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Research paper

Assessment of Justified Distribution Factors Versus Bialek's Methods for Transmission Usage Evaluation

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Abstract

In restructuring electricity market, the electricity business has been separated to three major parts which are generation, transmission and distribution companies. For transmission, the most important component is the transmission line because transmission lines transmitting the power flow from generation to distribution. One of the issues of transmission utility is allocating the charges to the transmission user. The charges must be fair and accurate to all of the transmission users. In addition, an efficient transmission usage evaluation is important to be developed for determining the actual power usage of generators and loads to transmission line. Hence, this paper presents the assessment of Justified Distribution Factors versus Bialek's methods for determine the efficient transmission usage scheme. The DC power flow method is used in this project as the transmission utilities prefer to choose this simple and easy method in determining the transmission service charges. A case study on 4 bus system was carried out in order to test the developed methodology. Power World Simulator also was used in order to identify the net power flow of each line. In conclusion, this paper focuses on to identify the best method of transmission usage evaluation for transmission service charge methodology.

Keywords: *Bialek method; DC power flow; Distribution Factor method; restructuring electricity market; transmission usage evaluation*

1. Introduction

Presently, electric utilities have demand to increase the efficiency in supply energy and lower the cost of operation. Electric utilities consist of three components which are distribution, transmission and generation. Each component has pricing services where for the transmission utility, the transmission pricing method is important in balancing the transaction from generator to the load. Besides that, it can create system integrity with all treated equally and no discrimination. By the deregulation of electric power industry, the transmission company will distribute its price to every user of its transmission facilities. The fair method for charging the transmission users for the usage of transmission facilities and in addition, allowing the transmission utilities to recover their transmission costs was one of the important issues for the transmission utilities. In order to recover the transmission revenues and to estimate the power contributed by the generators and loads, several methodologies have been developed. These methods are used to allocate the charge to the transmission users based on the usage of transmission lines [1].

2. Transmission Usage Evaluation

An efficient transmission service scheme should recover transmission service charges by allocation the costs to transmission users in an accurate and fair way. The usage–based cost allocation methods need an accurate knowledge of transmission usage to balance the cost between the transmission users. However, due to the nonlinear nature of power flows, it is very hard to allocate the network flows into components associated with individual line users. However, from the point of view of an engineering side, the contributions from individual user to the lines can be determined by applying the approximate models or sensitivity indices [2]. There are numbers of transmission usage evaluation methods that have been proposed based on direct current (DC) and alternate current (AC) model [3, 4]. However, the transmission utilities prefer to choose DC based method as this approach is more simple and easy to implement. Hence, in this project, two of the DC power flow based methods are investigated which are Justified Distribution Factors and Bialek's methods. Both methods are based on the model of DC, hence only the active power flow is considered [5].

2.1. Justified Distribution Factors (JDFs) Method

Based on [6-8], Justified Distribution Factors (JDFs) method was used for determining the usage of power for each transmission users to the network flows. In [9], these JDFs also were used for allocating the cost for transmission congestion case in restructuring electricity markets. This method uses the Generation Shift Distribution Factors (GSDF) of A factor [10] in order to obtain the JDF factor. The JDFs were superior to the original Distribution Factors method as even though different reference bus was chosen, the elements in the distribution matrix are similar. JDFs are designed by adding a justification factor Jij to the DFs where mathematically [7-8]:

$$J_{ij}^{m} = -\frac{DF_{ij}^{m}(i)+DF_{ij}^{m}(j)}{2} \quad (1)$$

$$JDF_{ij}^{m} = DF_{ij}^{m} + J_{ij}^{m}\{1\} \quad (2)$$

Arithmetic shows that:

$$JDF_{ij}^{m}(i) = JDF_{ij}^{n}(i) \quad (3)$$

The net power flow for line *i* can be traced using equation (4):

$$P_i = \sum_j^m JDF_i^j . P_j \quad (4)$$

2.1.1 Generalized Generation Justified Distribution Factors (GGJDFs) or JD Factors

GGJDFS or JD factors are used to estimate the usage of power for each generator to network flows. In [7-8], these factors can be determined by using equation (5) and (6).

$$JD_{i-j,g} = JDF_{i-j,g} + JD_{i-j} \quad (5)$$

where:

$$JD_{i-j} = \frac{(F_{i-j} - \sum_g JDF_{i-j,g} \times G_g)}{(\sum_g G_g)} \quad (6)$$

JD factors, *JDi-j,g* denotes the generation *Gg* in a given bus *g* with actual power flow *Fi-j* in a line *i-j*:

$$F_{i-j} = \sum_g JD_{i-j,g}\, G_g \quad (7)$$

GGJDFs measure the amount of usage of transmission line facilities generated by the power injection of generator. GGJDFs depend on the line parameter, state system, and independent on the bus location reference.

2.1.2 Generalized Load Justified Distribution Factors (GLJDFs) or JC Factors

The power injection of load to the transmission line can be determined by using GLJDFs. These factors are also formulated based on JDFs [7-8]:

$$JC_{i-j,d} = JC_{i-j} - JDF_{i-j,d} \quad (8)$$

where $JC_{i-j} = \frac{(F_{i-j} + \sum_d JDF_{i-j,d} \times L_d)}{(\sum_d Ld)}$ (9)

The actual power flow *Fi-j* in a line *i-j* can be traced by relating the JC Factors with load, *Ld* in a given bus *d*:

$$F_{i-j} = \sum_j C_{i-j,d}\, L_d \quad (10)$$

JC factors measures the amount of usage of transmission network facilities by the burden which many see as a negative injection. As GGJDFs, GLJDFs also depend on the line parameter, state system, and not on the bus location reference.

2.2. Bialek's Tracing Algorithm

In a pool based market, the Bialek's tracing algorithm is designed for the recover of transmission revenues [10]. The proportional sharing principle is used in this method where the nodal power inflows are shared proportionally among the nodal power outflows. Bialek's tracing algorithm has two versions of power flow which is upstream-looking algorithm and downstream-looking algorithm [9-10]. If using upstream-looking algorithm, the power injection for each bus of the system are determined by [10]:

$$P_i = \sum_{j \in \alpha_i^u} |P_{i-j}| + P_{Gi} \qquad i = 1, 2,...,n \quad (11)$$

Otherwise, if using downstream-looking algorithm, the power passing through each bus to the loads is calculated by [11]:

$$P_i = \sum_{j \in \alpha_i^u} |P_{i-j}| + P_{Li} \qquad i = 1, 2,...,n \quad (12)$$

Then, eliminated the losses it become, |P i-j| = |P j-i|. The line flow |P i-j| =|P j-i| can be related to the nodal flow at at node *j* by substituting | P i-j|= cijPj, where cij= |P j-i| / Pj to give:

$$P_i = \sum_{j \in \alpha^{(u)}} c_{ij} P_j + P_{Gi} \tag{13}$$

After rearrangement it becomes,

$$P_i - \sum_{j \in \alpha^{(u)}} c_{ij} P_j = P_{Gi} \tag{14}$$

Then simplify the equation it becomes,

$$A_u P = P_G \tag{15}$$

Where:
Au = upstream distribution matrix

The Au is n x n distribution matrix per injected powers, P is the vector of bus flows and PG is the vector of bus generations. The elements of matrix Au are defined as follow:

$$[A_u]_{ij} = \begin{cases} 1 & for\ i = j \\ -c_{ji} = \dfrac{|-P_{j-i}|}{P_j} & for\ j \in \alpha_i^u \\ 0 & e.o.c \end{cases} \tag{16}$$

Where, *j* must be a bus that supplies power to *i*.
if Au^{-1} exists, then the vector P = Au^{-1}. PG and its elements are equal to:

$$P_i = \sum_{k=1}^{n} \left[A_u^{-1}\right]_{ik} .P_{GK} \qquad for\ i = 1,2,..,n \tag{17}$$

Where:
P_{GK} = generation in node *k*

Therefore, the power usage for each generator to networks can be traced is equal to:

$$P_{ij} = \frac{P_{ij}}{P_i} \sum_{k=1}^{n} \left[A_u^{-1}\right]_{ik} P_{GK} \tag{18}$$

3. Case Study

This research reports on the case study of 4-test bus system as shown in Figure 3.1 in order to compare the transmission usage evaluation using two methods which are JDFs and Bialek's tracing schemes. The bus system is consists of 4 bus, 5 lines, 2 generators and 2 loads. The generator 1 (G1) and generator 2 (G2) injects power of 380MW and 120MW respectively. While, load 3 (L3) and load 4 (L4) received power of 300MW and 200MW from G1 and G2. The bus data of 4-test bus system was tabulated in Table 1.

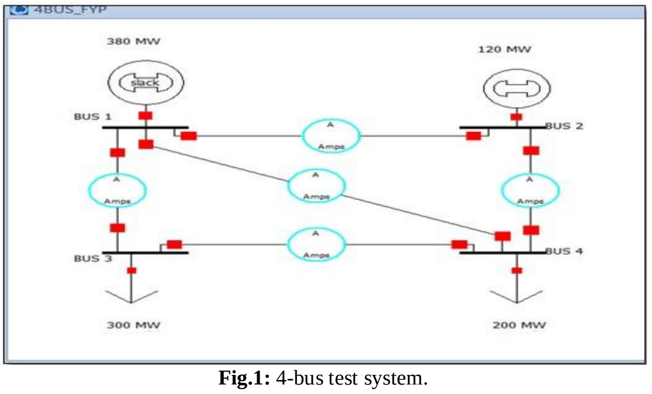

Fig.1: 4-bus test system.

Table 1: Line data of 4-test bus system.

From	To	Resistance, R (p.u)	Reactance, X (p.u)
1	2	0.06	0.18
1	3	0.05	0.10
1	4	0.05	0.18
2	4	0.05	0.02
4	3	0.06	0.18

The 4-test bus system is simulated using Power World Simulation [13] in order to estimate the net power flow of individual line. Then, the calculation in power contribution using JDFs and Bialek's method was carried out.
For JDFs method, there are number of steps for the calculation of the matrix before continuing on determination of the GGJDFs and GLJDFs.

Step 1: Determine the position of the matrix using the equation:
$B_{i\text{-}j} = -1 / X_{ij}$,

where Xij is a line reaction (19)

$$B_{ii} \text{ or } B_{jj} = \sum X_{ij} - 1^{-1} = 1/X_{ij} + 1/X_{ij} \quad (20)$$

Step 2: Determine the inverse matrix using the determining factor (determinant)

$$M = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$$

$$Det(M) = [a \times (ei - fh)] - [d \times (bi - ch)] + [g \times (bf - ce)] \neq 0 \quad (21)$$

$$M = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix} M^T = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$$

Find determinant of a 2x2 matrix

$$M_{11} = \begin{vmatrix} e & h \\ f & i \end{vmatrix} M_{12} = \begin{vmatrix} e & h \\ f & i \end{vmatrix} M_{13} = \begin{vmatrix} e & h \\ f & i \end{vmatrix}$$
$$M_{21} = \begin{vmatrix} d & g \\ f & i \end{vmatrix} M_{22} = \begin{vmatrix} a & g \\ c & i \end{vmatrix} M_{23} = \begin{vmatrix} a & d \\ c & f \end{vmatrix}$$
$$M_{31} = \begin{vmatrix} d & g \\ e & h \end{vmatrix} M_{32} = \begin{vmatrix} a & g \\ b & h \end{vmatrix} M_{33} = \begin{vmatrix} a & d \\ b & e \end{vmatrix}$$

Find the inverse matrix by dividing adjugate found in the previous step and determinant from the first step.

$$M^{-1} = \frac{1}{det\,(M)} \begin{pmatrix} a_{new} & d_{new} & g_{new} \\ b_{new} & e_{new} & h_{new} \\ c_{new} & f_{new} & i_{new} \end{pmatrix} \quad (22)$$

Step 3: The value of A factor can be determined using the equation:

$$A_{i-j,b} = \frac{Z_{ib} - Z_{jb}}{X_{i-j}} \quad (23)$$

Step 4: The value of JDFs factor can be obtained using equation (3) until (5).
Step 5: Equation (6) is used to identify the net power flow of each network.
Step 6: The GGJDFs and GLJDFs are used to allocate the power usage of each generation and load to the networks.
Overall flowchart for this project is shown in Figure 2.

Figure 3 shows the simulation of 4-test bus system in the run mode using Power World Simulator [14]. From Table 2, the net power flow for L_{12} is 58.48 MW, L_{13} is 243.20 MW, L_{14} is 78.31 MW, L_{24} is78.31 MW and L_{43} is 56.80 MW. The results were used for verification when using the calculation method.

Figure 4 and 5 show the usage of each generator to the networks using GGJDFs and Bialek's methods, respectively. Comparing both of the figures, GGJDFs shows that both generators used the transmission line meanwhile for Bialek's method, the generator 2 does not injecting power to the transmission line 1-2, 1-3 and 1-4 as it indicates 0 MW for those lines. This shows that, in Bialek's method only generator 1 contribute power in line 1-2, 1-3 and 1-4 while generator 2 did not contribute at all in the particular line. Basically, all of the element will contribute power in each transmission line when the power was injected. Generator 1 and 2 contributed power in all transmission line by using GGJDFs method as shown in figure 4. The negative power flow indicates that the generator has relieved the transmission congestion for the related transmission lines. Figure 6 shows the power flow contribution of each load using GLJDFs method. Meanwhile, Figure 7 shows the usage of each load to the networks using Bialek's method. From both figures, it can be seen that for GLJDFs method, both loads have been using the transmission system and follows the nature of power injection. However, for Bialek's method, the power contribution of load 2 only for line 2-4 and 4-3, while no power contribution for other lines.

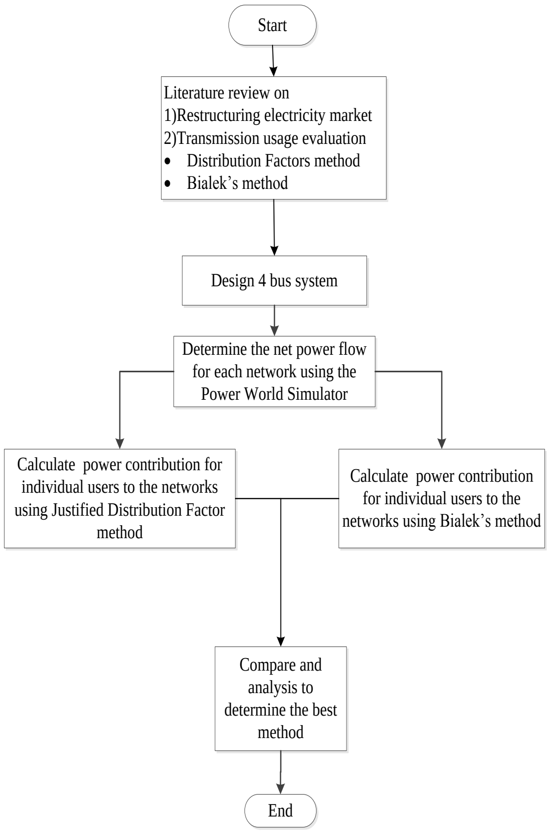

Fig. 2: Flow chart of the project.

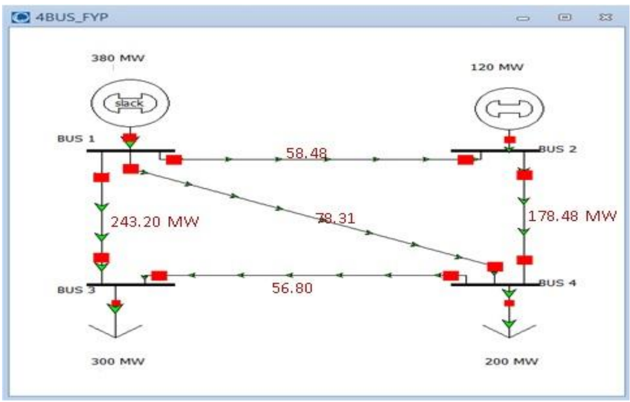

Fig. 3: Simulation results using power world simulator software.

Table 2: Net power flows for each transmission line.

From	To	Net power flow (MW)
1	2	58.48
1	3	243.20
1	4	78.31
2	4	178.48
4	3	56.80

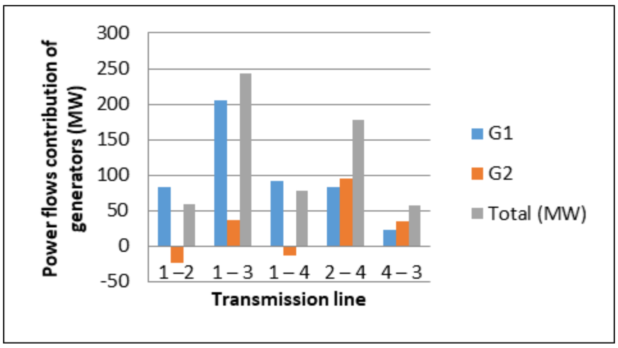

Fig. 4: The power usage for each generator to networks using GGJDFs method.

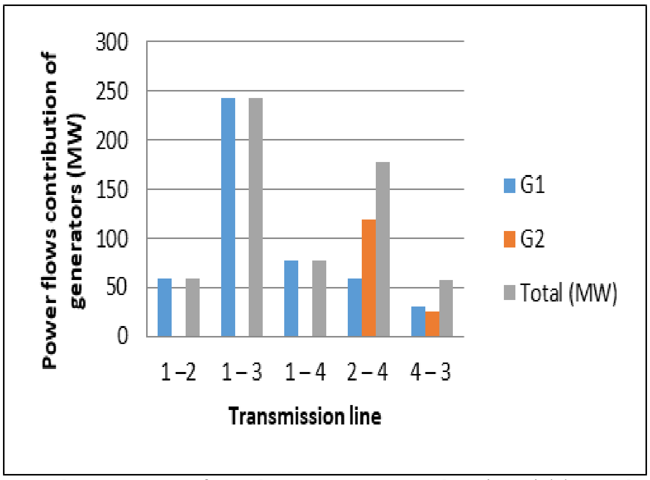

Fig. 5: The power usage for each generator to networks using Bialek's method.

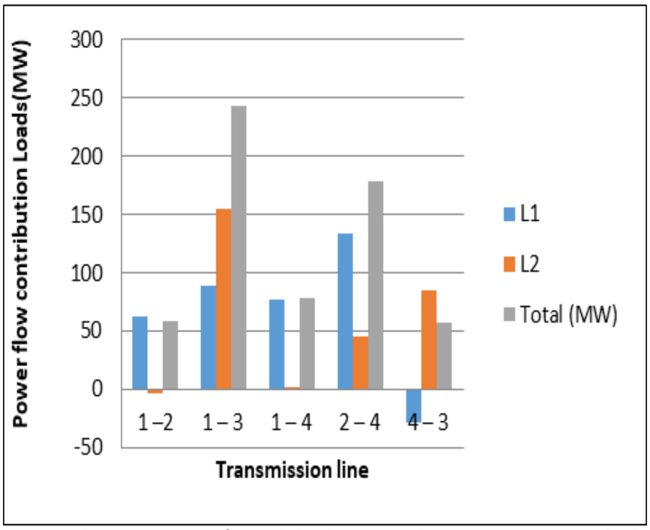

Fig. 6: The power usage for each load to networks using GLJDFs method.

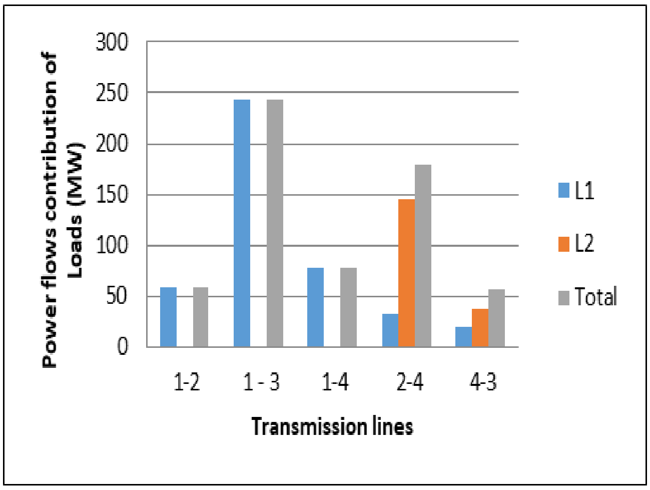

Fig. 7: The power usage for each load to networks using Bialek's method.

4. Conclusion

This paper has presented the assessment on the Justified Distribution Factors versus Bialek's methods for transmission usage evaluation. The Justified Distribution Factors was based on the transaction-related net power injections which is only to generators and only to loads. Meanwhile, Bialek's method applied the proportional sharing principle where the nodal inflows are shared proportionally among the nodal outflows. Therefore, from the results it shows that the Justified Distribution Factors method is more efiicient than Bialek's method. Moreover, proportionality principle by Bialek's method shows that there are power injection to the lines and others evacuate the power for any bus bar. It is totally different with Justified Distribution Factors method where the power contribution in each transmission line caused by all elements involves in the system. In addition, this will lead to a fair and efficient transmission pricing methodology.

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