A Comparative Study of Loss Allocation before and after Loss Reduction by RED Concept in Deregulated Power System

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Abstract- In the deregulated power system environment the transmission loss plays an important role. Both its allocation and reduction impact a lot on economic consideration. Due to the nonlinearity nature, the allocation of transmission loss among different utilities creates a challenging task. This paper proposes a new formula for transmission loss allocation based on actual usage of line. It splits a common transmission line into as many sub-lines corresponding to the number of loads attached to it. It divides the total loss of the common line among the sub-lines in proportion to their individual power sharing. The net loss allocated to a particular load is the combination of individual loss occurring in different sub-lines which are concerned to the said load under the whole system. To apply this formula, the load flow solution of the system network along with the power flow tracing of lossy lines are computed. This paper uses Newton-Raphson based iterative technique to obtain the load flow solutions and proportional sharing method for power flow tracing. The proposed formula is applied to a six-bus case to prove its viability and subsequently used to find the loss allocation in IEEE-14 and IEEE-30 bus systems. Relative Electrical Distance (RED) concept which is based on topology of the system and readjustment of generations has been utilized to reduce the loss in both the systems. The amounts of loss reduction in both the cases are found to be significant. Again the loss allocations of the two systems are worked out using the proposed formula and finally comparison of loss allocations before and after the loss reduction have been presented.

Keywords: Line flow, Power flow tracing, Lossy lines, Relative Electrical Distance (RED), Loss allocation

I. INTRODUCTION

Transmission loss arises when the electric power flows through the transmission line to meet the customer's load demand. In the pre-deregulated system, these losses were overlooked, as they did not pose any major problem in quality or operational supply of power. However, in the deregulated era transmission loss impacts a lot in the economic aspects. Therefore, minimization of transmission loss is a paramount task. Reduction of loss is quantified as savings in generation cost. In deregulated market structure, financial sectors are imposing condition to ensure less transmission loss mechanism before giving any financial assistance to the power company. In a larger interconnected network, factors like voltage regulation, circulating current, phase balancing, power factor, etc. influence more losses into the system. Network reconfiguration and resizing, preventing leakage at insulators, providing automatic voltage booster, better management of distribution transformers, load balancing and its management, fixing capacitors, adoption of high voltage distribution system are some of the ways that can be undertaken for loss reduction. Oke, et al. presented [1] a mathematical model of losses by taking ohmic loss and corona loss. It suggests operating of system under flat voltage loading and keeping the space between the conductors as large as compared to their diameter. Under practical field, maintaining flat voltage loading is a difficult task. Some of the action plans are described by Ibrahim [2] for loss reduction. However, it does not specify any particular one for loss reduction. Bidding mechanism has been employed by Yu, et al. [3] to reduce the loss. Rosa, et al. [4] inserted wind turbine generators into the power grid to reduce active and reactive losses. The place to connect wind turbine is decided by incremental transmission loss method. Though it sounds logical but intermittency of wind would affect the voltage profile of the system. The requirement of reduction in transmission loss persists in both regulated and deregulated power systems. However, in particular to deregulated power system, loss reduction along with its allocations among different utilities is very much needed. While deciding the tariffs under regulated system, losses were taken as an extra load and expenditure occurred due to the system loss were collected from all the utilities irrespective of losses they made. But in the deregulated system, the services of generation, transmission and distribution are unbundled and hence, fairer tariff has to be assigned to the individual services. To fix a fair tariff, it is essential and mandatory to know the individual's loss amount. Unfortunately, transmission loss is a nonlinear quantity involving cross terms. Allocating it in a larger network is a challenging task. Different methods have been developed and still research is going on to give it a viable conclusion. A comparison of different practical algorithms for transmission loss allocation is presented by Canejo, et al. [5]. The assignment of cross terms in

power equation, particularly when the involved transactions greatly differ in size, has been analyzed and some methods like proportional allocation, quadratic allocation, geometric allocation and fast geometric allocation are proposed by Exposito, *et al*. [6]. Converting all power injections into real and imaginary currents to avoid non-linear coupling between active and reactive power flows caused by losses have been presented by Canejo, *et al*. [7]. Radial equivalent network approach has been discussed by Canejo, *et al*. [8]. Bisnas, *et al*. [9] describes a methodology for aggregation of nodal generation loss factors into zonal loss factors by considering electrical proximity of nodes to the zonal centers. Loss allocation based on fuzzy memberships and supervised neural network have been presented by Choudhury, *et al*. [10]. Khan, *et al*.[11] have presented a combined methodology for transmission usage and loss allocation based on matrix formulation and game theory. Implications of India's new cost allocation method for Inter-State transmission have been analyzed by Beckman [12]. It describes the point of connection charging method. This works on flow-based transmission cost allocation framework. However, the successful implementation of this method largely depends on the robust open access regime and fair allocation of transmission loss. Loss allocation based on physical line flow of individual load gives more justification to the load. To know the individual line flow in a common transmission line, power flow tracing is required. A physical-flow-based approach in a multiple transaction system with a new concept of counter flow associated with the losses has been demonstrated by Gross, *et al*. [13]. Active and reactive power flow tracing between generators and loads based on proportional sharing principle are proposed in references [14-15]. Transmission cost allocations based on power flow tracing is presented by Khan, *et al*. [16]. Models have been proposed for effective reactive power flow tracing in references [17-18]. New power flow tracing methods based on directed circuit and extended incidence matrix have been presented in references [19] and [20], respectively. Calculation of transmission congestion price based on Bialek's power flow tracing principle has been presented by Chellam, *et al*. [21]. Here, both upstream and downstream algorithms were used to find out the power flow from generators to transmission lines and from generators to loads. Abdelkader [22] has proposed a new methodology that has been applied to transmission loss allocation based on power flow tracing. This presents more acceptable result over two widely applied methods such as proportional ratio (Pro-rata) and incremental transmission loss (ITL) in a six-bus system. However, this method gives some mismatch in justifying the total allocated loss equals with the total system loss particularly when applied to higher order bus systems.

As economic aspects in deregulated power system mainly depend on the active loss of a system, so this paper undertakes active power loss allocation of the system considering all the losses attributed to load sides. It uses proportional sharing method to trace out the active power in a common line, particular to the loss making line which is also called as lossy line. Based on physical flow of power, a new formula has been developed to allocate the loss for different loads. The main logic behind this formula is the segregation of each lossy line into as many sub-lines depending upon the numbers of loads attached to it, either directly or indirectly. Then total loss of the common line is divided among the loads with proportionate to their power receiving. This formula has been applied to the system in reference [22] and justified its viability. This is also used in the case study of IEEE-14 and IEEE-30 bus systems for loss allocations. Further, relative electrical distance (RED) concept [23-26] which depicts the idea of getting power form the nearest generator by the load with minimum loss has been employed here to reduce the loss in IEEE-14 and IEEE-30 bus systems. Thereafter, the re-allocations of transmission loss have been worked out using the proposed formula and finally a comparative study has been presented.

II. THE PROPOSED FORMULA

The proposed formula allocates transmission losses to loads based on the actual physical usage of the line. It undertakes the idea which is well demonstrated and proved in reference [22] that when two or more currents share a conductor, they will have equal chances to occupy the conductor cross section. It means the effective area each conductor occupies will be proportional to its magnitude. This provides the insight to split a common line into as many as sub-lines corresponding to the numbers of loads that are attached to it either directly or indirectly. It means a load may directly receive the power from the receiving end of the common line or through other line but originated from the same receiving end of the said common line. Now the total loss of the common line may be allocated to different sub-lines with respect to the power flow through each of them.
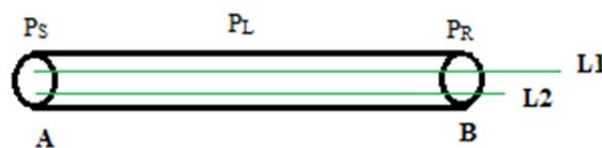
A. Mathematical Interpretation

Fig.1. Illustration of splitting line and loss

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Fig. 1 shows the splitting of a common line *AB* into the sub-lines of *L1* and *L2*. It is assumed that two loads 1 and 2 are taking powers through line *AB*. P_S is the sending end power at *A* and P_R is the receiving end power at *B*. P_L is the total loss of the line *AB*. Now this loss is occurring in *AB* due to the delivery of power, P_R at *B*. This delivering of power is necessitated due to the demands of loads 1 and 2. Hence the loss occurred in *AB* must be borne by the loads 1 and 2. Now to sort out the problem of total loss distributions or loss allocations between them, it is justified to allocate the loss in accordance with their individual power demand at the receiving end of line *AB*.

If P_{D1} and P_{D2} are the power demands of loads 1 and 2, then using proportional ratio principle;

Loss allocation to load 1, $P_{LOSS1} = \frac{P_{D1}}{P_R} \times P_L$ (1)

and loss allocation to load 2, $P_{LOSS2} = \frac{P_{D2}}{P_R} \times P_L$ (2)

B. Application to Power Systems

To apply this method to a larger power system network, firstly, the line flow of the system has to be found out and this can be done by using any programmed based numerical iterative technique. Secondly, by using any suitable power sharing method [15], the active line flows of individual loads are to be traced out in a common transmission lossy line. The active line flows in lossy lines caused by different loads of the system are to be arranged in a matrix form such as:

$[F_{active}] = [f_{i,j}]$ (3)

Where, $f_{i,j}$ is the active line flow caused by the load ' *i* ' in lossy branch ' *j* '.

Then, the active loss allocations for the different loads by using the proposed formula are computed as:

$[P_{LOSS}]_i = [F_{active}] * ([P_L]./[P_R])$ (4)

Where, $[P_L]$ and $[P_R]$ are the active line losses and receiving end active powers of lossy lines, respectively. Both are column matrices whose rows are equal to the number of lossy lines.

$[P_{LOSS}]_i$ is a column matrix of size $(L_B \times 1)$ and L_B is the number of load buses of the system.

III. APPLICATION OF PROPOSED FORMULA AND TEST RESULTS

The proposed formula is applied elaborately to the six-bus test system adopted from reference [22]. The results are compared with the two most commonly used methods such as ITL, Pro rata and the earlier results [22]. Subsequently, the proposed formula is used to find out the loss allocations in IEEE-14 and IEEE-30 bus test systems.

A. Case Study–I (Six-Bus Test System)

A six-bus system having two voltage-controlled buses and three load buses is shown in Fig. 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 reference [22].
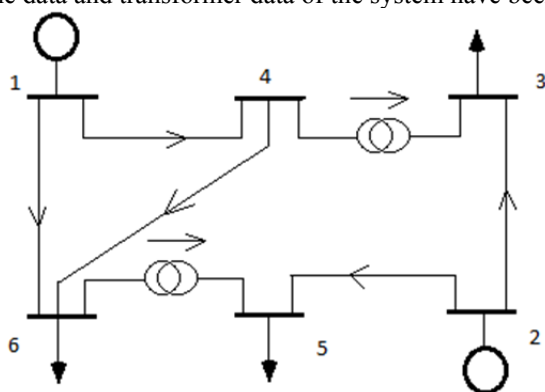
Fig.2. Line diagram of six-bus system

Table 1(a) Results of line flows and power loss

Line		Receiving end active power in MW	Active loss in MW
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(a) above.

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A.1. *Procedure to formulate matrix* $[F_{active}]$ *or* $[f_{i,j}]$

Matrix $[f_{i,j}]$ is the contribution of line flows to loads. The number of rows of matrix $[f_{i,j}]$ 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 [15] for power flow tracing to find the contributions of line flows, here the mostly used proportional sharing method is taken into consideration. The details of this method have been described below.

A.2. *Proportional 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. Fig.3 illustrates the method.
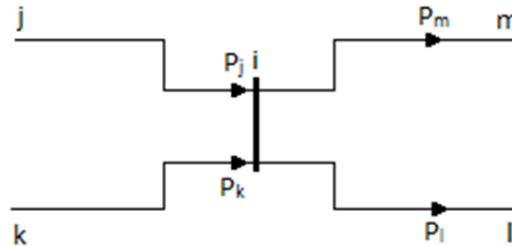

Fig.3. Illustration of proportional sharing method

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 power is equal with the total outgoing power 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.

A.3. *Implementation of proportional sharing method to formulate matrix,* $[F_{active}]$

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.4. *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 to be taken for the calculation of multiplying factors.

Bus 4
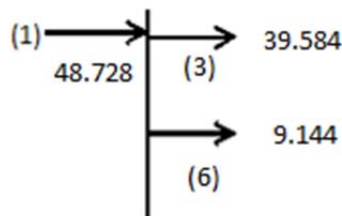
Bus 6

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
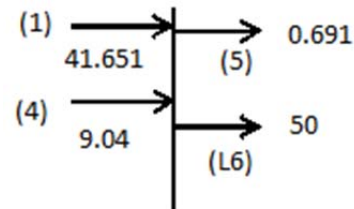
Total output = 0.691 + 50 = 50.691
Multiplying factor of (6-5) line = $\frac{0.691}{50.691}$ = 0.0136
Multiplying factor of load L6 = $\frac{50}{50.691}$ = 0.9863

A.5. *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 1(b).

Table 1(b) 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

A.6. *Formation of matrix* $[F_{active}]$

From the data of Table 1(b), 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,

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

A.7. *Computation of loss allocation*

Loss allocations to different loads have to be computed by using the Eq. (4). Now $[P_R]$ and $[P_L]$ matrices are formed by taking the data from Table 1(a) such that $[P_R]$ = [48.728; 41.651; 15.416; 29.309; 9.04] and $[P_L]$ = [2.524; 2.842; 1.768; 3.508; 0.104].

Therefore loss allocations to different loads are $[P_{LOSS}]_i = \begin{bmatrix} 3.8184 \\ 3.5545 \\ 3.3728 \end{bmatrix}$; this column matrix shows the amount of loss allocations to the load buses 3, 5 and 6 in MW, respectively.

A.8. *Interpretation of results*

Table 1.(c) Comparison of loss allocations between four methods

Load bus no.	Different Methods			
	Pro-Rata	ITL	Method[22]	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

Table 1(c) 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 power to load 5

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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(a) that the loss occurred only in the line of (2-5) is 3.508MW. So, it justifies that the loss allocation to load at bus 5 must be higher than this value. Now in Table 1(c), it is observed that the loss allocated to load at bus 5 by Pro-Rata and ITL methods are 2.388MW and 2.300MW, respectively which are quite below to the actual value. On the other hand, the other two methods including proposed method obtain the figures as 3.638MW and 3.5545MW, respectively. 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 [22] is not giving suitable results in the higher order bus systems which are presented hereafter.

B. Case Study–II (IEEE-14 Bus Test System)

In the IEEE-14 bus system as shown in Fig.4, generators are attached to the buss 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 reference [7]. Now using Newton-Raphson iterative technique, the load flow program in Matlab for the system was run and the results of receiving end active line flows, P_R and active power loss, P_L are presented in Table 2(a) above.

B.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 2(b) which shall be taken as $[F_{active}]$.

Fig.4. Line diagram of IEEE-14 bus test system

Table 2(a) Receiving end active line flows and active power loss of IEEE-14 bus test system

Line		Receiving end active power in MW	Active loss in MW
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

B.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 determined as:

$[P_R] =$
[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 Eq. (4), the loss allocation for the different loads is worked out and presented in Table 2(c) along with the results worked out by the method [22]. Losses are taken in MW.

Table 2(b) 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 2(c) Results of loss allocation in IEEE-14 bus system

Load Buses	2	3	4	5	6	9	10	11	12	13	14	Total
Method[22]	0.7225	5.5261	2.4245	0.3085	0.4630	1.4883	0.4779	0.1747	0.3037	0.7297	0.9439	13.5628
Proposed	0.4849	5.5608	2.4522	0.3078	0.4503	1.5103	0.4785	0.1725	0.3031	0.7206	0.9489	13.3899

B.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 2(a) is 13.419MW. This must be equal with the total loss allocations to different loads. But, it is observed that the mismatch obtained by the method [22] is 0.1438MW whereas by proposed method is 0.0291MW only. Hence, it is justified that the proposed method gives better result for the IEEE-14 bus system.

C. 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 Fig.5. The detailed data of its transformer tap settings, shunt capacitors, buses and lines have been adopted from reference [27]. Using Newton-Raphson iterative technique, the load flow program for the IEEE-30 bus system was run in Matlab. The results of receiving end active line flows and active line losses of different lines are given in Table 3(a) along with the total loss of the system.
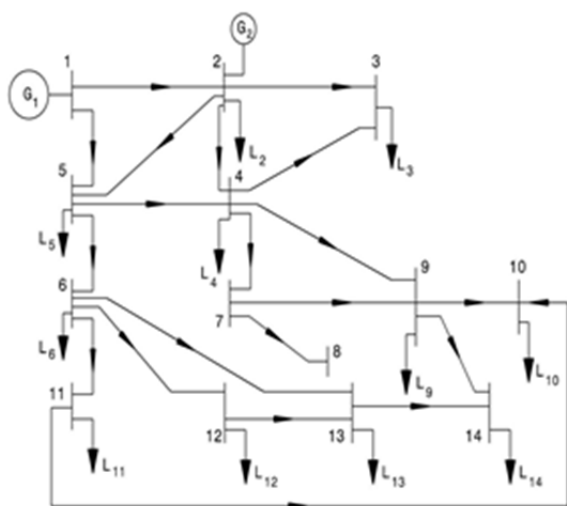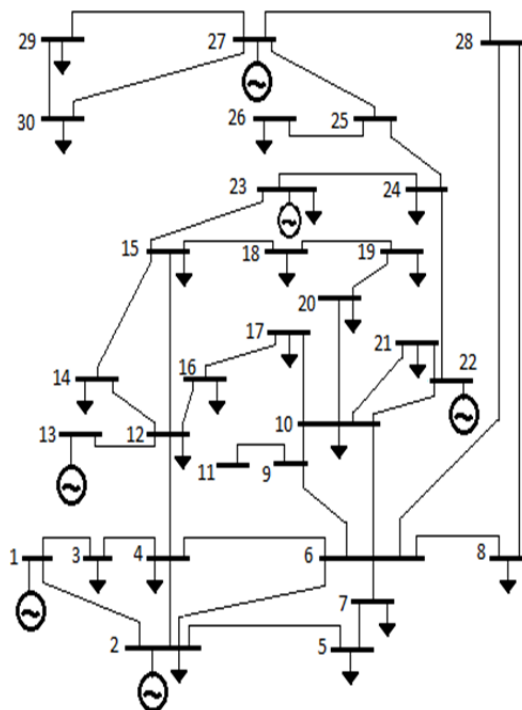

Fig.5. Line diagram of IEEE-30 bus test system

Table 3(a) Receiving end active line flows and active line loss of IEEE-30 bus test system

Line		Receiving end active power in MW	Active loss in MW
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

C.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), 3(c) and 3(d) 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), (20-19), (10-20), (10-17), (10-21), (10-22)] and [(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 three tables i.e., from line (1-2) to line (12-14) in Table 3(b), from line (12-15) to line (10-22) in Table 3(c) and from line (22-21) to line (6-28) in Table 3(d). These results constitute active power tracing matrix $[F_{active}]$.

Table 3(b) Contribution of active line flows to loads in IEEE-30 bus system for line (1-2) to line (12-14)

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

Table 3(c) Contribution of active line flows to loads in IEEE-30 bus system for line (12-15) to line (10-22)

Load bus	Lossy Branch										
	12-15	12-16	14-15	16-17	15-18	18-19	20-19	10-20	10-17	10-21	10-22
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0

12	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	7.5297	0	0.6772	0	0	0	0	0	0	0	0
16	0	3.5045	0	0	0	0	0	0	0	0	0
17	0	3.6548	0	3.646	0	0	0	0	5.332	0	0
18	2.9531	0	0.2656	0	3.19395	0	0	0	0	0	0
19	2.5612	0	0.2304	0	2.7701	2.774	6.703	6.7296	0	0	0
20	0	0	0	0	0	0	0	2.2048	0	0	0
21	0	0	0	0	0	0	0	0	0	15.613	1.8828
23	2.9513	0	0.2654	0	0	0	0	0	0	0	0
24	1.6335	0	0.1469	0	0	0	0	0	0	0	5.6708
26	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0

C.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 3(a) 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]

Now using the Eq. (4), the loss allocation to all the load buses have been calculated and presented in Table 3(e). Loss allocation by the method [22] has also been given for a comparative study. All the loss values are taken in MW.

Table 3(d) Contribution of active line flows to loads in IEEE-30 bus system for line (22-21) to line (6-28)

Load bus	Lossy Branch										
	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
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	1.849	0	0	0	0	0	0	0	0	0	0
23	0	3.2	0	0	0	0	0	0	0	0	0
24	0	1.7712	5.601	1.765	1.322	0	1.3343	0	0	0	1.3904
26	0	0	0	0	0	3.476	3.5327	0	0	0	3.6812
29	0	0	0	0	0	0	0	2.391	0	0	2.5069
30	0	0	0	0	0	0	0	3.7022	6.932	3.683	11.2268

C.3. *Interpretation of results of IEEE-30 bus system*

It is seen from Table 3(a) that the total active loss in IEEE-30 bus system is 17.594 MW. Now from Table 3(e), it is found out that the total allocated loss by method [22] is 22.2564MW and by the proposed method is 17.5901MW. As the total allocated loss to all the load buses cannot be more than the system loss, hence the proposed method sounds reasonable.

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Table 3(e) Results of loss allocations in IEEE-30 bus system

Load Bus No.	Methods		Load Bus No.	Methods	
	Method[22]	Proposed		Method[22]	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			

IV. APPLICATION OF RELATIVE ELECTRICAL DISTANCE (RED) CONCEPT FOR REDUCTION OF LOSSES

The loss reduction by RED method does not require any extra component to connect in the power system. It gives the data to readjust the generations with a desired value so that there will be a minimum loss in the system.

A. Concept of RED

The concept of RED is based on the information of the relative distances between the generator and load buses in a system. It is always desired that a load is predominantly met by the nearest generator maintaining all the constraints as far as possible. The concept of relative electrical distances is derived from the transmission network admittance matrix. Considering a system with 'N' total number of buses; 'G' number of generator buses, the following matrix equation can be written.

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \tag{5}$$

Where, 'L', the number of load buses. I_G, I_L and V_G, V_L represent injected current and complex voltage vectors at the respective buses. $[Y_{GG}]$, $[Y_{GL}]$, $[Y_{LL}]$ and $[Y_{LG}]$, are corresponding portions of network admittance bus matrix. Rearranging the equation (5), we get,

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{6}$$

Where, $F_{LG} = -[Y_{LL}]^{-1}[Y_{LG}]$ (7)

The columns and rows of $[F_{LG}]$ matrix correspond to the generator bus numbers and load bus numbers, respectively. The elements of this matrix are complex and it gives the information between the location of load nodes corresponding to generator nodes that is termed as relative electrical distance between load nodes and generator nodes. Basing on this, each load is well informed about the power that should be taken from each generator under normal and network contingencies. This matrix is used as the basis for the desired load sharing/generation rescheduling. Therefore the relative electrical distances, i.e., the relative locations of load nodes with respect to the generator nodes is given by,

$$[R_{LG}] = [A] - \text{abs} \{[F_{LG}]\} \tag{8}$$

Where, $[A]$ is the matrix with (N-G) rows and 'G' number of columns of all elements equal to '1' or unity. The imaginary part of $[F_{LG}]$ matrix elements is almost negligible, hence without any loss of generality, the desired proportions of generation for the desired load sharing/generation scheduling can be obtained from the $[F_{LG}]$ matrix and is given by,

$$[D_{LG}] = \text{abs} \{[F_{LG}]\} \tag{9}$$

Thus the desired generation schedule $[DGS]$, for the Gth generator is obtained by using the mathematical relation of

$$[DGS]_G{}^{th} = \sum_{j=G+1}^{No.of\ Buses}([D_{jG}] \times [P_j]) \tag{10}$$

where, $[P_j]$ is the load at the jth load bus and $[D_{jG}]$ values are taken from the $[D_{LG}]$ matrix of the given network.

B. Loss Reduction and Allocations

The following algorithm represents the detailed procedure for loss reduction and allocations for the system network based on RED.
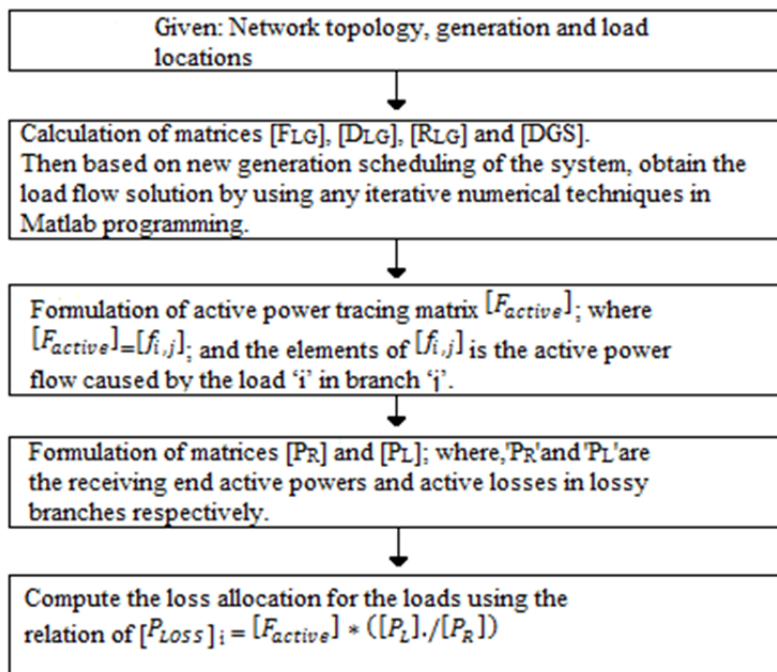
Given: Network topology, generation and load locations

↓

Calculation of matrices [F$_{LG}$], [D$_{LG}$], [R$_{LG}$] and [DGS].
Then based on new generation scheduling of the system, obtain the load flow solution by using any iterative numerical techniques in Matlab programming.

↓

Formulation of active power tracing matrix $[F_{active}]$; where $[F_{active}]=[f_{i,j}]$; and the elements of $[f_{i,j}]$ 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 $[P_{Loss}]_i = [F_{active}] * ([P_L]./[P_R])$

Fig.6. Flow chart for loss reduction and allocation using RED approach

C. Case study of IEEE-14 bus system using RED concept

C.1. *Calculation of [F$_{LG}$], [D$_{LG}$], [R$_{LG}$] and [DGS] matrices*

Adopting the line data from reference [7] and using the Eq. (7), the matrix [F_{LG}] is computed and basing on its values the desired load sharing/generation scheduling matrix is derived by using Eq. (9). Finally the matrix [D_{LG}]is shown in Table 4(a).

Table 4(a) [D$_{LG}$] matrix of IEEE-14 bus system

	Load Bus No.	Generator Sharing	
		G1	G2
[D_{LG}] =	3	0.1090	0.8910
	4	0.2069	0.7935
	5	0.2758	0.7247
	6	0.2532	0.7477
	9	0.2252	0.7751
	10	0.2301	0.7702
	11	0.2414	0.7591
	12	0.2511	0.7497
	13	0.2492	0.7516
	14	0.2356	0.7648

Table 4(b) [R$_{LG}$] matrix of IEEE-14 bus system

	Load Bus No.	Relative location of Load node with respect to Generator node	
		G1	G2
[R_{LG}] =	3	0.8910	0.1090
	4	0.7935	0.2069
	5	0.7247	0.2758
	6	0.7477	0.2532
	9	0.7751	0.2252
	10	0.7702	0.2301
	11	0.7591	0.2414
	12	0.7497	0.2511
	13	0.7516	0.2492
	14	0.7648	0.2356

In the calculation of matrix [D_{LG}], bus 2 is taken as the generator bus. Now relative electrical distance matrix [R_{LG}] is found out by using Eq. (8) and the result is shown in Table 4(b) in above. Now the Desired Generation Scheduling at generator bus 1 and 2 are found out by using Eq. (10) and shown in Table 4(c).

Table 4(c) [DGS] matrix of IEEE-14 bus system

	Load Bus No.	Generator Scheduling	
		G1	G2
[DGS] =	3	10.2678	83.9322
	4	9.8898	37.9293
	5	2.0961	5.5077
	6	2.8358	8.3742
	9	6.6434	22.8654
	10	2.0709	6.9318
	11	0.8449	2.6568
	12	1.5317	4.5732
	13	3.3642	10.1466
	14	3.5104	11.3955
	TOTAL	43.055	194.3127

Table 4(d) Receiving end active line flows and active power loss of IEEE-14bus system

Line		Receiving end active power in MW	Active loss in MW
From	To	P_R	P_L
1	2	5.928	0.113
1	5	44.759	1.065
2	3	75.645	2.651
2	4	64.083	2.348
2	5	53.984	1.607
4	3	18.555	0.241
5	4	47.368	0.298
4	7	28.529	0.000
4	9	16.326	0.000
5	6	43.387	0.000
6	11	6.848	0.056
6	12	7.680	0.072
6	13	17.320	0.211
7	8	0.000	0.000
7	9	28.529	0.000
9	10	5.665	0.013
9	14	9.559	0.118
11	10	3.335	0.013
12	13	1.574	0.006
13	14	5.341	0.053
		Total system loss	8.865

In the IEEE-14 bus system, bus 2 is attached to generator *G*2 and load *L*2. In desired load sharing calculation, *G*2 has been taken as generator bus so it is assumed that *G*2 is supplying power to load *L*2 directly from the bus 2 itself. Therefore, the above generator scheduling of *G*2 must be added with the demand of load *L*2. So, the generation scheduling of generator 2 becomes, *G*2 = 194.3127 + 21.7 = 216.0127 or 216 MW (say).

C.2. *Calculation of load flow*

Rescheduling generator 2 at 216MW and using Newton-Raphson iterative technique with matlab programming, the load flow solution has been computed and the result is shown in Table 4(d) above.

C.3. *Result Interpretation*

From Table 2(a), it is seen that the total loss for the IEEE-14 bus system was 13.419MW and after applying the RED concept, the loss has been reduced to 8.865MW as shown in Table 4(d). So, the net amount of loss reduction in IEEE-14 bus is 4.554MW.

C.4. *Calculation of Loss Allocations of IEEE-14 bus system*

For the loss allocations, all the procedures as stated earlier have been followed and the result is given in Table 4(e).

Table 4(e) *Loss allocations after loss reduction in IEEE-14 bus system*

Load Buses	2	3	4	5	6	9	10	11	12	13	14	Total
Loss allocations after loss reduction in MW	0.0111	3.6036	1.7092	0.2079	0.3065	1.0545	0.3488	0.1251	0.2256	0.5392	0.7321	8.8636

D. Case study of IEEE-30 bus system using RED concept

D.1 *Calculation of [F_{LG}], [D_{LG}], [R_{LG}] and [DGS] matrices*

Taking the line data from reference [27] and using the procedure as described above, the matrices [D_{LG}], [R_{LG}], and [*DGS*] are calculated and presented in Table 5(a), Table 5(b) and Table 5(c), respectively.

Table 5(a) [DLG] matrix of IEEE-30 bus system

	Load Bus No.	Generator Sharing		Load Bus No.	Generator Sharing	
		G1	G2		G1	G2
$[D_{LG}] =$	3	0.4017	0.5991	17	0.2304	0.7698
	4	0.2756	0.7247	18	0.2377	0.7627
	5	0.1032	0.8968	19	0.2340	0.7663
	7	0.1659	0.8342	20	0.2321	0.7682
	8	0.2097	0.7906	21	0.2268	0.7734
	10	0.2263	0.7739	23	0.2374	0.7629
	12	0.2500	0.7506	24	0.2289	0.7714
	14	0.2468	0.7537	26	0.2218	0.7784
	15	0.2438	0.7566	29	0.2174	0.7828
	16	0.2400	0.7603	30	0.2174	0.7828

Table 5(b) [R_LG] matrix of IEEE-30 bus system

	Load Bus No.	Relative location of Load node with respect to Generator node		Load Bus No.	Relative location of Load node with respect to Generator node	
		G1	G2		G1	G2
$[R_{LG}] =$	3	0.5991	0.4017	17	0.7698	0.2304
	4	0.7247	0.2756	18	0.7627	0.2377
	5	0.8968	0.1032	19	0.7663	0.2340
	7	0.8342	0.1659	20	0.7682	0.2321
	8	0.7906	0.2097	21	0.7734	0.2268
	10	0.7739	0.2263	23	0.7629	0.2374
	12	0.7506	0.2500	24	0.7714	0.2289
	14	0.7537	0.2468	26	0.7784	0.2218
	15	0.7566	0.2438	29	0.7828	0.2174
	16	0.7603	0.2400	30	0.7828	0.2174

Table 5(c) [DGS] matrix of IEEE-30 bus system

	Load Bus No.	Generator Scheduling		Load Bus No.	Generator Scheduling	
		G1	G2		G1	G2
$[DGS] =$	3	0.9640	1.4377	17	2.0740	6.9280
	4	2.0945	5.5077	18	0.7605	2.4406
	5	9.7190	84.4819	19	2.2231	7.2795
	7	3.7832	19.0208	20	0.5106	1.6899
	8	6.2918	23.7171	21	3.9682	13.5351
	10	1.3123	4.4887	23	0.7597	2.4414
	12	2.8004	8.4062	24	1.9910	6.7111
	14	1.5304	4.6731	26	0.7763	2.7243
	15	1.9993	6.2044	29	0.5218	1.8786
	16	0.8401	2.6612	30	2.3045	8.2972
				TOTAL	47.2247	214.5245

Bus 2 is attached to generator $G2$ and load $L2$. In desired load sharing calculation, $G2$ is taken as the generator bus. Thus, $G2$ is supplying power to load 2 directly from the bus 2. Therefore, the above generator scheduling of $G2$ must be added with the demand of load 2. So, the generator scheduling of $G2$ = 214.5245 + 21.7 = 236.2245 or 236.3 MW (say).

D.2. *Calculation of load flow*

Taking generation of $G2$ as 236.3MW, the load flow solution is carried out using Newton-Raphson iterative technique with Matlab program and the result is shown below in Table 5(d).

Table 5(d) Receiving end active line flows and active line loss of IEEE-30 Bus

Line		Receiving end active power in MW	Active loss in MW	Line		Receiving end active power in MW	Active loss in MW
From	To	P_R	P_L	From	To	P_R	P_L
1	2	7.705	0.151	13	12	0.042	0.000
1	3	49.847	1.093	12	14	7.698	0.073
2	4	58.932	1.942	12	15	17.207	0.209
2	5	84.714	3.372	12	16	6.653	0.048
2	6	70.460	2.873	14	15	1.455	0.005
3	4	47.172	0.292	15	18	5.707	0.036
4	6	55.049	0.372	15	23	4.661	0.029
4	12	43.024	0.000	16	17	3.157	0.010
7	5	9.476	0.082	18	19	2.509	0.004
6	7	32.356	0.278	20	19	6.997	0.018
6	8	29.449	0.104	22	21	1.744	0.001
6	9	28.249	0.000	22	24	5.704	0.044
6	10	16.142	0.000	23	24	1.486	0.005
6	28	18.919	0.061	25	24	1.498	0.009
28	8	0.531	0.000	25	26	3.484	0.044
9	11	0.016	0.000	27	25	5.030	0.027
9	10	28.253	0.000	28	27	18.377	0.000
10	20	9.214	0.084	27	29	6.092	0.086
10	17	5.840	0.016	27	30	6.926	0.161
10	21	15.691	0.110	29	30	3.675	0.033
10	22	7.586	0.052	Total system loss			11.727

D.3. *Result Interpretation*

Total system loss of IEEE-30 bus was 17.594MW as shown in Table 3(a). Now after applying RED method, the total system loss has been reduced to 11.727MW as shown in Table 5(d). So, there is a loss reduction of 5.867MW.

D.4. *Calculation of Loss Allocations of IEEE-30 bus system*

For the loss allocations, all the procedures as stated earlier have been followed and the results are given in Table 5(e) for the load buses 2 to 16 and in Table 5(f) for 17 to 30. The total loss of the system is shown in Table 5(f).

Table 5(e) Loss allocations after loss reduction in IEEE-30 bus system for load buses 2 to 16

Load Buses	2	3	4	5	7	8	10	12	14	15	16
Loss allocations after loss reduction in MW	0.0134	0.0526	0.2373	3.9762	1.1154	1.3085	0.2318	0.3489	0.2549	0.3593	0.1348

Table 5(f) Loss allocations after loss reduction in IEEE-30 bus system for load buses 17 to 30

Load Buses	17	18	19	20	21	23	24	26	29	30	Total
Loss allocations after loss reduction in MW	0.3820	0.1611	0.4954	0.1088	0.8258	0.1600	0.4805	0.2168	0.1393	0.7173	11.7201

V. COMPARATIVE STUDY OF LOSS ALLOCATIONS

The comparative figures of loss allocations before and after loss reduction by RED concept for IEEE-14 and IEEE-30 bus systems are presented in Table 6(a) and Table 6(b), respectively.

Table 6(a) Comparative figure of IEEE-14 bus system

Load Bus No.	Loss allocations before loss reduction in MW	Loss allocations after loss reduction in MW
2	0.4849	0.0111
3	5.5608	3.6036
4	2.4522	1.7092
5	0.3078	0.2079
6	0.4503	0.3065
9	1.5103	1.0545
10	0.4785	0.3488
11	0.1725	0.1251
12	0.3031	0.2256
13	0.7206	0.5392
14	0.9489	0.7321
Total	13.3899	8.8636

Table 6(b) Comparative figure of IEEE-30 bus system

Load Bus No.	Loss allocations before loss reduction in MW	Loss allocations after loss reduction in MW
2	0.5570	0.0134
3	0.0836	0.0526
4	0.3603	0.2373
5	6.2655	3.9762
7	1.5717	1.1154
8	1.8647	1.3085
10	0.3392	0.2318
12	0.5306	0.3489
14	0.3531	0.2549
15	0.4951	0.3593
16	0.1946	0.1348
17	0.5417	0.3820
18	0.2150	0.1611
19	0.6669	0.4954
20	0.1502	0.1088
21	1.1588	0.8258
23	0.2140	0.1600
24	0.6391	0.4805
26	0.2832	0.2168
29	0.1843	0.1393
30	0.9215	0.7173
Total	17.5901	11.7201

VI. CONCLUSION

This paper analyzes the importance of loss allocation and loss reduction in deregulated power system. It finds the mismatch in loss allocation by some of the widely used methods and proposes a new formula for loss allocation. The new proposed formula is based on the physical flow of power. The main logic behind this formula is the segregation of each lossy line into as many sub-lines depending upon the numbers of loads attached to it, either directly or indirectly. Then total loss of the common line is divided among the loads with proportionate to their power receiving. Hence, it gives more justification to the load attached into the system. The new formula is used in a six-bus system and proves its viability. In addition it is also applied to IEEE-14 and IEEE-30 bus systems to allocate the losses among different loads. The relative electrical distance concept is used to reduce the loss in both IEEE-14 and IEEE-30 bus systems. In both the cases a significant reduction in loss is obtained. After reduction in system loss, again the loss allocations for the different loads are carried out and the results show a sufficient loss reduction in almost all the load buses. As the tariff and other economic considerations are mainly based on active power loss so, the efforts may be made to deal with these problems using the proposed method.

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