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Allocation of Transmission Losses in a Deregulated Power System

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Abstract - This paper focuses on the problem of Transmission loss allocation in a power system .It is a centralized issue in today's deregulated market. Due to non linear nature of line flows, it is necessary to allocate the real power losses effectively without affecting the market participants. In this paper a simple novel methodologies are proposed to allocate the real power losses to the market participants by using simple circuits' laws and loss formulae .These methodologies are tested on IEEE 5-Bus and IEEE 30-Bus systems. The simulation results are compared by using MATLAB environment and analyzed.

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ALLOCATIONOFTRANSMISSIONLOSSESINADEREGULATEDPOWERSYSTEM

Strictly as per the compliance and regulations of :

Allocation of Transmission Losses in a Deregulated Power System

Ch.Chengaiah [α] & P.Jyoshna [σ]

Abstract - This paper focuses on the problem of Transmission loss allocation in a power system .It is a centralized issue in today's deregulated market. Due to non linear nature of line flows, it is necessary to allocate the real power losses effectively without affecting the market participants. In this paper a simple novel methodologies are proposed to allocate the real power losses to the market participants by using simple circuits' laws and loss formulae .These methodologies are tested on IEEE 5-Bus and IEEE 30-Bus systems. The simulation results are compared by using MATLAB environment and analyzed.

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I. Introduction

Deregulation has brought many market configurations and created competition among them in the electricity business. Transaction of electric energy may take many forms like bilateral contracts, power exchange or power pool. Since in deregulated power system generators and loads are connected to the same network, actions by one participant can have significant effect on others making it difficult to allocate the losses .So there is a need for allocating losses to the market participants in a more satisfactory and transparent mechanism. Market participants whether they are generators or consumers want to allocate the loss in more practical way and it is able to reflect each participant's contribution of generation or usage in the network.

In a deregulated power system transmission loss pertains to allocate the cost associated with losses to individual suppliers, generators and contracts of the network. Loss allocation does not affect generation levels or power flows and it is about the distribution of revenues and payments at the network buses among suppliers and consumers and every supplier has to supply the power they want to sell plus the transmission loss corresponding to that transaction. Transmission loss allocation became contentious issue as it corresponds to a huge amount of money. Transmission loss is a highly nonlinear function of line flows. If linearization techniques are used to allocate flow of a given line to generators and loads, the cross terms associated with quadratic functions doesn't allow assigning losses to generators and consumers in a unique manner. The main problem associated with loss allocation is the fact that transmission loss is a non-separable entity. If any attempt is made to separate it, becomes further complicated by its nonlinear nature.

The challenge facing by a typical power pool and an Independent System Operator (ISO) in [1] is how to allocate the transmission loss and what should be the criterion for charging other utilities. Utilities in general look for locational signal, consistency, simplicity, accuracy and predictability in a loss allocation method. It is extremely hard task to accommodate all these considerations in complex phenomenon of transmission loss allocation. So, in a deregulated environment the economic and market related factors are important as technical factors. In this environment not only accurate calculations but fair and equitable allocation of losses to the stake holders are also important. Hence the issue power loss allocation within the deregulated market still remains an unsolved set back to progress to a fully competitive electricity market. Based on these problems, simple novel methodologies are proposed to allocate the losses transparently, which is illustrated in subsequent sections.

II. Methodologies

a) Postage stamp method

Postage stamp (P.S) method is the simplest and easy to implement the methodology of transmission loss allocation [2]. It is a fixed charge per unit of power transmitted with in a particular zone. It is transparent and is easily understood by all .There is no mathematical rigor involved in this method. In this method 50% of losses are allocated to generators and 50% of losses to the loads. In this method network topology is never taken in to account. Further it will not be beneficial for two identical loads where one load is locating nearer to the load centre and another load is locating far away from load centre to allocate the loss with the same amount of cost.

i. *Transmission loss allocation*

Transmission loss allocation for generator is

$$L_{PGi} = \frac{L}{2}\frac{P_{Gi}}{P_G}$$

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$L_{PDj} = \frac{L}{2}\frac{P_{Dj}}{P_D}$

Where, P_{Gi}, P_{Dj} – real power generation and load at buses i and j

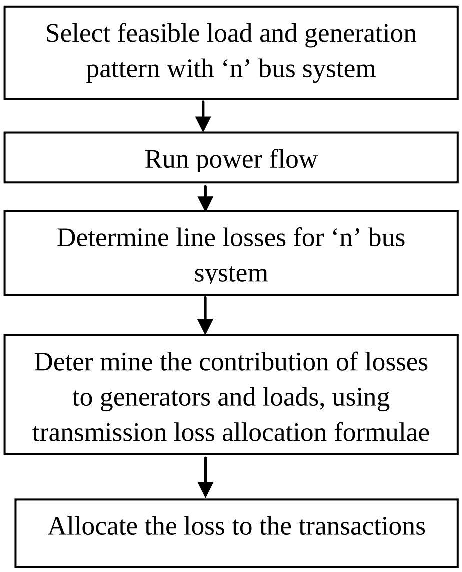
P_G, P_D –Total power generation and load of this system

L_{PGi}–Losses allocated to the generator i

L_{PDj}–Losses allocated to the demand j

L–Total losses of the system

ii. *Algorithm for postage stamp method*



b) Proportional sharing principle (Flow tracing method)

Proportional Sharing Principle (PSP) procedures on top of electrical laws requires the assumption of the proportional sharing principle [3]. Using this principle, losses are allocated by linear procedure and it is not dependent on slack bus and considers the network flow conditions.

To allocate the losses to individual generators and loads, the method depends on simple principle, that the losses associated with certain node in electrical network is proportionally shared by all the paths going out from that node thus satisfying Kirchhoff's current law. It should be noted that a systematic applications of this principle originates that all losses are allocated to generators and loads proportionally.

One of the main features of this method is that it is slack-bus independent. Though during the power flow, one bus is considered to be slack bus which supplies system loss, while forming transactions, this bus also participates. Once transactions are formed, loss is allocated to all transaction pairs, including one involving slack bus. So final result does not depend on the choice of slack bus.

The information required [4] to apply this method is the real power flow and the losses in every line and the power generated or consumed in every bus.

Since there is no unique or ideal procedures exist, the loss allocation should have some desirable properties stated below:

1. To be consistent with the results of power flow.
2. To depend on the amount of energy either produced consumed.
3. To be simple and transparent (important to market participants and public policy makers).
4. To be politically implementable (especially important to regulators and public policy makers).
5. To provide correct marginal signals to the network.

i. *Transmission loss allocation*

Proportional sharing principle method express branch flows as the sum of components supplied from individual generators or to loads.

$$P_{i-j}^{(gross)} = (P_{ij}/P_i)\Sigma[A_{u(i,k)}]^{-1}P_{GK} \text{ for } j€\alpha_i^d \quad (1)$$

α_i^d = set of nodes supplied from node i

P_i = nodal power

K= Buses (generator bus)

P_{GK} = generating power at bus k

P_{ij}=branch power flow (i €upstream,j € downstream)

A_u = upstream distribution matrix

$$[A_u]_{ij} = \begin{cases} 1 & \text{for } i=j \\ -|P_{ji}|/P_j & \text{for } j \in \alpha_i^u \\ 0 & \text{otherwise} \end{cases}$$

$$P_{i-j}^{(net)} = (P_{ij}/P_i)\Sigma[A_{d(i,k)}]^{-1}P_{DK} \text{for} j€\alpha_i \quad (2)$$

K=buses (load bus

P_{ij} = branch power flow (j € upstream, i € downstream).

α_i^u = set of nodes supplying node i.

A_d=downstream distribution matrix

$$[A_d]_{ij} = \begin{cases} 1 & \text{for } i=j \\ -|P_{ji}|/P_j & \text{for } j € \alpha_i^d \\ 0 & \text{otherwise} \end{cases}$$

In order to assign 50% of losses to the generation and 50% to the demand, the final generation and demand per bus are computed as,

$$P'_{Gi} = (P_{i-j}^{net} + P_{Gi})/2 \quad (3)$$

$$P'_{Dj} = (P_{i-j}^{(gross)} + P_{Di})/2 \quad (4)$$

Finally the real power losses allocated to every generator and demand are computed as

$$L'_{Gi} = P_{Gi} - P_{Gi}' \quad (5)$$

$$L'_{Di} = P'_{Dj} - P_{Dj} \quad (6)$$

c) Bus Wise Loss Allocation

Bus Wise Loss Allocation Method (BWLA) is based on simple circuit laws in [5] and does not involve any assumptions. Considering the real power injection and real power loss contribution factors of the buses transmission lines, transmission loss allocation can be done. It does not require any assumptions in the network

i. *Transmission loss allocation*

In this method entire data related to the network such as bus voltages, complex line flows, slack bus power generation etc are obtained from the load flow solution. From the load flow solution the complex line flow S_{ij} in terms of the node voltage V_i and line current I_{ij} through the line i→j as

$$S_{ij}= V_i I^*_{ij} \quad (7)$$

From the Z based system equations the voltage at node I is given by

$$V_i=\sum_{k=1}^{n} Z_{ik} I_k \quad (8)$$

The current through the line i→j is obtained as

$$I_{ij}= (V_i-V_j)\, y_{ij} +V_i y_{ij}^{sh} \quad (9)$$

Substituting (8) in (9)

$$I_{ij}=\sum_{k=1}^{n}[(Z_{ik}-Z_{jk})\, y_{ij} + Z_{ik} y_{ij}^{sh} \quad (10)$$

Substituting the values I_{ij} from (10) in (7)

$$S_{ij}= \sum_{k=1}^{n} factor1^{k}_{ij} \quad (11)$$

Thus the complex power flow S_{ij} through the line i→j is represented as a function of all bus currents; k=1, 2, 3……n Factor 1^k_{ij} represents contribution of k^{th} bus to i→j line power flow.
Similarly complex line flow

$$S_{ji}= \sum_{k=1}^{n} factor2^{k}_{ij} \quad (12)$$

Factor 2^k_{ij} represents contribution of kth bus to i→j line complex power flow i.e. counter flow.

Complex line loss in any line is the algebraic sum of active and counter complex line flows. Therefore

$$S_{line\ loss} =S_{ij}+S_{ji} = \sum_{k=1}^{n} factor^{k}_{ij} \quad (13)$$

Factor $^k_{ij}$ represents the contribution of kth bus to the i→j line loss and also the contribution of line i→j to the power injection at bus k.
The matrix [B] is the real part of $S_{line\ loss.}$

By using [B] matrix real power losses can be allocated in the following manner.

a. Find the sum of the "absolute contribution of all buses to the real power loss of line i→j(say "l^{th}line") i.e. cumulative power loss "Cploss(l)" where

$$\text{Cploss (l)} \quad \sum_{k=1}^{n} B(k,l) \quad (14)$$

b. to find the contribution of i^{th} bus to the real power loss of line i→j (l^{th}line) a power loss factor is given by

$$C\ (k,\ l) = \frac{B(k,l)}{cploss\ (l)} * r\ loss(l) \quad (15)$$

c. By summing up all individual real power loss factors C(k,l) of all lines , the total loss allocated to i^{th} bus is defined as LA(k) given by

$$LA\ (k) =\sum_{l=1}^{nline} C(k,l) \quad (16)$$

III. Case Study on IEEE- 5 Bus System

A case study on IEEE-5 bus system is illustrated to test the performance of the three methodologies which is discussed in section II. The layout of IEEE- 5 bus system taken from [6], consists of two generator buses and four load buses and is represented by bus power injections, line power flows and line power losses obtained from the base case solution i.e. Newton Raphson method. The total real power loss for 5 bus system is 4.802 MW. It can be obtained by using PS, PSP and BWLA methods, which is shown in Table.1.

Table 1

Bus	Loss allocation in MW (Total loss=4.802)		
	PS	PSP	BWLA
1	1.8355	2.0884	2.131
2	0.8566	0.4318	0.330
3	0.6549	0.6708	0.730
4	0.5821	0.5946	0.650
5	0.8731	1.0167	0.962
Total	4.802	4.802	4.802

From Table.1, shows that the results of loss allocation for the three methods, in PS Method, the network is not considered. It allocates the losses to the generators and loads marginally and it is independent of transmission distance. In this method, it allocates the losses of 1.8355MW to the bus -1 with its more contribution of 129.802MW (bus power injection from load flow studies) power flow to the other loads and it allocates losses of 0.8566 MW to the bus-2, but its contribution of power flow is only 40 MW(bus power injection from load flow studies) apart from its own load.

In PSP method taking the network in to consideration, loss allocation can be done. It allocates the losses of 2.0884MW to bus-1 as it contributes the 129.802MW to other loads and it allocates the 0.4318 MW to bus -2 with its contribution of 40 MW to the other loads.

In BWLA method allocation can be done directly by using circuit laws. It allocates the losses of 2.131MW to the bus-1 with its contribution of power flow to the other loads is 129.802MW and it allocates the losses of 0.330MW to the bus-2 with its contribution of power flow to other loads is 40MW.

Based the above analysis in PS method the participant with more contribution will get more benefited compared to less contribution of the participants. But with PSP method though network is taken in to consideration, customers are not reasonably benefited compared to the BWLA method. So Bus wise loss allocation method allocates losses more accurately compared to the other two methods.

IV. Case Study on IEEE - 30 Bus System

A case study of IEEE-30 Bus system is illustrated to test the performance of the three methodologies which is discussed in section II. The lay out of IEEE- 30 bus system taken from [7], it has 30 nodes and 41 branches and consists of one slack bus, 5 PV buses and 24 load buses and is represented by is represented by bus power injections, line power flows and line power losses obtained from the base case solution i.e. Newton Raphson method. The total real power loss for 30 bus system is 20.15MW It can be obtained by using PS, PSP and BWLA methods which is shown in Table.2..

From the Table.2 shows that the results of loss allocation for the three methods all the methods allot zero loss to the transfer bus which has zero injection power and in PSP method counter flows (negative losses) occur when no of buses increases, but in BWLA method counter flows (negative losses) never occur though no of buses increases as shown in Table .2 respectively.

Bus	Loss allocation in MW(Total loss=20.15)		
	PS	PSP	BWLA
1	8.8314	9.3567	9.833
2	1.9665	1.0322	0.544
3	0.0797	0.049	0.075
4	0.2524	0.2035	0.243
5	3.1288	-8.6284	3.056
6	0	0	0
7	0.7573	12.7622	0.736
8	0.9964	0.5869	0.987
9	0	0	0
10	0.1926	0.1869	0.306
11	0.3321	0.3223	0.422
12	0.372	0.3	0.327
13	0.3321	0.2679	0.41
14	0.2059	0.1968	0.206
15	0.2724	0.2723	0.27
16	0.1162	0.108	0.106
17	0.2989	0.2993	0.276
18	0.1063	0.1179	0.109
19	0.3155	-3.8748	0.308
20	0.0731	4.319	0.075
21	0.5812	0.6423	0.547
22	0	0	0
23	0.1063	0.1166	0.103
24	0.289	-1.4931	0.304
25	0	0	0
26	0.1162	-1.4823	0.162
27	0	0	0
28	0	0	0
29	0.0797	0.8176	0.116
30	0.3521	3.6936	0.624
Total	20.15	20.15	20.15

Table 2

V. Conclusions

From the three methodologies the following conclusions are drawn P.S method though simple and transparent to implement it does not take the network in to consideration and allocates the fixed real power losses to the participants irrespective of distance between the generators and loads.

Proportional sharing method takes the network in to consideration and allocates the real power losses proportionally to all the transactions. But in this method assumptions are made that the line inflows are equal to the line out flows. This method does not depend up on the choice of the slack bus.

Bus wise loss allocation method overcomes the disadvantages of postage stamp method and proportional principle method and it allocates the real power losses directly by using simple circuit laws. This method gives accurate results compared to the other two methods.

VI. Future Scope

In this paper only real power losses are considered for loss allocation. The three methods can be extended to allocate the reactive power losses for better voltage stability and pricing can also be done which is a major issue in today's competitive market.

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