International Journal of Electrical and Computer Engineering (IJECE)
Vol. 7, No. 4, August 2017, pp. 1725~1727
ISSN: 2088-8708, DOI: 10.11591/ijece.v7i4.pp1725-1737

A New Methodology for Active Power Transmission Loss Allocation in Deregulated Power System

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Article Info

Article history:

Received Jun 5, 2016
Revised Mar 22, 2017
Accepted Mar 6, 2017

Keyword:

Incremental transmission loss
Power flow contribution
Proportional sharing
Test systems
Transmission loss allocation

ABSTRACT

This paper presents a new method for transmission loss allocation in a deregulated power system. As the power loss is a nonlinear quantity, so to allocate the loss in a common transmission corrider is a difficult task. It allocates transmission losses to loads based on the actual power flow in the lossy lines due to the concerned load. Each lossy line is subdivided into as many sub-lines as corresponding to the numbers of load attached to it. The tracing of power flow through each sub-line is worked out by using proportional sharing method. The power loss in each lossy line is equal with the total loss due to all the sub-lines under it. Then by using Pro-rata for each lossy line, the individual loss for each sub-line is formulated. As the application of Pro-rata is limited to an individual line of the system, so the error in calculation is minimized. The total loss allocated to a particular load is the sum of losses occurred in each lossy lines through which the power is flowing to the concerned load. As this method is based on the actual flow of power in the transmission line corresponding to the concerned load, hence, the loss allocation made by the method gives proper and justifiable allocations to the different loads which are attached to the system. The proposed method is applied to a six-bus system and finds the mismatch in the commonly used methods. Then, it is applied to higher bus systems in which more accurate results are obtained compared to the other methods.

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1. INTRODUCTION

The earlier vertically integrated power systems have been unbundled into one or more generation companies, a transmission company and a number of distribution companies, in the parlance of deregulated power system. The main thrust in the deregulated system is to make the market more competitive. If companies are allowed to compete freely then the efficiency gains arising from the competition would ultimately benefit the consumers. In addition, competing companies would probably choose different technologies. In vertical system, the tariff plan had to be decided by taking the average of all the costs of the different services including generation, transmission and distribution. But in the deregulated system, the services are unbundled and fairer tariffs are assigned to individual services. With the separate pricing of generation, transmission and distribution, a fair and transparent use of transmission system's charge can be adopted for the different customers. In these aspects, problem arises due to the common sharing of transmission line by the different loads. So, suitable strategy should be adopted to trace out the power sharing between the generators and loads in a common transmission line. Then the transmission loss predominates in fixing the appropriate tariff rate. In real-time operation, consumer meters measure their actual consumptions, while generator meters measure their actual productions, i.e., the consumptions of customers plus the network losses. In the deregulated power systems, the loss minimization is quite important before loss allocation. A network reconfiguration method for loss reduction and voltage profile improvement has been discussed by Myint, *et al* [1]. Hlaing, *et al* [2] have developed an efficient technique for loss minimization of power distribution network using different types of distributed generation unit. Naturally, the problem of "who should pay for losses" arises, and those payments constitute a substantial amount of money [3]. Further in a complete system of power network, different customers are taking their required power through the different paths with different amount of loads and hence, the losses caused by them are not unique. So, it is an essential and challenging task to allocate the contributions of power flow and loss from individual generator to the loads through the transmission system. Different methods [4] have been proposed to trace out the power flow and loss in the arena of deregulated power system. The assignment of cross terms in power equation, particularly when the involved transactions are greatly different in sizes, have been analyzed and some results like Proportional allocation, Quadratic allocation, Geometric allocation, Fast geometric allocation are proposed by Exposito *et al*. [5]. Power tracing methods based on proportional sharing principle are proposed in [6-8]. All power injections are translated into real and imaginary currents to avoid the problems arising from the non-linear coupling between active and reactive power flows caused by losses. Bus impedance matrix and radial equivalent network approaches have been worked out in [9-11]. A physical-flow-based approach in a multiple transaction system with a new concept of counter flow associated with the losses has been demonstrated in ref. [12].

The Transmission and Distribution loss (T/D loss) figures prominently in the planning section of both government and public sector in the environment of deregulation. In India, T/D loss is 21% which is much higher to the World average [13] and also to the average value of Lower Middle Income group in which India belongs to. In comparison with a small and under developing country like Indonesia, India's T/D loss is 2.34 times more and in comparison to China, it is 3.5 times, whereas the per capita consumption of electrical energy in China is 4.82 times more than India. The government of India has failed to achieve the target rate of Aggregate, Technical and Commercial (ATC) losses under the Accelerated Power Development and Reform Programme (APDRP) [14]. Therefore, efforts have to be made in particular to the deregulated market parlance to reduce the T/D loss. To do so, two point strategies may be adopted. Firstly, a fair approach is to be utilized to trace out the system which is responsible for the loss and its amount. Secondly, suitable technologies are to be adopted to minimize the losses. Fair allocation of transmission loss in a power system is a complicated job due to the non-linearity nature of electric current. Accordingly the cost allocation of Transmission Losses in Electric Market Mechanism [15] is a research area to be explored. The research is going on to give a viable approach for loss allocation under deregulated enivironment. In the present day context, two types of methods such as Pro rata (Proportional Ratio) and ITL (Incremental Transmission Loss) are being prominently used to allocate the transmission loss. Even though the Pro rata method is a simple one but it does not take the relative locations of loads in a system. In ITL, there is a possibility of over-recovery. Another suitable method [16] has been formulated for aforesaid case which has been used in a Six-bus case. The transmission loss allocations obtained by this method were compared with the results obtained from ITL and Pro rata methods. The argument made by this method gives more justification in the case study of a Six-bus test system. However, for the higher bus system like IEEE-30 bus case, the sum of individual loss allocations appears to be very high in comparison to the total loss worked out by the power flow solution.

In this paper, a new method is proposed in modification to the above method [16], for the calculation of real power loss allocation to the loads while keeping the logic of physical power flow as it is. This proposed method is used for the same six-bus case and subsequently applied successfully to the standard case of IEEE-14 and IEEE-30 test bus systems.

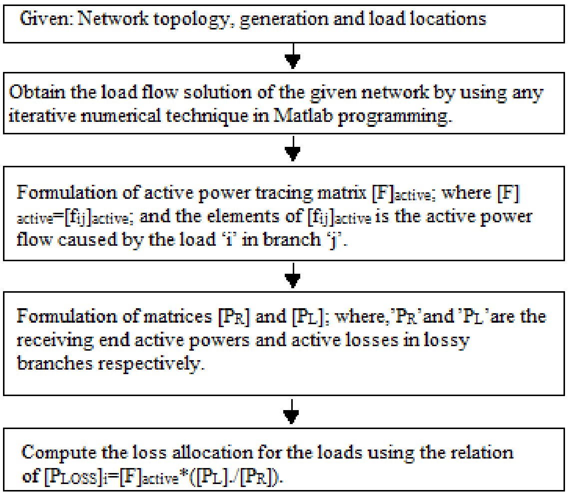
2. PROPOSED METHODOLOGY

The proposed method is based on the principle of physical line flows and the actual line sharing between the loads. It allocates transmission losses to loads based on the actual power flow in the lossy lines due to the concerned load. Each lossy line is subdivided into as many sub-lines as corresponding to the numbers of load attached to it. The tracing of power flow through each sub-line are worked out by using proportional sharing method. The power loss in each lossy line is equal with the total loss due to all the sub-lines under it. Then by using Pro-rata for each lossy line, the individual loss for each sub-line can be better formulated. As the application of Pro-rata is limited to an individual line of the system, so the error in calculation is minimized. The total loss allocated to a particular load is the sum of losses occurred in each lossy lines through which the power is flowing to the concerned load. As this method is based on the actual flow of power in the transmission line corresponding to the concerned load, hence, the loss allocation made by the method gives proper and justifiable allocations to the different loads which are attached to the system.

3. APPLICATION OF METHODOLOGY

Considering the fact that T/D loss is attributed to the system's active power loss, the loss allocated to the different loads would be based on the active power utilized by the loads in a system. The application of proposed methodology to compute the active power loss allocations to different loads in a system is explained through a flowchart as shown in Figure 1.

From the network topology information, obtain the load flow solution by using any iterative numerical technique. Compute the active power tracing matrix by using any suitable tracing method. Formulate the receiving end active powers matrix $[P_R]$ and the active losses matrix $[P_L]$ of lossy lines from the data of load flow solutions. Then loss allocations to the different loads will be found out by using the relation $[P_{LOSS}]_i=[F]_{active}*([P_L]./[P_R])$ where, * means multiplication.



Given: Network topology, generation and load locations

Obtain the load flow solution of the given network by using any iterative numerical technique in Matlab programming.

Formulation of active power tracing matrix $[F]_{active}$; where $[F]_{active}=[f_{ij}]_{active}$; and the elements of $[f_{ij}]_{active}$ is the active power flow caused by the load 'i' in branch 'j'.

Formulation of matrices $[P_R]$ and $[P_L]$; where,'P_R'and 'P_L'are the receiving end active powers and active losses in lossy branches respectively.

Compute the loss allocation for the loads using the relation of $[P_{LOSS}]_i=[F]_{active}*([P_L]./[P_R])$.

Figure 1. Flow chart of the proposed approach

4. APPLICATION OF PROPOSED METHOD AND TEST RESULTS

The proposed method is applied elaborately to the six-bus test system in ref. [16]. The results are compared with the two most commonly used methods such as ITL, Pro rata and the earlier results in ref. [16]. Subsequently, the proposed method is used to find out the loss allocations in IEEE-14 and IEEE-30 bus test systems.

4.1. Case Study–I (six-bus test system)

A six-bus system with having two voltage-controlled buses and three load buses is shown in Figure 2. Bus 1 and 2 are two voltage controlled buses and bus 3, 5 and 6 are load buses. Bus 1 is taken as the slack bus. The bus data, line data and transformer data of the system have been adopted from ref. [16].

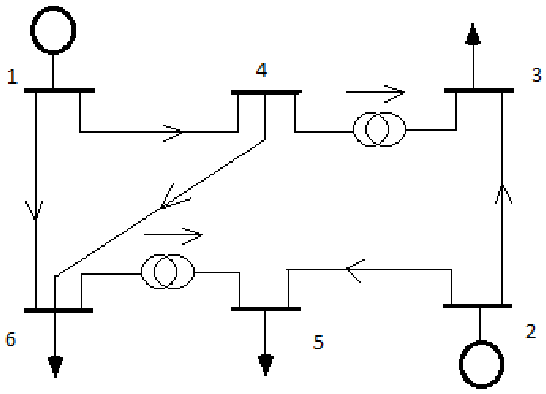


Figure 2. Line diagram of six-bus system

Table 1. Result of line flows and power loss

Line		Receiving end active power	Active loss
From	To	P_R	P_L
1	4	48.728	2.524
1	6	41.651	2.842
2	3	15.416	1.768
2	5	29.309	3.508
4	6	9.040	0.104
4	3	39.584	0.000
6	5	0.691	0.000
		Total system loss	10.746

It is stated earlier that to apply this method, a solved power flow of the system is needed. A Matlab program is developed and using the Newton-Raphson method the power flow solutions of the system is worked out. The results of receiving end active powers and the active power losses are shown in Table 1 above.

4.1.1. Procedure to Formulate Matrix $[F]_{active}$ or $[f_{i,j}]_{active}$

Matrix $[f_{i,j}]_{active}$ is the contribution of line flows to loads. The number of rows of matrix $[f_{i,j}]_{active}$ equals with the number of load bus and the number of columns equals with the number of lossy branches of the system. In this test system, the lossy branches are (1-4), (1-6), (2-3), (2-5), and (4-6). The load buses are 3, 5 and 6. Though different methods are available [9] in power flow tracing to find the contributions of line flows, here, the proportional sharing method is taken into consideration. The details of this method have been described below.

4.1.2. Porportional Sharing Method

In the proportional sharing method, it is assumed that power flowing in to the node can be considered as the proportional sum of the power flowing out of the node. Figure 3 illustrates the method.

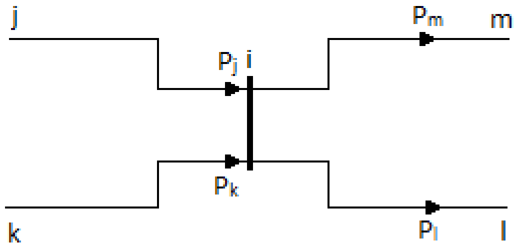


Figure 3. Illustration of proportional sharing method

Here 'i' is taken as the junction node where (j-i), (k-i) are incoming lines and (i-m), (i-*l*) are outgoing lines. P_j, P_k are the receiving powers and P_m, P_l are the outgoing powers at node 'i'.

By proportional sharing principle, each outgoing line takes the power from each incoming line in proportion to its multiplying factor. Now from the above figure, the multiplying factor of line (i-m) = $\frac{P_m}{P_j+P_k}$; and the multiplying factor of line (i-*l*) = $\frac{P_l}{P_j+P_k}$. As total incoming powers is equal with the total outgoing powers at a node, so, $(P_j + P_k) = (P_m + P_l)$ at the node 'i'. This relation may be used in the above expressions of calculation of multiplying factors. Thus, contribution of incoming power $'P_j'$ to the outgoing line (i-m) = $\frac{P_m}{P_m+P_l} \times P_j$. Similarly, contribution of incoming power $'P_j'$ to the outgoing line (i-l) = $\frac{P_l}{P_m+P_l} \times P_j$. This is repeated for other lines also.

4.1.3. Implementation of Proportional Sharing Method to Formulate Matrix, $[f_{i,j}]_{active}$

Step-1:Calculation of multiplying factors of lines and loads by taking active data from the load flow solution.
Step-2:Calculation of power flow contribution of the lossy line to the load.
Step-3:Formation of matrix, $[f_{i,j}]$ by taking the power flow contributions of lossy branches into load buses.

a. Calculation of Multiplying Factors

While calculating the multiplying factors for the different lines, emphasis must be given to choose the particular bus which has more than one outgoing lines and simultaneously acting as a mediatory path for the power flow. In the six-bus system, bus 4 and bus 6 are taken for the calculation of multiplying factors as shown in Figure 4 and Figure 5, respectively.

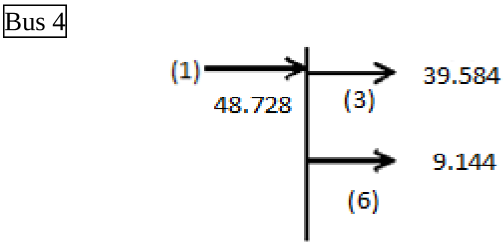


Figure 4. Bus-4 for calculation of multiplying factors

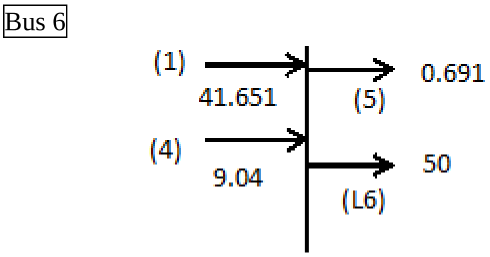


Figure 5. Bus-6 for calculation of multiplying factor

Total output = 39.584+9.144 = 48.728

Multiplying factor of (4-3) line = $\frac{39.584}{48.728}$ = 0.8123

Multiplying factor of (4-6) line = $\frac{9.144}{48.728}$ = 0.1877

Total output = 0.691 + 50 = 50.691

Multiplying factor of (6-5) line = $\frac{0.691}{50.691}$ = 0.0136

Multiplying factor of load L6 = $\frac{50}{50.691}$ = 0.9863

b. Calculation of Power flow Contribution

Now based on the multiplying factors and topology of the system, contributions of different lines towards the different loads are to be worked out. In six-bus case, the load buses are 3, 5 and 6.

For Load Bus 3

Contribution of (2-3) line = 15.416
Contribution of (1-4) line = 39.584

For Load Bus 5

Contribution of (2-5) line = 29.309
Contribution of (1-6) line = 41.651×0.0136 = 0.566
Contribution of (4-6) line = 9.04×0.0136 = 0.123
Contribution of (1-4) line = 48.728×0.1877×0.0136 = 0.124

For Load Bus 6

Contribution of (1-6) line = 41.651×0.9863 = 41.08
Contribution of (4-6) line = 9.04×0.9863 = 8.916
Contribution of (1-4) line = 48.728×0.1877×0.9863 = 9.02

The contributions of line flows to different loads in the six-bus case are shown in Table 2.

Table 2. Contribution of line flows to loads

Load Bus	Lossy branch				
	1-4	1-6	2-3	2-5	4-6
3	39.584	0	15.416	0	0
5	0.124	0.566	0	29.309	0.123
6	9.02	41.08	0	0	8.916

Formation of matrix $[F]_{active}$

From the data of Table 2, matrix $[F]_{active}$ is formed where rows and columns are listed by lossy branches (1-4), (1-6), (2-3), (2-5), (4-6) and load buses 3, 5, 6 respectively. Thus,

$$[F]_{\text{active}} = \begin{bmatrix} 39.584 & 0 & 15.416 & 0 & 0 \\ 0.124 & 0.566 & 0 & 29.309 & 0.123 \\ 9.02 & 41.08 & 0 & 0 & 8.916 \end{bmatrix}$$

4.1.4. Computation of Loss Allocation

Loss allocations to different loads has to be computed by using the relation of $[P_{LOSS}]_i = [F]_{active}*([P_L]. / [P_R])$, where, $[P_R]$ and $[P_L]$ are two column matrices. The elements of $[P_R]$ and $[P_L]$ matrices correspond to receiving end active powers and active power losses of lossy branches, respectively. Such data are shown in Table 1.

$$\text{Thus, } [P_R] = \begin{bmatrix} 48.728 \\ 41.651 \\ 15.416 \\ 29.309 \\ 9.04 \end{bmatrix} \text{ and } [P_L] = \begin{bmatrix} 2.524 \\ 2.842 \\ 1.768 \\ 3.508 \\ 0.104 \end{bmatrix}$$

Now using the relation of $[P_{LOSS}]_i = [F]_{active}*([P_L]. / [P_R])$, the result obtained as $[P_{LOSS}]_i = \begin{bmatrix} 3.8184 \\ 3.5545 \\ 3.3728 \end{bmatrix}$

This column matrix shows the amount of loss allocations to the load buses 3, 5 and 6 in MW, respectively.

4.1.5. Interpretation of Results

Table 3 shows the allocations of transmission loss to three different loads connected at buses 3, 5 and 6 along with the comparison between the three earlier methods with the proposed one. The result shows a big difference of loss allocation in particular to the load at bus 5. From the line diagram it is seen that the load at bus 5 is getting powers from bus 2 and 6. Lossy lines (1-4), (1-6), and (4-6) are partially contributing powers to load 5 through bus 6, whereas, line (2-5) is exclusively contributing its total power from bus 2 to load 5. So it is obvious that total loss incurred in line (2-5) and partial losses in other lines must be allocated to the load at bus 5. But it is verified from the load flow solution in Table 1 that the loss occurred only in the line of (2-5) is 3.508 MW. So, it justifies that the loss allocation to load at Bus 5 must be higher than this value. Now in Table 3, it is observed that the loss allocated to load at bus 5 by Pro-Rata and ITL methods are 2.388 MW and 2.300 MW, respectively which are quite below to the actual value. On the other hand, the other two methods propose the figures as 3.638 MW and 3.5545 MW. This sounds reasonable. Also it is observed that the total active loss found from the load flow solution is also equal with the total loss allocated to different loads. Thus, it can be claimed that baring Pro Rata and ITL, the other two methods are more accurate and its allocation of losses is justifiable. However, the method [16] is not giving suitable results in the higher order bus systems which are presented hereafter.

Table 3. Comparison of loss allocations between four methods

Load bus no.	Different Methods			
	Pro-Rata	ITL	Method[14]	Proposed
3	4.377	4.194	3.853	3.8184
5	2.388	2.300	3.638	3.5545
6	3.979	4.250	3.253	3.3728
Total Loss	10.744	10.7449	10.744	10.7457

4.2. Case Study–II (IEEE-14 bus test system)

In the IEEE-14 bus system as shown in Figure 6, generators are attached into the buses 1 and 2 and loads are attached to buses 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 and 14. Bus 1 is considered as the slack bus. The detailed data of this system have been adopted from ref. [10]. Now using Newton-Raphson iterative technique with programming in Matlab the load flow solution for the system was run and the results of receiving end active line flows and active power loss are presented in Table 4.

Table 4. Receiving end active line flows and active power loss of IEEE-14 Bus

Line		Receiving end active power	Active loss
From	To	P_R	P_L
1	2	152.705	4.305
1	5	72.676	2.762
2	3	71.035	2.331
2	4	54.406	1.675
2	5	40.616	0.907
4	3	23.191	0.382
5	4	60.991	0.504
4	7	27.973	0.000
4	9	16.003	0.000
5	6	44.278	0.000
6	11	7.398	0.061
6	12	7.751	0.073
6	13	17.609	0.216
7	8	0.047	0.000
7	9	27.946	0.000
9	10	5.144	0.011
9	14	9.210	0.111
11	10	3.876	0.015
12	13	1.649	0.007
13	14	5.661	0.058
		Total system loss	13.419

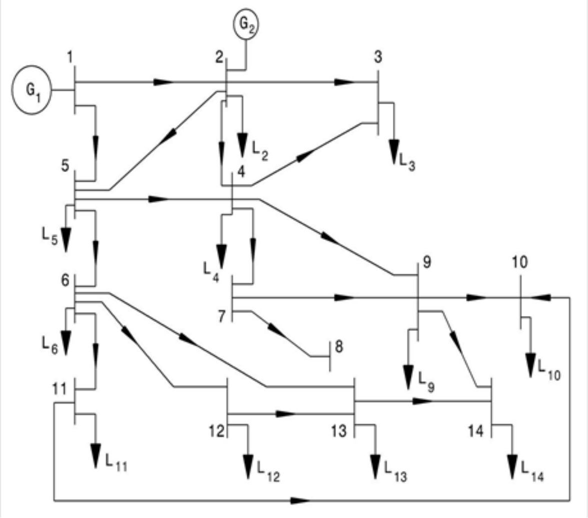


Figure 6. Line diagram of IEEE-14bus test system

4.2.1. Contribution of Active Line Flows

Here, buses 2, 4, 5, 6, 7, 9, 11, 12, and 13 are considered for obtaining multiplying factors and lossy lines are identified as (1-2), (2-3), (2-4), (1-5), (2-5), (4-3), (5-4), (9-10), (6-11), (6-12), (6-13), (9-14), (11-10), (12-13), (13-14). Then by adopting the procedure as mentioned above, the calculation for contribution of active line flows are carried out and presented in Table 5.

4.2.2. Computation of Loss Allocation

Now the receiving end active power matrix, $[P_R]$ and active power loss matrix, $[P_L]$are formed by taking the data from Table 2(a) for the lossy lines (1-2), (2-3), (2-4), (1-5), (2-5), (4-3), (5-4), (9-10), (6-11), (6-12), (6-13), (9-14), (11-10), (12-13), (13-14). Both are taken as column matrices. Thus, $[P_R]$ and $[P_L]$ are:
$[P_R]$ =[152.705;71.035;54.406;72.676;40.616;23.191;60.991;5.144;7.398;7.781;17.609;9.210;3.876;1.649; 5.661] $[P_L]$ = [4.305;2.331;1.675;2.762;0.907;0.382;0.504;0.011;0.061;0.073;0.216;0.111;0.015;0.007;0.058]

Now using the relation of $[P_{LOSS}]_i = [F]_{active}*([P_L]./[P_R])$, the loss allocation for the different load is worked out and presented in Table 6 along with the results worked out by the method [16]. Losses are taken in MW.

Table 5. Active power flow tracing of IEEE-14 bus system

Load bus	Lossy branch														
	1-2	2-3	2-4	1-5	2-5	4-3	5-4	9-10	6-11	6-12	6-13	9-14	11-10	12-13	13-14
2	17.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	70.8578	71.035	11.0988	8.0355	4.49	23.191	12.442	0	0	0	0	0	0	0	0
4	25.7863	0	22.524	16.307	9.11	0	25.25	0	0	0	0	0	0	0	0
5	2.2	0	0	4.8692	2.721	0	0	0	0	0	0	0	0	0	0
6	3.22	0	0	7.122	3.98	0	0	0	0	0	0	0	0	0	0
9	15.8827	0	13.8735	10.04	5.612	0	15.552	0	0	0	0	0	0	0	0
10	3.8826	0	2.3938	4.2571	2.3784	0	2.6836	5.144	3.898	0	0	0	3.898	0	0
11	1.027	0	0	2.271	1.27	0	0	0	3.5	0	0	0	0	0	0
12	1.76	0	0	3.8836	2.17	0	0	0	0	6.1	0	0	0	0	0
13	3.9648	0	0	8.7405	4.8896	0	0	0	0	1.159	12.361	0	0	1.158	0
14	6.6654	0	4.3524	6.8655	3.8356	0	4.8792	0	0	0.491	5.247	9.210	0	0.491	5.661

Table 6. Results of loss allocation in IEEE-14 bus system

Load Bus No.	Methods	
	Method[16]	Proposed
2	0.7225	0.4849
3	5.5261	5.5608
4	2.4245	2.4522
5	0.3085	0.3078
6	0.4630	0.4503
9	1.4883	1.5103
10	0.4779	0.4785
11	0.1747	0.1725
12	0.3037	0.3031
13	0.7297	0.7206
14	0.9439	0.9489
Total	13.5628	13.3899

4.2.3. Interpretation of results of IEEE-14 bus system

It is seen that the total active loss found out by load flow solution as shown in Table 4 is 13.419 MW. This must be equal with the total loss allocations to different loads. But it is observed that the mismatch of method [16] is 0.1438 and of proposed one is 0.0291. Hence, it justifies that the proposed method gives better result in the IEEE-14 bus system.

4.3. Case Study–III (IEEE-30 bus test system)

IEEE-30 test bus system having generators attached to buses 1, 2 and loads to 2, 3, 4, 5, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29, 30 is shown in Figure 7. The detailed data of its transformer tap settings, shunt capacitors, buses and lines have been adopted from ref. [17]. Using Newton-Raphson iterative technique, the load flow solution for the IEEE-30 bus system was carried out in Matlab programming. The results of receiving end active line flows and active line losses of different lines are given in Table 7 along with the total loss of the system.

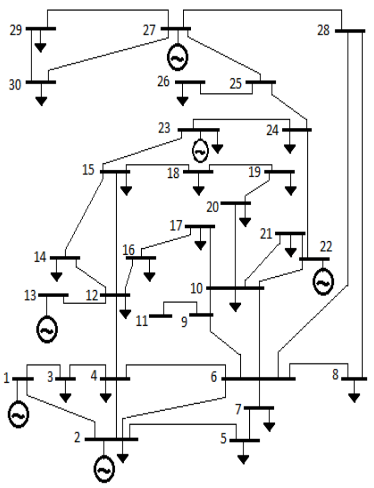


Figure 7. Line diagram of IEEE-30 bus test system

Table 7. Receiving end active line flows and active line loss of IEEE-30 Bus

Line		Receiving end active power	Active loss
From	To	P_R	P_L
1	2	172.282	5.461
1	3	80.390	2.807
2	4	44.596	1.106
2	5	79.995	2.995
2	6	59.858	2.047
3	4	77.263	0.771
4	6	69.527	0.605
4	12	44.131	0.000
7	5	14.210	0.151
6	7	37.170	0.368
6	8	29.431	0.103
6	9	27.687	0.000
6	10	15.828	0.000
6	28	18.780	0.060
28	8	0.570	0.000
9	11	0.003	0.000
9	10	27.731	0.000
10	20	8.937	0.081
10	17	5.332	0.014
10	21	15.613	0.110
10	22	7.531	0.052
13	12	0.021	0.000
12	14	7.778	0.074
12	15	17.634	0.217
12	16	7.152	0.053
14	15	1.586	0.006
15	18	5.970	0.039
15	23	4.972	0.031
16	17	3.646	0.012
18	19	2.774	0.005
20	19	6.703	0.017
22	21	1.849	0.001
22	24	5.601	0.043
23	24	1.765	0.006
25	24	1.322	0.008
25	26	3.476	0.044
27	25	4.866	0.026
28	27	18.192	0.000
27	29	6.093	0.086
27	30	6.932	0.162
29	30	3.683	0.034
Total system loss			17.594

4.3.1. Contribution of Active Line Flows

In this system, buses 2, 3, 4, 6, 7, 9, 10, 12, 14, 15, 16, 18, 20, 22, 23, 25, 27, 28 and 29 are taken for calculation of multiplying factors. Lines (1-2), (1-3), (2-4), (3-4), (2-5), (2-6), (4-6), (7-5), (6-7), (6-8), (12-14), (12-15), (12-16), (14-15), (16-17), (15-18), (18-19), (20-19), (10-20), (10-17), (10-21), (10-22), (22-21), (15-23), (22-24), (23-24), (25-24), (25-26), (27-25), (27-29), (27-30), (29-30) and (6-28) are identified as lossy lines. By using proportional sharing method and adopting the earlier procedure, the active power contributions of different lossy lines to loads are worked out. With respect to the load buses 2, 3, 4, 5, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29 and 30; Tables 3(b) and 3(c) show the contributions of lossy lines (1-2), (1-3), (2-4), (3-4), (2-5), (2-6), (4-6), (7-5), (6-7), (6-8), (12-14), (12-15), (12-16), (14-15), (16-17),(15-18), (18-19) and (20-19), (10-20), (10-17), (10-21), (10-22), (22-21), (15-23), (22-24), (23-24), (25-24), (25-26), (27-25), (27-29), (27-30), (29-30), (6-28), respectively. It is to be noted here that due to insufficient space for presenting the contribution of line flows in one table, the results are tabulated in two tables, from line (1-2) to line (18-19) in Table 8 and from line (20-19) to line (6-28) in Table 9. These results constitute active power tracing matrix $[F]_{active}$.

Table 8. Contribution of active line flows to loads in IEEE-30 bus sysem for line (1-2) to line (18-19)

Load bus	*Lossy branch*																
	1-2	1-3	2-4	3-4	2-5	2-6	4-6	7-5	6-7	6-8	12-14	12-15	12-16	14-15	16-17	15-18	18-19
2	17.573	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	2.3956	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	2.3113	4.8658	2.78279	4.8212	0	0	0	0	0	0	0	0	0	0	0	0	0
5	75.2093	5.028	2.8754	4.9817	79.995	6.7	7.783	14.21	14.348	0	0	0	0	0	0	0	0
7	12.7358	7.985	4.5664	7.9114	0	10.641	12.36	0	22.785	0	0	0	0	0	0	0	0
8	16.3343	10.2412	5.8567	10.1468	0	13.6476	15.8522	0	0	29.431	0	0	0	0	0	0	0
10	3.2095	2.0123	1.1508	1.9938	0	2.6816	3.11481	0	0	0	0	0	0	0	0	0	0
12	3.4041	7.1664	4.0985	7.1007	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1.8872	3.9731	2.2722	3.9366	0	0	0	0	0	0	6.1913	0	0	0	0	0	0
15	2.5237	5.3129	3.0384	5.2641	0	0	0	0	0	0	0.6773	7.5297	0	0.6772	0	0	0
16	1.0818	2.2775	1.3025	2.2566	0	0	0	0	0	0	0	0	3.5045	0	0	0	0
17	4.087	4.2303	2.4193	4.19143	0	2.4721	2.8715	0	0	0	0	0	3.6548	0	3.646	0	0
18	0.9898	2.0837	1.1917	2.0646	0	0	0	0	0	0	0.2656	2.9531	0	0.2656	0	3.19395	0
19	4.6184	4.1646	2.3817	4.1263	0	3.1415	3.649	0	0	0	0.2304	2.5612	0	0.2304	0	2.7701	2.774
20	1.2318	0.7723	0.4417	0.7652	0	1.0292	1.1954	0	0	0	0	0	0	0	0	0	0
21	9.7895	6.1379	3.5102	6.0814	0	8.1794	9.5007	0	0	0	0	0	0	0	0	0	0
23	0.9891	2.0823	1.1909	2.0632	0	0	0	0	0	0	0.2655	2.9513	0	0.2654	0	0	0
24	4.48	3.618	2.0691	3.5848	0	3.2857	3.8165	0	0	0	0.1469	1.6335	0	0.1469	0	0	0
26	2.042	1.28	0.7321	1.26835	0	1.70595	1.9815	0	0	0	0	0	0	0	0	0	0
29	1.3906	0.87168	0.4985	0.8637	0	1.1617	1.3494	0	0	0	0	0	0	0	0	0	0
30	6.2276	3.9037	2.2324	3.8679	0	5.2024	6.0431	0	0	0	0	0	0	0	0	0	0

Table 9. Contribution of active line flows to loads in IEEE-30 bus sysem for line (20-19) to line (6-28)

Load bus	LOSSY BRANCH															
	20-19	10-20	10-17	10-21	10-22	22-21	15-23	22-24	23-24	25-24	25-26	27-25	27-29	27-30	29-30	6-28
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	5.332	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	6.703	6.7296	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	2.2048	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	15.613	1.8828	1.849	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	3.2	0	0	0	0	0	0	0	0	0
24	0	0	0	0	5.6708	0	1.7712	5.601	1.765	1.322	0	1.3343	0	0	0	1.3904
26	0	0	0	0	0	0	0	0	0	0	3.476	3.5327	0	0	0	3.6812
29	0	0	0	0	0	0	0	0	0	0	0	0	2.391	0	0	2.5069
30	0	0	0	0	0	0	0	0	0	0	0	0	3.7022	6.932	3.683	11.2268

4.3.2. Computation of Loss Allocation

Receiving end active power matrix, $[P_R]$ and active power loss matrix, $[P_L]$ have been formulated by taking the data from Table 8 for the lossy lines (1-2), (1-3), (2-4), (3-4), (2-5), (2-6), (4-6), (7-5), (6-7), (6-8), (12-14), (12-15), (12-16), (14-15), (16-17), (15-18), (18-19), (20-19), (10-20), (10-17), (10-21), (10-22), (22-21), (15-23), (22-24), (23-24), (25-24), (25-26), (27-25), (27-29), (27-30), (29-30) and (6-28). Both $[P_R]$ and $[P_L]$ are column matrices and whose values are given below.

$[P_R]$ =
[172.282;80.39;44.596;77.263;79.995;59.858;69.527;14.210;37.170;29.431;7.778;17.634;7.152;1.586;3.646;5.970;2.774;6.703;8.937;5.332;15.613;7.531;1.849;4.972;5.601;1.765;1.322;3.476;4.866;6.093;6.932;3.683;18.780]

$[P_L]$ =
[5.461;2.807;1.106;0.771;2.995;2.047;0.605;0.151;0.368;0.103;0.074;0.217;0.053;0.006;0.012;0.039;0.005;0.017;0.081;0.014;0.110;0.052;0.001;0.031;0.043;0.006;0.008;0.044;0.026;0.086;0.162;0.034;0.06]

Using the relation of $[P_{LOSS}]_i = [F]_{active}*([P_L]./[P_R])$; the loss allocation to all the load buses have been calculated and presented in Table 10. Loss allocation by the method [16] has also been given for a comparative study. All the loss values are taken in MW.

4.3.3. Interpretation of Results of IEEE-30 bus System

It is seen from Table 7 that the total active loss in IEEE-30 bus system is 17.594 MW. Now from Table 10, it is found out that the total allocated loss by method [16] is 22.2564 MW and by the proposed method is 17.5901 MW. As the total allocated loss to all the load buses cannot be more than the system loss, hence the proposed method sounds reasonable.

Table 10. Results of loss allocations in IEEE-30 bus system

Load Bus No.	Methods		Load Bus No.		
	Method[16]	Proposed		Method[16]	Proposed
2	1.1323	0.5570	18	0.2038	0.2150
3	0.0965	0.0836	19	0.6947	0.6669
4	0.3878	0.3603	20	0.1707	0.1502
5	7.3572	6.2655	21	1.6770	1.1588
7	2.5037	1.5717	23	0.2149	0.2140
8	2.0083	1.8647	24	0.9136	0.6391
10	0.4204	0.3392	26	0.6456	0.2832
12	0.7470	0.5306	29	0.2970	0.1843
14	0.3579	0.3531	30	1.0637	0.9215
15	0.4913	0.4951	Total	22.2564	17.5901
16	0.2216	0.1946			
17	0.6514	0.5417			

5. CONCLUSION

The proposed method allocates transmission losses to loads based on the actual power flow in the lossy lines due to the concerned load. Each lossy line is subdivided into as many sub-lines as corresponding to the numbers of load attached to it. The tracing of power flow through each sub-line is worked out by using proportional sharing method. The power loss in each lossy line is equal with the total loss due to all the sub-lines under it. Then by using Pro-rata for each lossy line, the individual loss for each sub-line is formulated. As the application of Pro-rata is limited to an individual line of the system, so the error in calculation is minimized. The total loss allocated to a particular load is the sum of losses occurred in each lossy lines through which the power is flowing to the concerned load. Loss allocation based on the actual line flow of a system gives more justification to the load bus connected into it. As the tariff rates are mainly dependent on active power supply and active loss, hence emphasis has been given more on active power calculation. Instead of going into a complicated calculation, the process is developed in a simple manner with giving due weightage to the physical flow of power to the load in a system. The results obtained in six-bus system justify the logic and exposes the error produced by the two widely used methods namely Pro-rata and ITL. In dealing with the higher order bus system, the method also gives a fair approach to transmission loss allocation.

ACKNOWLEDGEMENTS

The support from the Electrical Engineering Department of Veer Surendra Sai University of Technology, Burla, India, extended to the authors for the work reported in this paper is gratefully acknowledged.

REFERENCES

[1] S. M. Myint, S. W. Naing, “Network Reconfiguration for Loss Reduction and Voltage Profile Improvement of 110-bus Radial Distribution System using Exhaustive Search Techniques”, *International Journal of Electrical & Computer Engineering (IJECE),* Vol.5, No.4, August-2015, pp.788-797.

[2] S. Hlaing, P. L. Swe, “Loss Minimization of Power Distribution Network using different Types of Generation unit”, *International Journal of Electrical & Computer Engineering (IJECE),* vol.5, no.5, October-2015, pp.918-928.

[3] A. J. Canejo, J. M. Arroyo, N. Alguacil, A. L. Guijarro, “Transmission Loss Allocation: A Comparison of different Practical Algorithms”, *IEEE Trans. on Power Syst.,* vol. 17, August-2002, pp.571-576.

[4] M. Y. Hassan, M. A. Almaktar, M. P. Abdullah, F. Hussin, M. S. Majid, H. A. Rahman, “Assessment of Transmission Loss Allocation Algorithms in Deregulated Power System”, *International Review of Electrical Engineering (I.R.E.E.),* vol.7, no.2, March-April 2012, pp.4065-4076.

[5] A. G. Exposito, J. M. R. Santos, T.G.Garcia, E.R.Velasco, “Fair Allocation of Transmission Power Losses”, *IEEE Trans. on Power Syst.,* vol. 15, February-2000, pp.184-188.

[6] G.Strbac, D. Kirschen, S. Ahmed, “Allocating Transmission System usage on the Basis of Traceable Contributions of Generators and Loads to Flows”, *IEEE Trans. on Power Syst.,* vol. 13, May-1998, pp. 527-534.

[7] J. W. Bailek, “Topological Generation and Load Distribution Factors for Supplement Charge Allocation in Transmission Open Access”, *IEEE Trans. on Power Syst*., vol. 12, August-1996, pp.1387-1392.

[8] D. Kirschen, G. Strbac, “Tracing Active and Reactive Power between Generators and Loads using Real and Imaginary Currents”, *IEEE Trans. on Power Syst.,* vol. 14, no. 4, November-1999, pp. 1312-1319.

[9] A. J. Canejo, F. D. Galiana, I. Kockar, "Z-buss Loss Allocation", *IEEE Trans. on Power Syst.,* vol. 16, no. 1, February-2001, pp. 105-110.

[10] A. Canejo, N. Alguacil, G. F. Ruiz, "Allocation of the Cost of Transmission Losses using a Radial Equivalent Network", *IEEE Trans. on Power Syst.,* vol. 18, November-2003, pp. 1353-1358.

[11] J. S. Savier, D. Das, "An Exact Method for Loss Allocation in Radial Distribution Systems", *Electrical Power and Energy Systems*, vol. 36, 2012, pp. 100-106.

[12] G.Gross, S.Tao, "A Physical-flow-based Approach to Allocating Transmission Losses in a Transaction Framework", *IEEE Trans. on Power Syst.,* vol. 15, no. 2, May-2000, pp. 631-637.

[13] "Power and Communications," *World Bank Report, 2013*.

[14] "Eleventh Five Year Plan, 2007-12, Inclusive Growth", Vol.I, *Government of India.*

[15] H. Zein, E. Dermawan, "Cost Allocation of Transmission Losses in Electric Market Mechanism", *TELKOMNIKA, Indonesian Journal of Electrical Engineering,* Vol.10, No.2, June-2012, pp.211-218.

[16] S. Abdelkader, "Transmission Loss Allocation in a Deregulated Electrical Energy Market", *Electric Power Systems Research,* vol. 76, 2006, pp. 962–967.

[17] Hadi Saadat, "*Power System Analysis*", *Tata McGraw-Hill*, New Delhi, Edition-2002, Reprint-2006.

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