Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 1 October-December (2014) pp. 60-65

http://www.krishisanskriti.org/areee.html

Reactive Power Tracing in Deregulated Environment

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Abstract: *Abstract: For transparency and accurate cost identification, ancillary services including reactive power supply are unbundled in a deregulated power system .Reactive power providers receives the revenue collected from consumers. Due to increasing demand in availability of reactive power, an appropriate and transparent reactive power pricing scheme will encourage more generators to participate in reactive power market. Here a circuit theory based method is applied which identifies different reactive power sources and allocates the amount of reactive power provided to different sources by using an improved Y-bus technique along with proportional or equal sharing principle. Computer tests are conducted using the IEEE 6 and 30-bus system and the results show that the applied method is reasonable and practical.*

***Keywords**: Deregulation, ancillary service, power flow tracing, transmission loss allocation*

1. INTRODUCTION

The major trend in the power industry reform throughout the world is Liberalization. The transmission system is open to access by all power market participants, with the independent system operator (ISO) in charge of system dispatch and operation. To keep the system running normally, some ancillary services either purchased by contract or from a bidding market are needed. Certainly, the costs of these services should be shared by the users, and how to fairly allocate the costs becomes an important issue. The reactive power is confined to mainly local consumption, which will motivate the market to determine the actual value of each supply. A fair and adequate method for allocating the costs may help the market participants make appropriate and efficient investments of reactive power sources, which include static capacitors, flexible ac transmission system (FACTS) devices, and synchronous condensers. All of these can offer system operators more tools and can strengthen the system security. While focusing on the part of reactive power consumed by the loads, this paper applies a scheme to allocate the costs of reactive power supplied by generators, synchronous condensers, or capacitors. So far, the methods of allocating real power and reactive power cost may fall into three categories. The first is the tracing of the electricity flow [2]. By calculating the upstream distribution matrix; this approach can deduce the real or reactive power from individual generators received by each load. Next is the approach to ascertaining the contributions of generators to the power flow [3]. It simplifies the power system to state graphs and then uses recursive equations to solve the real and reactive power that each generator contributes to individual loads. The third is graph theory [4]. Contribution factors are calculated to determine the real or reactive power that each generator contributes to individual lines and loads. These methods have made some contributions to the modern power industry for system operation security, consumers' pricing, and investment signals. This paper is not concerned about the aspect of the real power because bilateral transactions of the real power will take place after the liberalization of the power industry as effective power transactions will be performed by fixed buyers and fixed sellers.

The rest of the manuscript is organized as follows. Section II gives an insight into the power-flow tracing. Section III gives the description on Proportional Sharing Principle and its associated algorithm-Downstream algorithm which is used to determine transmission loss allocation. The results of its application on IEEE 6 and 30-bus test system are shown in Section IV and finally, the last section presents conclusion.

2. POWER TRACING

It is very important to know the function of individual generators and loads to transmission lines and power transfer between individual generators to load in a power system. The power tracing methods helps to know the power transfer between individual generator to loads. Tracing methods determine the contribution of transmission user to transmission usage. It is also used for transmission pricing. The methods for tracing the power flow are upstream and downstream algorithms. This manuscript proposes a power-flow tracing and loss allocation method based on the power-flow results. The proposed method uses graph theoretic and proportional sharing based approaches. The method utilizes the branch-bus flow direction matrix and power-flow results. Thus, the prime strength of the method is its simplicity, which is one of the major requirements of power tracing and loss allocation tools.

3. DOWNSTREAM LOOKING ALGORITHM

Now consider the dual, downstream-looking, problem when the nodal through-flow *P*, is expressed as the sum of outflows

$$P_i = \sum | P_{i-l} | + P_{Li}$$

$$P_i = \sum C_{li} P_i + P_{Li}$$

where alpha(i)^d is, as before, the set of nodes supplied directly from node i and

$$C_{li} = | P_{i-l} | / P_l$$

This equation can be rewritten as

$$P_i - \sum C_{li} P_i = P_{Li}$$

$$A_D P = P_L$$

Where A_d is the *(n* x *n)* downstream distribution matrix and P, is the vector of nodal demands. The (i.l) element of A_d is equal to

$$[A_d]_{il} = \begin{cases} 1 \\ -C_{li} = -| P_{i-l} | / P_l \\ 0 \end{cases}$$

Note that **A,** is also sparse and non symmetric. Adding and gives a symmetric matrix which has the same structure as the nodal. Admittance matrix. If A_d^{-1} exists then $P = A_d^{-1} P_L$ and its ith element is equal to

$$P_i = \sum [A_l^{-1}]_{ik} P_{ik} \text{ for i=1,2…..n}$$

This equation shows how the nodal power P, distributed between all the loads in the system. On the other hand, the same P_i is equal to the sum of the generation at node ***i*** and all the inflows in lines entering the node. Hence the inflow to node ***i*** from line **i-j** can be calculated using the proportional sharing principle as

$$| P_{i-l} | = \left(| P_{i-l} / P_i \right) P_i = \left(| P_{i-l} | / P_i \right) \sum [A_l^{-1}]_{ik} P_{ik}$$

$$= \sum D_{i=j}, k^L P_{LK}$$

Where $\sum D_{i=j}, k^L P_{LK}$ is the topological load distribution factor that is the portion of kth load demand that flows in line i-j.

This definition is again similar to that of the generalized load distribution factor based on DC load-flow sensitivity analysis. However, the topological factor represents the share (which is always positive) of the load in a line flow while the generalized factor determines the impact of the load on a line flow and may be negative. The generation at a node is also an inflow and can be calculated using the proportional sharing principle as

$$P_{Gi} = \left(P_{Gi} / P_i \right) P_i = (P_{Gi} / P_i) \sum [A_d^{-1}]_{ik} P_{ik}$$

This equation shows that the share of the output of the ith generator used to supply the kth load demand is equal to $P_{Gi} P_{LK} [A_d^{-1}]_{ik} / P_i$ and can be used to trace where the power of a particular generator goes to[1].

4. RESULTS AND DISCUSSIONS

a) An application with IEEE 6 bus system

To make the applied method easy to understand, a small test system was selected to explain the steps involved. The system data can be found in appendix. From the power-flow results, the direction of power flows through the lines can be determined. The reactive power-flow direction is indicated by the arrows placed under the branches

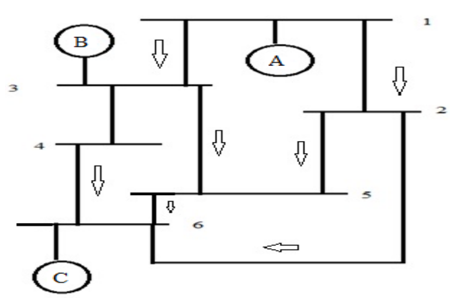

Fig. 2: One line diagram of 3 Generator 6 bus system

Three generators are connected to buses 1, 3 and 6. From the power-flow directions shown in the figure, it can be seen that only bus 1 is the start buses, as the buses get power from only the generator. All other generator buses, namely buses 3 and 6, do not get power only from the generators connected to that bus through the transmission lines. Bus 6 is only the bus where all of the connecting lines carry incoming power, and no line carries power out of this bus. So, bus 6 is the only end bus in this system. Although bus 2 is a load bus, it has an outward power carrying line connected with it, so this is not an end bus. This process of selecting start and end buses can be repeated for real power tracing .Once the start and end buses are selected, the flow-direction matrix (F) is formed. Matrix F (Flow Incidence Matrix) for active power allocation of the test system is-

Table 1: Flow Incidence Matrix

	1	2	3	4	5	6
1	0	1	1	0	0	0
2	0	0	0	0	1	1
3	0	0	0	1	1	0
4	0	0	0	0	0	1
5	0	1	0	0	0	1
6	0	0	0	0	0	0

The elements of F having value 1 indicate a direct connection between the corresponding buses. As bus 1 is directly connected to bus 2 and 3, and the direction of the power flow is from bus 1 to bus 2, so the first row of F has a 1 value in column 2 and 3. In bus 6, although there are three lines connected, power flow in all of these buses is toward this bus, so all of the elements in the last row of F are 0.

The total inflow for each of the buses is calculated using Step 4, followed by the calculation of the contribution for each of the generator buses on itself. This is taken as 1 if the generator is a start generator. So, for the six-bus system, the contribution of generator 1 towards itself will be 1. For all other generators at buses 3 and 4, their contributions on the bus where they are connected will be calculated as

$$C_{33} = P_{G3} / P_3$$

where PG3 is the output of the generator at bus 3, and P3 is the total inflow at bus 3. This value comes to be 0.9091 for the present test system. Once the contribution of generators toward their own buses are over, any of the start buses is selected (1, here), and the contribution of this bus is calculated for all the buses (j) having a non zero element of F corresponding to this new bus. From the flow-direction matrix shown above, it is seen that, corresponding to bus 1, only bus 2 has a non-zero element. So, the contribution of bus 1 on bus 2 will be

$$C_{12}=P_{12}/P_2$$

Where P_{12} is the power flow from bus 1 to bus 2, and P_2 is the total inflow at bus 2.

Bus 2 will now be considered as the start bus, and the process will be repeated for all other buses until it reaches any one of the end buses. These steps are repeated for all generators. The resulting contribution matrix, which gives the contribution of each bus on all other buses, is

Table 2: Contribution matrix of one bus with another

	1	2	3	4	5	6
1	1	1	0.091	0	0	0
2	0	0	0	0	0.714	0.4286
3	0	0	0	0	0.714	0.4286
4	0	0	0	0	0.143	0.2143
5	0	0	0	0	0	0.2143
6	0	0	0	0	0	0.1429

If any bus has a contribution value of less than 1 toward itself (here buses 2, 3, 4, 5 and 6), then its contribution for all other buses gets modified by multiplying each of the contribution value for that bus by its self-contribution, which is less than 1.The final contribution matrix of the generators toward the active load for the test system is

Table 3: Final Contribution matrix

	1	2	3	4	5	6
1	1	1	0.091	0.091	0.74	0.6309
2	0	0	0	0	0	0
3	0	0	0.909	0.909	0.26	0.2505
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0.1429

The contribution of generator buses on the other bus is as follows-

Table 4: Generator by load bus's contribution matrix

	1	3	6
1	1	0.0909	0.6039
2	0	0	0
3	0	0.9091	0.2505
4	0	0	0
5	0	0	0
6	0	0	0.1429

The graphical representation is as follows-

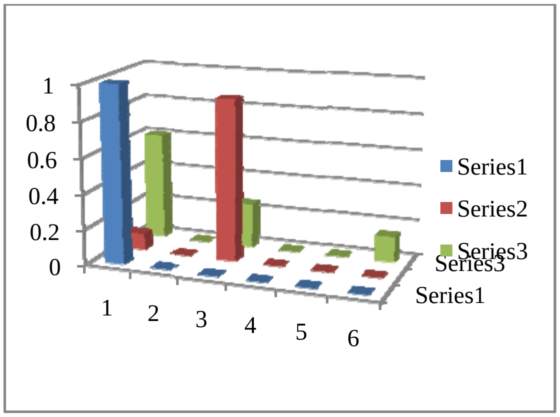

Fig. 3: Graphical representaion of generator by load contribution

From the figure, it is clear that

1) Generator 1 is supplying 100% power to Bus 1.
2) Generator 3 is supplying 9.09% power to Bus 1 and 90.9% power to Bus3
3) Generator 6 is supplying 60.3% power to Bus 1, 25.05% power to Bus 3 and 14.29% power to Bus 6.

(B) An application with IEEE 30 bus system

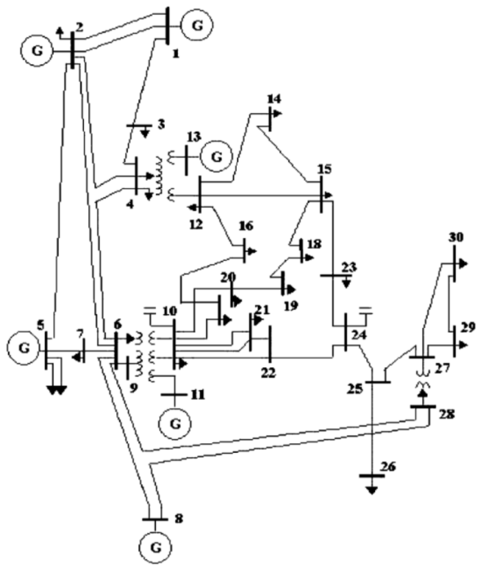

Fig. 4: IEEE 30 bus system with 6 generators

Considering bus 1 as the start bus, reactive power is traced in the above system. Starting with the flow-incidence matrix, the connections are checked between each lines are contribution is analyzed by proportional sharing principle.

Following the similar steps of Downstream Looking Algorithm, the above system is traced for reactive power and the updated contribution matrix is shown in **Table 5**

The contribution of generators to the other bus/loads are analyzed and graphically represented as follows-

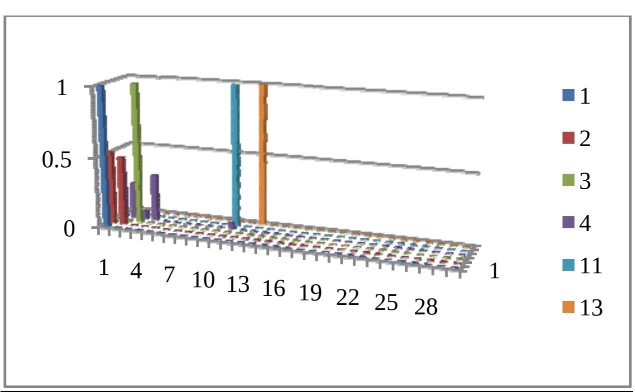

Fig. 5: Generator's Contribution on buses for 30 bus system

Table 5: Final contribution matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0.5139	0	0.3263	0.8063	1	0.4121	0.2416	0	0.034	0	0.0102	0	0.0102	0.0102	0.0102	0.0177	0.0102	0.0243	0.034	0.034	0.034	0.0102	0.0256	0.0256	0.0256	0.2363	0.4121	0.2356	0.2356
2	0	0.4861	0	0.2537	0.1937	0	0.099	0.0581	0	0.0082	0	0.0024	0	0.0024	0.0024	0.0024	0.0043	0.0024	0.0058	0.0082	0.0082	0.0082	0.0024	0.0061	0.0061	0.0061	0.0568	0.099	0.0566	0.0566
3	0	0	1	0.0527	0	0	0.2787	0.577	0	0.023	0	0	0	0	0	0	0.0073	0	0.0137	0.023	0.023	0.023	0	0.0148	0.0148	0.0148	0.4037	0.2787	0.4033	0.4033
4	0	0	0	0.3275	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
5	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
6	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
7	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
8	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
9	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
10	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
11	0	0	0	0.0398	0	0	0.2102	0.1233	1	0.9348	1	0	0	0	0	0	0.2908	0	0.5443	0.9174	0.9174	0.9174	0	0.5915	0.5915	0.5915	0.1349	0.2102	0.1202	0.1202
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
13	0	0	0	0	0	0	0	0	0	0	0	0.9874	1	0.9874	0.9874	0.9874	0.6743	0.9874	0.4016	0	0	0	0.9874	0.3508	0.3508	0.3508	0.0087	0	0.0087	0.0087
14	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
15	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
16	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
18	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
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
21	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
22	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
23	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
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
25	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
26	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
27	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
28	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
29	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
30	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

5. CONCLUSION

This method allows how to assess the reactive power generation from all the sources of reactive power, including lines and is distributed between all the sinks of reactive power in the system. This algorithm requires inverting a sparse matrix of the rank equal to sum of the number of nodes and the number of lines in the system. One of the possible applications of the electricity tracing method lies in the apportioning of the transmission loss to individual generators or loads in the network. This can be done by accumulating the losses as the power flows to individual loads (or from individual generators). The nodal loss is assumed to be shared between nodal outflows proportional to the square (or any other power) of the outflows. The method can also be used to assess the contribution of individual sources of reactive power in satisfying individual reactive power demands and therefore be used as a tool for reactive power pricing.

The proportional sharing and power tracing-based reactive power cost allocation methods result in reactive load allocation that is exactly same as the total load without any problem of over-allocation. The allocation resulting from this type of method will never result in over allocation or negative allocation as these are based on proportionality whereas the method applied in this work is based on principles of the circuit theory and therefore may have more acceptability than the intuition-based methods.

REFERENCES

[1] Janusz Bialek "*Tracing the flow of electricity* (IEEE Proc.-Gener. Transm. Distri"., Vol. 143, No 4, July 1996)

[2] M. W. Mustafa, Member, IEEE and H. Shareef, Student Member, IEEE "*A Comparison of Electric Power Tracing Methods Used in Deregulated Power Systems*" (First International Power and Energy Coference PECon 2006 November 28-29, 2006, Putrajaya, Malaysia)

[3] Daniel Kirschen, R.Ron Allan, and G.Goran Strbac "*Contributions of individual generators to loads and flows*,'(IEEE Trans. Power Syst., vol. 12, pp. 52–60, Feb. 1997.)

[4] F.Felix F. Wu, Y.Yixin Ni, and P.Ping Wei, "*Power transfer allocation for open access using graph theory—fundamentals and applications in systems without loopflow*," (IEEE Trans. Power Syst., vol. 15, pp. 923–929, Aug.2000.)

[5] M. De S.K. Goswami "*Reactive support allocation using improved Y-bus matrix method*" (Energy Conversion and Management 64 (2012) 43–51)

[6] Wen-Chen Chu, Bin-Kwie Chen and Chung-Hsien Li "*Allocating the Costs of Reactive Power Purchased in an Ancillary Service Market by Modified Y-Bus Matrix Method*" (IEEE Transactions on Power Systems Vol 19, No. 1, February 2004)

[7] Mala De, Swapan Kumar Goswami "*Voltage support cost allocation*" (Energy Conversion and Management 52 (2011) 1184–1191)

[8] Y. Dai a, X.D. Liu b, Y.X. Ni b, F.S. Wen b,*, Z.X. Han c, C.M. Shen b, Felix F. Wub "*A cost allocation method for reactive power service based on power flow tracing*" (Electric Power Systems Research 64 (2003) 59_/65)