ANALYSIS OF MULTI TCSC PLACEMENT IN TRANSMISSION SYSTEM BY USING FIRING ANGLE CONTROL MODEL WITH HEURISTIC ALGORITHMS

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ABSTRACT

With the inter connection of the power system, the complexity increases day by day. The increasing of the load also favours to the complexity of power system. The complexity of the power system can easily handled by analysing the performance of the transmission system by using load flows. The real and reactive power losses are largely effected at the transmission level. With the advancement in power electronics the advanced compensation devices are improved which are called FACTS. The improvement of voltage profile effects on the reactive power losses of the transmission system. With the series compensation to the system the reactive power losses are reduced by maintaining the voltage profile within the constraints. Thyristor controlled series capacitor (TCSC) is used in firing angel mode to maintain the voltage profile with in constraints. In this paper a new method called optimization is proposed to select the suitable location of TCSC, firing angle of TCSC and size of the TCSC are determined by different optimizing techniques to the same Objective function. This paper proposes the heuristic Algorithms such as Genetic algorithm, Particle Swarm Optimization and Dragonfly algorithm method for selection of the suitable branch, suitable firing angle of the thyristor in TCSC and size of the TCSC

Keywords: power system, transmission system, FACTS, TCSC, Firing Angle, heuristic algorithms (GA, PSO & DA).

1. INTRODUCTION

The network is expanding everyday with increase in demand, and to meet this situation, either new installation of power generating stations and transmission line are required or the operation of existing infrastructure has to be extended to its limits. Laying of new lines or installation of new generating stations imposes many environmental and economical constraints. As a result, the existing transmission lines are more heavily loaded than ever before. In steady state operation of heavily loaded power system, the main problems are increased losses, poor voltage profile, unwanted loop flows and line over loads. The objective of this present work is the optimal allocation of series FACTS devices in the transmission network so the transmission loss becomes minimized and also for the simultaneous increase of power transfer capacity of the transmission network

In the literature many people proposed different concepts about the placement and sizing of the TCSC, GAS, PSO and DA 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 machine power systems from different operating conditions viewpoint. There are different load flow analyses with incorporated FACTS controllers from different operating conditions in multimachine power systems for optimal power flow control. The Newton Raphson Methods have been proposed in literatures includes for different types of Modelling of Series FACTS controllers .Sahoo *et al* (2007) proposed the basic modelling 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 modelling 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 modelling 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 [18-20] papers proposed on the placement of the TCSC by using genetic algorithm concepts. Ref [21-23] papers proposed the concept of PSO for placement of both SVC and TCSC. S. Meerjaali (2015) proposed a new approach of optimization by using Dragon fly algorithm [24].

In this paper, the optimal location for placement of FACTS device has been formulated as a problem, and is solved using a new heuristic algorithm called the Dragonfly Algorithm. The Dragonfly Algorithm is used for finding out the optimal locations of Thyristor Controlled Series Compensator (TCSC) devices, to achieve minimum transmission line losses in the system. The Dragonfly Algorithm results are compared with the results of the Genetic Algorithm (GA) and the Practical Swarm Optimization (PSO) techniques. Computer simulations using MATLAB were done for a 30 bus system, and the IEEE118 bus system.

2. POWER FLOW ANALYSIS

Load flow studies are important in planning and designing future expansion of power systems. The study gives steady state solutions of the voltages at all the buses, for a particular load condition. Different steady state solutions can be obtained, for different operating conditions, to help in planning, design and operation of the power system. 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

ΔP = change of real power at the bus.

ΔQ = change of reactive power at the bus.

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

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

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

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

ΔV = change in voltage at the bus

$\Delta \theta$ = change in angle at the bus

3. 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 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.

3.1 Thyristor Controlled Series Capacitor (TCSC)

The basic conceptual TCSC [17] module comprises a series capacitor, *C*, in parallel with a thyristor-controlled reactor, LS, as shown in Fig. 2. 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. The basic module of a TCSC is shown in Figure-1. It consists of three components: capacitor banks C, bypass inductor L and bidirectional thyristors T1 and T2

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.

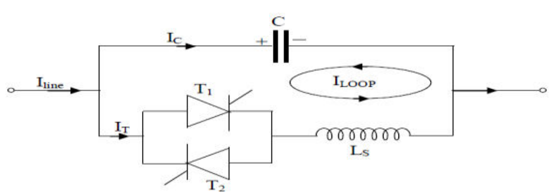

Figure-1. A basic module of TCSC.

3.2. Operation of the TCSC (Firing Angle Power Flow Model)

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 firing angles of the thyristors are controlled to adjust the TCSC reactance in

VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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 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 of $X_{TCSC(1)}$ equivalent reactance as a function of the TCSC firing angle α is shown in Figure-2.

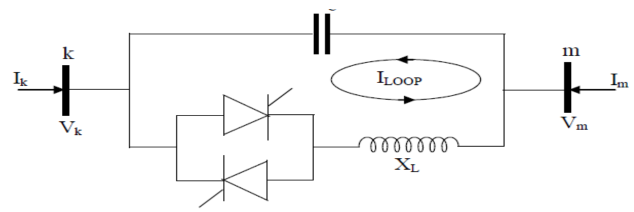

Figure-2. Fundamental frequency equivalent reactance XTCSC (1) of the TCSC module.

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

Where

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

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

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

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

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

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

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

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

4. GENETIC ALGORITHM

The goal of the optimization is to find the best location of a given number of FACTS devices in accordance with a defined criterion. A configuration of FACTS devices is defined with three parameters: the location of the devices, their types and their values. In order to take into account the three aforementioned parameters in the optimization, a particular coding is developed. An individual is represented with three strings of length, where is the number of devices to locate optimally. The first string corresponds to the individual represents the values of the devices. It can take discrete values contained between 0 and 1; 0 corresponding to the minimum value that the device can take and 1 to the maximum.

Genetic Algorithms were developed based on the evolutionary theories proposed by Darwin in the 19th century. These algorithms are based on the Darwinian principle that the elements that are most suitable to their environment have the highest probability of surviving and they are able to transmit their characteristics to their offspring. In each iteration of GA (referred as generation), a new set of string (i.e. chromosomes) with Improved fitness is produced using genetic operator (i.e. selection, crossover and mutation).

A population of individuals evolves from generation to generation using mechanisms that can be compared to genetic reproduction and mutation. Natural evolution works on genetic material that is the genotype of an individual: each alteration that improves the fitness of an individual emerges from the genetic heritage and natural selection promotes the reproduction of those individuals that enhance fitness qualities to the environment.

Reproduction is the core of the evolution process, since generational variations of a population are determined by genetic crossover and by random mutations that may occur. Reproduction sets the mix of genetic material from parents and this generates a quicker evolution compared to the one that would result if all descendants would contain only a copy of the genetic heritage from their parents. Evolution operates through cyclical and generational processes that are determined only by environmental issues and the interactions among different individuals. The possible solution of a certain problem is codified with a chromosome, through the

VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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definition of a bit string, whose genes are codified by 0 and 1. Individuals are evaluated through a function that measures their ability of problem solving and it identifies the most suitable to reproduction. The new population evolves based on random operators, using reproduction, mutation and crossover and the evolution exits the cycle when the stop criterion is reached.

The crossover promotes the exploration of new regions in the search space using randomized mechanism of exchanging information between strings. Two individuals previously placed in the mating pool during reproduction are randomly selected. A crossover point is then randomly selected and information from one parent up to the crossover point is exchanged with the other parent. This is specifically illustrated below for the used simple crossover technique, which was adopted in this work.

Parent 1: 1011 ↓ 1110 offspring 1: 10111011
⇒
Parent 2: 1010 ↓ 1011 offspring 2: 1010 1110

Another process also considered in this work is the mutation process of randomly changing encoded bit information for a newly created population individual. Mutation is generally considered as a secondary operator to extend the search space and cause escape from a local optimum when used prudently with the selection and crossover schemes.

The population is populated with bus numbers, firing angles.

With the firing angles the size of the TCSC is calculated. The Objective of selection of optimal value of firing angle at required location is minimization of losses

5. PARTICLE SWARM OPTIMIZATION (PSO)

PSO is originally attributed to Kennedy, Eberhart and Shi and was first intended for simulating social behaviour, 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.

In general, maximum number of iterations for termination of the search process and inertia weights is set according to the following equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{mac}} \cdot iter \qquad (11)$$

$$v^{(t+1)} = wi\,.\,^{(t)} + c1.\,r1.(xgbest^{(t)} - xi^{(t)} + c2.\,r2.\,(xipbest^{(t)} - xi^{(t)}) \qquad (12)$$
$$x^{(t+1)} = xi^{(t)} + vi^{(t+1)}$$

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.

6. DRAGONFLY ALGORITHM (DA)

Dragonflies are considered as small predators that hunt almost all other small insects in nature. Nymph dragonflies also predate on other marine insects and even small fishes. The interesting fact about dragonflies is their unique and rare swarming behaviour. Dragonflies swarm for only two purposes: hunting and migration. The former is called static (feeding) swarm, and the latter is called dynamic (migratory) swarm.

The main objective of any swarm is survival, so all of the individuals should be attracted towards food sources and distracted outward enemies. Considering these two behaviours, there are five main factors in position updating of individuals in swarms as shown in Figure-3.

According to Reynolds, the behaviour of swarms follows three primitive principles:

- Separation, which refers to the static collision avoidance of the individuals from other individuals in the neighbourhood.
- Alignment, which indicates velocity matching of individuals to that of other individuals in neighbourhood.
- Cohesion, which refers to the tendency of individuals towards the centre of the mass of the neighbourhood.

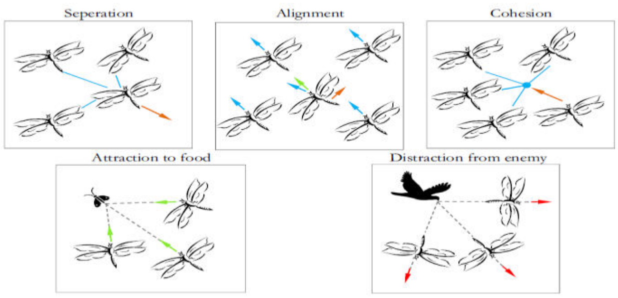

Figure-3. Primitive behaviour of Dragonflies

Each of these behaviours is mathematically modelled as follows:

The separation is calculated as follows

$$S_i = -\sum_{j=1}^{N} X - X_j \qquad (13)$$

Where X is the position of the current individual, Xj shows the position j-th neighbouring individual, and

VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
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N is the number of neighbouring individuals.
Alignment is calculated as follows:

$$A_j = \frac{\sum_{j=1}^{N} V_j}{N} \quad (14)$$

Where Vj shows the velocity of j-th neighbouring individual.

The cohesion is calculated as follows:

$$C_j = \frac{\sum_{j=1}^{N} X_j}{N} - X \quad (15)$$

Where X is the position of the current individual, N is the number of neighbourhoods, and Xj shows the position j-th neighbouring individual

Attraction towards a food source is calculated as follows:

$$F_i = X^+ - X \quad (16)$$

Where X is the position of the current individual, and X^+ shows the position of the food source.

Distraction outwards an enemy is calculated as follows:

$$E_i = X^- + X \quad (17)$$

Where X is the position of the current individual, and X^- shows the position of the enemy.

$$\Delta X_{t+1} = (sS_i + cC_i + fF_i + aA_i + eE_i) + w\Delta X_t \quad (18)$$

Where shows the separation weight, Si indicates the separation of the i-th individual, as is the alignment weight,
A is the alignment of i-th individual, c indicates the cohesion weight, Ci is the cohesion of the i-th individual, f is the food factor, Fi is the food source of the i-th individual, e is the enemy factor, Ei is the position of enemy of the ith individual, w is the inertia weight, and t is the iteration counter. After calculating the step vector, the position vectors are calculated as follows:

$$X_{t+1} = X_t + \Delta X_{t+1} \quad (19)$$

Where t is the current iteration.

To improve the randomness, stochastic behaviour, and exploration of the artificial dragonflies, they are required to fly around the search space using a random walk (Levy flight) when there is no neighbouring solutions. In this case, the position of dragonflies is updated using the following equation:

$$X_{t+1} = X_t + Levy(x)X_t \quad (20)$$

The dragon flies are populated with the bus numbers of the system and the firing angles to the switching device of the TCSC. The objective to finalize the optimal location with the suitable firing angle of the TCSC is the minimizing of the losses.

7. TEST CASES

The proposed method is used to analyse 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. The minimum voltage and maximum voltage in terms of p.u is shown in the Table-1 without installing of TCSC to the system

7. 1 IEEE 30 Bus systems

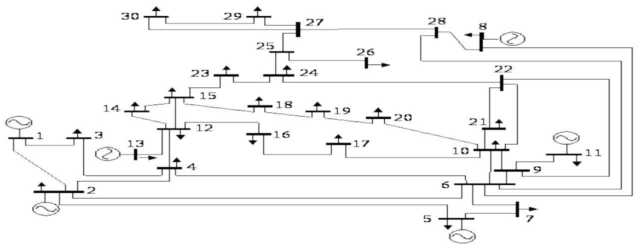

Figure-4. Single line diagram of IEEE 30 bus system.

Table-1. Minimum and maximum voltages of IEEE 30 bus system.

Minimum voltage (P.U)	**Maximum voltage** (P.U)
0.966 at bus8	1.00 at bus1

The Real power and reactive power losses of IEEE 14 bus system without TCSC are2.44 MW and 8.99MVar.

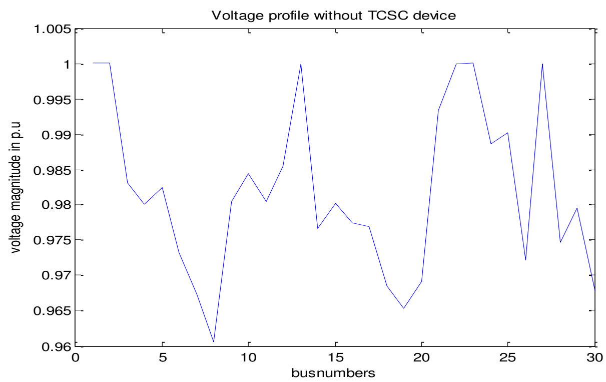

Figure-5. Voltage profile of IEEE 30 bus without TCSC.

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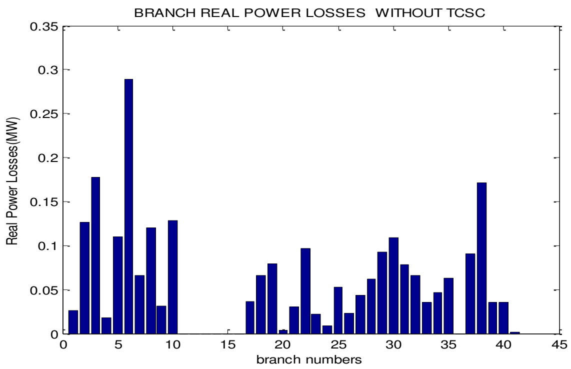

Figure-6. Branch real power losses for IEEE 30 bus without TCSC.

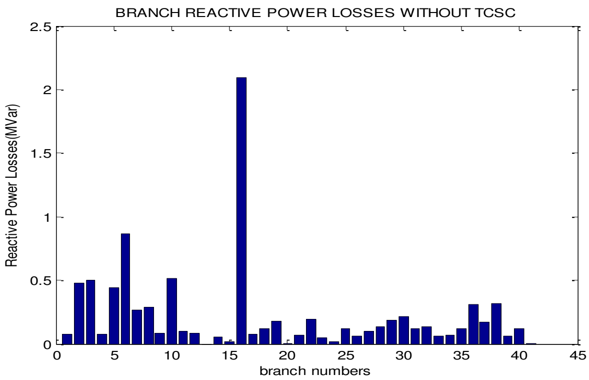

Figure-7. Branch reactive power losses for IEEE 30 bus without TCSC.

7.2 Single TCSC Placement

The placement of single TCSC by using different optimizing techniques such as GA, PSO and DA is implemented on IEEE 30 bus system. By placing TCSC at different locations of the transmission network the real and reactive power losses are reduced. With the reference of the Table-2.The losses are greatly reduced by dragonfly algorithm (DA),by placing the single TCSC. The real and reactive power losses are reduced to 1.501 MW and 7.02 MVar. The voltage profile, branch real and reactive power losses without placing of TCSC and with the placing of single TCSC are shown in the figure 7,8and 9 respectively.

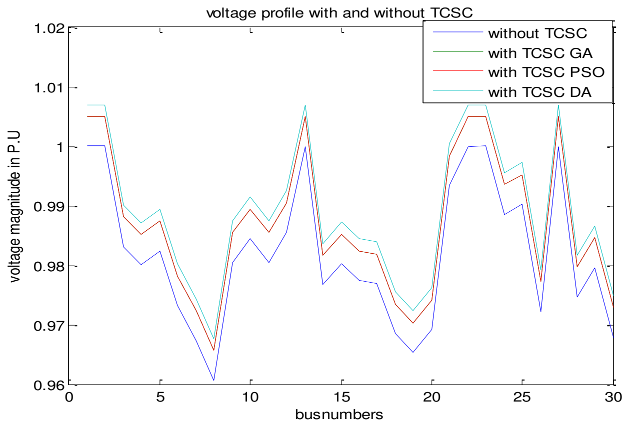

Figure-8. Voltage profile for IEEE 30 bus system.

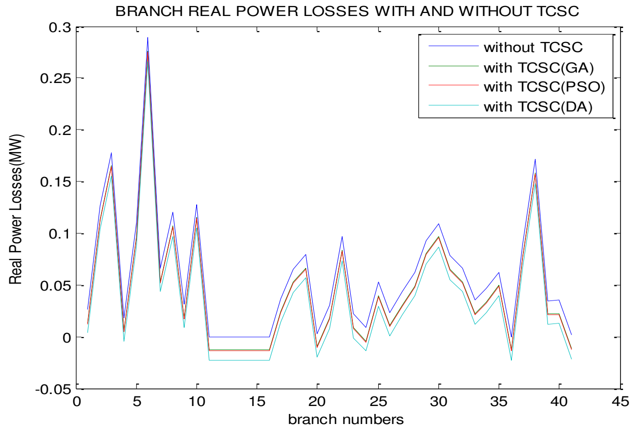

Figure-9. Branch real power losses of IEEE 30 bus with and without TCSC.

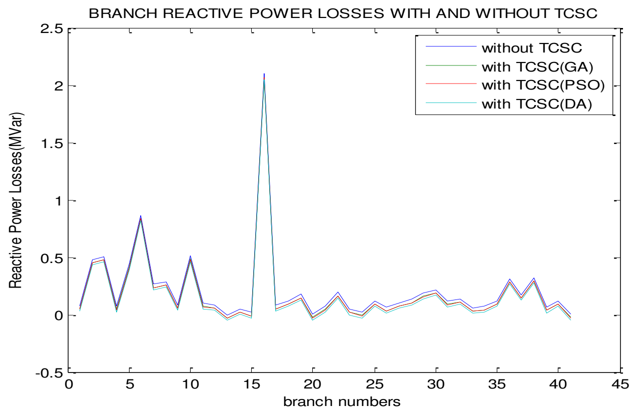

Figure-10. Branch reactive power losses of IEEE 30 bus with and without TCSC.

VOL. 11, NO. 21, NOVEMBER 2016 ISSN 1819-6608
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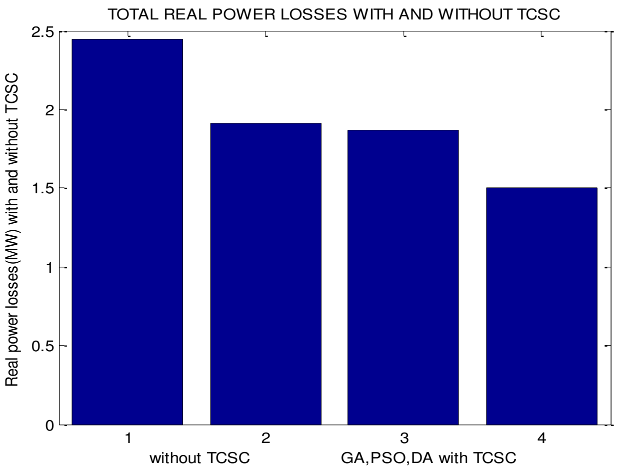

Figure-11. Comparative analysis of real power losses of IEEE 30buswith and without TCSC.

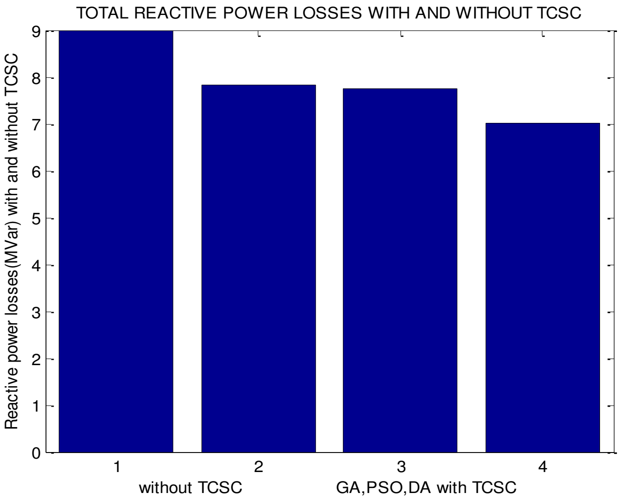

Figure-12. Comparative analysis of Reactive power losses of IEEE 30bus with and without TCSC.

7.3. Placement of Two TCSC's

With the inclusion of two TCSC's in the bus system i.e. one TCSC is locate at 15-23 line and second TCSC is locate at 25-26 line then the power flows are further improved and losses further are reduced which is shown in the Table-2.The voltage profile, branch real and reactive power losses without placing of TCSC and with the placing of single TCSC are shown in the Figure 13,14and 15 respectively.

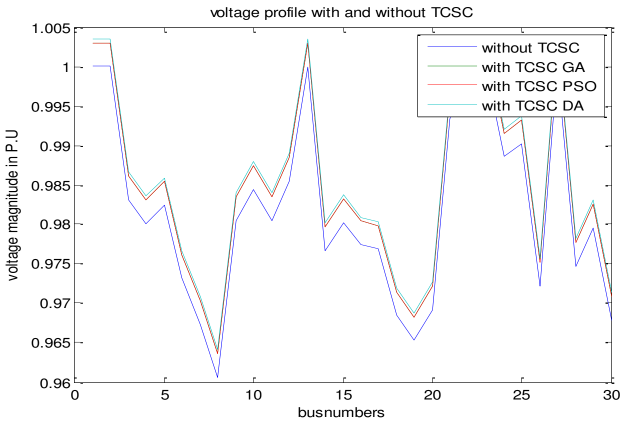

Figure-13. Voltage profile for IEEE 30 bus system with two TCSC's.

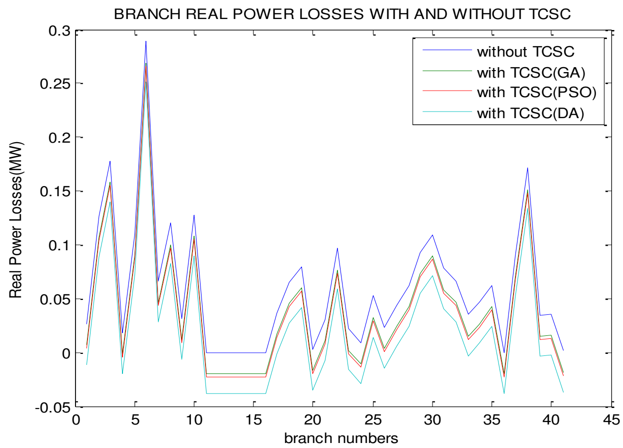

Figure-14. Branch real power losses of IEEE 30 bus with and without two TCSC's.

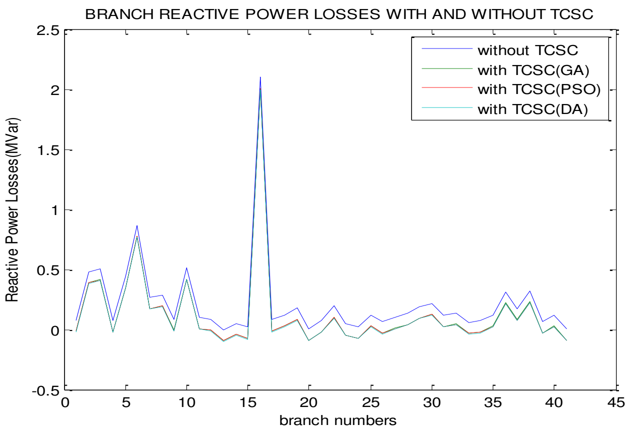

Figure-15. Branch reactive power losses of IEEE 30 bus with and without two TCSC's.

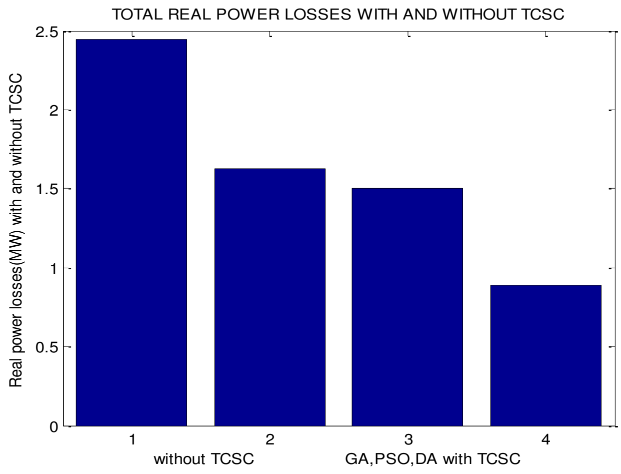

Figure-16. Comparative analysis of real power losses of IEEE 30buswith and without two TCSC's.

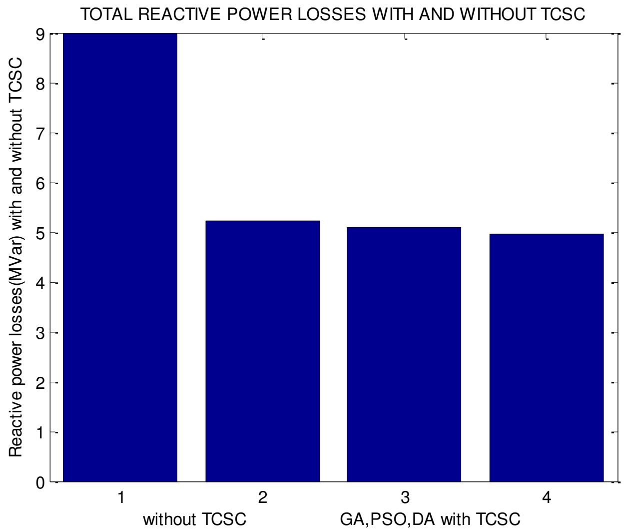

Figure-17. Comparative analyses of real power losses of IEEE 30 bus with and without two TCSC's.

Table-2. Comparative system parameters of IEEE 30 bus with and without TCSC by using GA, PSO and DA.

Parameters	Without TCSC	With SINGLE TCSC(GA)	With TWO TCSC(GA)	With SINGLE TCSC(PSO)	With TWO TCSCs(PSO)	With SINGLE TCSC(DA)	With TWO TCSCs(DA)
Minimum Voltage(p.u)	0.966 at bus8	0.968 at bus 8	0.962 at bus 8	0.969 at bus 8	0.964 at bus 8	0.972 at bus 8	0.967 at bus 8
Maximum Voltage(p.u)	1.00 at bus1	1.006 at bus 1	1.002 at bus 1	1.008 at bus 1	1.004 at bus 1	1.016 at bus 1	1.009 at bus 1
Real power losses(Mw)	2.44	1.911	1.624	1.87	1.501	1.501	0.886
Reactive power losses(MVar)	8.99	7.84	5.22	7.76	5.09	7.02	4.97
Location of TCSC	----------	6 -8 line	15 -23 line 25-26 line	10 -17 line	28 -27 line 10-22 line	25 -26 line	16-17 line 10-17 line
TCSC 1firing angle(deg)	----------	144.3	149.3	144.3	149.3	144.3	149.3
TCSC2 firing angle(deg)	----------	-------	114.3	-------	114.3	-------	114.3
Size of TCSC1(KVar)	-----------	2.72	1.94	2.72	1.94	2.72	1.94
Size of TCSC2(KVar)	----------	-------	1.35	-------	1.35	-------	1.35

From the above Table, it is shown that without TCSC the Real and Reactive power losses are 2.44 MW and 8.99 MVar. In case of Genetic Algorithm for placing single TCSC the losses are Reduced i.e Real and Reactive power losses are 1.911 MW and 7.84 MVar and for two TCSC's 1.624 MW & 5.22 MVar. By applying Piratical Swarm Optimization (PSO) for placing single TCSC the Real and Reactive power losses are further reduced to 1.87 MW and 7.76MVar and by using two TCSC's the losses are 1.501 MW and 5.09 MVar. By applying Proposed method i.e. Dragonfly Algorithm (DA) for placing single TCSC, the Real and Reactive power losses are most further reduced to 1.501 MW and 7.02 MVar and by using two TCSC's the losses are reduced to 0.886 MW and 4.97MVar,So,The DA method gives better losses reduction as compared to GA and PSO.

7.4 Test case 2: IEEE 118 Bus system

The proposed method is applied to IEEE 118 bus system. The single line diagram is shown in the Figure-17.The improving of system parameters by placing single TCSC and two TCSCs are shown in following figures and listed in Table-3.

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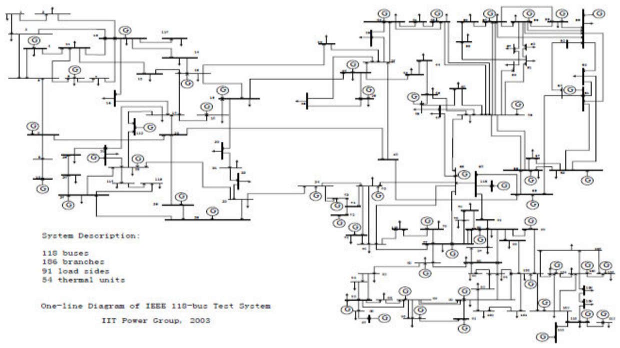

Figure-18. Single line diagram of IEEE 118 bus system.

Voltage profile of the buses, real and reactive power losses without using TCSC are shown in Figures 18, 19, & 20 respectively. The real and reactive power losses without TCSC are 132.83 MW and 783.79 MVar

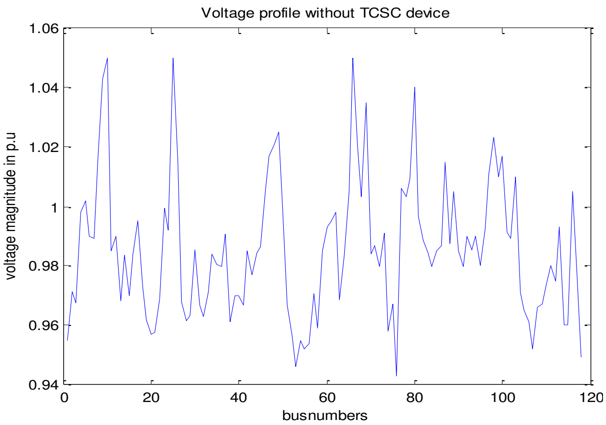

Figure-19. Voltage profile of IEEE 118 bus Without TCSC.

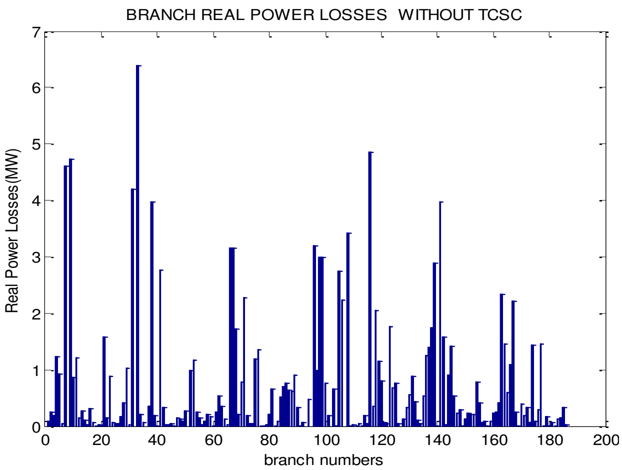

Figure-20. Branch real power losses for IEEE 118 bus without TCSC.

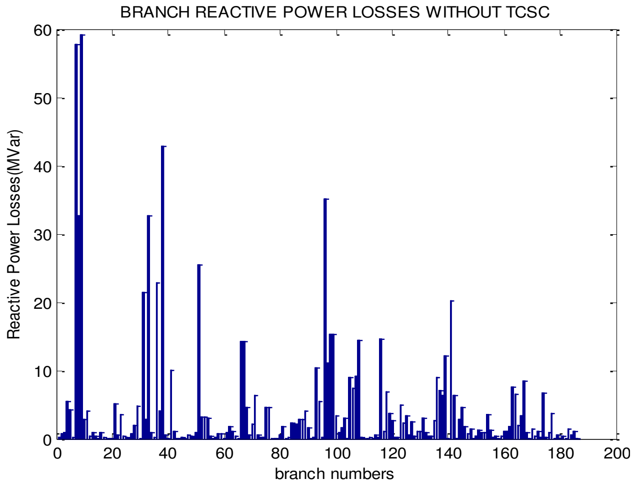

Figure-21. Branch reactive power losses of IEEE 118 bus without TCSC.

7.5 Single TCSC Placement

The placement of TCSC by using different optimizing techniques such as GA, PSO and DA is implemented on IEEE 30 bus system. By placing TCSC at different locations of the transmission network the real and reactive power losses are reduced. With the reference of the Table-2.The losses are greatly reduced by dragonfly algorithm (DA),by placing the single TCSC. The real and reactive power losses are reduced to 128.585 MW and 774.86 MVar. The voltage profile, branch real and reactive power losses and their comparative analysis without placing of TCSC and with the placing of single TCSC are shown in the Figures 21, 22, 23, 24and 25 respectively.

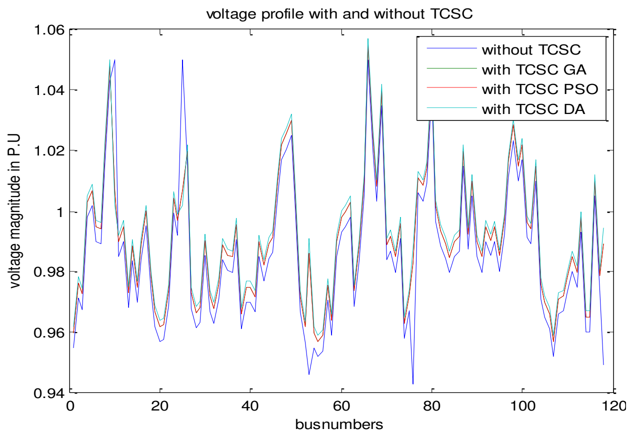

Figure-22. Comparative voltage profile of IEEE 118 bus with and without TCSC.

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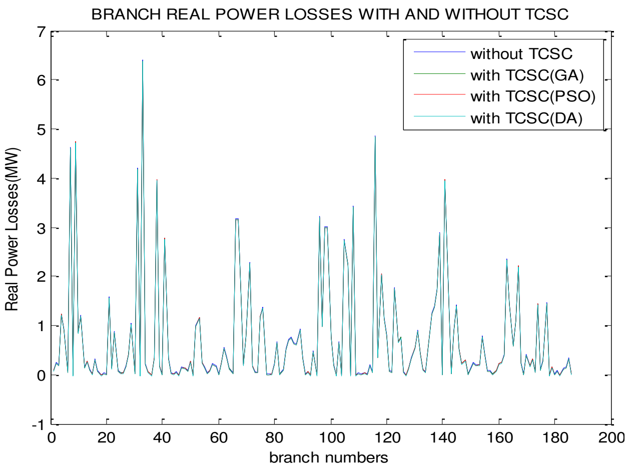

Figure-23. Branch real power losses for IEEE 118 bus without & with TCSC.

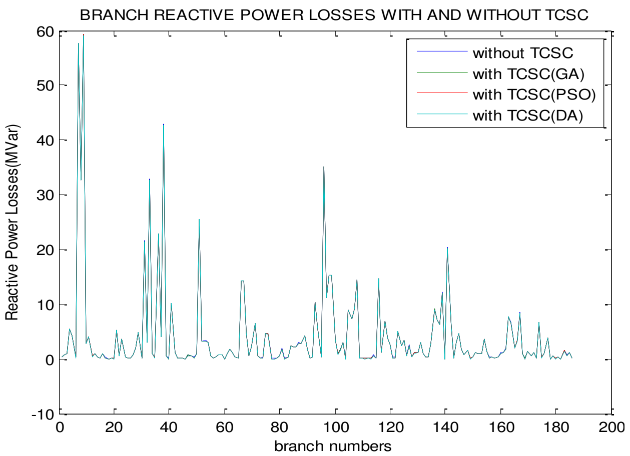

Figure-24. Branch reactive power losses for IEEE 118 bus without & with TCSC.

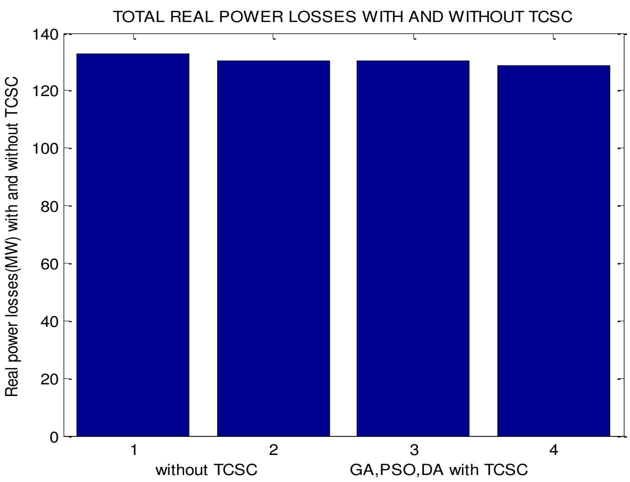

Figure-25. Comparative analysis of Real power losses of IEEE 118 bus with and without TCSC.

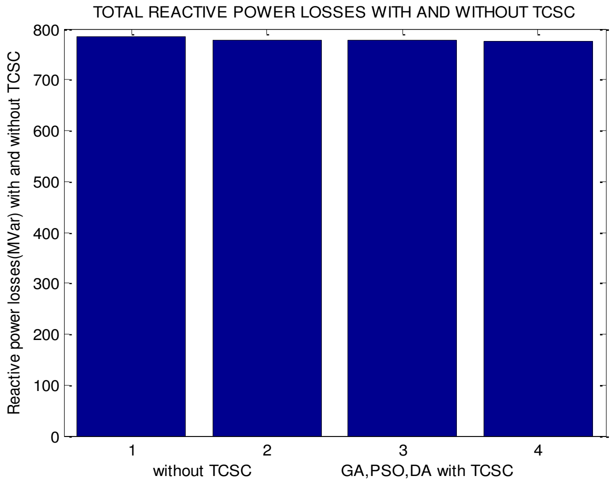

Figure-26. Comparative analysis of Real power losses of IEEE 118 bus with and without TCSC.

7.6. Placement of two TCSC's

With the inclusion of two TCSC's in the IEEE 118 bus system i.e. one TCSC is locate at 75-180 line and second TCSC is locate at 92-100 line for GA .For PSO, one TCSC is locate at 114-115 line and second TCSC is locate at 72-75 line .For Proposed method(DA), one TCSC is locate at 69- 75 line and second TCSC is locate at 100-106 line then the power flows are further improved and losses further are reduced in case of DA as compared to GA and PSO which is shown in the Table-2.The voltage profile, branch real and reactive power losses without placing of TCSC and with the placing of two TCSC's are shown in the figures from 27-31.

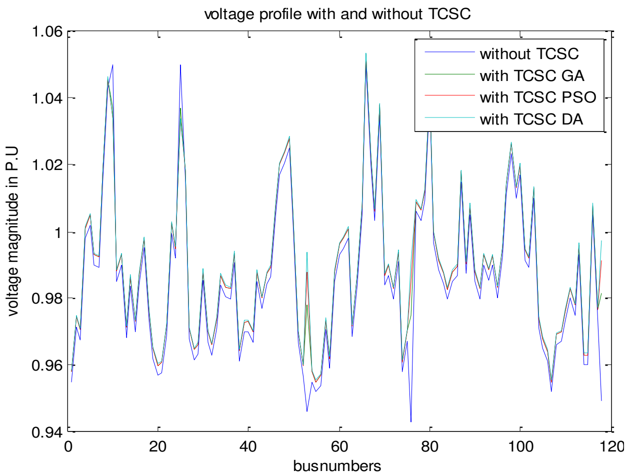

Figure-27. Comparative voltage profile of IEEE 118 bus with and without two TCSC's.

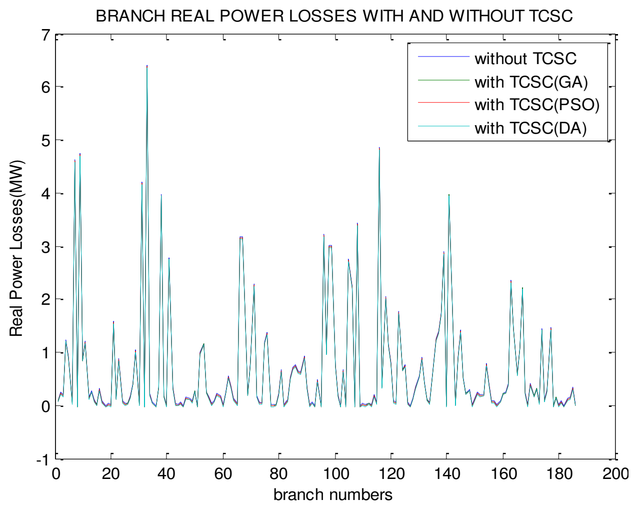

Figure-28. Branch real power losses for IEEE 118 bus system with & without two TCSC's.

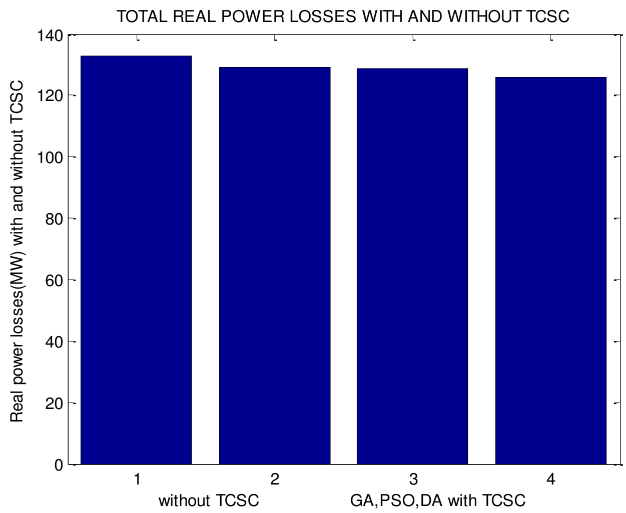

Figure-30. Comparative analysis of Real power losses of IEEE 118 buswith and without two TCSC's.

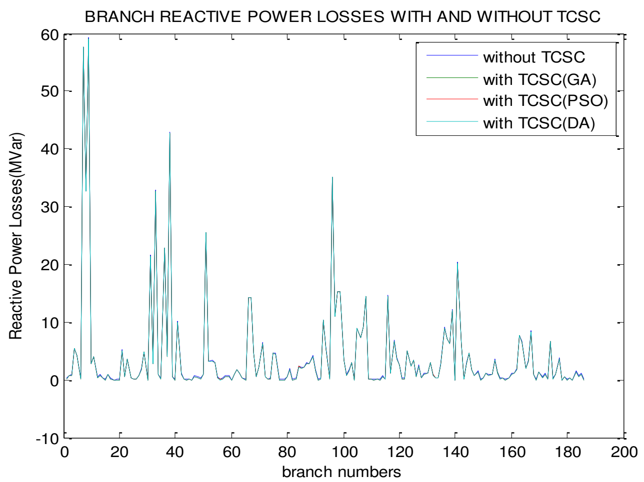

Figure-29. Branch reactive power losses for IEEE 118 bus system with & without two TCSC's.

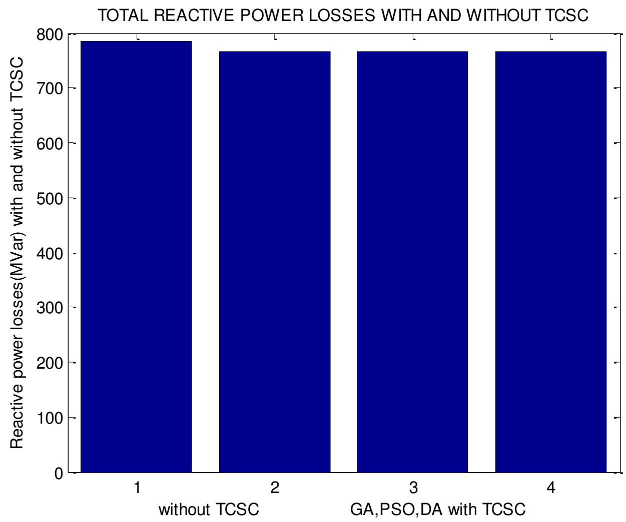

Figure-31. Comparative analysis of Reactive power losses of IEEE 118 bus with and without two TCSC's.

Table-3. Comparative system parameters of IEEE 118 bus with and without TCSC by using GA, PSO and DA.

Parameters	Without TCSC	With SINGLE TCSC(GA)	With TWO TCSC(GA)	With SINGLE TCSC(PSO)	With TWO TCSCs(PSO)	With SINGLE TCSC(DA)	With TWO TCSCs(DA)
Minimum Voltage(p.u)	0.943 at bus 76	0.959 at bus 55	0.956 at bus 55	0.961 at bus 55	0.958 at bus 55	0.961 at bus 55	0.958 at bus 55
Maximum Voltage(p.u)	1.05 at bus10	1.047 at bus 9	1.045 at bus 9	1.048 at bus 9	1.046 at bus 9	1.048 at bus 9	1.046 at bus 9
Real power losses(Mw)	132.83	130.445	129.143	130.259	128.585	128.585	125.795
Reactive power losses(Mvar)	783.79	778.58	766.68	778.21	766.12	774.86	765.56
Location of TCSC	----------	103-110 line	75-180 line 92-100 line	17-113line	114-115line 72-75 line	101-102 line	69-75line 100-106 line
TCSC 1firing angle(deg)	----------	147.4	133.3	141.4	123.3	136.4	123.3
TCSC2 firing angle(deg)	----------	-------	156.3	-------	146.2	-------	136.3
Size of TCSC1(Kvar)	-----------	4.672	2.74	4.472	2.64	4.372	2.04
Size of TCSC2(Kvar)	----------	-------	2.68	-------	2.18	-------	2.18

From the above Table, it is shown that without TCSC the Real and Reactive power losses are 132.83 MW and 783.79MVar.In case of Genetic Algorithm for placing single TCSC the losses are Reduced i.e. Real and Reactive power losses are 130.445 MW and 778.58 MVar and for two TCSC's 129.143 MW &766.68 MVar. By applying Practical Swarm Optimization (PSO) for placing single TCSC the Real and Reactive power losses are further reduced to 130.259 MW and 778.21 MVar and by using two TCSC's the losses are 128.585 MW and 766.12 MVar. By applying Proposed method i.e. Dragonfly Algorithm (DA) for placing single TCSC, the Real and Reactive power losses are most further reduced to 128.585 MW and 774.86 MVar and by using two TCSC's the losses are reduced to 125.795 MW and 765.56 MVar, So, The DA method gives better losses reduction as compared to GA and PSO.

8. CONCLUSIONS

The Firing Angle Model of Thyristor controlled series capacitor (TCSC) using GA, PSO and DA methods has been implemented on IEEE 30 and IEEE 118 test systems to investigate the performance of power transmission line in absence of TCSC and presence of single and double TCSC devices.

In this paper, Dragonfly Algorithm has been proposed to analyse firing angle model of TCSC .The results obtained for different bus systems using proposed method with and without TCSC compared and observations reveal that the Real and Reactive power losses are less 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 analyse the firing angle model of TCSC and the results are compared with proposed methods which are shown in Tables 2 and 3. From this we can conclude that when the single and two TCSC's are placed in the different IEEE bus systems, The Dragonfly algorithm gives better voltage profile improvement and better reduction in transmission line losses. Also the results indicate that the Dragonfly algorithm was an easy to use and best optimization technique compared with the Genetic algorithm (GA) and the Particle Swarm Optimization (PSO).

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