International Journal of Power, Energy and Artificial Intelligence, December 2009, No.1, Vol. 3, (ISSN: 1985-6431) *Page:166-172*

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Full Recovery of Transmission System Fixed Cost in Pool Electricity Market

IJPEAI
International Journal of Power, Energy and Artificial Intelligence

Abstract—This paper presents the reliability of different usage-based methods for transmission cost allocation under open access. The study is based on generalized generation distribution factors algorithm (GGDF), Bialek and Kirschen tracing algorithms and graph theory. MW-Mile and Postage-Stamp (P.S) methods are also investigated to cover the total transmission system fixed cost among all network users. Numerical example based on 6-bus system is used to demonstrate the fairness of different usage allocation methods in recovery of the total transmission fixed cost in pool electricity market. The results obtained show that the GGDFs method can provide a good tool for dealing with transmission pricing for pool electricity market.

Keywords – Open access, pool market, usage allocation methods, transmission cost, MW-Mile method, Postage-Stamp method.

I. INTRODUCTION

Over the last three decades, deregulation has been the most significant event influencing the operation of power networks. It has been an urgent need to create a competitive environment among users in transmission network under open access and has been practiced in many developed countries.

In power market, it is becoming increasingly important as how to quantify the contributions of individual generators and loads. It is also widely recognized that it should be in a fair and non-discriminatory manner to allocate the total cost of transmission system among all network users that provide correct, market based economical signals. Therefore, many approaches have been proposed for allocating the line flow in pool electricity market which answer questions such as:

1. Which generators are supplying a specific load?
2. How are different generators making use of a transmission line?

Therefore, the goal of power market is constantly introducing competition and lowering the average energy price for end users. Pool model, bilateral-transaction model and the hybrid model are three basic transaction models of power markets. In pool model the transmission company buys the electricity from generation companies and then sells it to distribution companies. The transmission system is centrally controlled by an independent system operator which is disassociated from all market participants and ensures open access. In bilateral contract model, the transmission company provides a brokerage service for generation companies and consumers. In this model, trades (quantity and price) are determined directly between suppliers and customers. The hybrid model combines pool model and bilateral model i.e. the pool will exist simultaneously with bilateral and multilateral transactions. In its own interests and the fairness of the market, the transmission company, the decision-maker, needs to know to allocate the transmission costs to the network users [1], [3].

In this respect, MW-Mile is considered as the first pricing strategy proposed for the recovery of fixed transmission costs based on the actual use of transmission network [2].

The basic concept of MW-Mile is that the loading of each transmission is to be obtained separately; this is multiplied by the line length and then summed over all lines in the grid to obtain a measure of how much each transaction uses the grid. Different transactions are then charged in proportion to their utilization of the grid [3].

MW-Mile method is not sufficient to recover the total transmission system cost. To cover the total transmission system cost, it will be necessary to share among the generators the costs associated with unused capacity. The simplest method of charging for transmission services is the so-called Postage-Stamp method, which depends only on the megawatt rating of the generating units for a producer or the peak demand for a consumer and the duration of use, irrespective of supply and delivery points, distance of transmission usage i.e. this charge usually does not depend on where the energy is coming from or going to [3], [4].

The main goal of this paper is to show the ability of different usage-based methods in reflecting the recovery of fixed transmission cost along with a crucial investigation about the recovery of the total transmission system cost.

In this paper, an overview of different tracing methods is presented in section II. In section III, a brief about different pricing methods is stated. In section IV, numerical example based on 6-bus system is given to show the transparency of different usage-based methods in the allocation of the total of the transmission system cost compared with Ireland scheme, followed by a conclusion in section V.

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II. TRANSMISSION USAGE EVALUATION

The use of system allocation is being assigned by many regulating approaches worldwide.

A method based on superposition principle which has linear characteristic is commonly used in the domain of power system security. Another approaches based on sharing principle and a method uses a directed graph is also presented in this paper. In the above mentioned methods, the question that is posed is how far these methods are capable to identify the contribution of individual generators and loads to line flows as well as the real power transfer between individual generators and loads. However, the focus of this paper will be tracing the line flows only among generators, as our assumption is transmission cost allocation is totally levied to generators in the power network.

A. Distribution Factors

The DC distribution factors at present are the most important method in use in power system security analysis and transmission congestion cost allocation in competitive electricity market [5]. These factors have been the most common techniques presently in use in deregulated power system for calculation of transmission pricing and related issues because of its simplicity in derivations, linearity and physical comprehension [2]. Generalized Shift Distribution Factors (GSDFs) or A Factors, Generalized Generation Distribution Factors (GGDFs) or D Factors, and Generalized Load Distribution Factors (GLDFs) or C Factors are the three types of Distribution Factors.

A Factors represent the incremental use of node injections of the network and can be used to allocate the costs to node net injections. D Factors allocate the costs to all generations via calculating the impact of all generations in line flows and C Factors represent the total use of the network of loads and are used to allocate the costs to all loads.

A distribution factor $A_{i-j,k}$ is defined through sensitivity analysis and indicates the relation between a change in power injection ΔP_{ik} in a given bus k and a change in the power flow ΔF_{i-j} in a particular line $i-j$ [6].

$$B_{ij} = -x_{ij}^{-1}, \quad B_{ii} = \sum x_{ij}^{-1} \tag{1}$$

$$A_{i-j,k} = (z_{ik} - z_{jk}) / x_{ij} \tag{2}$$

$$\Delta F_{i-j} = \sum_{k \neq R} A_{i-j,k} \Delta PI_k \tag{3}$$

with

$$\sum_{k \neq R} \Delta PI_k + \Delta PI_R = 0 \tag{4}$$

Having calculated the bus susceptance matrix B as stated in equation (1), A distribution factor affects by the choice of reference nodes and can be calculated by using equation (2). Hence, the flow in each circuit is obtained by the expression shown in equation (3).

GGDFs have been formulated rescinding the need of reference bus and the restriction of constant total generation.

$$F_{i-j} = \sum_g D_{i-j,g} G_g \tag{5}$$

Equation (5) estimates the contribution by each generator to the line flow on the transmission grid and D factors may be obtained from factors $A_{i-j,g}$ as follows

$$D_{i-j,g} = A_{i-j,g} + D_{i-j,R} \tag{6}$$

where

$$D_{i-j,R} = (F_{i-j} - \sum_{P \neq R} A_{i-j,g} G_P) / (\sum_g G_g) \tag{7}$$

B. Bialek Tracing Algorithm

The proportional sharing is the main principle of this method [7]. As electricity is indistinguishable and each of the outflows down the line from node i is dependent only on the voltage gradient and impedance of the line, it may be assumed that each MW leaving the node contains the same proportion of the inflows as the total nodal flow P_i. This theory is illustrated in fig.1 where the total flow through the node is $P_i = P_{j-i} + P_{k-i} = P_{i-m} + P_{i-l}$ of which P_{j-i} / P_i is supplied by line $j-i$ and P_{k-i} / P_i by line $k-i$. Hence P_{i-m} consists of $P_{i-m}(P_{j-i} / P_i)$ supplied by line $j-i$ and $P_{i-m}(P_{k-i} / P_i)$ supplied by line $k-i$. Similarly P_{i-l} consists of $P_{i-l}(P_{j-i} / P_i)$ supplied by line $j-i$ and $P_{i-l}(P_{k-i} / P_i)$ supplied by line $k-i$.

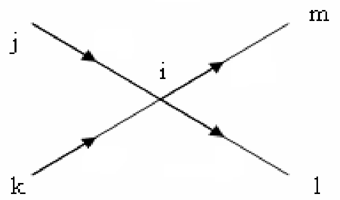


Fig. 1. Proportional sharing principle

Bialek Tracing algorithm has two versions: upstream-looking algorithm and downstream-looking algorithm [8]. The upstream-looking algorithm allocates the transmission usage/supplement charge to individual generators and this will be the focus in this paper. In contrast, the downstream-looking algorithm allocates the transmission usage/supplement charge to individual loads.

In the upstream-looking algorithm, the total flow P_i through node i after eliminating the losses when looking at the inflows is expressed as

$$p_i = p_{Gi} + \sum_{j \in \propto_i^{(u)}} c_{ji} p_j \quad \text{or} \quad A_u P = P_G \tag{8}$$

where $\propto_i^{(u)}$ is the set of nodes j supplying directly node i, P is the vector of nodal through-flows and P_G is the vector of nodal generations. The vector A_u is the (n×n) upstream distribution matrix and the (i, j) element of A_u is equal to

$$[A_u]_{ij} = \begin{cases} 1 & \text{for i = j} \\ -c_{ji} = -\left|p_{j-i}\right| / P_j & \text{for } j \in \propto_i^{(u)} \\ 0 & \textit{otherwise} \end{cases} \tag{9}$$

The i^{th} element of $P = A_u^{-1} P_G$ can be expressed as follows,

$$P_i = \sum_{k=1}^{n} \left[A_u^{-1} \right]_{ik} P_{Gk} \qquad \text{for } i = 1, 2, 3\ldots \text{n} \tag{10}$$

Equation (10) shows that the contribution of the *k*th system generator to *i*th nodal power is equal to $\left[A_u^{-1} \right]_{ik} P_{Gk}$. Using the proportional sharing principle, the impact of a particular generator on line flows can be calculated by

$$\left|p_{i-j}\right| = \frac{\left|P_{i-j}\right|}{P_i} \sum_{k=1}^{n} \left[A_u^{-1} \right]_{ik} .P_{GK} \tag{11}$$

The method is conceptually very simple and suitable for systems with loop flows but it requires inverting a sparse matrix of the rank equal to the number of network nodes and the speed is a problem for a big network.

C. Kirschen Tracing Algorithm

Based on the active power flows obtained from the results of power flow program, the proposed method [9] suggests new concepts of domain, common, and link which can be summarized as follows:

Domain of a Generator: Based on the direction of the flow as computed by a power flow program or a state estimator, the domain of a generator is defined as the set of buses which are reached by power produced by this generator.

Common and Rank: A common is defined as a set of neighboring buses supplied by the same generators. A bus belongs to one and only one common. Unconnected sets of buses supplied by the same generators are treated as separate commons. The rank of a common is defined as the number of generators supplying power to the buses comprising this common. The rank of a certain common can never be lower than one or higher than the number of generators in the system.

Link: Having divided the buses into commons, each branch is either internal to a common (i.e. it connects two buses which are part of the same common) or external (i.e. it connects two buses which are part of different commons). One or more branches connecting the same commons form what is called a link. It is very important to note that the actual flows in all the branches of a link are all in the same direction. Furthermore, this flow in a link is always from a common of rank N to a common of rank M where M is always strictly greater than N.

The state of the system can be represented by a directed, a cyclic graph when the commons are represented as nodes and the links as branches. This graph is directed because the direction of the flow in a link is specified. It is a cyclic because links can only go from a common supplied by fewer generators to a common supplied by more generators.

To allocate the contribution of a generator to individual loads and branch flows, a few more definitions and a fundamental assumption are required.

The inflow of a common is defined as the sum of the power injected by sources connected to buses located in this common and of the power imported in this common from other commons by links. The outflow of a common is equal to the sum of the power exported through links from this common to commons of higher ranks. For a given common, if the proportion of the inflow which can be traced to generator i is x_i then the proportion of the outflow/load which can be traced to generator i is also x_i. The following equations can be used to compute the contribution of each generator to each common:

$$F_{ijk} = C_{ij} * F_{jk} \tag{12}$$

$$I_k = \sum_j F_{jk} \tag{13}$$

$$C_{ik} = \frac{\sum_j F_{ijk}}{I_k} \tag{14}$$

where

C_{ij} : Contribution of generator i to the load and the outflow of common j.

C_{ik} : Contribution of generator i to the load and the outflow of common k.

F_{jk} : Flow on the link between commons j and k.

F_{ijk} : Flow on the link between commons j and k due to generator i.

I_k : Inflow of common k.

It is clear that the application of the proposed method to pricing problems raises important and complex issues of fairness as the method becomes weak when the internal region of the commons must be analyzed.

D. Graph Theory

The method is based on the concept of a generator has the priority to provide power to the load on the same bus [10]. The flows of electricity obey the proportional sharing rule and based on the following lemmas of graph theory.

Lemma 1: A lossless, finite-nodes power system without loop flow has at least one pure source, i.e. a generator bus with all incident lines carrying outflows. This lemma guarantees to start and continue a downstream tracing from an existing pure source.

Lemma 2: A lossless, finite-nodes power system without loop flow has at least one pure sink, i.e. a load bus with all incident lines carrying inflows. This lemma guarantees to start and continue an upstream tracing from an existing pure sink.

The downstream tracing (DSTR) is used for calculating the contribution factors of individual generators to line flows and loads. Starting from a pure source and building up two matrices, one is extraction factor matrix of lines A_l and loads A_L from bus total passing power as stated in equations (15), (16) respectively. The other is contribution factor matrix of generators to bus total passing power B as stated in equation (14). The product of these two matrices constitutes the contribution factors of generators to line flows and loads.

$$\left(A_l\right)_{linej,busi} = \frac{\text{line j's power flow}}{\text{bus i's total pass power p}_\text{i}} \tag{15}$$

$$\left(A_L\right)_{ii} = \begin{cases} 0 & \text{i} \notin \text{net load buses} \\ \dfrac{\text{net load power on bus i}}{\text{P}_\text{i}} & \text{i} \in \text{net load buses} \end{cases} \tag{16}$$

where bus i is the upstream bus of line j, P_i includes both line inflow power and net generator injection power to bus i calculated from load flow solution.

$$B_{bus-i,busk} = \begin{cases} 1 & \left(\text{k=i,k} \in \text{net gen. buses}\right) \\ 0 & \left(\text{k=i,k} \notin \text{net gen. buses}\right) \\ 0 & \left(\text{k>i}\right) \\ 0 & \left(\text{k<i,k} \notin \text{net gen. buses}\right) \\ \sum_{lj \in i} (\text{A}_{\text{lj}} - m \\ \quad .B_{m-k}) & \left(\text{k<i,k} \notin \text{net gen. buses}\right) \end{cases} \tag{17}$$

Based on matrices A_l, A_L and B, we are ready to determine the contribution factors of individual generators to line flows K_{lG} and loads K_{LG} where

$$K_{lG} = A_l \,.\, B \quad \text{and} \quad K_{LG} = A_L \,.\, B \tag{18}$$

The method shares an assumption of proportional sharing principle with Bialek and Kirschen methods. The application of the three methods to pricing problems raises complex issues of fairness as will be demonstrated by the following example.

III. DIFFERENT PRICING STRATIGIES

In this section and as in [11], MW-Mile , Postage-Stamp methods are investigated to recover the total cost of transmission network taking into account the fact that some transactions reduce the flow on some lines due to counter-flow.

A. *MW-Mile method*

MW-Mile method is used to determine the actual paths the power follows through the network. The amount of MW-Mile of flow that each transaction causes is calculated. This amount is then multiplied by an agreed per-unit cost of transmission capacity to determine the wheeling charge. The method can be refined to take into account the fact that some transactions reduce the flow on some lines [4].

For this regard, the zero counter-flow pricing method suggests that only those that use the transmission facility in the same direction of the net flow should be charged in proportion to their contributions to the total positive flow. On the other hand, proposals of giving a negative charge or credit to the users producing counter flows may not be easily accepted by the transmission service providers [5]. The charge levied on generator i by using circuit k may be expressed mathematically as:

$$C_{i,k} = W_k^i (C_k / K_k) \tag{19}$$

where

$C_{i,k}$: generator i's charge for using the circuit k

W_k^i : circuit flow caused by generator i on circuit k

C_k : cost of circuit k includes the circuit distance

K_k : capacity of circuit k

$$TC_{i,k} = \sum_{k=1}^{nlin} W_k^i (C_k / K_k) \tag{20}$$

where

$TC_{i,k}$: total charge remunerated to generator i for using the set of circuits k's

Now one can calculate the generation locational charge as follows

$$\pi_i = \frac{\sum_{k=1}^{nlin} \dfrac{C_k}{K_k} . W_k^i}{G_i} \quad (\text{€/KW}) \tag{21}$$

$$R_i = \pi_i . PG_i^{MAX} \quad (\text{€}) \tag{22}$$

where

π_i : locational tariff for generator i

G_i : dispatch of generator i

R_i : amount paid by the generator at bus i

PG_i^{MAX} : maximum produced power of generator i

B. *Postage-Stamp Coverage*

Postage-Stamp is the simplest charging method for transmission services. The method depends only on the amount of power moved and the duration of use, irrespective of supply and delivery points, distance of transmission usage or the distribution of loading imposed on different transmission circuits by a specific transaction [3].

The charge that each user pays thus reflects the average usage of the entire network rather than the use of specific transmission facilities. Charges are adjusted proportionally to ensure that the transmission company recovers all the revenue that it is entitled to collect.

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 the charges paid by each user do not reflect the actual use that they make of the network or the value they derive from being connected. In many cases, some users cross-subsidize others. For example, generators connected close to the 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 though long and expensive transmission lines to reach the consumers [4].

So the Postage-Stamp (or average) coverage is the methodology used to distribute the cost which is not remunerated among the generators. This methodology is presented below:

$$\text{Transmission Revenue(€)} = \sum_{k=1}^{nlin} C_k \qquad (23)$$

$$\text{Transmission System Cost Not Remunerated } C_{NR} \text{ (€)}$$

$$= \sum_{k=1}^{nlin} C_k - \sum_{i=1}^{n} R_i \qquad (24)$$

$$\text{Postage-Stamp } \Delta \text{ (€ / KW)} = C_{NR} / \sum_{i=1}^{n} PG_i^{MAX} \qquad (25)$$

In Postage-Stamp method, only the magnitude of transacted power is considered and neither the injection point nor withdrawal point is considered. This is the simplest method but it cannot provide any economic signal related with location.

IV. RESULTS AND DISCUSSIONS

The performance of the most common DC tracing methods is tested by a comparison with Ireland scheme [11] in allocating transmission cost under open access.

A simple 6-bus system shown in fig.2 is used and its parameters are presented in table I. The system is assumed to have 3 generators serving a total system demand of 100 MW. For simplicity, the capacity of all circuits is assumed to be 50 MW and the annual value (i.e. includes depreciation, RoR and O&M of each circuit is assumed to be €50,000).

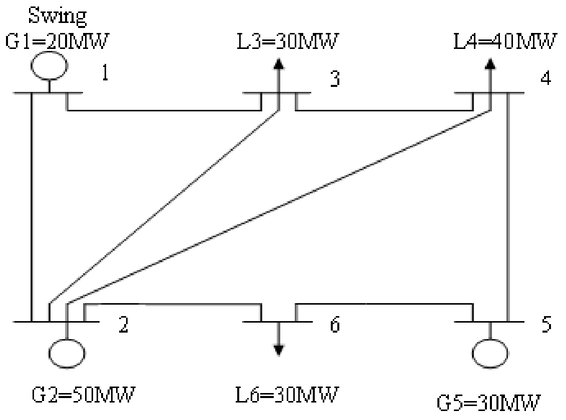


Fig. 2. 6-Bus system example

TABLE I: ELECTRICAL PARAMETERS, ANNUAL COST, AND CAPACITY OF THE 6-BUS SYSTEM

Line	X (p.u)	Total Flow(MW)	Capacity (MW)	Cost(10^3) (€)
1-2	0.04	-3.21	50	0
1-3	0.02	23.21	50	50
2-3	0.04	14.81	50	50
2-4	0.05	15.06	50	50
2-6	0.02	16.91	50	50
3-4	0.02	8.02	50	0
4-5	0.04	-16.91	50	50
5-6	0.02	13.09	50	50

For simplicity (as mentioned above) it is assumed that the distance is already taken into account on circuit cost and the value of each circuit is equal to € 50,000 except those circuits where less than 20% of their capacity is used. These circuits have an assumed value of € 0. To clarify the fairness of such methods along with recovery of the total cost of transmission network (8*50000 = €400000), we assume that there are two transmission owners for this system. The owner A owns lines 1-2, 1-3, 2-3, and 2-4, while the owner B owns 2-6, 3-4, 4-5, and 5-6.

TABLE II: TRANSMISSION USAGE ALLOCATION (G1)

Circuit	Ireland (MW)	GGDF (MW)	Bialek (MW)	Kirschen (MW)	Graph Theory (MW)
1-2	7.09	7.094	0	0	0
1-3	12.09	12.905	20	12.21	20
2-3	-0.64	-0.642	0	0	0
2-4	1.99	1.9915	0	0	0
2-6	5.74	5.7448	0	0	0
3-4	6.26	6.2644	4.2188	4.219	4.22
4-5	0.25	0.2552	0	0	0
5-6	0.25	0.2550	0	0	0

Tables II, III, and IV show the generator-related flows for the base case determined by generalized generation distribution factors (GGDFs), Bialek and Kirschen tracing algorithms, and graph theory. The original MW-Mile cost allocation rule as presented earlier is used to distribute the revenue requirements to each generator. Then Postage-Stamp is used to ensure that the transmission company can recover the total revenue.

From tables II, III, and IV, it can be noticed that the generator-related MW flows determined using Bialek, Kirschen, and graph theory are almost the same since the methods share the proportional sharing principle. From table V, although the total locational transmission charges allocated to the generators using the four proposed methods are very close, Bialek, Kirschen and graph theory methods result in zero charging for G1 and G5 and full responsibility of G2 to the use of lines 1-2, 2-3, 2-4, and 2-6.

TABLE III: TRANSMISSION USAGE ALLOCATION (G2)

Circuit	Ireland (MW)	GGDF (MW)	Bialek (MW)	Kirschen (MW)	Graph Theory (MW)
1-2	-7.98	-7.9829	3.21	3.21	3.21
1-3	7.98	7.9839	3.21	11	3.21
2-3	11.98	11.975	14.81	14.81	14.81
2-4	11.56	11.564	15.06	15.06	15.06
2-6	18.48	18.475	16.91	16.91	16.91
3-4	4.96	4.9593	3.801	3.8012	3.8
4-5	-3.48	-3.4759	0	0	0
5-6	-3.48	-3.4756	0	0	0

Similarly, the three methods result in zero charging for G1 and G2 and full responsibility of G5 to the use of lines 4-5 and 5-6. From table II, it is clear that the three methods result in zero charging for G1 to the use of lines 2-6, 4-5, and 5-6 (i.e. the transmission owner B receives zero transmission revenue).

TABLE IV: TRANSMISSION USAGE ALLOCATION (G5)

Circuit	Ireland (MW)	GGDF (MW)	Bialek (MW)	Kirschen (MW)	Graph Theory (MW)
1-2	-2.32	-2.321	0	0	0
1-3	2.32	2.321	0	0	0
2-3	3.48	3.4814	0	0	0
2-4	1.51	1.5055	0	0	0
2-6	-7.31	-7.306	0	0	0
3-4	-3.2	-3.199	0	0	0
4-5	-13.7	-13.69	16.91	16.91	16.91
5-6	16.31	16.307	13.09	13.09	16.91

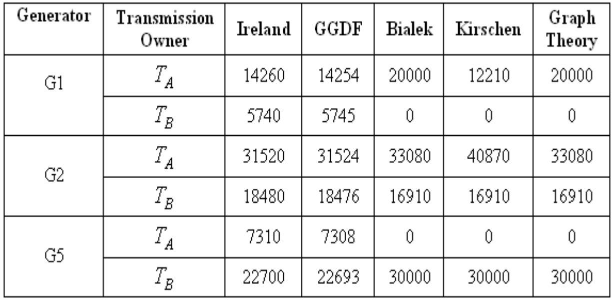
From table III, the transmission owner B only receives a payment for using the line 2-6 via the three proportional sharing methods while in table IV the revenue is totally received by the same owner and zero transmission revenue is received by the transmission owner A.

TABLE V: TOTAL LOCATIONAL CHARGES (€)

Generator	Ireland	GGDF	Bialek	Kirschen	Graph Theory
G1	20000	19999	20000	12210	20000
G2	50000	50000	49990	57780	49990
G3	30010	30001	30000	30000	30000
Total MW-Mile Payment	100010	100000	99990	99990	99990

However, very different results can be observed from the GGDFs method since the method traces the power flow in all the lines in the power network and this reflect the fairness of the method in allocating transmission cost under open access.

TABLE VI: TRANSMISSION OWNER REVENUE (€)



Generator	Transmission Owner	Ireland	GGDF	Bialek	Kirschen	Graph Theory
G1	T_A	14260	14254	20000	12210	20000
	T_B	5740	5745	0	0	0
G2	T_A	31520	31524	33080	40870	33080
	T_B	18480	18476	16910	16910	16910
G5	T_A	7310	7308	0	0	0
	T_B	22700	22693	30000	30000	30000

Meanwhile, table VI shows the transmission revenue received by the transmission owner A to the use of lines 1-3, 2-3, and 2-4 as well as the total transmission revenue received by the transmission owner B to the use of lines 2-6, 4-5, and 5-6. It is clear that the locational charges depend on the actual transmission network usage taking into account the counter flow caused by a particular participant and giving a negative charge or credit to the user who contribute relieving the congestion of the transmission network.

TABLE VII: TOTAL POSTAGE STAMP CHARGES (€)

Generator	Ireland	GGDF	Bialek	Kirschen	Graph Theory
G1	59998	60000	60002	60002	60002
G2	149995	150000	150005	150005	150005
G3	89997	90000	90003	90003	90003
Total P.S Payment	299990	300000	300010	300010	300010

As MW-Mile method is not sufficient to recover the total transmission system cost, it will be necessary to share among the generators the costs associated with unused capacity by a simplest method so called Postage-Stamp. From tables VII and VIII, it can be seen that the consistency of GGDF method in distributing the transmission cost for both transmission owners but not in the case of Bialek, Kirschen, and graph theory methods.

Because of its robustness, GGDF has been adopted for tracing the power flow as well as distributing the transmission cost among all users. As can be seen from tables VII and VIII, MW-Mile recovers 25% of the total cost while Postage-Stamp recovers 75% of the total cost.

TABLE VIII: TOTAL TRANSMISSION COST RECOVERY (€)

		Locational & P.S Charge (€)		Total Revenue (€)	
Generator	Owner	MW-Mile	P.S	T_A	T_B
G1	T_A	14254	29400	43654	
	T_B	5745	30600		36345
G2	T_A	31524	73500	105024	
	T_B	18476	76500		94976
G5	T_A	7308	44100	51408	
	T_B	22693	45900		68593
		100000	300000	200000	200000
Transmission Cost Recovered (€)		400000		400000	

V. CONCLUSION

The equitable allocation of the contributions of the generators to line flows and loads in the power system network has become an important issue since the deregulation of the electric power industry. This knowledge is necessary for the operation of the system, congestion management, proper transmission pricing, ancillary services and related issues.

This paper attempts to test the fairness of different usage-based transmission cost allocation methods along with methods used to recover the total transmission network cost. The design of such methods involves two major issues: accurate and efficient algorithms for transmission usage evaluation and fair and equitable pricing rules.

The results obtained from the 6-bus system show that the GGDFs method can provide a good tool for dealing with transmission pricing for pool electricity market. As MW-Mile method is not sufficient to recover the total transmission system cost, it will be necessary to share among the generators the costs associated with unused capacity. The simplest method of charging for transmission services is the so-called Postage-Stamp method. In Postage-Stamp method, only the magnitude of transacted power is considered and neither the injection point nor withdrawal point is considered. Although the method is the simplest but it cannot provide any economic signal related with location.

VI. ACKNOWLEDGEMENT

The authors wish to acknowledge the Ministry of Science, Technology and Innovation (MOSTI) for the financial funding of this project.

VII. REFERENCES

[1] Zihong Liu, Haozhong Cheng, “Loss allocation methods for different power market models,” in *proc. IPEC2003 Sixth International Power Engineering Conference*, 27-29 Nov. 2003.

[2] P.R. Sebastian, A.R. Khathib and H. Nouredine, “Tracing the path of electric power flow- a study for deregulated power systems,” in *proc. 2001 IEEE Power Engineering Society Winter Meeting*, vol. 3, pp.1479-1484, 2001.

[3] Loi Lei Lai, “Power system restructuring and deregulation,” WILEY, 2001.

[4] D. Kirschen, G. Strbac, “Fundamentals of Power System Economics,” John Wiley & Sons, Ltd, 2004.

[5] J. Pan, Y. Teklu, S. Rahman and K. Jun,” Review of usage-based transmission cost allocation methods under open access,”*IEEE Trans. Power System*, vol. 15, no. 4, pp. 1218-1224, Nov. 2000.

[6] H. Rudnick, R. Palma, and J. E. Fernandez, “ Marginal pricing and supplement cost allocation in transmission open access,”*IEEE Trans. Power System*, vol. 10, no. 2, pp. 1125-1142, May 1995.

[7] J. Bialek, “Tracing the flow of electricity,” *IEE proc. Gener. Transm. Distrib.*, vol. 143, no. 4, pp. 313-320, Jul 1996.

[8] J. Bialek, “Topological generation and load distribution factors for supplement charge allocation in transmission open access,” *IEEE Trans. Power Systems*, vol.12, no. 3, pp. 1185-1193, Aug. 1997.

[9] D. Kirschen, R. Allan, and G. Strbac, “Contributions of individual generators to loads and flows,”*IEEE Trans. Power System*, vol. 12, pp. 52-60, Feb 1997.

[10] F.F. Wu, Y. Ni., and P. Wei., “Power transfer allocation for open access using graph theory – Fundamentals and applications in systems without loop flows,” *IEEE Trans. Power Systems*, vol. 15, no. 3, pp.923-929,Aug 2000.

[11] Explanatory paper for the 2007 statement of charges, v1.0 – Publication Date: 10/05/2007, Page 1-27. www.eirgrid.com.

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