Reactive Power Cost Allocation in Deregulated Power Systems

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Abstract- In this paper two methodologies are developed based on circuit theory for allocation of reactive power including its cost. These methods are applied on The sample 5 bus system to test its effectiveness as case study. Customised Y Bus method uses superposition principle to evaluate voltage and currents in the network. The enhanced Y bus method with line charging admittance, proportional sharing has been developed and has given the better results than customized Y bus method.

Keywords- Customised Y Bus, enhanced Y bus method etc.,

I. INTRODUCTION

The transmission system has a main role in electricity market. In deregulated power system, the transmission system is a place from where generators will be ready to send the power to consumers at distribution system. As end users to the transmission system, the generators and consumers at load points have to pay the usage charges to the transmission system operator. The transmission system usage costs have the main effect on system operation and development. For this, TCA methods [1-5] must be initiated and meet the financial efficiency and transparency. These methods are classified into two categories: flat rate and power flow tracing methods. The TLA is one of the key issues of the deregulated power system [6]. The TLA to the end users has a main role to create competition and development in the system. The total losses are equal to the waste of 4 to 8% of the generation in the system and this is worth of huge for amount of money per year. It is necessary to allocate these losses to the end users in fair and transparent manner. ASM plays a main role for the system security and stability [7-10]. The reactive power service is one of the ancillary services and is required for controlling the voltage of the system. It is the responsibility of the TSO to provide the reactive power when it is required. The cost investment by the reactive power producers is treated as cost of ancillary services. The ancillary service cost can be computed by various methods like power flow tracing, circuit theory and sensitivity indices. The reactive power cost allocation can be done by two different methods like OPF based and circuit theory based. The ATC is an unused capacity of the network and that has been stored for the purpose of providing services in the emergency cases like congestion and further expansion of the system [11]. It is needed to assess the ATC of the system using rapid and accurate approaches in the electricity market. Hence, it is required to introduce the ATC evaluation and allocation techniques in the electricity market.

II. REACTIVE POWER ALLOCATION METHODS

A. customized Y bus method

The customized Y bus method will distinguish the providers ofreactive power for the required demand in the system. This methodworks based on circuit theory and this method follows the superposition principle. According to this rule, this method determines thevoltage of load bus as the sum of sharing of all generator bus voltageswith respect to the load bus.

B. Reactive Power and its Cost Allocation

In this method, the Y bus matrix is customized to compute theload bus voltage which has been shared by generators. Thecustomized Y bus matrix consists of Y bus elements related togenerator buses as a first term. After this, the elements of load busare added in the remaining terms. The fundamental equation for thesystem can be expressed as:

$$YV = I$$

The size of the Y bus matrix is (nxn) and the size of the voltage and
current matrices is (nx1).
where, n = Number of buses
Now, the above matrices can be modified as:

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

Now, the Y bus matrix is customized by together with the loadadmittance which is computed using load bus voltage and power. Theload admittance is computed as:

$$Y_{L_j} = \frac{1}{V_{L_i}} \left(\frac{S_{L_i}}{V_{L_i}} \right)^*$$

$$Y'_{LL_{ij}} = \begin{cases} (Y_{LL_{ij}} + Y_{L_j}) \; for\; i = j \\ Y'_{LL_{ij}} = Y_{LL_{ij}} \; for\; i \neq j \end{cases}$$

There is no load current, as the currents of the load are previouslywith the Y bus matrix through its corresponding admittance. Now

$$\begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y'_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} = \begin{bmatrix} I_G \\ 0 \end{bmatrix}$$

From the Eqn. it is expressed as:

$$Y_{LG}V_G + Y'_{LL}V_L = 0$$

Now, from above Eqn.

$$V_L = -[Y'_{LL}]^{-1} Y_{LG} V_G$$

$$\Delta V_{L_{ij}} = -[Y'_{LL}]^{-1} Y_{LG} V_{G_i}$$

Now, the reactive power allocation by the generator (i) to each load (j)
is expressed as:

$$\Delta Q_{L_{ij}} = \text{Im}(\Delta V_{L_{ij}} I^*_{L_j})$$

$$I_{L_j} = \left(\frac{S_{L_j}}{V_j}\right)^* = \text{Load current}$$

Allocation of the reactive power cost by the generators to each load
can be expressed as

$$Q_{L_{ij}(Cost)} = [\text{Im}(\Delta V_{L_{ij}} I^*_{L_j})] * C_{ij}$$

where, C_{ij}= Rate of the reactive power in Rs./MVAR

C. ENHANCED Y BUS METHOD

According to enhanced Y bus method, the reactive power of the system can also be generated from the admittance of the line charging (YC) and this line charging admittance acts as one of the reactive power generators. In this method, this admittance is considered. The reactive power provided by this admittance to the load bus can be expressed as:

$$Q_C = \text{Im}\left(\frac{V^2 Y_C}{2}\right)$$

The reactive power generated by line charging admittance also will be considered in the process of reactive power allocation and is considered as separate source of reactive power irrespective of actual reactive power from the generators.

$$Q_{L_{ij}} = \text{Im}(\Delta V_{L_{ij}} I^*_{L_j})$$

$$Q_{L_{ij}} = \text{Im}(\Delta V_{L_{ij}} V^*_j Y^*_{ij})$$

$$= \text{Im}\left(\Delta V_{L_{ij}}\left(\sum_{i=1}^{N} \Delta V_{L_{ij}} Y_{ij}\right)^*\right)$$

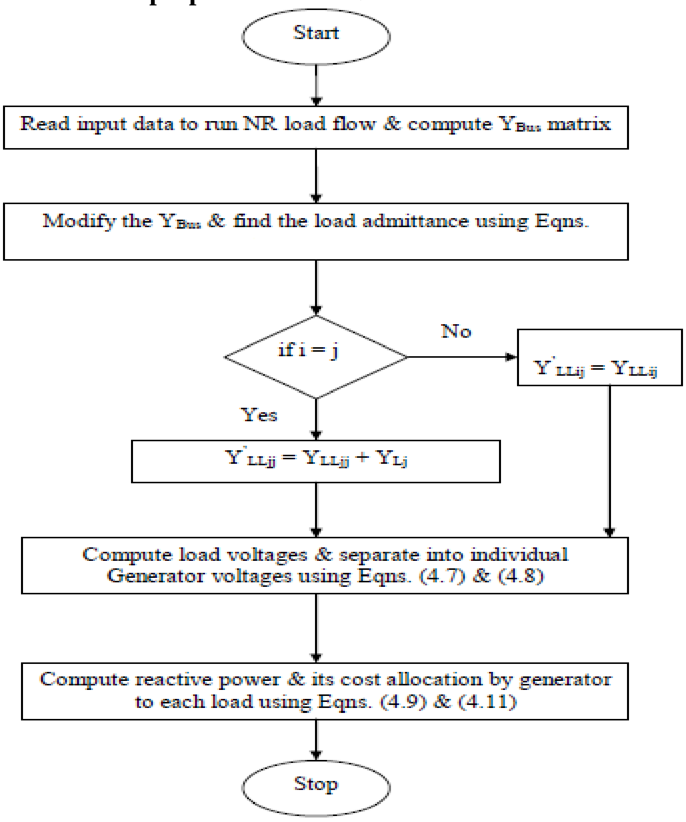
$$= \text{Im}\left(\Delta V^2_{L_{ij}} Y_{ij} + \Delta V_{L_{ij}}\left(\sum_{\substack{i=1\\ i\neq j}}^{N} \Delta V_{L_{ij}} Y_{ij}\right)^*\right)$$

Allocation of the reactive power cost by the generators to each loadcan be expressed as

$$Q_{L_{ij}(Cost)} = [\text{Im}(\Delta V_{L_{ij}} I^*_{L_j})] * C_{ij}$$

where, C_{ij}= Rate of the reactive power in Rs./MVAR

Flow chart for proposed methods:



III. RESULTS AND ANALYSIS

To test the Proposed methodologies IEEE 5 bus system is considered.

Case.i: Customized Y Bus Method

The results for reactive power allocation are presented in Table.1
and the cost results are presented in Table.2

Table.1 Allocation of Reactive Power (in MVAR)

Load Bus	Generator Bus		Total MVAR/Bus
	1	2	
3	2.419	17.582	20.001
4	7.217	2.784	10.001
5	14.698	16.412	31.110
Total			61.112

Table 4 Allocation of Reactive Power Cost (in Rs./h)

Load Bus	Generator Bus		Total Cost/Bus
	1	2	
3	362.85	2637.30	3000.15
4	1082.55	417.60	1500.15
5	2204.70	2461.80	4666.50
Total			9166.80

Case.ii: Enhanced Y Bus Method

The results for reactive power allocation for enhanced Y busmethod with line charging admittance and its cost results arepresented in Tables.3 and 4.

Table.3 Allocation of reactive power (in MVAR) with line charging admittance

Load Bus	Generator Bus		Due to Line Charging Admittance Bus No.					Total MVAR/Bus
	1	2	1	2	3	4	5	
3	1.398	11.722	0.595	2.487	3.798	0.000	0.000	20.000
4	1.784	0.413	0.759	0.088	0.000	6.956	0.000	10.000
5	8.360	11.623	3.559	2.466	0.000	0.000	3.992	30.000
							Total	60.000

Table.4 Allocation of reactive power cost (in Rs./h) with line
charging admittance

Load Bus	Generator Bus		Due to Line Charging Admittance Bus No.					Total Cost/Bus
	1	2	1	2	3	4	5	
3	209.70	1758.30	89.25	373.05	569.70	0.00	0.00	3000.00
4	267.60	61.95	113.85	13.20	0.00	1043.40	0.00	1500.00
5	1254.00	1743.45	533.85	369.90	0.00	0.00	598.80	4500.00
							Total	9000.00

From the above results, it can be observed that the reactive power and its cost allocation as two parts i.e., the reactive power generated from generators and reactive power generated from line charging admittance. The above result includes the reactive power and its cost allocation using enhanced Y bus method (with proportional sharing) considering reactive power generated from linecharging admittance. From the above results, it is observed that, the allocation ofreactive power to the loads is equal to the actual load (60 MVAR) thathas consumed by them. From this, it is concluded that, the enhanced Y bus method is more fair and transparent to the consumers.

IV. CONCLUSIONS

Proposed methodologies are developed based on circuit theory is presented for allocation of reactive power including its cost. The sample 5 bus system is used as case studies. The enhanced Y bus method with line charging admittance, proportional sharing and equal sharing has given the better results than customized Y bus method by eliminating the drawbacks in existing method.

V. REFERENCES

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