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Wheeling Charges Methodology for Deregulated Electricity Markets using Tracing-based Postage Stamp Methods

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Abstract: MW-mile and Postage-stamp methods is traditionally used by electric utilities to determine a fixed transmission cost among users of firm transmission service. MW-Mile method is charging the users by determining the actual paths the power follows through the network. However, this method is not sufficient to recover the total transmission system cost. To recover the total transmission system cost, the Postage Stamp Method is adopted. This method is simple but its main drawback is that the charges paid by each user do not reflect the actual use of the network but based on the average usage of the entire network. This paper proposes a new wheeling charges methodology using tracing-based postage stamp methods. The proposed method allocates transmission costs among the generators proportional to the total power delivered to the load through transmission lines. The proposed method incorporates with generalised generation distribution factors to trace the contribution of each generator to the line flow. One unique feature of the proposed method is the consideration of the local load on the power flow allocation. Two case studies of 3-bus and IEEE 14-bus systems are used to illustrate the proposed method. Results show that the proposed method provides fair and equitable wheeling charges to generators reflecting the actual usage of the transmission system.

Keywords: Postage Stamp method, MW-Mile method, generalized generation distribution factors, wheeling charges.

1. Introduction

The electric utility industry throughout the world has been undergoing significant changes due to the process of deregulation. Under the deregulation scheme, electricity businesses have unbundled into three components: generation, transmission and distribution. The interaction among these components would be on pure commercial basis. In the case of transmission, transmission (wheeling) services represent unbundled services. Since then, the pricing of the transmission services has become one of the major issues. The pricing issue refers to the way the cost of transmission services is satisfactorily allocated among all involved participants, taking into account as accurately as possible the real impact of every transaction on the transmission system. Moreover, as power flows influence transmission charges, transmission pricing may not only determine the right entry but also encourage efficiencies in power markets. A proper transmission pricing could meet revenue expectations, promote an efficient operation of electricity markets, encourage investment in optimal locations of generation and transmission lines, and adequately reimburse owners of transmission assets. Most importantly, the pricing strategies that could be implemented should be fair and practical [6].

Many methods have been used or proposed to evaluate the cost of transmission services. Most methods attempt at least two basic measurements: the amount of transmission capacity used and the per-unit cost of transmission capacity [4]. These methods can be classified into one of these categories; embedded cost, incremental or marginal cost. The concept of these methods has been discussed by some of the authors [1], [2], [4], [5] to show their ability to provide reasonable economic signal. Among these methods, the embedded cost method is commonly used throughout the utility industry. This method offered several benefits, i.e. practical and fair to all parties and easy to measure and provides an adequate remuneration of transmission systems.

There are four types of embedded cost methods extensively used to allocate the transmission transaction cost namely; postage stamp, contract path, distance based MW-mile and power flow based MW-mile method. The MW-mile method is more widely used as a basis of locational use of system charges since it has been shown to be more reflective of actual usage of the transmission system in allocating the transmission cost. This method allocates the charges for each wheeling participant based on the extent of use of transmission facilities by their transactions [3], [7]-[10]. These allocated charges are then added up over all transmission facilities to evaluate

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the total price for use of transmission system. Meanwhile, the postage stamp method is commonly used by transmission utility to remunerate the remaining total transmission cost [11]-[13], [16].

This paper proposes a new method for allocating wheeling charges among the generators in transmission services using a tracing-based postage stamp method. In the proposed method, the existence of local load on the power flow allocation is considered in determining the charges based on postage stamp method. This method is incorporated with the Generalized Generation Distribution Factor to trace the power contribution of each user to the line flow. Two case studies of 3 bus and IEEE 14 bus systems are used to illustrate the proposed method. Results show that the proposed method has a merit over the traditional postage stamp method in the context of fair and accurate charges to the generators for the use of the network.

This paper is organized as follows. In section II, the transmission service charge methods are described in the context of their capability in recovering the cost of transmission services. The traditional postage stamp method and the proposed method is explained and formulated in Section III. In section IV, case studies results are presented to highlight the merit of the proposed method over the traditional postage stamp method that is commonly used by transmission utilities in providing a fair and equitable transmission charges to reflect the real usage of transmission network. Section V concludes the paper.

2. Transmission Service Charge Method

In the context of recovering the cost of transmission services, the transmission utilities must have a means to charge for the transmission services rendered. This is to ensure that they are able to recover the transmission revenue requirement. Revenue requirement of transmission service reflects the costs associated with all components needed to pay for a transmission facilities such as return of investment (usually depreciation), taxes and expenses (operating, maintenance, administrative and other expenses that are related or allocated to the facility). The cost of facility depends on whether the cost basis is embedded, incremental or marginal.

As mentioned earlier, embedded cost methods are commonly used throughout the utility industry to allocate the cost of transmission services. These methods have been suggested to allocate such pricing since the application of marginal cost in pricing the transmission services is not effective mainly due to revenue reconciliation problems. In these methods, transmission system is assumed to be one integrated facility and all costs to meet transmission system revenue requirements are distributed across all customers. There are four types of embedded cost methods extensively used to allocate the transmission transaction cost namely, postage stamp method, contract path method, distance based MW-mile method and power flow based MW-mile method. These methods which have pros and cons in allocating the transmission cost has been discussed extensively by some authors [5], [14].

In postage stamp method, transmission charges are allocated based on average embedded cost and the magnitude of transacted power. This method is popular because of its simplicity; however it ignores actual system power flows. Transmission charge for this scheme can be written mathematically as:

$$WC_t = TC.\frac{P_t}{P_{peak}} \tag{1}$$

In equation (1), TC is the total transmission cost, P_t is the power of transaction and P_{peak} is the system peak load.

The contract path method, on the other hand, based on the assumption that the transaction is confined to flow along a specified electricity continuous path throughout the wheeling company's transmission system. The embedded capital costs correspondingly are limited to those facilities that lie along this assumed path. Further, the actual path taken by the transaction does not flow only along the specified contract path but also involves the use of other transmission paths outside the contracted one. As a result it affects the cost of transmission system outside the contract path. The transmission charge using this scheme can be written as:

$$WC_t = TC_k.\frac{P_t}{P_k} \tag{2}$$

where

TC_k : Transmission cost in path

P_k : Transmission line capacity in path

In equation (2) TC_k is the transmission cost in path and P_k is the transmission line capacity in path.

Meanwhile, power flow based MW-mile method is more widely used since it has been shown to be more reflective of actual usage of the transmission system in allocating the transmission cost [4]. This method allocates the charges for each wheeling participant based on the extent of use of transmission facilities by these transactions. These allocated charges are then added up over all transmission facilities to evaluate the total price for use of transmission system. Unlike the contract path and the postage stamp methods, this method considers the changes in MW flows due to the wheeling in all transmission lines of the wheeling companies, and the line length in miles. Two power flows executed successively, with and without the wheeling, yield the changes in MW flows in all transmission lines. Many economists prefer this method because it encourages the efficient use of the transmission facility and, further the expansion of the system. The transmission charge for this scheme can be mathematically expressed as

$$WC_t = \sum_i TC_i . \frac{\sum_i \Delta P_{i,t}}{\sum_i P_{i,t}} \quad (3)$$

ΔP can be either positive or negative flow impacts. Negative ΔP occurs when the lines loading decreases due to wheeling transaction while positive ΔP occurs when the lines loading increases. Depending upon the sign of ΔP, three approaches can be distinguished [26]:

a) absolute impact : the absolute value of positive and negative ΔP are added.

$$\sum_i | \pm \Delta P_i | \quad (4)$$

b) dominant impact : only positive value of ΔP are added.

$$\sum_i + \Delta P_i \quad (5)$$

c) reverse impact: the negative value of ΔP are subtracted from positive value of ΔP.

$$\sum_i \pm \Delta P_i \quad (6)$$

The difference between these approaches is the way it provides reward to the users for their contribution in the counterflow. As far as a transmission service charge is concerned, MW-mile method and Postage stamp method are commonly used by the transmission utilities to determine their transmission revenue [11]-[13]. MW-mile method is used to determine the locational charges while Postage stamp method is used to recover the non-locational charges as the former method is unable to recover appropriate revenue return. The proportion charges which are remunerated by postage stamp method differed among the transmission utilities. For example, the Electric Reliability Council of Texas Interconnection System (ERCOT) determined the transmission service charges based upon 70% postage stamp method and a 30% distance-sensitive MW-mile method [15] while the Electricity Supply Board National Grid (ESBNG), Republic of Ireland and National Grid Company (NGC), United Kingdom used the postage stamp method for remaining total transmission cost which cannot be remunerated by the MW-mile method. [12], [13]. On the other hand, the use of postage stamp method in Latin America varies from one country to another. The transmission utilities in El Salvador and Guatemala and Nicaragua for example use Postage Stamp alone to charge the transmission services. Meanwhile the Mexico and Chile mix the Postage Stamp to and MW-mile to recover the transmission cost [16]. Furthermore, this method is widely used as a transmission service charge for the cross-border trades in Europe because it is technically and administratively simple [17]. Meanwhile, an attempt to use this method either to cater for transmission cost allocation or to manage the congestion in the electricity cross-border has been proposed in some ASEAN countries [18]-[20]. Although this method is simple and able to recover the transmission revenue but it would give undesirable economic incentive since it does not respect the use of line. In fact the generator situated close to the main load does not make use of the transmission line or grid will be charged same degree as a generator located far from the load.

3. Proposed Method

Postage-stamp method is traditionally used by electric utilities to allocate fixed transmission cost among users of firm transmission service [21]. This method is an embedded cost method also known as the rolled-in embedded method. Postage-stamp method is based on the assumption that the entire transmission system is used, regardless of actual facilities that carry the transmission service. The method allocates charges to a transmission user based on the average embedded cost and the magnitude of user's transacted power. The magnitude of the transacted power is usually measured at the time of system peak load [14]. The transmission (wheeling) charge for this scheme can be written mathematically as in (1). Because of its simplicity, this method is the most common charging mechanism for the utilization of the local transmission network.

However, its main drawback is that charges paid by the user do not reflect actual use of the network or the value derived from being connected. In many cases, some user cross-subsidize others. For example, generators connected close to main load centers could argue that they should not pay the same charges as remote generators because the energy they produce does not need to transit through long and expensive transmission lines to reach the consumers. As a result it would give undesirable economic incentives to the use of the network as this method does not prefer local to large-distance transfer [22], [27].

In the proposed method, generators are being charged based on total power they deliver to the load through the transmission line. In this regard, the transacted power P_t in equation (1) is now based on the amount of generator's power flow in the transmission line. This transacted power is equal to the generated power if there is no local load but will be reduced if the local load exists. Meanwhile the system peak load, P_{peak} of equation (1) is now calculated based on the sum of power delivered by an individual generator to the transmission line at peak system load. With the proposed method, those generators local loads will have an opportunity to pay less charge. In this proposed method, the power contribution of generators either in the transmission line or to the local load can be traced using the generalized generation distribution factors (GGDFs) or D factors. These factors have been developed based on a linearized DC model of the power system and describe the impact of every generator on the active power flow of a line [23], [24], [25], [28]. For instance, the power contribution of generator G_k on the line l can be expressed as fraction $D_{l,k}$ of the total injection by generator G_k , i.e., P_{Gk} as:

$$P_{GK}^{l} = D_{l,k} P_{Gk} \tag{7}$$

To illustrate how transmission service charges can be determined using the proposed method, consider a single bus system as shown in Fig.1.

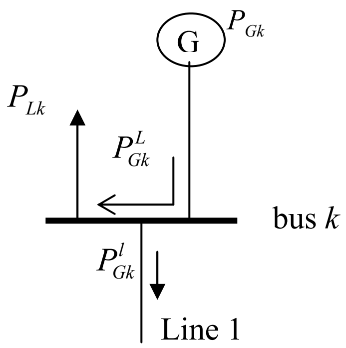

Fig.1 *Single bus system*

Let P_{Gk} the power served by generator at bus k, P_{Lk} local load at bus k, P_{Gk}^{L} the power P_{Gk} flow to the local load at bus k and P_{Gk}^{l} the power flow from P_{Gk} flow to transmission lines. Therefore, the power served by generator P_{Gk} at bus k can be written mathematically as:

$$P_{Gk} = P_{Gk}^{L} + P_{Gk}^{L} \tag{8}$$

and

$$P_{Gk}^{l} = P_{Gk} - P_{Gk}^{L} \text{ when } P_{Lk} \neq 0 \tag{9}$$

$$P_{Gk}^{l} = P_{Gk} \text{ when } P_{Lk} = 0 \tag{10}$$

P_{Gk}^{l} is determined using GGDF algorithm as in equation (7).Hence, total power of n generators flowing to transmission lines at system peak load can be written as follows:

$$P_{Gnpeak}^{l} = \sum_{n=1}^{Gn} P_{Gn} - P_{Gn}^{L} \tag{11}$$

In equation (11) , P_{Gn} is the power served n generators and P_{Gn}^{L} is the power of n generator flows to the local load.

The transmission service charge for generator at bus k based on the proposed method can be determined as follows:

$$WC_{Gk} = TC.\frac{P_{Gk} - P_{Gk}^{L}}{\sum_{n=1}^{Gn} P_{Gn} - P_{Gn}^{L}} \tag{12}$$

$$WC_{Gk} TC.\frac{P_{Gk}^{l}}{P_{Gnpeak}^{l}} \tag{13}$$

In equation (12) and (13) P_{Gk} , P_{Gk}^{L} , P_{Gk}^{l} and P_{Gnpeak}^{l} are power served by generator at bus k, Power P_{Gk} flow to the local load, Power P_{Gk} from flow to transmission lines and Power served n generators at peak load respectively.

Comparing equation (13) and (1), equation (14) can be expressed in form of transaction t as follows:

$$WC_{t} = TC.\frac{P_{t}^{l}}{P_{peak}^{l}} \tag{14}$$

In equation (14), P_{t}^{l} is the transacted power by an individual generator to transmission lines and P_{peak}^{l} is the total power by all generators at peak load.

With the proposed method, the generator being charged proportional to actual usage of the transmission system. This method provides a merit to the generators with the local load to reduce their transmission charges.

4. Case Studies

The proposed method is tested on a 3-bus system and IEEE 14-bus system. The transmission network data and the transmission cost of services used for IEEE 14-bus system are referred to in [14]. These case studies are based on DC power flow and losses are neglected. The wheeling transaction is assumed to involve only real power and the contributions of reactive power flows are also neglected. For simplicity, it is assumed that generators have to pay 100% of the transmission cost of services to the transmission owner. The proposed method is compared with the traditional postage stamp which is used by transmission utilities as described in Section II, to investigate its ability to provide a better economic signal to transmission system users.

4.1 Three bus system

A three bus system is used to illustrate the proposed method as shown in Fig.2. The system consists of two generators and two loads. Generator 1 is assumed to deliver 800MW while generator 2 contributed 400MW to the network system. The total transmission cost for the three lines is $90,000.

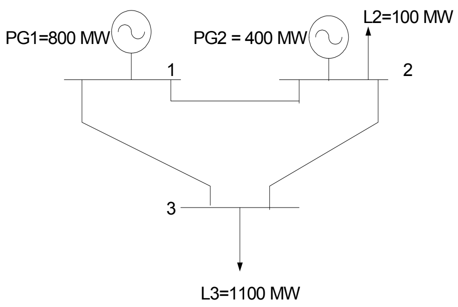

Fig. 2 3-bus system

Table 1 illustrates the power contribution of each generator to the line using Generalized Generation Distribution Factors (GGDFs). It can be seen that the power contribution of both generators to lines 1-3 and 2-3 is in the same direction of the total power flow but for line 1-2 the power flow by generator G_2 is the reverse direction of the total power flow. This situation could assists generator G_2 to reduce the transmission charges if the reward of reducing transmission load is taken into account in the charging method.

Table 1: Generator's power contribution to line flow

Line	Cost($)	Capacity (MW)	Line Flow (MW)	Gen1	Gen2
2-Jan	30,000	800	125	216.67	-91.67
3-Jan	30,000	800	675	583.33	91.67
3-Feb	30,000	800	425	150	275

Fig 3 shows the analysis of generator G_2 with local load. It can be observed that generator G_2 contributes 91.67MW to line 1-2 and 275 MW to line 2-3 which result 366.67 MW. The remaining power, 33.33MW is delivered to the local load L_2.

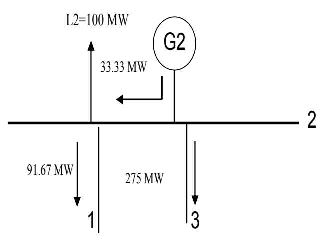

Fig. 3 Local load case

As shown in table II, the tariff of the proposed method is slightly higher compared to the traditional postage stamp method. However, it provides an incentive to the generators with a local load.

Table 2: Transmission charges for traditional and proposed postage stamp method

Generator	Traditional PS Tariff ($/KW)	PS charge	Proposed PS Tariff ($/KW)	PS charge
G1	0.075	60000	0.077	61714
G2	0.075	30000	0.077	28286

It can be seen that the generator G_2 pays $28,286 or 5.8% less than the traditional postage stamp method since the charge is based on its total contribution to the line flow which is 366.67MW and not 400MW as generated. On the other hand, the charges for generator G1 increased to $61,714 or 2.9% because it fully utilized the lines.
Meanwhile, table 3 and table 4 show the transmission charges resulted from both traditional and proposed postage stamp methods when it is incorporated with three different approaches in MW-mile methods.

Table 3: Transmission charges based on combined MW-mile and traditional postage stamp

Generator	Transacted Power (MW)	PS+MWM Absolute ($)	PS+MWM Dominant ($)	PS+MWM Reverse ($)
G1	800	60416	62698	65000
G2	400	29584	27302	25000

It can be seen that the charge for generator G_2 has decreased ranging from 2.4% to 3.4% depending on the chosen approach in MW-mile method. However, the charge for generator G1 has increased in the region from 1.2% to 1.3%. Again it can be noticed that the consideration on the local load in the proposed method reflects a fair and equitable transmission charges as the generator only pay charges based on actual usage of the transmission line.

Table 4: Transmission charges based on combined MW-mile and proposed postage stamp methods

Generator	Transacted Power (MW)	PS+MWM Absolute ($)	PS+MWM Dominant ($)	PS+MWM Reverse ($)
G1	800	61120	63472	65840
G2	366.67	28880	26528	24160

14.2. IEEE 14-Bus System

In this case study, the proposed method is tested on the IEEE 14 bus system as shown in Fig. 4. This system includes 5 generators at buses 1, 2, 3, 6 and 8 while 11 loads are located at buses 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 and 14. The generators serve a total system demand of 400 MW. In this system, there are two generators with the local load at buses 2 and 3.

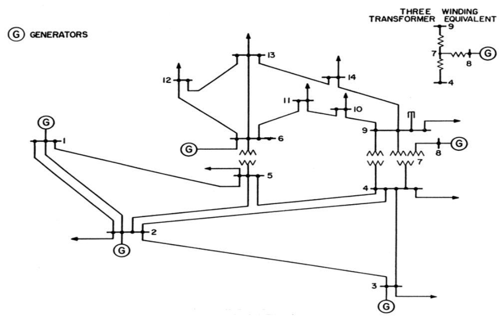

Fig. 4 IEEE 14-bus system

Table 5 tabulates generators contribution to the line flow using GGDF distribution factors. It can be seen that generators G1, G6 and G8 has fully utilized the transmission lines to deliver their available power to the load. For instance, G1 delivers 143.7423 MW to line 1-2 and 76.2577 MW to line 1-5 which total of 220 MW of its available capacity. The same case happens to generator G6 and G8 but not for generator G2 and G3 since these generators have local load.

Fig. 5 shows the power flow contribution of generator G2 to the local load and transmission line. It can be seen that

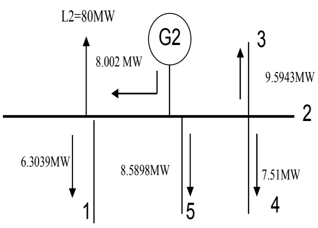

Fig. 5 Local load at bus 2

Table 5: Generator's contribution to the line flow

Line	Line Flow (MW)	G1 (MW)	G2 (MW)	G3 (MW)	G6 (MW)	G8 (MW)
1-2	144.7	143.74	-6.3	-0.12	5.24	2.11
2-3	47.1	41.59	9.6	-3.6	0.85	-1.34
2-4	31.03	30.35	7.51	-0.69	-2.47	-3.67
1-5	75.33	76.26	6.3	0.12	-5.24	-2.11
2-5	26.54	27.8	8.59	0.17	-7.14	-2.88
3-4	-32.9	-13.41	-0.4	11.4	-16.65	-13.84
4-5	-56.56	-47.85	-4.89	4.33	-15.9	7.75
5-6	15.31	39.71	7	3.12	-33.52	-1
4-7	-3.31	23.69	4.44	2.47	-7.61	-26.3
7-8	-50	0	0	0	0	-50
4-9	7.99	13.59	2.55	1.42	-4.37	-5.2
7-9	46.69	23.69	4.44	2.47	-7.61	23.7
9-10	10.35	10.03	1.95	1.21	-11.16	8.32
6-11	19.65	6.47	1.05	0.29	16.41	-4.57
6-12	28.24	14.9	2.69	1.31	6.85	2.5
6-13	37.42	18.35	3.27	1.52	13.21	1.07
9-14	14.34	10.75	2.04	1.17	-6.06	6.43
10-11	0.35	4.53	0.95	0.71	-12.91	7.07
12-13	-11.76	-7.1	-1.31	-0.69	-0.15	-2.5
13-14	5.66	0.24	-0.04	-0.17	9.56	-3.93

generator G2 used the line 1-2, 2-3, 2-4 and 2-5 to deliver 6.3039 MW, 9.5963 MW, 7.51MW and 8.5898 MW of its power to the line respectively while the remaining power of 8.421 MW were consumed by the local load. Similarly, generator G3 used line 3-2 and 3-4 to deliver 3.5968 MW and 11.4032 MW of its power to the line and the remaining 5MW to the local load. In this regard, generator G2 and G3 contributes 31.998 MW and 15MW of its generated power to the line. As a result, the total power delivered to the line with the participation of other three generators is 386.998 MW.

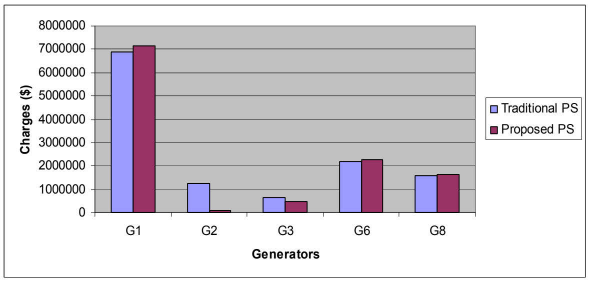

Fig. 6 Transmission charges based on traditional and proposed PS methods

Fig. 6 shows the transmission charges for the generators calculated based on traditional and proposed postage stamp methods. It can be clearly seen that the generator with the existence of local load pay less charges compared to those generator without local load. With the proposed method, the charges for generator G2 and G3 is reduced by 17.3% and 22.5% respectively and on the other hand it increases the charge for other generators by 3.4%.

Table 6: Transmission charges based on combined MW-mile and traditional postage stamp methods

Gen.	Transacted Power (MW)	PS+MWM Absolute ($)	PS+MWM Dominant ($)	PS+MWM Reverse ($)
G1	220	6701300	7035000	7368800
G2	40	1186900	1239000	1291100
G3	20	554400	544900	535300
G6	70	2432800	2170700	1908600
G8	50	1678300	1564100	1449900

Table 6 and table 7 tabulate the transmission service charges for generators based on postage stamp method incorporated with the MW-mile method. Again, it can be observed that the proposed method provides an opportunity to the generator G_2 and G3 to pay less charge due to the existence of the local load.

Table 7: Transmission charges based on combined MW-mile and proposed postage stamp methods

Gen	Transacted Power (MW)	PS+ MWM Absolute ($)	PS+ MWM Dominant ($)	PS+MWM Reverse ($)
G1	220	6859200	7,205,500	7,551,700
G2	31.998	1038900	1,079,300	1,119,700
G3	15	458400	441,200	423,900
G6	70	2483100	2,225,000	1,966,900
G8	50	1714200	1,602,800	1,491,500

5. Conclusions

In the context of deregulated environment, it is important to design and develop an appropriate methodology that could allocate the transmission charge among the users in a fair and equitable manner. This methodology should reflect the real impact of every transaction the transmission line. This paper has proposed a tracing-based postage stamp method to allocate transmission charges among the users of transmission system services. The proposed method incorporated with generalized generation distribution factor (GGDF) to identify the contribution of each generator to the line flows. The results show that the proposed method successfully provides a fair and an equitable transmission charges to the generators as charges reflect the actual usage of the transmission line. Besides, the use of the proposed method benefited the generator with the local load; it could also encourage future generators to be installed with local demand consideration.

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