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Deregulated Power Market: Loss Allocation by Using Generators Voltage Difference in Electric Power Industries

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Abstract*:* In this country development of electrical power system particular for transmission line expansion and interconnection of neighbouring power system try to improve system security and economic operation. Due to this province in large scale power system, operation , control and expansion planning for particular system become challenging task to reduce transmission loss as minimum as possible for optimal operation. Now days, One of the major problems in opened power markets is loss division. In this paper, a different method for allocating and identify real power transmission losses to pool market participants is proposed. The proposed method is fundamentally based on decomposition of loss function and different in generators voltage concept. The method has been implemented and tested on several networks and IEEE 5-bus test system sample summarized in the paper. The results show that the method is inclusive and fair to splitting the energy losses of a deregulated power market to its participants.

Keywords: Differentiate of Transmission loss, Basic Concept, Load loss, Loss due to Difference in voltage at generation point.

I. INTRODUCTION

In recent two decades, the electrical power systems of many countries have been subjected to deregulation. After deregulation, competition has been introduced with respect to productions, but transmission system is still performed by regional monopoly. Changing prevalent rules in power system and transmission policy with wide availability would make the calculation of loads and generators participation rate more visible in active and reactive power loss in network. [1] In monopoly markets, generation and transmission is under supervision of a system, so expenses of transmission loss cost could be a part of generation expenses and therefore there is no need to allocate cost to loads and generators and find the share of each in total cost. But, in deregulated market the problem is that **who pays the expenses of this cost?** That is the key issue for all markets participants. The rate of this loss is significant as it includes 5-10 % of total generation. The electric power industry is experiencing important changes brought about by the deregulation. Electric power generators and users engage in power transactions which take place over the transmission system and hence create losses [2].

Transmission loss allocation is not an easy task. Even in a simple two node system with one generator supplying a single load, loss separation between the generator and the load has to be agreed upon as there is no physical measurement or mathematical method that determines the loss shares in a unique manner. In a real system, matters get more complicated because of two facts. The first is that the determination of the line flows caused by each load through each transmission line has a good degree of arbitrariness. The second is that the transmission line loss is a nonlinear function of the line flow, and hence cannot be separated between partial flows through the same line in a unique convincing way. The difficult task is to selecting a loss separation method where absence of a standard means for comparing the different methods.

A number of loss allocation schemes have been presented to allocate the system losses to generators/loads in a pool market or to individual transactions in a bi-lateral contracts market. Based on different assumptions and approximations there are mainly three families of schemes: Pro rata methods, incremental transmission loss (ITL) methods, proportional sharing procedures, game theory.

Method based on Pro rata: It is clear that this method is totally reliant on the power injections at buses and independent of the network topology. Losses are distributed across all buses, according to their level of generation or consumption only. Two loads in different locations but not fair with two identical demands, which locate near generators and far away from generators respectively, to be allocated with the same amount of losses [3, 4]. This type of methods is simple to understand and implement. However, the network topology is never taken into account.

The proportional sharing method has been introduced by J. Bialek in. This method is based on power flow tracing and relies on the assumption that a network node is a perfect mixer of incoming flows. For each node, every out coming active power flow is proportionally composed of the incoming flows. For each line, the losses are proportionally divided to the incoming flows into this line. The problem with this approach, however, is that the distribution of power flows is built on the proportional sharing principle, which lacks physical and economic justification. This departure from electrical behaviour of the network may mean that proposed strategies to reduce losses may not be technically satisfactory [5, 6].

ITL methodologies use the sensitivities of losses to bus injections to separate the losses to generators and loads.

The paper [10] provides analysis and test results from a practical implementation of an incremental division procedure in the Norwegian electric system. The paper [11] solves a system of differential equations by using numerical integration where a distributed slack bus concept is used. ITL (Incremental Transmission Losses) technique, allocate the system losses to network participant through assigning a coefficient known as ITLs to each one that represent the total network losses sensitivity to that particular user power injection [12, 13]. The ITL methods depend on the selection of the slack bus and also the slack bus is separated with no losses.

A modified Y bus is used to determine the relationship between the branch currents and the load/generator current injections allowing the power loss of each line to be expressed in terms of current injections. AC power flow-based injection shift distribution factors are exploited for computing generalized generation distribution factors and generalized shift distribution factors, and these factors are used to allocate transmission losses to each market player [14]. Another loss allocation method is based on the bus impedance Z-bus matrix [9] and allocates transmission losses among loads and generators assuming a pool dispatch. A natural separation of the system losses among the network buses is derived using the loss formula. It does not however account for the interaction between different injections.

This paper presents a method for differentiate of transmission loss is based on separation of the transmission losses into load losses, caused by the flow of load currents only, and losses caused by the differences in voltages at the generation nodes. This is the advance method for transmission loss separation.

II. BASIC CONCEPT AND THEORIES

When two or more generator sets are operated in parallel, a current may circulate between the generators. This current will exist when the internal voltage generated by each generator is slightly different, current will flow out the line leads of one generator, through the paralleling bus and into the second generator. It does not flow into the load, this current, called “circulating current”. A loss produce due to circulating current is called circulating current loss. When circulating currents pass through the generator coils, these currents heat the coils the same way as does the load current,and circulating currents are superimposed on the load current passing through the circuit breaker, circulating currents can cause a breaker to trip as the breaker could notice an actual ampere overload. Currents in excess of the relay getting will actuate the circuit breaker trip mechanism. So the circulating current is also important for consideration for loss allocation method [8].

Transmission loss is decomposed into three components. The first is due to current flow from generators to loads. The second is due to the circulating current between generators. The third is due to network structure.

Consider the DC system shown in Fig. 1 One load bus is fed from two stations at voltages V_1 and V_2 through two lines with resistances r_1 and r_2. Such a simple system is used for the simplicity as well as clarity, but the same results can be proved for more complicated systems.

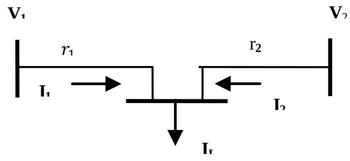


Fig.1: Simple 3 bus dc system

By applying current divider rule

$$I_1 = \frac{r_2}{r_1+r_2} \cdot I_L + \frac{V_1-V_2}{r_1+r_2} \text{ and} \quad (1)$$

$$I_2 = \frac{r_1}{r_1+r_2} \cdot I_L - \frac{V_1-V_2}{r_1+r_2} \text{ and} \quad (2)$$

The losses in line 1 and line 2 can be find out as

$$P_{r1}^{Loss} = \left(\frac{r_2}{r_1+r_2}.\ I_L + \frac{V_1-V_2}{r_1+r_2}\right)^2 . r_1, \text{ and} \quad (3)$$

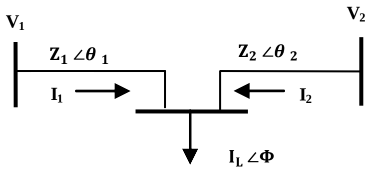
$$P_{r2}^{Loss} = \left(\frac{r_1}{r_1+r_2}.\ I_L - \frac{V_1-V_2}{r_1+r_2}\right)^2 . r_2 \quad (4)$$

And the total loss in the line is sum of the losses in the two lines.

$$P_t^{Loss} = \frac{r_1 r_2}{r_1+r_2}.\ I_L^2 + \frac{(V_1-V_2)^2}{r_1+r_2} \quad (5)$$

The first term of equation (5) is indicates the load loss, and the second term indicate the power loss resulting from circulating current due to the difference between the voltages of the two sources.

The same idea applies in an AC system but with some differences all physical parameters and quantities are complex. Consider the AC simple system of Fig. 2. It is similar to the DC system of Fig.1 except that line impedances, voltages and currents are all complex quantities. Also, the difference between the voltages of the source nodes 1 and 2, V_1-V_2, is a complex quantity with a



magnitude of ΔV and angle δ, i.e. $V_1 - V_2 = \Delta V \angle\delta$

Fig.2: Simple 3 bus ac system

The same steps follow as in the case of DC system, the total power loss in the transmission lines of the AC system can be proved to be as follows.

$$P_t^{Loss} = \frac{|I_L|^2 (Z_1^2.Z_2.\cos(\theta_2) + Z_1\, Z_2^2.\cos(\theta_1))}{|Z_1+Z_2|^2} + \frac{|\Delta V|^2.(r_1+r_2)}{|Z_1+Z_2|^2} + \frac{2|\Delta V||I_L||z_1.z_2|}{|Z_1+Z_2|^2}.\sin(\emptyset-\delta).\sin(\theta_1-\theta_2)$$

(6)

The first term of equation (6) is the load loss, and the second term is show the circulating current loss. The third term is due to the difference of X/R ratio of the two lines

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and can be considered as a sort of impedance mismatch loss. Also, the presence of transformers which have X/R ratio larger than that of the lines gives rise to this term, if the two lines have the same X/R ratio, i.e. θ1 = θ2 = θ, the total loss becomes closely like the case of a DC system.

$$P_t^{Loss} = \frac{|I_L|^2 |Z_1.Z_2|.\cos(\theta)}{|Z_1+Z_2|} + \frac{|V_1-V_2|^2.(r_1+r_2)}{|Z_1+Z_2|^2} \quad (7)$$

The first term of equation (7) determines the load loss and load loss can be determined by short-circuiting the all the sources and letting the load currents alone flow through the network and the second term determines the circulating current loss. It can be calculated by simply letting the load current equal to zero.

III. MATHEMATICAL MODEL

Transmissions losses are divided in two parts are following:

1) Load Loss:

Loss due to load currents are obtained by assuming that all generators act as ideal voltage sources with no circulating currents between them. In such a case, generation nodes are short circuited and the load nodes are considered as current sources [9]. Considering the node equations of the power system, and by proper partitioning of Y_{BUS}, the power system equations can be written as:

$$I=Y\,V \quad (8)$$

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \quad (9)$$

I_G, V_G, I_L and V_L are the current and voltage vectors for generation and load nodes, respectively. Y_{GG} is the self-admittance matrix of generator nodes, Y_{GL} is the mutual admittance matrix between generation and load nodes, Y_{LG} is the mutual admittance matrix between load and generation nodes, Y_{LL} and is the self-admittance matrix of load nodes.

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

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

To determine the current flow through branches due to loads are determined while the voltages at generation nodes are set to zero in (11). In this condition, the load node voltages will be

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

With N_G the number of generation nodes and N_L the number of load nodes, generation node voltages can also be expressed as

$$V_G = 0_{NG\times NL}\ \ I_L \quad (13)$$

The branch currents I_b can be calculated as follows:

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

Where Y_b is the branch admittance matrix, which is a diagonal matrix with its main diagonal elements are the branch admittances. A^T is transpose of the branch to node incidence matrix. To decompose the branch current into its components caused by individual load currents, the current column is replaced by diag (I_L), which is a diagonal matrix having load currents as its main diagonal elements

$$[I_{br}^L] = K_{.}\ \text{diag}[I_L] \quad (15)$$

Where, $K = [Y_{br}]\ [A^T] \begin{bmatrix} 0_{N_G\times N_{Load}} \\ Y_{LL}^{-1} \end{bmatrix}$

K is the load current distribution factors matrix, where k_{br}^L is the fraction of the current of load L that flows through branch b, that is, $I_{br}^L = k_{br}^L . I_i$

$[I_{br}^L]$ is $N_{br}\times N_{Load}$ matrix with its ij[th] element equals the current flowing in the i[th] branch due to the current injection of the j[th] load. The summation of each row gives the total branch current due to all loads. Using this total branch current and the resistance of the line, the power loss through this line can be determined.

Using the partial currents, elements of the row, the loss due each load through this line can be determined using the equation of loss allocation [10].

$$\Delta P_{ij} = r_i\ [I_{br\,ij}^L] \bullet [I_i] \quad (16)$$

Where,

ΔP_{ij} = the power loss in branch i due to load at node j,

$I_{br\,ij}^L$ = the current through branch i due load at node j,

I_i = the current through branch i due to all loads,

• = the dot product of a vector defined as follows:

$$I_{br}^L \bullet I_i = \Re(I_{br}^L)\Re(I_i) + \Im(I_{br}^L)\Im(I_i)$$

$\Re$= real part of an expression

$\Im$= imaginary part of an expression

2) Loss due to Difference in voltage at generation point:

Another loss can be obtained by voltage difference at generator node during operating condition which is known as circulating current loss. The generator circulating current is obtained by setting the load currents to zero in equation (9), and the generator voltage as obtained the from power flow solution. The generator circulating current is calculated as follows.

$$[I_G^{cir}] = [[Y_{GG}]-[Y_{GL}].\ [Y_{LL}]^{-1}.\ [Y_{LG}]][V_G] \quad (17)$$

The voltage vector of load nodes is determined as,

$$[V_L] = -\ [Y_{LL}]^{-1}.\ [Y_{LG}].\ [V_G] \quad (18)$$

The node voltage vector in this case can be written in terms of the generator circulating current as,

$$\begin{bmatrix} V_G \\ V_L \end{bmatrix} = \begin{bmatrix} Z_{GG} \\ -Y_{LL}^{-1}.Y_{LG}\ .Z_{GG} \end{bmatrix} [I_G^{cir}] \quad (19)$$

So,

$$[Z_{GG}] = [[Y_{GG}]-[Y_{GL}]\ [Y_{LL}]^{-1}\ .[Y_{LG}]]^{-1} \quad (20)$$

The branch current due to the generators' circulating current can thus be obtained as follows.

$$[I_{br}^{cir}] = [Y_{br}][A^T] \begin{bmatrix} Z_{GG} \\ -Y_{LL}^{-1}.Y_{LG}\ .Z_{GG} \end{bmatrix} .\text{diag}[I_G^{cir}] \quad (21)$$

$[I_{br}^{cir}]$ is $N_{br}\times N_G$ matrix with its ij[th] element equals the current flowing in the i[th] branch due to the circulating current of j[th] generator. The summation of each row equals the total current flowing in the branch due to the circulating current of the generators.

The circulating current losses in each branch due to each generator can be calculated the same way as for the load losses using (16).

$$\Delta P_{ij} = r_i\ [I_{br}^{cir}] \bullet [I_i] \quad (22)$$

Where,

ΔP_{ij} = the power loss in branch i due to load at node j,

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I_{br}^{cir} =the branch current due to the generators' circulating current,

I_i = the current through branch i due to all loads,

• = the dot product of a vector defined as follows:

$$I_{br}^{cir} \bullet I_i = \Re(I_{br}^{cir})\Re(I_i) + \Im(I_{br}^{cir})\Im(I_i)$$

$\Re$= real part of an expression

$\Im$= imaginary part of an expression

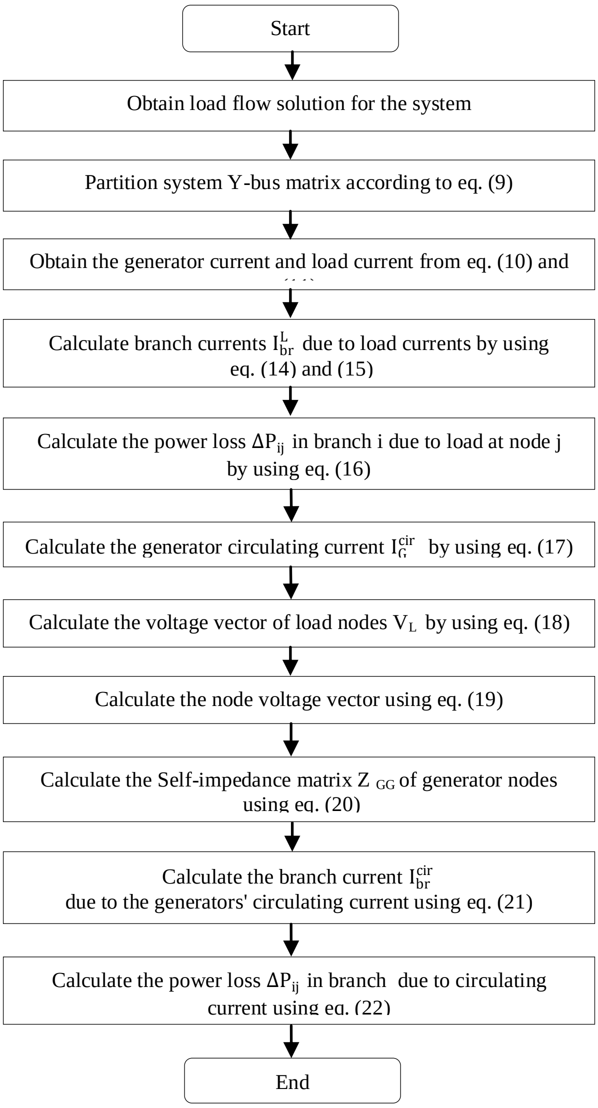

Fig.3:-Flow chart of real power loss division method

IV TEST SYSTEM

The simple 5 bus system with Bus and line data is shown in table I and II. In the proposed method separating load losses and circulating current losses. In the first case the generation at bus 2 is changed while loads are kept unchanged. The changes in bus 2 generation are made according to the calculated circulating power between the two generators. Load losses, circulating current losses and the circulating power between the two generators are determined as proposed. The generation on bus 2 is then changed by amount equal to and opposite to the circulating power, and load flow solution for the new condition is obtained as well losses and circulating power. These results are shown in table III.

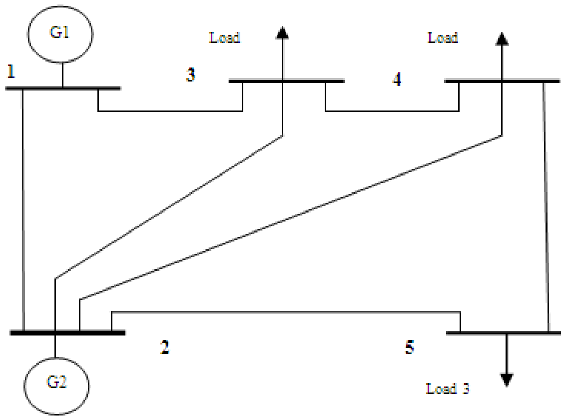

Fig.4: 5- Bus test system

Table I: BUS DATA FOR THE 5 BUS SYSTEMS

Bus No	Bus Type	Generation		Load		Voltage (pu)
		P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	
1	Slack	---	---	0	0	1.06
2	PV	40	0	0	0	1.045
3	PQ	0	0	20	15	1.0
4	PQ	0	0	50	30	1.0
5	PQ	0	0	60	40	1.0

Table II: LINE DATA FOR THE 5 BUS SYSTEM

Line		R(pu)	X(pu)	B_{sh}(pu)
From	To			
1	2	0.02	0.06	0.030
1	3	0.08	0.24	0.025
2	3	0.06	0.18	0.020
2	4	0.06	0.18	0.020
2	5	0.04	0.12	0.015
3	4	0.01	0.03	0.010
4	5	0.08	0.24	0.025

Table III: DIFFERENT LOSSES FOR DIFFERENT OUTPUTS OF GENERATOR 2

P_{G2}	*Total Loss (MW) By N-R Method*	*Load loss (MW)* P_L	*Circulating current Loss (MW)* P_C	*Total Loss (MW)* P_L+P_C	*Circulating Power*	
					G_1-G_2 *(MW)*	G_2-G_1 *(MW)*
40	4.555	3.7049	0.8499	4.5548	74.8751	-74.0361
70	4.041	3.7049	0.3364	4.0413	44.1789	-43.8534
90	3.874	3.7049	0.1688	3.8737	23.9004	-23.7425
100	3.841	3.7049	0.1367	3.8416	13.8034	-13.6776
110	3.844	3.7049	0.1389	3.8438	3.7579	-3.6299
113 .75	3.853	3.7049	0.1486	3.8535	-0.0219	0.1596
115	3.858	3.7049	0.1528	3.8577	-1.2584	1.4003
120	3.880	3.7049	0.1753	3.8802	-6.2704	6.4348
125	3.911	3.7049	0.2063	3.9112	-11.2781	11.4734
130	3.950	3.7049	0.2455	3.9504	-16.2470	16.4815

From table III, it is clear that the load loss is constant and almost independent of the generator output, which approves the validity of the proposed method. The variation of the

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circulating power and the circulating current loss with changes with generation. In the first row of table III, when P_{G2} was 40 MW, the circulating power calculated by the proposed method was found to -74.0361 MW, P_{G2} is increased up to 130 MW, 16.4815MW circulate from bus 2 to bus 1. This is very near to the circulating power expected (90-74.0361=15.9639 MW), which again proofs the accuracy of the proposed method in determining the circulation power in addition to the load loss. The dependence of circulating current loss on the amount of circulating power is clear from the table III. The small difference between the total loss calculated and loss due to circulating power is due to the difference in voltage magnitude. This difference causes a reactive power to flow in the system causing active power loss.

V CONCLUSION

Restructuring electrical energy markets, the split determination for each loads and generators from total loss has been necessary. It should be performed sincerely and all loads and generators should participate. In this paper a proposed new method has been introduced based on difference in generators voltage which gives better reliability, least amount limitation and specified equation should be calculated both the type of losses AC and DC. The losses and circulating power calculated by this method and the data provides the system operator which gives suggestion about economic operation for the power system network and also gives him instruction for possible actions for reducing the losses as minimum as possible.

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