Reactive Power Loss Allocation in a Deregulated Power System

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Abstract **- In a deregulated environment, it is important to allocate the transmission loss to the Genco and Disco participants for which they are responsible. Even a slight change in the allocation of loss ends up in significant loss or gain for the participants. Although real power is the main traded commodity in the market, reactive power is essential for the transfer of real power through the transmission lines, with security. Since generators and loads are present in the same interconnected network, transmission usage of one participant has significant effect on other participants. Hence reactive power loss should be allocated equitably among the Genco and Disco participants with minimized cross subsidies. This project proposes a new method of reactive power loss allocation for a pure reactive power market based on the proportional sharing rule. This method is based on the concept of orthogonal current projection. A sample four bus system has been studied for the allocation of reactive power loss to the participants**.

Index Terms **- allocation; orthogonal current projection; proportional sharing; Q market; reactive power loss.**

I. INTRODUCTION

Deregulation of power system has made it difficult for the allocation of loss for the participants due to the non-linearity and complexity in the power flow through the transmission lines in the system. A system is reliable only when the generation is equal to the loads plus demand for every second. Loss for each participant would be different based on their network utilization. So an accurate and a transparent method has to be developed to charge the participants accordingly. Several methods were developed for appropriate allocation of reactive power loss. These approaches are *Pro rata, Incremental transmission loss (ITL), Proportional sharing.* In *pro rata* method the participants are allocated based on their active power levels, without taking into account about their relative positions. Many methods were developed based on the incremental transmission loss: Integral-based incremental method, concept of center of losses method. Recently methods based on the proportional sharing rule has been implemented widely in the allocation of losses. This method based on the concept of orthogonal current projection using circuit theory is found to integrate the network characteristics and circuit theory concepts to allocate losses according to the branch losses.

This paper presents the reactive power loss allocation by using the method of circuit theory and the concept of orthogonal current injection for a pure Q market. This method involves two equivalent modes where, generations (loads) are transformed into current injection and loads (generations) into admittances. The allocation of loss is done only to the generators, when the generations are converted as current injection. And only to loads when the loads are converted as current injections. According to the method of orthogonal current projection, the allocation of losses solely depend on the branch current contribution of the current injections.

II. ASSUMPTIONS MADE FOR PURE Q MARKET

The Real Power Demands are made zeros (P_D =0), Line Resistances are made zeros(R=0), Bus Voltage Angle are made zeros ($\delta = 0$), Real Power Generation are made zeros (P_G =0). Only Line Reactance (X_r,) Half Line Charging Susceptance (Bc), Reactive Power Generation (Q_G) and Reactive power Demands (Q_D) are considered.

III. PROPORTIONAL SHARING RULE

Proportional sharing rule determines the contribution of the participants to the transmission line usage. This method can be dealt with both DC-power flow and AC- power flows to find the contributions of both active and reactive power flows. The proportional sharing rule is illustrated form the fig.1. It shows a node with a local demand and a generator connected to the system by two transmission lines. Power to the load is supplied by the demand and the upper line which is determined using this rule as (40/ (40+60)*30=12MVAR which is from upper line to the load and (60/ (40+60))*30=18MVAR which is from the local generator.

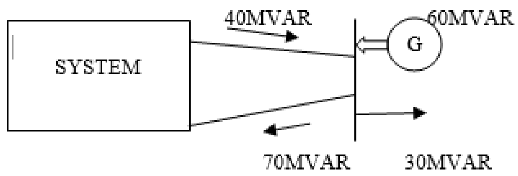


Fig. 1Proportional Sharing Rule

IV. CONCEPT OF ORTHOGONAL CURRENT PROJECTION

In a power system several generators as well as loads are present. Let us consider one generator at a time. The current injection due to generation is I^k. The contribution of current injection to the power flow through a branch say r is I_r^k. The total current through the branch r due to all current injections is I_r. The total current through the branch r is found using the superposition principle theorem and expressed as

$$I_r = \sum_{r=1}^{nl} I_r^k$$

Where nl is the number of branches in the network.

According to the concept of orthogonal current projection the reactive power loss allocation is based on the ratio of contribution of a current injection to the current through a branch to the total current through that branch.

V. CIRCUIT THEORY AND EQUIVALENCE MODES

Consider a network of *nb* bus and *nl* transmission lines for which the line flow results are known. In a network a bus is said to be generation bus only if net power injection is positive otherwise it is classified as a load bus. Converting a generation into a current injection through a bus is given by

$$I_k = \left(\frac{jQ_k}{V_k}\right)^* \quad (1)$$

$$\textbf{when } Q_{gk} - Q_{dk} > 0$$

And loads are converted into admittances and expressed as,

$$y_{dk} = \frac{jQ_k^*}{|V_k|^2} \quad (2)$$

$$\textbf{When } Q_{gk} - Q_{dk} < 0$$

where k = 1, 2, .nb and V is the bus voltages from the load flow results.

This y_{dk} is den added to the original Y bus matrix to get a new admittance bus matrix (Y_G). This matrix is then inverted to get the bus impedance matrix (Z_G).

$$Y_G = Y_{bus} + y_{dk} \quad (3)$$

$$Z_G = [Y_G]^{-1} \quad (4)$$

The contribution of current injection at the bus k to the bus voltages is expressed as,

$$V^k = Z_G * I^k \quad (5)$$

Where I^ka vector of nb is whose value will be I at the position k and zeros in other positions.

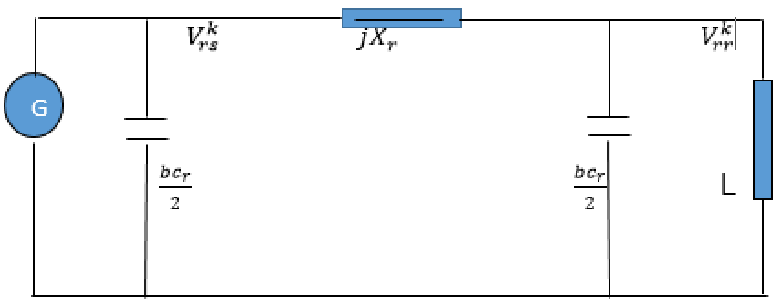


Fig. 2 Equivalent pi model of the transmission lines.

The contribution of current injection to the bus voltage drop is given by,

$$\Delta V_r^k = V_{rs}^k - V_{rr}^k \quad (6)$$

Where V_{rs}^k and V_{rr}^k are the contribution of current injection at bus k to the bus voltages at the sending and receiving end of the branch r referred with fig .2.

The contribution of current injection to the branch current through the branch is given by,

$$I_r^k = \frac{\Delta V_r^k}{X_r} \quad (7)$$

Where ΔV_r^k is the potential difference between the sending end voltages and receiving end voltages, X_r is the reactance at the branch *r*.
The total current through the branch *r* due to the current injection at each bus is obtained by using the superposition principle as,

$$I_r = \sum_{k=1}^{nb} I_r^k \quad (8)$$

VI. REACTIVE POWER LOSS ALLOCATION

In power system reactive power plays a crucial in maintaining system stability and reliability. The reactive power losses should be optimized to maintain a better system voltage profile. In a system of *ng* generators and *nd* loads the reactive power loss due to the branch reactance.

$$Q_{xlossr} = \left(I_r^{K1} + I_r^{K2} + \cdots + I_r^{Kng}\right)^2 * X_r \quad (9)$$

Where $I_k^{G_1}, I_k^{G_2}, \dots . I_k^{G_{ng}}$ are the contribution to the branch current due to the generations $G_1, G_2, \dots . G_{ng}$ respectively and X_r is the reactance of the branch *r*.
Reactive power loss due to the branch susceptance in the r[th] branch is expressed as,

$$Q_{bclossn} = (|V_n|^2) * \frac{bc}{2} \quad (10)$$

Where $V_n$contribution of each current injection to the bus voltages is, $\frac{bc}{2}$ is the line charging suscptences.
Reactive power loss allocation to the i[th] generator for the loss due line reactance is calculated by,

$$Q_{xlr}^{G_i} = 0.5 * Q_{xlossr} * \frac{|I_r^{k_i}|}{\sum_{k=1}^{ng} |I_r^{kng}|} \quad (11)$$

$in\ which\ i = 1,2 \dots ng;\ r = 1,2, \dots nl$

Where $Q_{lr}^{G_i}$ is the loss allocated to the i[th] generator for the loss due to line reactance, $I_r^{G_i}$ is the contribution of the i[th] generator to the current through the branch *r*.
Reactive power loss allocation to the i[th] generator for the loss due to the branch susceptance is calculated as,

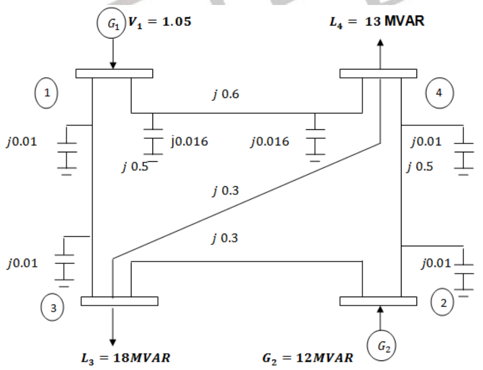
$$Q_{lbc}^{G_i} = 0.5 * Q_{bclossn} * \frac{|V_n^{G_i}|}{\sum_{k=1}^{ng} V_n^{G_k}} \quad (12)$$

$in\ which\ i = 1,2 \dots ng;\ \ n = 1,2, \dots nb$

Where $Q_{lbc}^{G_i}$ is the reactive power loss allocated to the i[th] generator for the loss due line charging susceptance in the branch *r*, $V_n^{G_i}$ is the contribution of the i[th] generator to the n[th] bus voltage. The same procedure can be applied to find the loss allocated to the loads.

VII. NUMERICAL EXAMPLE

A. SAMPLE BUS SYSTEM



B. LINE FLOW RESULTS:

TABLE 1

Lines	Forward flow	Reverse flow	Total
1-4	5.0060	-8.0616	-3.0556
1-3	7.3801	-9.1177	-1.7376
3-4	-0.6524	0.6536	0.0013
4-2	-5.5614	3.6164	-1.9450
2-3	8.4193	-8.2205	0.1988
Total			-6.500

TABLE 2

C. REACTIVE POWER LOSS ALLOCATION FOR THE PARTICIPANTS:

Lines	Genco 1	Genco 2	Disco 1	Disco 2	Total
1-4	-1.4338	-0.1453	-0.6808	-0.8983	-3.1583
1-3	-0.8181	-0.0816	-0.6456	-0.2541	-1.7995
3-4	0.0006	0.0000	-0.0015	0.0021	0.0013
4-2	0.0079	-1.0040	-0.3768	-0.6194	-1.9923
2-3	0.0067	0.0928	0.0713	0.0281	0.1988
Total	-2.2368	-1.1382	-1.6333	-1.7417	-6.7500

Line charging susceptances in any line reduce the reactive power loss by injecting VAR to the same line. Reactive power losses are given in the table 1. And loss allocation for loss is given in the table 2. From the table 2, loss allocation for genco 2 and disco 1 are found to be more than genco 1 and disco 2 because of higher generation or demand. From table 2 total loss allocation for each line due to the participants is found to be more at line 1-3 & 2-3 because disco 1 is directly fed from genco 1 & 2. Higher loss allocation in line 3-4 is due to the absence of line charging susceptances. The loss allocation in the line 3-4 is very less this ensures that bus 3 and 4 are load buses. It is worth noting from table 3, line 4-2 for genco 1 and line 3-4 for disco 1 yields negative loss allocation and consider counter flow which reduces the flow through the lines. In this method remotely located participants are allocated more losses this ensure the practical situation.

VIII. CONCLUSION

This method is more efficient method of allocating reactive power losses that could be applicable all market structure. In some loss allocating and pricing method reactive power is included with active power cost and in some method power factor is regarded for cost allocation. But in this proposed method reactive power loss due to line reactance is allocated according to the branch current and loss due to half line charging susceptance is allocated according to the bus voltages. This method presents a new transmission loss allocation method applying the concept of orthogonal current projection with the characteristics as follows:

Here generations are converted into current injections and loads are convereted as equivalent admittances.

This paper proposes loss allocation among the participants based on the branch currents for inductive loss and bus voltages for capacitive loss.

This method yields negative loss allocation indicating the reward to the partiipants.

This method allocates reactive power loss based on the network utilization and independent of slack bus .

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