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A NEW APPROACH OF REACTIVE LOSS ALLOCATION IN DEREGULATED POWER SYSTEM

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ABSTRACT: Restructured or deregulated power system has thrown a challenge to the participants in economical as well as technical basis due to non-linear nature and complexity associated with the power flow within transmission network . Although real power is considered as the main traded commodity in electricity market , reactive power plays a crucial role in power system stability and security. Losses for each participants would be different according to their network utilization .So a fair and accurate loss allocation method is essential to have correct charges for each participants. Appropriate reactive power management is essential for system security and effective real power transfer and thus it is to be investigated. This paper presents a new methodology of reactive loss allocation among generators and loads for each transmission line. This proposed method is based on orthogonal current projection concept and (generators) loads buses (produce)consume more reactive power are penalized to improve system stability .As for illustration a sample 4-bus cyclic transmission systems have been studied to test the effectiveness and viability of the proposed method compared to others .

Keywords: circuit theory, deregulated system, loss allocation, orthogonal current projection, superposition theorem**.**

I.INTRODUCTION

In a balanced, stable and secured power system, generation should be equal to loss plus load in each and every second. Moreover ,reactive power is considered as an important support hand to the system operator. So loss of reactive power leads to loss of reliability of the system. Active power loss allocation has been focused mostly as main essential commodity in electricity market. As the generators and loads are connected within same network the change in one participant effects on others significantly resulting difficulty in determining the cost of each participants responsible for. So, it is very essential to develop a fair and transparent reactive power loss allocation method to avoid cross subsidies and to charge the participants as they deserve. In vertically integrated electricity industry, reactive power support is considered as a part of system operator's activities and its cost which should be recovered is usually calculated based on approximate methods.

Many investigations have been carried out for appropriate pricing of reactive power [1–15]. Some of these methods utilize various search techniques such as genetic and ant colony algorithms for pricing [4], others have focused on formulating reactive power pricing [4-6]. Muchayi [6] have presented a survey on some of the reactive pricing algorithms. Dona and Paredes [7] have proposed a pricing technique based on minimization of the operation cost as well as the transmission losses using decoupled OPF. Cost allocation of reactive power using modified Y-bus matrix method has been reported by Chu and Chen [8]. Ro [9] has presented the reactive charging scheme composed of recovering capital cost and operational cost. Pricing of real and reactive power as bundled products in synchronous machine has been investigated in [10]. Rider and Paucar [11] have proposed a nonlinear reactive power pricing method. They have presented the total cost of reactive power production as an nonlinear model which is solved by modified predictor corrector interior-point method. Active and reactive pricing using interior point nonlinear optimization method has been demonstrated by Xie [12]. Chung et al. [13] have presented a method for cost-based reactive power pricing in which the cost of reactive power production by generators and capacitors are minimized. Also a methodology for calculation of cost of reactive power by generators, synchronous condenser and static reactive power sources has been reported by Deksnys and Staniulis [14]. Proportional sharing technique[15] provide a computationally efficient method for loss allocation. Here ,it is assumed that nodal inflows are shared proportionally among nodal outflows .

A very recent paper [16] presents a circuit based method for branch power flow decomposition and branch loss allocation based on concept of orthogonal projection .In paper [16] ,it is shown that the share of power injection at any bus on the power flow through any branch equals the ratio of its current projection component to the total branch current. In view of this analogy, paper[16] allocate loss to generators and loads proportionate to their current projection component .But this fact comes true as long as bus voltages remain constant .Where as bus voltages of a transmission network are ever changing ,due to variation of any loads or generations.

This paper also use the concept of orthogonal current projection component [16] where loss allocated to each branch solely depends on the orthogonal projection of current contributions. As per literature, one of the equivalence mode(CC) converts all generators and loads into current injection. But this equivalence mode fails when the bus admittance matrix is singular due to no shunt elements. Thus another equivalence mode(CE) is proposed. In paper [16] loads(generators) are converted into equivalent admittances when generators(loads) are converted into current injection. Here we use later method for loss allocation to each branch and the proposed method is independent of choice of slack bus.

II.CURRENT PROJECTION COMPONENTS

In power system network several generators as well as loads are present. Here we will consider each generator as current *injection* separately at a time. Let current injection at bus k is I_k . The contribution of I_k to the current through branch r (I_r^k) has been computed in paper [16].As per superposition principle branch current contribution due to each current injection [16]

$$I_r = \sum_{k=1}^{n} I_r^k$$

Total current through any branch due to individual current injection is demonstrated in the following fig.1

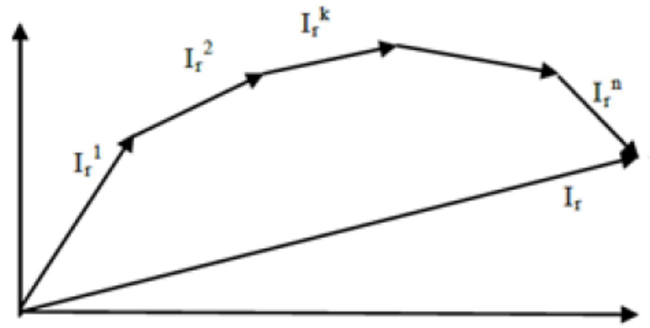

Fig. 1 Net current through rth branch due to current injections at different buses.

In fig. 1 it shows the net current through any branch (say for rth branch I_r) by vectorial addition of the branch currents due to injections at different buses. This is obtained using superposition theorem.

Orthogonal Current projection component[16] is the key technique in our paper.Net current through any branch due to all all current injections at different buses are supposed to be I_r . Let current contribution to the branch **r** due to current injection at the **kth** and **(k+1)th** bus is I_r^k and I_r^{k+1} respectively shown in fig.2

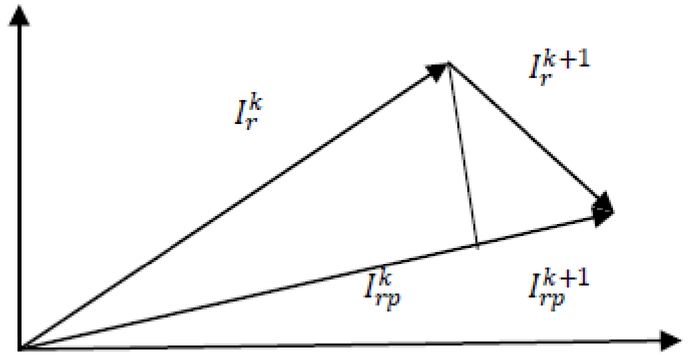

Fig. 2 Orthogonal current projection component.

In fig. 2 it shows the current projection components (I_{rp}^k and I_{rp}^{k+1}) on net branch current (I_r) due to the current injections (I_r^k and I_r^{k+1}) at kth and (k+1) th buses.

Let I_{rp}^k denote the orthogonal projection vector I_r^k of in the direction of I_r, which is defined to be the current projection component of branch r produced by the current injection at bus k,and it is expressed as

$$I_{rp}^{k} = \frac{I_r^k}{|I_r|}.I_r e^{j\varphi_r}$$
$$= |I_r^k| \cos(\varphi_r^k - \varphi_r)e^{j\varphi_r} \qquad (1)$$

Where φ_r^k and φ_r are angle of I_r^k and I_r respctively

In fig. 2 magnitude of I_{rp}^{k+1} is less than I_r^{k+1} . If I_r^{k+1} is directly used during loss allocation then obtained result would not be so accurate as this component is not mainly responsible for loss allocation. This is similar to the work force analogy where work is done mainly by the horizontal component of force not by the vertical component of force. Similarly the projection component of current is responsible for loss occurrence. The value of the orthogonal projection component of current through any branch(say branch r) due to current injection at bus depends on the angle($\varphi_r^k - \varphi_r$) between net branch current(I_r) and branch current due to bus injection(I_r^k).Depending upon this angle($\varphi_r^k - \varphi_r$) the participants(generators or loads) may be penalized or rewarded (negative current projection component). Hence loss allocation by the proposed method using the orthogonal current projection technique is more fair and effective and can be used in pricing market.

III.PROPOSED METHOD

Proposed method will give an idea for reactive power loss allocation in a simple and efficient way. For sake of simplicity we have divided this method into following section viz….

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A. POWER EQUIVALENCE AND CIRCUIT THEORY

Consider an n-bus power system and solved power flow result is known. At first let us consider allocation to generators. A bus is considered to be a generator bus if its net real power injection is nonnegative, otherwise it is classified as a load. Then convert the generators into current injections and the loads into equivalent admittances as

$I_k =(S_k/V_k)^*$ when $P_{gk}-P_{dk}>=0$ (2)

$y_d =-S_k^*/|V_k|^2$ when $P_{gk}-P_{dk}<0$ (3)

This Y_d is then added to the original bus admittance matrix(Y_{Bus}) to get new admittance matrix(Y_G).Then invert the new bus admittance matrix including the equivalent load admittance to get the bus impedance matrix(Z_G) as

$$Y_G=Y_{Bus}+\mathrm{diag}(y_d) \qquad (4)$$
$$Z_G=(Y_G)^{-1} \qquad (5)$$

Where $y_d=[\, y_{d,1}\ldots\ldots\ldots\; y_{d,k}\ldots\ldots\ldots\ldots\ldots\ldots\; y_{d,n}]^T$

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Then contribution of current injection at bus k to the bus voltages can be computed as

$$V^k = [V_1^k, \ldots\ldots\ldots V_i^k, \ldots\ldots\ldots, V_n^k]^T = Z_G e I_k \qquad (6)$$

Where, e is an nX1 dimension vector with value of 1 at position k and all the others equal 0(zero).

Contribution of I_k to the voltage drop(ΔV_r^k) across branch r is computed as $\Delta V_r^k = \Delta V_{r\,f}^{k} - \Delta V_{r\,t}^{k}$

The contribution (I_r^k) of injection I_k to the current through branch r I_r is computed as

$$I_r^k = \frac{\Delta V_r^k}{Z_r} \qquad (7)$$

Using superposition principle branch current contribution due to each current injection is calculated.

net branch current is $I_r = \sum_{k=1}^{n} I_r^k = \sum_{k=1}^{n} I_{rp}^k$ (8)

B. REACTIVE POWER LOSS ALLOCATION

In power system network reactive plays a crucial role for system security and reliable operation. For maintaining better voltage profile reactive power losses should be optimized .For a system of no of generators and no of loads, let I_{rp}^{G1}, I_{rp}^{G2}…and $I_{rp}^{Gn_g}$ are the orthogonal current projection component of generator 1,2,...and n_g respectively.Then total reactive power loss in r^th branch is expressed as

$$Q_{lossr} = (I_{rp}^{G1} + I_{rp}^{G2} + \cdots + I_{rp}^{Gn_g})^2 X_r \qquad (9)$$

Reactive power generation (Q_{genr}) in r^th branch due to branch succeptance (B_c) is is expressed as

$$Q_{genr} = (|V_{rf}|^2 + |V_{rt}|^2) * B_c \qquad (10)$$

Where V_{rf} and V_{rt} is the from bus and to bus voltage of rth branch having line reactance X_r ,and line charging succeptance B_c

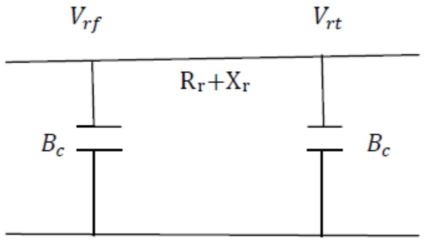

Fig. 3 Equivalent Π model of transmission line

In fig.3 it shows the equivalent Π model of a transmission line having line resistance R_r and line reactance X_r .Here it also shows that the *from bus voltage* and *to bus voltage* of rth branch is V_{rf} and V_{rt} respectively.Here B_c indicates line charging succeptance .

So net reactive power loss ($Q_{netlossr}$) in rth branch is calculated as

$$Q_{netlos\ sr} = Q_{lossr} - Q_{genr}$$
$$=(I_{rp}^{G1} + I_{rp}^{G2} + \cdots + I_{rp}^{Gn_g})^2 X_r - (|V_{rf}|^2 + |V_{rt}|^2) * B_c \quad (11)$$

Now reactive power loss occur in rth branch allocated to ith generator bus($Q_{l\,r}^{Gi}$) is calculated as

$$Q_{l\,r}^{Gi} = 0.5Q_{netlossr}\frac{|I_{rp}^{Gi}|}{\sum_{k=1}^{ng} I_{rp}^{Gk}} \quad (12)$$

where, i=1,2,….,ng and reactive power loss in rth branch allocated to jth load bus($Q_{l\,r}^{Lj}$) is calculated as

$$Q_{l\,r}^{Lj} = 0.5Q_{netlossr}\frac{|I_{rp}^{Lj}|}{\sum_{k=1}^{nl} I_{rp}^{Lk}} \quad (13)$$

where, j=1,2,….,nl

IV.NUMERICAL PROBLEMS AND RESULTS ANALYSYS

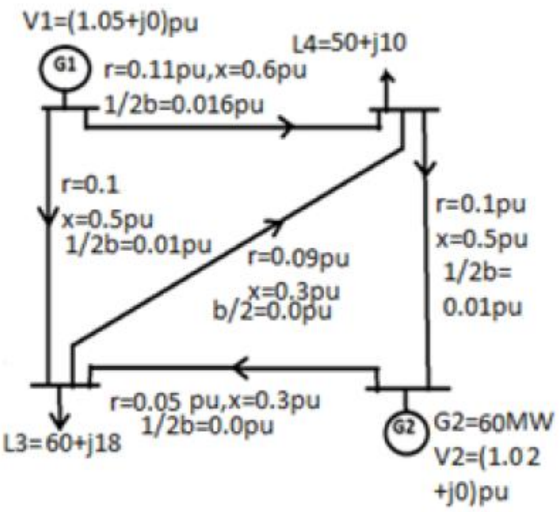

Fig. 4 Sample four bus ring main system

In fig.4 it shows the sample four bus ring main system to test the validity of the proposed method. Here it also shows the line data and bus data for each of the lines and buses. Here line charging succeptance (b/2) and base MVA is assumed zero and 100 respectively

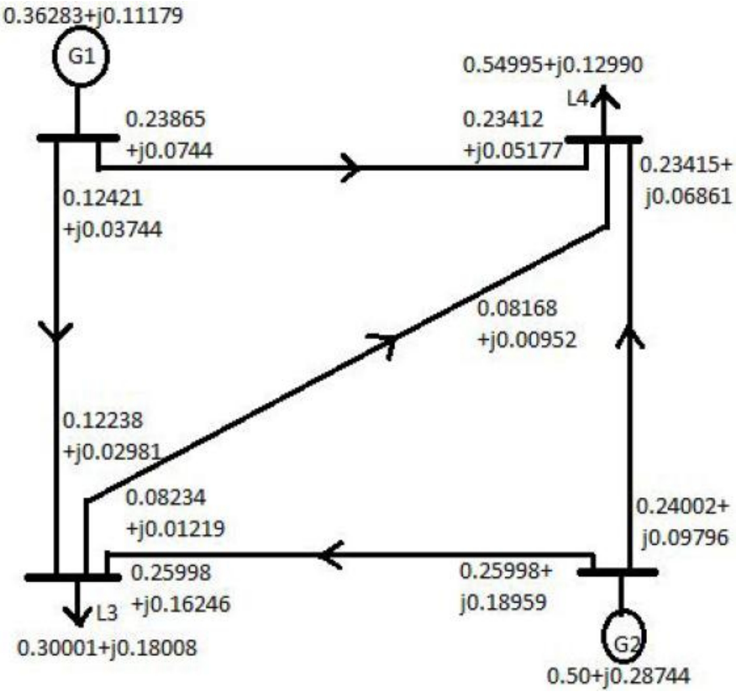

Fig. 5 Power flow diagram of four bus ring main system

In fig.5 it shows the power flow diagram of four bus ring main system. Here power flow (flow in and flow out) through each lines obtained from load flow study are shown. Here it also shows the power injections (at generator bus 1 and 2) and power drawn (load bus 3 and 4).

TABLE 1
REACTIVE LOSS ALLOCATION IN BASE CASE

Line	*Gen1*	*Gen2*	*Load3*	*Load4*
1-4	0.3108	0.0114	0.1170	0.2053
1-3	1.0968	-0.0192	0.7772	0.3010
3-4	0.0033	0.0124	-0.0533	0.0691
4-2	0.0002	0.4408	0.1212	0.3201
2-3	0.0056	2.0977	1.5325	0.5718
Total	1.4167	2.5431	2.4944	1.4674

TABLE 2
REACTIVE LOSS ALLOCATION IN MVAR FOR REAL POWER DEMAND INCREASED AT LOAD BUS L4 BY 0.1PU

Line	*Gen1*	*Gen2*	*Load3*	*Load4*
1-4	1.2170	0.0543	0.4278	0.8445
1-3	1.8273	-0.0593	1.1828	0.5866
3-4	0.0188	0.0417	-0.1358	0.1964
4-2	0.0163	0.6223	0.1390	0.5001
2-3	-0.0262	2.0359	1.4218	0.5894
Total	3.0533	2.6949	3.0355	2.7170

TABLE 3
REACTIVE LOSS(MVAR) ALLOCATION FOR REAL POWER DEMAND INCREASED AND VAR INJECTED AT LOAD BUS L4 BY 0.1PU EACH

Line	*Gen1*	*Gen2*	*Load3*	*Load4*
1-4	1.0520	0.0449	0.3737	0.7238
1-3	1.6962	-0.0532	1.1123	0.5317
3-4	0.0367	0.0531	-0.1024	0.1923
4-2	0.0146	0.5262	0.1208	0.4204
2-3	-0.0217	1.9355	1.3716	0.5434
Total	2.7779	2.5066	2.8759	2.4116

For illustration purpose here we have considered sample four bus rig main system whose line data and bus data are given in fig. 4.We have considered convergence tolerance of 0.001 pu and base MVA 100 for load flow study. Power flow through lines and generator (load) bus power injection(drawn) obtained from MATLAB simulation are given in fig. 5.

A.BASECASE: Reactive loss allocation to each participants (generators or loads) for each transmission lines are given in table 1. As in table 1 reactive loss allocation of L3 and G2 is higher than of L4 and G1due to the higher power demand or generation. Reactive losses in branch 1-3and 2-3 are MVAR and MVAR respectively ,which is more comparative to other branches due to higher demand and directly fed from G1 and G2. Reactive power loss in line 3-4 is minimum (0.031 MVAR) as power flow is minimum through this line, conforms to the practical situation as both the buses 3 and 4 are load bus. High line charging succeptance in any line(line1-4) comparative to other also reduce reactive power loss by injecting VAR to the same line.

B.CASE-1: (L4 is increased by 10 MW):When demand of L4 is increased by 10 MW, from simulation result it is seen that total MVAR loss is increased from 7.923 to 11.505. Increased demand of L4 is met by increased generation of G1 from 52.89MW to 63.58MW.As a result reactive loss allocation of is increased by 1.25 MVAR which is significant than 0.541 MVAR increase in loss allocation of L3(Table2) .As G1 mainly supply the increased demand , so reactive loss allocation of G1 is increased (1.636)by more amount than MVAR of G2(0.151).Power flow through line 1-4 is increased and as a result reactive loss allocation of is increased by 1.9 MVAR, whereas increase in reactive power loss in other lines are not so much prominent as in case of line1-4.

C.CASE-2: (10 MVAR injected at bus 4):Now at bus 4,10 MVAR is injected keeping other parameter fixed as in case-1.As reactive power is injected locally, L4 meets the reactive power demand mainly from bus 4.There is no need to increase of reactive power generation by more amount at generator bus1and2 as in case-1.As a result reactive loss allocation of G1 and G2 is decreased by 0.2752MVAR and 0.1874MVAR(table:2&3) respectively which reflect that shared of reactive loss of G1 is decreased significantly. Decrease of loss allocations(MVAR) in case-2 with respect to case -1 are 0.306,0.16,0.2752,0.1874 for L4,L3,G1 and G2 respectively. Due to local MVAR generation at bus -4, reactive power flow through line 1-4 is decreased and as a result reactive loss in line 1-4 is decreased by 0.349 MVAR which is more prominent than other lines . Moreover ,power factor(pf) of L4 is improved due to VAR injection and this fact is reflected in the result of less loss allocation of L4,although L3,G1and G2 also get benefit from this VAR injection.

It is worth noting that the proposed method can yield negative loss allocation (line1-3 for G2,line3-4 for L3) and consider counter flow which reduces the flow through some branches. In the proposed method remotely located participants are allocated more losses which confirms that this method considers the relative positions of the participants within network. Moreover the proposed method takes into consideration the nature of the loads also ,as lagging power factor load burdens the system more than unity power factor load. Hence in case -2 , reactive loss allocation of L4 is decreased prominently due to VAR injection at bus-4.

VI.CONCLUSION

So far there is no such efficient transmission loss allocation method that could fit all market structure in different locations .The ongoing research on transmission pricing indicates the criticality and scarcity of a generalized pricing methodology .In some system reactive power cost is included to active power cost and in some other systems power factor is regarded during reactive power cost calculation. But in our proposed method reactive power loss in each branch is allocated to generators or loads proportion to their current projection component and it can be used in pricing market. This paper presents a new transmission loss allocation method applying orthogonal projection concept and having following characteristics-

1) Here generators (loads) are converted into current injection when loads (generators) are converted into equivalent admittance conforms to the practical fact and thus it should be adopted.

2) This paper propose loss allocation among participants (generators or loads) proportion to their current projection component ,leading fair way of loss allocation.

3) Likewise incremental loss allocation method and Z bus loss allocation method, this method can yield negative loss allocation to indicate *reward* to the participants.

4)It is easy to understand and implement numerically.

5)Proposed method allocate losses to participants depending on their utilization of network and is independent of voltage reference bus.

6)It creates incentives or disincentives to participants with respect to their relative location and magnitude.

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