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Analytical Review of Power Flow Tracing in Deregulated Power System

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Abstract Electric Power starts flowing when there is a Source and Sink gets connected. Transmission corridor facilitates that power to flow. The problem arises in the analysis of individual power through a common transmission corridor of a larger system which is called power flow tracing. In the pre-deregulated system, due to the monopolistic nature of governance, the consumer was nothing to say about the tariff or choosing its service provider. But in the free-market or deregulated market system, the price to be charged must be based on fair and transparent manner. So analysis of individual customer's power in a common supply corridor is a major contribution towards the fair and transparent analysis of price. Efficient power flow tracing would make it possible to charge the generators and/or consumers on the basis of actual transmission facility used. This paper deals with the detailed procedure for obtaining active and reactive power tracing for the actual active and reactive power transmitted through a common corridor between generators and loads. Initially, from the Newton-Raphson based load flows, the line flows are computed and then the multiplying factors of the lossy lines are calculated using proportional sharing method. Finally, based on the multiplying factors, the contributions of each line to concerned loads are obtained for both active and reactive power flow tracing. The method is used elaborately in a Six-bus system and subsequently applied to standard IEEE-14 and IEEE-30 Bus test systems and the results are presented.

Keywords: *power flow tracing, proportional sharing method, deregulated power system, lossy line, multiplying factor*

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1. Introduction

The electric industry around the world is undergoing a radical paradigm shift towards deregulation. With the endeavor to achieve diversified customer choice of power suppliers and competitive electricity rates, the vertically integrated utilities are broken down into generation, transmission and distribution entities. Transmission system, which acts as a common corridor between suppliers and customers, plays a significant role in the deregulated market structure.Transmission capability, gauging the ability of the transmission network to carry through electric power, is a major and timely issue of electricity deregulation.UK starts the deregulating of its vertical integrated system in 1989 and the process was followed by Norway, California and other countries. Deregulation process introduces the competition. Though the competition registers in generation and distribution, still transmission enjoys its natural monopoly [1]. Like all monopolies that provide an essential service, electricity transmission must be regulated to ensure that it delivers an economically optimal combination of quality of service and price. Itcaters the matching of supply with demand and maintenance of system reliability and security. The establishment of energy markets has brought a new scenario in the field of power system economics. The buyer always wants to purchase the power with a cheaper rate. This wanting creates a new phenomenon, called congestion, in certain transmission line of the system. The smooth management of congestion is a challenging task for the system operator. To manage anything extra, extra cost is required. Any extra cost incurred in the transmission will finally go to the consumer head. In competitive market, the customer is willing to pay but, he/she wants a justifiable manner forthe cost. Congestion is happened in some of the line. But the point arises that which load is creating the congestion more. Hence, analysis of individual power through a single line is very much needed. It is also very much required for both active and reactive component of the load. Different tracing based methods for congestion management are presented in ref. [2,3].

The power losses in the system play a major role while deciding the tariff. In the pre-deregulated era, the power losses were usually taken as an extra load in the system. But, in present competitive era, the cost due to losses must be allocated in fair manner with different entities connected into the system. Thus allocation of transmission loss is turned up as a major discussion in the deregulated market analysis. Unfortunately, technical losses are nonlinear functions of line flows, and nonlinear electrical laws do not allow determining the amount of a line power flow which is the responsibility of a given generator or demand [4]. Different methodologies, investigations and discussions [5-13] have been worked out on transmission loss allocation. Some methods are based on the bus generators or loads, but not on their relative location within the network and some took the topology of the system into account. A method proposed in [14] is based on the physical line flows and the actual line sharing between loads. The application of this method to a six-bus test system is giving a justified and logical result in comparison to other two widely used methods such as Pro-rata and incremental transmission loss (ITL). The successful application of this method depends mainly on the power tracing of lossy branches. A proper power tracing in a transmission line gives the idea of active and reactive power flow from the source to an individual load. This helps, in the analysis of loss calculation, loss reduction, congestion management, bus voltage profile modification, compensation, etc. which are highly required in the deregulated power market. Out of different power tracing methods, the Proportional sharing method has been adopted in this paper as it is based on the physical line flows and the actual line sharing between the loads.

A detail description of Proportional Sharing method followed by a flow chart for power flow tracing is presented in this paper. A Six-bus test system is taken as case study-I. As the method needs the power flow solution of the system, a Matlab programme based on Newton-Raphson iterative technique [15] is developed to get the load flow data. Based on this data, a thorough calculation has been worked out to find out the multiplying factors of different buses followed by the calculation of power flow contribution of each lossy line to the respective load. From these results, the active and reactive power tracing in the lossy lines for the concerned load are summed up and tabulated separately. The same procedure is applied to IEEE-14 and IEEE-30 bus systems as Case-II and Case-III, respectively. The results of both the systems are tabulated separately.

2. Proportional Sharing Method

The proportional sharing principle [4] states that the power flow reaching a bus from any power line splits among the lines evacuating power from the bus proportionally to their corresponding power flows, which is neither provable nor disprovable. This has been illustrated below in Figure 1.

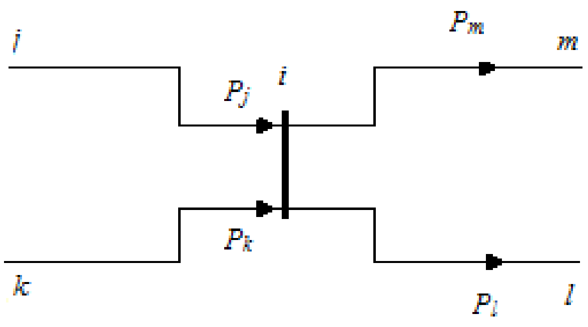


Figure 1. Illustration of Proportional Sharing method

Here '*i*' is taken as the junction node where (*j-i*), (*k-i*) are incoming lines and (*i-m*), (*i-l*) are outgoing lines. P_j, P_k are the receiving powers and P_m, P_l are the outgoing powers at node '*i*'.By proportional sharing principle, each outgoing line takes the power from each incoming line in proportion to its multiplying factor. Now from the figure,the multiplying factor of line (*i-m*) = $\frac{P_m}{P_j + P_k}$; and the multiplying factor of line (*i-l*) = $\frac{P_l}{P_j + P_k}$. As total incoming powers is equal with the total outgoing powers at a node, so, $(P_j + P_k) = (P_m + P_l)$at the node '*i*'.This relation may be used in the above expressions of calculation of multiplying factors.Thus, contribution of incoming power $'P_j'$ to the outgoing line (*i-m*) = $\frac{P_m}{P_m + P_l}$ $\times P_j$.

Similarly, the contribution of incoming power $'P_j'$ to the outgoing line (*i-l*) = $\frac{P_l}{P_m + P_l} \times P_j$. This is repeated for other lines also.

3. Procedure for Power Flow Tracing

The procedure for power flow tracing is presented in form of a flow chart in Fig**ure** 2.

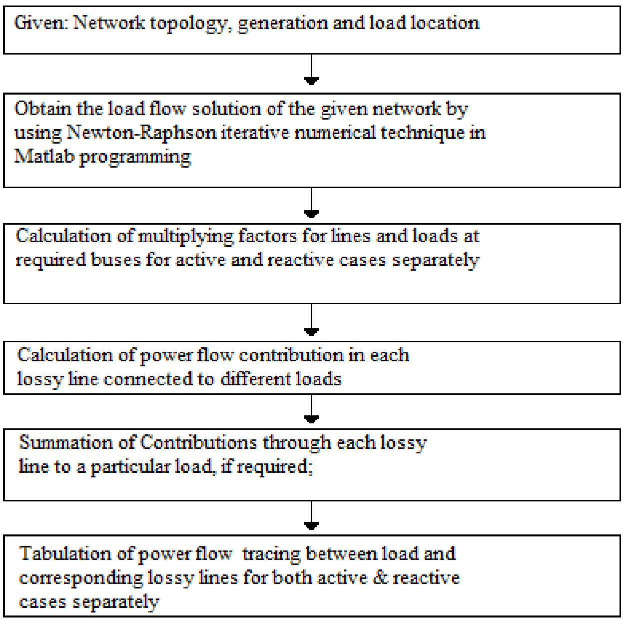


Figure 2. Flow chart for Power Flow Tracing

For a given network topology, generation and load location, load flow solution is obtained by Matlab programming employing Newton-Raphson iterative technique. Then the multiplying factors for line and load are calculated. Power flow contributions in each lossy line connected to different loads are then calculated. After then, summations of contributions through each lossy line to a particular load, if required are calculated. Finally, power flow tracing between load and corresponding lossy lines for both active and reactive cases are separately tabulated.

4. Application of Power Flow Tracing Method and Test Results

4.1. Case Study –I (Six-Bus Test System)

A Six-bus test system with having two voltage-controlled buses and three load buses is shown in Fig.3. Bus 1 and Bus 2 are the two voltage controlled buses and Bus 3, Bus 5 and Bus 6 are the load buses. Bus 1 is taken as the Slack bus. The Bus data, Line data and transformer data are shown in Table 1(a), Table 1(b) and Table 1(c), respectively.

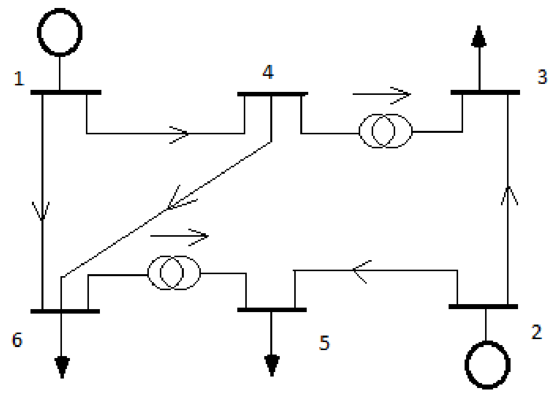


Figure 3. Six-bus test system

Table 1(a). Bus data

Bus No.	Bus Voltage Mag.(pu)	Generator		Load	
		MW	MVAR	MW	MVAR
1	1.05	-	0	0	0
2	1.1	52	0.0	0	0
3	-	0.0	0.0	54	13
4	-	0.0	0.0	0	0
5	-	0.0	0.0	32	18
6	-	0.0	0.0	52	11

Table 1(b). Line data

Line		Line Impedance		Half line Charging Susceptance in p.u.
From	To	R p.u.	X p.u.	
1	4	0.080	0.370	0.014
1	6	0.123	0.518	
2	3	0.723	1.050	
2	5	0.282	0.640	
4	6	0.097	0.407	0.015

Table 1(c). Transformer data

Bus		X in(p.u.)	Tap Setting Value In p.u.
From	To		
4	3	0.133	0.90909
6	5	0.300	0.97560

4.1.1. Calculation of Load Flow

As per the procedure stated above, the load flow calculation has been done using Matlab program based on Newton-Raphson iterative technique and the solution is presented in Table 1(d).

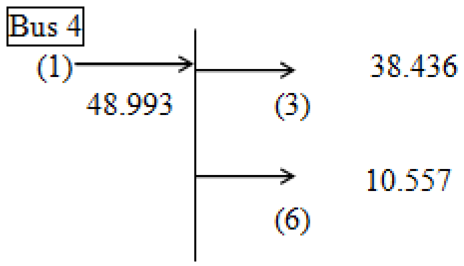
Table 1(d). Load flow solution of Six-bus system

Line		Sending end		Receiving end	
From	To	P	Q	P	Q
1	4	51.573	28.391	-48.993	-19.184
1	6	45.887	25.242	-42.827	-12.356
2	3	17.372	0.930	-15.564	1.696
2	5	34.628	21.477	-30.758	-12.695
4	6	10.557	2.189	-10.415	-4.060
4	3	38.436	16.995	-38.436	-14.696
6	5	1.242	5.415	-1.242	-5.305

4.1.2. Calculation of Multiplying Factors

The calculation of multiplying factors for the different lines is needed for deciding the contribution of power flow through different lines to a particular load. Besides the slack bus, the bus having more than one outgoing line acting as a mediatory path, has to be taken into consideration while deciding to calculate the multiplying factor. In the Six-bus case, bus4 has more than one outgoing line and acts as the mediatory path for the load at buses 3, 6 and 5. Similarly, bus6 acts for load at buses 6 and 5. Even though, bus2 is having more than one outgoing line still it does not act as a mediatory path. Hence, for the Six-bus case, only bus4 and bus6 are to be taken into account. Now the multiplying factors are to be calculated for active and reactive case separately by taking the data from the line flow solution as shown in Table 1(d).

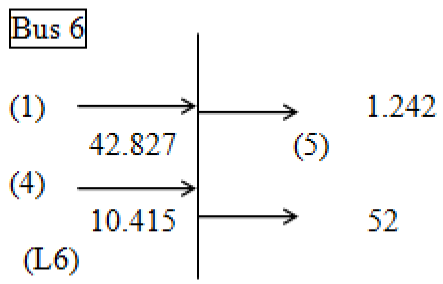
Active Case



Total outgoing active power at bus4 = 38.436+10.557 =48.993. Thus,

$$\text{Multiplying factor of (4-3) line} = \frac{38.436}{48.993} = 0.78452$$

$$\text{Multiplying factor of (4-6) line} = \frac{10.557}{48.993} = 0.21548$$

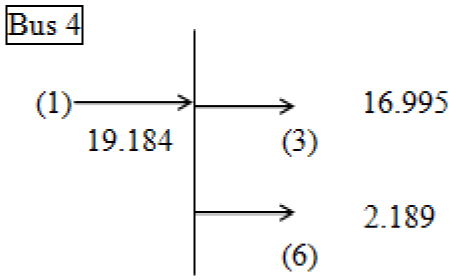


Total outgoing active power at bus6 = 1.242+52 = 53.242.

$$\text{Multiplying factor of (6-5) line} = \frac{1.242}{53.242} = 0.023332$$

$$\text{Multiplying factor of load L6} = \frac{52}{53.242} = 0.97667$$

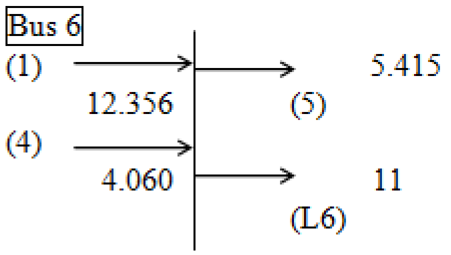
Reactive Case



Total outgoing reactive power at bus4 = 16.995+2.189 = 19.184. Thus,

Multiplying factor of (4-3) line = $\frac{16.995}{19.184}$ = 0.88589

Multiplying factor of (4-6) line = $\frac{2.189}{19.184}$ = 0.1141



Total outgoing reactive power at bus6 = 5.415+11 = 16.415. Thus,

Multiplying factor of (6-5) line = $\frac{5.415}{16.415}$ = 0.33

Multiplying factor of load L6 = $\frac{11}{16.415}$ = 0.67

4.1.3. Calculation of Power Flow Contribution

Now using load flow solution data from Table 1(d) and the above calculated multiplying factors, power flow contributions by different lines to the respective loads are calculated for the cases of active and reactive powers separately.

Active Case

For Load Bus 3:
Contribution of (2-3) line = 15.564
Contribution of (1-4) line = 48.993-10.557 = 38.436
For Load Bus 5:
Contribution of (2-5) line = 30.758
Contribution of (1-6) line = 42.827×0.023332 = 0.9992
Contribution of (4-6) line = 10.415×0.023332 = 0.243
Contribution of (1-4) line = 48.993×0.21548×0.023332 = 0.24631
For Load Bus 6:
Contribution of (1-6) line = 42.827×0.97667 = 41.8278
Contribution of (4-6) line = 10.415×0.97667 = 10.172
Contribution of (1-4) line = 48.993×0.21548×0.97667 = 10.3107

Reactive Case

For Load Bus 3:
Contribution of (2-3) line = -1.696
Contribution of (1-4) line = 19.184-2.189 = 16.995
For Load Bus 5:
Contribution of (2-5) line = 12.695
Contribution of (1-6) line = 12.356×0.33 = 4.07748
Contribution of (4-6) line = 4.060 ×0.33 = 1.3398
Contribution of (1-4) line = 19.184×0.1141×0.33 = 0.7223
For Load Bus 6:
Contribution of (1-6) line =12.356×0.67 = 8.2785
Contribution of (4-6) line = 4.060 × 0.67 = 2.7202
Contribution of (1-4) line = 19.184×0.1141×0.67 = 1.4666.

4.1.4. Tabulation of Power Flow Tracing

In this Six-bus case, the lossy lines are (1-4), (1-6), (2-3), (2-5) and (4-6). The load buses are 3, 5 and 6. Power flow tracing figures are tabulated by taking the relation between load bus and corresponding lossy lines/branches. Table 1(e) and Table 1(f) show the power tracing figures for active and reactive power, respectively. Each element of the table represents the contribution of power flow through the particular lossy branch to the concerned load.

Table 1(e). Active Power Flow Tracing

Load Bus	LOSSY BRANCH				
	1-4	1-6	2-3	2-5	4-6
3	38.436	0	15.564	0	0
5	0.24631	0.9992	0	30.758	0.243
6	10.3107	41.8278	0	0	10.172

Table 1(f). Reactive Power Flow Tracing

Load Bus	LOSSY BRANCH				
	1-4	1-6	2-3	2-5	4-6
3	16.995	0	-1.696	0	0
5	0.7223	4.07748	0	12.695	1.3398
6	1.4666	8.27852	0	0	2.7202

4.2. Case Study –II (IEEE-14 Bus Test System)

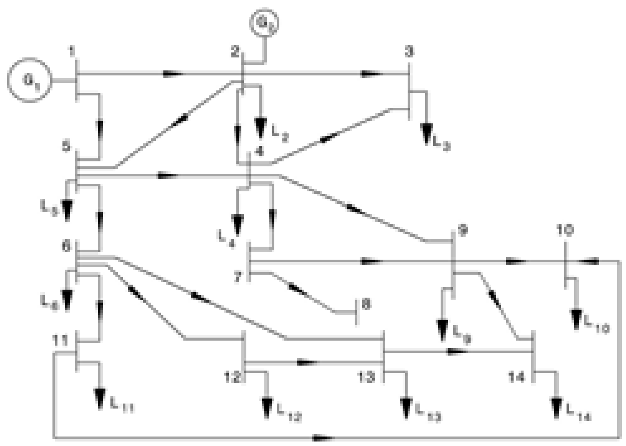


Figure 4. Single Line Diagram of the IEEE 14-Bus Test System

In the IEEE-14 bus system as shown in Fig.4, two generators G1 and G2 are attached to bus1 and bus2, respectively. Bus1 is taken as the Slack bus and loads are attached into the buses 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 and 14. The details of Bus data, line data, transformer tap setting and shunt capacitor data are given in Table 2(a), 2(b), 2(c), and 2(d), respectively.

Table 2(a). Bus data

Bus No.	Bus Voltage Mag.(pu)	Generator		Load		Reactive Power Limits	
		MW	MVAR	MW	MVAR	Qmin	Qmax
1	1.060	0	0	0	0	0	0
2	1.045	40.0	0.0	21.7	12.7	-40.0	50.0
3	1.010	0.0	0.0	94.2	19.1	0	40.0
4	1.000	0.0	0.0	47.8	3.9	0	0
5	1.000	0.0	0.0	7.6	1.6	0	0
6	1.070	0.0	0.0	11.2	7.5	-6.0	24.0
7	1.000	0.0	0.0	0.0	0.0	0	0
8	1.090	0.0	0.0	0.0	0.0	-6.0	24.0
9	1.000	0.0	0.0	29.5	16.6	0	0
10	1.000	0.0	0.0	9.0	5.8	0	0
11	1.000	0.0	0.0	3.5	1.8	0	0
12	1.000	0.0	0.0	6.1	1.6	0	0
13	1.000	0.0	0.0	13.5	5.8	0	0
14	1.000	0.0	0.0	14.9	5.0	0	0

Table 2(b). Line data

Line		Line Impedance		Half line Charging Susceptance in p.u.
From	To	R p.u.	X p.u.	
1	2	0.01938	0.05917	0.02640
2	3	0.04699	0.19797	0.02190
2	4	0.05811	0.17632	0.01870
1	5	0.05403	0.22304	0.02460
2	5	0.05695	0.17388	0.01700
3	4	0.06701	0.17103	0.01730
4	5	0.01335	0.04211	0.00640
5	6	0.0	0.25202	0
4	7	0.0	0.20912	0
7	8	0.0	0.17615	0
4	9	0.0	0.55618	0
7	9	0.0	0.11001	0
9	10	0.03181	0.08450	0
6	11	0.09498	0.19890	0
6	12	0.12291	0.25581	0
6	13	0.06615	0.13027	0
9	14	0.12711	0.27038	0
10	11	0.08205	0.19207	0
12	13	0.22092	0.19988	0
13	14	0.17093	0.34802	0

Table 2(c). Transformer Tap setting

Bus		Tap Setting Value in p.u.
From	To	
4	7	0.978
4	9	0.969
5	6	0.932

Table 2(d). Shunt Capacitor data

Bus No.	Susceptance value in p.u.
9	0.19

4.2.1. Calculation of Load Flow

The load flow solution of IEEE-14 Bus system has been done by Matlab programming using Newton-Raphson iterative technique and the result is presented in Table 2(e).

Table 2(e). Load flow solution of IEEE-14 Bus

Line		Sending end		Receiving end	
From	To	P	Q	P	Q
1	2	156.974	-20.426	-152.705	27.725
1	5	75.439	4.520	-72.676	1.568
2	3	73.366	3.544	-71.035	1.652
2	4	56.082	-0.284	-54.406	1.398
2	5	41.523	2.039	-40.616	-2.888
4	3	23.573	-7.396	-23.191	4.822
5	4	61.495	-12.242	-60.991	12.510
4	7	27.973	-9.907	-27.973	11.617
4	9	16.003	-0.326	-16.003	1.625
5	6	44.278	11.816	-44.278	-7.380
6	11	7.459	4.217	-7.398	-4.090
6	12	7.823	2.532	-7.751	-2.381
6	13	17.825	7.496	-17.609	-7.071
7	8	0.047	-18.362	-0.047	18.891
7	9	27.946	6.792	-27.946	-5.981
9	10	5.156	3.625	-5.144	-3.595
9	14	9.322	3.203	-9.210	-2.966
11	10	3.891	2.320	-3.76	-2.285
12	13	1.656	0.855	-1.649	-0.848
13	14	5.719	2.192	-5.661	-2.073

4.2.2. Tabulation of Power Flow Tracing of IEEE-14 Bus System

Adhering to the procedure described earlier, the multiplying factors have been calculated for the different lines considering the buses 2, 4, 5, 6, 7, 9, 11, 12, and 13. With respect to the loss occurred in lines of the system, the lossy lines are identified as (1-2), (2-3), (2-4), (1-5), (2-5), (4-3), (5-4), (9-10), (6-11), (6-12), (6-13), (9-14), (11-10), (12-13), (13-14). Now the calculation of power flow tracing of the different lossy lines with respect to concerned load are made and the final results of active power tracing and reactive power tracing are presented in Table 2(f) and Table 2(g), respectively.

Table 2(f). Active Power Flow Tracing of IEEE-14 Bus System

Load bus	LOSSY BRANCH														
	1-2	2-3	2-4	1-5	2-5	4-3	5-4	9-10	6-11	6-12	6-13	9-14	11-10	12-13	13-14
2	17.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	70.8578	71.035	11.0988	8.0355	4.49	23.191	12.442	0	0	0	0	0	0	0	0
4	25.7863	0	22.524	16.307	9.11	0	25.25	0	0	0	0	0	0	0	0
5	2.2	0	0	4.8692	2.721	0	0	0	0	0	0	0	0	0	0
6	3.22	0	0	7.122	3.98	0	0	0	0	0	0	0	0	0	0
9	15.8827	0	13.8735	10.04	5.612	0	15.552	0	0	0	0	0	0	0	0
10	3.8826	0	2.3938	4.2571	2.3784	0	2.6836	5.144	3.898	0	0	0	3.898	0	0
11	1.027	0	0	2.271	1.27	0	0	0	3.5	0	0	0	0	0	0
12	1.76	0	0	3.8836	2.17	0	0	0	0	6.1	0	0	0	0	0
13	3.9648	0	0	8.7405	4.8896	0	0	0	0	1.159	12.361	0	0	1.158	0
14	6.6654	0	4.3524	6.8655	3.8356	0	4.8792	0	0	0.491	5.247	9.210	0	0.491	5.661

Table 2(g). Reactive Power Flow Tracing of IEEE-14 Bus System

Load bus	LOSSY BRANCH														
	1-2	2-3	2-4	1-5	2-5	4-3	5-4	9-10	6-11	6-12	6-13	9-14	11-10	12-13	13-14
2	-19.5626	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	-6.9048	-1.652	0.5187	-0.641	1.1807	-4.822	4.6412	0	0	0	0	0	0	0	0
4	0.7638	0	-0.274	0.3387	-0.6237	0	-2.4519	0	0	0	0	0	0	0	0
5	-0.4521	0	0	-0.2257	0.4158	0	0	0	0	0	0	0	0	0	0
6	-2.1195	0	0	-1.0584	1.9494	0	0	0	0	0	0	0	0	0	0
9	3.2426	0	-1.1631	1.4376	-2.6478	0	-10.4083	0	0	0	0	0	0	0	0
10	0.0393	0	-0.2544	-0.0201	0.037	0	-2.2768	3.595	2.29	0	0	0	2.29	0	0
11	-0.52	0	0	-0.2596	0.4783	0	0	0	1.8	0	0	0	0	0	0
12	-0.466	0	0	-0.2327	0.4286	0	0	0	0	1.6	0	0	0	0	0
13	-1.7196	0	0	-0.8587	1.5815	0	0	0	0	0.567	5.1335	0	0	0.6156	0
14	-0.0215	0	-0.225	-0.0459	0.0845	0	-2.0141	0	0	0.214	1.9374	2.966	0	0.2323	2.073

4.3. Case study –III (IEEE-30 Bus Test System)

Studies are carried out on an IEEE-30 bus system as shown in Figure 5. The system consists of two generators at buses 1 and 2. Bus1 is taken as the Slack bus. Loads are attached into the buses 2, 3, 4, 5, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29, and 30. The details of Bus data, line data, transformer tap setting and shunt capacitor data are shown in Table 3(a), 3(b), 3(c), and 3(d), respectively.

Table 3(a). Bus data of IEEE-30 Bus

Bus No.	Bus Voltage Mag.(pu)	Generator		Load		Reactive Power Limits	
		MW	MVAR	MW	MW	MVAR	MW
1	1.060	0.0	0.0	0.0	0.0	0	0
2	1.043	40.0	0.0	21.7	12.7	-40.0	50
3	1.0	0.0	0.0	2.4	1.2	0	0
4	1.06	0.0	0.0	7.6	1.6	0	0
5	1.01	0.0	0.0	94.2	19.0	-40	40
6	1.0	0.0	0.0	0.0	0.0	0	0
7	1.0	0.0	0.0	22.8	10.9	0	0
8	1.01	0.0	0.0	30.0	30.0	-10	40
9	1.0	0.0	0.0	0.0	0.0	0	0
10	1.0	0.0	0.0	5.8	2.0	0	0
11	1.082	0.0	0.0	0.0	0.0	-6	24
12	1.0	0.0	0.0	11.2	7.5	0	0
13	1.071	0.0	0.0	0.0	0.0	-6	24
14	1.0	0.0	0.0	6.2	1.6	0	0
15	1.0	0.0	0.0	8.2	2.5	0	0
16	1.0	0.0	0.0	3.5	1.8	0	0
17	1.0	0.0	0.0	9.0	5.8	0	0
18	1.0	0.0	0.0	3.2	0.9	0	0
19	1.0	0.0	0.0	9.5	3.4	0	0
20	1.0	0.0	0.0	2.2	0.7	0	0
21	1.0	0.0	0.0	17.5	11.2	0	0
22	1.0	0.0	0.0	0.0	0.0	0	0
23	1.0	0.0	0.0	3.2	1.6	0	0
24	1.0	0.0	0.0	8.7	6.7	0	0
25	1.0	0.0	0.0	0.0	0.0	0	0
26	1.0	0.0	0.0	3.5	2.3	0	0
27	1.0	0.0	0.0	0.0	0.0	0	0
28	1.0	0.0	0.0	0.0	0.0	0	0
29	1.0	0.0	0.0	2.4	0.9	0	0
30	1.0	0.0	0.0	10.6	1.9	0	0

Table 3(b). Line data

Line		Line Impedance		Half line Charging Susceptance in p.u.
From	To	R p.u.	X p.u.	
1	2	0.0192	0.0575	0.02640
1	3	0.0452	0.1852	0.02040
2	4	0.0570	0.1737	0.01840
3	4	0.0132	0.0379	0.00420
2	5	0.0472	0.1983	0.02090
2	6	0.0581	0.1763	0.01870
4	6	0.0119	0.0414	0.00450
5	7	0.0460	0.1160	0.01020
6	7	0.0267	0.0520	0.00850
6	8	0.0120	0.0420	0.00450
6	9	0.0	0.2080	0.0
6	10	0.0	0.5560	0.0
9	11	0.0	0.2080	0.0
9	10	0.0	0.1100	0.0
4	12	0.0	0.2560	0.0
12	13	0.0	0.1400	0.0
12	14	0.1231	0.2559	0.0
12	15	0.0662	0.1304	0.0
12	16	0.0945	0.1987	0.0
14	15	0.2210	0.1997	0.0
16	17	0.0824	0.1923	0.0
15	18	0.1073	0.2185	0.0
18	19	0.0639	0.1292	0.0
19	20	0.0340	0.0680	0.0
10	20	0.0936	0.2090	0.0
10	17	0.0324	0.0845	0.0
10	21	0.0348	0.0749	0.0
10	22	0.0727	0.1499	0.0
21	22	0.0116	0.0236	0.0
15	23	0.1000	0.2020	0.0
22	24	0.1150	0.1790	0.0
23	24	0.1320	0.2700	0.0
24	25	0.1885	0.3292	0.0
25	26	0.2544	0.3800	0.0
25	27	0.1093	0.2087	0.0
28	27	0.0000	0.3960	0.0
27	29	0.2198	0.4153	0.0
27	30	0.3202	0.6027	0.0
29	30	0.2399	0.4533	0.0
8	28	0.0636	0.2000	0.0214
6	28	0.0169	0.0599	0.065

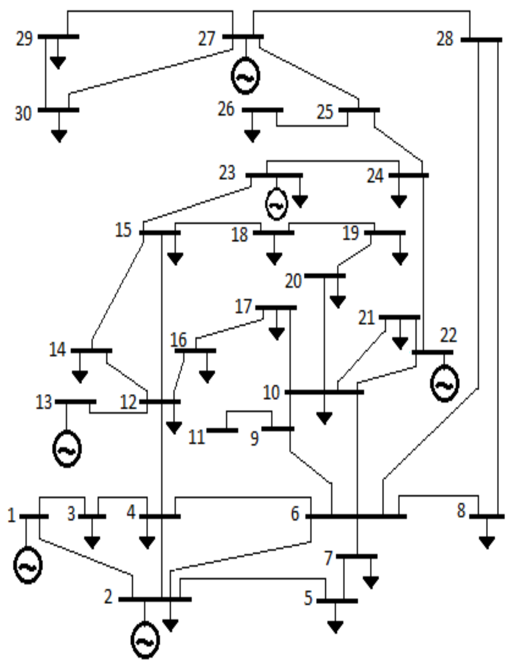


Figure 5. Single Line diagram of IEEE-30 Bus Test System

Table 3(c). Transformer Tap setting

Bus		Tap Setting Value in p.u.
From	To	
4	12	0.932
6	9	0.978
6	10	0.969
28	27	0.968

Table 3(d). Shunt Capacitor data

Bus No.	Susceptance in p.u.
10	19
24	4.3

4.3.1. Calculation of Load Flow

The load flow calculation of IEEE-30 Bus system was done using Matlab programme and the result is presented in Table 3(e).

Table 3(e). Load flow solution of IEEE-30 Bus

Line		Sending end		Receiving end	
From	To	P	Q	P	Q
1	2	177.743	-22.140	-172.282	32.657
1	3	83.197	5.125	-80.390	1.954
2	4	45.702	2.720	-44.596	-3.239
2	5	82.990	1.704	-79.995	6.474
2	6	61.905	-0.966	-59.858	3.229
3	4	78.034	-3.087	-77.263	4.432
4	6	70.132	-17.624	-69.527	18.805
4	12	44.131	14.627	-44.131	-9.941
7	5	14.361	-12.154	-14.210	10.467
6	7	37.537	-1.915	-37.170	1.317
6	8	29.534	-3.712	-29.431	3.154
6	9	27.687	-7.318	-27.687	8.911
6	10	15.828	0.656	-15.828	0.623
6	28	18.840	-9.575	-18.780	-3.510
28	8	0.570	-2.003	-0.570	-2.366
9	11	0.003	-15.653	-0.003	16.114
9	10	27.731	6.747	-27.731	-5.936
10	20	9.018	3.569	-8.937	-3.389
10	17	5.347	4.393	-5.332	-4.355
10	21	15.723	9.846	-15.613	-9.609
10	22	7.582	4.487	-7.531	-4.380
13	12	0.021	10.406	-0.021	-10.274
12	14	7.852	2.428	-7.778	-2.273
12	15	17.852	6.968	-17.634	-6.540
12	16	7.206	3.370	-7.152	-3.257
14	15	1.592	0.708	-1.586	-0.702
15	18	6.009	1.741	-5.970	-1.661
15	23	5.004	2.963	-4.972	-2.900
16	17	3.658	1.440	-3.646	-1.413
18	19	2.779	0.787	-2.774	-0.777
20	19	6.720	2.709	-6.703	-2.675
22	21	1.850	1.628	-1.849	-1.627
22	24	5.643	2.795	-5.601	-2.728
23	24	1.771	1.282	-1.765	-1.270
25	24	1.330	-1.590	-1.322	1.604
25	26	3.520	2.372	-3.476	-2.306
27	25	4.892	0.835	-4.866	-0.786
28	27	18.192	5.463	-18.192	-4.152
27	29	6.178	1.675	-6.093	-1.513
27	30	7.093	1.663	-6.932	-1.359
29	30	3.716	0.601	-3.683	-0.537

Table 3(f). Active Power Tracing of IEEE-30 Bus System for lines (1-2 to 12-14)

Load bus	LOSSY BRANCH									
	1-2	1-3	2-4	3-4	2-5	2-6	4-6	7-5	6-7	6-8	12-14
2	17.573	0	0	0	0	0	0	0	0	0	0
3	0	2.3956	0	0	0	0	0	0	0	0	0
4	2.3113	4.8658	2.78279	4.8212	0	0	0	0	0	0	0
5	75.2093	5.028	2.8754	4.9817	79.995	6.7	7.783	14.21	14.348	0	0
7	12.7358	7.985	4.5664	7.9114	0	10.641	12.36	0	22.785	0	0
8	16.3343	10.2412	5.8567	10.1468	0	13.6476	15.8522	0	0	29.431	0
10	3.2095	2.0123	1.1508	1.9938	0	2.6816	3.11481	0	0	0	0
12	3.4041	7.1664	4.0985	7.1007	0	0	0	0	0	0	0
14	1.8872	3.9731	2.2722	3.9366	0	0	0	0	0	0	6.1913
15	2.5237	5.3129	3.0384	5.2641	0	0	0	0	0	0	0.6773
16	1.0818	2.2775	1.3025	2.2566	0	0	0	0	0	0	0
17	4.087	4.2303	2.4193	4.19143	0	2.4721	2.8715	0	0	0	0
18	0.9898	2.0837	1.1917	2.0646	0	0	0	0	0	0	0.2656
19	4.6184	4.1646	2.3817	4.1263	0	3.1415	3.649	0	0	0	0.2304
20	1.2318	0.7723	0.4417	0.7652	0	1.0292	1.1954	0	0	0	0
21	9.7895	6.1379	3.5102	6.0814	0	8.1794	9.5007	0	0	0	0
23	0.9891	2.0823	1.1909	2.0632	0	0	0	0	0	0	0.2655
24	4.48	3.618	2.0691	3.5848	0	3.2857	3.8165	0	0	0	0.1469
26	2.042	1.28	0.7321	1.26835	0	1.70595	1.9815	0	0	0	0
29	1.3906	0.87168	0.4985	0.8637	0	1.1617	1.3494	0	0	0	0
30	6.2276	3.9037	2.2324	3.8679	0	5.2024	6.0431	0	0	0	0

Table 3(g). Active Power Tracing of IEEE-30 Bus System for lines (12-15 to 10-22)

Load bus	LOSSY BRANCH										
	12-15	12-16	14-15	16-17	15-18	18-19	20-19	10-20	10-17	10-21	10-22
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	7.5297	0	0.6772	0	0	0	0	0	0	0	0
16	0	3.5045	0	0	0	0	0	0	0	0	0
17	0	3.6548	0	3.646	0	0	0	0	5.332	0	0
18	2.9531	0	0.2656	0	3.19395	0	0	0	0	0	0
19	2.5612	0	0.2304	0	2.7701	2.774	6.703	6.7296	0	0	0
20	0	0	0	0	0	0	0	2.2048	0	0	0
21	0	0	0	0	0	0	0	0	0	15.613	1.8828
23	2.9513	0	0.2654	0	0	0	0	0	0	0	0
24	1.6335	0	0.1469	0	0	0	0	0	0	0	5.6708
26	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0

Table 3(h). Active Power Tracing of IEEE-30 Bus System for lines (22-21 to 6-2)

Load bus	LOSSY BRANCH										
	22-21	15-23	22-24	23-24	25-24	25-26	27-25	27-29	27-30	29-30	6-28
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	1.849	0	0	0	0	0	0	0	0	0	0
23	0	3.2	0	0	0	0	0	0	0	0	0
24	0	1.7712	5.601	1.765	1.322	0	1.3343	0	0	0	1.3904
26	0	0	0	0	0	3.476	3.5327	0	0	0	3.6812
29	0	0	0	0	0	0	0	2.391	0	0	2.5069
30	0	0	0	0	0	0	0	3.7022	6.932	3.683	11.2268

Table 3(i). Reactive Power Tracing of IEEE-30 Bus System for lines (1-2 to 12-14)

Load bus	LOSSY BRANCH										
	1-2	1-3	2-4	3-4	2-5	2-6	4-6	7-5	6-7	6-8	12-14
2	-25.668	0	0	0	0	0	0	0	0	0	0
3	0	1.2426	0	0	0	0	0	0	0	0	0
4	-2.072	-1.2051	1.2211	-1.6708	0	0	0	0	0	0	0
5	-53.8929	-27.03	27.3893	-37.4774	-6.474	6.5721	38.275	-10.467	-12.7646	0	0
7	45.2456	24.2418	-24.5633	33.6106	0	-5.8941	-34.326	0	11.4476	0	0
8	-10.1132	-5.4184	5.4903	-7.5125	0	1.3174	7.6724	0	0	-3.154	0
10	5.4494	2.9205	-2.9592	4.0492	0	-0.71	-4.1354	0	0	0	0
12	-9.7176	-5.6519	5.7269	-7.836	0	0	0	0	0	0	0
14	-2.1796	-1.2677	1.2845	-1.7576	0	0	0	0	0	0	1.5757
15	-3.4666	-2.0161	2.0429	-2.7952	0	0	0	0	0	0	0.2419
16	-2.4221	-1.4087	1.4274	-1.9531	0	0	0	0	0	0	0
17	10.02502	5.28464	-5.35468	7.32712	0	-1.5587	-9.0788	0	0	0	0
18	-1.2878	-0.749	0.7589	-1.0383	0	0	0	0	0	0	0.0899
19	6.6118	3.4921	-3.5383	4.8418	0	-1.0082	-5.8722	0	0	0	0.0786
20	1.9974	1.07	-1.0851	1.4848	0	-0.2603	-1.5164	0	0	0	0
21	31.2461	16.7458	-16.9677	23.2176	0	-4.07109	-23.7112	0	0	0	0
23	-2.281	-1.3265	1.3441	-1.8392	0	0	0	0	0	0	0.1592
24	16.5298	8.7737	-8.8902	12.1641	0	-0.38084	-13.9286	0	0	0	0.1276
26	-15.8776	-8.5068	8.6197	-11.7946	0	2.0683	12.0456	0	0	0	0
29	-6.2701	-3.3594	3.4039	-4.65775	0	0.8168	4.7569	0	0	0	0
30	-14.6399	-7.8439	7.9477	-10.8754	0	1.907	11.1068	0	0	0	0

Table 3(j). Reactive Power Tracing of IEEE-30 Bus System for lines (12-15 to 10-22)

Load bus	LOSSY BRANCH									
	12-15	12-16	14-15	16-17	15-18	18-19	20-19	10-20	10-17	10-21	10-22
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	2.2694	0	0.2436	0	0	0	0	0	0	0	0
16	0	1.8076	0	0	0	0	0	0	0	0	0
17	0	1.4461	0	1.413	0	0	0	0	4.355	0	0
18	0.8431	0	0.0905	0	0.886	0	0	0	0	0	0
19	0.7374	0	0.0791	0	0.7749	0.777	2.675	2.6943	0	0	0
20	0	0	0	0	0	0	0	0.6958	0	0	0
21	0	0	0	0	0	0	0	0	0	9.609	1.6123
23	1.4933	0	0.1603	0	0	0	0	0	0	0	0
24	1.1965	0	0.1284	0	0	0	0	0	0	0	2.7677
26	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0

Table 3(k). Reactive Power Tracing of IEEE-30 Bus System for lines (22-21 to 6-28)

Load bus	LOSSY BRANCH									
	22-21	15-23	22-24	23-24	25-24	25-26	27-25	27-29	27-30	29-30	6-28
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	1.627	0	0	0	0	0	0	0	0	0	0
23	0	1.61	0	0	0	0	0	0	0	0	0
24	0	1.29	2.728	1.27	-1.604	0	-1.5978	0	0	0	-1.4269
26	0	0	0	0	0	2.306	2.384	0	0	0	2.1292
29	0	0	0	0	0	0	0	0.9072	0	0	0.8418
30	0	0	0	0	0	0	0	0.6052	1.359	0.537	1.9654

4.3.2. Tabulation of Power Tracing of IEEE-30 Bus System

In this system, buses 2, 3, 4, 6, 7, 9, 10, 12, 14, 15, 16, 18, 20, 22, 23, 25, 27, 28 and 29 are taken for calculation of multiplying factors. Similarly, lines (1-2), (1-3), (2-4), (3-4), (2-5), (2-6), (4-6), (7-5), (6-7), (6-8), (12-14), (12-15), (12-16), (14-15), (16-17),(15-18), (18-19), (20-19), (10-20), (10-17), (10-21), (10-22), (22-21), (15-23), (22-24), (23-24), (25-24), (25-26), (27-25), (27-29), (27-30), (29-30) and (6-28)are identified as lossy lines. Using the procedure stated above, results for active power tracing of the lossy lines (1-2), (1-3), (2-4), (3-4), (2-5), (2-6), (4-6), (7-5), (6-7), (6-8), (12-14) with corresponding to the load buses 2, 3, 4, 5, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29, 30 are presented in Table 3(f). Similarly the lossy lines of (12-15), (12-16), (14-15), (16-17),(15-18), (18-19),(20-19), (10-20), (10-17), (10-21), (10-22), and (22-21), (15-23), (22-24), (23-24), (25-24), (25-26), (27-25), (27-29), (27-30), (29-30), (6-28) with corresponding to the same load buses are presented in Table 3(g) and Table 3(h), respectively. Now the reactive power tracing for the lossy lines of (1-2), (1-3), (2-4), (3-4), (2-5), (2-6), (4-6), (7-5), (6-7), (6-8), (12-14) with corresponding to the load buses 2, 3, 4, 5, 7, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 26, 29, 30 are presented in Table 3(i), similarly the lossy lines of (12-15), (12-16), (14-15), (16-17),(15-18), (18-19),(20-19), (10-20), (10-17), (10-21), (10-22), and (22-21), (15-23), (22-24), (23-24), (25-24), (25-26), (27-25), (27-29), (27-30), (29-30), (6-28) with corresponding to the same load buses are presented in Table 3(j) and Table 3(k), respectively. In these tables the figures indicating active and reactive power flows are in MW and MVAR, respectively.

5. Conclusion

The paper utilizes the proportional sharing method to trace out the individual power drawn by the different load in a common lossy line. Both active and reactive parts of the power are traced out separately in details under the observations of physical load flows. The power tracing data of the standard IEEE-14 and IEEE-30 test system can be used as a ready reckoner for the future application in loss allocation, loss reduction, congestion management, voltage compensation, etc.

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