First International Power and Energy Coference PECon 2006
November 28-29, 2006, Putrajaya, Malaysia

A Hybrid Power Transfer Allocation Approach for Deregulated Power Systems

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***Abstract*--Power transfer allocation is one of the major issues in deregulated power industry. This paper presents a hybrid technique for power transfer allocation. It is based on combining the existing power flow tracing methods that determines the power share from generators to line flows and loads. The advantages of the proposed method are demonstrated by the tests conducted on the IEEE 30-bus system and also on a practical 25-bus equivalent power system of south Malaysia. The proposed method provides better reliability and minimizes the limitations of conventional power flow tracing methods.**

***Index Terms*--Power tracing, energy management, load flow analysis, losses.**

I. INTRODUCTION

LIBERALIZATION is the major trend in the electric power industry throughout the world. The aim is to optimize the system welfare by introducing competitive environment mainly among the suppliers.

In deregulated power systems, technical data such as line usage and loss association to each source are some of the essential information. This knowledge permits system operator to incorporate the level and cost of losses in pricing of transmission service. Besides, supplier's contributing factors to loads and losses are equally important in optimizing the benefit to the participants.

To date, several methods of allocating real and reactive power among system participants are proposed in the current publications on electricity reform and restructuring. Power flow tracing is one of the most popular methodologies that contribute to the modern power industry in transmission pricing, power transfer and loss allocation.

A novel topological power tracing method is proposed in [1]-[3]. The algorithm, commonly known as the Node power flow tracing method, is constructed on the matrix formulation of producer's (or load's) shares in the line flows and by the use of linear algebra. But, even though these features make the method very simple, it requires inverting a large matrix of rank at least equal to the number of network buses. Moreover it considers transmission losses by introducing fictitious nodes on every branch and therefore the calculation becomes very complex and time consuming for large systems.

The method reported in [4]-[6] is based on clustering the network into small groups of buses which are classified as Commons, i.e. a set of buses supplied by same set of generators. The obtained clusters are considered as new buses, connected together with tie lines. The disadvantage of this method is that the share of each generator in each Common is assumed to be the same.

In [7] and [8], graph theory is applied to calculate the contributing factors that each generator contributes to individual lines and loads. In general, this algorithm shares many feature with the Node tracing approach such as modeling the line losses. The most attractive aspect of the method is that it does not require matrix inversion. However, the method is only applicable to systems without loop flows. This method is also called the Graph power flow tracing method. A comprehensive comparison of all the three methods mentioned above can be found in [9].

This paper proposes a hybrid power transfer allocation approach, a combination of existing methods for allocating power to each power producer (or consumer). Starting from load flow solutions, it first clusters the system into number of groups. The obtained clusters are then treated as small independent systems. Finally the Node or Graph approach which is more appropriate for small systems is used to determine the contributing factors to the line flows and loads within each cluster of buses.

II. METHODOLOGY

The main objective of this work is to develop an alternative methodology for power transfer allocation by collecting the useful information from the existing approaches namely the Commons, Graph and Node power tracing method. The Commons approach by itself is very practical for large power systems although the validity of equal contribution to the line flows and loads within a Common is exactly not true. This inconsistency may be improved if it is possible to calculate the contributing factors more accurately inside the Commons. The idea of the proposed method is to adopt the Graph or Node method to each independent cluster obtained from the Commons method. Graph method may be applied to the clusters where there are no loop flows and to those where Node method could not find the inverse of the distribution matrix. On the other hand, the Node method may be adapted to Commons having loop flows. The exact algorithms and formulations for the Commons, Graph and

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This work was supported by the Malaysian Technical Cooperation

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1-4244-0273-5/06/$20.00 ©2006 IEEE

Node method can be found in [4], [7] and [1] respectively. All procedures of the computation mentioned above can be demonstrated as a flowchart illustrated in Fig. 1.

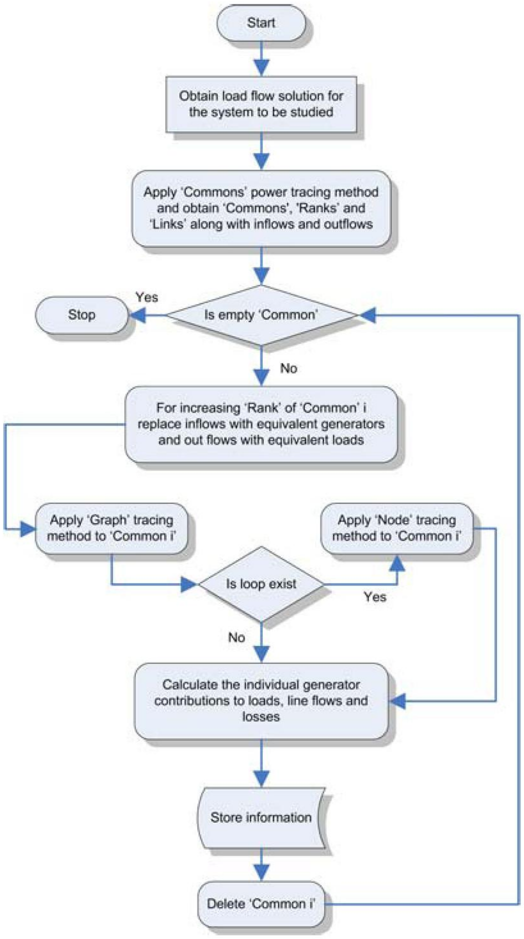

Fig. 1. Flow chart of methodology.

III. DISCUSSION OF POWER TRANSFER ALLOCATION

The IEEE 30-bus system is considered to explain the proposed method in more depth. Focusing on the part of real power, the computed power flow and the clusters of buses obtained through the Commons power tracing technique is show in Fig. 2.

With further information about the link flows and rank of these Commons, it is possible to model an equivalent system for each cluster of buses starting from the Commons having lowest rank. Fig. 3 depicts the equivalent system constructed for the Common marked as C1 in Fig. 2. By adopting the Graph or Node tracing algorithm to the equivalent system shown in Fig. 3, it is a simple matter to trace the power flow paths. Power contributed from generator at bus 1 in Fig. 3 to its loads at bus 2 to bus 4 is 45.92, 2.4 and 17.58 MW respectively. The amount of power loss attributed to the generator at bus 1 while providing power to the respective loads is 0.69 MW. Note that the loads at bus 2 and bus 4 in this case are fictitious and therefore possibly take part in supplying to its own Common (i.e. C5).

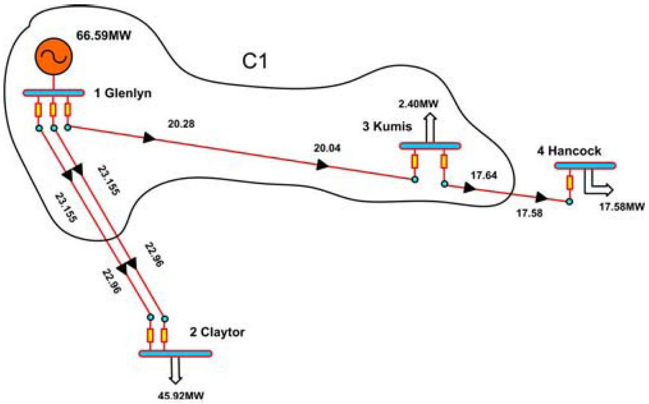

Fig. 3. Equivalent system constructed for the Common, C1. Loads at bus 2 and 4 represent fictitious loads.

To clarify this point further, the study is extended to Common, C5. The equivalent system generated for the C5 is shown in Fig. 4 and the amount of power transfer computed from the Graph method is given in Table I.

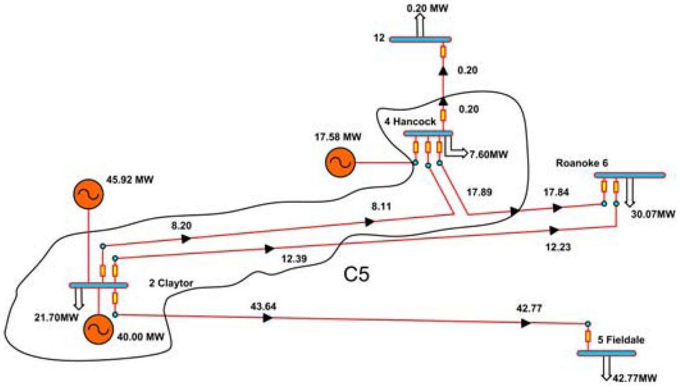

Fig. 4. Equivalent system for C5.

TABLE I
ACTIVE POWER SHARED BY INDIVIDUAL GENERATORS TO LOAD FOR THE EQUIVALENT SYSTEM C5

Load bus no.	Load (MW)	Supplied by	
		Gen-1	Gen-2
2	21.70	0.00	21.70
4	7.60	6.92	0.68
5	42.77	30.58	12.19
6	30.07	24.98	5.09
12	0.20	0.18	0.02
Loss:	1.16	0.84	0.32
Total:	-	63.500	40.00

The final power transfer allocation for the IEEE 30-bus system obtained from the proposed method is shown in Table II. Fig. 5 presents, the share of generators at buses 1 and 11 to all system loads obtained through the proposed method and Commons power flow tracing approach. As expected, it is interesting to note that the constant sharing within the cluster of buses is no longer constant when the proposed method is utilized.

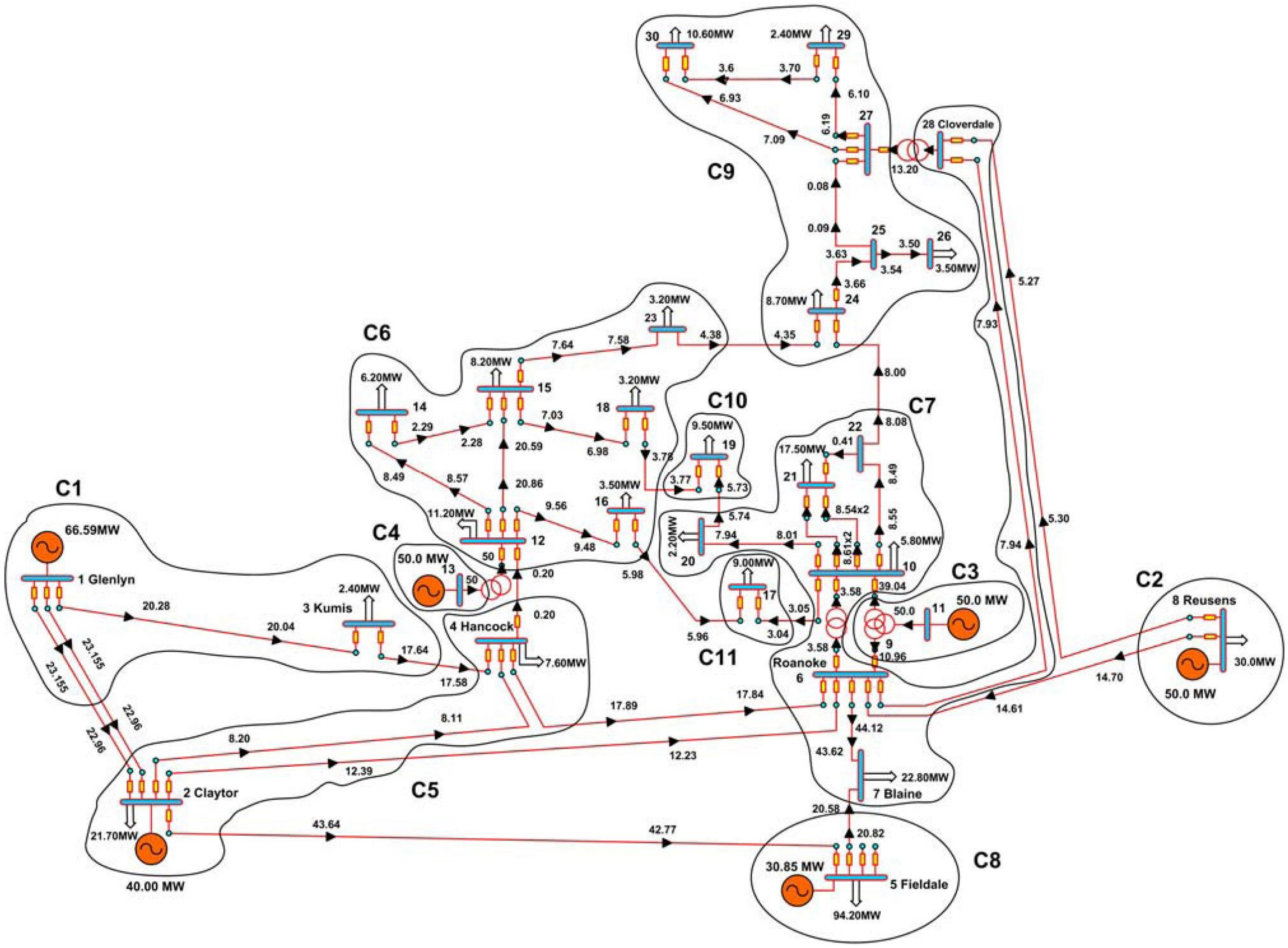

Fig. 2. Single line diagram of the IEEE 30-bus system with computed AC load flow solution. The contours represent the clusters of buses.

TABLE II
ANALYSIS OF REAL POWER TRANSFER ALLOCATION FOR THE IEEE 30-BUS SYSTEM

Load	Load	Supplied by					
bus no.	**(MW)**	**Gen-1**	**Gen-2**	**Gen-5**	**Gen-8**	**Gen-11**	**Gen-13**
2	21.70	0	21.700	0	0	0	0
3	2.40	2.400	0	0	0	0	0
4	7.60	6.916	0.684	0	0	0	0
5	94.20	39.822	14.070	30.85	5.404	4.054	0
7	22.80	10.236	2.086	0	5.987	4.491	0
8	30.00	0	0	0	30	0	0
10	5.80	0.219	0.045	0	0.128	5.409	0
12	11.20	0.041	0.004	0	0	0	11.155
14	6.20	0.022	0.002	0	0	0	6.175
15	8.20	0.030	0.003	0	0	0	8.167
16	3.50	0.013	0.001	0	0	0	3.486
17	9.00	0.136	0.025	0	0.067	2.835	5.936
18	3.20	0.012	0.001	0	0	0	3.187
19	9.50	0.230	0.045	0	0.126	5.344	3.755
20	2.20	0.083	0.017	0	0.049	2.052	0
21	17.50	0.660	0.134	0	0.386	16.320	0
23	3.20	0.012	0.001	0	0	0	3.187
24	8.70	0.224	0.044	0	0.124	5.256	3.052
26	3.50	0.090	0.018	0	0.050	2.114	1.228
29	2.40	0.644	0.131	0	1.329	0.291	0.005
30	10.60	2.843	0.579	0	5.869	1.285	0.022
Loss:	4.04	1.958	0.408	0	0.481	0.550	0.643
Total:	**287.440**	**66.590**	**40.000**	**30.850**	**50.000**	**50.000**	**50.000**

For example, Commons method assigns a constant amount of 15.36 percent contribution to generator at bus 1 in the loads at buses 24, 26, 29 and 30. Note that these buses belong to same cluster marked as C9 in Fig. 2. On the other hand, when the proposed method is employed, the contributions of the generator at bus 1 to the loads at buses 24 and 26 is decreased to 2.57 percent and its share to loads at buses 29 and 30 shifts to 26.41 percent.

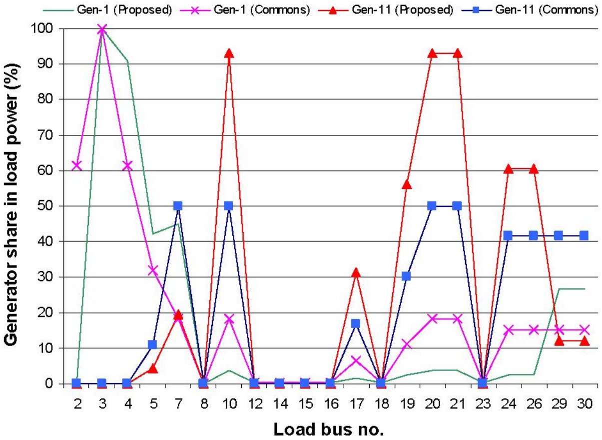

Fig. 5. A comparison of load power distribution in percentage.

As discussed earlier, this improvement is achieved because the Node method or Graph method, which is applied inside each cluster, traces the contribution from each generator to every single line and load, while the Commons method identifies the contribution of each generator to a broader area.

IV. CHARACTERISTICS OF THE PROPOSED APPROACH

There are several promising characteristics to be discussed below:

- Limitations of the individual power flow tracing techniques integrated in the approach are no longer prominent. For example, the constant sharing inside the clusters is replaced by the Graph or Node method, which traces the contribution from each generator to every single line and load without combining many lines to a single tie line and several buses into one cluster.
- Clustering the actual system into small groups helps to avoid large matrix calculations. This reduces the computational burdens of the Graph and Node method.
- More reliable. The possibility of failure for all the three methods is negligibly small.
- Computation time may be improved if parallel processing can be adopted.

V. PRACTICAL SYSTEM EXAMPLE

The proposed technique has been applied on the equivalent power system of south Malaysian peninsular as depicted in Fig. 6. The real power generations, consumptions and line flows are also given in Fig. 6. The system consists of 12 generators, five consumers and 37 branches.

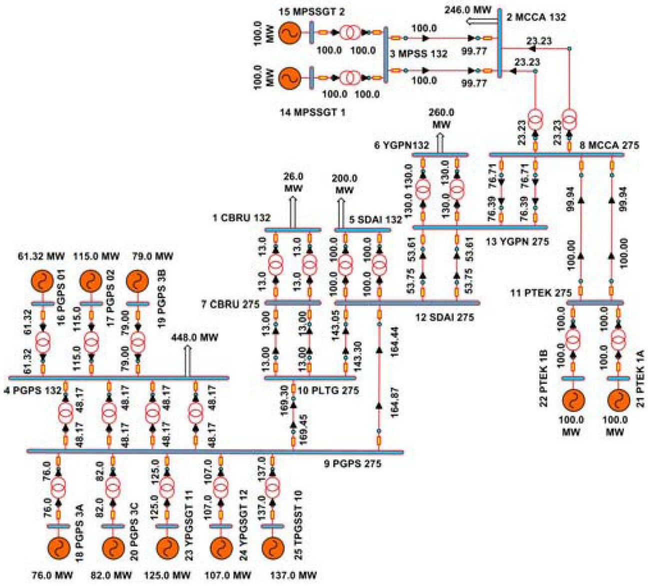

Fig. 6. 25-bus equivalent of south Malaysian power system.

First, the system is clustered into number of groups by using the procedure to obtain the Common buses. The acquired clusters, supply generators and ranks are listed in Table III.

TABLE III
CLUSTER INFORMATION FOR THE 25-BUS EQUIVALENT OF SOUTH MALAYSIAN POWER SYSTEM

Common no.	Rank	Supply generators	Buses of Common
1	1	14	14
2	1	15	15
3	1	16	16
4	1	17	17
5	1	18	18
6	1	19	19
7	1	20	20
8	1	21	21
9	1	22	22
10	1	23	23
11	1	24	24
12	1	25	25
13	2	14,15	3
14	2	21,22	8,11
15	4	14,15,21,22	2
16	5	18,20,23,24,25	1,5,7,9,10,12
17	7	18,20,21,22,23,24,25	6,13
18	8	16,17,18,19,20,23,24,25	4

Second, the Graph (or Node) method is applied to each equivalent circuit constructed to study the path of power flow from generators. Due to the non existence of loop flows in the system, it is observed that only the Graph method is sufficient to evaluate the allocations in each equivalent circuit. The desired power transfer analysis is shown in Table IV. Loss sharing by individual generators is also given in Table IV.

TABLE IV
ANALYSIS OF REAL POWER TRANSFER ALLOCATION FOR THE 25-BUS EQUIVALENT OF SOUTH MALAYSIAN POWER SYSTEM

Supplied by	Generation (MW)	Loss share	Supplied load buses				
			1	2	4	5	6
Gen-14	100	0.231	0	99.770	0	0	0
Gen-15	100	0.231	0	99.770	0	0	0
Gen-16	61.32	0.000	0	0	61.316	0	0
Gen-17	115	0.000	0	0	115.000	0	0
Gen-18	76	0.159	3.750	0	27.788	28.843	15.462
Gen-19	79	0.000	0	0	79.000	0	0
Gen-20	82	0.171	4.046	0	29.981	31.120	16.682
Gen-21	100	0.376	0	23.231	0	0	76.393
Gen-22	100	0.376	0	23.231	0	0	76.393
Gen-23	125	0.261	6.167	0	45.703	47.438	25.430
Gen-24	107	0.224	5.279	0	39.122	40.607	21.768
Gen-25	137	0.286	6.759	0	50.091	51.992	27.872
Total:	**1182.32**	**2.316**	**26**	**246**	**448**	**200**	**260**

VI. CONCLUSION

In this paper, a hybrid power transfer allocation method is proposed. It is done by combining the useful features of existing methods namely the Commons, Graph and Node power flow tracing method with the intension of improving their limitations. Since all the tracing methods discussed allocate the power transfer on the basis of measurable active power flows, these methodologies including the proposed method are most suitable for pool based electricity market model.

The simulation results show that the proposed method can provide promising improvement in the way various conventional power tracing method allocates power transfer. The main advantage of the developed method lies on its ability to calculate the allocation factors fairly and its applicability to almost any system. It also minimizes the computational burdens by clustering the system into small groups.

Focusing on the part of real power, the proposed method has been tested on the IEEE 30-bus system and also on a practical 25-bus equivalent of south Malaysian power system. The test results are presented to illustrate the proposed approach.

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VIII. BIOGRAPHIES

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