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Cost Allocation of Transmission Line using a New Approach of MW Mile Method

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Abstract

Objective: Many methods have been proposed to evaluate the cost of transmission lines. The MW mile method is a kind embedded pricing method to find transmission cost. The proposed method considers the active power flow in the network and it is the first pricing strategy to consider the real network conditions and power flow in the network. MW mile method is also useful to cover the total transmission system fixed cost among all network users. The primary objective of this paper is to provide charges economically to the customers by considering not only the active power flow but also the power factor.**Findings:** The power flow values are calculated by using DC power flow and generalized load distribution factors are used to determine load contribution to line flows. **Application/Improvements:** This method is tested on IEEE 14 bus test system with considering all network parameters to fairly allocate cost to the end users.

Keywords: Cost Allocation, MW Mile Method, Power Factor, Transmission Pricing

1. Introduction

The electric utility industry has been undergoing significant changes throughout the world due to the process of deregulation. Under deregulation the pricing of transmission services is a major issue because it involves the allocation of cost satisfactorily among the customers. Many methods have been used to evaluate the cost of transmission services. Among all the methods embedded pricing method is widely used since this method offers various benefits as it is fair to all users and it is easy to measure.

There are four types of embedded cost pricing methods. They are postage stamp method, contract path method, distance based MW mile method and power flow based MW mile method. Among all the methods power flow based MWmile methodhas shown to be more reflective of actual usage of the transmission system. This method mainly focuses on the active power flow in the network. But this method does not consider power factor of the load which affects the power quality. The power factor is expressed as ratio of real power to reactive power. Low power factor can decrease in capacity of transmission. The benefits of improving power factor are, the transmission line capacity will increase and utility charge a penalty for system having power factor less than 0.95, by improving the power factor we can avoid this penalty[1].

Some of the studies considered the power factor using reactive power parameters. A new MW+MVAr mile methodology is used based on the extent of use of network facilities to allocate the cost of transmission lines[2]. MW mile methodology is used to allocate the transmission supplementary charges to real and reactive loads[3,4] proposes a real power tracing based method for recovery of transmission service charge by using proportionality based approach. Point to point method is proposed in [5–7]on monetary power flow method and transmission pricing based on long run average incremental cost respectively.

This paper mainly focuses on cost allocation of transmission lines by using the power based approach. In this paper section 2 describes the problem description,

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Section 3 presents algorithm of proposed method, Section 4 presents the results of proposed method tested on IEEE 14 bus system. Conclusion of the paper is given in section 5.

2. Problem Description

MW mile methodology is amply used since it considers the actual power flow of the network. There are two types of MW mile methodology: distance based MW mile method and power flow based MW mile method. Distance based MW mile method allocates the charges to the customers based on the magnitude of transacted power and distance between the delivery and receipt points. Power flow based MW mile methodology allocates the charges based on the extent of use of the transaction facility. Although it considers the active power flow of the network, the power factor which affects the power quality has not been taken in to account. In this paper power factor, the load is considered in order to fairly allocate the cost to all the customers. In this method the transmission charge was determined based on the actual power flow in each transmission line. But the disadvantage of this method is every change in transaction needs recalculation of line flows. The transmission cost using MW mile method can be calculated as

$$C_k = \sum_{i=1}^{N} \frac{T_c \cdot L_i \cdot P_i^k}{P_i} \tag{1}$$

where

C_k=transmission cost for k_{th} user

T_c=pre-determined cost of line

L_i=transmission line length

P_i^k=power flow in line i by k_{th} user

P_i= i_{th} line power flow (capacity)

N=number of line.

According to equation (1) the transmission charge is calculated using the actual Power flow (P) in each transmission line. The reactive power of the load is not considered. If power factor of load is equal to reference power factor, the user pays the transmission cost as in equation (1). When reactive power is added to load, the transmission charge does not change because the active power flow does not change and transmission capability decreases. When the power factor is increased and the transmission cost is the same but transmission capability of line increases. In this case the transmission line owner gets benefit. In general, the apparent power, real and reactive power can be expressed as

$$S=P+jQ \tag{2}$$

The power factor can be expressed as

$$\cos\phi = \frac{P}{S} \tag{3}$$

The load with reactive power Q_1 can be written as

$$\cos\phi_1 = \frac{P}{S_1} = \frac{P}{P+jQ_1} \tag{4}$$

A new power factor is acquired by addition of reactive power to the load, given as

$$\cos\phi_2 = \frac{P}{S_2} = \frac{P}{P+jQ_2} \tag{5}$$

The line current due to load added with reactive power Q_2 can be written as

$$I' = \frac{P+jQ2}{V} \tag{6}$$

Where

$$I'=I+\Delta I' \tag{7}$$

where I is the line current and ΔI' is the change in line current due to reactive power.Line losses will be smaller when the line current is small. This will increase the transmission line carrying capacity.

3. Algorithm of Proposed Method

The real power of load can be written as

$$P=VI*\cos\phi \tag{8}$$

This can also be written as

$$P=VI\cos\phi_1=VI'\cos\phi_2 \tag{9}$$

Let us consider V as constant value and $\cos\phi_1 = \cos\phi_{ref}$. Thus the equation can be modified as

$$\frac{P}{V} = I\cos\phi_{ref} = I'\cos\phi_2 \tag{10}$$

Thus the relationship is

$$I\cos\phi_{ref} = I'\cos\phi_2 \tag{11}$$

By substituting (7) in (11)

$$I\cos\phi_{ref} = (I + \Delta I')\cos\phi_2 \tag{12}$$

Therefore,

$$I\cos\phi_{ref} = I\cos\phi_2 + \Delta I'\cos\phi_2 \tag{13}$$

This can be written as

$$I\cos\phi_{ref} - I\cos\phi_2 = \Delta I'\cos\phi_2 \tag{14}$$

By rewriting the equation, we get

$$\frac{\Delta I'}{I} = \frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2} \quad (15)$$

If the transmission line's resistance is constant then the power flow change ($\Delta P'$) is equivalent to current flow change. Therefore, equation (15) can be written as

$$\frac{\Delta P'}{P} = \frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2} \quad (16)$$

Therefore,

$$\Delta P' = P\left[\frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2}\right] \quad (17)$$

$\Delta P'$ is an additional power flow when load power factor less than reference power factor and P is the power flow of the line.

The same calculation can be done to prove load power factor greater than reference power factor. This can be expressed as

$$\frac{\Delta I''}{I} = \frac{\cos\phi_{ref} - \cos\phi_3}{\cos\phi_3} \sim \frac{\Delta P''}{P} = \frac{\cos\phi_{ref} - \cos\phi_3}{\cos\phi_3} \quad (18)$$

where, $\cos\phi_3$ is the power factor of load with load power factor>reference power factor

$$\Rightarrow \quad \Delta P'' = P\left[\frac{\cos\phi_{ref} - \cos\phi_3}{\cos\phi_3}\right] \quad (19)$$

Now by substituting (17) in (1) we get

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.(P_i^k + \Delta P')}{P_i} \quad (20)$$

By substituting $\Delta P'$ value in above equation

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.\left[P_i^k + P_i^k\left(\frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2}\right)\right]}{P_i} \quad (21)$$

This equation can be rewritten as

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.P_i^k\left[1 + \left(\frac{\cos\phi_{ref} - \cos\phi_2}{\cos\phi_2}\right)\right]}{P_i} \quad (22)$$

In general, we take $\cos\phi_2$ as $\cos\phi_{act}$ which is actual value of power factor
Therefore, we get

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.P_i^k\left[1 + \left(\frac{\cos\phi_{ref} - \cos\phi_{act}}{\cos\phi_{act}}\right)\right]}{P_i} \quad (23)$$

This equation can be written as

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.(P_i^k.C_{LF})}{P_i} \quad (24)$$

where, C_{LF} is the power factor correction coefficient.

$$C_{LF} = \left[1 + \left(\frac{\cos\phi_{ref} - \cos\phi_{act}}{\cos\phi_{act}}\right)\right] \quad (25)$$

From the above equation we can derive three conditions

Case 1: $\cos\phi_{ref} = \cos\phi_{act}$

The power factor correction coefficient for this condition is

$$C_{LF} = 1 + \frac{\cos\phi_{ref} - \cos\phi_{act}}{\cos\phi_{act}} = 1$$

When actual power factor is equal to reference power factor the user pays the fee according to the total MW amount used.

Case 2: $\cos\phi_{ref} > \cos\phi_{act}$

The power factor correction coefficient for this condition is

$$C_{LF} = 1 + \frac{\cos\phi_{ref} - \cos\phi_{act}}{\cos\phi_{act}} > 1$$

When actual power factor is less than reference power factor the user pays additional fees because the power factor correction coefficient is greater than 1

Case 3: $\cos\phi_{ref} < \cos\phi_{act}$

The power factor correction coefficient for this condition is

$$C_{LF} = 1 + \frac{\cos\phi_{ref} - \cos\phi_{act}}{\cos\phi_{act}} < 1$$

When actual power factor is greater than reference power factor the user pays lesser fees.

Finally, the new MW mile method cost equation is

$$C_k = C_{LF}\left[\sum_{i=1}^{N} \frac{T_c.L_i.P_i^k}{P_i}\right] \quad (26)$$

where, C_{LF} is power factor correction coefficient.

4. Results

The algorithm of new method is tested on IEEE 14 bus system. The power flows are calculated by using DC power flow method and losses are neglected. The IEEE 14 bus system is shown in fig.1. It contains two generators located at buses 1 and 2 and 11 loads located at buses 2,3,4,5,6,9,10,11,12,13 and 14. The Generalized Load Distribution Factors (GLDF) were used to calculate the contribution of load to line flows[8]. The proposed method is also tested on IEEE 14 bus test system by including transformer tap setting values. The line length and cost values are taken from[9].

Table 1 shows the IEEE 14 bus system data and power flows obtained from DC load flow. The last two columns show the comparison of power flows with and without transformer tap setting values. From the table we can observe that without transformer generator absorbs power at the buses. With the addition of transformer, we can reduce the power absorbed at the buses. Table 2 shows the results of power factor correction coefficient. It is observed that correction coefficient is increased gradually with the decrease of average power factor. For reference power factor 0.95 and average power factor 0.8 the coefficient value is 0.8421 and average power factor is 0.9 the value is 0.8888. Table 3 shows the results for cost values obtained by MW mile method without including transformer tap setting values. As the average power factor increases there is a gradual decrease in cost value. For example, the cost value for average power factor of 0.8 is k$13.6219 and for an average power factor 0.95 the cost value is k$11.4711. There is a cost reduction of about k$2.1508 for change of power factor from 0.8 to 0.95. The Table 4 shows the cost values for IEEE 14 bus system with transformer tap setting values. Figure 1 shows IEEE 14 bus system. All the cost values are in k$.

Table 2. Results for power factor correction coefficient

Average power factor	Reference power factor=0.8	Reference power factor=0.85	Reference power factor=0.9	Reference power factor=0.95
1	0.8	0.85	0.9	0.95
0.95	0.8421	0.8947	0.94736	1
0.9	0.8888	0.9444	1	1.0555
0.85	0.9411	1	1.05882	1.1176
0.8	1	1.0625	1.125	1.1875
0.75	1.0666	1.1333	1.2	1.2666
0.7	1.1594	1.2143	1.3043	1.3768

Table 1. IEEE 14 bus data

Line no	From bus	To bus	Resistance	Reactance	Transformer tap values	Power flows (MW)	Power flows with out transformer tap setting(MW)
1	1	2	0.01938	0.05916	1	146.8832	144.7
2	1	5	0.05403	0.22303	1	81.9326	75.33
3	2	3	0.04699	0.19796	1	67.6144	47.1
4	2	4	0.05811	0.17631	1	65.1261	31.03
5	2	5	0.05695	0.17387	1	52.7817	26.54
6	3	4	0.06701	0.17102	1	-9.0747	-32.9
7	4	5	0.01335	0.04211	1	-55.0796	-56.56
8	4	7	0	0.20911	0.978	36.8919	-3.31
9	4	9	0	0.55617	0.969	21.1681	7.99
10	5	6	0	0.25201	0.932	49.6398	15.31
11	6	11	0.09498	0.19890	1	7.2149	19.65
12	6	12	0.12291	0.25580	1	9.5468	28.24
13	6	13	0.06615	0.13026	1	26.1587	37.42
14	7	8	0	0.17614	1	0.0000	-50
15	7	9	0	0.11001	1	36.8919	46.69
16	9	10	0.03181	0.0844	1	6.3998	10.35
17	9	14	0.12711	0.27037	1	24.9406	14.34
18	10	11	0.08205	0.19206	1	-3.2739	0.35
19	12	13	0.22092	0.19987	1	3.7339	-11.76
20	13	14	0.17093	0.34801	1	13.7359	5.66

Table 3. Cost values without transformer tap setting with reference p.f=0.8

Cost value	cos average=0.8	cos average=0.85	cos average=0.9	cos average=0.95
13.6219	13.6219	12.8206	12.1083	11.4711
52.0826	52.0826	49.0189	46.2956	43.8590
38.1473	38.1473	35.9034	33.9088	32.1241
44.9988	44.9988	42.3518	39.9989	37.8937
41.1085	41.1085	38.6904	36.5409	34.6177
9.7283	9.7283	9.1561	8.6475	8.1923
7.2672	7.2672	6.8397	6.6475	6.1197
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
15.4008	15.4008	14.4948	13.6896	12.9691
25.6160	25.6160	24.1092	22.7689	21.5714
21.6404	21.6404	20.3674	19.2359	18.2235
0	0	0	0	0
0	0	0	0	0
2.9819	2.9819	2.8065	2.6506	2.5111
41.496	41.496	39.0551	36.8854	34.9440
3.6018	3.6018	3.3899	3.2016	3.0331
4.8966	4.8966	4.6086	4.3525	4.1235
29.224	29.224	27.5049	25.9769	24.6097

Table 4. Cost values with transformer tap setting with reference p.f=0.8

Cost value	cos average=0.8	cos average=0.85	cos average=0.9	cos average=0.95
13.9339	13.9339	13.1143	12.3857	11.7338
53.3135	53.3135	50.1774	47.3898	44.8956
38.5201	38.5201	36.2542	34.2401	32.438
45.9702	45.9702	43.2661	40.8624	38.7117
42.1085	42.1085	39.6315	37.4298	35.4598
8.9895	8.9895	8.4607	7.9907	7.5701
7.345	7.345	6.913	6.5289	6.1853
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
13.9712	13.9712	13.1494	12.4189	11.7652
25.4102	25.4102	23.9155	22.5868	21.3981
21.345	21.345	20.0894	18.9733	17.9747
0	0	0	0	0
0	0	0	0	0
3.3334	3.3334	3.1373	2.963	2.8071
42.2328	42.2328	39.7485	37.5402	35.5644
2.7873	2.7873	2.6233	2.4776	2.3472
4.7663	4.7663	4.4859	4.2367	4.0137
28.2668	28.2668	26.6041	25.1261	23.8037

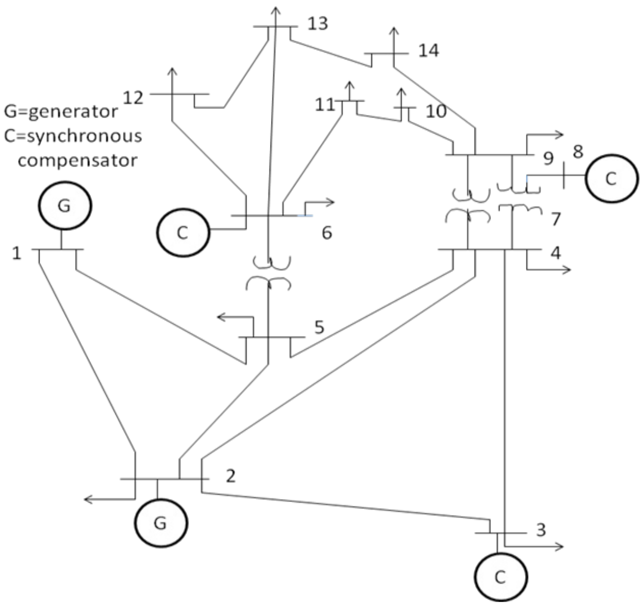

Figure 1. IEEE 14 bus system.

5. Conclusion

This paper shows the results for a new algorithm of MW mile method with power factor correction coefficient. This allows the fair allocation of cost to the users by increasing the power factor. The algorithm is tested on IEEE 14 bus system for two cases i.e., with and without including transformer tap setting values. The new algorithm showed gives more incentives to the customers. This algorithm can be extended by including the transmission losses.

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