Implementation of Modified MW-Mile Method for Transmission Cost Allocation by Incorporation of Transmission losses considering Power Factor

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***Abstract*—MW-Mile Method is frequently used for allocating the transmission cost among the users. This method is formulated based on the actual usage of transmission network by each user. But, this method allocates the unfair charges to the users as it doesn't consider the transmission losses and the variation these losses according to the user power factor. In this paper MW-Mile Method is modified by considering the transmission losses and the variation of the losses according to the user power factor. Improved DC load flow algorithm is used for getting the transmission losses. For accounting the variation of transmission losses with reference to the variation of user power factor, Transmission loss correction coefficient is formulated for the first time. The proposed method is tested on an IEEE-14 Bus system for allocating the transmission cost to each user and observed that the transmission cost is allocated fairly.**

Keywords:Transmission cost allocation, MW-Mile Method, Load power factor, Transmission loss correction coefficent.

I. Introduction

The modernization of business environment all over the world leads to restructuring of the electric power industry into three components. viz Generation,Transmission and Distribution. In the deregulated environment, Pricing the transmission services has become a major concern. Most of the pricing methodologies are developed by considering at least two parameters into account viz amount of transmission capacity used and the per unit cost of transmission capacity [1]. These methods are mainly fall under two categories: a) Incremental or marginal cost method b) Embedded cost method. Incremental transmission pricing methods for allocating the transmission cost among participants are reported in [2]–[5]. The Embedded cost method is commonly used method all over the electric utility industry. This method is most practical and fair to all participants and easy to allocate, simple to understand and gives an adequate revenue to the transmission entity.

There are four types of embedded cost methods that are widely used to allocate transmission cost among the participants. viz, postage stamp method, Contract path method, Distance based MW-Mile method and Power flow based MW-Mile method [6]–[9].

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In the Postage stamp method, the transmission cost is allocated based on the magnitude of the transacted power. In the Contract path method, transmission cost is allocated based on the assumption that the transaction is taking place only in the contracted path and in the Distance based MW-Mile method, transmission cost is allocated based on the magnitude of the transacted power and air-line distance between the utility and the user. The above three methods haven't considered the actual usage of the transmission network and sends the unfair economic signal to the participants.

The Power flow based MW-Mile method is frequently used method, which allocates transmission cost among the users based on the usage of transmission facilities by each user. However, this method fails to consider the transmission losses and load power factor while allocating the transmission cost. One of these drawbacks is overcome by improving the MW-Mile method as reported in [10].

In this paper, MW-Mile method is modified first time by considering transmission losses and their variation with reference to user power factor. For achieving this objective Transmission loss correction coefficient has been formulated first time for accounting variation of transmission losses with reference to user power factor.

In this paper, a Modified MW-Mile method is proposed for allocating the transmission cost among the users. This method has incorporated Generalized Load Distribution Factors (GLDF's) for determining the contribution of each user to the line flow [11], [12] and also Improved DC load flow algorithm for determining the transmission losses [13]. Each line transmission losses are shared among each user squarely proportional to the DC power flow contributions of that line with reference to each non counter flow user [14]. A mathematical model is formulated for accounting the variation of transmission losses with the variation of load power factor.

The organization of the remainder of the paper is as follows. The problem formulation is reported in section II. The proposed modified MW-Mile method has been elaborated in section III.The Analytical study and discussion of the results have been reported in section IV and the outcome of paper is summed up as conclusions in section V.

II. PROBLEM FORMULATION

In general, allocation of transmission cost among the users based on the MW-Mile method can be calculated by using cost formula [15]. as stated in equation (1)

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.P_i^k}{P_{max,i}} \tag{1}$$

where

C_k	Transmission cost of the user k (k$)
T_c	Predetermined unit cost of line (k$/mile)
L_i	Length of the transmission line (mile)
P_i^k	Power flow in line i by user k (MW)
$P_{max,i}$	Power flow capacity in line i (MW)
N	number of line

Transmission losses were assigned to the users by the following equation

$$P_{loss,i}^k = \frac{P_{loss,i}.P_i^{k^2}}{\sum_{j\in m} P_i^{k^2}} \quad if \quad P_i^k > 0 \tag{2}$$

$$= 0 \qquad if \quad P_i^k < 0$$

where
m is the set of non counter flow users
P_i^k = k^{th} user DC power flow contribution in i^{th} line using GLDF's method. This paper introduces a Transmission loss correction coefficient for the first time in calculating the cost for transmission services based on the reference power factor and average power factor of the user with the MW-Mile method.

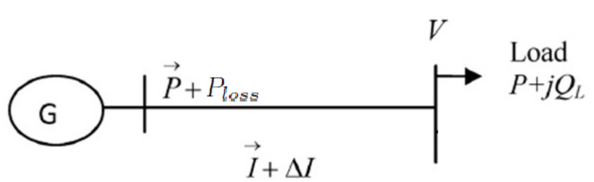

Fig. 1. TWO BUS SYSTEM.

Consider the two Bus system shown in the figure.1. The real power demand of the load bus remains constant. But the power factor of the load bus is changing. Initially assume load bus or user is operating at a power factor= $\cos\phi_{ref}$(which is set by the utility). Let us say current flow in the line is I. Transmission losses of the line due to I is

$$P_{loss} = I^2 R \tag{3}$$

where R is the resistance of the line. Line current is changed to I_1 because of change in load power factor to $\cos\phi_1$

$$I_1 = I + \Delta I \tag{4}$$

Therefore, Transmission loss due to I_1 is

$$P_{loss1} = (I + \Delta I)^2 R \tag{5}$$

$$P_{loss1} = I^2 R + \Delta I^2 R + 2I\Delta I R \tag{6}$$

By neglecting the second order term in the equation (6)

$$P_{loss1} = I^2 R + 2I\Delta I R \tag{7}$$

Change in transmission loss due to change in the load power factor is

$$\Delta P_{loss} = 2I\Delta I R \tag{8}$$

By dividing the equation (8) with equation (3)

$$\frac{\Delta P_{loss}}{P_{loss}} \approx \frac{2\Delta I}{I} \tag{9}$$

III. MODIFIED MW-MILE METHOD

Under the assumption that all the buses have been maintaining voltage profile magnitudes nearly equal to unity and from the [10] current flow change with reference to variation of power factor as stated in equation (10)

$$\frac{\Delta I}{I} = \frac{\cos\phi_{ref} - \cos\phi_1}{\cos\phi_1} \tag{10}$$

Here, $\cos\phi_1$ is the average power factor of the user for each period of time [16].

By substituting equation (10) in equation (9)

$$\Delta P_{loss} = 2.P_{loss}.[\frac{\cos\phi_{ref} - \cos\phi_1}{\cos\phi_1}] \tag{11}$$

Transmission loss in the line with the change of load power factor from $\cos\phi_{ref}$ to $\cos\phi_1$ is

$$P_{loss1} = P_{loss} + \Delta P_{loss} \tag{12}$$

from equation (11) and (12)

$$P_{loss1} = P_{loss}[1 + 2[\frac{\cos\phi_{ref} - \cos\phi_1}{\cos\phi_1}]] \tag{13}$$

Let

$$T_{lcc} = 1 + 2[\frac{\cos\phi_{ref} - \cos\phi_1}{\cos\phi_1}] \tag{14}$$

$$P_{loss1} = P_{loss}.T_{lcc} \tag{15}$$

where, T_{lcc} is known as Transmission loss correction coefficient with the variation of load power factor.
Therefore Total power flow in the line is $P + P_{loss}.T_{lcc}$ and by substituting the total power flow in the cost formula i.e, equation (1), We get

$$C_k = \sum_{i=1}^{N} \frac{T_c.L_i.(P + P_{loss}.T_{lcc})_i^k}{P_{max,i}} \tag{16}$$

Algorithm for implementing the modified MW-Mile Method is shown in the Figure.2

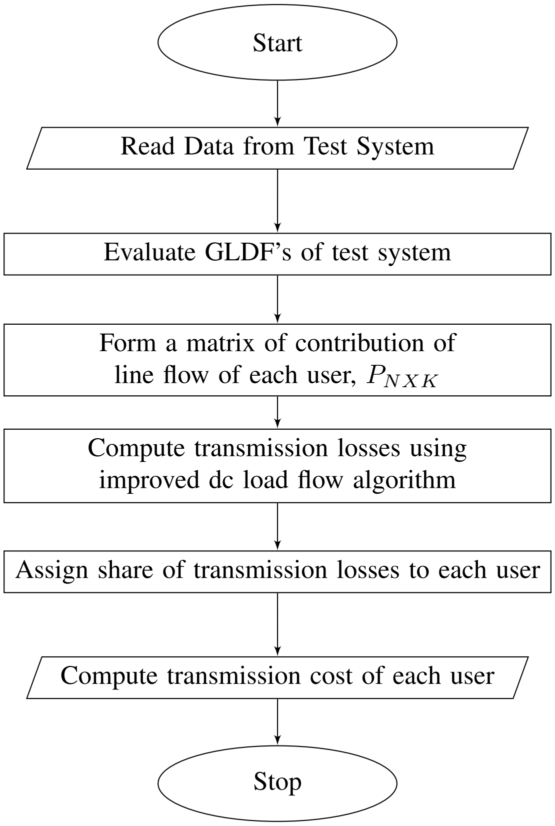

Fig. 2. Flow chart of Modified MW-Mile Method

IV. Analytical study and Discussion

The proposed method was tested on an IEEE-14 Bus system. The proposed method was compared with the normal MW-Mile Method. This method has evaluated the GLDF's for determining the contribution of each user to the line flow [11], [12] and also used the improved DC load flow algorithm for determining transmission losses [13]. Each line transmission losses are shared among each user squarely proportional to the DC power flow contributions of that line with reference to each non counter flow user as in [14]. The network line data and cost data has been drawn from [8] and the data is reproduced in Appendix for ready reference.

Table I and Table II shown bellow allocates the transmission cost among the users using normal MW-Mile method and the proposed method by considering the transmission losses and their variation with reference to variation of load power factors 0.8, 0.85 and 0.9 for the reference power factors 0.8 and 0.9 set by the utility.

For example, In the Table I allocated transmission cost to the user 3 using normal MW-Mile method and the proposed method is k$ 671.6069 and k$ 713.1980 .This cost is reduced to the k$ 705.4959 for maintaining better load power factor (i.e, 0.9) compared with the reference power factor (i.e, 0.8) set by the utility. Incentive is given to the user 3 for maintaining better load power factor in terms of reduction of allocated transmission cost.

TABLE I

COMPARISON OF ALLOCATED TRANSMISSION COST USING MW-MILE METHOD AND PROPOSED METHOD AT $\cos\phi_{ref} = 0.8$

Bus .No	MW-mile Method k$	Incor-poration Tr. loss k$	$\cos\phi_{ref} = 0.8$ lagging proposed(k$)		
			$\cos\phi_{av} = 0.8$	$\cos\phi_{av} = 0.85$	$\cos\phi_{av} = 0.9$
L2	054.1053	054.4963	054.6918	054.6343	054.5832
L3	671.6069	699.3343	713.1980	709.1204	705.4959
L4	340.8286	349.1696	353.3401	352.1134	351.0231
L5	048.6890	049.9607	050.5966	050.4096	050.2434
L6	200.5184	201.1227	201.4249	201.3360	201.2570
L9	507.4709	511.4031	513.3692	512.7910	512.2769
L10	164.9756	165.3895	165.5964	165.5356	165.4815
L11	068.7701	068.8725	068.9238	068.9087	068.8953
L12	222.6020	223.3428	223.7132	223.6043	223.5075
L13	373.7337	375.7655	376.7814	376.4826	376.2170
L14	428.0503	431.2257	432.8134	432.3465	431.9314

TABLE II

COMPARISON OF ALLOCATED TRANSMISSION COST USING MW-MILE METHOD AND PROPOSED METHOD AT $\cos\phi_{ref} = 0.9$

Bus .No	MW-mile Method k$	Incor-poration Tr. loss k$	$\cos\phi_{ref} = 0.9$ lagging proposed(k$)		
			$\cos\phi_{av} = 0.9$	$\cos\phi_{av} = 0.8$	$\cos\phi_{av} = 0.85$
L2	054.1053	054.4963	054.5832	054.6918	054.6343
L3	671.6069	699.3343	705.4959	713.1980	709.1204
L4	340.8286	349.1696	351.0231	353.3401	352.1134
L5	048.6890	049.9607	050.2434	050.5966	050.4096
L6	200.5184	201.1227	201.2570	201.4249	201.3360
L9	507.4709	511.4031	512.2769	513.3692	512.7910
L10	164.9756	165.3895	165.4815	165.5964	165.5356
L11	068.7701	068.8725	068.8953	068.9238	068.9087
L12	222.6020	223.3428	223.5075	223.7132	223.6043
L13	373.7337	375.7655	376.2170	376.7814	376.4826
L14	428.0503	431.2257	431.9314	432.8134	432.3465

By observing the results in the Table II allocated transmission cost to the user 4 using normal MW-Mile method and the proposed method is k$ 340.8286 and k$ 351.0231.This cost is increased to the k$ 353.3401 for maintaining poor load power factor(i.e, 0.8) compared with the reference power factor (i.e, 0.9) set by the utility. User 4 is penalized by increasing the allocated transmission cost for maintaining the poor load power factor. The proposed method not only allocates the transmission cost among the users based on the accurate usage of transmission network capacity by each user but also encourages efficient operation of transmission network.

V. Conclusion

This paper proposes a modified MW-Mile method, which allocates transmission cost among the users more accurately. The proposed method has fairly allocated the transmission cost by considering the transmission losses and their variation with reference to variation of load power factor. This paper introduces a Transmission loss correction coefficient for the first time in calculating the cost for transmission services based on the reference power factor and average power factor of the user with the MW-Mile method. The results infer that transmission cost allocation has been improved in comparison with the normal MW-Mile method. The proposed method is giving incentive to the user who is operating at better power factor and is penalizing the user who is operating at poor power factor.

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VI. Appendix

The line data and transmission cost data in the following Table III pertaining to IEEE 14 bus test system has been drawn from [8] and the data is reproduced here for ready reference.

TABLE III
IEEE14-BUS SYSTEM LINE DATA AND TRANSMISSION COST DATA

BUS i	BUS j	R (in p.u)	X (in p.u)	COST(10^6 \$)
1	2	0.01938	0.05917	0.1805
1	5	0.05403	0.17388	0.4952
2	3	0.04699	0.17632	0.3300
2	4	0.05110	0.22304	0.5513
2	5	0.05695	0.17103	0.5219
3	4	0.01335	0.04211	0.1305
4	5	0.01335	0.04211	0.1305
4	7	0.00000	0.20912	0.1673
4	9	0.00000	0.55618	0.4450
5	6	0.00000	0.25202	0.2016
6	11	0.09498	0.19890	0.9795
6	12	0.12291	0.25581	1.2675
6	13	0.06615	0.13027	0.5547
7	8	0.00000	0.17615	0.1409
7	9	0.00000	0.11001	0.0880
9	10	0.03181	0.08450	0.2234
9	14	0.12711	0.27038	1.3090
10	11	0.08205	0.19207	0.8213
12	13	0.22092	0.19988	2.2625
13	14	0.17093	0.34802	1.7531

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