Assessment on Average Participation Versus Bialek's Methods for Transmission Usage Evaluation Scheme

N. S. Ahmad, N. H. Radzi, S. A. Jumaat, M. N. Abdullah, and S. Salimin

Abstract Nowadays, most developing countries have been moved toward the energy restructuring market. There have several primaries in energy elements within this deregulation scheme which are power generation, transmission, and distribution firms. One of the problems that arise with respect to transmission utility is the development of a fair and equitable methodology for the price of transmission that already used by consumers. An effective method of transmission price assessment is an important framework that needs to be built in the transmission pricing methodology in order to solve the problem that arises in the transmission pricing. Next, a direct current load flow (DCLF) approach needs to be used to define the network power flow for each line. By using the Power World Simulator software, the results using the DCLF approach that was used in this research was been specified accurately and correctly. the power contribution for each transmission line that used it either generation or distribution line will be identifiable to ease and solve problems that arise in this transmission pricing. The method that was used to investigate this problem using in this research is Average Participation and Bialek's methods. In order to investigate the problem that arises in the transmission pricing issues, Average Participation and Bialek's methods were used in this research to solve the problem. For the case study, used IEEE 14 bus systems and the simulation has been carried out using the Matlab software. Then, the results for Average Participation and Bialek's methods were compared for identifying and determining the best approach in this transmission usage evaluation scheme.

Keywords Deregulation scheme · Transmission pricing · Average participation method · Bialek's method

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1 Introduction

In Malaysia, three entities which are generation, transmission and distribution are controlled by Tenaga Nasional Berhad (TNB). Hence, all the electrical charge from the generation to distribution should be pay to TNB. The electricity industry in other countries like the United States indeed has long been privately owned. By owning a private company this will increase competition and decreased regulation [1, 2]. However, it is different for developing countries which the electricity business is managed by different companies such as generator companies (GENCOs), transmission companies (TRANSCOs) and distribution companies (DISCOs). The new scheme established free access to the transmission lines and boosting competition among generator and customer. In this situation, the transmission line is the key factor of the electricity markets. To deliver energy from generation to load, transmission is an important role as a separate business. There have many issues arise in transmission pricing. The transmission pricing methodology is a connection charge, interconnection charge, service charge that imposed on power generation and distribution. There have six principles of transmission pricing that should be followed when designing electricity transmission prices. This principle was organized by the Energy Modelling Forum of Stanford University [3].

One of the transmission pricing issues is determining the efficient transmission usage allocation method. Transmission system usage (TSU) cost allocation problem is a complex problem [4]. The purpose of this scheme is to identify the power usage of transmission users to the networks. Hence, in this paper, two methods were explored which are the Average Participation and Bialek's methods in order to determine the best method for transmission usage evaluation scheme. The Average Participation method deals when the net power flow is determined. The idea is to determine the participation share of the generators and loads in the flow of all elements [5]. In this case, the flows of electricity trace from a generator to its consumption buses while the Bialek's method is an algorithm which works only on lossless flows when the flows at the beginning and end of each line are the same [6–8].

1.1 Transmission Usage Evaluation Scheme

Accurate erudition in transmission usage is basically important in the performance of usage-based expense allocation methods. In theory is immensely difficult to decompose the network flows into components linked with individual customers based on the nonlinear nature of power flow equations, On the contrary, from an engineering point of opinion, it is a likelihood and tolerable to request approximate models or sensitivity indices to define the contributions to the network flow from individual user [9]. The DC power flow is considered as this is the simplest way to calculate the actual power flow that flows for each line which is the net power flow at the transmission lines rather than AC power flow method. The net power flow for each line can be calculated by using Eqs. (1)–(7).

$$P_{ij} = -X_{ij}^{-1}\theta_{ij} \tag{1}$$

where,

$$\begin{aligned} P_{ij} &= circuit\ flow\ (p.u) \\ X_{ij} &= circuit\ reactance\ (p.u) \\ \theta_{ij} &= angle\ between\ the\ buses\ i\ and\ j\ (rad) \end{aligned}$$

$$P_i = P_{Gi} - P_{Li} \tag{2}$$

where,

$$\begin{aligned} P_i &= net\ injection \\ P_{Gi} &= MW\ of\ generator\ at\ bus\ i \\ P_{Li} &= MW\ of\ load\ at\ bus\ i \end{aligned}$$

In matrix form:

$$[P_i] = \left[B_{ij}\right] \times \left[\theta_{ij}\right] \tag{3}$$

$$B_{ij} = -X_{ij}^{-1} \tag{4}$$

$$B_{ii} = \sum X_{ij}^{-1} \tag{5}$$

where,
[B] = the bus susceptance matrix

Matrix B:

$$B = \begin{bmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{bmatrix}$$

Let B = 0, matrix is singular, no inverse (delete row 1and column 1-reference bus)

$$[P] = \left[B'\right] \times [\theta] \tag{6}$$

From (3) the value of angle can be calculated as below:

$$[\theta] = \left[B'\right]^{-1} \times [P] \tag{7}$$

After identified the net power flow of each line, the power contribution can be determined by using the transmission usage evaluation schemes. In this paper, the Average Participation and Bialek's methods were used in order to identify the best method for transmission usage evaluation scheme. The flowchart in Fig. 1 shows the

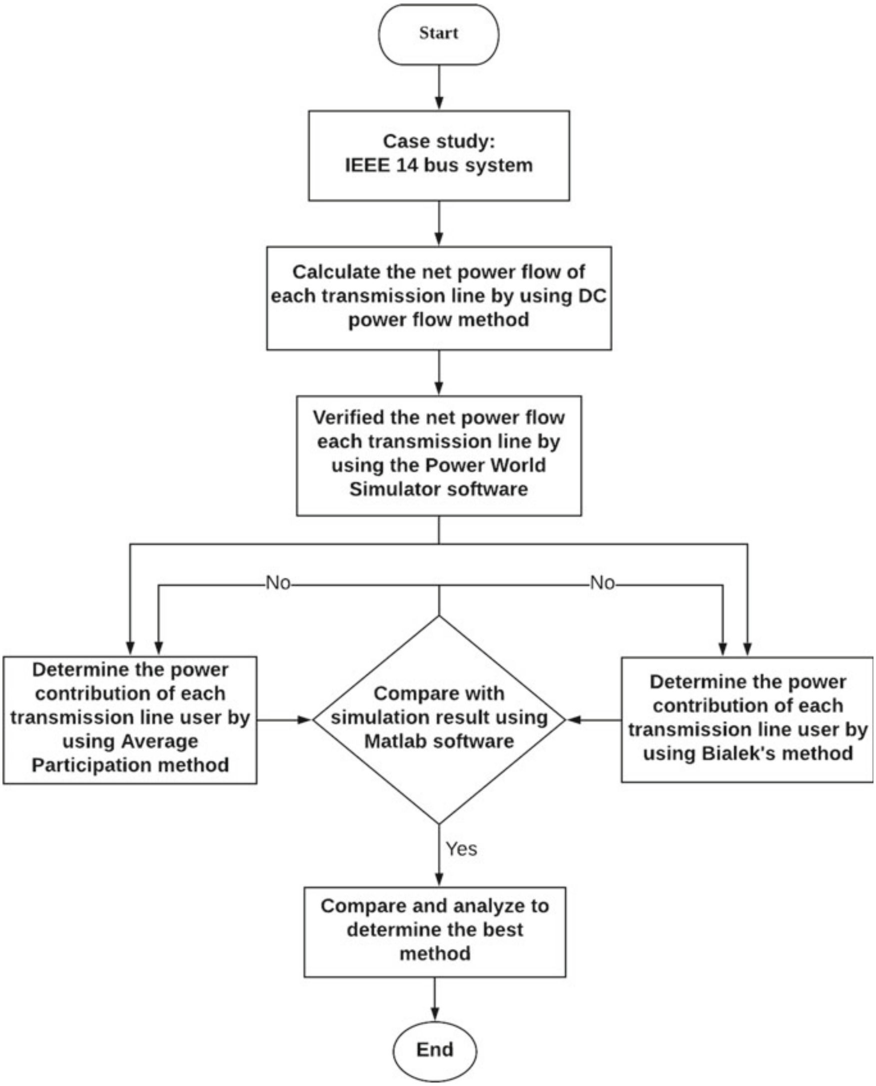

Fig. 1 Flowchart of research methodology

summarization of the transmission usage evaluation process for both methods that has been used in this research.

1.2 Average Participation Method

Complete power flow is needs as an input replying to the required system condition of importance in the Average Participation method. Based on an algorithm, the assumption that electricity supply flows can be detected or the responsibility to produce can be tasked by supposing at any network node and the inflows being distributed proportionally between the outflows [9]. Each generator is injecting power into the network then power flow starting at the generator into the grid until that reach certain loads. By using Average Participation method, the calculation uses the nodal method to calculate the power flow usage each line at the transmission line. The calculation of Average Participation method will use Eq. (8) and Eq. (9).

For generator:

$$L_{ij} = \frac{G_x}{G_T} \times l_{ij} \tag{8}$$

where,

$$\begin{aligned} G_x &= Generation\ at\ bus\ x\ (MW) \\ G_T &= Total\ power\ of\ generation\ (MW) \\ L_{ij} &= Power\ contribute\ to\ line\ i - j \\ l_{ij} &= Power\ flow\ at\ line\ i - j \end{aligned}$$

For load:

$$L_{ij} = \frac{L_x}{L_T} \times l_{ij} \tag{9}$$

where,

$$L_x = Load\ at\ bus\ x\ (MW)$$

$$L_T = Total\ power\ load\ (MW)$$

1.3 Bialek's Method

Bialek's method is used to determine the power usage at of each transmission line for transmission usage evaluation method that used for transmission pricing and also to know the fixed costs at the transmission line [10]. Generally, this method is the proportional sharing principle and uses a topological approach to determine the contribution of individual generators or loads to every line flow. By using Bialek's method, which will assume the nodal inflows is share proportionally between nodal outflows. To calculate the power flow for each line at the transmission by using the Bialek's method, there have two algorithms which are the downstream-looking and upstream-looking method. The calculation of Bialek's method will use Eqs. (10)–(17).

If using the upstream-looking method, the power injection in each bus to the generator is given by [10]:

$$P_i^g = \sum_{j \in \alpha_i^u} \left| P_{ij}^g \right| + P_{Gi} \quad \text{for i} = 1, 2, \ldots, \text{n} \tag{10}$$

where,

$$\begin{aligned} P_i^g &= an\ unknown\ gross\ nodal\ power\ flow\ through\ node\ i \\ P_{ij}^g &= an\ unknow\ gross\ line\ flow\ in\ line\ i - j \\ \alpha_i^u &= set\ of\ buses\ suppliying\ directly\ bus\ i \\ P_{Gi} &= generation\ in\ node\ i \end{aligned}$$

For the downstream-looking method, the power passing through each bus to the loads is given by [6]:

$$P_i^g = \sum_{j \in \alpha_i^u} \left| P_{ij}^g \right| + P_{Li} \text{ for i} = 1, 2, \ldots, \text{n} \tag{11}$$

where,

$$P_{Li} = load\ in\ node\ i$$

After that, eliminating the losses it will be, $\left| P_{ij}^g \right| = \left| P_{ij}^g \right|$. Then, the line flow $\left| P_{ij}^g \right| = \left| P_{ij}^g \right|$ can be related to the nodal flow at the node j by substituted the $\left| P_{ij}^g \right| = c_{ij} P_j^g$. So, simplify the equation that will become:

$$P_i^g = \sum_{j \in \alpha_i^u} c_{ij} P_j^g + P_{Gi} \tag{12}$$

where,

$$c_{ij} = An\ unknown\ gross\ line\ flow\ in\ line\ i - j\ divide\ by\ an\ unknown\ gross\ nodal\ power\ flow\ through\ node\ i$$

Then can simplify the equation:

$$P_g = A_u P_G \tag{13}$$

$$[A_u]_{ij} = \begin{cases} 1 & i = j \\ -c_{ij} = -\frac{\left|P_{ij}^g\right|}{P_j^g} & j \in \alpha_i^u \\ 0 & otherwise \end{cases} \tag{14}$$

where,

$$A_u = upsteamdistributionmatrix$$

Invert matrix A_u:

$$P_g = A_u^{-1} P_G \tag{15}$$

The gross power at node i:

$$P_i^g = \sum_{k=1}^{n} [A_u^{-1}]_{ik} P_{Gk} \tag{16}$$

where,

$$P_{Gk} = generationinnodek$$

Then, the gross outflow of line i-j by using the proportional sharing principle is given as:

$$P_{ij}^g = \frac{P_{ij}^g}{P_i^g} \sum_{k=1}^{n} [A_u^{-1}]_{ik} P_{Gk} \quad \text{for i} = 1, 2, \ldots, \text{n} \tag{17}$$

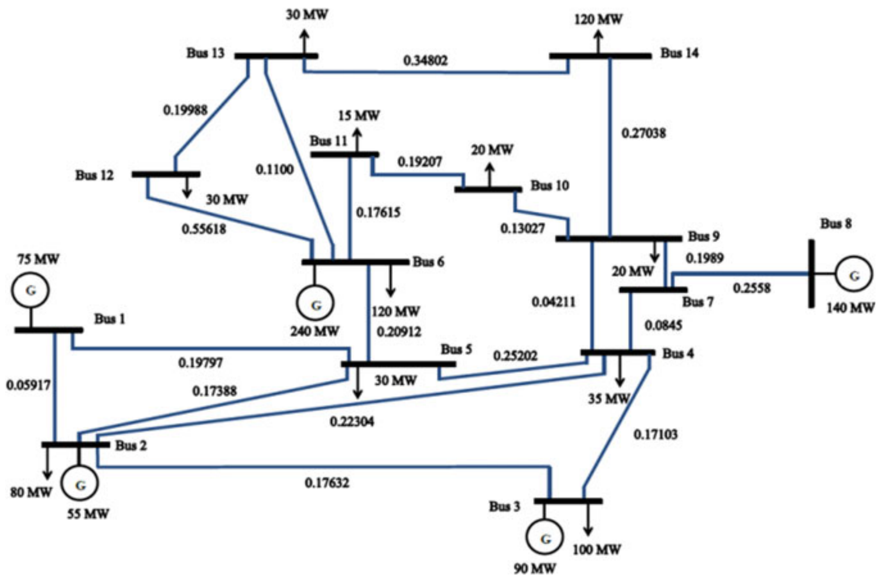

Fig. 2 IEEE 14-bus system [11]

1.4 Case Study

The proposed approach has been tested on IEEE 14-bus system. This case study was based on DC power flow and tested by using Power World Simulator and Matlab programming system. The IEEE 14-bus system is shown in Fig. 2.

Figures 3 and 4 show the result of power flow contribution for each generator and load to networks using Average Participation method for IEEE 14 bus system.

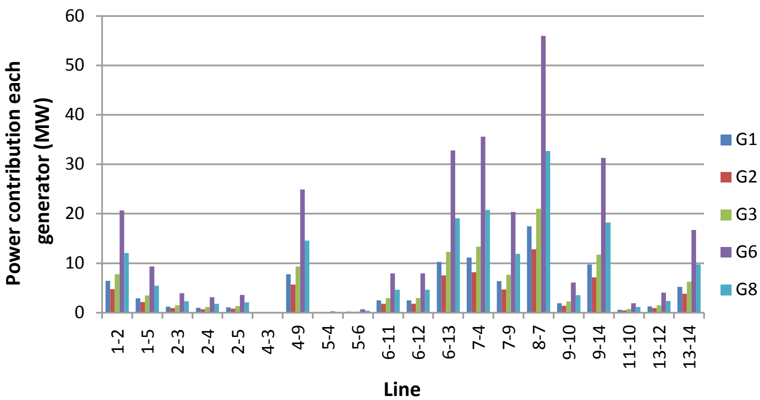

Fig. 3 Power contribution for each generator to networks by using average participation method

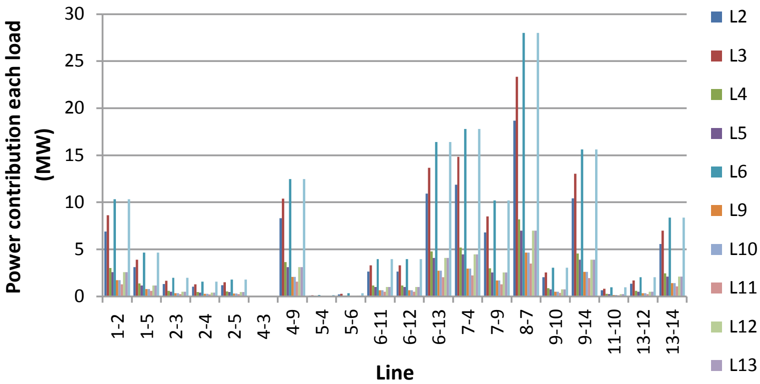

Fig. 4 Power contribution of IEEE 14 bus system for each load to networks by using average participation method

From these both figures, it can be seen that the generators and loads for this method have contributed power flow for each line and follows the nature of power injection. Based on that, all elements have contributed power in each transmission line when the power was injected. It is because the assumption that electricity supply flows can be detected or the responsibility to produce can be tasked by supposing at any network node and the inflows being distributed proportionally between the outflows.

Meanwhile, Figs. 5 and 6 show the result of power flow contribution for each transmission users to the transmission line using Bialek's method. Based on these both figures, it can be seen that for Generator 3, Load 4 and Load 13 have no power contribution for all transmission lines where the value is 0 MW. Load 14 only contribute the power flow at line 11-10 otherwise no power contributes at other lines.

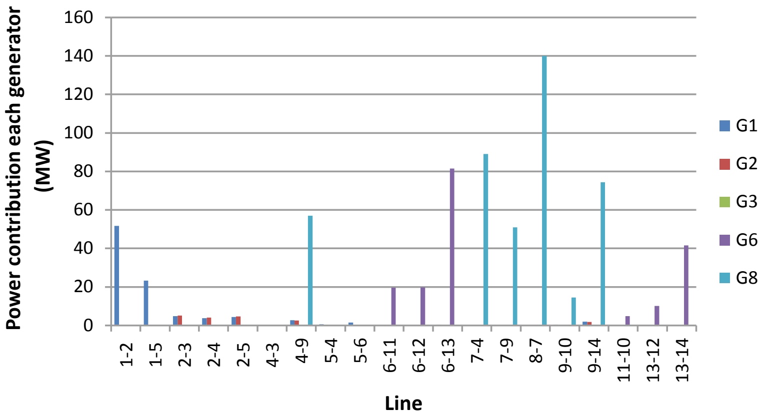

Fig. 5 Power contribution of IEEE 14-bus system for each generator to networks by using Bialek's method

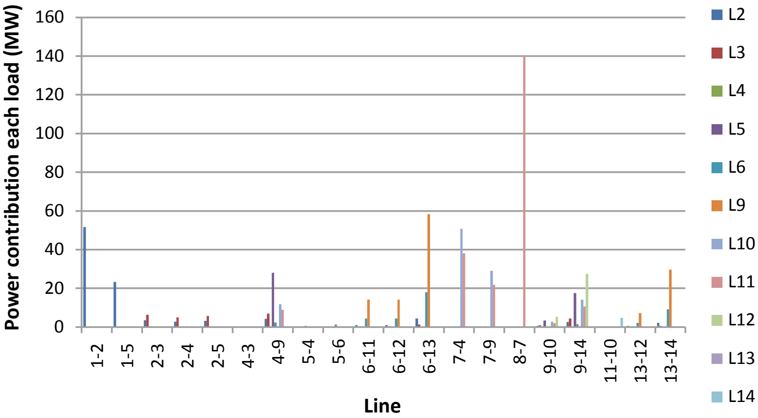

Fig. 6 Power contribution of IEEE 14 bus system for each load to networks by using Bialek's method

This is because of the Bialek's method applied the proportional sharing principle and uses a topological approach to determine the contribution of individual generators or loads to every line flow.

By comparing both of the methods that used in this research, for Average Participation method, each network have the power flow contribution from each user. Meanwhile, for Bialek's method there has no power contribution from few generators and loads to the networks. Based on the nature power injection, all users will be using the transmission services.

2 Conclusion

This paper has presented the assessment on the Average Participation method versus Bialek's method for transmission usage evaluation scheme. In this research work, the Average Participation method is the best method for transmission usage evaluation scheme in order to determine the power flow contribution of each transmission users to each network. The results show that this method has followed the nature of power injection where all the elements of the transmission lines used the networks when power was injected. In addition, with the implementation of this method will leads to fair and equitable transmission service charges scheme.

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