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IMPLEMENTATION OF TCSC FOR ENHANCEMENT OF ATC

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ABSTRACT

The objective of this paper is to enhance the Available Transfer Capability using TCSC controller. The TCSC controller is implemented and included in the N-R load flow algorithm to minimize the losses of the system. The analysis is performed on IEEE-14 bus system.

Keywords: Available Transfer Capability (ATC), MATLAB, Newton-Raphson Load Flow, Thyristor Controlled Series Capacitor (TCSC).

I. INTRODUCTION

Nowadays load requirement is increasing because of industrialization and urbanization process. Due to the outage of one or the other lines in the system, overloading increases in rest of the lines. Thus, most of the transmission lines cross their thermal loading capacity.

To cope up with the load, we have to either place new transmission line or improve the capability of the existing system. But the former method is not economical so we have to improve the capability of existing system by using FACTS devices. It is an important issue in current de-regulated environment of power system. This paper presents enhancement of ATC.

The ATC of the transmission system is the unused capabilities of a transmission network. By reducing the MW losses of the system we can improve the ATC. To reduce the MW losses, the circuit reactance must be reduced. To reduce the reactance of the line we have to use FACTS devices in the system.

FACTS devices control voltage magnitude, phase angle as well as circuit reactance. By using FACTS devices the load flows are redistributed. The Thyristor Controlled Series Capacitor (TCSC) is one of the most efficient FACTS devices. In High voltage transmission networks it offers fast acting reactive power compensation as compared to the traditional control devices [1], [2]. In this research work, TCSC is used for improving ATC. IEEE-14 bus system is used for the system under consideration and the implementation is done in MATLAB software. This paper has been organized in the following manner. Section II discusses the operation and modelling of TCSC. Section III presents the algorithm for calculating the ATC using N-R method. Section IV presents results of load flow for IEEE-14 bus system with and without the TCSC.

II. THYRISTOR CONTROLLED SERIES CAPACITOR

2.1 Structure and Operation of TCSC

Fig. 1 shows the structure of TCSC [7]. It basically works in three modes [3], [8] 1.Thyristor by-pass mode 2.Thyristor blocked mode 3.Vernier mode.

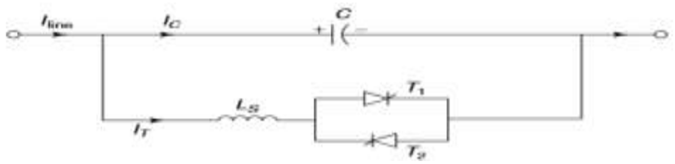

Figure 1. Schematic Diagram of TCSC

In the thyristor by-pass mode, firing angle is α=0°. In Thyristor blocked mode, firing angle is α=180°. It is also called waiting mode of thyristor. In vernier mode, it can work either in capacitive vernier mode or inductive vernier mode. It depends upon the firing angle α, shown in figure 2[9]. For capacitive vernier mode, firing angle must be αClim≤ α≤180°. For inductive vernier mode, firing angle must be 90≤ α≤ αLmin. If firing angle is between αLlim≤ α≤ αClim, then it works in resonant region. As resonant region is present between the two modes, transform from one region to other region is difficult.

2.2 Modelling of TCSC

For implementing TCSC device in to the N-R load flow the modelling of TSCS is required. Modelling of TCSC is done in two ways,

1. Variable Reactance Model
2. Firing Angle Model

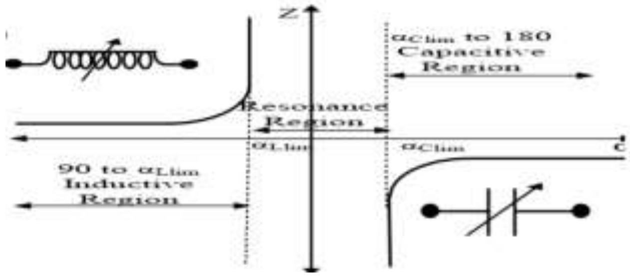

Figure 2. Operating Principle of TCSC.

In this paper, Firing Angle model is used. Fig. 2 shows TCSC reactance-firing angle characteristic [2]. It is in the form of non-linear relation. Once the value of reactance is computed using Newton's method, the associated firing-angle can be calculated. However, such calculation involves the iterative procedure so the characteristic between TCSC reactance and firing angle are non-linearly related.

The fundamental frequency equivalent reactance XTCSC of the TCSC controller is given as equation (1), [2],[10].

$$X_{TCSC} = -X_C + C_1(2(\pi-\alpha)+\sin(2(\pi-\alpha))) - C_2\cos^2(\pi-\alpha)(w*\tan(w(\pi-\alpha)) - \tan(\pi-\alpha)) \quad (1)$$

Where,

$$X_{LC} = \frac{X_C X_L}{X_C - X_L}$$

$$C_1 = \frac{X_C + X_L}{\pi} \quad \& \quad C_2 = 4\frac{X^2_{LC}}{X_L \pi}$$

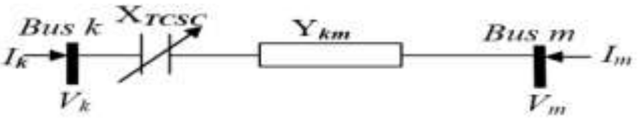

Figure 3. Modelling of Transmission line with TCSC.

Fig. 3 shows the TCSC controller is placed between the bus-k and bus-m, because of that Ybus gets modified. So it is required to find XTCSC from equation (1), after finding the XTCSC Ybus is modified which is shown by equation (2),

$$Y'bus = Ybus + \begin{matrix} 0 & 0 & \cdots & 0 & 0 \\ 0 & \Delta Ykk & \cdots & \Delta Ykm & 0 \\ 0 & 0 & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 0 & 0 \\ 0 & \Delta Ymk & \cdots & \Delta Ymm & 0 \\ 0 & 0 & \cdots & 0 & 0 \end{matrix} \qquad (2)$$

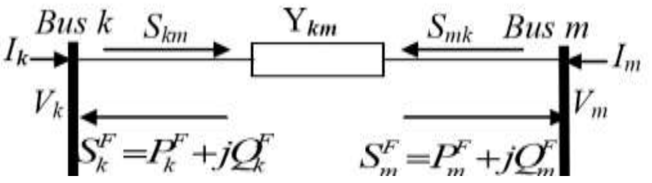

Figure 4. Power Injection Model.

Fig. 4 shows the power injection model. The injected apparent power [11], [12] is given by equation (3),

$$S_k^F = V_k\left(\frac{jX_{TCSC}}{R_{km} + jX_{km}} \frac{V_k - V_m}{R_{km} + j(X_{km} - X_{TCSC})}\right)^*$$

$$S_m^F = V_m\left(\frac{-jX_{TCSC}}{R_{km} + jX_{km}} \frac{V_k - V_m}{R_{km} + j(X_{km} - X_{TCSC})}\right)^* \qquad (3)$$

Real and reactive power injections at bus-k and bus-m are given by equation (4) and equation (5) respectively, [11], [12].

$$P_k^F = V_k{}^2 G_{kk}^F - V_k V_m [G_{km}^F \cos\delta_{km} + B_{km}^F \sin\delta_{km}]$$

$$Q_k^F = V_k{}^2 B_{kk}^F - V_k V_m [G_{km}^F \sin\delta_{km} - B_{km}^F \cos\delta_{km}]$$

(4)

$$P_m^F = V_m{}^2 G_{mm}^F - V_k V_m [G_{km}^F \cos\delta_{km} + B_{km}^F \sin\delta_{km}]$$

$$Q_m^F = -V_m{}^2 B_{mm}^F - V_k V_m [G_{km}^F \sin\delta_{km} - B_{km}^F \cos\delta_{km}] \qquad (5)$$

III. ALGORITHM FOR CALCULATION OF ATC USING N-R METHOD

Load flow studies are required for better planning of system. By load flow study [4], [5], [6], we get information about different parameters like power flow on lines, voltage magnitude and angle, total losses, etc. If the losses of the system are high then the generation demand increases. The main objective of this paper is to reduce the MW losses of the whole system. By reducing the MW losses of the system, the demand of the generation is also reduced simultaneously and thus ATC of the system gets improved. The algorithm for calculating the ATC using N-R method is as follow,

i) Read the system Line data, Bus data and TCSC data.

ii) Form Ybus and modify it according to the equation (2).

iii) Now calculate Pshed and Qshed from generation and load data that are given in the system data.

iv) Set iteration=0, ΔPmax=0 and ΔQmax=0.

v) Calculate apparent power from equation (6).

$$S = V^* \mathrm{conj}\,(I) \qquad (6)$$

Pcal = real(S); Qcal = imag(S)

vi) ΔP=Pshed-Pcalc, ΔQ=Qshed-Qcalc and ΔPkm Pkmshed-Pkmcalc

vii) ΔPmax, ΔQmax & ΔPkmmax is calculated from ΔP, ΔQ & ΔPkm vector.

viii) Check for ΔPmax<ε & ΔQmax<ε if yes then print result otherwise go for Jacobian matrix.

ix) Fig. 5 shows that Jacobian matrix after inserting the TCSC is modified [10], [12].

x) Form Right hand side vector B[i] =ΔP[i] & B[i+n]=ΔQ[i].

xi) Use Gauss-elimination method [A][J]=[B] and update the solution δ I = δ i+Δδ & Vi = Vi+ΔV.

xii) Check for convergence criteria if it is satisfied then print the solution otherwise go for next iteration (itr≥itr_max).

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{km}^{\alpha TCSC} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \delta_k} & \frac{\partial P_k}{\partial \delta_m} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial V_m} V_m & \frac{\partial P_k}{\partial \alpha} \\ \frac{\partial P_m}{\partial \delta_k} & \frac{\partial P_m}{\partial \delta_m} & \frac{\partial P_m}{\partial V_k} V_k & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \alpha} \\ \frac{\partial Q_k}{\partial \delta_k} & \frac{\partial Q_k}{\partial \delta_m} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial V_m} V_m & \frac{\partial Q_k}{\partial \alpha} \\ \frac{\partial Q_m}{\partial \delta_k} & \frac{\partial Q_m}{\partial \delta_m} & \frac{\partial Q_m}{\partial V_k} V_k & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \alpha} \\ \frac{\partial P_{km}^{\alpha TCSC}}{\partial \delta_k} & \frac{\partial P_{km}^{\alpha TCSC}}{\partial \delta_m} & \frac{\partial P_{km}^{\alpha TCSC}}{\partial V_k} V_k & \frac{\partial P_{km}^{\alpha TCSC}}{\partial V_m} V_m & \frac{\partial P_{km}^{\alpha TCSC}}{\partial \alpha_{TCSC}} \end{bmatrix} \begin{bmatrix} \Delta \delta_k \\ \Delta \delta_m \\ \frac{\Delta V_k}{V_k} \\ \frac{\Delta V_m}{V_m} \\ \Delta \alpha_{TCSC} \end{bmatrix}$$

Figure 5. Modified Jacobian Matrix

xiii) If it converges within itr_max then it gives the solution for 1) Power flows 2) Line losses 3) Voltage Magnitude and Angle 4) Total System Losses. If not, then it that the program is not converged in itr_max.

IV. CASE STUDY AND RESULTS

Fig. 6 shows IEEE-14 bus system. In this paper, I used MATLAB software for programming of N-R load flow to calculate the losses of the system and Power flow of the lines without the TCSC controller. After placing the TCSC between the line 2-5 load flow is done and the losses and Power flow of the line is calculated again. By comparing both the results we conclude that the losses of the system are reduced by 47.52%, and the ATC of the line 2-5 in which TCSC is placed gets improved by 19.83%.

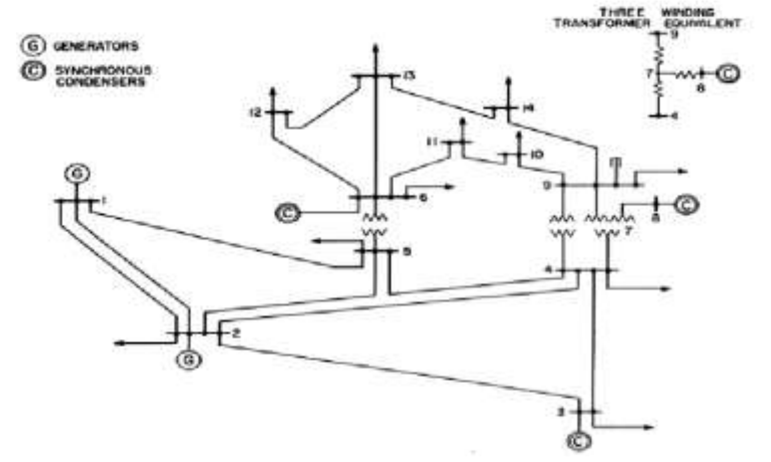

Figure 6. IEEE-14 Bus System

4.1 Results

TABLE I. **Real Power flow without the TCSC controller**

Bus System	***Line Number***	***Real Power Flow (MW)***
14-Bus	2-5	41.727

TABLE II. **Real Power flow with the TCSC controller**

Bus System	***Line Number***	***Real Power Flow (MW)***
14-Bus	2-5	49.998

TABLE III. **Total System loss without the TCSC controller**

Bus System	***Total System loss (MW)***
14-Bus	27.153

TABLE IV. **Total System loss with the TCSC controller**

Bus System	***Total System loss (MW)***
14-Bus	14.251

V. CONCLUSIONS

Now a days the load requirement increases, because of industrialization and urbanization. It leads to dependency on electrical energy. The rapid growth of power requirement leads to some uncertainty in the system. Because of this many contingency and outages occurs. This causes the overloading of the other lines and makes them to reach to their thermal limit.

It also affects the quality of power delivered. So after inserting the TCSC device in IEEE-14 bus system the total loss of the system is reduced by 47.52% and ATC of the system is improved 19.83%. So we can use the same line for transferring more power without any extra cost of equipment.

VI. ACKNOWLEDGEMENTS

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