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A Power Flow Tracing Based Method for Transmission Usage, Loss & Reliability Margin Allocation

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Abstract

Restructuring of Electricity supply industry introduced many issues such as transmission pricing, transmission loss allocation and congestion management. Many methodologies and algorithms were proposed for addressing these issues. In this paper a graph theory based method is proposed which involves Matrices methodology for the transmission usage, loss and transmission reliability margin (TRM) allocation for generators and demands. This method provides loss and TRM allocation in a direct way because all the computation is previously done for usage allocation. The proposed method is simple and easy to implement in a large power system. Further it is less computational because it requires matrix inversion only a single time. A comparison between proposed method and already exiting methods also presents. Results are shown for the sample 6 bus system and IEEE 14 bus system.

Keywords: Modified Kirchhoff Matrix; Power flow tracing;Transmission Pricing; Transmission Loss Allocation; Transmission Reliability Margin Allocation.

1. Introduction

In many parts of the world electricity supply industry undergoes transformation from regulated to deregulated structure. Many new issues such as transmission embedded cost allocation, loss allocation; congestion management etc. arises due to this transformation. As transmission sector is the backbone of power sector, the question of transmission pricing is great importance. The main aim of any transmission pricing methodology is to introduce a fair competition in the electricity sector and provide efficient economic signals. Transmission pricing methods are the overall processes of translating transmission costs into overall

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transmission charges. The main transmission pricing methodologies are embedded cost and incremental pricing methodology. Countries like Colombia, UK and Brazil, have used long run marginal cost (LRMC) methodology due to its easy implementation. On the other hand countries like Argentina, Chile and Panama adopting marginal participation method. Power flow tracing provide us a complete view of usage allocation problem which is very important for transmission cost allocation. When usage allocation is known it is straightforward to allocate the transmission cost to generators and loads. The first attempt to trace power flows was done by Bialek et al. when Topological Generation Distribution factors based Power flow tracing were proposed in March 1996 [2] which explained the method for tracing generator's output. They introduce a simple topological method of tracing the flow of real and reactive power in transmission networks. In Feb 1997, Kirschen et al. [3] explained a power flow tracing method based on the proportional sharing assumption which introduces the concept of domains, commons, and links. In Nov 2000, Gubina et al. [4] described the method to determine the generators' contribution to a particular load by using the nodal generation distribution factors. In Aug 2000, Wu et al. [5] explained the use of graph theory to calculate the contributions of individual generators and loads to line flows and the real power transfer between individual generators and loads. In 2009 Xie et al.[6] proposed and explained the power flow tracing algorithms founded in the extended incidence matrix considering loop flows.

Similarly many different loss allocation schemes have been proposed for transmission loss allocation. The existing transmission loss allocation methods may be classified into prorata method, marginal methods, power flow tracing-based methods, and circuit theory based methods [1]. A usage based transmission loss allocation method is proposed in [7]. In [8] method based on circuit theory and the concept of orthogonal projection for pool based electricity market is proposed.

Due to deregulation, the number of interaction entitles on the electric grid increases dramatically. At the same time capacity margin reduced. Hence this rapid growth threatened reliability of transmission network greatly. That's why transmission reliability margin allocation should be addressed in a fair way. Many researchers proposed methodology which incorporate reliability cost element in total transmission cost. For this first usage and TRM allocation is done. In [9] Silva et al. considered the transmission network operation under normal as well as contingency condition for allocation reliability cost to users. In [10-11] D. Hur et al. proposed various variants of procedures to allocate reliability contribution to market participants.

This paper presents a model of usage, loss and transmission reliability margin allocation based on the concept of the matrices methodology. In the proposed method modified Kirchhoff matrix is developed for usage allocation. After that loss allocation matrix is formed for transmission loss allocation to loads and generators. Further by incorporation (n-1) reliability criteria, maximum flow of transmission lines is calculated. After that the TRM of every transmission line is allocated to generators by using modified Kirchhoff matrix.

2. Proposed Matrices Methodology

Let consider a simple diagraph G showed in Fig1.

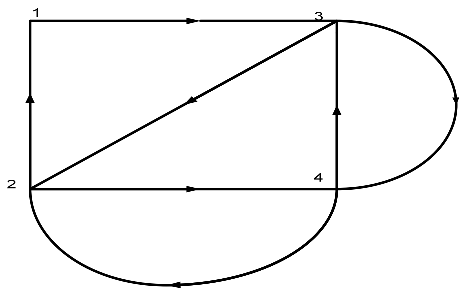

Fig.1. Simple Diagraph G

Hence from the above example for a simple digraph *G* of *n* vertices, an *n* by *n* matrix called the Kirchhoff matrix $K(G)$ or $K=[Kij]$ is defined as [1],

$$K = \begin{cases} d^{-}(V_i) & \text{for } i = j \\ -X_{ij} & \text{for } i \neq j \end{cases} \tag{1}$$

Where, $d^{-}(V_i)$ = in-degree of the ith vertex

$-X_{ij}$ = (i,j)th entry in the adjacency matrix

This matrix is the basis of the proposed methodology. Authors construct a power flow matrix from the Newton Raphson load flow. This matrix gives a complete overview of power flows in the system. It is formed between nodes of the system. Diagonal elements give net flows at nodes and off diagonal elements give the actual flows and counter flows in the system. The proposed matrix is defined as follows: active power in branch *i-j* from bus *1* to bus *J* as Pij(> 0) nd total inflow at bus *1* as P_{Ti}

$$P \quad f_{ij} = \begin{cases} -P_{ij} & \text{for } i \neq j \text{ and } P_{ji} > 0 \\ P_{ij} & \text{for } i \neq j \text{ and } P_{ij} > 0 \\ P_{Ti} & \text{for } i = j \end{cases} \tag{2}$$

Where *PTi=net flows on the nodes*

From the above matrix and using Eq. 1 the Modified Kirchhoff matrix is constructed as follows. Denoting Modified Kirchhoff matrix of a Power Network as, $k_m = (k_{ij}^m) n \times n$ authors define the following expression for elements of the Modified Kirchhoff matrix:

$$K_{ij}^m = \begin{cases} -P_{ij} & \text{for } i \neq j \text{ and } P_{ji} > 0 \\ P_{Tj} & \text{for } i = j \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Now from the above Modified Kirchhoff matrix, Kirchhoff loss matrix can be formed as follows:

$$kl_{ij} = \begin{cases} P_{ij}^1 & \text{for } i \neq j \text{ and } P_{ji} > P_{ji} \text{ and } P_{ji} < 0 < P_{ij} \\ P_{ji}^1 & \text{for } i \neq j \text{ and } P_{ji} > P_{ij} \text{ and } P_{ij} < 0 < P_{ji} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

Where

P_{ij}^1= transmission loss in line i-j in actual direction

P_{ij}^1= transmission loss in line i-j in counter direction

3. Procedure for Tracing Power Flow and Loss Allocation

In this paper authors adopt the tracing procedure which is proposed in [6]. But authors modified this tracing algorithm for transmission loss allocation.

3.1 Model for Power Flow Tracing

The procedure for power flow tracing is same as preaented in [6]. Power flow allocated to generators from the lines flow as shown in Eq. (5). It is assumed that a $\alpha_g : \alpha_1$ (23:77) split in the transmission usage occurs between generators and demand. For example the generator share situated as bus s to the line s-t is given by

$$P_{i \uparrow s-t} = t_{is} P_{st} a_g \tag{5}$$

Hence eq. (5) gives the generators share in lines flows. Similarly, the usage allocated to a load for the use of all lines can be defined by using α_1 instead of α_g. For calculating the loads shares in line flows and generated power same procedure is followed.

$$P_L = P_{LL}(K_m^{-1})P_G \tag{6}$$

Where the diagonal matrix P_{LL}= diag (P_{L1}, P_{L2}, …., P_{Ld}) and R= R=P_{LL} $(K_m^{-1})^T$ is the extraction factor matrix of loads from generators [6]. By using an extraction factor matrix, loads share in generating power and line flows is calculated.

3.2 Model for Transmission Loss Allocation

For transmission loss allocations to generator consider Eq. (5). In this equation line flows P_{st} is replaced by the transmission Loss in lines which is coming from the elements of the Kirchhoff loss matrix. Hence transmission losses of line s-t allocated to generator located at bus i is given by:

$$P^i_{i \to s-t} = t_{is} P \tag{7}$$

Similarly transmission losses of line s-t allocated to load situated at bus j is given by:

$$P^i_{j \to s-t} = r_{js} P \tag{8}$$

From the equations (18) and (19) losses are allocated to generators and loads respectively. This method of loss allocation is said to be direct because all the calculation is already done for usage allocation.

3.3 Model for TRM Allocation

For transmission reliability margin allocation to generator and load, considered eq. 5,

TRM = maximum capacity of the line in p.u. – usage of the line in p.u.

$$TRM_{ij} = 1 - pf_{ij} \tag{9}$$

Where for a particular line the calculation of TRM has considered Maximum capacity of the all line is 1 p.u. In this equation line flows is replaced by the transmission reliability margins in lines which is coming from the elements of TRMij.

Hence transmission reliability margin of line s-b allocated to generator located at bus i is given by:

$$TRM^1_{i-s \to b} = t_{is} trm \tag{10}$$

Similarly transmission reliability margin of line s-b allocated to load situated at bus j is given by:

$$TRM^1_{i-s \to b} = r_{is} trm \tag{11}$$

4. Result and Discussion

The proposed matrices methodology is applied to the sample 6 and IEEE 14 bus power system to demonstrate the feasibility and effectiveness of the methodology. A computer program coded in MATLAB is developed.

4.1Sample 6 Bus System

4.1.1 Transmission Usage Allocation

The sample 6 bus power system is used to illustrate the proposed methodology. The summation of powers extracted by the load buses from all the generators equals the total load demand similarly the addition of powers contributed by the generator buses to all the demands equals the total generation power. Table 1 gives the generators contributions to losses and line flows.Total system losses occurred in the system is 0.084697 pu from which 23% is allocated to generators and 77% is allocated to demands.

Table.1 Transmission Usage Allocation to Loads & Generators

Line	Flow(pu)	Loss(pu)	Usage Allocated G1	Usage Allocated G2	Usage Allocated G3	Loss Allocated G1	Loss Allocated G2	Loss Allocated G3
1-2	0.29	0.0094	0.29	0.00	0.00	0.0022	0.0000	0.0000
1-4	0.44	0.0113	0.44	0.00	0.00	0.0026	0.0000	0.0000
1-5	0.36	0.0112	0.36	0.00	0.00	0.0026	0.0000	0.0000
2-3	0.03	0.0004	0.01	0.02	0.00	0.0000	0.0001	0.0000
2-4	0.33	0.0164	0.12	0.21	0.00	0.0014	0.0024	0.0000
2-5	0.16	0.0056	0.06	0.10	0.00	0.0005	0.0008	0.0000
2-6	0.26	0.0062	0.10	0.17	0.00	0.0005	0.0009	0.0000
3-5	0.19	0.0123	0.00	0.01	0.18	0.0001	0.0001	0.0027
3-6	0.44	0.0108	0.01	0.01	0.42	0.0000	0.0001	0.0024
4-5	0.04	0.0004	0.03	0.01	0.00	0.0001	0.0000	0.0000
5-6	0.02	0.0006	0.01	0.00	0.00	0.0001	0.0000	0.0000

4.1.2Transmission Reliability Margin Allocation

From the equations (10) and (11) TRM are allocated to generators and loads respectively. From the table 2 it is observed that the generators which contribute more power to line flows, have more TRM allocated. Also table 3 provides a comparison between TRM allocated by proposed method and method presented in [11].

Table 2.Transmission Reliability Margin Allocation

	TRM Allocation By Proposed Method			**TRM Allocation By [22] Method**		
Line	**G1(pu)**	**G2 (pu)**	**G3(pu)**	**G1(pu)**	**G2 (pu)**	**G3(pu)**
1	1	0	0	0.934546	0.003	0.062017
2	1	0	0	0.737646	0.221	0.041229
3	1	0	0	0.78099	0.138	0.080909
4	0.36632	0.63368	0	0.323005	0.289	0.078781
5	0.36634	0.63366	0	0.800014	0.118	0.082555
6	0.36602	0.63398	0	0.545261	0.300	0.154956
7	0.36633	0.63367	0	0.273916	0.171	0.555305
8	0.02	0.03	0.95	0.337897	0.194	0.468735
9	0.02	0.03	0.95	0.253548	0.384	0.362786
10	0.72381	0.27619	0	0.572841	0.285	0.141905
11	0.6	0.15238	0.24762	0.301848	0.183	0.515473

Total	5.82881	3.02357	2.14762	5.861511	2.286	2.544651

4.2 IEEE 14 Bus System

4.2.1Transmission Usage Allocation

The proposed method is also applied on IEEE 14 bus system [12]. Authors assume that cost of the line is proportional to the length of the line. After this the share of each generator (load) in load (generator) and line flows is calculated. Fig 2 gives generators shares to various line flows respectively. Y axis shows the usage allocation in MW and x axis provide no of lines.

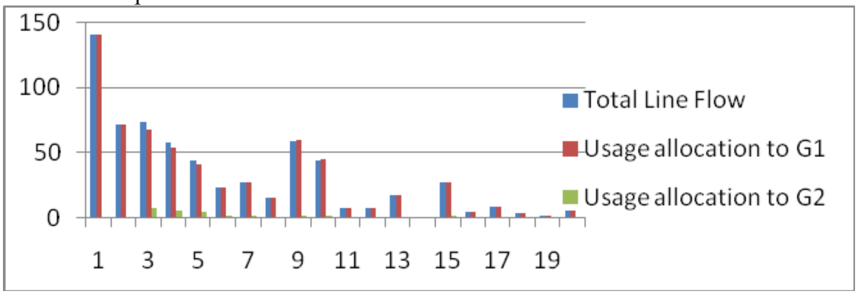

Fig 2: Generators shares to Line flows

4.2.2Transmission Loss Allocation

Fig 3 presents the transmission loss allocation between generators respectively. Total system losses occur in IEEE 14 Bus system is 15.87016 MW. 23% of total losses i.e. 3.70114478 MW is allocated to generators and 77% i.e. 12.16902 is allocated to loads.

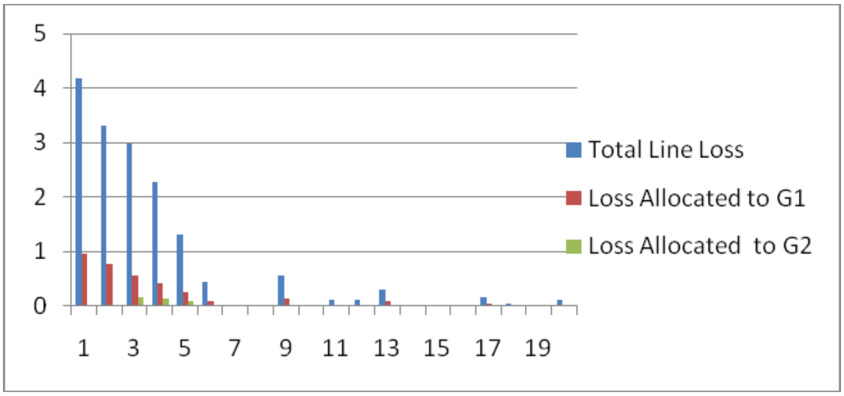

Fig 3: Generators shares to Line loss

5. Conclusion

In the proposed work authors presents a combined methodology for the transmission usage, loss and reliability margin allocation which is based on the matrices methodology. This method is simple and easy to implement in large power system. Furthermore transmission loss and reliability margin allocation by this method is direct because all the calculation previously done for usage allocation. This method requires less calculation as compared to other methods such as Topological generator distribution factors proposed by Bialek [4] because matrix inversion is required only one time. Further TRM allocation by this method is more as compare to method presented in [11]. Results are shown for the sample 6 bus system and IEEE 14 bus system.

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