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Transmission Cost Allocation Using Improved MVA-km Method by Optimal Power Flow

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Abstract.

Abstract - In the recent years, with restructuring in power systems and arising of electricity markets result in considerable changes in power system operation. An important challenge in power systems is transmission pricing. Transmission pricing has important effects on competition in the electricity markets, return of the transmission system investment and attracting new investments. In this paper, transmission pricing is done using improved MVA-km method. This method is based on the Zbus and MVA-km methods. Three different approaches are defined in order to analysis the effect of the reverse power flows on transmission cost. For compatibility with the electricity market environments, AC optimal power flow (ACOPF) is used for power dispatch of generation units. The proposed methods are simulated on a 12 bus test systems and the results of three MVA-km based methods are reported and compared. Moreover, the results of transmission cost calculation based on optimal power flow and power flow are compared.

Keywords: Electricity markets; Transmission system; Transmission pricing; Improved MVA-km method; AC optimal power flow (ACOPF);

1. Introduction

In the recent years, restructuring of power systems and the forming of competitive electricity markets create the significant differences in the operation of power systems. One of the most important characteristics of electricity markets is the technical characteristics of the transmission network, compared with other markets. The accepted producers of the market need the transmission network to deliver the generated power to consumers. Therefore, open access to transmission network plays an important role in the competitive electricity markets [1, 2].

One of the most important challenges in the electricity market is the allocation of transmission network costs between market participants [3]. In electricity markets, the generated power can not deliver to consumers through a specific path due to the technical characteristics of the transmission network and the theory of electrical circuits, it's not possible to deliver consumer, generated power from a specific path, but in the transmission network, the production power of a network inject by manufacturer and it is consumed in the other side, by the consumers and meanwhile, all of the other powers of production and consuming, can affect the exchange. In other words, passing power of transmission lines don't follow the markets financial laws, but follow the laws of load flow [2]. Therefore, for determining the transmission network pricing mechanism it is required to consider the specific characteristics of the electricity systems. Transmission pricing plays a significant role in the presentation of correct economic information, network utilization and capacity of the existing network. Also the transmission pricing plays an important role to enhance and expansion of the transmission network in the future. An appropriate mechanism for transmission pricing can cause optimal resource allocation in the network in the long-term horizon [3, 4]. Transmission pricing mechanism should pursue the following objectives [5]:

- To compensate the cost of transmission system and expected income of investors of transmission system.
- Fair allocation of costs between all participants of the transmission system
- Improve economic efficiency of network

Until now various methods are proposed for transmission pricing in electricity markets. References [6-9] have provided a review of the network pricing methods. These methods can be categorized in two general categories: "incremental (marginal) cost transmission pricing" and "embedded cost transmission pricing". In the incremental cost transmission pricing methods only short-term (operational) cost are considered [8]. This category includes nodal [10, 11], zonal [12,13] and regional [9] pricing methods. In the nodal pricing method, the electricity market settlement is done by using locational marginal pricing method and for this reason electricity market prices in different buses of system will vary. This difference is the base of transition pricing in the nodal method. On zonal and regional pricing methods, transmission pricing is done based on the difference in energy prices between zones and regions of the system. On embedded cost transmission pricing methods, the long-term (investment) costs of the network is considered in transmission pricing [8]. This category includes pricing methods such as postage stamp [14], contract path [1,15], MW-Mile or MW-km, power distribution coefficients[18] and Zbus [19]. In the postage stamp method, based on investment costs of the network, is received a fixed and same fee for all participants. In the contract path method, a financial path is considered for power flow in the network and accordingly, the cost of using the network is calculated. In the MW-mile method, the share of each participant in the active power flow through any of the lines is calculated using dc load flow calculation and accordingly, the allocation of the cost of the transmission network is done. The principles of power distribution coefficients and Zbus MW-mile methods are similar with the difference that in the power distribution coefficients method for calculating the contribution of the participants in power flows generation power shift distribution coefficients (GSDF) is used whilst in the Zbus method the theory of electrical circuits and network impedance matrix is used.

A transmission pricing mechanism has to allocate costs between network participants fairly in addition to ensuring the return of all investment costs of the transmission network. Some methods, such as the postage stamp, even though satisfy all the costs of the transmission network, but the costs are allocated between network participants, unfairly, because don't consider the location of the participant in the network and their distance from the centers of production and power consumption. On the other hand, it is possible that some methods such as nodal pricing method, with fairness, receive the cost of network participants much more or less than the actual cost of the transmission network. From another point of view, disadvantage of more transmission pricing methods is that they only active power flows are considered in pricing, while the reactive power flows have an important role in occupying of line capacity and congestion in the transmission lines [20]. In the meantime, just MVA-km method and Zbus method consider the lines reactive power flow. The MVA-km method is similar to MW-km, with the difference that the reactive powers are considered in calculation of transmission costs in the MVA-km method [8]. In this method the results are low accuracy because the laws governing the load flow is considered to be linear. Although Zbus method calculates contribution of each participant of active and reactive power, as well, but on calculation of the cost of transmission method, does not consider the difference between sent and receive lines power and the counter-flow powers role [21, 22]. The authors of this paper present a new transmission pricing method based on both Zbus and MVA-km method called improved MVA-km method. In this reference, Zbus is used to determine network participant shares from the power flows and MVA-km is used to determine their transmission costs.

In this paper, transmission cost allocation is done using the improved MVA-km method. As a contribution, in order to compatibility with the power markets, power dispatch is done by AC optimal power flow (ACOPF) that is presented comprehensively in [24]. The results of transmission cost allocation based on ACOPF are compared with the results of [23]. Moreover, the transmission cost of network participants per generated or consumed MVA are calculated and compared.

The rest of this paper is as follows: In the second section, will express how to calculate the participant contribution of the network lines power flow by Zbus method and how to calculate costs by MVA-km method. The proposed approaches for calculating the cost of transmission by MVA-km method are introduced in the third section. A simulation is done for a 12 bus case test network and the results and analysis are presented in the fourth section. The conclusions are presented in the fifth section.

2. Aallocation of transmission costs by the combination of Zbus and MVA-km methods

2.2. Zbus method

In the current section, with using Zbus method, the contribution of each participant is calculated in the network lines power flow. In Zbus method, π equivalent circuit is used for network modeling. π equivalent circuit shown in Figure 1. Apparent power flow of j-k transmission line that is caused by an injection of current in the network i bus is calculated as follow [21,22]. The used parameters in these equations are based on using ACOPF for power dispatch in the network [23].

$$S_{jk}^{i} = U_j \, . \, I_{jk}^{i*} \qquad (1)$$

S^i_{jk} : j-k line apparent power flow from j-bus to k-bus resulting of current injection in the i-bus

U_j : the voltage of j-bus

I^i_{jk} : current flow of j-k line from j-bus to k-bus resulting of the injection at i-bus

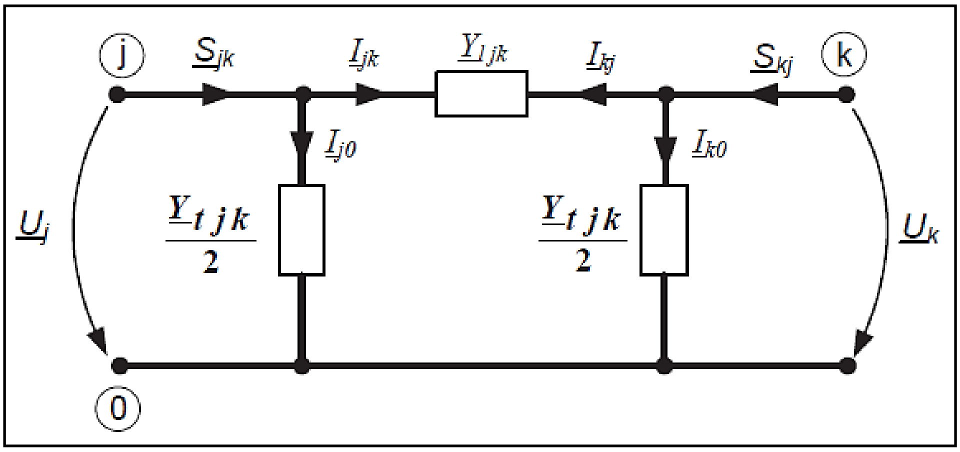

Figure 1. π equivalent circuit of j-k line

Note: the asterisk * means conjugate of complex number

Using mathematical equations that are presented in [21, 22]:

$$I^i_{jk} = D^i_{jk} . I_i \qquad (2)$$

$$D^i_{jk} = (Z_{ji} - Z_{ki}) . Y_{ljk} + Z_{ji} . \frac{Y_{tjk}}{2} \qquad (3)$$

I_i: injected current in the i-bus

D^i_{jk} : electrical distance between i-bus and j & k-buses

Z_{ji} : elements of j row and i column of network impedance matrix

Z_{ki} : elements k row and i column of network impedance matrix

Y_{ljk} : admittance of transmission line j-k

Y_{tjk} : susceptance of entire of transmission line

Now, by substituting equation (2) in (1), apparent power flow through the jk line resulting of the injection in the i-th bus is obtained as follows [23]:

$$S^i_{jk} = U_j . D^{i*}_{jk} . I^*_i \qquad (4)$$

By substituting D^{i*}_{jk} in (4), flowing active and reactive power through the jk line from j to k, resulting of power injection in i bus is calculated as follows [23]:

$$P^i_{jk} = Re\left\{U_j . \left[(Z^*_{ji} - Z^*_{ki}) . Y^*_{ljk} + Z^*_{ji} . \frac{Y^*_{tjk}}{2}\right] . \frac{S_i}{U_i}\right\} \qquad (5)$$

$$Q^i_{jk} = Im\left\{U_j . \left[(Z^*_{ji} - Z^*_{ki}) . Y^*_{ljk} + Z^*_{ji} . \frac{Y^*_{tjk}}{2}\right] . \frac{S_i}{U_i}\right\} \qquad (6)$$

$$P^i_{kj} = Re\left\{U_k . \left[(Z^*_{ki} - Z^*_{ji}) . Y^*_{ljk} + Z^*_{ki} . \frac{Y^*_{tjk}}{2}\right] . \frac{S_i}{U_i}\right\} \qquad (7)$$

$$Q^i_{kj} = Im\left\{U_k . \left[(Z^*_{ki} - Z^*_{ji}) . Y^*_{ljk} + Z^*_{ki} . \frac{Y^*_{tjk}}{2}\right] . \frac{S_i}{U_i}\right\} \qquad (8)$$

P^i_{jk} : jk line active power flow from j-bus to k-bus resulting from flow injection in the i-bus

Q^i_{jk} : jk line reactive power flow from j-bus to k-bus resulting from flow injection in the i-bus

Using the equations (5) to (8), the amount of sent and received active and reactive power from each of the network lines, caused by power injection can be calculated on each of the network buses. Thus, the share of each buses of network in the lines power flow is calculated. The S_i represents injected net power at bus number i. Production net power in each bus equal to the production power minus the consumption power of the bus.

2.3.- MVA-km method

In the MVA-km method, the amount of MVA-km of power flow that are made by each participant in each of the lines of network, is calculated from multiplying the apparent power flow that is created by the participant by the length of that line. Then in order to calculate transmission cost in the line for the participant, this amount multiplying by the cost of transmission capacity unit.

Because of the losses of reactive and active then, sent and received reactive and active powers, are not similar. Then, on this paper, unlike previous researches, to calculate the costs of transmission use the lines average apparent power flow. The j-k line apparent power flow of, resulting of the injected power in i-bus is calculated by the following equation:

$$\hat{S}^i_{jk} = \sqrt{(\hat{P}^i_{jk})^2 + (\hat{Q}^i_{jk})^2} \qquad (9)$$

$\hat{S}^i_{jk}$: j-k line average apparent power flow of resulting from flow injection in the i-bus

$\hat{P}^i_{jk}$: j-k lines average apparent active power resulting from power injection in the i-bus

$\hat{Q}^i_{jk}$: j-k lines average apparent reactive power resulting from power injection in the i-bus

Also, the average power flow and reactive powers of lines are calculated from following equations:

$$\hat{P}^i_{jk} = \frac{P^i_{jk} - P^i_{kj}}{2} \qquad (10)$$

$$\hat{Q}^i_{jk} = \frac{Q^i_{jk} - Q^i_{kj}}{2} \qquad (11)$$

The parameters P^i_{jk}, Q^i_{jk}, P^i_{kj} and Q^i_{kj} , are calculated from equations (5) to (8). The reason of negative mark on up equations is the sent and received lines average power, have opposite sign each other. With lines apparent power flow resulting from power injection in the i-bus, obtained the total costs allocated to the participant on the i-bus by the following equation [23]:

$$C_i = \sum_{n=1}^{N} T_n . L_n . \hat{S}^i_n \qquad (12)$$

C_i : the allocated costs to the participant in i-bus ($)

n: counter of lines of network

N: total number of lines of network

T_n: the base cost of n-th transmission line ($/MVA.km)

L_n: the length of n-th transmission line (km)

$\hat{S}^i_n$: the average apparent power flow of n-th transmission line resulting from power injection in i-th bus (MVA).

3. Proposed methods for calculating the cost of transmission by counter flow approaches

In the previous section, how to calculate the allocated costs to each of the participant was shown by the combination of Zbus and MVA-km methods. As it was seen in MVA-km conventional method for calculating the cost of transmission, in equation (12), the of the line apparent power flow average amount was used. In a power system, lines average power flow caused generation or consumption of power by participants, may be in opposite direction to each other, always. In these conditions, power flow share of one participant of one line may neutralize power flow share of another participant and thus reduce net power flow of transmission line and will increase power transmission capacity of line. If the power flow share of a participant from one line be opposite direction of line net power flow, that named " counter power ". In

[14, 23], based on the lines counter power, three different approaches introduced for MW-km method: since the MVA-km method, unlike MW-km method, is considered active and reactive power simultaneously, it is needed to improve the MVA-km method, according to the lines counter power. In this section as an innovation, proposed method for taking into account the lines counter power in the calculation of costs by MVA-km method are presented, in three approaches, as below [23]:

3.1. Absolute MVA-km approach

In this approach, the transmission costs is calculated regardless of the power direction of transmission lines, based on the absolute amount of MVA-km of each of the network participants. Thus, for each of transmission lines, by substituting of participant share in lines apparent power flow ($\hat{S}^{i}_{jk}$), in equation 12, the cost of transmission will calculate and cash out the participant.

3.2. Reverse MVA-km approach

In this approach, the costs of transmission will be counted, based on, the net amount of lines apparent power flow. Also those participants who cause power flow that opposing main power of lines and thereby, reduce the lines net power flow, they will be charged for this work. In this approach, four modes may occur:

Mode 1: the participant share of lines active and reactive powers, is in the same direction of line active and reactive power flow. In this mode, the costs are calculated and are cashed out from the participant by substituting the participant share in the lines apparent power flow $\hat{S}^{i}_{jk}$, in equation (12).

Mode 2: the share of participant in lines active and reactive powers, is opposite direction of line active and reactive powers flow. In this mode, the costs are calculated and are paid the participant by substituting the participant share in the lines apparent power flow $\hat{S}^{i}_{jk}$, in equation (12).

Mode 3: the share of participant in active power is same direction by line active power and the share of participant in reactive power is opposite direction of lines apparent power flow. In this mode, the cost of transmission of active power is calculated and is cashed out from the participant by substituting the participant share in the lines active power flow of $\hat{P}^{i}_{jk}$, in equation (12). Also, cost of transmission of reactive power is calculated and is paid the participant, by substituting the participant share in the lines reactive power flow of $\hat{Q}^{i}_{jk}$, in equation (12).

Mode 4: the share of participant in reactive power is same direction of line active power and the share of participant in active power is opposite direction of line average apparent power flow. In this mode, the cost of transmission of active power is calculated and is paid to the participant by substituting the participant share in the lines apparent power flow $\hat{P}^{i}_{jk}$, in equation (12). Also, cost of transmission of reactive power is calculated and is cashed out from the participant, by substituting the participant share in the line reactive power flow $\hat{Q}^{i}_{jk}$, in equation (12).

3.3. Zero counter-flow MVA-km approach

In this approach, the transmission costs are calculated based on the net amount of lines apparent power flow. In this approach, unlike absolute MVA-km approach, the participants who caused the counter power in the network, do not pay cost for using the network. On the other hand, unlike reverse MVA-km approach, do not pay any cost to this category of participants for this counter power. In this approach, four modes may occur:

Mode 1: the participant share of line active and reactive powers, is same direction of line active and reactive powers flow. In this mode, the cost of transmission is calculated and is cashed out from the participant, by substituting the participant share in the lines apparent power flow $\hat{S}^{i}_{jk}$, in equation (12).

Mode 2: the share of participant in lines active and reactive powers, is opposite direction of line active and reactive powers. In this mode, no cost is paid to the participant or is cashed out from participant for transmission.

Mode 3: the share of participant in active power is same direction by line active power and the share of participant in reactive power is opposite direction of line reactive power flow. In this mode, the cost of transmission of active power is calculated and is cashed out from the participant by substituting the participant share in the lines active power flow $\hat{P}^{i}_{jk}$, in equation (12). Also, no cost is paid or cashed out for transmission of reactive power.

Mode 4: the share of participant in reactive power is same direction of line active power and the share of participant in active power is opposite direction of line reactive power. In this mode, no cost is paid or cashed out for participant for transmission of active power. the cost of transmission of reactive power is calculated and is cashed out from the participant, by substituting the participant share in the lines active power flow $\hat{Q}^{i}_{jk}$, in equation (12).

In the next section, the three approaches based on ACOPF are simulated on a test case and the results of them are compared with each other and the results of the [23].

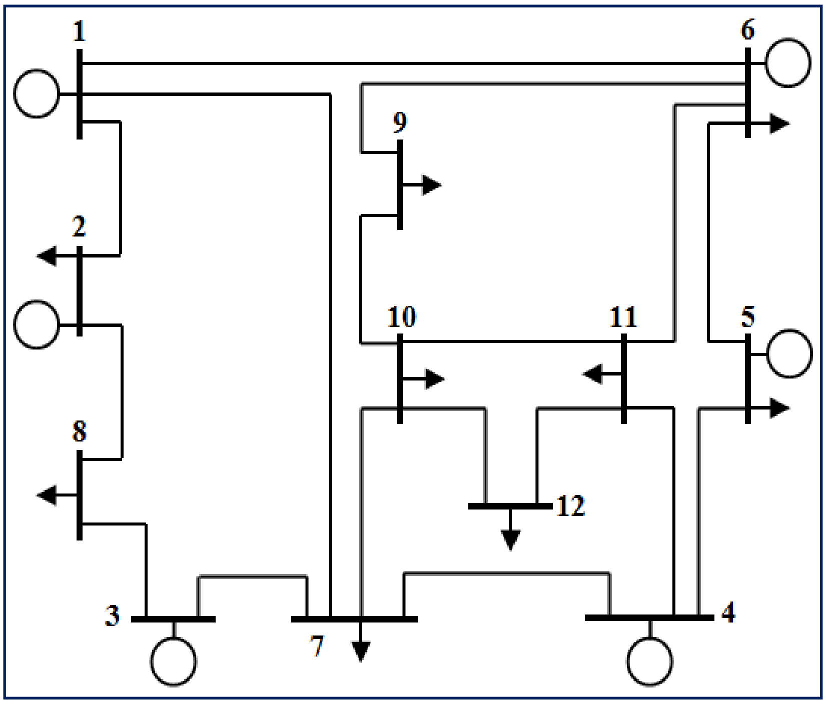

Figure 2. Single-line diagram of test network of 12 bus

Table1. the information of test network buses of 12 bus

Consumption active power (MW)	Consumption active power (MW)	Productive reactive power (MW)	Productive active power (MW)	Voltage angle (deg)	Amount of voltage (p.u.)	Type of the bus	Number of the bus
0	0	-	-	0	1.05	slack	1
35	300	-129.38	375.56	-	1	PV	2
0	0	13.43	350	-	1	PV	3
0	0	40.51	303.71	-	1	PV	4
25	350	-15.71	600	-	1	PV	5
60	230	125.73	200	-	1	PV	6
38	350	0	0	-	-	PQ	7
25	300	0	0	-	-	PQ	8
30	208	0	0	-	-	PQ	9
20	170	0	0	-	-	PQ	10
23	210	0	0	-	-	PQ	11
15	130	0	0	-	-	PQ	12

4. Case study

4.1. information of test network

In this section, simulation of proposed method is done for calculating the cost of transmission on 12 bus sample network. Its network diagram is shown in figure 2. This network has 6 generators and 17 transmission line. Buses 1 to 6 have generators [23]. Information of buses and lines of the network, are taken of references [21, 23], are presented on table 1 and table 2, respectively. The amount of T_n (the base cost of n-th transmission line) that is used in equation 12 is considered 2$/MVA-km for all of lines, according to reference [21, 23].

Simulation of the proposed method by software package of matpower5.1 in MATLAB software environment is done. In this software Newton - Raphson method is used for ACPF [26].

Table 2. the information of test network lines of 12 bus

The length of line (km)	The susceptances of line (p.u.)	The reactance of line (p.u.)	Line resistance (p.u.)	End bus	Initial bus	Number of line
30	0.04	0.025	0.00415	2	1	1
70	0.0949	0.05838	0.00969	6	1	2
120	0.16132	0.1	0.0166	7	1	3
30	0.04	0.025	0.00415	8	2	4
38	0.0511	0.03169	0.00526	7	3	5
45	0.06	0.03752	0.00623	3	8	6
60	0.08	0.05	0.0083	4	5	7
28	0.03765	0.02335	0.00387	4	7	8
60	0.08	0.05	0.0083	11	4	9
40	0.05379	0.03335	0.00554	5	6	10
30	0.02	0.0125	0.002075	9	6	11
50	0.06725	0.0417	0.00692	11	6	12
40	0.05379	0.03335	0.00554	7	10	13
20	0.0269	0.01667	0.00277	10	9	14
50	0.06725	0.0417	0.00692	11	10	15
34	0.047	0.02912	0.00484	12	10	16
25	0.0336	0.0208	0.00346	12	11	17

4.2. Results of ACOPF

In this subsection, ACOPF results are presented on the test network. The related results to network buses are presented in table 3 and the related results to network lines are presented in table 4.

Table 3. the information of buses of test network from ACOPF results

Number of the bus	Amount of voltage (p.u.)	Voltage angle (deg)	Productive active power (MW)	Productive reactive power (MW)	Consumption active power (MW)	Consumption reactive power (MW)
1	1.0986	0.00	68.16	-5.97	0	0
2	1.0999	0.27	482.20	52.99	300	35
	1.1000	0.93	331.15	22.35	0	0
4	1.1000	0.82	491.70	41.79	0	0
5	1.0944	-0.49	349.96	16.98	350	25
6	1.0909	-1.38	537.15	96.69	230	60
7	1.0867	-1.89	-	-	350	38
8	1.0897	-1.60	-	-	300	25
9	1.0809	-3.14	-	-	208	30
10	1.0778	-3.85	-	-	170	20
11	1.0787	-3.67	-	-	210	23
12	1.0746	-4.51	-	-	130	15

Table 4. the information of test network lines from ACOPF results

number of line	Initial bus	End bus	Active power of initial of line (MW)	Active power of end of line (MW)	Reactive power of initial of line (MVAR)	Reactive power of end of line (MVAR)
1	1	2	-22.73	22.75	-4.15	-0.58
2	1	6	50.39	-50.18	0.95	-11.07
3	1	7	40.51	-40.28	-2.76	-15.10
4	2	8	159.45	-158.56	18.56	-18.01
5	3	7	188.66	-187.10	16.22	-12.91
6	8	3	-141.44	142.49	-6.99	6.12
7	5	4	-55.54	55.76	-7.27	-1.07
8	7	4	-244.40	246.37	-17.77	25.13
9	4	11	189.58	-187.08	17.73	-12.16
10	6	5	-55.36	55.50	-4.81	-0.75
11	6	9	297.10	-295.53	41.62	-34.52
12	6	11	115.60	-114.81	10.95	-14.11
13	10	7	-121.08	121.78	-9.86	7.78
14	9	10	87.53	-87.35	4.52	-6.55
15	10	11	-8.64	8.64	-4.95	-2.84
16	10	12	47.06	-46.97	1.36	-6.25
17	11	12	83.24	-83.03	6.11	-8.75

Using of obtained information from the ACOPF and by equations (5) to (8), will obtain the share of each of the network participants of active and reactive powers of initial and end of network lines. For this purpose, according to the method that is used in the reference [21], it is assumed that each of the participants, are placed in a buses of network. Thus, in the studied test network, there are 12 participants that each of them are placed on one of the buses 1 to 12. Because of huge amount of resulting for share of network participants in lines active and reactive powers flow, it is ignored presenting these results, in this paper.

4.3. Calculation of transmission pricing by three improved MVA-km based approaches using ACOPF

In this subsection, the results of calculating transmission pricing by three improved MVA-km based approaches using ACOPF are presented and compared by each others. The results are shown in Table. 5 and Figure.3.

Table 5. The allocated transmission costs based on the improved MVA-km method

Bus number	Approach 1: Absolute MVA-km	Approach 2: Reverse MVA-km	Approach 3: Zero reverse MVA-km
1	13,772	6,711	10,898
2	41,797	25,828	33,813
3	60,933	32,740	46,876
4	78,027	29,643	53,838
5	1,510	-51	731
6	44,879	-9,140	17,870
7	48,596	4,914	26,763
8	68,554	-15,947	26,304
9	34,509	18,194	26,352
10	25,986	20,865	23,425
11	36,590	18,396	27,494
12	24,845	20,884	22,865
sum	479,999	153,038	317,227

As seen in the last row of the Table 5, the first approach has the highest transmission cost whilst the second approach has the lowest cost. Since the absolute of apparent powers are used the first approach and the sign are not considered, it has the highest transmission cost with $479,999. In the second approach, participants do not pay for the reverse power flows and even are paid for them. Thus, it is expected that the second approach has the lowest value. In the second approach, despite the first and second approaches, do not pay and are not paid for the for the reverse power flows. Therefore the transmission cost of the third approach is lower than the cost of the first approach and is higher than the cost of the second approach and equals to $317,227.

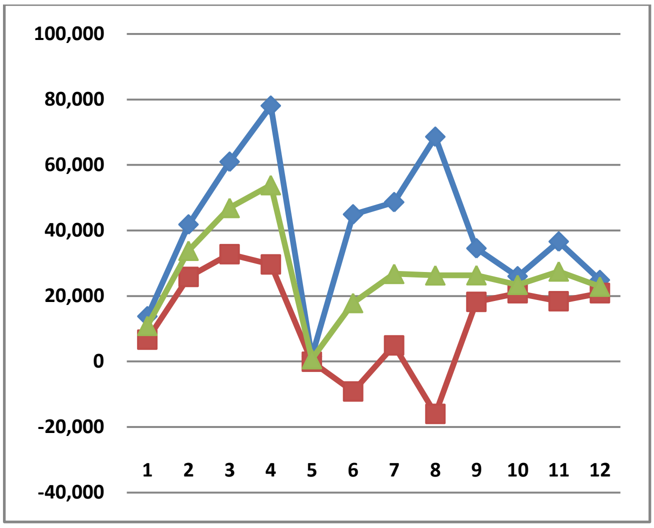

Figure 3. The comparison of cost of transmission participants by different MW-km approaches

As seen in the Figure 3, for all system participants, the transmission costs of the first approach have the highest values while the transmission costs of the third approach have the lowest values. Thus, from the transmission investment cost return point of view, the first and second approaches have highest and lowest return rates, respectively. As seen, the transmission costs of participants have considerable difference in three approaches. In addition, for some participants, the differences are low while they are high for some of some participants. For example, the cost of the bus 5 participant is almost 0 in three approaches based on the Table 3. The reason of this observation is that the generation and consumption of power in this bus is similar and thus the net injection to the grid is low. Since the transmission cost is a function of sending and receiving apparent power, the curve of the mean transmission costs of the participants are shown in the Figure 4 in order to provide a better comparison between the participants. The values in this figure are obtained by dividing the transmission costs on the received or injected apparent powers for each participant. As seen in the Figure 4, the average transmission costs of some players, such as participants in buses 10 and 12, in three approaches have not considerable differences whereas for some players, such as participants in buses 5, 6 and 8, the transmission costs in the three approaches have considerable differences.

The average transmission costs of participants in buses 2 and 8 are analyzed in more details for example. The participant in the bus 2 pays $228, $141 and $185 per MVA in first to third approaches, respectively. On the other hand, the participant in the bus 8 pays $228, $87 and $53 per MVA in first to third approaches, respectively. The reason of this observation is that the location of the bus 8 participant in the network results to reverse power flow such that in the second approach is paid because of decreasing the system power flows. However, the bus 2 participant does not have such prevalent location in the network such that reverse power flows because of this participant are low and it increase the power flows usually. Therefore, if the three approaches are compared based on the fairness, the first and second approaches are the fairest and unfairest approaches, respectively. In the first approach, both participant pay equivalent costs and the contribution of participant in producing reverse power flows and therefore decreasing of power flows does not take into account. On the other hand, the reverse power flows are considered in calculation of transmission costs and thus the bus 2 participant is paid instead of paying because of its contribution in reducing power flows and alleviating transmission capacity. The second approach is not desirable from the transmission investment point of view since it leads to lower investment return rate. The third approach with more return rate in comparison with the second approach and more fairness in comparison with the first approach may be a good candidate for electricity market policy makers.

As seen in the Figure 4, in the first approach, the highest average cost equals 228 $/MVA (participant of buses 2 and 8) and the lowest value equals 138 $/MVA (bus 7). Therefore, the difference between the highest and lowest values in the first approach is 90 $/MVA. In the second approach, the highest average cost equals 160 $/MVA (bus 12) and the lowest value equals -53 $/MVA (bus 8). Therefore, the difference between the highest and lowest values in the first approach is 213 $/MVA. In the third approach, the highest average cost equals 185 $/MVA (bus 2) and the lowest value equals 58 $/MVA (bus 6). Therefore, the difference between the highest and lowest values in the first approach is 127 $/MVA. By comparing these results, it can be deduced that the range of average transmission cost between the participants have the lowest and highest differences in the first and second approaches, respectively. This observation shows that considering the reverse power flows in transmission cost calculation results in increasing of difference of the transmission costs of the participants. Moreover, it shows that the second approach is fairer than the first approach since in this method, considering the reverse power flows results in take the shares of the participants in occupation of the transmission system into account in a more exact way.

4.4. Comparing the transmission cost allocation by the improved MVA-km method based on ACPF and ACOPF

As said before, in [23] AC power flow is used for calculation transmission cost based on the improved MVA-km method. In this paper, ACOPF is used instead of ACPF. In this subsection, the results of the proposed method are compared with the results of [23] in order to determine the effect of power dispatch on transmission cost allocation. The summation of allocated costs to the participants by ACPF and ACOPF methods are shown in Table 6 and Figure 5.

As shown in Table 6 and Figure 5, for each of the three approaches of the improved MVA-km, using ACOPF leads to decreasing of allocated transmission costs. The reason of this observation is that in the ACOPF, dispatch of the powers is done such that the operation cost of the system minimized. A way for decreasing of the system cost is decreasing of power loss. For decreasing of power loss, the power flows should be decreased. Therefore, the results of the ACOPF results in decreasing of the power flows and thus the summation of the transmission costs is decreased. Whereas in the ACPF, the economic aspect is not considered and only the technical aspect is take into account. Therefore, it can be deduced that considering of the economic aspect in the power system operation results in decreasing of the occupied transmission capacity.

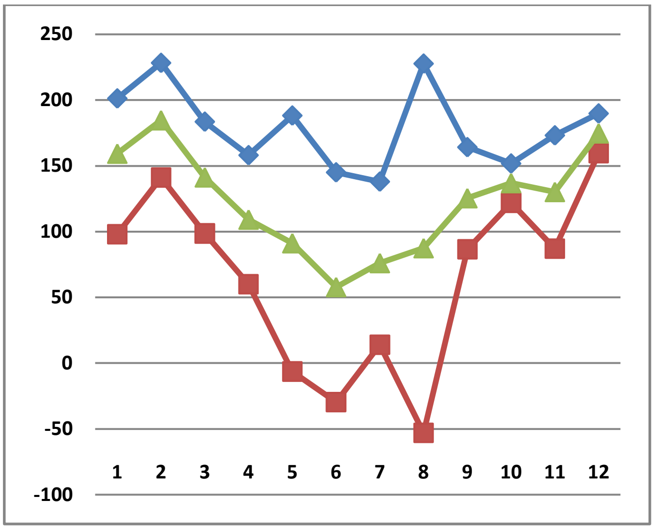

Figure 4. the comparison of average costs of transmission participants by different MVA-km method approaches

The results shown in Table 6 and Figure 5 show that in both ACPF and ACOPF, the first and second approaches have the highest and lowest transmission costs, respectively. This observation shows that the merit of the first approach from the investment return rate point of view and the merit of the second approach from the fairness point of view are independent of power dispatch methods. Based on the Table 6, the transmission costs of the second and third approaches are %37 and %71 of the first approach in the ACPF power dispatch, respectively, while these values are %32 and %66 for the ACOPF power dispatch, respectively. Comparing of these values show that considering of reverse power flows are considered more in calculation of transmission costs and thus results to more decrease.

Table 6. The sum of allocated transmission costs by ACPF and ACOPF

Power dispatch	Approach 1: Absolute MVA-km	Approach 2: Reverse MVA-km	Approach 3: Zero reverse MVA-km
ACPF [23]	558,565	208,034	398,796
ACOPF (this paper)	479,999	153,038	317,227

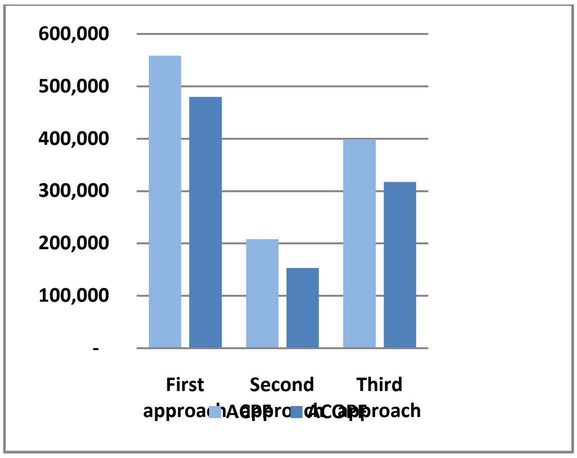

Figure 5. the comparison of sum of allocated transmission costs by ACPF and ACOPF

5. Conclusion

In this paper, an improved MVA-km method is used for transmission pricing. In this method, ZBUS and MVA-km methods are used. In order to consider the effects of the reverse powers on transmission cost, three approaches for MVA-km method are defined and the related formulations were presented and compared. The results show that although the MVA-km with absolute of power flows has a higher investment return rate, this approach is not fair. In addition, the reverse MVA-km has the lowest investment return rate, it is the fairest method among them. Finally, it is analyzed that the MVA-km method with zero reverse power has both advantages of the both other mentioned methods and thus it is a better candidate for transmission pricing. Moreover, comparing the results of ACPF and ACOPF show that using ACOPF leads to decrease line capacity occupation and decrease the allocated transmission costs to the system participants.

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