namely optimization of production and optimization of distribution simultaneously. As a guarantee of a feasible solution, the SEED model is also equipped with 3 restrictions.

4. Experiments Using the SEED MODEL

This chapter discusses experimental SEED models. Divided into two parts, the basic model, supply and demand data.

4.1. Basic Model

$$Minimize\ \ Fi = \sum_{i=1}^{I}\sum_{j=1}^{J} a_i\, P_{ij}^2 + \ b_i P_{ij} + \ c_i \tag{4.1}$$

$$Minimize\ \ Ei = \sum_{i=1}^{I}\sum_{j=1}^{J} d_i\, P_{ij}^2 + \ e_i P_{ij} + f_i \tag{4.2}$$

Generation Constraints:

$$\sum_j P_{ij} \ \geq \ P_{i\,min} \tag{4.3}$$

$$\sum_j P_{ij} \ \leq \ P_{i\,max} \tag{4.4}$$

Power Balance Constraint

$$\sum_i P_{ij} \ = L_j + P_{Lij} \ \ (j = 1, \dots . J) \tag{4.5}$$

Non-negativity constraint

$$P_{ij} \ \geq 0 \tag{4.6}$$

Where,

Fi : Fuel Cost (Rp)
Ei : Emission of CO_2
a_i, b_i, c_i : coefficient of fuel cost curve for i-generation.
d_i, e_i, f_i : CO2 emission curve coefficient for i-generation
P_{ij} : Amount of electricity generator i sent to customer j (MW)
$P_{i\,min}$: Lower production limit for power plant-i (MW)
$P_{i\,max}$: The upper limit of production for power plant-i (MW)
L_j : Amount of demand for customers j (MW)
P_{Lij} : Losses on the transmission network between i and j (MW)

4.2. Supply and Demand Data

The SEED model is validated using the electric power system in East Kalimantan. For this validation, two data are needed, namely supply and demand capacity. Supply capacity in the form of generator characteristics as in Table 4.1. While the number of demand referred to as load is shown in Table 4.2.

Table 4.1. Generator constraint

Pi	Pi max (MW)	Pi min (MW)
P1	23.50	14.00
P2	16.00	5.00
P3	3.10	2.00
P4	3.60	2.00
P5	7.80	6.00
P6	14.20	5.00
P7	65.00	5.00
P8	10.00	7.00
P9	2.40	1.60
P10	1.00	0.00
P11	200.00	20.00

Table 4.2. Electricity demand under peak and low load conditions

Area	Peak load (MW)	Low load (MW)
L1	16.00	9.00
L2	16.81	11.34
L3	84.80	50.52
L4	25.19	11.57
L5	10.09	4.37
L6	18.70	12.65
L7	16.86	5.81
L8	15.40	7.20
L9	24.05	5.90
L10	8.00	4.80
L11	39.60	28.20
L12	67.90	43.50
Total	343.4	194.86

5. Results and Analysis

The SEED model is able to optimize power plants by minimizing fuel costs as the Economic Dispatch. In addition, this model is also capable of distributing electricity from a source to a destination as in the transportation model. The way the SEED model works is similar to the transportation model that has been enriched with an economic dispatch model so that the SEED model is able to perform joint optimization simultaneously between the generator side and the distribution side.

Table 5.1: Allocation of Loading of PLN Generators when the load is low

Pi	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	Total
P1	0.00	2.82	12.36	2.05	0.59	1.10	0.04	0.17	0.00	0.00	1.51	2.87	23.50
P2	0.00	0.00	10.50	0.00	0.00	0.31	0.00	0.00	0.00	0.00	1.63	3.56	16.00
P3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10	3.10
P4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60	3.60
P5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.80	7.80
P6	0.00	0.07	0.49	0.17	0.22	5.91	0.00	4.80	0.00	0.00	0.75	1.78	14.20
P7	8.46	7.64	24.58	6.14	1.97	2.03	0.26	0.64	0.00	0.05	1.96	3.12	56.85
P8	0.00	0.08	0.29	0.17	0.25	1.38	5.15	0.96	0.00	0.00	0.51	1.22	10.00
P9	0.00	0.02	0.11	0.02	0.01	0.66	0.00	0.01	0.00	0.00	0.42	1.16	2.40
P10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.92	1.00
P11	0.54	0.71	2.23	3.04	1.33	1.28	0.36	0.64	5.90	4.75	21.43	14.57	56.78
Supply	9.00	11.35	50.56	11.58	4.37	12.66	5.81	7.20	5.90	4.80	28.28	43.71	195.22
Demand	9.00	11.34	50.52	11.57	4.37	12.65	5.81	7.20	5.90	4.80	28.20	43.50	194.86
Loss	0.0004	0.01	0.04	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.08	0.21	0.36

On the generator side, the SEED model is able to optimize generator scheduling so that a minimum total fuel cost is obtained. To achieve this, the SEED model has determined the amount of production of each generator as Table 5.1. When the load is low, Generator 1 (P1) must produce as much as

23.50 MW, P2 as much as 16 MW, and then up to Generator 11. Not only determining the amount of production per generator, but the SEED model also optimizes the electricity distribution network. Production of P1 of 23.5 MW is sent to 9 areas, namely L2, L3, L4, L5, L6, L7, L8, L11, and L12 like Table 5.1. P2 production of 16 MW is sent to 4 areas, namely L3, L6, L11, and L12. The total electricity demand when the load is low is 194.86 MW, but the total production of all plants is 195.22 MW. There is a difference in the production of 0.36 MW as compensation for losses. This loss occurs due to the distance between the generator and the customer.

During peak loads, the SEED model is also capable of performing joint optimization. Electricity demand when the peak load is 343.4 MW, while the total production of all plants is 345.76 MW, there is a production difference of 2.36 MW which is used for losses on the network. P11 produces 199.16 MW. This makes P11 the largest supplier at peak times. P11 supplies to all areas, the largest supply in area 11 (L11) is 39.82 MW.

6. Conclusions

1. The SEED model is able to perform a joint optimization between the generator side and the distribution side simultaneously. Optimization on the generator side uses the most minimal fuel costs as a parameter, while optimization on the distribution side uses the most minimal distance. Optimization on the distribution side also produces a more detailed electricity distribution than the economic dispatch model.
2. The SEED model is able to make optimal generator scheduling during low loads and peak loads.

Acknowledgements

This research was funded by the Directorate of Higher Education Ministry of National Education Republic of Indonesia Fiscal Year 2019

References

[1] Wahyuda, Santosa B, Rusdiansyah A. Load allocation of power plant using multi echelon economic dispatch. In: AIP Conference Proceedings. 2017.

[2] Gani I, Wahyuda, Santosa B, Muliati. Multi Echelon Distribution Model for Electric Market Deregulation Collaboration Strategy in East Kalimantan Multi Echelon Distribution Model for Electric Market Deregulation Collaboration Strategy in East Kalimantan. In: IOP Conference Series: Materials Science and Engineering. 2019.

[3] Gani I, Wahyuda, Santosa B, Rusdiansyah A. Analysis of costs and emissions on the addition of production capacity of the power plant using multi echelon economic dispatch Analysis of Costs and Emissions on The Addition of Production Capacity of The Power Plant Using Multi Echelon Economic Dispatch. In: AIP Conference Proceedings [Internet]. 2019.

[4] Muslimin, Wahyuda, Tambunan W. Cooperation between power plant in East Kalimantan by integrating renewable energy power plant Cooperation between power plant in East Kalimantan by integrating renewable energy power plant. In: IOP Conference Series: Materials Science and Engineering. 2019.

[5] Wahyuda, Santosa B, Rusdiansyah A. Cost analysis of an electricity supply chain using modification of price based dynamic economic dispatch in wheeling transaction scheme. In: IOP Conference Series: Materials Science and Engineering. 2018.

[6] Hitchcock, F. L. The Distribution of a Product from Several Sources to Numerous Localities.In: *Journal of Mathematics and Physics*. 1941

[7] Pablo YO, Ramirez JM, Coello CAC. An optimal power flow plus transmission costs solution. Electr Power Syst Res. 2009;79:1240–6.

[8] Daskin MS. Network and Discrete Location. Model, Algorithm, and Applications. Vol. 1, Wiley Interscience Series in Discrete Mathematics and Optimization. Canada: John Wiley &

Sons, Inc; 1995.
[9] Sabbagh MS, Ghafari H, Mousavi SR. A new hybrid algorithm for the balanced transportation problem. Comput Ind Eng [Internet]. 2015;82:115–26.
[10] Estrada, H. Economical Load Allocations. In: *Electrical World*, *96*, 685–690.1930
[11] Stahl, E. C. Economic loading of generating stations. In: *Electrical Engineering.* 1931
[12] Wilstam, A. Dividing load economically among power plants by use of the kilowatt. In: *Journal of the A.I.E.E*, *47*(6), 430–432. 1928
[13] Steinberg MJ, Smith TH. Incremental loading of generating stations. Electr Eng. 1933;52(10):674–7.
[14] El-Hawary ME. Electrical Power Systems: Design and Analysis. New York: IEEE Press Power Systems Engineering Series; 1995.