International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || REETA-2K16 ǁ PP. 544-551

Placement of Firing Angle Model OF TCSC FACTS Devices for Voltage Profile Improvement and Loss Reduction by using PSO algorithm

Mr.A.HEMA SEKHAR[1]
Dr.A.LAKSHMI DEVI[2]
[1] *Research Scholar, Department of EEE, S.V.University College Of Engineering,Tirupati,India*
[2] *Professor & HOD, Department of EEE ,S.V.University College Of Engineering,Tirupati, India*
E-mail: ahemasekar@yahoo.com

Abstract: In today‘s highly complex and interconnected power systems, mostly made up of thousands of buses and hundreds of generators, there is a great need to improve electric power utilization maintaining reliability and security. Available power generation, usually not situated near a growing load center, is subject to regulatory policies and environmental issues. The majority of the losses are occurred at the transmission level. So by controlling or managing the transmission system with FACTS the losses will be reduced. Although the voltage constraints are within limits but the reactive power losses are majorly high in transmission system. So by suitable placement of series FACTS devices at the transmission system the reactive power losses are controlled. In this paper the concept of firing angle control for the series compensating device is introduced for flexible control of the device at transmission system. The optimized firing angles of TCSC and location of the buses are determined by PSO.

Keywords: Power system, Transmission system, FACTS, TCSC, Firing Angle, Particle Swarm Optimization(PSO)

Introduction: The 21st century power system network faces lot of complexities in terms of stability and meeting the power crisis. The stability of a power system is a main concern. The need for analyzing and improving the stability is a challenging task. The need of controlling the power system especially transmission system is increases. So by including the Series Facts devices the reactive power losses will reduces and voltage profile of the system will be better. The placement of FACTS devices will be determined by using the load flow analysis and loss suitability indices. 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. The selection of the location, firing and size of the TCSC is determined by Particle Swarm Optimization. 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.

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 (Peterson and Scott Meyer, 1971; Tinney and Hart, 1967). 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.

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

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.

III.I 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.

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.

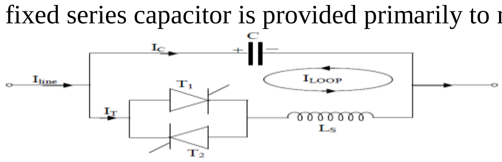

Fig 1. A Basic Module of TCSC

III.II 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

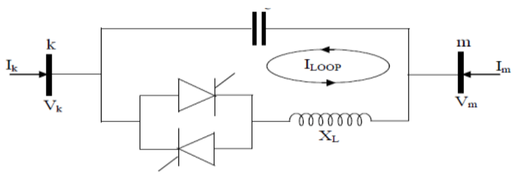

Fig 2. TCSC Firing angle Power flow model.

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

(2)

Where

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

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

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

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

TCSC active and reactive power equations at bus k are

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

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

Where

$$B_{kk} = B_{km} = B_{T\,\mathrm{csc}(1)} \qquad (9)$$

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

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

III.II Particle Swarm Optimization(PSO): PSO is originally attributed to Kennedy, Eberhart and Shi and was first intended for simulating social behavior, as a stylized representation of the movement of organisms in a bird flock or fish school. PSO is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best known position and is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.

The particles are initialized by the location of the buses and firing angles. The selection of the buses and firing angles is carried out by minimization of the losses.

IV Results: 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.

IV.I Test case1: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 fig 5,fig 6,fig 7 .

The minimum voltage and maximum voltage in terms of p.u is shown in the table 1 without installing of TCSC to the system.

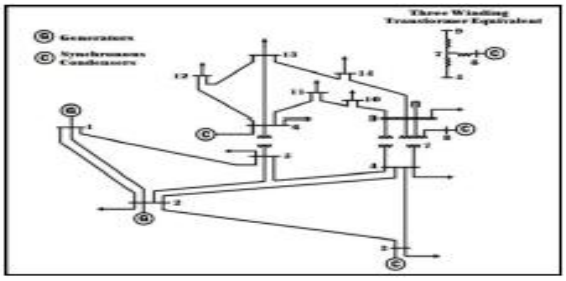

Fig 3. Single line diagram of IEEE 14 bus system

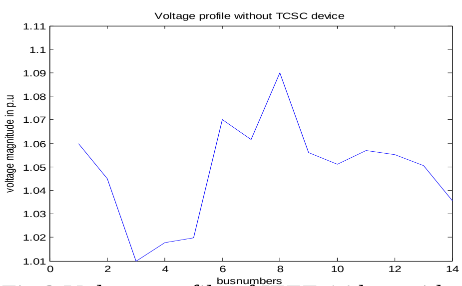

Fig.3 Voltage profile of IEEE 14 bus without TCSC

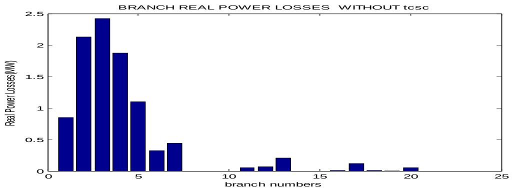

Fig 4 Branch real power losses for IEEE 14 bus without TCSC

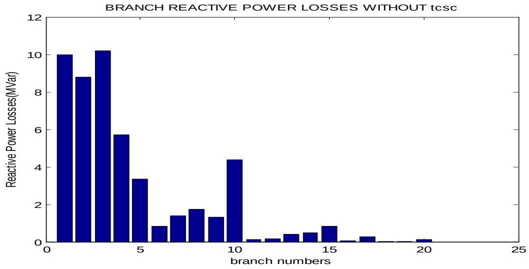

Fig 5. Branch reactive power losses of IEEE 14 bus without TCSC

IV.I Single TCSC placement: The effect of single tcsc placement for the IEEE 14 bus system is detailed shown in the fig 6 and fig 7

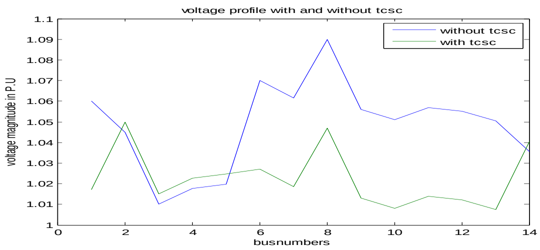

Fig 6. Comparative voltage profile of IEEE 14 bus with and without TCSC

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 real and reactive power losses are shown in the fig 9

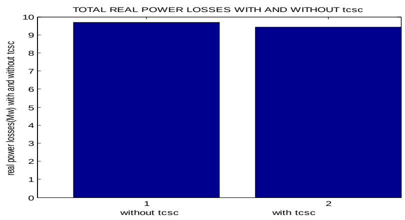

Fig 7.Comparative analysis of Real power losses of IEEE 14 bus with and without TCSC

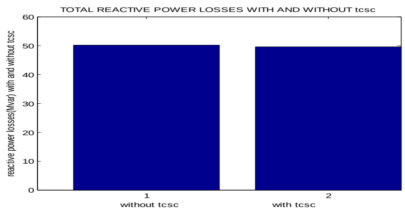

Fig 8. Comparative analysis of Reactive power losses of IEEE 14 bus with and without TCSC

The firing angle ,size and location of the TCSC is shown in table 1.

Table 1. Comparative analysis of IEEE 14 bus with and without TCSC

Parameters	Without TCSC	With TCSC
Minimum Voltage(p.u)	1.01 at bus 3	1.0052 at bus 13
Maximum Voltage(p.u)	1.09 at bus 8	1.05 at bus 2

Real power losses(Mw)	9.682	9.339
Reactive power losses(Mvar)	50.04	48.12
Location of TCSC	----------	7-8 line
TCSC firing angle(deg)	----------	133.3
Size of TCSC(Kvar)	-----------	2.29

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 2

Table 2. Comparative analysis of IEEE 14 bus with two TCSCs and without TCSC

Parameters	Without TCSC	With TCSCs
Minimum Voltage(p.u)	1.01 at bus 3	1.018 at bus 10
Maximum Voltage(p.u)	1.09 at bus 8	1.048 at bus 2
Real power losses(Mw)	9.682	9.162
Reactive power losses(Mvar)	50.04	45.92
Location of TCSC	----------	7-8 line 3-4 line
TCSC 1firing angle(deg)	----------	130.3
TCSC2 firing angle(deg)	----------	128.3
Size of TCSC1(Kvar)	-----------	1.2380
Size of TCSC2(Kvar)	----------	1.128

IV.II Test case 2 IEEE 30 bus system

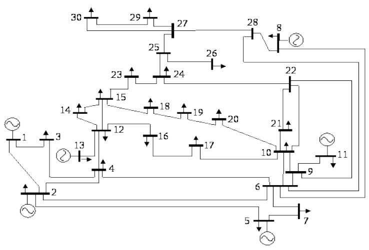

Fig 9. Single line diagram of IEEE 30 bus system.

The proposed firing angle model of TCSC are applied to IEEE 30 bus system which is shown in the fig 9.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 10 and table 3 respectively.

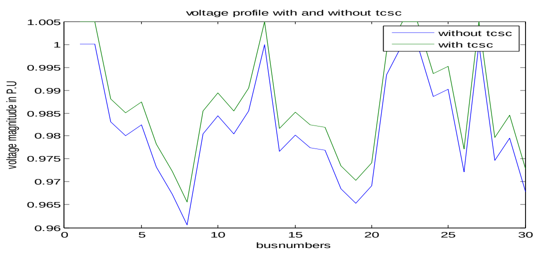

Fig 10 voltage profile of IEEE 30 bus without and with single TCSC

Table 3 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	0.969 at bus 8	0.964 at bus 8
Maximum Voltage(p.u)	1.00 at bus1	1.008 at bus 1	1.004 at bus 1
Real power losses(Mw)	2.44	1.873	1.514
Reactive power losses(Mvar)	8.99	7.44	5.02
Location of TCSC	----------	12 -13line	12 -13line 4-12 line
TCSC 1firing angle(deg)	----------	142.3	145.3
TCSC2 firing angle(deg)	----------	-------	116.8
Size of TCSC1(Kvar)	-----------	2.12	1.784
Size of TCSC2(Kvar)	----------	-------	1.265

After placing the TCSC to the IEEE 30 bus system at 12-13 line with size of 2.12 Kvar at 143.3 degrees of firing angle. The real and reactive power losses are reduced to much extent. The voltage profile is improve to which is shown in figure 10. The effect of placing to another TCSC at the line 4-12 is shown in the Table 3.

IV.III Test case 3: IEEE 57 bus system.

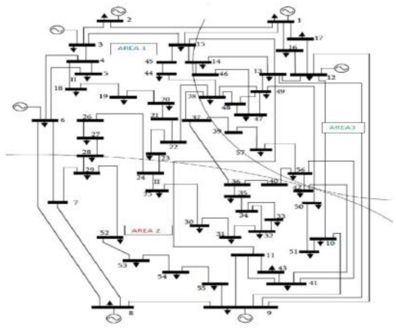

Fig 11 single line diagram of IEEE 30 bus system

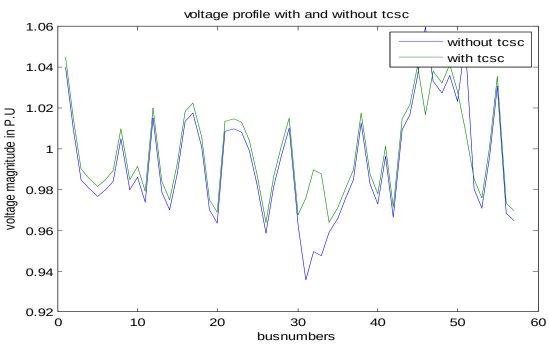

Fig 12 Voltage profile of IEEE 57 bus with and without TCSC

Table 4 Comparative system parameters of IEEE 57 bus with and without TCSC

Parameters	Without TCSC	With TCSC	With two TCSC
Minimum Voltage(p.u)	0.936 at bus 31	0.972 at bus 26	0.968 at bus 8
Maximum Voltage(p.u)	1.06 at bus1	1.048 at bus 1	1.025 at bus 1
Real power losses(Mw)	27.864	26.714	26.069

Reactive power losses(Mvar)	121.67	118.13	113.21
Location of TCSC	----------	1-15line	1 -15line 1-17 line
TCSC 1firing angle(deg)	----------	125.7	124.9
TCSC2 firing angle(deg)	----------	-------	123.8
Size of TCSC1(Kvar)	-----------	3.62	1.621
Size of TCSC2(Kvar)	----------	-------	2.705

After placing the TCSC to the IEEE 57 bus system the parameters are improved. The minimum voltage of the system is improved from 0.936 p.u at bus 31 to 0.972 p.u at bus 26 for single TCSC placement for 0.968 at bus 26 for Two TCSCs. The reduction of power losses are shown in the table 4

CONCLUSION

The Firing Angle Model of Thyristor controlled series capacitor (TCSC) using PSO method has been implemented on IEEE 14, IEEE 30 and IEEE 57 test systems to investigate the performance of power transmission line in absence of TCSC and presence of single and double TCSC devices. From this we can conclude that when the single and two TCSC's are placed in the different IEEE bus systems, The PSO algorithm gives better voltage profile improvement and better reduction in transmission line losses. And also with the analysis of the different test cases, the performance of the system is degraded with multi TCSCs. So the placement of the TCSCs are limited up to two. Although the losses are reduced but the voltage profile is reduced with the addition of second TCSC with the first at another line, which will displayed at every test case.

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AUTHOR PROFILES

Mr.A.Hema Sekhar received his B.Tech degree in Electrical and Electronics Engineering from JNT University,Hyderabad,at SVEC,A.Rangampet.he received his M.Tech in PSOC from S.V.University College of Engineering,Tirupati he is . He is a Research Student in SVU College of Engineering. Currently he is an Associate Professor in Sri Venkatesa Perumal College of Engineering & Technology, Puttur. His areas of interest are power systems, Distribution Systems,Electrical Machines and Power system Stability & Control, Power system optimizations.

Dr.A.Lakshmi Devi received her B.Tech in Electrical & Electronics Engineering from SVUniversity,college of engineering,Tirupati and M.E from IISc,Bangolore and Ph.D from SV.University college of engineering,Tirupati. She is currently working as Professor and HOD in SV University College of Engineering,Tirupati.Her Areas of interest are load flow studies,load frequency control,Reactive power control,Power system operation & Controland power system stability.