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REACTIVE POWER COST ANALYSIS IN RESTRUCTURED POWER SYSTEM

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ABSTRACT: As the deregulated electricity market is moving towards the competition, different services those are provided by the system operator are separated. Ancillary services like power factor control, frequency control, voltage control and reactive power management are secondary services to ensure that the system is more secured. It is required that the system voltage is always to be maintained with in the specified limits of the system. To achieve this, system operator has to provide the voltage control service using the reactive power sources. The function of the system operator is to identify the reactive power sources and loads. According to this, the payments are allocated to the customers and distributed among the providers. For this, a transparent reactive power cost allocation technique is to be identified.

In this paper, an existing reactive power cost allocation method i.e., modified Y bus method is compared with proposed method i.e., improved Y bus method of reactive power allocation and its cost including line charging admittance, proportional sharing and equal sharing. The sample 5 bus system and IEEE 24 bus system are used to illustrate the proposed method. The simulation of computation of reactive power and its cost has been carried out using MATLAB programming. The simulation results are presented and analyzed.

Keywords: Reactive Power Cost Allocation, Improved Y – Bus Method, Proportional Sharing, Equal Sharing and Line charging Admittance.

I INTRODUCTION

Ancillary services are required to ensure the uninterrupted power in the system. The reactive power service is one of the ancillary services which require ensuring the system security and reliability [2]. The system operator is having the responsibility of providing the reactive power service to the customers. Some times the operator wants to encourage the generators to produce the more reactive power. The payments to the reactive power service are allocated to loads and then the amount is distributed to generators. For this, the ISO has to identify the sources of reactive power and loads which consume it [8, 9]. Different reactive power pricing methods are available in the literature [4]. This allocation mainly done by two ways, first one is OPF based and second one is circuit theory based [1, 3].

Compared to OPF based methods, the circuit theory based methods have some advantages. The network characteristics are considered in this circuit theory based methods. The proposed method is based on modification of the Y - bus method and is referred to as improved Y bus method [7].

In Section II, the modified Y bus method is described. In Section III, the improved Y bus method is presented. In Section IV, case study I the sample 5 bus system results are presented. In Section V, the case study II IEEE 24 bus system results are presented and analyzed. In Section VI, conclusions are presented.

II MODIFIED Y – BUS METHOD

This method finds the reactive power generators and corresponding loads to consume it. This method works based on super position theory [5, 6]. It refers that every load bus voltage is the summation of the contributions of all the source bus voltages towards the load bus. From the base case load flow analysis, the load current is determined and the load voltage component because of source will determines reactive power component of the load because of that source. To find the load voltage component contributed by sources, the system Y – bus is modified. The Y – bus is modified in such a way that the first terms in the matrix will correspond to the source buses and then the load buses are considered one by one. The basic system equation is as follows:

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$$YV = I \quad (1)$$

This Y-bus matrix has a dimension of (n × n), V and I have dimension (n × 1), where n is the total number of buses present in the system. The modified matrices are as follows:

$$\begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} = \begin{bmatrix} I_G \\ I_L \end{bmatrix} \quad (2)$$

The Y- bus matrix is separated into four sub-matrices known as Y_{GG},Y_{GL}, Y_{LG} andY_{LL}. Y_{GG} and Y_{LL} include all terms related to only source buses and only load buses, respectively. The other two terms include the admittances between the generators and loads. By including equivalent admittance of loads (calculated from power and voltage of load bus) the Y bus matrix is now modified. The admittance of the load is determined as follows

$$Y_{L_j} = \frac{1}{V_{L_i}} \left(\frac{S_{L_i}}{V_{L_i}} \right)^* \quad (3)$$

where, S_{L_i} is the load requirement of bus i and V_{L_i} is the load bus voltage. These values can be achieved by a power flow analysis. By adding the load admittance the Y_{LL} matrix is modified, equivalent to injected load current, with the corresponding diagonal element of Y_{LL} matrix which leads to a new matrix called Y'_{LL} .

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

where $Y'_{LL_{jj}}$ represents the diagonal terms of Y'_{LL} Matrix and $Y'_{LL_{jj}}$ represents all other terms of this matrix. For further computations, this modified matrix can be used. The load currents will be zero as load currents are included in the Y bus matrix using its equivalent admittance and Eqn. (2) can be written as

$$\begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y'_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} = \begin{bmatrix} I_G \\ 0 \end{bmatrix} \quad (4)$$

Now it can be written from the lower portion of the modified Y bus as follows

$$Y_{LG} V_G + Y'_{LL} V_L = 0 \quad (5)$$

Now Eqn. (5) will lead to

$$\boldsymbol{V_L = -\left[Y'_{LL}\right]^{-1} Y_{LG} V_G} \quad (6)$$

$$\Delta V_{L_{ij}} = -\left[Y'_{LL}\right]^{-1} Y_{LG} V_{G_i} \quad (7)$$

The relation between source voltage and the load voltages is given by Eqn. (6). The load voltage can be dividing into the contributions of individual voltages as in Egn. (7). The contributions of a source i on the voltage of a load j is already known, then the reactive power contribution of the individual sources towards the load bus is as follows

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$$\Delta Q_{L_{ij}} = \mathrm{Im}(\Delta V_{L_{ij}} I^*_{L_j}) \qquad (8)$$

where I_{L_j} is the load current and it is determined as

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

The cost of the reactive power can also be allocated to all the loads in the system using modified Y – bus method as follows. The cost for one MVArh is taken as Rs. 150 and it is represented by C.

$$Q_{Cost} = [\mathrm{Im}(\Delta V_{L_{ij}} I^*_{L_j}]*C \qquad (9)$$

III IMPROVED Y – BUS METHOD

Based on improved Y-bus method [7], the line charging admittances work as a generator of reactive power in the system. While calculating reactive power availability at generators, these line charging admittances to be considered in the system. The reactive power calculation including these reactive sources can be done as follows. The reactive power supplied by a line having shunt admittance Yc to the end bus having voltage magnitude V is given by

$$Q_C = \mathrm{Im}\left(\frac{V^2 Y_C}{2}\right) \qquad (10)$$

A) Improved Allocation Method for the Reactive Power Sources

The Eqn. (8) represents the reactive power contribution of any generator i towards a load j, which shows that reactive power contribution can be find by multiplying the contribution of a particular generator towards this load voltage $\Delta V_{L_{ij}}$ with the complex conjugate of load current I_{L_j}. The reactive power contribution can be rewritten from Eqn. (8) as

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

$$= \mathrm{Im}\left(\Delta V_{L_{ij}} V_j^* Y_{jj}^*\right)$$

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

$$= \mathrm{Im}\left(\Delta V_{L_{ij}}^2 Y_{jj} + \Delta V_{L_{ij}}\left(\sum_{\substack{i=1 \\ i\neq j}}^{N} \Delta V_{L_{ij}} Y_{jj}\right)^*\right) \qquad (11)$$

In the above equation $N = N_g + N_{lc}$; where Ng is the number of generators there in the system and N_{lc} is the number of equivalent reactive power generators referring line charging reactance.

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B) Improved Allocation using Proportional sharing

By dividing the sum of terms proportional to their voltage contribution that is, if the contribution of generators i and k towards j[th] load bus voltage are $\Delta V_{L_{ij}}$ and $\Delta V_{L_{kj}}$, then this part of the reactive power contribution $\Delta Q = \mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)$ can be shared by generators i and k, respectively, as

$$\Delta Q_i = \mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\left(\frac{\Delta V_{L_{ij}}}{\Delta V_{L_{ij}} + \Delta V_{L_{kj}}}\right) \tag{12}$$

and

$$\Delta Q_j = \mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\left(\frac{\Delta V_{L_{kj}}}{\Delta V_{L_{ij}} + \Delta V_{L_{kj}}}\right) \tag{13}$$

The cost of the reactive power can also be allocated to all the loads in the system using Improved Y - bus method considering the proportional sharing as follows.

$$Q_{CostPi} = \left[\mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\left(\frac{\Delta V_{L_{ij}}}{\Delta V_{L_{ij}} + \Delta V_{L_{kj}}}\right)\right] * C \tag{14}$$

and

$$Q_{Costpj} = \left[\mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\left(\frac{\Delta V_{L_{kj}}}{\Delta V_{L_{ij}} + \Delta V_{L_{kj}}}\right)\right] * C \tag{15}$$

C) Improved Allocation using Equal or 50–50 sharing

By dividing each of these sum of the above terms equally between two generators (50–50 sharing). This equal sharing based allocation also analyzed using both sample 5 bus system and IEEE 24 bus system.

$$\Delta Q_i = \frac{1}{2}\left[\mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\right] \tag{16}$$

and

$$\Delta Q_j = \frac{1}{2}\left[\mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\right] \tag{17}$$

The cost of the reactive power can also be allocated to all the loads in the system using Improved Y - bus method considering the equal sharing as follows.

$$Q_{CostEi} = \left[\frac{1}{2}\left[\mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\right]\right] * C \tag{18}$$

and

$$Q_{CostEj} = \left[\frac{1}{2}\left[\mathrm{Im}\left(\Delta V_{L_{ij}}\left(Y_{jj}\Delta V_{L_{kj}}\right)^{*}\right)\right]\right] * C \tag{19}$$

IV CASE STUDY – I, SAMPLE 5 BUS SYSTEM

The sample 5 bus system is used as a case study – I to illustrate the proposed method for allocation of reactive power and its cost.

A) Results for Modified Y Bus Method

The reactive power and its cost allocation results obtained for modified Y-bus method using MATLAB programming are shown in the Tables I and II respectively.

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TABLE I
Reactive Power (in MVAr) Allocation using Modified Y – Bus Method

Load Bus	Generator Bus		Total MVAr/Bus
	1	4	
2	7.217	2.784	10.001
3	2.419	17.582	20.001
5	13.698	16.312	30.010
Total			60.012

TABLE II
Reactive Power Cost (in Rs./MVArh) Allocation using Modified Y – Bus Method

Load Bus	Generator Bus		Total Cost/Bus
	1	4	
2	1082.55	417.60	1500.15
3	362.85	2637.30	3000.15
5	2054.70	2446.80	4501.50
Total			90001.80

B) Results for Improved Y Bus Method

The reactive power and its cost allocation results obtained for Improved Y - bus method including line charging admittance using MATLAB programming are shown in the Tables III and IV respectively.

TABLE III
Improved Y – Bus Reactive power (in MVAr) allocation including line charging admittance

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

TABLE IV
Improved Y – Bus Reactive power Cost (in Rs./MVArh) allocation including line charging admittance

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

The reactive power and its cost allocation results obtained for Improved Y - bus method including proportional sharing using MATLAB programming are shown in the Tables V and VI respectively.

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TABLE V
Improved Y – Bus Reactive power (in MVAr) allocation including proportional sharing

Load Bus	Generator Bus		Line No.					Total MVAr/Bus
	1	4	1	2	3	4	5	
2	1.749	0.453	0.746	6.956	0.000	0.096	0.000	10.000
3	0.421	12.871	0.179	0.000	3.798	2.731	0.000	20.000
4	7.754	12.336	3.300	0.000	0.000	2.618	3.992	30.000
							Total	60.000

TABLE VI
Improved Y – Bus Reactive power Cost (in Rs./MVArh) allocation including proportional sharing

Load Bus	Generator Bus		Line No.					Total Cost/Bus
	1	4	1	2	3	4	5	
2	262.35	67.95	111.90	1043.40	0.00	14.40	0.00	1500.00
3	63.15	1930.65	26.85	0.00	569.70	409.65	0.00	3000.00
4	1163.10	1850.40	495.00	0.00	0.00	392.70	598.80	4500.00
							Total	9000.00

The reactive power and its cost allocation results obtained for Improved Y - bus method including equal sharing using MATLAB programming are shown in the Tables VII and VIII respectively.

TABLE VII
Improved Y – Bus Reactive power (in MVAr) allocation including equal sharing

Load Bus	Generator Bus		Line No.					Total MVAr/Bus
	1	4	1	2	3	4	5	
2	1.434	0.824	0.610	6.956	0.000	0.176	0.000	10.000
3	1.273	11.869	0.541	0.000	3.798	2.519	0.000	20.000
4	8.130	11.893	3.461	0.000	0.000	2.524	3.992	30.000
							Total	60.000

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TABLE VIII

Improved Y – Bus Reactive power Cost (in Rs./MVArh) allocation including equal sharing

Load Bus	Generator Bus		Line No.					Total CostBus
	1	4	1	2	3	4	5	
2	215.10	123.60	91.50	1043.40	0.00	26.40	0.00	1500.00
3	190.95	1780.35	81.15	0.00	569.70	377.85	0.00	3000.00
4	1219.50	1783.95	519.15	0.00	0.00	378.60	598.80	4500.00
							Total	9000.00

V CASE STUDY – II, IEEE 24 BUS SYSTEM

The IEEE 24 bus test system [10] is used as a case study – II to illustrate the proposed method for allocation of reactive power and its cost.

A) Results for Modified Y Bus Method

The reactive power and its cost allocation results obtained for modified Y-bus method using MATLAB programming are shown in the Tables IX and X respectively.

TABLE IX

Reactive Power (in MVAr) Allocation using Modified Y – Bus method

Load Bus	Generator Bus								Total MVAr/Bus
	1	2	7	13	14	15	16	23	
3	2.469	0.584	0.337	2.437	- 0.955	12.485	0.000	0.687	19.000
4	0.620	7.260	0.675	2.361	1.402	1.728	0.000	0.954	15.000
5	7.824	1.239	- 0.608	2.089	1.958	0.178	0.000	0.832	14.000
6	2.649	1.170	1.379	4.360	2.472	0.342	0.000	1.627	14.000
8	1.103	1.296	9.702	2.533	1.457	0.939	0.000	0.969	18.000
9	2.491	4.048	2.622	9.592	5.799	7.449	0.000	3.999	36.000
10	3.925	3.813	1.927	6.476	4.778	0.541	0.000	2.539	23.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	11.665	6.334	18.000
20	0.000	0.000	0.000	0.000	0.000	0.000	3.149	9.851	13.000
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
								Total	171.120

TABLE X

Reactive Power Cost (in Rs./MVArh) Allocation using Modified Y – Bus method

Load Bus	Generator Bus								Total Cost/Bus
	1	2	7	13	14	15	16	23	
3	370.35	87.60	50.55	365.55	- 143.25	1872.75	0.00	103.05	2850.00
4	93.00	1089.00	101.25	354.15	210.30	259.20	0.00	143.10	2250.00
5	1173.60	185.85	- 91.20	313.35	293.7	26.70	0.00	124.80	2100.00
6	397.35	175.50	206.85	654.00	370.80	51.30	0.00	244.05	2100.00
8	165.45	194.40	1455.30	379.95	218.55	140.85	0.00	145.35	2700.00
9	373.65	607.20	393.30	1438.80	869.85	1117.35	0.00	599.85	5400.00
10	588.75	571.95	289.05	971.40	716.70	81.85	0.00	380.85	3450.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	1749.75	950.10	2700.00
20	0.00	0.00	0.00	0.00	0.00	0.00	472.35	1477.65	1950.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
								Total	25668.00

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Form the Tables IX and X, it is observed that there is some over allocation of the reactive power and its cost by using modified Y bus allocation of reactive power. The total reactive power allocation i.e., 171.120 MVAr shown in Table IX is some what more than actual reactive power demand i.e., 170 MVAr.

This over allocation of reactive power may leads to collection of excess amount of cost from the customers and it is observed from the Table X. In Table X, it shows the total allocated cost as 25668 Rs./MVAr and it is more than the actual cost (25500 Rs./MVAr) of the actual reactive power demand.

Another observation from the Tables IX and X is negative allocation of the reactive power and its cost. From the Table IX it shows that the reactive power allocation from generator 7 to load 5 and generator 14 to load 3 is negative and from the Table X it shows that cost allocation from generator 7 to load 5 and generator 14 to load 3 is also a negative value. This negative allocation of the reactive power represents that instead of allocating a reactive power a generator taking the power from the load. These are the two disadvantages of the modified Y bus method of reactive power allocation.

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B) Results for Improved Y Bus Method

The reactive power and its cost allocation results obtained for Improved Y - bus method including line charging admittance using MATLAB programming are shown in the Tables XI and XII respectively.

TABLE XI

Improved Y – Bus Reactive power (in MVAr) allocation including line charging admittance

Load Bus	Generator Bus						Line No.													
	1	2	7	9	10	11	1	2	3	4	5	6	7	8	12	16	19	20	24	
3	1.81	0.49	0.36	0.00	0.00	1.20	0.20	0.03	4.66	0.00	0.00	0.00	0.00	0.00	1.11	0.00	0.00	0.00	9.08	19.00
4	0.46	5.23	0.56	0.00	0.00	1.89	0.05	0.33	0.00	3.15	0.00	0.00	0.01	0.00	1.77	0.00	0.00	0.00	1.50	15.00
5	5.69	1.01	0.53	0.00	0.00	1.78	0.64	0.06	0.00	0.00	2.51	0.00	0.01	0.00	1.69	0.00	0.00	0.00	0.04	14.00
6	1.25	1.29	0.65	0.00	0.00	2.13	0.14	0.08	0.00	0.00	0.00	9.14	0.01	0.00	1.96	0.00	0.00	0.00	0.07	14.00
8	0.72	0.89	6.07	0.00	0.00	1.87	0.08	0.05	0.00	0.00	0.00	0.00	0.13	5.65	1.77	0.00	0.00	0.00	0.72	18.00
9	2.03	3.27	2.45	5.35	0.00	8.13	0.22	0.20	0.00	0.00	0.00	0.00	0.05	0.00	7.62	0.00	0.00	0.00	6.63	36.00
10	2.10	2.38	1.07	0.00	9.98	3.49	0.37	0.15	0.00	0.00	0.00	0.00	0.02	0.00	3.19	0.00	0.00	0.00	0.12	23.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.55	9.98	2.47	0.00	19.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00	0.00	13.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																			Total	170.00

TABLE XII

Improved Y – Bus Reactive power Cost (in Rs./MVArh) allocation including line charging admittance

Load Bus	Generator Bus						Line No.													
	1	2	7	9	10	11	1	2	3	4	5	6	7	8	12	16	19	20	24	
3	271.5	73.5	54.0	0.0	0.0	180.0	30.0	4.5	699.0	0.0	0.0	0.0	0.0	0.0	166.5	0.0	0.0	0.0	1362	2850.0
4	69.0	784.5	84.0	0.0	0.0	283.5	7.5	49.5	0.0	472.5	0.0	0.0	1.5	0.0	265.5	0.0	0.0	0.0	225.0	2250.0
5	853.5	151.5	79.5	0.0	0.0	267.0	96.0	9.0	0.0	0.0	376.5	0.0	1.5	0.0	253.5	0.0	0.0	0.0	6.0	2100.0
6	187.5	193.5	97.5	0.0	0.0	319.5	21.0	12.0	0.0	0.0	0.0	1371	1.5	0.0	294.0	0.0	0.0	0.0	10.5	2100.0
8	108.0	133.5	910.5	0.0	0.0	280.5	12.0	7.5	0.0	0.0	0.0	0.0	7.5	847.5	265.5	0.0	0.0	0.0	108.0	2700.0
9	304.5	490.5	367.5	802.5	0.0	1220	33.0	30.0	0.0	0.0	0.0	0.0	7.5	0.0	1143	0.0	0.0	0.0	994.5	5400.0
10	315.0	357.0	160.5	0.0	1497	523.5	55.5	22.5	0.0	0.0	0.0	0.0	3.0	0.0	478.5	0.0	0.0	0.0	18.0	3450
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	982.5	1497	370.5	0.0	2850.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1950	0.0	1950.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
																			Total	25500

The reactive power and its cost allocation results obtained for Improved Y - bus method including proportional sharing using MATLAB programming are shown in the Tables XIII and XIV respectively.

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TABLE XIII

Improved Y – Bus Reactive power (in MVAr) allocation including proportional sharing

Load Bus	Generator Bus						Line No.													
	1	2	7	9	10	11	1	2	3	4	5	6	7	8	12	16	19	20	24	
3	2.07	0.16	0.11	0.00	0.00	0.86	0.23	0.01	4.66	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	10.0	19.00
4	0.08	7.45	0.20	0.00	0.00	1.57	0.01	0.47	0.00	3.15	0.00	0.00	0.00	0.00	1.56	0.00	0.00	0.00	0.47	15.00
5	7.63	0.32	0.15	0.00	0.00	1.24	0.86	0.02	0.00	0.00	2.51	0.00	0.00	0.00	1.23	0.00	0.00	0.00	0.00	14.00
6	0.70	0.14	0.29	0.00	0.00	1.83	0.07	0.01	0.00	0.00	0.00	9.14	0.01	0.00	1.77	0.00	0.00	0.00	0.00	14.00
8	0.18	0.25	9.25	0.00	0.00	1.15	0.02	0.01	0.00	0.00	0.00	0.00	0.20	5.65	1.13	0.00	0.00	0.00	0.11	18.00
9	0.68	2.33	1.60	5.35	0.00	11.17	0.07	0.14	0.00	0.00	0.00	0.00	0.03	0.00	11.15	0.00	0.00	0.00	3.44	36.00
10	1.55	1.37	0.64	0.00	9.98	4.49	0.17	0.08	0.00	0.00	0.00	0.00	0.01	0.00	4.43	0.00	0.00	0.00	0.00	23.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.74	9.98	3.28	0.00	19.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00	0.00	13.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																			Total	170.00

TABLE XIV

Improved Y – Bus Reactive power Cost (in Rs./MVArh) allocation including proportional sharing

Load Bus	Generator Bus						Line No.													
	1	2	7	9	10	11	1	2	3	4	5	6	7	8	12	16	19	20	24	
3	310.5	24.0	16.5	0.0	0.0	129.0	34.5	1.5	699.0	0.0	0.0	0.0	0.0	0.0	127.5	0.0	0.0	0.0	1500	2850.0
4	12.0	1118	30.0	0.0	0.0	235.5	1.5	70.5	0.0	472.5	0.0	0.0	0.0	0.0	234.0	0.0	0.0	0.0	70.5	2250.0
5	1144	48.0	22.5	0.0	0.0	186.0	129	3.0	0.0	0.0	376.5	0.0	0.0	0.0	184.5	0.0	0.0	0.0	0.0	2100.0
6	105.0	21.0	43.5	0.0	0.0	274.5	10.5	1.5	0.0	0.0	0.0	1371	1.5	0.0	265.5	0.0	0.0	0.0	0.0	2100.0
8	27.0	37.5	1387	0.0	0.0	172.5	3.0	1.5	0.0	0.0	0.0	0.0	3.0	847.5	169.5	0.0	0.0	0.0	16.5	2700.0
9	102.0	349.5	240.0	802.5	0.0	1675	10.5	21.0	0.0	0.0	0.0	0.0	4.5	0.0	1672	0.0	0.0	0.0	516.0	5400.0
10	77.5	205.5	96.0	0.0	1497	673.5	25.5	1.2	0.0	0.0	0.0	0.0	1.5	0.0	664.5	0.0	0.0	0.0	0.0	3450.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	861.0	1497	492.0	0.0	2850.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1950	0.0	1950.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
																			Total	25500

The reactive power and its cost allocation results obtained for Improved Y - bus method including equal sharing using MATLAB programming are shown in the Tables XV and XVI respectively.

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TABLE XV

Improved Y – Bus Reactive power (in MVAr) allocation including equal sharing

Load Bus	Generator Bus						Line No.													
	1	2	7	9	10	11	1	2	3	4	5	6	7	8	12	16	19	20	24	
3	2.68	0.50	0.42	0.00	0.00	1.50	0.30	0.03	4.66	0.00	0.00	0.00	0.01	0.00	1.53	0.00	0.00	0.00	7.33	19.00
4	0.25	5.89	0.57	0.00	0.00	2.02	0.02	0.37	0.00	3.15	0.00	0.00	0.01	0.00	2.05	0.00	0.00	0.00	0.62	15.00
5	6.09	0.59	0.49	0.00	0.00	1.75	0.68	0.03	0.00	0.00	2.51	0.00	0.01	0.00	1.78	0.00	0.00	0.00	0.01	14.00
6	0.54	1.19	0.36	0.00	0.00	1.28	0.06	0.08	0.00	0.00	0.00	9.14	0.01	0.00	1.30	0.00	0.00	0.00	0.01	14.00
8	0.45	0.55	7.49	0.00	0.00	1.65	0.05	0.03	0.00	0.00	0.00	0.00	0.16	5.65	1.67	0.00	0.00	0.00	0.25	18.00
9	1.25	3.28	2.78	5.35	0.00	9.85	0.14	0.21	0.00	0.00	0.00	0.00	0.06	0.00	9.98	0.00	0.00	0.00	3.04	36.00
10	1.71	1.38	1.14	0.00	9.98	4.06	0.19	0.08	0.00	0.00	0.00	0.00	0.02	0.00	4.12	0.00	0.00	0.00	0.04	23.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.23	9.98	3.79	0.00	19.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.00	0.00	13.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
																			Total	170.00

TABLE XVI

Improved Y – Bus Reactive power Cost (in Rs./MVArh) allocation including equal sharing

Load Bus	Generator Bus						Line No.													
	1	2	7	9	10	11	1	2	3	4	5	6	7	8	12	16	19	20	24	
3	402.0	75.0	63.0	0.0	0.0	225.0	45.0	4.5	699.0	0.0	0.0	0.0	1.5	0.0	229.5	0.0	0.0	0.0	1100	2850.0
4	37.5	883.5	85.5	0.0	0.0	303.0	3.0	55.5	0.0	472.5	0.0	0.0	1.5	0.0	307.5	0.0	0.0	0.0	93.0	2250.0
5	913.5	88.5	73.5	0.0	0.0	262.5	102.0	4.5	0.0	0.0	376.5	0.0	1.5	0.0	267.0	0.0	0.0	0.0	1.5	2100.0
6	81.0	178.5	54.0	0.0	0.0	192.0	9.0	12.0	0.0	0.0	0.0	1371	1.5	0.0	195.0	0.0	0.0	0.0	1.5	2100.0
8	67.5	82.5	1123	0.0	0.0	247.5	7.5	4.5	0.0	0.0	0.0	0.0	24.0	847.5	250.5	0.0	0.0	0.0	37.5	2700.0
9	187.5	492.0	417.0	802.5	0.0	1477	21.0	31.5	0.0	0.0	0.0	0.0	9.0	0.0	1497	0.0	0.0	0.0	456.0	5400.0
10	256.5	207.0	171.0	0.0	1497	609.0	28.5	12.0	0.0	0.0	0.0	0.0	3.0	0.0	618.0	0.0	0.0	0.0	6.0	3450.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	784.5	1497	568.5	0.0	2850.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1950	0.0	1950.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
																			Total	25500

From the Tables XI to XVI it is observed that the allocation of reactive power i.e, 170 MVAr and its cost i.e., 25500 Rs./MVAr are same as actual reactive power demand.

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Another observation from the Tables XI and XVI is that there is no negative allocation of reactive power and its cost to the loads. With these two observations it is concluded that the Improved Y bus method of reactive power allocation including line charging admittance, proportional sharing and equal sharing is gets eliminated the disadvantages which are in the modified y bus method.

VI CONCLUSIONS

The circuit theory based method for reactive power allocation is presented in this paper. The proposed method is illustrated using sample 5 bus system and IEEE 24 bus system. The proposed method including line charging admittance, proportional sharing and equal sharing has been eliminated the drawbacks in the modified Y bus method. This improved Y bus method technique can provide the more transparent allocation of reactive power and its cost to the customers. The proportional sharing and equal sharing allocation techniques are basically works from power flow tracing analysis and they can calculated the power and its cost at each and every node point and with these techniques there is no chance of getting over and negative allocation of the reactive power and its cost to the customers.

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