Transmission Cost Allocation Schemes in Competitive Power Systems

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Abstract: - This paper presents different flow-based transmission cost allocation (TCA) schemes for distributing the transmission usage costs to system individuals. Different independent system operator (ISO) visions are suggested using the proportional rata method. In addition to the suggested schemes, three other approaches are proposed. The first proposed approach generalizes the equivalent bilateral exchanges (EBE) concepts presented in [2] for lossy networks through multi-stage procedure. The second proposed approach is based on modified sensitivity factors (MSF). These MSF factors are developed from the actual measurements of power flows in transmission lines and the power injections at different buses. The proposed approaches 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 proposal's capability for flow-based TCA schemes.

Key-Words: - transmission cost allocation, deregulated, modified sensitivity factors, bilateral exchanges

1 Introduction

The transmission cost allocation (TCA) to system individuals is one of the important goals of deregulated power systems. The problem is how to allocate the total cost of transmission between all the users in an equitable way which at the same time provides them with the correct, market based economical signals. The TCA concepts are more general than wheeling which is the transfer of transacted power between two or more utilities through a transmission network of the third one. The cost of transmission usage and the methodology by which it is computed is a high priority problem throughout the power industry due to the growth in transmission facilities, the cost differentials between utility companies, and the dramatic growth in non-utility generation capacity.

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 and power transmission losses. In real time operation, generators and consumers engage in power transactions. Commonly agreed features of TCA methods are to provide locational signals and incentives to encourage efficient use of the transmission facilities. They also must comply with some conditions to avoid cross-subsidies and to be transparent and easy to implement, to ensure cost recovery, to provide adequate economic signals and to have continuity with time.

Consumer meters measure their actual consumption, while generator meters measure their actual production level. The importance of the transmission system in the new deregulated environment was emphasized 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 usage 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.

The cost allocation methods presented in literature could be classified as embedded cost methods and marginal cost methods [1]. Marginal cost methods do not guarantee cost recovering in real networks. Embedded cost methods allocate the transmission costs according to the extent of use of generators and consumers. Several methods based on the embedded cost have been proposed for 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 drawbacks are that they ignore actual network use and that they do not send adequate economic signals to grid users. Flow-based methods charge the users in proportion to their use the of grid facilities. The flow-based methods classified as proportional or differential methods. The advantages of proportional method are: it is simple to understand and provides grid use and load sharing among generators. Differential methods are well known in literature and are based on the sensitivities of branch flows to power injection in nodes. These sensitivities depend on the choice of the slack bus in the studied case therefore; there is a part of arbitrariness in the allocation.

A flow based method reported in [2] used the so-called EBE. 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. Reference [3] 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 [4] presented a method that integrates cooperation and coordination among the agents and their physical and economic use of the network to allocate charges among users of a transmission system. In particular, cooperative game theory arises as a most convenient tool to solve cost allocation problems [5]. The cost of transmission system usage was presented based on an economic measure of power markets in [6]. In [7], the co-operative game theory based procedure was presented for electricity tracing. A variety of applications in both planning and operation require repetitive computation of power flow and power losses in transmission lines. Sensitivity factors play a key role in many system security analysis and market applications. In [8], the contribution of individual generators to loads and flows was discussed. In [9], 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 [10] to consider the effects of transmission losses as separate nodes. The generalized generation distribution factors (GGDF) for obtaining the power flows in transmission lines in terms of the injected power generations [11]. Different proportional-based schemes are presented to allocate the transmission losses to network users [12]. A loss allocation scheme using the bus impedance Z-bus was presented in [13]. Other allocation schemes are presented in references [14-16].

The main contribution of this paper is to propose modified versions of transmission cost allocation schemes. Some of the proposed schemes are based on proportional concept and other schemes are based on the EBE principles and the modified sensitivity factors.

2 Modified Sensitivity Factors

The proposed Modified Sensitivity Factors (MSF) are introduced depend on the actual power system measurements for initial power flows in transmission lines and the corresponding injected powers at different buses, as:

$$PF = D_m . PI \tag{1}$$

$PF = [PF_1\ PF_2\ PF_3\ .....,\ PF_k,\ .....,\ PF_{NL}\ ]$,

$k=1,2,\ .....,\ NL$

$$PI = [PI_1\ PI_2\ PI_3 .....,\ PI_i,\ ....,\ PI_{NB}\ ], \tag{2}$$

$i=1,2,\ ......,\ NB$

$PI_i = PG_i - PD_i$

Where, Dm is the proposed MSF.

The initial power flows $\left(PF^0\right)$ in terms of initial injected powers $\left(PI^0\right)$ can be expressed as:

$$PF^0 = D_m . PI^0 \tag{3}$$

By multiplying the both sides of Equation (3) by $\left(\left(PI^0\right)^t \cdot \left(\left(PI^0\right).\left(PI^0\right)^t\right)^{(-1)}\right)$ it can be getting:

$$\begin{aligned} &PF^0.\left(PI^0\right)^t.\left(\left(PI^0\right).\left(PI^0\right)^t\right)^{(-1)} = \\ &D_m.\left(PI^0\right).\left(PI^0\right)^t.\left(\left(PI^0\right).\left(PI^0\right)^t\right)^{(-1)} = D_m \end{aligned} \tag{4}$$

Or $D_m = PF^0.\left(PI^0\right)^t.\left(\left(PI^0\right).\left(PI^0\right)^t\right)^{(-1)}$ (5)

From Equation (5), it can be founded that the proposed MSF are dependent on the actual initial measurements of the power flows in transmission lines and the injected power at different buses. The power flow in transmission line k (PF_k) can be expressed as:

$$PF_k = \sum_{i=1}^{NB} \left((D_m)_{k,i} \, .PI_i \right) \tag{6}$$

$$(D_m)_{k,i} = PF_k^0 . \left(PI_{k,i}^0\right)^t . \left(\left(PI_{k,i}^0\right) . \left(PI_{k,i}^0\right)^t \right)^{(-1)} \tag{7}$$

$(D_m)_{k,i}$ is the MSF between line k and generation i, and $\left(PI_{k,i}^0\right)^t$ is the transpose of power generation vector $PI_{k,i}^0$.

3 Suggested Transmission Cost Allocation Schemes

This paper generalizes the loss allocation options presented in [12] for TCA problems. The cost allocated at each bus is computed through obtaining the TCA allocation vector S_i for different options as:

$$C_{a,k}^i = S_i \cdot C_k \tag{8}$$

Where:

$C_{a,k}^i$ is the cost allocated at bus i to usage of line k,

S_i is the allocation factor at bus i.

C_k is the total costs of line k.

The suggested TCA allocation schemes are:

Scheme 1: Current injected allocation based

This scheme is based on the injected current (I_i) at bus i. The S_i vector is computed as a percentage of the total injected current at NB- buses, as:

$$S_i = I_i \Big/ \sum_{i=1}^{NB} I_i \tag{9}$$

Scheme 2: Power demand based

This scheme is suggested based on the power demand at bus j, (PD_j). The vector S_j is computed as a percentage of the total power demand at ND-buses, as:

$$S_j = PD_j \Big/ \sum_{j=1}^{ND} PD_j \tag{10}$$

Scheme 3: Maximum bus power used

This scheme is suggested based on the maximum bus power used of PD_i and/or PG_i. The vector S_i is computed as a percentage of the maximum bus power used each bus to the total maximum power used by all buses as:

$$S_i = Max.(PG_i, PD_i) \Big/ \sum_{i=1}^{NB} Max.(PG_i, PD_i) \tag{11}$$

Scheme 4: Combined bus power used

This scheme is suggested based on the combined bus power used. The vector S_i is computed as a percentage of the sum of generation and demand powers at certain bus to their sum power used at all buses as:

$$S_i = (PG_i + PD_i) \Big/ \sum_{i=1}^{NB} (PG_i + PD_i) \tag{12}$$

Scheme 5: 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 and/or load demand on their companies. The vector S_i can be computed as:

$$S_i = Aver\left(\left(PG_i \Big/ \sum_{i=1}^{NB} PG_i \right) and/or \left(PD_i \Big/ \sum_{i=1}^{NB} PD_i \right) \right) \tag{13}$$

Scheme 6: Interested participant allocation

This suggested scheme is based on the network configuration and the net injected bus powers. This allocation procedure divides the power usage of each line into two components. The first component is for the sending side (s) and the second for the receiving side (r). The allocation usage factors are computed as a percentage of the net injected power to the sum of the injected power at both sides of each line. The allocation components usage costs $(U_{k,sr})$ of line k at both sides are computed as:

$$P_{k,s} = \left(|PI_s| \Big/ \left(|PI|_s + |PI_r| \right) \right) U_{k,sr} \tag{14}$$

$$P_{k,r} = \left(|PI_r| \Big/ \left(|PI|_s + |PI_r| \right) \right) U_{k,sr} \tag{15}$$

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

$$P_{ar} = \sum_{s=1}^{NR} \left(|PI_r| \big/ \left(|PI_s| + |PI_r| \right) \right) U_{k,rs} \tag{16}$$

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

$$P_{as} = \sum_{r=1}^{NS} \left(|PI_s| \big/ \left(|PI_s| + |PI_r| \right) \right) U_{k,sr} \tag{17}$$

Scheme 7: Modified Equivalent Bilateral Exchanges

The EBE between the generation at bus i and demand bus at bus j was defined as [2]:

$$GD_{ij} = \frac{PG_i \, .PD_j}{P_d^{sys}} \tag{18}$$

Where, in lossless network, the system demand $P_d^{sys} = \sum_j PD_j = \sum_i PG_i$

The equivalent exchanges GD_{ij} can be viewed as the fraction of generation (PG_i) that supplies the bus demand P_{dj} or equivalent to fraction of power demand (PD_j) supplied by the power generation (PG_i). It was decomposed each individual generation and demand level into linear combination of the EBE. It is straightforward to decompose each individual generation and consumer into a linear combination of the EBE as:

$$PG_i = \sum_j GD_{ij} \tag{19}$$

$$PD_j = \sum_i GD_{ij} \tag{20}$$

The effects of EBE on the power flow at line k (PF_k) are expressed in terms of EBE as:

$$PF_k = \sum_{i,j} \left(\gamma_{kij} .GD_{ij}\right) \tag{21}$$

The coefficients γ_{kij} are to the generation distribution factors which computed under DC load flow. This parameter describes the sensitivity of (PF_k) through line k, with respect to the EBE between power generation at bus i and power demand at bus j.

The properties of the presented EBE in [2] were:

i) Bilateral exchanges between generators and demand at the same bus m 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.

In this paper, the EBE is developed for the lossy network through two-stage procedure. In the first stage, the transmission losses are allocated to system users. Allocation of system losses modifies actual power generation or power demand levels at different buses. The power generation (PG_i) and power demand (PD_j) are replaced by their virtual power generation levels (PG_i^v) at generation buses or virtual power demand (PD_j^v) at demand buses.

At the generation buses, the loss allocated component to generation buses side, the power loss components allocated at the generation buses (P_i^{lg}) are subtracted from the actual power generation levels. PG_i^v, at bus i, is computed as: $PG_i^v = PG_i - P_i^{lg}$.

At demand buses side, the loss allocated component to demand buses (P_j^{ld}) is added to the actual power generation level. PD_j^v is computed as: $PD_j^v = PD_j + P_j^{ld}$. Allocating the transmission losses will carry out in the Stage 1, as:

Stage 1: Allocation of the transmission losses

In this stage, the transmission losses are allocated to different systems buses. After allocation the transmission losses, both consumer and generation levels are modified from their physical levels to new virtual levels. The amount of losses allocated is either added to the demand levels or subtracted from the generation levels. In this paper we consider three schemes in the first stage. Three studied cases (Cases 1-3) based on three loss allocation schemes. These loss schemes are Z-bus loss allocation [13], proportional rata based on power demand loss allocation [13], and voltage based loss allocation scheme [12]. Two conditions for the modified EBE are discussed as:

1. If the total losses added to demand levels at different buses, then the modified EBE is computed using the new virtual load demands as:

$$GD_{ij} = PG_i PD_j^v / P_d^{sys} \tag{22}$$

The P_d^{sys} in this case equals to the total power generation or virtual demand levels as:

$$P_d^{sys} = \sum_{i=1}^{NG} PG_i = \sum_{l=1}^{ND} PD_j^v \tag{23}$$

2. If the total losses subtracted from generation levels at different buses, then the new virtual power generation are used to compute the EBE as:

$$GD_{ij} = PG_i^v PD_j / P_d^{sys} \tag{24}$$

The virtual power generation subtracts the loss component certain bus from the power generation at this bus. The P_d^{sys} in this case equals to the total power generation/ virtual demand levels as:

$$P_d^{sys} = \sum_{i=1}^{NG} PG_i^v = \sum_{j=1}^{ND} PD_j \tag{25}$$

Stage 2: Allocation of the transmission usage costs

For the proposed TCA approach, the power flows in the transmission lines are computed using the MSF in (7). With the above decomposition, the effects of EBE on the power flow (PF_k) is determined by, an operation that doesn't a defined slack bus. After modifying the power generation and power demand levels at different buses to their virtual levels, The EBE between generators and demands is obtained. The power flow in transmission line k in terms of the EBE is computed as:

$$PF_k = \sum_{i,j} \left(\left(D_m\right)_{k,ij} \cdot GD_{ij}\right) \tag{26}$$

Under the modified EBE principle, each flow component $\left(\left(D_m\right)_{k,ij} \cdot GD_{ij}\right)$, is deemed to "use" line (k) irrespectively to its sign with respect to the net flow in line (k). Under the EBE principle, each line flow component is deemed to use the line k irrespectively to the sign of the net flow in this line. Equation (27) presents the use of transmission line k by EBE (GD_{ij}). The use of line k by demand at bus j is the sum of all EBE involved demand at bus j, as:

$$UD_{kj} = \sum_{i \in \Omega j} \left| \left((D_m)_{k,ij} \cdot GD_{ij} \right) \right| \quad (27)$$

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

$$UG_{ki} = \sum_{j \in \Omega_i} \left| (D_m)_{k,ij} \cdot GD_{ij} \right| \quad (28)$$

The total line k usage (UL_k) due to all EBE is:

$$UL_k = \sum_{\substack{i \in \Omega_j, \\ j \in \Omega_i}} \left| (D_m)_{k,ij} \cdot GD_{ij} \right| \quad (29)$$

The transacted power rate (r_k) is computed from:

$$r_k = C_k / UL_k \quad (30)$$

Scheme 8: Proposed MSF-Based TCA

The suggested scheme is based on the proposed MSF. In this scheme, the power flows in transmission line connected between buses i and j, in terms of the injected power at different buses, are computed from the following:

$$PF_k = \sum_{i=1}^{NB} \left((D_m)_{k,i} . PI_i \right) \quad (31)$$

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

$$PF_k^i = (D_m)_{k,i} . PI_i \quad (32)$$

Line usages computed from both sides ($(U1)$ and $(U2)$) are based on the transacted power as:

$$U1_k^i = \left| \left(D_m^{(1)} \right)_{k,i} . PI_i \right| \quad (33)$$

$$U2_k^i = \left| \left(D_m^{(2)} \right)_{k,i} . PI_i \right| \quad (34)$$

Where, $\left(D_m^{(1)} \right)_{k,i}$ and $\left(D_m^{(2)} \right)_{k,i}$ refer to the MSF for both sides of line k with respect to injection power at bus i.

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

$$Ue_k^i = \max \left(U1_k^i, U2_k^i \right) \quad (35)$$

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

$$Ue_k^i = \min \left(U1_k^i, U2_k^i \right) \quad (36)$$

The transacted power rate in line k (r_k) is computed from:

$$r_k = C_k \Big/ \sum_{i=1}^{NB} Ue_k^i \quad (37)$$

Where :

C_k refers to the total annual cost of line k.

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

$$C_k^i = r_k \cdot Ue_k^i \quad (38)$$

Cases 4 and 5 consider minimum and maximum rates.

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4 Applications

a. Test Systems

The 5-bus test system [17], IEEE 14-bus test systems [18] are used to perform the required computation in this paper. To illustrate the working and the methods for TCA, we consider the five-bus test system (Fig.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 total annual costs of the transmission network are still the same for studied cases.

b. Results and Comments

Tables III and IV show different transmission cost allocation schemes for different options for the five bus test system. Tables V and VI show different transmission cost allocation schemes for different options for the 14-bus test system. In Tables III and V present the TCA components per bus for different schemes. Columns 1 through 6 represent the cost of the allocated bus costs due to network usage for the suggested TCA schemes. These six-schemes are based on the bus power used. The studied schemes are reported as: Current injected allocation based (Scheme 1), Power demand based (Scheme 2), Maximum bus power used (Scheme 3), Combined bus power used (Scheme 4), ISO comparable based (Scheme 5) and Interested participant allocation (Scheme 6). Tables V and VI present the TCA components per bus for schemes 7 and 8 and two other conventional TCA methods. A two-stage TCA scheme (Scheme 7) has three studied cases (cases 1-3 in Tables IV and VI). While, the modified sensitivity based TCA scheme (8) has two studied cases (Cases 4 and 5 in Tables IV and VI). Schemes 1 through 8 are compared with three methods presented in the literature. These methods are postage stamp method and Z-bus allocation method.

1) five bus test system

In Table III, Scheme 1 allocates the highest cost to the generation at bus 1 comprising the highest generation level (Generator 1 is with about 32.25 % of the total generation). Scheme 2 allocates the highest cost to the combined generator/load at bus 5 comprising the highest loading level (40% of the system load). In Scheme 3, the maximum TCA scheme at bus 2 equals 28.08 % of the total network costs. The remaining schemes allocate varying allocation levels depending on the network topology, injected power at different buses and emphasis on current injection with some differences being relatively significant. Schemes 2 through 5 allocate the same TCA levels at consumer buses 3 and 4. But, in Schemes 1 and 6 the TCA levels at buses 3 and 4 aren't the same. These changes are due to the network topology. Both Scheme 1 and Schemes 6 allocates more TCA at bus 2 due to large number of line connected to bus 2 (4-lines as shown in Fig. 1). Due to the same reason, schemes 1 and 6 allocate low TCA levels at bus 5 compared to other allocation schemes.

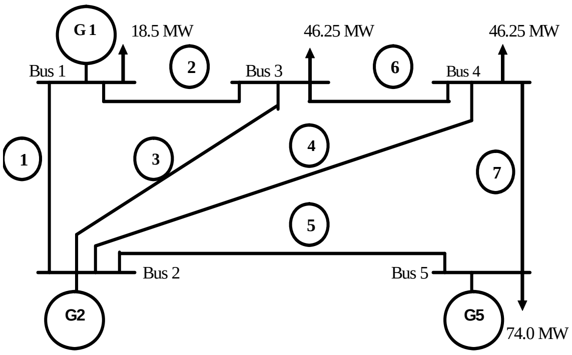

Fig. 1 The line Diagram for the 5-bus test system

Table I Five-bus test system transmission line data

Line No.	Bus *From*	Bus *To*	*Impedance Z*	Line Charge Y/2	Line Admittance
1	1	2	0.02+j 0.06	j 0.030	5.00-j 15.0
2	1	3	0.08+j 0.24	j 0.025	1.25-j 3.75
3	2	3	0.06+ j 0.18	j 0.020	1.67-j 5.00
4	4	2	0.06+j 0.18	j 0.020	1.67-j 5.00
5	2	5	0.04+j 0.12	j 0.015	2.50-j 7.50
6	3	4	0.01+j 0.03	j 0.010	10.0-j 30.0
7	4	5	0.08+j 0.24	j 0.025	1.25-j 3.75

Table II Five-bus test system bus data

Bus No.	PG^{max} MW	PG^{min} MW	PG_0 MW	Load MW
1	120	10	90.44	18.5
2	90	10	60	0
3	0	0	0	46.25
4	0	0	0	46.25
5	60	10	40	74.0

Table III Different proportional TCA schemes for 5-bus system (schemes 1-6)

Buses	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6
1	341.25	117.6	209.26	233.72	231.9	136.1
2	323.65	0	294.87	247.81	243.91	368.48
3	136.34	259	151.63	127.43	129.5	186.43
4	140.74	259	151.63	127.43	129.5	199.68
5	108.02	414.4	242.61	313.61	315.19	135.39
Total $	1050	1050	1050.01	1050	1050	1050.01

Table IV Transmission cost allocation results for 5-bus system schemes 7 & 8

Bus	Postage Stamp Method [4]	Z-bus TCA [3]	Scheme 7			Scheme 8	
			Case 1	Case 2	Case 3	Case 4	Case 5
1	301.82	460.472	120.643	383.241	383.214	383.214	372.669
2	137.83	239.87	2.602	249.69	249.69	249.690	242.798
3	131.25	153.63	259.001	198.757	198.757	198.757	207.747
4	131.25	154.289	259.429	198.757	198.757	198.757	207.747
5	347.83	41.49	408.325	19.582	19.582	19.582	19.038
Total ($)	1050	1050	1050	1050	1050	1050	1050

Table V Different proportional TCA schemes for 14-bus system (schemes 1-6)

Buses	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6
1	2068.8	0	1542.2	1480.1	1424.9	279.22
2	863.65	303.94	420.88	550.02	540.85	296.77
3	475.52	1319.4	660.78	634.17	659.7	258.88
4	116.91	669.5	335.3	321.8	334.75	749.29
5	3.066	106.45	53.312	51.165	53.224	144.52
6	8.9901	156.87	78.564	75.401	78.435	529.56
7	0	0	0	0	0	0
8	0	0	0	0	0	0
10	57.785	413.19	206.93	198.6	206.59	566.79
11	5.8594	126.06	63.132	60.59	63.028	158.78
12	0.78509	49.022	24.551	23.563	24.511	114.15
13	2.0339	85.439	42.79	41.066	42.719	155.22
14	11.15	189.09	94.698	90.885	94.543	374.46
Total ($)	3627.65	3627.64	3627.64	3627.65	3627.64	3627.64

Table VI Transmission cost allocation results for schemes 7 & 8

Bus	Postage Stamp method [4]	Z-bus TCA [3]	Scheme 7			Scheme 8	
			Case 1	Case 2	Case 3	Case 4	Case 5
1	1414.11	560.97	177.476	212.326	157.412	2808.46	2803.28
2	551.67	1554.18	314.266	339.239	809.596	85.234	85.077
3	659.70	488.88	1243.82	1221.094	1097.93	515.607	514.652
4	334.76	138.98	629.484	619.623	480.174	132.762	132.517
5	53.22	36.87	99.825	98.518	**-62.221**	3.356	3.350
6	78.44	126.63	147.087	145.183	286.609	7.289	7.275
7	0.00	0.00	0.000	0.000	0.000	0.000	0.000
8	0.00	0.00	0.000	0.000	0.000	0.000	0.000
9	206.59	303.03	389.377	382.405	458.620	45.631	50.473
10	63.03	102.17	119.244	116.666	76.086	4.247	4.698
11	24.51	33.99	46.271	45.370	26.577	0.642	0.710
12	42.72	41.98	80.923	79.073	63.716	1.951	2.158
13	94.54	120.09	179.792	174.997	100.889	9.556	10.570
14	104.35	119.88	200.070	193.145	132.254	12.900	12.876
Total ($)	3627.65	3627.64	3627.64	3627.640	3627.64	3627.64	3627.64

In Table IV, two methods are presented from the literature. These methods allocate different allocation levels compared to the suggested Schemes 1 through 6 and the proposed Schemes 7 and 8. The Z-bus TCA method allocate the maximum TCA at bus 1 (the highest generation level) and the minimum TCA level (41.49 $) at bus 5 whose has the minimum power injection level. Scheme 7 is multi-stage TCA scheme which has three studied cases. Case 1 of Scheme 7 allocates the transmission usage costs with minimum values at bus 2 (this bus has low minimum consumer level) and maximum allocation level at bus 5 which has the highest consumer level. Cases 2 and 3 of Scheme 7 reallocate the transmission usage costs with minimum values at bus 5 and maximum allocation level at bus 1 as obtained from Z-bus TCA method. Cases 4 and 5 in Scheme 8 reallocate the transmission usage costs in a similar to Z-bus TCA method with minimum values at bus 5 and maximum allocation level at bus 1. Schemes 7 and 8 allocate the same allocation levels at consumer buses 3 and 4 as obtained from other schemes expect the changes which are appeared with Z-bus TCA method.

2) 14-bus test system

In Table V, Scheme 1 allocates the highest cost to the generation at bus 1 comprising the highest generation level Scheme 2 allocates the highest cost to load at bus 3. In Scheme 3, the maximum TCA scheme at bus 1 equals (1542.2$) of the total network costs. The remaining schemes allocate varying allocation levels depending on the network topology, injected power at different buses and emphasis on current injection with some differences being relatively significant. Schemes 1 through 5 allocate the same TCA levels at consumer buses 7 and 8. But, Scheme 6 allocates TCA levels to buses 7 and 8. These changes are due to the network topology. In Table VI, the Z-bus TCA method allocate the maximum TCA at bus 2 (the highest consumer level) and the minimum TCA levels at buses 7 and 8 whose has the minimum power injection level. Scheme 7 is multi-stage TCA scheme which has three studied cases. Cases 1 and 2 of Scheme 7 allocate the transmission usage costs with maximum values at bus 3. Case 3 of Scheme 7 reallocate the transmission usage costs with maximum values at bus 3. It is appeared in case 3 at bus 5, a negative TCA level is obtained at bus 5 for encourage the market individuals to compete and share in system emergency events. Cases 4 and 5 in Scheme 8 reallocate the transmission usage costs with maximum allocation level at bus 1.

5 Conclusion

In this paper, the problem of transmission cost allocation has been discussed in the deregulated power systems. Different TCA schemes are presented. Proportional TCA schemes are presented based on different ISO options for power used by both generators and consumers. Also, this paper suggested another TCA scheme for generalization the EBE for lossy networks. The modified EBE based TCA scheme established the transmission individuals' cooperation and coordination. Another scheme was suggested based on the modified sensitivity factors which dependent on the actual system measurements. The main advantage of the MSF-based TCA schemes is it is independent on the choice of slack bus. The proposed schemes allow encouraging the effective contribution of different users in the recovery of network usage costs. The TCA solutions are efficient, fair and equitable to participant agents. The advantages of the suggested schemes are:

- Emphasizing the interaction among complex power and current associated with each network users.

- Promoting more efficient expansion and utilization of generation and transmission resources.
- Defining the contributions of each generator/load and assigning the transmission usage costs to system individuals should encourage the market participants to take appropriate corrective actions that will reduce market risks.

Some of the opportunities for future work based on the proposed allocation procedures are: the generalization of these methodologies for market recovery problems such as transmission loss allocation, congestion cost allocation wheeling cost allocation and risk analysis problems. Some other power systems' applications of the proposed sensitivity factors are: for obtaining the optimal solutions of power flow problems and maximizing the effects of security analysis of transmission networks. In the case of these problems, the need to choosing the suitable optimization techniques is necessary.

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