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Power Flow Tracing and Contribution of Each Generator to Load

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Abstract

This paper proposes a new method for tracing AC power flow. The graph theory and extended incidence matrix are employed to solve the power flow tracing problem.Graph theory is applied to determine the directed path from any generator-bus to load-buses.By considering simultaneously of mutual coupling of active power and reactive power, the complex power flow graph has been equivalently represented as a weighted directed flow graph. Because of competition in the electricity supply industry, it has become much more important to be able to determine which all generators supply a particular bus or load. Further, how much use each generator make of a transmission line and each generator's contribution to the system losses. The proposed technique first identifies the busses which are reached by power produced by each generator. Numerical examples cases are presented to demonstrate the effectiveness of proposed method.

Keywords: Power flow tracing, deregulation, contribution matrix, contribution of generator.

INTRODUCTION

In recent years, power system operation faces new challenges due to deregulation and restructuring of electricity markets. The old system known as monopoly based is substituted by a competitive market place. This information, which can be determined by power-flow tracing, not only enables the independent system operators (ISOs) to pay proper revenue to the generators, but it also proves to be a very important tool for different analytical purposes[1].Power-flow tracing should be done separately for both active and reactive power, as the direction of the reactive power flow from a generator through a particular line may not be same as the direction of the active power flow

[2]. Thus, proper power-flow tracing makes the new privatized power system structure more equitable for finding the contribution of generators to loads [3].

The paper is organized as follows: Section II discusses various power tracing methods. Section III Results and discussion is given in section. Finally conclusions and comparison are drawn in section III. And the conclusion is carried out in section IV.

EXISTING METHOD

Power tracing has been tacked mainly by two ways. These are:

A. Proportional sharing method
B. Extended incidence matrix

PROPORTIONAL SHARING METHOD

After performing power-flow result, the method follows the power-flow path and identifies the buses where power is injected only from the generators. Starting with any of these buses, it simply follows the power-flow path, calculating the contribution of this starting bus on each of the buses encountered in the path, until it reaches a bus from where no branch has an outward power flow. This process is repeated for all the starting buses to allocate the loss from generators to the load.The algorithm is comprised of the following steps[2]:

Step 1. Run power flow.

Step 2. Find start buses. The start bus is purely a generator bus, where no incoming line flow is present.

Step 3. Form flow-direction matrix (F) of order ($n \times n$), where n is the number of buses in the system, as per the following relation:

$F_{ij} = 1$ if buses i and j are directly connected and power flows from i to j, and

$F_{ij} = 0$ if buses i and j are not connected or power flows from j to i.

Note that the flow-direction matrix will be highly sparse.

Step 4. Calculate total inflow (P) of each bus, which is the sum of the incoming power due to all generators and lines connected to that bus:

$P_i = P_{Gi} + \sum P_{ij}$

Where, P_{ij} is the amount of power flowing into bus i from bus j, and the summation is taken over all the buses, which are directly connected to bus i.

Step 5. Calculate the contribution (C) of a generator toward all buses, starting from the generator buses, as follows. The contribution of a generator toward itself is

$C_{ii} = 1$ if it is a start generator;

$C_{ii} = P_{Gi}/P_i$ otherwise,

Where, P_{Gi} is the output of generator i, and Pi is the total inflow at bus i.

Repeat the same for all the generators.

Step 6. Starting with a start bus, the contribution of this generator is calculated for all other buses as follows:

If F_{ij} =0, the contribution of the i^{th} generator to the j^{th} bus is zero.

If F_{ij} = 1, the contribution of the i^{th} generator to the j^{th} bus is given by

$C_{ij} = P_{ij}/P_j$

Where P_{ij} is the active power flow in line i to j from generator i toward bus j, and P_j is the total inflow at bus j.

Repeat the same for all the buses.

Step 7. Consider the j^{th} bus as a generator and repeat Steps 7 and 8 until the j^{th} bus becomes the end bus.
Step 8. Repeat Steps 6–8 for all generator buses.
Step 9. The resulting contribution matrix is an (n × n) matrix that gives the contribution of each bus to all other buses present in the system.
Step 10. For all buses (k) that are not directly connected to the generator bus (i), the contribution of the generator to the bus is:

$C_{ik} = \sum_j cij \times C_{jk}$;

Where j is a bus directly connected to the k^{th} bus and directly/indirectly connected to i^{th} bus.

Step 11. If $C_{ii} < 1$ for any bus i, then the i^{th} row of the contribution matrix is modified as follows:

$C_{ij} = C_i \times C_{ii}$.

This method takes the line flows, generation capacity, and load values directly from the power-flow result and applies simple calculations to find out the contribution of the generators to the buses.

EXTENDED INCIDENCE MATRIX

The proposed method is an analytical method for tracing of power flow based on the concept of extended incidence matrix (EIM). The proposed method does not need any assumption associated with the power sharing principle. It can handle any power system with or without loop flows and is flexible to start with an AC or DC power flow solution [8]. The elements of the EIM will represent the power flow relationship between the buses.

Formation of EIM:

According to Kirchhoff's first law, the total inflow at a bus equals the total outflow from the same bus inany network. The inflow here is defined as the sum of powers injected by sources and powers imported to a bus from other buses. The outflow is defined as the sum of powers extracted from a bus by loads and powers exported to other buses. The elements of the EIM are formed based on the Eqn. (1) and it is denoted by matrix "A"

$$A_{ij=} \begin{cases} -p_{ij} & for\, i \neq j \quad and \quad p_{ij} > 0 \\ 0 & for\, i \neq j \quad and \quad p_{ji} > 0 \\ p_{Ti} & for\, i \neq j \end{cases} \qquad (1)$$

$$PTi = \sum_{k=1}^{n} Pki + Pgi, \qquad Pki>0i,\ j = 1,2,\ldots\ldots n \qquad (2)$$

Properties of Extended incidence matrix:

Property 1.

The sum of all elements in any row of an EIM equals the active load power at that bus and it is given in Eqn. 3

$$AE=P_L \tag{3}$$

The sum of all elements in every column of the EIM is the row vector of generation outputs, i.e.,(P_G^T)

Property 2.

The sum of all elements in any column of an EIM equals the total active power of generators at that bus k. i.e,

$$A^TE = P_G \tag{4}$$

Property 3.

EIM is a diagonally dominant and full rank matrix. In other words, an EIM is an invertible matrix. The Inverse matrix B is

$$B= A^{-1} \tag{5}$$

From Eqns. (3) and (4)

$$E = A^{-1} P_L \tag{6}$$

$$E = (A^{-1})^T P_G \tag{7}$$

Tracing of power flow:

Contribution of each generator to the each load: The Generator capacity of the system can be represented in a matrix and the diagonal matrix is P_{GG}=diag(P_{G1},P_{G2} …..P_{GN}). Then the individual generator capacity of the system is given in Eqn. (8)

$$P_G = P_{GG} E \tag{8}$$

By substituting the Eqn. (8) in the Eqn. (6), then

$$P_G = P_{GG} A^{-1} P_L \tag{9}$$

Eqn. (9) directly describes the relationship between and, which gives the contribution of each generator to each load. Rewriting the Eqn. (9)

$$P_G = K P_L$$

Where

$$K = P_{GG}A^{-1} \tag{10}$$

And K is known as Distribution-Factor-Matrix (DFM). In general, the individual generator capacity is

$$P_{Gi} \sum_{j=1}^{n} K_{ij} P_{li} \tag{11}$$

Where equals the active power contribution of generator output at bus *i to* the load at bus *j*. We denote:

$$P_{ij} = K_{ij} P_{LJ} \quad (12)$$

It can be seen that the sum of all elements in every column of matrix K equals 1.

$$E^T K = E^T \quad (13)$$

RESULTS AND DISCUSSIONS

RESULTS FOR IEEE 6 BUS SYSTEM

Flow Direction Matrix

Once the start bus and bus are selected, the flow direction matrix (F) is formed as per step 3 of the algorithm. Matrix F for active power allocation of the test system is shown below:

$$F = \begin{bmatrix} 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The elements of F having value 1 indicate a direct connection between the corresponding buses. As bus 1 is directly connected to bus 2 only, and the direction of the power flow is from bus 1 to bus 2, otherwise it is zero (0).

CONTRIBUTION MATRIX

The resulting contribution matrix, which gives the contribution of each bus on all other buses, is

$$C = \begin{bmatrix} 1.00 & 0.199 & 0.0007 & 0.4397 & 0.360 & 0.059 \\ 0 & 0.8180 & 0.0028 & 0.4032 & 0.1676 & 0.2418 \\ 0 & 0 & 0.9959 & 0 & 0.3265 & 0.6690 \\ 0 & 0 & 0 & 0 & 0.0424 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0124 & 0 \end{bmatrix}$$

For determining the contribution of a generator toward the line flow, the contribution of the generator on all the buses is determined first. The contribution of a generator toward a bus is considered to be same as the generator’s contribution to all branches connected to that bus.

Contribution of Generator toLoads (A) Active Load (B) reactive Load

(A) **(B)**

Bus no.	Gen.1(p.u.)	Gen.2(p.u.)	Gen.3(p.u.)	Bus no.	Gen.1(p.u.)	Gen.2(p.u.)	Gen.3(p.u.)
1	1	0	0	1	0.728	0.221	0.050
2	0.181	0.817	0	2	0	0.846	0.1539
3	0.000735	0.0032	0.9958	3	0	0	1
4	0.548	0.45	0	4	0.275	0.596	0.128
5	0.474	0.198	0.326	5	0.159	0.266	0.551
6	0.062	0.281	0.652	6	0	0.147	0.850

RESULTS OF EXTENDED INCIDENCE MATRIX SIX BUS SYSTEM

Contribution of Generator to Loads (A) Active load (B) Reactive load

(A) **(B)**

Bus no.	GEN1(p.u.)	GEN.2(p.u.)	GEN.3(p.u.)	Bus no.	GEN.1(p.u.)	GEN.2(p.u.)	GEN.3(p.u.)
1	1	0	0	1	0.7286	0.2296	0.0418
2	0.1820	0.8180	0	2	0	0.8461	0.1539
3	0.0007	0.0034	0.9959	3	0	0	1
4	0.5489	0.4511	0	4	0.2438	0.6116	0.1446
5	0.4532	0.2203	0.3265	5	0.1599	0.2898	0.5503
6	0.0633	0.2845	0.6522	6	0	0.1477	0.8523

(A) Contribution of Generator to Branch Flow (B) Contribution of Load to Branch flow

(A) **(B)**

Line	PG1(p.u.)	PG2(p.u.)	PG3(p.u.)		Branch	L1(p.u.)	L2(p.u.)	L3(p.u.)
1	15.41	0	0		1	0	0	0
2	33.95	0	0		2	0	0	0
3	27.86	0	0		3	0	0	0
4	0.6528	0.2372	0		4	0	0	0
5	7.59	34.144	0		5	0.0266	0.1331	0
6	3.15	14.19	0		6	0.0110	0.0553	0
7	4.55	20.47	0		7	0.6154	0.0798	0
8	0.0173	0.0778	23.084		8	0	0	0.0098
9	0.0355	0.1594	47.30		9	0	0.0001	0.0202
10	1.762	1.448	0		10	1.65	1.513	0
11	0.0570	0.2560	0.5870		11	0.0528	0.2648	0.5971

CONCLUSIONS

Continuing trend towards deregulation and unbundling of transmission services has resulted in the need to assess what is the impact of a particular generator or the load on the power system. In this paper a new method of tracing the flow of electricity in electrical networks has been proposed which may be applied to both real and reactive power flows. The method is of a topological nature and works on the results of optimal load flow program. The method results in a table allows one to assess how much of the real and reactive power output from a particular station goes to a particular load. It is also possible to assess contributions of individual generators (or loads) to individual line flows. 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).

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