www.serd.ait.ac.th/reric

Transmission Cost Allocation through Modified Equivalent Bilateral Exchanges

R.A. El-Sehiemy*[1] and A.A. Abou El- Ela[+]

Abstract – *This paper proposes the use of two procedures to allocate the transmission usage costs. The first proposed procedure is a multi-stage transmission usage allocation procedure which is based on the equivalent bilateral exchanges (EBE). In the first stage, the system operator allocates the transmission losses to bus generators and consumers. Thus, the actual power generation and consumer levels are modified to new virtual levels according to the allocated component of the transmission power losses. In the second stage, the EBEs between power generation and power demand, at different buses, are computed then the usage costs of the transmission lines are allocated. The second proposed procedure is based on modified sensitivity factors (MSF). The proposed procedures are aimed at controlling the market transactions levels and rates between market users. Also, the proposed procedures exhibit desirable apportioning properties and are easy to implement and understand. Case studies based two test systems 5-bus test system and the IEEE 14-bus test systems are carried out to show the applicability of the proposed procedures.*

Keywords – Deregulation, equivalent bilateral exchanges, sensitivity factors, transmission usage cost allocation

1. INTRODUCTION

Allocation of the transmission costs to system individuals is one of the main important goals of deregulated power systems. In real time operation, generators and consumers engage in power transactions. Consumer meters measure their actual consumption, while generator meters measure their actual production level. The allocation problems are those associated with determination of generators' contribution to supply of concrete loads, power flows from each generator by the network equivalent circuit, power transmission losses.

Different authors have emphasized the importance of the transmission system in the new deregulated markets as a facilitator of generator competition, allowing generators to allocate their production in consumer centers and enabling consumers to benefit from that competitive environment. Within that framework, the transmission tariff system and the user-cost allocation must preserve an adequate resource allocation among market agents. It is desired that transmission prices and payment do not disturb decisions for new-generation investment, for generator operation, and for consumer demand. Transmission cost allocation (TCA) methods are of increasing importance in the deregulating process.

The allocation algorithms can be used to:

- determine a fraction of power transmitted from each generation node to load nodes or a power fraction that is received by each load node from generation nodes;
- determine a power fraction that is transmitted in the electric network branches from each generation node or a fraction of power transmitted in a branch that is supplied to the load nodes;

* The Arab Contractor (Osman Ahmed Osman & Co.), Marine Construction Department, 10th of Ramadan City, Egypt. Postal Address: Bakhaty, Shebin El Kom, Minoufiya - POX: 32735, Egypt.

[+] Minoufiya University, Faculty of Engineering, Shebin El-Kom, Minoufiya, Egypt.

[1] Corresponding author;
Tel: + 20101281051, Fax: +2015410470.
E-mail: elsehiemy@hotmail.com, draaa50@hotmail.com.

A commonly agreed feature that a TCA method must provide locational signals and incentives in order to encourage efficient use of the transmission facilities. They also must comply with some conditions, namely to avoid cross-subsidies, to be transparent and easy to implement, to ensure cost recovery, to provide adequate economic signals and to have continuity with time. The TCA methods proposed in literature could be classified [1] as embedded cost methods and marginal cost methods. The latter, however, do not guarantee cost recovering in real networks. Embedded cost methods, on the other hand, allocate the transmission costs according to the extent of use of generators and consumers. Several methods of this kind have been proposed and are in use in different systems. They can be divided into rolled-in methods and load based methods. Rolled-in methods charge a fixed amount per energy unit, and their main drawback is that they ignore actual network use and that they do not send adequate economic signals to grid users. Flow-based methods, on the other hand, charge the users in proportion to the use they make of grid facilities. Some proposed methods of this kind may be classified as proportional or differential methods. The proportional method has several advantages as it is simple to understand and provides several results such as loss allocation, grid use and load sharing among generators. Differential (or incremental) methods are, on the other hand, well known in literature and are based on the sensitivities of branch flows to power injection in nodes. These sensitivities, however, depend on the choice of the slack bus in the studied case, and, therefore, there is a part of arbitrariness in the allocation.

A usage-based method reported in [2] uses the so-called equivalent bilateral exchanges (EBEs). To build the EBEs, each demand is proportionally assigned a fraction of each generation, and conversely, each generation is proportionally assigned a fraction of each demand, in such a way as both Kirchhoff's laws are satisfied. In [3], the Z-bus allocation procedure was presented for loss allocation to system users. While, Reference [4] presented two procedures based on the Z-impedance matrix and the injected powers. Both procedures to allocate the cost of the transmission network to generators and demands are based on circuit theory. Reference [5] presented a method to allocate charges among users of a transmission system, either in an existing network or an expanding one. The method was based on a model that integrates cooperation and coordination among the agents as basic principles. It also considered the physical and economic use of the network by the different agents. It's assumed a rational behavior of the agents, the formation of coalitions among agents, along with cooperative game solution mechanisms. Game theory was provided interesting concepts, methods and models that may be used when assessing the interaction of different agents in the competitive markets and in the solution of conflicts that arise in that interaction. In particular, cooperative game theory arises as a most convenient tool to solve TCA problems [6].

In [7] and [8] the radial equivalent networks (REN) were presented to model the market formats. A quadratic programming was used to obtain the component of the radial network. In [8], the REN was used to direct allocation of losses costs among users of a transmission system. In [9], the contribution of individual generators to loads and flows was discussed. In [10], a topological sensitivity distribution factors for both of generation and load for supplement charge allocation in transmission open access were found. The modified topological distribution factors were presented in [11] to consider the effects of transmission losses as separate nodes. The cost of transmission system usage was presented based on an economic measure of power markets in [12]. In [13], the co-operative game theory-based procedure was presented for electricity tracing. In [14], the authors proposed different options for independent system operator for allocating the costs of transmission losses. One of these options is dependent on economic signal. The economic signal presented in [14] considered the objective function as minimizing the market payment. The transmission loss allocation components at different buses were included in the optimal market payment model. The generalized generation distribution factors (GGDF) in Reference [15] were used for computing the power flows in transmission lines.

This paper proposes the use of two flow based procedures to allocate the transmission usage costs. Two-stages procedure to allocate the transmission costs allocation (TCA) to the power system individuals is based on the EBE. Another procedure depends on modified sensitivity factors also, used to allocate the transmission usage costs. These procedures are based on controlling the market transactions levels and rates between market users.

2. EQUIVALENT BILATERAL EXCHANGES

The authors in [2] used the EBEs to allocate the transmission cost to system participate applied for lossless network. To build the EBE, each demand is proportionally assigned a fraction of each generation, and conversely, each generation is proportionally assigned a fraction of each demand, in such a way as both Kirchhoff's laws are satisfied. The EBE between the generation and demand buses was defined as:

$$GD_{ij} = \frac{PG_i PD_j}{P_d^{sys}} \tag{1}$$

In [2], the network is lossless network then the total system demand equals to the summation of power demand at consumers' buses or the summation of the power generation outputs for generation buses as:

$$P_d^{sys} = \sum PD_j , \quad P_d^{sys} = \sum PG_i \tag{2}$$

It is straightforward to decompose each individual generation and consumer levels into a linear combination of the EBE as:

$$PG_i = \sum_j GD_{ij} \tag{3}$$

$$PD_j = \sum_i GD_{ij} \tag{4}$$

With the above decomposition, the effects of EBE on the power flow in line k, PF_k is determined by $D_{ijk} GD_{ij}$, an operation that doesn't a defined slack bus. The total power flow can be expressed in terms of EBE as:

$$PF_k = \sum_{i,j} D_{ijk} GD_{ij} \tag{5}$$

where,

D_{ijk} are the GGDF [15].

GD_{ij} is the EBE between generator at bus i and demand at bus j.

PF_k is the power flow in line k

PG_i is the power generation outputs at bus i

PD_j is the power demand at bus j

P_d^{sys} The total system power demand

3. TRANSMISSION LOSS ALLOCATION SCHEMES

Reference [14] suggested different TLA schemes according to different ISO visions using S-allocation vector as:

$$P_{ai} = S_i . P_L \tag{6}$$

Different transmission loss allocation (TLA) schemes are presented in [3], [14] to allocate the transmission loss, P_L , to network users as**:**

Scheme 1: Absolute power injected allocation based

This scheme is based on the net power injection level at each bus, PI_i . The TLA component at bus i, S_i , which is computed as a percentage of the total absolute injected power, at a number of NB buses, as:

$$S_i = |PI_i| \Big/ \sum_{i=1}^{NB} |PI_i| \tag{7}$$

Scheme 2: Current injected allocation based

This scheme is based on the current injection levels, I_i, at each bus. The TLA component at bus i which is computed as a percentage of the total injected current as:

$$S_i = I_i \Big/ \sum_{i=1}^{NB} I_i \tag{8}$$

Scheme 3: Z-bus scheme

This scheme was presented for TLA in [3]. The TLA component, L_i in MW, is obtained from:

$$L_i = \text{real}\left\{ I_i^* Z_{bus} I_i \right\} \tag{9}$$

Scheme 4: Squared current injected based

This scheme is suggested based on the squared current injection at each bus. The S-vector of TLA is computed as a percentage of the total net squared injected current as:

$$S_i = I_i^2 \Big/ \sum_{i=1}^{NB} I_i^2 \tag{10}$$

Scheme 5: Power generations based

This scheme is suggested based on the generation power injection at each bus. The S-vector of TLA is computed as a percentage of the total generated power as:

$$S_i = PG_i \Big/ \sum_{i=1}^{NB} PG_i \tag{11}$$

Scheme 6: Load demand based

This scheme is suggested based on the power demand at each bus. The S-vector of TLA is computed as a percentage of the total power demand as:

$$S_i = PD_i \Big/ \sum_{i=1}^{ND} PD_i \tag{12}$$

Scheme 7: Maximum bus used

This scheme is suggested based on the maximum bus power used. The S-vector of TLA is computed as a percentage of the maximum used at each bus to the total maximum use of all buses as:

$$S_i = Max.(PG_i, PD_i) \Big/ \sum_{i=1}^{NB} Max.(PG_i, PD_i) \tag{13}$$

Scheme 8: Minimum bus used

This scheme is suggested based on the minimum power use bus. The S-vector of TLA is computed as a percentage of the minimum use at each bus to the total minimum use of all buses as:

$$S_i = Min.(PG_i, PD_i) \Big/ \sum_{i=1}^{NB} Min.(PG_i, PD_i) \tag{14}$$

Scheme 9: Average generation and demand used

This scheme is suggested based on the average power used at each bus. Then the allocation loss S-vector is computed as a percentage of the average power generation and power demand used at each bus related to the total average use of all buses as:

$$S_i = Aver(PG_i, PD_i) \Big/ \sum_{i=1}^{NB} Aver(PG_i, PD_i) \tag{15}$$

Scheme 10: ISO comparable based

In this scheme, the suggested allocation process is considered by the ISO as an intermediate vision for the average contribution of each power generations/ load demand on their companies. The allocation vector S_i can be computed as:

$$S_i = Aver\left(\left(PG_i \Big/ \sum_{i=1}^{NB} PG_i \right) and/or \left(PD_i \Big/ \sum_{i=1}^{NB} PD_i \right) \right) \tag{16}$$

Scheme 11: Interested participant allocation

This scheme is suggested based on the network configuration and the net injected powers. This allocation procedure divides the power losses of each line into two components. The first component is for the sending side and the second component is for the receiving side. The allocation loss factors are computed as a percentage of the net injected powers related to the sum of the injected power at both sides of each line. The allocated loss power at sending bus (s) and receiving bus (r), due to the power losses are computed as:

$$P_{as,sr} = \left(|PI_s| \Big/ \left(|PI|_s + |PI_r| \right) \right) P_{L,sr} \tag{17}$$

$$P_{ar,sr} = \left(|PI_r| \Big/ \left(|PI_s| + |PI_r| \right) \right) P_{L,sr} \tag{18}$$

Then, the allocated losses at receiving bus (r), due to connection of NR-lines to bus (r), are computed as:-

$$P_{rs} = \sum_{s=1}^{NR} \left(|PI_r| \Big/ \left(|PI_s| + |PI_r| \right) \right) P_{L,rs} \tag{19}$$

Similarly, the allocated losses at sending bus (s), due to connection of NS- lines to bus s, are computed as:-

$$P_{as} = \sum_{s=1}^{NS} \left(|PI_s| \Big/ \left(|PI_s| + |PI_r| \right) \right) P_{L,sr} \tag{20}$$

Scheme 12:- Voltage based allocation scheme

A voltage based allocation scheme is dependent on the voltage levels at the sending and receiving buses on the of the interested transmission network systems.

The proposed scheme steps are:

- Computing the transmission power losses using the following formula

$$P_{L,rs} = Y_{rs}(V_r - V_s)(V_r^* - V_s^*) \tag{21}$$

- Allocating a part of the computed transmission losses at each line side as:

$$\begin{aligned} PL_{ar,rs} &= Y_{rs} V_r (V_r^* - V_s^*) \\ PL_{as,rs} &= -Y_{rs} V_s (V_r^* - V_j^*) \end{aligned} \tag{22}$$

4. PROPOSED MULTI-STAGE EBE PROCEDURE

The allocation procedure of the modified EBE is performed through two stages, as the following:

Stage 1: Allocation of the transmission losses

In this stage, different schemes are used to allocate the transmission losses to different buses as presented in [14]. In this paper we consider three schemes in the initial stage for transmission losses allocation. These schemes are voltage based loss allocation scheme, power demand loss allocation scheme, and Z-bus loss allocation scheme. All other transmission losses schemes are validated to use them to the same purpose. The main effect of loss allocation in this stage is to modify the consumer and /or generation levels from their physical levels to new virtual levels. The later virtual levels are used for obtaining the EBEs. The amount of losses allocated is either added to the demand levels or subtracted from the generation levels.

If the total losses added to demand levels at different buses, then the new virtual load demands, PD_j^v, are used to compute the EBEs:

$$GD_{ij} = \frac{PG_i \, PD_j^v}{P_d^{sys}} \tag{23}$$

The dominator in this case equals to the total power generation as:

$$P_d^{sys} = \sum_{i=1}^{NG} PG_i = \sum_{j=1}^{ND} PD_j^v \tag{24}$$

Where, the virtual power demand at bus j is computed by adding the allocated power loss component (P_j^a) to actual power demand as:

$$PD_j^v = PD_j + P_j^a \tag{25}$$

Another condition is considered if the total losses subtracted from the generation levels, then the new virtual power generations (PG_i^v) are used to compute the EBEs as:

$$GD_{ij} = \frac{PG_i^v . PD_j}{P_d^{sys}} \tag{26}$$

Where, the virtual power demand at bus j is computed by adding the allocated power loss component (P_i^a) to the actual power demand as:

$$PG_i^v = PG_i + P_i^a \tag{27}$$

The dominator in this case, in (26), equals to the total power generation as:

$$P_d^{sys} = \sum_{i=1}^{NG} PG_i^v = \sum_{l=1}^{ND} PD_j \tag{28}$$

Stage 2: Allocation of the transmission usage costs

As stage 1 modifies the power generation and power demand levels at different buses. The power flow in transmission line k which connected between buses m-n is computed using Equation 29 as:

$$PF_{m-n} = \sum_{i=1}^{NB} D_{m-n,i} \cdot GD_{ij} \tag{29}$$

For allocating the transmission costs, the power flow in the transmission lines are computed using the modified sensitivity factors. The proposed sensitivity factors are based on the actual measurements of power systems voltage, currents and circuit topology. The modified distribution factors are computed, in terms of the initial power flows and the injected power at generation buses as [16]:

$$D_{m-n,i} = PF_{m-n}^{(0)} \cdot \left(PG_i^{(0)}\right)' \cdot inv\left(\left(PG_i^{(0)}\right)' \cdot PG_i^{(0)}\right) \tag{30}$$

A part of the power flow in line k is assigned for each injection power and transacted as:

$$U_k^i = \left| D_{ijk} \cdot GD_{ij} \right| \tag{31}$$

Under the EBE principle, each line flow component is deemed to use the line m irrespectively to the sign of the net flow in this line. Equation 31 presents the use of transmission line m by EBE (GD_{ij}). Also, the properties of the EBE presented in [2] are still validated in this work as:

i) Bilateral exchanges between generators and demand at the same bus i do not make use of the network.
ii) Every generators and load contribute a positive amount to the combined network use.
iii) The rate of line used remains stable for different operating conditions.

The use of line k by demand at bus j is the sum of all EBE involved demand at bus j, that is

$$UD_{kj} = \sum_i \left| D_{kji} \cdot GD_{ij} \right| \tag{32}$$

The total line usage due to all EBE is:

$$UL_k = \sum_{i,j} \left| D_{kji} \cdot GD_{ij} \right| \tag{33}$$

The transacted power rate (r_k) is computed from:

$$r_k = C_k \Big/ \sum_{i=1}^{NB} UL_k^i \tag{34}$$

The transacted bus power rate at bus i, (r_i) can be computed as computed from:

$$r_i = C_i \Big/ \sum_{j=1}^{NB} UL_i^j \tag{35}$$

The proposed multi-stage TCA procedure (Procedure 1) follows the next steps, for certain operation condition, starting from the load flow solution or optimal power flow solution as:

- Solve the load flow problem.
- Compute the transmission power losses in each transmission line.
- Allocate the transmission power losses to system buses using the TLA schemes.
- Modify the physical levels of generation or

demand power levels to new virtual levels.

- Compute the EBE using the virtual values of power generation or the virtual power demand level.
- Compute the lines usage using the modified EBE.
- Compute the rate of transmission usage.
- Allocate the transmission usage to the system buses.
- Obtain the buses usage rates.

Three cases are considered in this procedure. The three cases consider three loss allocation schemes in the first stage as:

Case 1: this case considers the Z bus TLA method.
Case 2: this case considers the demand based scheme.
Case 3: this case considers the voltage based TLA scheme.

5. MODIFIED SENSITIVITY BASED ALLOCATION PROCEDURE (Procedure 2)

Another procedure based on the proposed sensitivity factors is proposed for allocation the transmission usage costs. In this procedure, the power flows in transmission line k which connected between buses m and n, in terms of the injected power at different buses, are computed from the following:

$$PF_{m-n} = \sum_{i=1}^{NB} D_{m-n,i} \cdot PI_i \quad (36)$$

A part of the power flow in line j-k is assigned directly to each injection power and transacted as:

$$\therefore PF_{m-n}^{i} = D_{m-n,i} \cdot PI_i \quad (37)$$

Line usage is based on the rate of transacted power are calculated as:

$$U_{m-n}^{i} = \left|PF_{m-n}^{i}\right| \quad (38)$$

$$U_{n-m}^{i} = \left|PF_{n-m}^{i}\right| \quad (39)$$

The effective transmission line usage for each line k (Ue_k^i) is carried out for minimum usage rates as:

$$Ue_k^i = \max.\left(U_{m-n}^{i}, U_{n-m}^{i}\right) \quad (40)$$

And, the effective transmission line usage Ue_k^i is carried out for maximum usage rates as:

$$Ue_k^i = \min\left(U_{m-n}^{i}, U_{n-m}^{i}\right) \quad (41)$$

As in Equation 34, the transacted power rate (r_k) is computed from:

$$r_k = C_k \Big/ \sum_{i=1}^{n} Ue_k^i \quad (42)$$

The cost allocated of each effective line usage is computed from:

$$C_k^i = r_k \cdot Ue_k^i \quad (43)$$

Another two studied cases are considered based on the sensitivity factors. These two additional cases consider the minimum and maximum usage rates as:

Case 4: considers minimum transmission usage rates.
Case 5: considers maximum transmission usage rates.

6. APPLICATIONS

Test Systems

Application examples are performed to show the applicability of the proposed procedure for different transmission loss allocation schemes in the first stage. The proposed procedure is applied with the 5-bus test system [17], and IEEE 14-bus test systems [18] which are used for an extensive study. The initial power flow calculations are performed using MATPOWER 3.0 [19] using MATLAB software version 7 in [20]. To illustrate the working and the methods for transmission cost allocation, we consider the five-bus test system depicted in [17] as shown in Figure 1. All buses data in terms of generation/demand are reported in Table 1. The data of transmission lines in the system have the values of series resistances and reactance's and the shunt admittance as reported in Table 2.

The 5-bus test system allows visualizing the proximity effect, as it is expected that buses directly connected to a line would be apportioned most of the usage of that line.

The total annual costs of the transmission network are 1050 and 3627.64 $/hr for the two test systems, respectively.

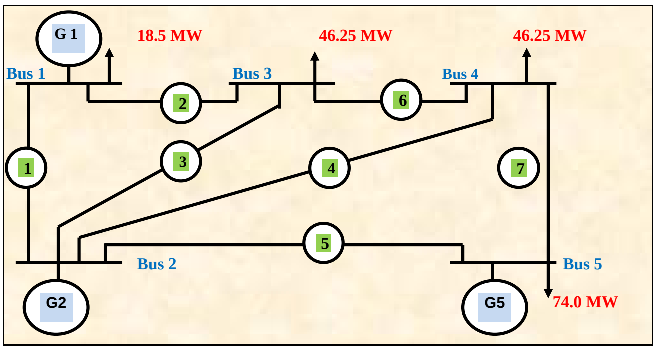

Fig. 1. The line Diagram for the 5-bus test system

Table 1. Five-bus test system transmission line data.

Line No.	Bus From	Bus To	Impedance Z	Line Charge Y/2
1	1	2	0.02+j 0.06	j 0.030
2	1	3	0.08+j 0.24	j 0.025
3	2	3	0.06+ j 0.18	j 0.020
4	4	2	0.06+j 0.18	j 0.020
5	2	5	0.04+j 0.12	j 0.015
6	3	4	0.01+j 0.03	j 0.010
7	4	5	0.08+j 0.24	j 0.025

Table 2. Five-bus test system bus data.

Bus No.	Power generation (MW) Maximum	Minimum	Initial	Load Demand MW
1	120	10	90.44	18.50
2	90	10	60	0
3	0	0	0	46.25
4	0	0	0	46.25
5	60	10	40	74.00

7. RESULTS AND COMMENTS

Five Bus Test System

To explain the use of the proposed modified EBE procedure in its two stages. In the first stage, the transmission losses are allocated to system individuals using different ISO options presented in Equations 6 to 22. The transmission network losses are allocated referred to both of power generation levels and power demand levels.

In Table 3, the total virtual power generation is decreased to 185 MW by subtracting the transmission loss allocation component to physical power generation levels. While, In Table 4, the total virtual power demand is increased to 190.445 MW, for all studied cases, after adding the transmission loss component to power demand level. There is no limitation to use any loss allocation methodology to perform the first stage of the proposed procedure.

To explain the use of the proposed modified EBE method in its second stage. Tables 5 to 7 show the equivalent usage factors for transmission network using Cases 1 to 3 of Procedure 1. In these cases, the EBEs are based on different generation levels in the first stage. There is no limitation to use other loss allocation methodologies presented in [14] or others.

Table 5 shows the equivalent usage factors for Case 1of the suggested multi-stage EBE procedure. In this table, the relative relation between each line and the injected power at different buses. The last column of this table shows the usage rate of transmission network. While the last transmission costs allocated to system buses. The highest allocated TCA using Case 1/Procedure 1 is 408.32 $/hr at bus 5. While the lowest allocated TCA level (2.602 $/hr) is located at bus 2**.** The TCA levels are dependent on the power demand levels. The highest TCA is founded at the highest power demand bus at bus 5.

Table 6 shows the equivalent usage factors for Case 2 of the suggested multi-stage EBE procedure. The last column of this table shows the usage rate of transmission network. While the last transmission costs allocated to system buses. The highest allocated TCA using Case 2/Procedure 1 is 383.21 $/hr at the largest power generation bus 1. While the lowest allocated TCA level (19.58 $/hr) is located at bus 2**.** As similar to Case 2, Case 3 of the suggested multi-stage EBE procedure allocates The highest allocated TCA using Case 3/Procedure 1 equals to 383.21 $/hr while, the lowest allocated TCA level (19.58 $/hr) is located at bus 2 in Table 7.

Tables 8 and 9 show the equivalent usage factors for transmission network using Cases 4-5 of Procedure 2. These cases are based on the minimum and maximum rates.

Table 8 shows the equivalent usage factors for Case 4 of procedure 2. The highest allocated TCA using Case 4 /Procedure 1 is 383.21 $/hr at the largest power generation bus 1. While the lowest allocated TCA level (19.58 $/hr) is located at bus 2**.** As similar to Cases 2 and 3 of the suggested multi-stage EBE procedure allocates The highest allocated TCA using Case 3/Procedure 1 equals to 372.67 $/hr while, the lowest allocated TCA level (19.04 $/hr) is located at bus 2 in Table 9.

Figure 2 shows a comparison between different bus rates for different allocation schemes based on two sensitivity factors. These sensitivity factors are either computed as:

A. based on the power generation levels
B. based on the injected power at different buses.

Case 1.A means that the allocation usage is Case 1 of Procedure 1 and the sensitivity factors are based on the power generation levels. While, Case 1.B means that the allocation usage is Case 1 of procedure 1 and the sensitivity factors are based on the power injected.

The same transmission usage allocation levels using the two sensitivity factors are found. It is shown that, the rates at different buses are remains at level (6.2$/hr) in the first case. While, the use of the second sensitivity factors in terms of the power injected leads to increase the rate level to 10.5 $ /hr using Cases 1.A, 1.B, 2.A and 2.B . In case 3, the rate level of buses decreased to 8.5 ($/hr). The change in buses rate reflects the bus usage of the network. The best allocation schemes the schemes high network usage. The highest allocation level occurred at bus 2 using case 3.This result reflects the importance of generator 2 in the system performances.

Figure 3 shows a comparison between different line rates for different allocation schemes (in the second stage of the studied transmission usage allocation schemes). This figure dealt with the line rates for different allocation schemes. It is clear that; line 7 of the network has the highest rates compared to other line. The main factor leads to line 7 lightly used (highly rates) is: line 7 connected tied between buses 5 and 4. The first side of line 7, bus 5, has a generation unit of 50 MW and demand of 74 MW.

This insufficient generation level for this demand. The rest quantity of the needed load demand is fed by generator 2. On the other side, bus 4, has only a load of 26.25 MW. Feeding the demand at bus 4 is not mainly depending on bus 5 generation. More feeding paths are available (Lines 2-4, 3-4, and 5-4)

Table 10 presents the final allocation of transmission usage costs using different proposed procedures. The proposed procedures are compared with postage stamp procedure and the relative power injected procedure. These procedures are depending on the generation and demand levels.

Observing Table 10, it can be noted that, for all the lines, the proposed procedures have the property that they allocate a significant amount of the cost of each line to the buses directly connected to it. The buses with the highest line usage are these at the ends of the corresponding line. Taking into account that the power injected and extracted at each bus; the results reflect the location of each bus in the network. These users have more benefits from the network. They receive money for their contribution in the market equilibrium state. The most allocation levels of the transmission losses occurred at generation buses 1 and 2 while the largest allocation level at consumer sides occurred equally at buses 3 and 4.

These results are very consistent with physical concepts as:

1. Generation unit at bus 1 has the largest generation level.
2. Generation unit at bus 2 has an effective role in equilibrium of the market.
3. Consumer at buses 3 and 4 has the same demand level.

Table 3. Virtual power demand for different loss allocation schemes.

Bus No.	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6	Scheme 7	Scheme 8	Scheme 9	Scheme 10	Scheme 11	Scheme 12
1	20.044	20.554	21.882	21.456	20.799	19.044	19.975	19.783	19.935	19.922	20.738	72.361
2	1.246	1.470	0.472	1.515	1.429	0	0.917	0	0.725	0.715	1.801	-23.758
3	47.403	47.051	46.976	46.700	46.250	47.611	47.098	46.250	46.921	46.930	47.139	31.377
4	47.403	47.054	47.054	46.704	46.250	47.611	47.098	46.250	46.921	46.930	46.669	31.370
5	74.349	74.314	74.060	74.069	75.715	76.178	75.357	78.161	75.943	75.946	74.097	79.095
Total	190.445	190.443	190.444	190.440	190.443	190.440	190.440	190.444	190.445	190.440	190.444	190.445

Table 4. Virtual power generation for different loss allocation schemes.

Bus No.	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6	Scheme 7	Scheme 8	Scheme 9	Scheme 10	Scheme 11	Scheme 12
1	78.90	78.39	77.06	77.49	78.14	79.90	78.97	79.16	79.01	79.02	78.20	26.58
2	48.75	48.53	49.53	48.49	48.57	50.00	49.08	50.00	49.28	49.28	48.19	73.75
3	-1.15	-0.80	-0.73	-0.45	0	-1.36	-0.85	0	-0.67	-0.68	-0.89	14.87
4	-1.15	-0.80	-0.80	-0.45	0	-1.36	-0.85	0	-0.67	-0.68	-0.42	14.88
5	59.65	59.68	59.94	59.93	58.29	57.82	58.64	55.84	58.06	58.05	59.90	54.90
Total	184.99	185.00	184.99	185.00	185.00	184.99	185.00	185.00	184.99	185.00	185.00	184.99

Table 5. Equivalent usage factors of transmission network using Case 1/ Procedure 1 for 5-bus test system.

Line No	From bus	To bus	bus 1	bus 2	bus 3	bus 4	bus 5	Total usage	Cost $/hr	Rate $/MW
1	1	2	3.70	0.080	7.934	7.947	12.508	32.164	60	1.865
2	1	3	3.42	0.074	7.346	7.358	11.581	29.780	240	8.059
3	2	3	3.12	0.067	6.692	6.703	10.550	27.129	180	6.635
4	4	2	3.28	0.071	7.043	7.054	11.103	28.551	180	6.304
5	2	5	2.76	0.060	5.926	5.935	9.342	24.023	120	4.995
6	3	4	0.99	0.021	2.136	2.139	3.367	8.658	30	3.465
7	4	5	1.10	0.024	2.366	2.370	3.731	9.594	240	25.010
Total $/hr			120.64	2.602	259.00	259.42	408.32	----	1050	----

Table 6. Equivalent usage factors of transmission network using Case 2/ Procedure 1 for 5-bus test system.

Line No	From bus	To bus	bus 1	bus 2	bus 3	bus 4	bus 5	Total usage	Cost $/hr	Rate $/MW
1	1	2	11.41	7.438	6.364	6.364	0.583	32.164	60	1.865
2	1	3	10.56	6.887	5.892	5.892	0.540	29.780	240	8.059
3	2	3	9.63	6.274	5.368	5.368	0.492	27.131	180	6.634
4	4	2	10.13	6.602	5.649	5.649	0.518	28.551	180	6.304
5	2	5	8.53	5.555	4.753	4.753	0.436	24.023	120	4.995
6	3	4	3.07	2.002	1.713	1.713	0.157	8.658	30	3.465
7	4	5	3.48	2.264	1.397	1.397	0.178	8.712	240	27.548
Total $/hr			383.21	249.690	198.750	198.750	19.580	-----	1050	-------

Table 7. Equivalent usage factors using Case 3 / Procedure 1 for 5-bus test system.

Line No	From bus	To bus	bus 1	bus 2	bus 3	bus 4	bus 5	Total usage	Cost $/hr	Rate $/MW
1	1	2	11.41	7.438	6.364	6.364	0.583	32.164	60	1.865
2	1	3	10.56	6.887	5.892	5.892	0.540	29.780	240	8.059
3	2	3	9.63	6.274	5.368	5.368	0.492	27.131	180	6.634
4	4	2	10.13	6.602	5.649	5.649	0.518	28.551	180	6.304
5	2	5	8.53	5.555	4.753	4.753	0.436	24.023	120	4.995
6	3	4	3.07	2.002	1.713	1.713	0.157	8.658	30	3.465
7	4	5	3.48	2.264	1.397	1.397	0.178	8.712	240	27.548
Total $/hr			383.21	249.690	198.750	198.750	19.580	-----	1050	-------

Table 8. Equivalent usage factors using Case 4/ procedure 2 for minimum transmission usage network rates.

Line No	From bus	To bus	bus 1	bus 2	bus 3	bus 4	bus 5	Total usage	Cost $/hr	Rate $/MW
1	1	2	11.41	7.438	6.364	6.364	0.583	32.164	60	1.865
2	1	3	10.56	6.887	5.892	5.892	0.540	29.780	240	8.059
3	2	3	9.63	6.274	5.368	5.368	0.492	27.131	180	6.634
4	4	2	10.13	6.602	5.649	5.649	0.518	28.551	180	6.304
5	2	5	8.53	5.555	4.753	4.753	0.436	24.023	120	4.995
6	3	4	3.07	2.002	1.713	1.713	0.157	8.658	30	3.465
7	4	5	3.48	2.264	1.397	1.397	0.178	8.712	240	27.548
Total $/hr			383.21	249.690	198.750	198.750	19.580	------	1050	-------

Table 9. Equivalent usage factors using case 5/procedure 2 for maximum transmission network usage rates.

Line No	From bus	To bus	bus 1	bus 2	bus 3	bus 4	bus 5	Total usage	Cost $/hr	Rate $/MW
1	1	2	10.542	6.869	5.877	5.877	0.539	29.704	60	2.0199
2	1	3	10.026	6.532	5.589	5.589	0.512	28.249	240	8.4960
3	2	3	9.462	6.165	5.275	5.275	0.483	26.660	180	6.7517
4	4	2	9.943	6.479	5.543	5.543	0.508	28.016	180	6.4250
5	2	5	8.444	5.502	4.707	4.707	0.431	23.792	120	5.0436
6	3	4	3.067	1.998	1.710	1.710	0.157	8.641	30	3.4717
7	4	5	3.405	2.218	1.898	1.898	0.174	9.593	240	25.0180
Total $/hr			372.670	242.800	207.750	207.750	19.040	-----	1050	---------

Table 10. Final transmission cost allocation results using different methods for network buses.

Bus	Postage Stamp Method [4]	Relative power Injected TCA	Proposed Multi-Stage Allocation Procedure			Proposed Modified Sensitivity Procedure	
			Case 1	Case 2	Case 3	Case 4	Case 5
1	301.82	316.80	120.64	383.24	383.21	383.21	372.67
2	137.83	220.18	2.60	249.69	249.69	249.69	242.80
3	131.25	203.67	259.00	198.75	198.75	198.76	207.75
4	131.25	203.67	259.43	198.75	198.75	198.76	207.75
5	347.83	105.69	408.32	19.58	19.58	19.58	19.04
Total ($/hr)	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00	1050.00

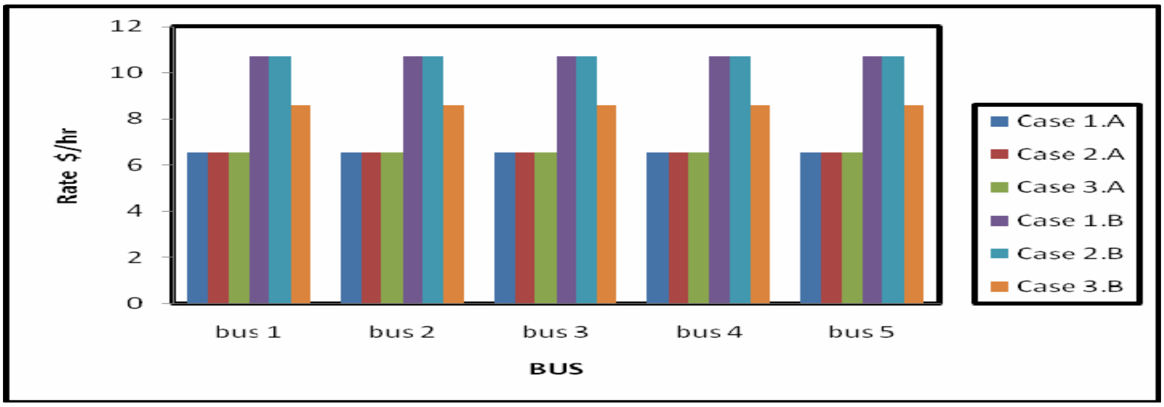

Fig. 2. Comparison between different bus rates for different allocation schemes.

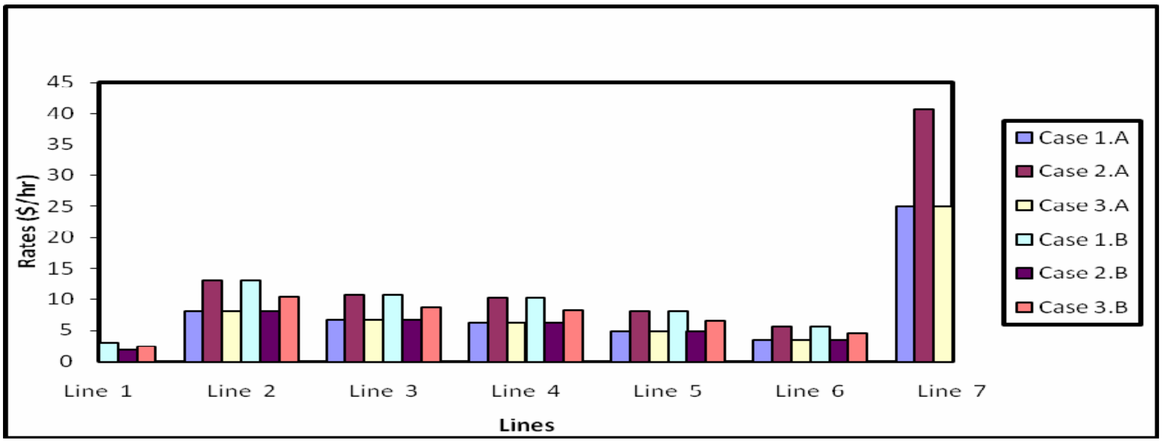

Fig. 3. Comparison between different lines rates for different allocation schemes.

Table 11. Transmission cost allocation using different methods for 14-bus test system.

Bus	Postage Stamp method [4]	Relative Power Injected TCA	Proposed Multi-Stage Allocation Procedure			Proposed Modified Sensitivity Procedure	
			Case 1	Case 2	Case 3	Case 4	Case 5
1	1414.11	1578.39	177.47	212.32	157.41	2808.40	2803.20
2	551.67	284.78	314.27	339.24	809.60	85.23	85.08
3	659.70	700.42	1243.8	1221.09	1097.93	515.61	514.65
4	334.76	355.43	629.48	619.62	480.17	132.76	132.52
5	53.22	56.51	99.83	98.52	-62.22	3.36	3.35
6	78.44	83.28	147.09	145.18	286.61	7.29	7.27
7,8	0	0	0	0	0	0	0
9	206.59	219.35	389.38	382.41	458.62	45.63	50.47
10	63.03	66.92	119.24	116.67	76.09	4.25	4.70
11	24.51	26.02	46.27	45.37	26.57	0.64	0.71
12	42.72	45.36	80.92	79.07	63.71	1.95	2.16
13	94.54	100.38	179.79	175.00	100.88	9.56	10.57
14	104.35	110.79	200.07	193.15	132.25	12.90	12.88
Total ($/hr)	3627.65	3627.64	3627.64	3627.64	3627.64	3627.64	3627.64

Application to 14-bus Test System

Observing Table 11, it can be noted that, the proposed procedures have the property that they allocate a significant amount of the cost of each line to the buses directly connected to it. Taking into account that the power injected and extracted at each bus; the results reflect the location of each bus in the network. Bus 5 in Case 3 has the most benefits from the network as these buses receive money for their contribution in the market equilibrium state in the multi-stage allocation procedure. The most allocation levels of the transmission usage costs occurred at generation buses 1 and 2 while the most allocation level at consumer sides occurred at bus 4. These results are very consistent with the physical concepts of the studied test system. Cases 4 and 5 are the most preferable case for consumers as low allocation levels to be allocated due to their transmission usage. The amount of the TCA levels at consumer buses is related to their consumed power demand.

8. EVALUATION OF THE PROPOSED PROCEDURES

The advantages of the suggested schemes are:

- Emphasizing the interaction among complex power and current associated with each network users and depending on the actual nodal currents, the exact network equations and circuit topology.
- Promoting more efficient expansion and utilization of generation and transmission resources.
- Defining the contributions of each generator/load and assigning the transmission usage costs.

The future researches in this subject will aims to cover the drawbacks of the suggested schemes as:

- Different emergency effects on the TCA levels.
- Considering the effects of different loading conditions.
- The TCA methods should consider the initial state from optimal power dispatch as similar as the power flow solutions.

9. CONCLUSION

The problem of transmission cost allocation has been discussed in this paper. Different proposals for transmission cost allocation are suggested. These allocation levels helps the ISO to determines the system users states after adding these allocation levels to their initial payments or benefits. An early detection of market equilibrium can be deduced with respect to the allocation levels. The proposed procedures allow to negative allocation related to the contribution of different users in the equilibrium state of the network. Using the suggested allocation options, the ISO can prepare the responsible management strategy that maximizes the benefits from the available resources.

REFERENCES

[1] Pan, J., Teklu, Y., Rahman, S., and Jun, K. 2000. Review of Usage-Based Transmission Cost Allocation Methods under open access. *IEEE Transactions Power System*. 15 (4): 1218–1223.

[2] Galiana, F.D., Conejo, A.J., and Gil, H.A. 2003. Transmission Network Cost Allocation Based on Equivalent Bilateral Exchanges. *IEEE Transactions Power Systems*. 18 (4): 1425–1431.

[3] Zolezz, J.M., and Rudnick, H. 2002. Transmission Cost Allocation by Cooperative Games and Coalition Formation. *IEEE Transactions Power System*. 17 (4): 1008–1015.

[4] Conejo, A.J., Galiana, F.D., and Kockar, I. 2001. Z-Bus Loss Allocation. *IEEE Transactions Power System*. 16 (1): 105-110.

[5] Conejo, A.J., Contreras, J., Lima, D.A., and Padilha-Feltrin, A. 2007. Z-bus Transmission Network Cost Allocation. *IEEE Transactions on Power Systems*. 22 (1): 342–349.

[6] Usaola, J. 2005. Transmission cost allocation in pool systems. In *Proceeding of 15th PSCC*, Liege, 22-26 August 2005 Session 40, Paper 1.

[7] Rau, N.S. 2001. Radial Equivalent to Map Network to Market Formats-An Approach Using Quadratic Programming. IEEE Transactions Power Systems. 16 (4): 856-861.

[8] Conejo, A.J. Alguacil, N., and Fernandez-Ruiz, G. 2003. Allocation of the Cost of Transmission Losses Using a Radial Equivalent Network. *IEEE Transactions Power Systems*. 18 (1): 1353–1358.

[9] Kirschen, D., Allan, R., and Strbac, G. 1997. Contributions of Individual Generators to Loads and Flows. *IEEE Transactions on Power Systems* 12 (1): 52-60.

[10] Bialek, J. 1997. Topological Generation and Load Distribution Factors for Supplement Charge Allocation in Transmission Open Access. *IEEE Transactions on Power Systems.* 12 (3): 1185-1193.

[11] Pantoš, M., Verbic, G., and Gubina, F. 2005. Modified Topological Generation and Load Distribution Factors. *IEEE Transactions on Power Systems*. 20 (4): 1998-2005.

[12] Sedaghati, A. 2006. Cost of Transmission System Usage Based on an Economic Measure. *IEEE Transactions on Power Systems*. 21 (2): 466-473,.

[13] Kattuman, P.A., Bialek, J., and Abi-Samra, W. N. 1999. Electricity Tracing and Co-operative Game Theory. In *Proceedings of the 13th Power System Computation Conference*, Trondheim, June 28-July 2: 238-243.

[14] Abou El-Ela, A.A., and El-Sehiemy, R.A. 2007. Different Transmission Loss Allocation in Deregulated Power Markets. *In Proceeding of the 42nd International Universities Power Engineering Conference (UPEC 2007)*, 4-6 September 2007, Brighton, England, Paper No. 177: 634-640.

[15] Ng, W.Y. 1981. Generalized Generation Distribution Factors for Power System Security Evaluations. *IEEE Transactions on Power Apparatus and Systems*, PAS-100: 1001-1005.

[16] El-Sehiemy, R.A., and Abou El-Ela, A.A. 2008. Optimal Generation Costs Considering Modified Sensitivity Factors and Modified Particle Swarm Optimization Model, to be appear *International Energy Journal (IEJ)*, 9 (2): 129-138.

[17] Abou El-Ela, A.A., Bishr, M. Allam S., and El-Sehiemy, R. 2005. Optimal Preventive Control Actions in Power System Using Multi-Objective Fuzzy Linear Programming Technique. *Electric Power System Research Journal* 74 (1): 147-155.

[18] Pai, M.A. 1979. *Computer Technique in Power System Analysis*. Mc Graw-Hill.

[19] Zimmerman, R.D. 2005. MATPOWER Version 3.0, a MATLAB™ Power System Simulation Package. [Available on-line] at: www.pserc.cornell.edu/matpower .

[20] [Online]. www.mathwork.com/