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A new approach for placement of firing angle model of TCSC to improve the performance of transmission system

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For the efficient transmission of power from power plants to consumer loads, the power losses are reduced and voltage profiles are improved in modern power system. In order to reduce such losses and improve voltage levels , a recently evolved FACTS technology is used. In this paper, Thyristor Controlled Series Capacitor (TCSC) is selected to enhance the load ability in the transmission line. This paper presents a new approach on modeling of the device by changing the firing angle of the power electronic device of the FACTS device. This is done by using Hybrid GA-PSO and DA-PSO which is participated to finalize the best location of the TCSC device and optimal firing angle of the TCSC. The location of the device is optimized by either GA or DA and the optimized firing angle is done with PSO algorithm. Because of the two different Optimizing techniques are used to solve single objective function. This type of optimization is called Hybrid optimization. The proposed hybrid optimization method is an effective method for finding the optimal location of TCSC device and also for enhancing the voltage profiles of the line and reducing the power system losses. This hybrid GA-PSO and DA-PSO is tested on IEEE 57 test system and simulation results are presented.

Keywords: *Power system, transmission system, TCSC, hybrid optimization (GA-PSO, DA-PSO)*

1.0 INTRODUCTION

With the rapid development of power system, especially the increased use of transmission facilities due to higher industrial output and deregulation, it becomes necessary to explore new ways of maximizing power transfer in existing transmission facilities, while at the same time maintaining the acceptable levels of the network reliability and stability. On the other hand, the fast development of power electronic technology has made FACTS (Flexible AC Transmission System) promising solution of future power system. FACTS controllers like Thyristor Controlled Series Compensator (TCSC) is able to change the network parameters in a fast and effective way in order to achieve better system performance. These FACTS devices provide strategic benefits for improved transmission system management through: better utilization of existing transmission assets; increased transmission system reliability and availability; increased voltage profiles and reducing power system losses. In the literature many people proposed different concepts about the placement and sizing of the TCSC by using hybrid GA-PSO and DA-PSO algorithms.

Hadi Saadat presented real and reactive power flow equations in polar form by considering two bus power system. A Jacobean matrix is then constructed and newton raphson method is used to solve these equations [1]. Ref.[2]-[6] papers proposed in literatures for load flow analysis with incorporated FACTS controllers in multi

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machine power systems from different operating conditions viewpoint. There are different load flow analysis with incorporated FACTS controllers from different operating conditions in multi machine power systems for optimal power flow control. The Newton Raphson Methods have been proposed in literatures includes for different types of Modeling of Series FACTS controllers. Sahoo *et al.* (2007) proposed the basic modeling of the FACTS devices for improving the system performance [7]. Zhang, X.P *et.al* explains Jacobian Matrix of Power flow Newton Raphson algorithm and Newton Raphson strong convergence characteristics [8]. 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) [9]. 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 [10]. Modelling of the FACTS devices with various techniques with complete computer programming is proposed by Acha *et al.* [11]. The impact of multiple compensators in the system was proposed by Radman.G and R.S Raje [12]. The important concepts of the power systems with different load flow was proposed by Stagg.G.W *et al.*(1968) [13]. Tong Zhu and Gamg Haung proposed(1999) the accurate points of the buses which were suitable for the FACTS devices installation [14]. P. Kessal and H. Glavitsch (1986) proposed increase the transmission capability, improvement of stability by installing FACTS devices in transmission network [15]. 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 [16]. Hugo Ambriz-Perez *et.al* presented a novel power flow model for the Thyristor Controlled Series Compensator (TCSC).The model takes the form of a firing angle-dependant, nodal admittance matrix that is then incorporated in an existing Power flow algorithm [17]. Ref [18-19] papers proposed on the placement of the TCSC by using genetic algorithm concepts. There are various stochastic search algorithms which have proved to be very efficient in solving complex power system problems. PSO is a novel population based method which utilizes the swarm intelligence generated by the cooperation and competition between the particle in a swarm and has emerged as a useful tool for engineering optimization.[20-21]. S Meerjalili (2015) proposed a new approach of optimization by using dragon fly algorithm [22].

2.0 POWER FLOW ANALYSIS

The power flow analysis (also known as load-flow study) is an importance tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis, a power flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various form of AC power (i.e: reactive, real and apparent) rather than voltage and current. The advantage in studying power flow analysis [24] is in planning the future expansion of power systems as well as in determining the best operation of existing systems. Power flow analysis is being used for solving power flow problem by Newton-Raphson method and Gauss Seidel method. 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.

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

Where

ΔP is the change of real power at the bus.

ΔQ is the change of reactive power at the bus. is

$\frac{\partial P}{\partial \theta}$ the change in real power w.r.t angle at the buses

$\frac{\partial P}{\partial V} V$ is the change in real power w.r.t change in voltage magnitude at the buses

$\frac{\partial Q}{\partial \theta}$ is the change in reactive power w.r.t angle at the buses

$\frac{\partial Q}{\partial V}V$ is the change in reactive power w.r.t change in Voltage magnitude at the buses

ΔV is the change in voltage at the bus

$\Delta\,\theta$ is the change in angle at the bus

3.0 MODELING OF THE TCSC

3.1 Series Compensation

Series compensation [23] plays the vital role in modern heavily loaded grid transmission lines. The series capacitor makes sense because it is simple and could be installed for 15 to 30% of the cost of installing a new line. Series compensation in modern power systems influences the power flow in particular network segment, reduces active power losses prevents system and sub synchronous oscillations, and connects more robustly different subsystems to stronger integrated network .The introduction of series compensation in existing networks requires not only extensive studies into the expected performance of the new system but also into the influence of its introduction on the operation of existing protection control and monitoring systems. The introduction of the capacitance in series with the line reactance adds certain complexities to the effective application of impedance based distance relays.

3.2. Thyristor Controlled Series Capacitor (TCSC)

TCSC (Thyristor Controlled Series Capacitor) [17] is a variable impedance type FACTS device which is connected in series with the transmission line to improve the power transfer capability also decreases the transmission losses and enhances transient stability. TCSC consists of capacitor connected in series with the transmission line and a thyristor-controlled inductor connected in parallel with the capacitor. Impedance of the transmission line can be varied using bi-directional valves. TCSC generates or absorbs reactive power by capacitor or reactor banks, which is required for compensation. It cannot exchange real power with the AC system. The main objective of TCSC is to enhance the power transfer capability and to control the power flow by increasing or decreasing the series transmission reactance. The TCSC basic model circuit is shown in Figure 1.

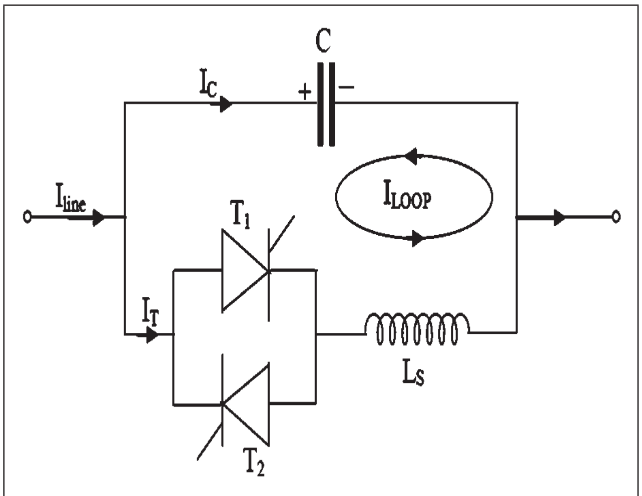

FIG. 1. BASIC MODEL OF TCSC

3.3 Firing Angle Model of TCSC

TCSC is one of the most important and best known series FACTS controllers. It has been in use for many years to increase line power transfer as well as to enhance system stability. The basic module of a TCSC is shown in Figure 2. It consists of three components: capacitor banks C, bypass inductor L and bidirectional thyristors T1 and T2. The firing angles 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- f and bus- t where the TCSC is installed). The fundamental frequency of TCSC equivalent reactance as a function of the TCSC firing angle α is

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

Where

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

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

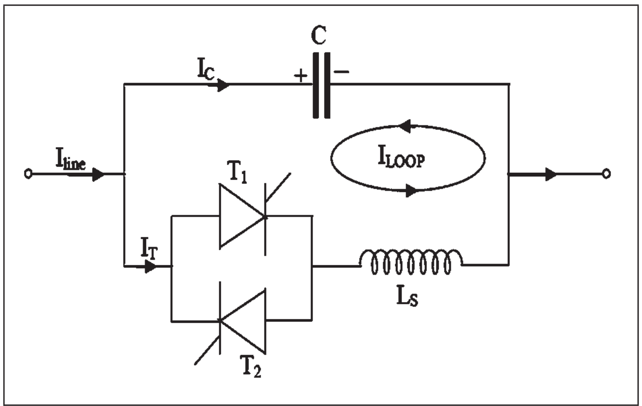

FIG. 2. FIRING ANGLE MODEL OF TCSC

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

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

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

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

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

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.

4.0 HYBRID OPTIMIZATION

The different types of optimizing techniques which are used to solve the single objective function by sharing different parameters is called hybrid optimization. In this a paper hybrid optimizing techniques such as GA-PSO and DA-PSO are used to optimize the losses of the transmission system.

GA-PSO: In this optimization Genetic algorithm[19] is used to select the suitable location of the transmission network and PSO[21] is used to select the suitable firing angle of the internal power electronic device of the system. The parameters of the Genetic Algorithm are shown below

Population=10.

Generations=30

Crossover=0.9.

Mutation=0.03

The initialization vector is randomized with the bus numbers of the system. Compensation device like TCSC is placed at bus number which generated at each iteration. By crossover and mutation the suitable location of the device is selected by optimizing the losses of the transmission network.

With particle swarm Optimization technique the suitable firing angles of the internal power electronic device is selected by considering the following parameters.

No of Particles=30

Iterations=150

Wmax= 0.9

Wmin=0.4

C1=1.5

C2=1.5.

By using the GA-PSO algorithms the minimum losses are finding by optimal location of TCSC with Optimal size.

DA-PSO: In this hybrid optimization Dragonfly Algorithm (DA)[22] is used to find the optimal location of TCSC by using the parameters of the DA which are mentioned below.
Number of searching Agents=40;

Iterations=500;

By considering the suitable line or branch from DA the particle swarm optimization is used to find the optimal value of the firing angle for reducing the losses of the system. The parameters which are mentioned in GA-PSO.

5.0 RESULTS

The proposed hybrid optimization techniques are implemented in one test case which is IEEE 57 bus system The single diagram and the effect of voltage profile for each system by installing single and two TCSC's with GA –PSO and DA-PSO are shown in the figures and Tabular columns respectively.

5.1 Test case : IEEE 57 bus system

The single line diagram of IEEE 57 bus system is shown in Figure 3.

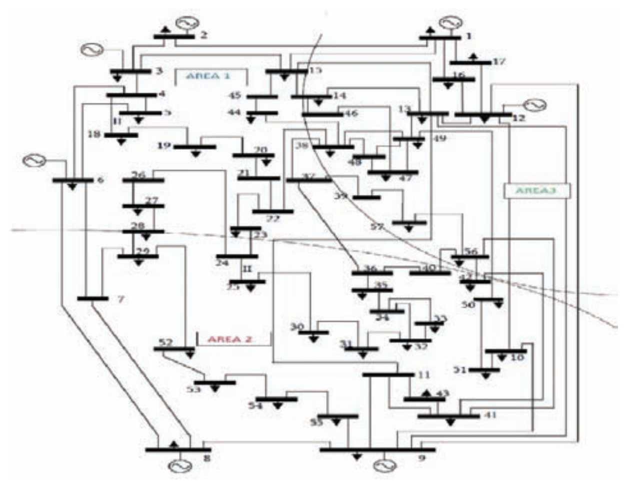

FIG. 3. SINGLE LINE DIAGRAM OF IEEE 57 BUS SYSTEM

5.1.1 Single TCSC Placement

The placement of single TCSC by using hybrid optimization technique such as GA - PSO and DA-PSO are implemented on IEEE 57 bus system. By placing single TCSC at different locations of the transmission network the real and reactive power losses are reduced. With the reference of the table 1. The losses are greatly reduced by GA – PSO as compared to DA –PSO. The real and reactive power losses are reduced to 26.024 MW and 118.63 MVar. The voltage profile, total real and reactive power losses without placing of TCSC and with the placing of single TCSC are shown in the Figure 4,5,6,7,8 and 9 respectively.

GA-PSO: GA-PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles.

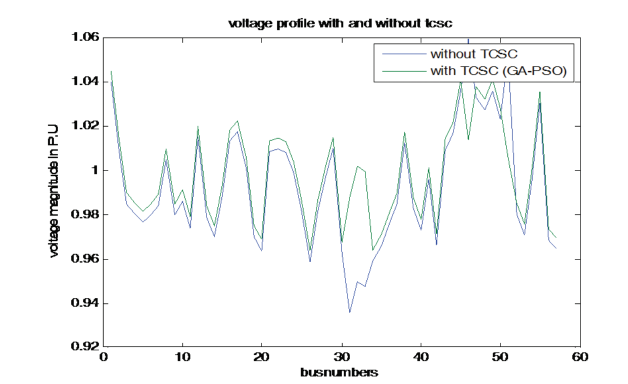

FIG. 4. COMPARATIVE VOLTAGE PROFILE OF IEEE 57 BUS WITH AND WITHOUT TCSC

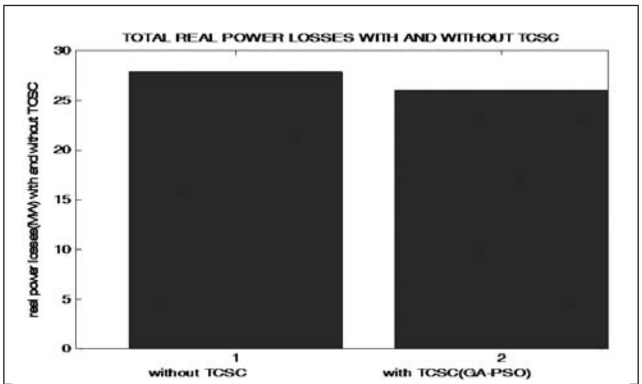

FIG. 5. TOTAL REAL POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT TCSC

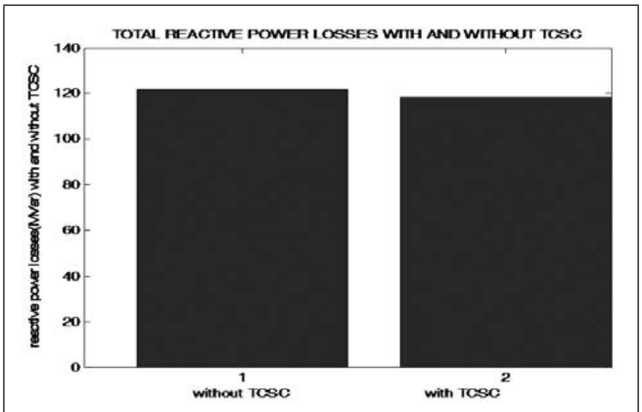

FIG. 6. TOTAL REACTIVE POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT SINGLE TCSC

DA-PSO: DA - PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles.

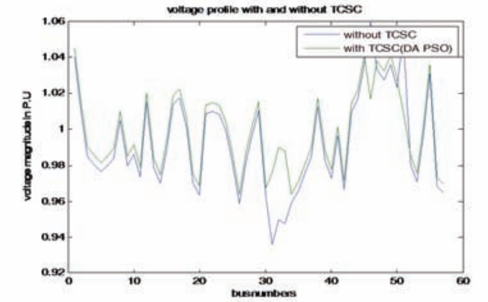

FIG. 7. COMPARATIVE VOLTAGE PROFILE OF IEEE 57 BUS WITH AND WITHOUT SINGLE TCSC

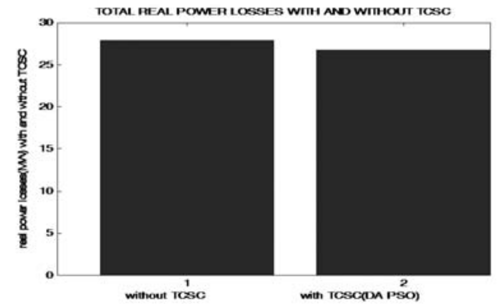

FIG. 8. TOTAL REAL POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT SINGLE TCSC

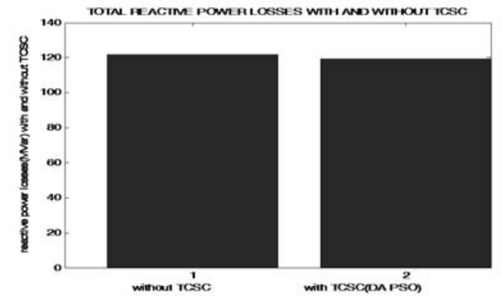

FIG. 9. TOTAL REACTIVE POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT SINGLE TCSC

5.1.2 Placement Two TCSC's

With the inclusion of two TCSC's in the bus system i.e one TCSC is locate at 48-49 line and second TCSC is locate at 56-41 line (GA-PSO) then the power flows are further improved and losses further are reduced which is shown in the table 1. The voltage profile, total real and reactive power losses without placing of TCSC and with the placing of two TCSC's are shown in the figures 10, 11 ,12 , 13, 14 and 15 respectively.

GA-PSO: GA-PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles.

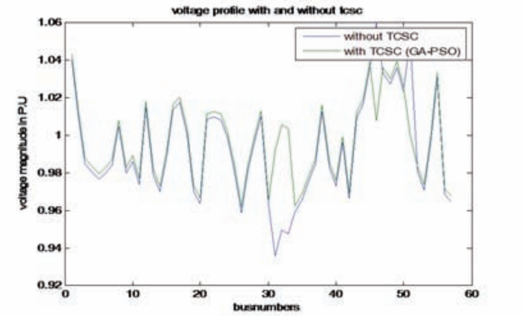

FIG. 10. COMPARATIVE VOLTAGE PROFILE OF IEEE 57 BUS WITH AND WITHOUT TWO TCSC'S(GA-PSO)

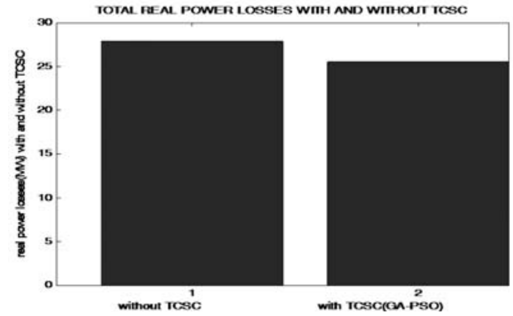

FIG. 11. TOTAL REAL POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT TWO TCSC'S(GA-PSO)

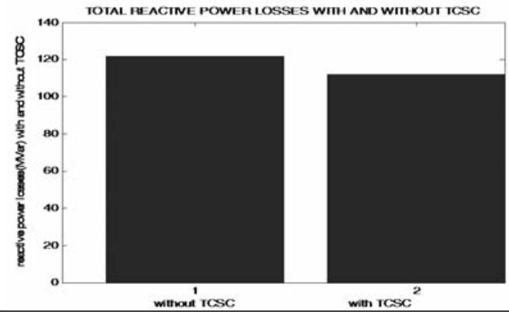

FIG. 12. TOTAL REACTIVE POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT TWO TCSC'S(GA-PSO)

DA-PSO: DA - PSO technique is implemented to IEEE 57 bus system and the results are tabulated as follows with the respective figures of change of voltage profiles total real and reactive power losses

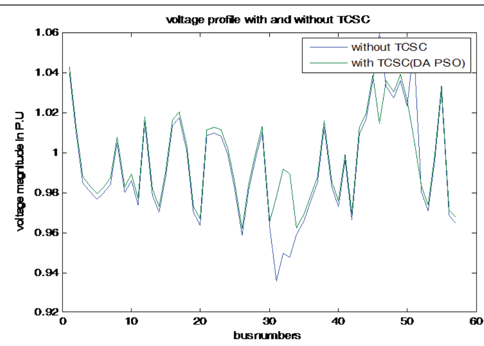

FIG. 13. COMPARATIVE VOLTAGE PROFILE OF IEEE 57 BUS WITH AND WITHOUT TWO TCSC'S (DA-PSO)

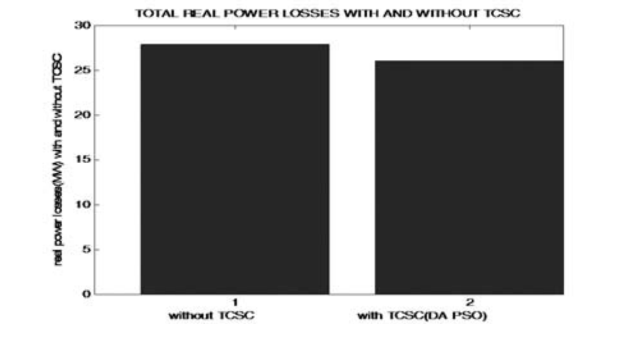

FIG. 14. TOTAL REAL POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT TWO TCSC'S (DA-PSO)

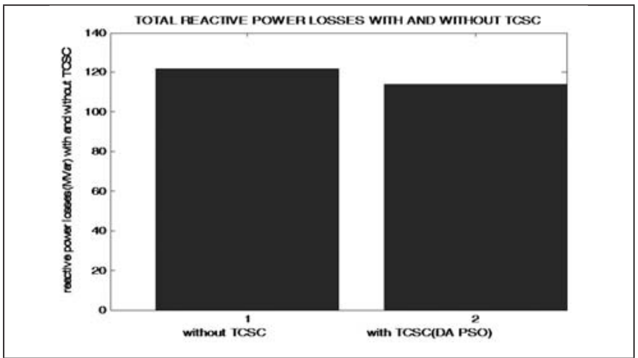

FIG. 15. TOTAL REACTIVE POWER LOSSES OF IEEE 57 BUS WITH AND WITHOUT TWO TCSC'S (DA-PSO)

TABLE 1

COMPARATIVE SYSTEM PARAMETERS OF IEEE 57 BUS WITH AND WITHOUT TCSC BY USING GA - PS0 AND DA - PSO

S. No	Parameters	Without TCSC	With Single TCSC (GA-PSO)	With Two TCSC (GA PSO)	With Single TCSC (DA-PSO)	With Two TCSC (DA PSO)
1	Minimum Voltage(p.u)	0.936 at bus 31	0.9638 at bus 26	0.9618 at bus 26	0.968 at bus 26	0.964 at bus 8
2	Maximum Voltage(p.u)	1.06 at bus1	1.0412 at bus 49	1.0392 at bus 49	1.045 at bus 1	1.003 at bus 1
3	Real power losses(Mw)	27.864	26.024	25.464	26.824	26.264
4	Reactive power losses(Mvar)	121.67	118.63	112.07	119.43	114.31
5	Location of TCSC	----------	14-15 line	48 -49 line 56-41 line	56-41 line	41 -42 line 37-38 line
6	TCSC 1firing angle(deg)	----------	126.7	129.9	128.7	129.9
7	TCSC2 firing angle(deg)	----------	-------	122.8	-------	127.8
8	Size of TCSC1(kvar)	-----------	3.93	1.84	3.92	1.84
9	Size of TCSC2(kvar)	----------	-------	2.95	-------	2.95

The voltage profile of the system improved by installing of the single TCSC between the buses 14 and 15. The losses are reduced to 26.024 MW and 118.63 Mvar with TCSC size of 3.93 kvar. The voltage profile further improved by installing two TCSCs between the buses 48 -49 and the buses 56-41. The losses are further reduced to 25.464 MW and 112.07 Mvar. By using DA-PSO optimization the voltage profiles of the system are improved with the suitable location of the single TCSC and Double TCSC's at 56-41 buses and 41-42 and 37-38 buses respectively with the TCSC size of 3.92 kvar,1.84 kvar and 2.95 kvar respectively and with single TCSC the losses are further reduced to 26.824 MW and 119.43Mvar and by using two TCSC's the losses are 26.264 MW and 114.31 Mvar.

6.0 CONCLUSION

Thyristor Controlled Series Capacitor (TCSC) firing angle control model using hybrid optimization i.e GA-PSO,DA-PSO methods have been implemented on IEEE 57 bus test system to determined the optimum location and suitable firing angle of the TCSC. The results obtained for above bus system using hybrid method with and without TCSC compared and observations reveal that the real and reactive power losses are very low and voltage profiles are more with TCSC. The obtained results are supportive, and show that the TCSC is one of the most effective series compensation devices that can significantly increase the voltage profile of the system. GA and PSO methods were also presented to analyze the firing angle model of TCSC and the results are compared with proposed method which is shown in Table 1. From this we can conclude that when the single and two TCSC's are placed in the IEEE 57 bus systems, The Hybrid GA – PSO gives better voltage profile improvement and optimum reduction in transmission line power losses as compared to GA, PSO, Hybrid DA-PSO

REFERENCES

[1] Hadi Saadat, Power system analysis, Tata MC graw hill, edition 2002.

[2] Abdel-Moamen and M A Narayana Prasad Padhy, Power flow control and transmission loss minimization model with TCSC for practical power networks, Power Engineering Society General Meeting, IEEE, Vol.2, pp. 880-884, July 2003 .

[3] T Venegas and C R Fuerte-Esquivel , Steady-state modelling of Thyrister controlled series compensator for phase domain load flow analysis of electric network, electric utility deregulation and restructuring and power technologies, Proceedings of DRPT International Conference, pp. 191 – 196, April 2000.

[4] G R Kumar Rao, R K Ram and S S T, Power flow control and transmission loss minimization model with TCSC and SVC for improving system stability and security, Industrial and Information Systems, ICIIS, IEEE Region and the third International Conference , pp. 1 – 5, December 2008.

[5] M O Hassan, S J Cheng and Z A Zakaria, Steady-state modeling of static synchronous compensator and Thyristor Controlled Series Compensator for power flow analysis, Information Technology Journal, Vol. 8, No. 3, pp. 347-353, 2009.

[6] Xiao-Ping Zhang, Advanced modeling of the multi control functional Static Synchronous Series Compensator (SSSC) in newton power flow, IEEE Transactions on Power Systems, volume 18, issue 4, pp.1410 - 1416 , November 2003.

[7] A K Sahoo, S S Dash and T Thyagarajan, Modeling of STATCOM and UPFC for Power System Steady State Operation and Control, IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES), pp. 458 – 463, 2007 .

[8] X P Zhang, C Rehtanz and B Pal, Flexible AC Transmission Systems: Modelling and Control, Springer Verlag: Berlin, Germany , 2006.

[9] D J Gotham and G T Heydt, Power flow control and power flow studies for systems with FACTS devices, IEEE Trans. Power Systems 13(1): pp. 60–66, 1998.

[10] D Povh, Modeling of FACTS in power system studies, Proc. IEEE Power Eng. Soc. Winter Meeting. 2: pp.1435–1439, 2000.

[11] E Acha, C R Fuerte-Esquivel, H Ambriz-Pe´rez, and C Angeles-Camacho, *FACTS*: Modelling and simulation in power networks, John Wiley and Sons: West Sussex, UK, 2004.

[12] G Radman and R S Raje, Power flow model/calculation for power systems with multiple FACTS controllers, Electric Power Systems Research. Vol.77, pp. 1521–1531, 2007.

[13] G W Stagg and A H Ei-Abiad, Computer Methods in Power Systems Analysis, McGraw-Hill, New York, NY, 1968.

[14] Zhu and Huang, Find the accurate point of voltage collapse in real-time, Proc. of the 21st IEEE International Conference on Power Industry Computer Applications, PICA, Santa Clara, CA, May 1999.

[15] P Kessal and H Glavitsch, Estimating the voltage stability of a power system, IEEE Transaction on Power Delivary vol. PWRD-1.N3, July 1986.

[16] N G Hingorani and L Gyugyi, Understanding FACTS: concepts and technology of Flexible AC Transmission Systems, Wiley–IEEE Press, New York, NY. ISBN: 0-7803-3464-7, 2000.

[17] H Ambriz-Pérez, E Acha and C R Fuerte-Esquivel, TCSC-firing angle model for optimal power flow solutions using Newton's method, International Journal of Electrical Power & Energy Systems, Volume 28, No. 2, pp. 77-85, February 2006.

[18] Samini and Naderi, A new method for optimal placement of TCSC based on sensitive analysis for congestion Management, Smart grid and Renewable Energy, February 2012.

[19] Gerbex, Cherkaoui, and Alain J Germond, Optimal location of multi-type FACTS devices in a power system by means of Genetic Algorithms, IEEE Transactions on Power Systems, Vol. 16, No. 3, pp. 537-544, August 2001.

[20] K Kavitha and R Neela, Optimal placement of TCSC and SVC using PSO, IOSR Journal of Electrical and Electronics Engineering, e-ISSN:2278-1676, p-ISSN:2320-3332, Vol 7, No. 2, pp. 45-52 , July - August 2013.

[21] D Mondal, A Chakrabarti and A Sengupta, Optimal placement and parameter setting of SVC and TCSC using PSO to mitigate small signal stability problem, ELSEVIER, Electrical Power and Energy Systems Vol.42, pp. 334–340, 2012

[22] Merjalili, Dragonfly Algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems, Spinger Neural Comput & Application DOI 10.1007/s00521-015-1920-1, May 2015.

[23] Khanzode, Nemade, Punse, A karte and Ankush Dhanorkar, Series compensated transmission line protected with MOV, International Journal of Innovative Research In Electrical, Electronics, Instrumentation and Control Engineering Vol. 2, No. 2, February 2014.

[24] Dharamjit and D K Tanti, Load flow analysis on IEEE 30 bus System, International Journal of Scientific and Research Publications, ISSN 2250 – 3153, Vol. 2, No. 11, November 2012.