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Optimal Placement of Advanced Multi TCSC for Enhancement of Power System Performance by using Conventional Method

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ABSTRACT: Flexible Alternating Current Transmission Systems (FACTS) represents a vast development in the area of power system operation and control. As we know that under heavily loaded conditions our power system is at high risks of consequent voltage instability problem. This paper gives an overview about application of series connected Flexible alternating current transmission system (FACTS) for improvement of power system performance like transfer stability, secure voltage profile and reduce the system losses etc. FACTS devices require huge capital investment. Therefore, FVSI technique is used for optimal location and sizing of series FACTS controllers like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) etc. These techniques are used to solve the optimization problem. This paper gives details of optimal placement and sizing of FACTS devices based on different evolutionary techniques which is used for minimization of transmission loss, enhancement of stability of power system. In this study one of the FACTS devices is used as a scheme for enhancement of power system stability. Proper installation of FACTS devices also results in significant reduction of transmission loss. In this review, TCSC is selected as the compensation device

KEYWORDS: Power system, Transmission system, FACTS, TCSC, Firing Angle, FVSI.

I. INTRODUCTION

In recent years power demand has increased substantially while the expansion of power generation and transmission has been limited due to limited resources and environmental restrictions. As a consequence some transmission lines are heavily loaded and system stability becomes a power transfer limiting factor. Flexible AC transmission system (FACTS) controllers are mainly used for solving various power system steady state control problems. However recent studies reveal that FACTS controllers could be employed to enhance power system stability in addition to their main function of power flow control. It is known that the power flow through an ac transmission line is a function of line impedance, the magnitude and the phase angle between the sending and the receiving end voltages. By proper coordination of FACTS devices in the power system network, both the active and reactive power flow in the lines can be controlled. The literature mainly concentrated on the series compensation placement and its size based on the target value of the voltage (p.u) at the buses by selecting the suitable line. This paper is divided in to four section. In section-I introduction to the power system and series compensation, section-II Load flow analysis for analyzing the steady state system, section –III introduces the firing angle control of TCSC and modeling of the TCSC with the Newton Raphson method of load flow analysis and In section-IV the proposed method is adopted to the different test cases to analyses the power flows, voltage profile, real and reactive power losses.

In the literature many people proposed different concepts about the placement and sizing of the Analytical method of TCSC

Sahoo et.al (2007) proposed the basic modeling of the FACTS devices for improving the system performance[1]. About the modeling and selection of possible locations for the installation of FACTS devices have been discussed by Gotham.D.J and G.T Heydt (1998) [2]. Povh.D(2000) proposed the nice concepts of the modeling of the power systems and the impact of the FACTS devices on the transmission network[3]. Modeling of the FACTS devices with various techniques with complete computer programming is proposed by Acha et.al. [4].The impact of multiple compensators

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in the system was proposed by Radman.G and R.S Raje [5].The important concepts of the power systems with different load flow was proposed by Stagg.G.W et.al(1968)[6]. Hingorani N.G et.al presented about FACTS devices ,which are a family of high-speed electronic devices, which can significantly increase the power system performance by delivering or absorbing real and/or reactive power [7]. Tong Zhu and Gamg Haung proposed(1999) the accurate points of the buses which were suitable for the FACTS devices installation [11].P.Kessal and H. Glavitsch(1986) proposed increase the transmission capability, improvement of stability by installing FACTS devices in transmission network [12].

II. POWER FLOW ANALYSIS

In large-scale power flow studies the Newton–Raphson method has been proved most successful owing to its strong convergence characteristics .This approach uses iteration to solve the following set of nonlinear algebraic equations.
The power mismatch equations ΔP and ΔQ are expanded around a base point (θ(0),V(0)) and, hence, the power flow Newton–Raphson algorithm is expressed by the following relationship.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V}V \\ \frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V}V \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \frac{\Delta V}{V} \end{bmatrix} \quad (1)$$

Where
P is the real power at the buses
Q is the reactive power at the buses
V is the voltage at the bus
θ is the voltage angle at the bus
ΔP is the change of real power at the bus.
ΔQ is the change of reactive power at the bus.

III. SERIES COMPENSATION

FACTS controllers can be broadly divided into four categories, which include series controllers, shunt controllers, combined series-series controllers, and combined series-shunt controllers. Their operation and usage are discussed below.

A series controller may be regarded as variable reactive or capacitive impedance whose value is adjusted to damp various oscillations that can take place in the system. This is achieved by injecting an appropriate voltage phasor in series with the line and this voltage phasor can be viewed as the voltage across an impedance in series with the line. If the line voltage is in phase quadrature with the line current, the series controller absorbs or produces reactive power, while if it is not, the controllers absorb or generate real and reactive power. Examples of such controllers are Static Synchronous Series Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), Thyristor-Controlled Series Reactor (TCSR), to cite a few. They can be effectively used to control current and power flow in the system and to damp oscillations of the system.

A. THYRISTOR CONTROLLED SERIES CAPACITOR(TCSC)

The basic conceptual TCSC module comprises a series capacitor, *C*, in parallel with a thyristor-controlled reactor, LS, as shown in Fig. 1. However, a practical TCSC module also includes protective equipment normally installed with series capacitors. A metal-oxide varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high-capacitor over- voltages. Not only does the MOV limit the voltage across the capacitor, but it allows the capacitor to remain in circuit even during fault conditions and helps improve the transient stability.

Also installed across the capacitor is a circuit breaker, CB, for controlling its insertion in the line. In addition, the CB bypasses the capacitor if severe fault or equipment-malfunction events occur. A current-limiting inductor, *Ld*, is incorporated in the circuit to restrict both the magnitude and the frequency of the capacitor current during the capacitor-bypass operation.

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An actual TCSC system usually comprises a cascaded combination of many such TCSC modules, together with a fixed-series capacitor, *CF*. This fixed series capacitor is provided primarily to minimize costs.

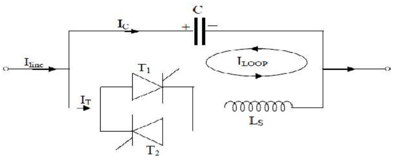

Figure 1. A Basic Module of TCSC

B. OPERATION OF THE TCSC (FIRING ANGLE POWER FLOW MODEL)

The computation of the firing angle is carried out. However, such calculation involves an iterative solution since the TCSC reactance and firing angle are nonlinearly related. One way to avoid the additional iterative process is to use the alternative TCSC Variable Impedance Power Flow model presented in this section. The fundamental frequency equivalent reactance XTCSC(1) of the TCSC module [4] shown in Figure

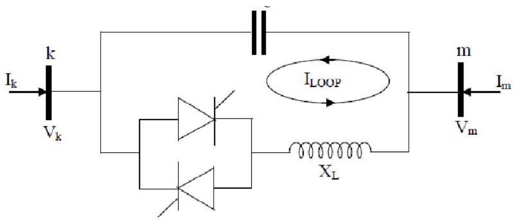

Figure 2. TCSC Firing angle Power flow model.

$$X_{T\csc(1)} = -X_c + C_1\{2(\pi-\alpha)+\sin[2(\pi-\alpha)]\} - C_2\cos^2(\pi-\alpha)\{\omega\tan[\omega(\pi-\alpha)]-\tan(\pi-\alpha)\} \quad (2)$$

Where

$$C_1 = \frac{X_c X_{Lc}}{\pi} \quad (3)$$

$$C_2 = \frac{4X_{LC}^2}{X_L \pi} \quad (4)$$

$$X_{LC} = \frac{X_c X_L}{X_c - X_L} \quad (5)$$

$$\omega = \left(\frac{X_c}{X_L}\right)^{\frac{1}{2}} \quad (6)$$

TCSC active and reactive power equations at bus k are

$$P_k = V_k V_m B_{km}\sin(\theta_k - \theta_m) \quad (7)$$

$$Q_k = -V_k^2 B_{kk} - V_k V_m B_{km}\cos(\theta_k - \theta_m) \quad (8)$$

Where

$$B_{kk} = B_{km} = B_{T\csc(1)} \quad (9)$$

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$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{km}^{\alpha_{TCSC}} \end{bmatrix} - \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial V_m} V_m & \frac{\partial P_k}{\partial \alpha_{TCSC}} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial V_k} V_k & \frac{\partial P_m}{\partial V_m} V_m & \frac{\partial P_m}{\partial \alpha_{TCSC}} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial V_m} V_m & \frac{\partial Q_k}{\partial \alpha_{TCSC}} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial V_k} V_k & \frac{\partial Q_m}{\partial V_m} V_m & \frac{\partial Q_m}{\partial \alpha_{TCSC}} \\ \frac{\partial P_{km}^{\alpha_{TCSC}}}{\partial \theta_k} & \frac{\partial P_{km}^{\alpha_{TCSC}}}{\partial \theta_m} & \frac{\partial P_{km}^{\alpha_{TCSC}}}{\partial V_k} V_k & \frac{\partial P_{km}^{\alpha_{TCSC}}}{\partial V_m} V_m & \frac{\partial P_{km}^{\alpha_{TCSC}}}{\partial \alpha_{TCSC}} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \Delta \theta_m \\ \frac{\Delta V_k}{V_k} \\ \frac{\Delta V_m}{V_m} \\ \Delta \alpha_{TCSC} \end{bmatrix} \quad (10)$$

Where $\Delta P_{km}^{\alpha_{T\,csc}} = P_{km}^{reg} - P_{km}^{\alpha_{T\,csc}}$ is the active power mismatch for TCSC module. $\Delta\alpha_{T\,csc}$ is the incremental change in the TCSC firing angle.

C. FAST VOLTAGE STABILITY INDEX (FVSI)

Fast voltage stability index (FVSI) is formulated this as the measuring instrument in predicting the voltage stability condition in the system. Taking the symbols 'i' as the sending bus and 'j' as the receiving bus. Hence, the fast voltage stability index, FVSI can be defined by:

$$FVSI_{ij} = \frac{4Z_{ij}^2 Q_j}{V_i^2 X_{ij}} \quad (12)$$

Where: **Zij**= line impedance
Xij = line reactance
Qj = reactive power at the receiving end
Vi = sending end voltage
The value of FVSI that is evaluated close to 1.00 indicates that the particular line is closed to its instability point which may lead to voltage collapse in the entire system. To maintain a secure condition the value of FVSl should be maintained well less than 1.00.

Table 1 : FVSI Values for IEEE 14 bus system

From bus	To bus	FVSI
1	2	0.0250
2	3	0.1075
2	4	0.0019
1	5	0.0820
2	5	0.0262
3	**4**	**0.1577**
4	5	0.0038
5	6	0.2318
4	7	0.0974
7	**8**	**0.1616**
4	9	0.0185
7	9	0.0857
9	10	0.0013
6	11	0.1030
6	12	0.0490
6	13	0.0794
9	14	0.0112
10	11	0.0826
12	13	0.0328
13	14	0.1078

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IV. TEST CASES

The proposed method is used to analyze the different standard IEEE transmission network. The important parameters that can be determined by proposed methods are power flows, voltage profile of the buses,real and reactive power losses.

A. IEEE 14 BUS SYSTEM

The single line diagram of IEEE 14 bus system is shown in the fig 3.which consists of 5 PV buses, and 11 PQ buses. The power flow results of IEEE 14 bus system without installing TCSC are shown in the figures
The minimum voltage and maximum voltage in terms of p.u is shown in the table 2 without installing of TCSC to the system.

Table 2.Minimum and maximum voltages of IEEE 14 bus system

Minimum voltage(P.U)	Maximum Voltage(p.u)
1.01 at bus 3	1.09 at bus 8

The Real power and reactive power losses of IEEE 14 bus system are 9.68 Mw and 50.04 Mvar.

The maximum real and reactive power losses through the branches of IEEE 14 bus system are 2.42 Mw and 10.19Mvar at line 2-3.

The placement series FACTS devices i.e, TCSC are determined by FVSI . The FVSI for IEEE 14 bus is shown in table 1. From the table 1, the placement of the TCSC is deciced by the highest value in the table, which is line 7-8 for single TCSC placement and lines 7-8 and 3-4 for double placement of TCSC. The effect of placing TCSC for IEEE 14 bus is shown in the figures 3,4,5 and 6 res.

Single TCSC placement

The effect of single TCSC placement for the IEEE 14 bus system is detailed shown in the figures 3,4 and 5 res.

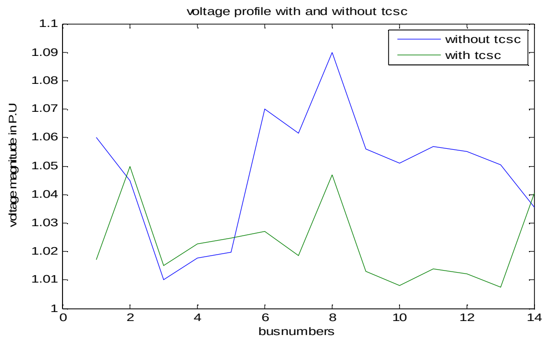

Figure 3. Comparative voltage profile of IEEE 14 bus with and without TCSC

The voltage profile of the system is standardized by placing single TCSC at line 7-8. The minimum voltage is 1.004 p.u at bus 13 and the maximum voltage is 1.05 at bus 2. The reduction of total real and reactive power losses are shown in the fig 4 and 5 res.

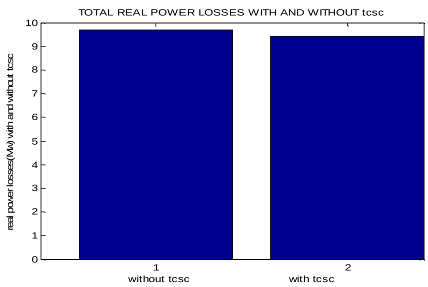

Figure 4.Comparative analysis of Real power losses of IEEE 14 bus with and without TCSC

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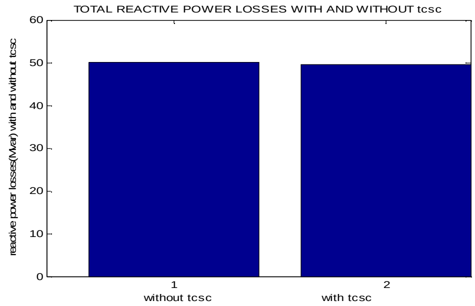

Figure 5. Comparative analysis of Reactive power losses of IEEE 14 bus with and without TCSC

The firing angle ,size and location of the TCSC is shown in table 3.

Table 3. Comparative analysis of IEEE 14 bus with and without TCSC

Parameters	Without TCSC	With TCSC
Minimum Voltage(p.u)	1.01 at bus 3	1.004 at bus 13
Maximum Voltage(p.u)	1.09 at bus 8	1.05 at bus 2
Real power losses(Mw)	9.682	9.422
Reactive power losses(Mvar)	50.04	49.48
Location of TCSC	----------	7-8 line
TCSC firing angle(deg)	----------	136.3
Size of TCSC(Kvar)	-----------	2.43

With the inclusion of the another TCSC at the line 3-4 the power flows are further improved and losses are reduced which is shown in the table

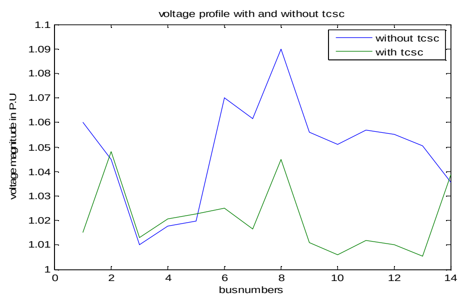

Figure. 6 Comparative analysis of Reactive power losses of IEEE 14 bus with and without two TCSC’s

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Table 4. Comparative analysis of IEEE 14 bus with two TCSCs and without TCSC

Parameters	Without TCSC	With two TCSC's
Minimum Voltage(p.u)	1.01 at bus 3	1.006 at bus 10
Maximum Voltage(p.u)	1.09 at bus 8	1.048 at bus 2
Real power losses(Mw)	9.682	9.282
Reactive power losses(Mvar)	50.04	48.2
Location of TCSC	----------	7-8 line 3-4 line
TCSC 1firing angle(deg)	----------	136.3
TCSC2 firing angle(deg)	----------	129.3
Size of TCSC1(Kvar)	-----------	1.440
Size of TCSC2(Kvar)	----------	0.993

B. TEST CASE 2 IEEE 30 BUS SYSTEM

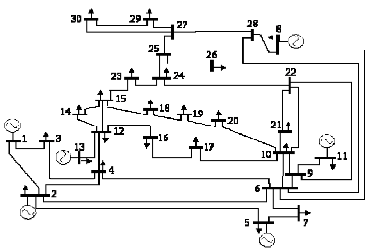

Figure 7 Single line diagram of IEEE 30 bus system.

The proposed firing angle model of TCSC are applied to IEEE 30 bus system which is shown in the fig 11.The voltage profile, real and reactive power losses without placing of TCSC and with the placing of single TCSC and two TCSCs are shown in the fig and table respectively.

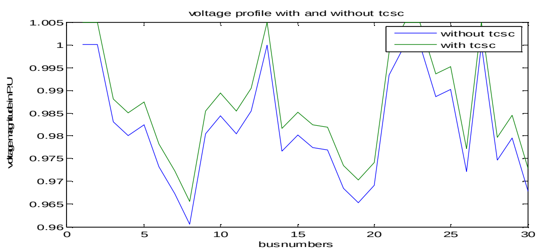

Figure 8 voltage profile of IEEE 30 bus without and with single TCSC

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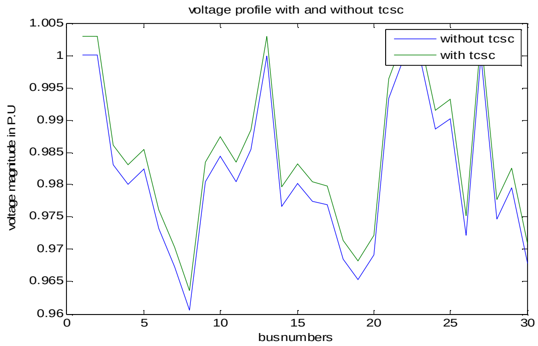

Figure 9 voltage profile of IEEE 30 bus without and with two TCSC's

Table 6 Comparative system parameters of IEEE 30 bus with and without TCSC

Parameters	**Without TCSC**	**With TCSC**	**With two TCSC**
Minimum Voltage(p.u)	0.966 at bus8	0.966 at bus 8	0.964 at bus 8
Maximum Voltage(p.u)	1.00 at bus1	1.005 at bus 1	1.003 at bus 1
Real power losses(Mw)	2.44	1.911	1.624
Reactive power losses(Mvar)	8.99	7.84	5.22
Location of TCSC	----------	12 -13line	12 -13line 4-12 line
TCSC 1firing angle(deg)	----------	144.3	149.3
TCSC2 firing angle(deg)	----------	-------	114.8
Size of TCSC1(Kvar)	-----------	2.72	1.94
Size of TCSC2(Kvar)	----------	-------	1.35

After placing the TCSC to the IEEE 30 bus system at 12-13 line with size of 2.72 Kvar at 144.3 degrees of firing angle. The real and reactive power losses are reduced too much extent. The voltage profile is improve to which is shown in figure 8 and 9 . The effect of placing to another TCSC at the line 4-12 is shown in the Table 6

V. CONCLUSION

The Firing Angle Model of Thyristor controlled series capacitor (TCSC) using Newton Raphson method has been implemented on IEEE 14 & 30 bus test systems to investigate the performance of power transmission line in absence as well as in presence of single and double TCSC devices. It is found that during presence of single TCSC there is reduction of real and reactive power losses and also voltage profile improvement as compared to absence of TCSC and with double TCSCs also there is reduction in losses but voltage profile is more or less constant .Based on this firing angle model of single TCSC is sufficient towards voltage improvement

The results obtained by application of the N-R technique during firing-angle model based control are found to be very much similar with the reactance model. It is noted that as compared to Reactance method, the implementation of the firing-angle based control of TCSC using NR technique is much easier. It is also noted that the firing-angle calculation of TCSC using firing-angle model based control is much easier as compared to impedance model based control and this proposed method is better than earlier published works like reactance models and power injection models.

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