Transmission Loss Allocation among Generators and Loads

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***Abstract:** Transmission lines are important in power system to transfer power for different loads from generators. This paper presents allocation of real power losses on transmission lines between generators and loads. Partial load losses are caused in lines due to load currents with respective loads. The generator circulating losses are caused due to the production of circulating current between generators. This paper also calculates the network losses present in the system. This paper investigates on loss distribution in the entire system. The entire algorithm is tested with simple 6-bus dc, ac systems and also analyzed on standard IEEE- 6bus and IEEE 30 bus system. Test result shows the efficacy of the algorithm and also a comparison is made with the result of Newton Raphson load flow procedure.*

***IndexTerms:** Transmission lines, Real power loss allocation, Load loss, Circulating power loss, Network Loss.*

I. INTRODUCTION

Transmission loss plays a major role in power system network to maintain system planning and operation because a substantial portion of the entire power transfer used along the entire network (4%-6%) is indulged. The present day's energy markets are being more competitive by adding an un usual aspect of engrossment in transmission losses and that is by which the system losses and its cost [1] are assigned to the attentive consumers. Transmission loss allocation (TLA) has been focused based on the significance of industries and academia's for the utter most decade years or so,and alotmanyen trusted methods[2] were developed tofindeachandeverycountenanceofTransmissionlossallocationinthesystem. Prior to the opportunity of purpose is considered, market models are available based on the techniques for TLA amongst a single energy market affiliated either with a pool [3], [4] or bilateral transactions [5],[6].

Several Methods were adopted for Transmission loss allocation based on loads, generators, or both [7]. Transmission loss allocation techniques as a vast series of interpretive procedures in which some of them are Tracing of power flow, either active power [8] or complex power [9], [10]. Components of losses that are collaborated with variety of buses are obtained by using Z-bus method [11]. Each loss of the line expressed as current injections are given by developing a modified Y-bus approach [12], [13]. Loss allocation is done by computation of generalized generator distribution factors & shift distribution factors [14]. Comparative analysis on most common practical algorithms is discussed [15]. Loss proportion of particular fractional flow in the entire loss of the line is retrieved by the novel works depending upon the circuit theory and orthogonal projection of fractional flows on the entire current which is due to the proper allocation of transmission losses [16]. Recently, a technique is suggested for TLA by consolidating the fractionalderivativesofthetransmissionlosswithreferencetonodepoint,besides path of the transaction is proposed in [17].

However in all these methods loss allocation is being caused by the line flow and power flow between generators to loads. In fact, flow of current occurs through a path when a direct flow of energy occurs between the two nodes of distinct potential differences. The circulating currents obtained in the midst of the generators via that network, which are subjected to the transformer network create conducting paths between generators and distinct potential differences. Due to the over lapped current flow from generators to loads, these currents which are nothing but circulating currents will obviously create an appended loss in the system which can't be applied to the current flow due to the loads.

Allocationofrealpowerlossesontransmissionlinesbetweengeneratorsandloadsisgiveninthispaper. Allocation of real losses on transmission line is based on partial load losses due to load currents; losses due to circulating currents between generators and also the network losses in the system. This method is tested by considering simple 6-bus dc and ac systems, and also on standard IEEE-6 bus and IEEE 30 bus system. Test result shows the efficacy of the algorithm and also made comparison with Newton Raphson method load flow result.

Basic theory of transmission loss is presented in section-II. The transmission loss allocation concept isillustratedinsection-III.Simulationtestresultsarepresentedinsection-IVandconclusionispresented in section-V.

II. BASIC THEORY OF TRANSMISSION LOSS

Beginning with the standard network equations in YBUS form

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (1)$$

Here, notation G represents the generator components and L represents the load components that are described in [11]. Using the basic concept the transmission losses were calculated. From above Y bus matrix equations find the load voltage expression are given below.

$$V_L = Z_{LL} \times I_{LL} - Z_{LL} \times Y_{LG} \times V_G \quad (2)$$

Where $Z_{LL} = (Y_{LL})^{-1}$ substituting V_L expression in the generator current I_G equation yields

$$I_G = (Y_{GG} - Y_{GL} Z_{LL} Y_{LG}) V_G + Y_{GL} Z_{LL} I_L \quad (3)$$

The total real and imaginary power injected is

$$S_G = V_G^T I_G^* \quad (4)$$

$$S_G = V_G^T (Y_{GG} - Y_{GL} Z_{LL} Y_{LG})^* V_G^* + V_G^T Y_{GL}^* Z_{LL}^* I_L^* \quad (5)$$

$$S_L = V_L^T I_L^* \quad (6)$$

$$S_L = I_L^T Z_{LL}^T I_L^* - V_G^T Y_{LG}^T Z_{LL}^T I_L^* \quad (7)$$

$$S_{total} = S_G + S_L \quad (8)$$

The above equation can also be represented in DC case by considering only real parts. These equations are used to calculate the losses directly by equation (8). Here the paper contributes the calculation of losses depends on load, generators and network parameters. Using this above fundamental theory concept the loss allocation can be determined. These contributions are explained briefly in the next section.

III. TRANSMISSION LOSS ALLOCATIONS

The transmission losses are classified based on different factors. One of the factors is dependent on generators produce partial losses due to the differences between their voltages. Other is Load losses due to depending on their load currents. The losses are generated by the network itself, which may be + ve or else -ve, based on the controlling specifications. Accordingly, the losses need not to be authentic depending upon the adoption that the losses are due to loads only. The losses may share among the entire systemas50/50,or some different proportion,lossdivisionamongthegeneratorsandloadsmaynotbereasonablein rightful derivation of losses. The entire procedure for loss allocation is discussed [18]. This section gives brief explanation on the method of allocating the real losses on the transmission network with different components like loads, generator, or even the ISO for transmission loss. The loss allocation procedures are explained for three factors as shown below.

A. Load Loss

Firstly, the transmissions losses are generated by a load through a line are determined. The line current, flows not only by single load but also by the other loads, then the calculation of load contributions is determined by current flowing in the line due to that load to the entire current over that particular line. Loss due to the load is there after obtained as a loss division assigned to the line. Appropriate rationing of Y_{BUS} gives power system equation and it is defined in below equation as[21]-[22].

$$I = YV \quad (9)$$

$$I_G = Y_{GG}V_G + Y_{GL}V_L \quad (10)$$

$$I_L = Y_{LG}V_G + Y_{LL}V_L \quad (11)$$

Here suffix G represents generator components and L represents load components that are described in [11].

$$V_L = Z_{LL}I_L \quad (12)$$

$$V_G = O_{NGxNL}I_L \quad (13)$$

Here, NG and NL are the nodes of generator and load:

$$I_b = [Y_{bus}][A^T]V_{bus} \quad (14)$$

The equation for branch current is

$$I_{br}^{1} = K.\ \mathrm{Diag}[I_L] \quad (15)$$

Where, K is current distribution factor

$$K = [Y_{bus}][A^T]\hat{I}^{0_{NG\times NL}Y_{LL}^{-1}}] \quad (16)$$

$$\Delta P_{ij} = r_i[I_{brij}^{L}]\ [I_i] \quad (17)$$

Where, ΔP_{ij} is branch Power loss,

$$[I_{brij}^{L}][I_i] = R(I_{brij}^{L})R(I_i) + \mathrm{Img}\ (I_{brij}^{L})\ \mathrm{Img}\ (I_i) \quad (18)$$

The total power loss due to individual loads, is resolved as the sum of the losses contributed by each line load and is obtained as below

$$P_{\text{load loss}} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{ij} \quad (19)$$

m = total number of loads

n = total number of branches

P_{ij} = power losses in j^{th} branch due to i^{th} load.

B. CIRCULATING CURRENT LOSS DUE TO GENERATORS

By equating load currents to zero, circulating currents are obtained

$$[I_G^{cir}] = [[Y_{GG}] - [Y_{GL}]\ .\ [Y_{LL}]\ .\ [Y_{LG}]][V_G] \quad (20)$$

Load nodes are

$$[V_L] = -[Y_{LL}]^{-1}[Y_{LG}].[V_G] \quad (21)$$

The node potential difference vector can be categorized in terms of circulating current of the generator as below,

$$\begin{bmatrix} V_G \\ V_L \end{bmatrix} = \begin{bmatrix} Z_{GG} \\ -Y_{LL}^{-1}Y_{LG}Z_{GG} \end{bmatrix}[I_G^{cir}] \quad (22)$$

Where,

$$Z_{GG} = [[Y_{GG}] - [Y_{GL}][Y_{LL}]^{-1}.[Y_{LG}]]^{-1} \quad (23)$$

$$[I_{br}^{cir}] = [Y_{bus}][A^T]\hat{I}^{Z_{GG}}_{-Y_{LL}^{-1}Y_{LG}Z_{GG}}].\ \mathrm{diag}[\ I_G^{cir}] \quad (24)$$

Power loss,

$$\Delta P_{ij} = r_i[I_{brij}^{cir}] \cdot [I_i] \quad (25)$$

$$[I_{brij}^{cir}] \cdot [I_i] = R(I_{brij}^{cir})R(I_i) + \mathrm{Img}\ (I_{brij}^{cir})\ \mathrm{Img}\ [I_i] \quad (26)$$

The total power loss due to individual loads, is resolved as the sum of the losses contributed by each load in each line is given below as

Where, m= total number of generators

n=total number of branches

$$P_{\text{gen circulating loss}} = \sum_{i=1}^{m}\sum_{j=1}^{m} P_{ij}\ \mathrm{cir} \quad (27)$$

'P_{ij}' = power losses in j^{th} branch due to i^{th} generator.

C. NETWORK LOSS

A small percentage of losses are defined by network parameters. The losses are +ve/-ve in nature depends on network condition, it will add to total losses.

$$S_{Net} = (V_G^T Y_{GL}^* Z_{LL}^* I_L^*) - (V_G^T Y_{LG}^T Z_{LL}^T I_L^*) \quad (28)$$

D. Total Losses

The total losses are calculated by adding loss powers obtained due to circulating currents between the generators, due to load and network losses.

$S_{totallosses} = P_{gencirculatingloss} + S_{Net} + P_{loadloss}$ (29) The entire algorithm is simulated with test cases like DC and ACanalysis.

IV. Simulation Results

A contribution of detailed study and evaluation of [18] is carried out by considering its algorithm and is additionally tested on IEEE 6 bus ward and hale test system with and without considering transformers. Besides the comparative analysis is performed amongst present allocation method algorithm and the conventional Newton Raphson load flow procedure for IEEE 6busand 30 bus systems and it is demonstrated below in detail.

a. Simple 6-busSystem

To test the loss allocation algorithm, consider a simple 6 bus system. The system configuration and parameters are considered in both supplies of dc and ac cases as shown in Figure 1. The Line resistances are considered in pu values are given in circuit diagram. The bus 1, 2, and 3 are generator buses with constant voltages. Buses 4, 5, and 6 are load buses with load currents of 1, 0.8, and 1.2 pu, respectively. The simulation tests are conducted by considering different cases like dc and ac with equal and unequal voltages at the generators. The results are tabulated for both dc and ac cases respectively.

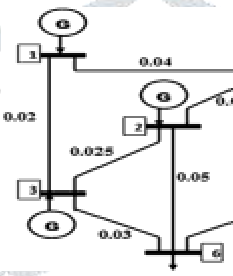

Figure 1: a simple 6-Bus system

A. DC Case

(a) *With Equal GeneratorVoltage*

The results obtained from Table 1 shows that during equal case the total losses are dependent on the load nodes 4, 5 and 6 only and circulating losses, network losses are absent. Until the generator's voltages are the results obtained from Table 1 shows that during equal case the total losses are dependent on the load nodes 4, 5 and 6 only and circulating losses, network losses are absent.

Table 1: Branch partial currents and Branch partial loss analysis with equal voltage case

Branches	*Branch Current* I_{BR} *(pu)*	*Branch Power Loss* P_{BR} *(pu)*	*Partial branch currents and partial branch loss due to load*					
			I4		*I5*		*I6*	
			Ib4	*Pb4*	*Ib5*	*Pb5*	*Ib6*	*Pb6*
1-3	0	0	0	0	0	0	0	0
2-3	0	0	0	0	0	0	0	0
1-4	0.921	0.0340	0.589	0.0217	0.277	0.0102	0.054	0.0020
2-4	0.491	0.0181	0.314	0.0116	0.148	0.0055	0.029	0.0011
3-6	0.991	0.0295	0.060	0.0018	0.233	0.0070	0.697	0.0208
2-6	0.595	0.0177	0.036	0.0011	0.140	0.0042	0.418	0.0125
4-5	0.412	0.0170	–0.09	–0.004	0.426	0.0176	0.083	0.0034
5-6	–0.38	0.0187	–0.09	0.0047	–0.37	0.0181	0.083	–0.0040
Total loss		0.1351	Pb4	0.0369	Pb5	0.0625	Pb6	0.0357

Until the generator's voltages are identical, the losses assigned to a load do not rely on the current path.Thereforetheloadlossdoesnotdependbothonthegeneratorfurnishingthatparticularloadandalso the current path existing among the generator and load. Simply, it can be described as the loss due to the power within any two different points is same as the product of the voltage and current streaming in the midst of the two points.

(b) *Un Equal Voltages at the GeneratorsCase*

Table 2: Branch partial currents and Branch partial loss analysis With unequal voltage case

Branches	*Branch Current* I_{BR} *(pu)*	*Branch Power Loss* P_{BR} *(pu)*	*Partial branch currents and partial branch loss due to load*			*Circulating currents losses between the generators*
			Pb4	*Pb5*	*Pb6*	$I_c . I_{br} . R$
1-3	0	0	0	0	0	0.0125
2-3	0	0	0	0	0	0.400

1-4	0.922	0.034	0.022	0.010	0.002	0.0320
2-4	0.491	0.018	0.012	0.006	0.001	–0.0181
3-6	0.992	0.03	0.002	0.007	0.021	0.1307
2-6	0.595	0.018	0.001	0.004	0.013	0.0011
4-5	0.413	0.017	–0.004	0.018	0.003	–0.0079
5-6	–0.387	0.019	0.004	0.018	–0.004	0.00123
Total loss		0.136	0.037	0.063	0.036	0.6751

Consider a case with unequal distribution of voltages at the buses1, 2 and 3 are given, as bus1iskept constantas1pu whereas potential difference at bus 2 is decreased to 0.95pu and bus3 is increased to 1.05pu. During this case both partial load losses on each branch due to load and circulating losses are also obtained. Load losses are similar when compared to equal generator voltage case, but the circulating currents perturb the distribution among its branches. Nevertheless, the concern regards with percentage of loss produced by every particular load and also the fraction of loss assigned to generators in the entire loss. The results tabulated in Table 2 show that the losses due to the circulating currents and the loss assigned to the loads can be totally separated.

B. AC CASEANALYSIS

Unlike in the dc system, here in the ac system reactive power is taken into account which creates variations among transmitted and received power leading to network mis-match losses besides losses allocated to load and generator. The load currents and generator voltages are considered as I_4=-1+j0.5,I_5=-0.8+j0.2, I_6=-1.2+j0.15,V_1=1+j0,V_2=-0.95-j0.05 andV_3=1.05+j0.06 respectively. The line impedances are considered in p.u. The ac system is analyzed in three cases, the base case is B in which each and every line is considered to have X/R ratio as3. The remaining two cases are considered from case B by modifying the X of line 1-4 alone, increased to 0.18 p.u for case A and decreased to0.06p.u for case C.

Table 3: active and Reactive Power loss consumption for different AC cases

	CASE A		*CASE B*		*CASE C*	
	Del P	*Del Q*	*Del P*	*Del Q*	*Del P*	*Del Q*
Load	0.150	0.493	0.148	0.443	0.153	0.370
Gen	0.151	0.454	0.152	0.455	0.153	0.456
Net	–0.004	0.002	0.000	0.0000	0.008	-0.003
Total	0.297	0.949	0.3	0.898	0.314	0.823

The partial components of load loss and circulating current loss are calculated using above procedures. The entire loss is calculated by the addition of all line flows from buses and addition of real and reactive power losses. By considering the difference between sums of total load loss components, circulating current loss components and the total loss, the network loss is determined. Transmission Loss components are listed in Table 3 for the three cases. From the executions in the above table it is clear that, in Case B, when the X/R ratio is similar for all the lines, zero net work losses are observed while in Case A and Case C because of the change in a line1-4 non zero network loss components are observed. Consequently, in Case A, the network is more reactive because of the positive reactive power while the active power is negative because of the lower X/R ratio when compared to the remaining lines whereas the counter part is justified in CaseC.

When the current distribution in a load is similar to that of the pure resistive case, there exists minimum load loss elements, but by modifying the X/R ratio current distribution differs resulting in the increase of load losses. Moreover, circulating current loss of the generators are not directly proportional to X/R ratio, therefore it is higher for Case C when the X/R ratio is reduced and vice-versa is applicable for Case A. The final and the most important conclusion that can be made from the above executions is that the losses obtained by the network mismatch comprise a very small share of the total loss.

C. TEST CASE OF IEEE 6BUS SYSTEM

Consider a standard IEEE-6bus Ward and Hale test system and the system parameters are considered [19].The above system is tested with allocation of losses algorithms and results are compared with Newton's Raphson method. This test system is considered with and without transformers. The result shows that loss allocation methods give fewer amounts of losses when comparing to N.R method. In all case studies with and without transformer in standard IEEE system the loss allocation method gives accurate results.

Table 4: IEEE-6 bus system results with and without transformer

	Without Transformer		*With Transformer*	
	Allocation of losses method (MW)	*Newton's Raphson Method (MW)*	*Allocation of losses method (MW)*	*Newton's Raphson Method (MW)*
Load loss	12.88		10.81	
Gen loss	0.29	18.1242	1.43	17.0068
Net loss	4.609 e-15		2.74 e-15	
Total loss	13.1629	18.1242	12.2445	17.0068

D. TEST CASE OF IEEE 30 BUSSYSTEM

Consider a standard IEEE-30 bus and the system parameters are assumed [20]. The system is tested with allocation of losses algorithms and results are compared with Newton's Raphson methods. The result in the table shows that the loss allocation method gives fewer amounts of losses when compared to N.R method. The network losses will either be positive ornegative. Load losses in Newton Raphson load flow procedure are retrieved by solving the load flows and furthermore, the total losses are estimated by power flow injections from generator to load.Nevertheless, this present proposed loss allocation method characterizes the individual losses depending upon their origin i.e. generators, loads and network parameters and thereafter gives the total losses. Thus, the total losses in the allocation ofloss method and Newton Raphson method are correlated for the above cases and the comparative statement shows that the loss allocation method discussed in the paper is efficient in the calculation of losses and this method claims to be an accurate method for loss allocation insystem.

Table 5: IEEE-30 bus system results

	Allocation of losses method (MW)	*Newton's Raphson Method (MW)*
Load loss	3.3245	15.124
Gen loss	8.2642	
Net loss	–5.4504	
Total loss	6.1383	15.124

V. CONCLUSION

Allocation of transmission loss between generators and load is proposed in this paper. Most of the methods calculate losses directly using line flow formulas from existing methods like G.S. method, N.R. method. Loss allocation is done by finding losses that depend on loads and generator circulating currents and also focuses on network losses from line parameters. In all case studies considering simple dc & ac 6-bus system, IEEE 6-bus system including and excluding transformers and IEEE 30-bus system gives accurate results by this method.

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