2013 2nd AASRI Conference on Power and Energy Systems

A TCSC Incorporated Power Flow Model for Embedded Transmission Usage and Loss Allocation

Baseem Khan[a*], Ganga Agnihotri[b], Samina E. Mubeen[c], Garima Naidu[d] *

[a,b,d]MANIT, Link road no.3, Bhopal 462003, India
[b]REC, Bhopal, 462003, India

Abstract

Authors present a power flow tracing based method for usage and loss allocation along with FACTS devices. Graph theory is the basis for usage allocation. Modified Kirchhoff matrix is used for this purpose. FACTS devices are used in the system for various purposes such as reactive power compensation; voltage profile improvement etc. hence in this paper Thyristor controlled series controller (TCSC) with voltage source modeling is used for finding the effect of FACTS device on transmission usage and loss allocation. A sample 5 bus is used for this purpose.

Keywords: Modified kirchhoff matrix; transmission pricing; power flow matrix; transmission loss allocation;tcsc.

1. Introduction

The electricity supply sector in many parts of the world is going to transform from government owned monopolistic structure to a utility driven competitive structure. In this deregulation process, transmission sector plays a very critical role because it connects generators to the loads. All participants in this deregulated structure try to obtain the power from the economical resources for more earnings, which put our system on

* Corresponding author. Tel.: +91-9827754258;
E-mail address: baseem_khan04@yahoo.com.

their maximum limits. Hence the question of transmission usage allocation and reactive power compensation is of great importance. In a modern power system Transmission usage allocation must be intended in a reasonable and apparent manner that is economically equitable to each and every one market players, not only with the intent of correct revenue reconciliation strategies that recover system-wide transmission asset and operational costs, but also with the goal of increasing market efficiency. In present era FACTS devices play a vital role to solve the problems like overloading and reactive power compensation in efficient way. Many FACTS devices are used around the world to regulate active and reactive power flow along with maintaining desired voltage profile. The first attempt to allocate power flows was done by Bialek et al. when Topological Generation Distribution factors based power flow tracing were proposed in March 1996 [1], 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. [2] 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. [3] 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. [4] explained the use of graph theory to calculate the contributions of individual generators and loads to line flows and the real power transfer among distinctive generators and loads. In 2009, Xie et al.[5] proposed and explained the power flow tracing algorithms founded in the extended incidence matrix considering loop flows. Similarly, the existing loss allocation methods may be classified into prorata method, marginal method, power flow tracing-based methods, and circuit theory based methods [6]. Prorata method allocated losses to load and generators in equal manner [6]. In marginal procedure, incremental transmission coefficients are used for allocation of transmission losses to demands and generators [7]. The use of tracing methods for allocation of transmission losses is presented in [8].A method based on a combination of cooperative game theory and circuit theory is presented in [9]. In [10] a novel algorithm is proposed for transmission loss allocation, which is used path integral and based on transaction strategy. A usage based loss allocation method is proposed in [11]. In [12] method based on circuit theory and the concept of orthogonal projection for pool based electricity market is proposed. FACTS device has the capability of regulating the power flow and voltage support at the buses. It provides the properties of both shunt and series compensations in order to regulate the power flow and simultaneously support the voltage at the bus. Modeling of these devices such as SVC, STATCOM and UPFC has been done effectively in [16, 17]. In [14] Newton Raphson algorithm for large power system with FACTS devices was presented [15].

In this paper authors presented a usage and loss allocation method along with TCSC incorporation in power flow model. A tracing algorithm presented in [5] is used and modified for usage and loss allocation. Newton Raphson method of load flow is used for power flow which is modified for incorporation of TCSC. Results with and without TCSC is presented on Sample 5 bus system.

2. Proposed Matrices Methodology
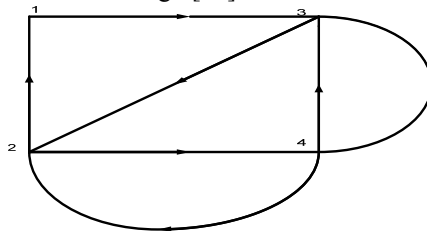
Let consider a simple diagraph G showed in Fig1.[13]

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= [K $_{ij}$] is defined as [1],

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

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 ^{I} to bus ^{J} as P $_{ij}$ (>0) and total inflow at bus ^{i} as P$_{Ti}$

$$pf_{ij} = \begin{cases} -p_{ij} & \text{for } i \neq j \text{ and } p_{ji} > 0 \\ p_{ij} & \text{for } i \neq j \text{ and } p_{ij} > 0 \\ p_{Ti} & \text{for } i = j \end{cases} \quad (2)$$

Where P$_{Ti}$ = net flows on the node

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:

$$k_{ij}^m = \begin{cases} -p_{ij} & \text{for } i \neq j \text{ and } p_{ij} > 0 \\ p_{Ti} & \text{for } i = j \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

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

$$kl_{ij} = \begin{cases} p_{ij}^l & \text{for } i \neq j \text{ and } p_{ij} > p_{ji} \text{ and } p_{ji} < 0 < p_{ij} \\ p_{ji}^l & \text{for } i \neq j \text{ and } p_{ji} > p_{ij} \text{ and } p_{ij} < 0 < p_{ji} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

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

Authors adopt the tracing procedure which is proposed in [5]. But authors modified this tracing algorithm for transmission loss allocation.

3.1 Model for power flow tracing

Steps for tracing are same as presented in [6]. Power flow allocated to generators from the lines flow as shown in Eq. (5). For this allocation 23% share is allocated to generators and 77% is allocated to loads. For example the generator share situated as bus s to the line s-t is given by

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

Hence eq. (5) gives the generators share in lines flows. For calculating the loads shares in line flows and generated power same procedure is followed.

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

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:

$$P_{i\to s-t}^1 = t_{is}P \tag{7}$$

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

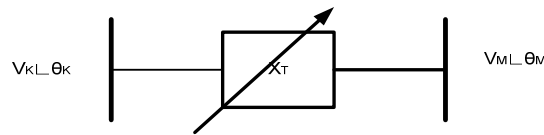$$P_{j\to s-t}^1 = r_{js}P \tag{8}$$

3. Mathematical Model of TCSC

Figure 2 TCSC model

The idea of changeable series reactance is used to make the power flow model with TCSC in which value of series reactance adjusted to control the power flow. The modelling of TCSC in Newton Raphson load flow is presented in [16].

Power flow equation of TCSC can be written as

$$PK=V_K V_M B_{KM} \sin(\Theta_k-\Theta_M) \tag{9}$$

$$QK=-V_K^2 B_{KK}-V_K V_M B_{KM}\cos(\Theta_k-\Theta_M) \tag{10}$$

Where $B_{KM}= 1/ X_T$

$B_{KK}= -1/ X_T$, Where b X_T is equivalent reactance.

4. Result And Discussion

The proposed matrices methodology is apply to the 5 bus structure to demonstrate feasibility and effectiveness of the methodology. An Executable code is developed under MATLAB. Test is conducted on standard 5 bus system. For analysis bus 1is slack bus, bus 2 is voltage controlled bus and 3, 4, 5 are load buses. TCSC is installed between bus 3 and 4 by introduced an additional bus 6. For TCSC starting value of the inductive reactance is taken 0.015 pu (50% of value of the inductive reactance of the transmission line).

5.1 Power Flows Results with TCSC in 5 Bus system

Table 1 presents a comparison between power flows with and without TCSC in 5 bus system.

Table 1 Comparison between Power Flows

Line	Line Flows (TCSC)	Line Flows normal case	Power Loss (normal case)	Power Loss (TCSC)
1-2	0.7078	0.7209	0.0250	0.0212
1-3	0.3994	0.3862	0.0150	0.0143
2-3	0.2796	0.2589	0.0040	0.0047
2-4	0.2661	0.2884	0.0050	0.0042
2-5	0.5410	0.5522	0.0125	0.0119
3-4	0.2100	0.1775	0.0010	0.0005
4-5	0.0714	0.0606	0.0005	0.0005

5.2 Transmission Usage and Loss Allocation with and without TCSC

Table 2 provides the generator contribution to line flows. Total flow in line 1-2 is 0.7209 pu which is totally supplied by generator 1. In this similar way all generators contributes to line flows.

Table 2 Generators contribution to line flows and Losses without TCSC

Line	Flows	loss	Usage to Allocated G1	Usage to Allocated G2	Loss to Allocated G1	Loss to Allocated G2
1-2	0.7209	0.0250	0.7209	0	0.0250	0
1-3	0.3862	0.0150	0.3862	0	0.0150	0
2-3	0.2589	0.0040	0.41357761	0.09240141	0.0025724	0.0014276
2-4	0.2884	0.0050	0.18547004	0.10292996	0.0032155	0.0017845
2-5	0.5522	0.0125	0.35511982	0.19708018	0.00797444	0.00442556
3-4	0.1775	0.0010	0.152082	0.025418	0.00025704	0.00004296
4-5	0.0606	0.0005	0.0439047	0.0166953	0.0002898	0.0001102

Table 3 Generators contribution to line flows and Losses with TCSC

Line	Line Flows with TCSC	Loss with TCSC	Usage to Allocated G1	Usage to Allocated G2	Loss to Allocated G1	Loss to Allocated G2
1-2	0.7078	0.0212	0.7078	0	0.0212	0
1-3	0.3994	0.0143	0.3994	0	0.0143	0
2-3	0.2796	0.0047	0.1786	0.1010	0.0030	0.0017
2-4	0.2661	0.0042	0.1700	0.0961	0.0027	0.0015
2-5	0.5410	0.0119	0.3457	0.1953	0.0076	0.0043
3-4	0.2100	0.0005	0.1788	0.0312	0.0004257	0.0000743
4-5	0.0714	0.0005	0.0523	0.0191	0.0003663	0.0001337

5. Conclusion

Author presents a tracing based usage and loss sharing methodology with incorporation of FACTS devices. TCSC is incorporated with voltage source modelling structure for compensating the reactive power and

improving the voltage profile. With TCSC power flow of transmission is increased hence transmission usage allocation and transmission loss allocation also increased. Voltage source modelling is used for FACTS incorporation because by this effect of TCSC at each iteration is incorporated in system. Further usage and loss allocation is done in direct way because matrix inversion is required only single time. The methodology is applied on sample 5 bus.

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