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A Power Flow Control in Multi-bus System with Auxiliary control of TCSC Controller

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ABSTRACT – In power system networks there are several issues, among those issues optimal power flow problem is very essential to save power. Real time monitoring and accurate computation of electrical data is quite difficult and time consuming. Due to development of high computing machines and efficient computational algorithms fast computing is possible in short duration of time. As the load changes the imbalance in the power flow occurs, with this there more losses takes place. By managing the reactance of the transmission lines this problem of power flow can be managed. To solve this problem, in this paper a thyristor control series capacitor (TCSC) based power electronic device is proposed. Only the TCSC is not sufficient in itself, so to control this a Newton Raphson's based auxiliary control technique is used. For experimentation point of view an IEEE 5-bus power system is considered and complete work is implemented in MATLAB. Results validated the method used and effectiveness of technique used.

***Keywords*— Power system, TCSC, FACTS controllers, NR, power flow**

I. INTRODUCTION

The flexible AC transmission system (FACTS) has received much attention in the last 2 decades. It uses high current power electronic devices to control the voltage, power flow, stability, etc. of a transmission system. FACTS technologies can essentially be defined as highly engineered power-electronics-based systems, integrating the control and operation of advanced power semiconductor-based converters (or valves) with software-based information and control systems, which produce a compensated response to the transmission network that is interconnected via conventional switchgear and transformation equipment. FACTS devices can be connected to a transmission line in various ways, such as in series with the power system (series compensation), in shunt with the power system (shunt compensation), or both in series and shunt. For example, the static VAR compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt; static synchronous series compensator (SSSC) and thyristor-controlled series capacitor (TCSC) are connected in series; thyristor-controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) are connected in a series and shunt combination. In series compensation, the FACTS is connected in series with the power system. It works as a controllable voltage source. Series inductance occurs in long transmission lines, and when a large current flow causes a large voltage drop. To compensate, series capacitors are connected. In shunt compensation, power system is connected in shunt with the FACTS.

It works as a controllable current source. The term and definition of various FACTS devices are described in references [1]-[5]. The pressure associated with economic and environmental constraints has forced the power utilities to meet the future demand by fully utilizing the existing resources of transmission facilities without building new lines. FACTS devices are very effective and capable of increasing the power transfer capability of a line, as thermal limits permit, while maintaining the same degree of stability [3]-[9]. Numerous recent applications of FACTS have proven to be cost-effective, long-term solutions. With the improvements in current and voltage handling capabilities of the power electronic devices that have allowed for the development of Flexible AC Transmission System (FACTS), The possibility has arisen in using different types of controllers for efficient shunt and series compensation. Applying FACTS on a broad-scale basis for both local and. Shunt FACTS devices are used for controlling transmission voltage, power flow, reducing reactive losses, and damping of power system oscillations for high power transfer levels [5]-[8]-[9]. With the wide spread and active consideration of the installation of FACTS controllers for better controllability.

Transmission line model:

Overhead transmission lines are modeled by their equivalent pi (π) model as shown in Fig. 1. The series impedance Z or its inverse which is the admittance Y depends on the short circuit current, Ish, whereas the admittance ($g_l + jb_l$) is a function of the no-load current I_o.

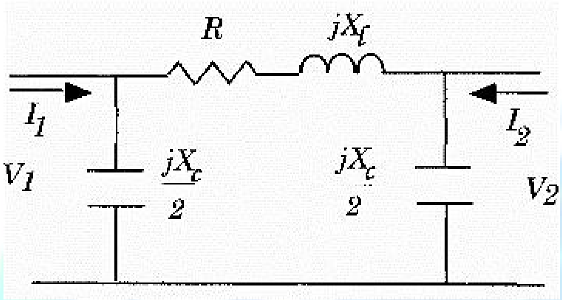


Fig. 1. Transmission line pi (π) model [1]

There some most usable power flow methods are: (i) Gauss–Seidel method (ii) Fast-decoupled-load-flow method (iii) Holomorphic embedding load flow method (iv) Backward-Forward Sweep (BFS) method. In this paper the Newton Raphson method is used to converge the load flow problem. This method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations. The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels. It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances and system transmission loss minimizes. There are basically three types of busses in power system. To balance the active power |P| and reactive power |Q| in a system while performing load flow studies and defined as a Vδ bus, also termed slack bus *(or swing bus)*. It is known P_i and $|V_i|$ but not Q_i or θ_i known as PV buses or Generator Buses. For known P_i and Q_i but not $|V_i|$ or θ_i, the defined as PQ buses or load bus.

Let the $V_i\angle\delta_i$ and $V_j\angle\delta_j$ are the voltages buses i and j with phase angle δ_i and δ_j respectively. The admittance of a line is Y_{ij} and effective phase angle is θ_{ij}. Then we can write:

$$P_k = \sum_{j=1}^{N} |V_i||V_j|\left(Y_{ij}\cos\left(\delta_i - \theta_{ij} - \delta_j\right)\right) \tag{1}$$

$$Q_k = \sum_{j=1}^{N} |V_i||V_j|\left(Y_{ij}\sin\left(\delta_i - \theta_{ij} - \delta_j\right)\right) \tag{2}$$

The Jacobian matrix is formed as:

$$\underline{\overbrace{M_J}^{(2N-1-N_G)\times(2N-1-N_G)}} = \begin{bmatrix} \underline{\overbrace{M_J{}^{P\delta}}^{(N-1)\times(N-1)}} & \underline{\overbrace{M_J{}^{PV}}^{(N-1)\times(N-N_G)}} \\ \underline{\overbrace{M_J{}^{Q\delta}}^{(N-N_G)\times(N-1)}} & \underline{\overbrace{M_J{}^{QV}}^{(N-N_G)\times(N-N_G)}} \end{bmatrix} \tag{3}$$

Iteration vies there will be four equations. For the load flow problem, this equation is of the

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = M_J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{4}$$

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} \Delta\delta_2 \\ \vdots \\ \Delta\delta_n \\ \Delta V_2 \\ \vdots \\ \Delta V_n \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \vdots \\ \Delta P_n \\ \Delta Q_2 \\ \vdots \\ \Delta Q_n \end{bmatrix} \tag{5}$$

Where, M_J is the Jacobian matrix

II. MTCSC Modelling

The proposed TCSC model is based on the power injection approach. The total number of buses for the system is increased according to the TCSC number, where, one reference bus should be added for each TCSC [1]. the TCSC implementation between sending bus S and receiving bus R, where bus A is the auxiliary bus (reference bus). This device is used to adjust the active power between sending and receiving buses to equal the specified value, P. However, this device can be modelled simply as two loads injected at sending and auxiliary buses. TCSC have the capacitor C, bypass inductor L and antiparallel thyristors T1 and T2. The triggering pulses of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to some system parameter variations. According to the operating principle of the TCSC, it can control the active power flow for the line l (between bus- i and bus- j where the TCSC is installed).

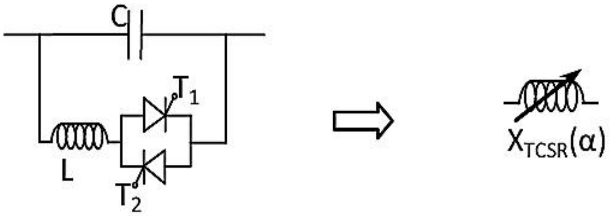


Fig. 2. TCSC model adjusted between two buses [6]

The real power P_{iinj}^{TCSC} and reactive power Q_{iinj}^{TCSC} injected at bus I can be expressed as:

$$P_{iinj}^{TCSC} = G_{ii}V_i^2 + (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij})V_iV_j \tag{8}$$

$$Q_{iinj}^{TCSC} = -B_{ii}V_i^2 + (G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij})V_iV_j \tag{9}$$

Where,

$$G_{ij} = r_{ij}/(r_{ij}^2 + (X_{ij} - X_c)^2) \quad \text{and} \quad B_{ij} = (X_{ij} - X_c)/(r_{ij}^2 + (X_{ij} - X_c)^2)$$

TCSC works to performs like a fixed series capacitor, specified as *Blocking mode and* TCSC behaves like a parallel connection of the series capacitor and the inductor specified as *Bypass mode.*

$$X_{TCSC} = \frac{X_C.X_{Lmax}\left[\frac{\pi}{\pi-2\alpha-\sin(2\alpha)}\right]}{X_C + X_{Lmax}\left[\frac{\pi}{\pi-2\alpha-\sin(2\alpha)}\right]} \tag{10}$$

The rating of TCSC depends on the reactance of the transmission line where the TCSC is located.

$$X_{ij} = x_{line} + x_{tcsc} \tag{11}$$

$$x_{tcsc} = r_{tcsc}.x_{line} \tag{12}$$

Where, x_{line} is the reactance of the transmission line and r_{tcsc} is the coefficient which represents the degree of compensation by TCSC. To avoid overcompensation, the working range of the TCSC is chosen between (-0.016 X line and 0.016 X line). By optimizing the reactance values between these ranges optimal settings of reactance values can be achieved.

Inequality constraints for convergence

for the optimal power flow, the inequality constraint are the important assumptions to ensure the system stability in power systems. Generators real and reactive power outputs: $P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1,\ldots,N_G$ and $Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i = 1,\ldots,N_G$

Voltage magnitudes at each bus in the network $V_i^{\min} \le V_i \le V_i^{\max}, i = 1,\ldots,N_L$ TCSC Reactance constraint $X_{TCSCi}^{\min} \le X_{TCSCi} \le X_{TCSCi}^{\max} i = 1,2,\ldots,n_{TCSC}$ Where, X_{TCSCi} = Reactance of TCSC at line $X_{TCSCi}^{\min}$ = Minimum reactance of TCSC at line $X_{TCSCi}^{\max}$ = Maximum reactance of TCSC at line *I* NN_{TCSC}= number of TCSC's.

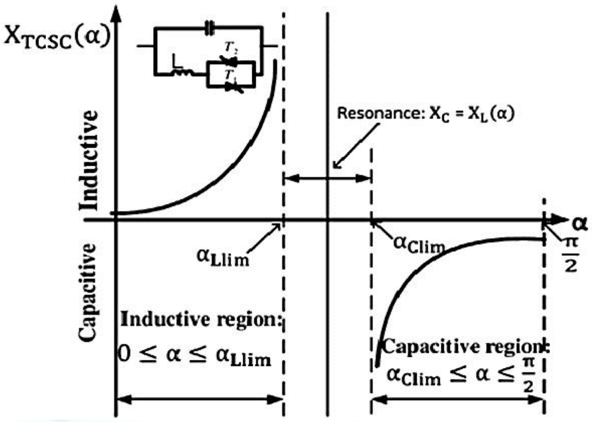


Fig. 3. Relationship Between Firing Angle (α) and X_{TCSC} [1]

III. IEEE 5-Bus structure and paremeters

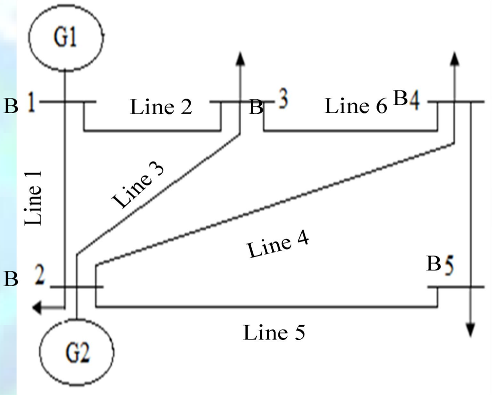


Fig.4. Standard IEEE 5-bus system

Figure 4 shows a single line diagram of a 5-bus system with two generating units, seven lines. Per-unit transmission line series impedances and shunt susceptance are given in p.u. in Table1.

Real power generation, real and reactive power loads in p.u. are given in Table 2. With Bus 1is a slack bus, obtain a load flow solution by using Newton-Raphson method with tolerance of 0.002 p.u for the real and reactive bus powers.

Table1

Bus code (Bus-Bus)	Impedance (R +jX)	Line Charging Susceptance (B/2)
1 - 2	0.02+j0.05	0.0+j0.030
1 -3	0.08 + j 0.24	0.0 + j0.025
2-3	0.06 + j0.18	0.0 + j0.02
2-4	0.06 + j0.18	0.0 + j0.02
2-5	0.04 + j0.12	0.0 + j 0.015
3-4	0.01 + j0.03	0.0 + j0.010
4-5	0.08 + j0.24	0.0 + j0.025

Table 2

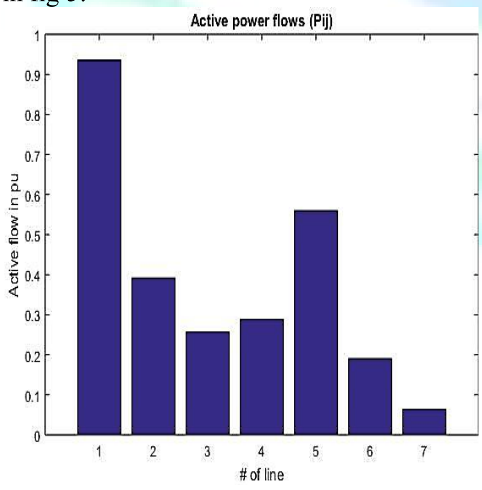
Bus No	Bus Voltages (pu)	Generation (MW)	Generation (MVAR)	Load (MW)	Load (MVAR)
1	1.06+j0.0	0	0	0	0
2	1.00+j0.0	40	29	20	10
3	1.00+j0.0	0	0	44	15
4	1.00+j0.0	0	0	41	4
5	1.00+j0.0	0	0	61	12

IV. RESULT AND DISCUSSION

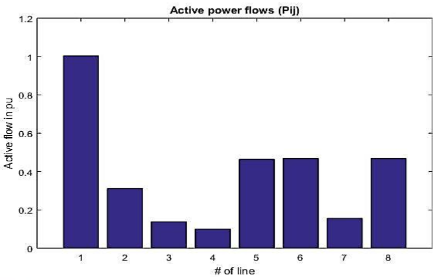
The proposed algorithm is implementation using MATLAB and analysed for its perfectness. The TCSC is implemented between bus 3 and bus 4, the 5-bus system stability improves because of the reactive power compensated by TCSC within the system. The effectiveness of the proposed method is clearly validated from the experimentation and results found.

(a) Real power flow (MW) with TCSC and without TCSC

The buses active power stabilised with the TCSC implementation. Mismatch in the real power with the pupation of reactance in the line where the TCSC is implemented shown properly in fig 5.



(a)



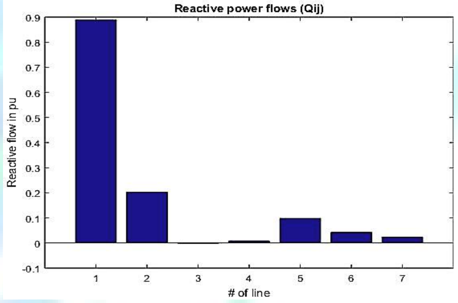
(b)

Fig 5 (a) Real Power without TCSC (b) Real Power with TCSC

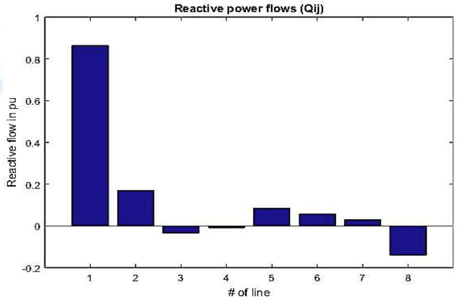
The reactive power mismatch is minimum with the TCSC implementation. TCSC works to modify the required effective reactance in the system to overcome the power mismatch problem and optimize the power flow.

(b) Reactive power (MVR) flow with TCSC and without TCSC

The buses reactive power responsible for the real power flow, TCSC implementation works to control the power flow. Iteration by iteration according to the adjustment of reactance of in line, where the variable reactance device is implemented. Mismatch in the reactive power with the updation of reactance of line where the TCSC is implemented shown properly in fig 6.



(a)



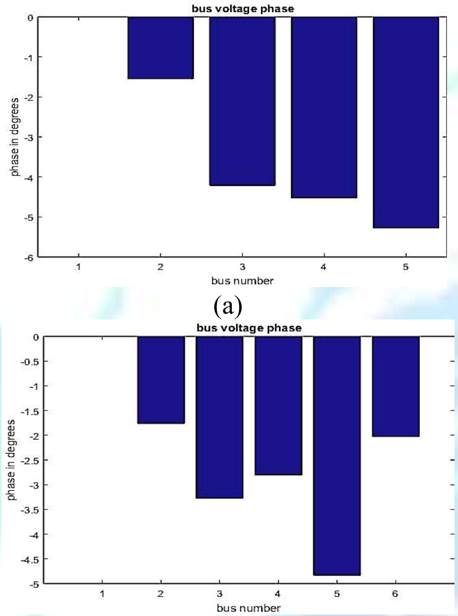
(b)

Fig 6 (a) Reactive Power without TCSC (b) Real Power with TCSC

From fig 6 (a) and (b) it is very clear and justified that the reactive power can be managed optimized by using FACTS controllers.

(c) Bus by bus load angle with TCSC and without TCSC

The load angle mismatch response is shown in the figure 7 (a) and (b) with and without respectively. The load angle stabilizes with the compensation of phase with the TSCS whenever it is required. More is the stability more is the power optimization. Variation in the load angle shown in fig. 7 (a) and (b) respectively, for the optimal power flow is achieved. Adjustment of phase is exactly done with the help of TCSC reactance injected in the line where it is placed. Here TCSC is placed in the line 2 between bus 3and bus 4.



(a)

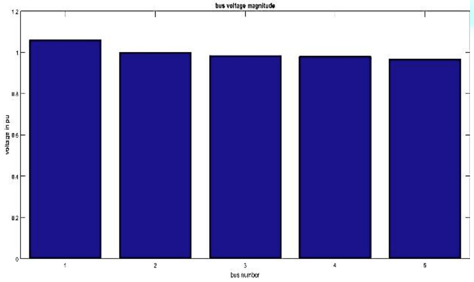
(b)

Fig 7 Bus by Bus (a) Load angle without TCSC (b) Load angle with TCSC

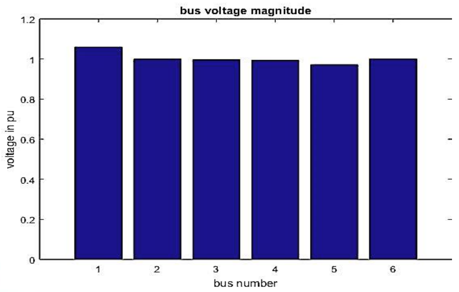
Change in the line effective reactance directly affect the phase angle between two busses. We all are aware of the max power transfer theorem where the maximum power can be transferred by managing the impedance of load in reference to the network along with the source.

(d) Buses Voltage Magnitude with TCSC and without TCSC

If we look in the fig 8 it is clear that the bus voltage changes as per the system stability requirement. The comparison results depicting the effectiveness of the proposed method.



(a)



(b)

Fig 8 Bus by Bus (a) Bus voltage magnitude without TCSC (b) Bus voltage magnitude with TCSC

As the effective reactance changes the buses voltage also changes accordingly to ensure the system stability requirement. Total real power losses in the network without TCSC is 0.0672444 pu .i.e 6.7244 MW and real power losses in the network with TCSC is 0.0562107 pu .i.e 5.62107 MW, so it is very clear that there is total power saving in is of 1.10337 MW. This is the significant amount of power saving, and hence we can say that TCSC working effectively for the power flow optimization with auxiliary control using Newton Raphson method.

V. CONCLUTION

In this work the TCSC power flow model is introduced. The complete work is implemented in MATLAB, using optimization or convergence method (Newton-Raphson) for load flow, with this control method, it is possible to solve large power networks very reliably. The method with FACTS controller: TCSC retains Newton's quadratic convergence and the effectiveness is illustrated by some power flow solutions of the multi-bus systems. Power calculations in conventional manner indicates some suggestions related to the position of TCSC. The case studies for implementing the variable series impedance power flow model of TCSC is an effective and put evidence with respect to modelling and using TCSC to control power flows in multi bus systems. The experimental results show the effectiveness of the model and method used for voltage and power flow control.

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