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Transmission Loss Minimization and Cost allocation Model in Restructured Power System

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Abstract: - The main aim behind deregulated electricity market is to improve quality of electricity and make available cheaper energy to customer. This can be achieved by resolving major issues like Fair Transmission pricing, loss, stability, security and reliability. The Flexible A.C. Transmission Controller e.g. STATOM plays a vital role to improve technical as well as the economic aspect. In this paper, Author proposed method for Reactive power allocation to individual participant and cost allocation towards transaction of reactive power. The model is based on power flow tracing in conjunction with the proportional sharing principle. The STATCOM controller incorporated to magnify power flow and minimize transmission losses... The Proposed Methodology Tested on 5 bus System and influence of STATCOM in terms of loss minimization and enhancement of Allocated cost is reflected.

Keyword — Cost Allocation, Extended Incidence Matrix, STATCOM, Transmission Loss.

INTRODUCTION

In the current era of modern power sector the change from regulated structure to deregulated one. Numerous modernistic obstacles arise throughout this process. Beside with this, many new apparatuses such as FACT controller also come into the picture to supervise the operation of the power system. After deregulation, all the three sectors worked as segregate entity. Hence there are conflicts of interests amongst them. So the issues like transmission usage allocation, cost allocation, congestion management, etc. are of big interest. Many methodologies were suggested to address these issues such as postage stamp, MW Mile, incremental cost, power flow tracing, etc. Every method has some superiority and drawback moreover these approaches have their own deficiency to address such issues. With the advent of FACTS devices controlling of voltage profile and reactive power in the power system is much comfortable. There are many FACTS devices which are categorized according to their working. FACTS device has the competence of controlling the power flow and voltage support at the buses. It serves the properties of both shunt and series compensations in order to control the power flow and simultaneously substantiate the voltage at the bus. Modeling of these devices such as SVC, STATCOM, TCSC and UPFC has been done effectively in [10, 11]. Hence in this fast-changing scenario, the effects of FACTS devices on the deregulated market are of great interest. Restructured market deals with problems like fair and equitable allocation of transmission pricing, transmission loss minimization, congestion management, contingency related issues etc. FACTS devices have a great influence on these issues because these devices controlled the active and reactive power flow in transmission line. In this paper authors resented the effect of STATCOM on transmission pricing and transmission loss minimization. The power flow tracing based on Topological generation Distribution factors was first presented by Bialek et al. in 1996 to trace the real and reactive power flow through the transmission network [1]. Moreover, based on proportional sharing assumptions a method for power flow tracing was introduced by Krishchen et al. in 1997 [2]. The method based on the Nodal Generation Distribution Factors to determine the generator contribution to a particular load has been reported by Gubina et al. in 2000 [3]. The idea of Graph Theory to calculate the contribution of individual generator and load in line flows has been addressed by Wu et al in 2000 [4]. By deploying the properties of the matrix an Extended Incidence Matrix Method for power flow tracing with considering loop flows has been proposed by Xie et al. in 2009 [5]. The Z-bus based network cost allocation method has been reported by Conejo et al in 2007 [6]. An optimization based approach has been reported for power flow tracing in 2006 by Abhyankar et al. [7]. The Min-Max fair allocation criterion for transmission usage allocation has been proposed in 2010 by Rao et al. [8]. E. acha et al. presented FACT devices model based on voltage source converter such as for shunt connected FACTS devices an ideal voltage source connected in shunt while for series connected devices voltage source connected between two buses [10-11]. Y.H. song and Nemat-Talebi et al. presented FACTS devices model based on power injection [12-13]. In power injection model conversion of voltage source in terms of active and reactive power injected at nodes. The original dimensions of the mismatch vector and Jacobian are not changed this is the basic benefit of power injection model but due to ignorance of active power line losses make this model less approachable. By incorporated these models in power flow the solution can be achieved. In [14] Newton Raphson algorithm for large power system with FACTS devices was presented. In [15] derived a UPFC DC load flow model and discussed its use in restructured power systems. In [16] power transfer distribution factors are determined with FACTS devices

MATHEMATICAL MODELING OF STATCOM

The modelling of Fact Controller can be carried-out to evaluate steady-state operation with the system by two ways. The first way is power injection modeling and another way is voltage source modeling. In this paper voltage source, modeling has been adopted for due to their various benefits over power injection modeling. The voltage source converter of the STATCOM can be represented by an ideal voltage source connected in shunt to bus k. the bus k is taken as a PV bus which can change to a PQ bus in the case if limits are violated. In this case the generated or absorbed power will be equal to the violated limit. The ideal voltage source can be put mathematically as:

$$V_{sh} = V_{sh}(\cos\theta_{sh} + j\sin\theta_{sh}) \qquad (1)$$

The voltage magnitude Vsh is given maximum and minimum limits, which are a function of STATCOM capacitor rating and the voltage angle θsh may take any value between 0 and 2π radian. With reference to the equivalent circuit shown in fig. 1 the transfer admittance equation can be written as equation (2)

$$[I_k] = [Y_{sh} \; -Y_{sh}]\begin{bmatrix} V_k \\ V_{sh} \end{bmatrix} \qquad (2)$$

Where Ik is the current entering the node k and Zsh is the leakage inductance and the resistance of the coupling transformer.

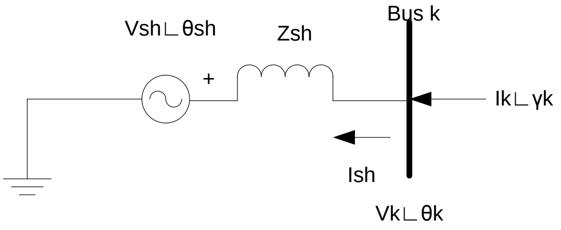

Fig.1. Equivalent circuit of STATCOM

Let $Y_{sh} = \frac{1}{z_{sh}}$

The power flow equations for the STATCOM are derived on the basis of shunt connection shown in fig.1 the apparent power for the converter is

$$S_{sh} = V_{sh} I_{sh}^{*} \qquad (3)$$

$$S_{sh} = V_{sh} Y_{sh}^{*} (V_{sh}^{*} - V_k^{*}) \qquad (4)$$

Substituting the conventional representations of the quantities in the above equations, the active and reactive powers for the converter are represented by the equations

$$P_{sh} = V_{sh}^2 G_{sh} + V_{sh} + V_k[V_{sh}\cos(\theta_{sh} - \theta_k) + B_{sh}\cos(\theta_{sh} - \theta_k)] \qquad (5)$$

$$Q_{sh} = -V_{sh}^2 B_{sh} + V_{sh} V_k[G_{sh}\sin(\theta_{sh} - \theta_k) - B_{sh}\cos(\theta_{sh} - \theta_k)] \qquad (6)$$

Where

$$Y_{sh} = G_{sh} + jB_{sh}$$

Similarly the equations for the bus power k is

$$S_{ksh} = V_k I_k^{*} \qquad (7)$$

Substituting Ik as in (2) and Vk in equation (7) the active and reactive power for bus k are represented by the equations (9) below

$$P_{ksh} = V_k^2 G_{sh} + V_k V_{sh}[G_{sh}\cos(\theta_k - \theta_{sh}) + B_{sh}\sin(\theta_k - \theta_{sh})] \qquad (8)$$

$$Q_{ksh} = -V_k^2 B_{sh} + V_k V_{sh}[G_{sh}\sin(\theta_k - \theta_{sh}) - B_{sh}\cos(\theta_k - \theta_{sh})] \qquad (9)$$

MODEL FOR REACTIVE POWER FLOW ALLOCATION

The electrical power system network consists with different component so their behaviors towards tracing of power flow become topological, so power flow by tracing theory is based on true flows in transmission system with consideration of proportional sharing principle. It handles the common issue regarding distribution of VAR (reactive power) flows in a meshed system [1]-[4]. To determine electricity at the nodes, the nodal power flow based on tracing which generally use implementation of the KCL (Kirchhoff's current law). To determine the correlation in conjunction with incoming and outgoing flows the proportional sharing and nodal method is adopt. Hence this principle is similar for the validation of true power and reactive power flows. The model proposed and implemented in this paper considered network is as lossless [5], [6]. Let $ln = 1 \ldots\ldots\ldots e$ shows entire transmission line in the power system structured, $G_n = 1 \ldots\ldots\ldots g$ is entire quantity of generating units and $D = 1 \ldots\ldots d$ is the entire quantity of users in the structure. Again $P_{GG} = \mathrm{diag}\,(P_{G1}, P_{G2}, \ldots.., P_{Gg})$ represents generation in diagonal matrix. Thus from [16]

$$U = K_m{}^{-1} P_L \qquad (10)$$

$$U^T P_{GG} = (P_G)^T \text{ or } P_G = P_{GG} U \qquad (11)$$

By combining equation (10) and (11)

$$P_G = P_{GG} K_m{}^{-1} P_L \qquad (12)$$

Obtained matrix $P_{GG} K_m{}^{-1}$ is called generation production matrix. The generation production matrix is indicated by $GPM = (t_{ij})$, i. e., Where,

$$GPM = P_{GG} K_m{}^{-1} \qquad (13)$$

$$R_{i \to j} = t_{ij} R_{Lj} \qquad (14)$$

Here $t_{ij} R_{Lj}$ represent the reactive flow contribution of generator situated at bus i to the load at bus j.

Reactive power allocated to generator placed at bus i share the line $s - b$ can be calculated by,

$$RP_{i \to s-b} = t_{is} rf_{s-b}$$

To obtaining the contribution of reactive power by loads similar procedure is repeated. Where the diagonal matrix $P_{LL} = \mathrm{diag}\,(P_{L1}, P_{L2}, \ldots.., P_{Ld})$ and $EFM = P_{LL}(K_m{}^{-1})^T$ is the extraction factor matrix of loads to generators [6].

COST ALLOCATION MODEL FOR REACTIVE FLOWS

For allocation of reactive power cost following algorithm is developed. For this purpose MVAr-mile method is used. In this model, reactive power charge is allocated with respect to the reactive power base capacity of the transmission line. If the cost of the line is denoted as TC_{s-b} (in Rs/hr) then reactive power cost allocated to users is given by: For generator G_i full transmission usage cost allocation is given by, $FTRC_{s-b}^{G_i}$

$$FTRC_{s-b}^{G_i} = \frac{RP_{i\to s-b}}{rf_{(base)s-b}} \times TC_{s-b} \qquad (15)$$

Total transmission Reactive power cost by $TRC_f^{G_i}$ allocated to generator G_i is given by:

$$TRC_f^{G_i} = \sum_{ln=1}^{e} FTRC_{ln}^{G_i} \qquad (16)$$

Similarly for Load L_h full transmission usage cost allocation is given by, $FTUC_{s-b}^{L_h}$

$$FTRC_{s-b}^{L_h} = \frac{RP_{j\to s-b}}{rf_{base\ s-b}} \times TC_{s-b} \qquad (17)$$

Total transmission Usage cost $TRC_f^{L_h}$ allocated to Load L_h

$$TRC_f^{L_h} = \sum_{ln=1}^{e} FTRC_{ln}^{L_h} \qquad (18)$$

Result and analysis

The 5 bus system has two generators and three loads with 7 transmission line. For cost allocation it is assume that cost of the transmission lines is proportional to the length of the lines.

Table (1) Reactive Power Allocation without FACT

Line no	Reactive Power flows in P.U.	L3	L4	L5
1-2	0.7916	0.2757	0.2072	0.2794
1-3	0.1757	0.0612	0.0460	0.0620
2-3	0.0297	0.0048	0.0082	0.0156
2-4	0.0207	0.0033	0.0057	0.0108
2-5	0.0541	0.0087	0.0149	0.0283
3-4	0.0351	0.0245	0.0083	0.0012
4-5	0.0072	0	0.0062	0.0009

Table (2) Cost Allocation without FACT

Line no	MVAR Transaction Cost in Rs/hr	L3	L4	L5
1-2	63.25	17.44	13.11	17.67
1-3	252.98	15.48	11.64	15.69
2-3	189.74	0.91	1.55	2.95
2-4	189.74	0.63	1.08	2.06
2-5	126.49	1.10	1.89	3.58
3-4	31.62	0.77	0.26	0.04
4-5	252.98	0.00	1.56	0.23
	Total	36.33	31.09	42.22

Reactive Power flow through different transmission line and cost allocation towards the reactive power wheeling charges which have to be recovered from the different load participants for 5 bus system without FACT controller are given in Table (1) and Table (2). The reactive power allocation and cost allocation analysis with the FACT Controller (STATCOM) is given in Table (3) and Table (4). Table (5) shows that total transmission loss is also reduced by using STATCOM.

Table (3) Reactive Power Allocation with STATCOM

Line no	Reactive Power flows in P.U.	L3	L4	L5
1-2	0.8258	0.2876	0.2164	0.2915
1-3	0.1488	0.0518	0.0390	0.0525
2-3	0.0791	0.0128	0.0218	0.0414
2-4	0.0473	0.0076	0.0130	0.0248
2-5	0.0716	0.0115	0.0197	0.0375
3-4	0.1820	0.1266	0.0433	0.0066
4-5	0.0674	0	0.0576	0.0088

Table (4) Cost Allocation with STATCOM

Line no	MVAR Transaction Cost in Rs/hr	L3	L4	L5
1-2	63.25	18.19	18.43	18.43
1-3	252.98	13.11	9.86	13.28
2-3	189.74	2.42	4.13	7.86
2-4	189.74	1.45	2.47	4.70
2-5	126.49	1.46	2.49	4.74
3-4	31.62	4.00	1.37	0.21
4-5	252.98	0.00	14.57	2.23
	Total	40.63	67.88	53.69

Table (5) Transmission loss

	Without STATCOM in P.U.	With STATCOM in P.U.
Total loss	0.0571	0.0568

Table (6) Line Data 5 Bus System

Line No.	From Bus	To Bus	R	X	Susceptance
1	1	2	0.02	0.06	0.06
2	1	3	0.08	0.24	0.05
3	2	3	0.06	0.18	0.04
4	2	4	0.06	0.18	0.04
5	2	5	0.04	0.12	0.03
6	3(6)	4	0.01	0.03	0.02
7	4	5	0.08	0.24	0.05

Table (7) Bus data 5 Bus System

Bus No	Bus Type	Voltage	Angle	P_L	Q_L	P_G	Q_G
1	1	1.06	0.0	0	0	0	0
2	2	1.05	0.0	0	0	0.40	0
3	0	1.0	0.0	0.45	0.15	0	0
4	0	1.0	0.0	0.40	0.05	0	0
5	0	1.0	0.0	0.60	0.710	0	0

CONCLUSION

As requirement of power supply rises day by day in developing countries like India so the demand of reactive power support in the form of ancillary services also increased. The trustworthy pricing policy towards reactive power is necessary; by applying the proposed method this issue can be dealt. From the result shown in table 1 to table 4 for 5 bus system it is clear that the reactive power flow through the transmission line can be regulate by using FACT controller. The influence of the FACT controller on the transaction cost of reactive power to be recovered from different load participant is also reflected. By using STATCOM the transmission loss is also reduced.

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