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PERFORMANCE ANALYSIS OF TCSC DEVICE IN POWER SYSTEM NETWORK BASED ON PARTICLE SWARM OPTIMIZATION

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ABSTRACT: A single-objective Particle Swarm Optimization (PSO) approach to tune the parameters of a Thyristor Controlled Series Compensator (TCSC), for minimizing the cost of generation, real power loss and improve the voltage stability L-index. In this paper, TCSC FACTS device is incorporated in solving optimal power flow problems using Particle Swarm Optimization (PSO) for a standard IEEE 30 bus system. Series compensation has been successfully utilized for many years in electric power networks. With Series compensation, it is possible to increase the transfer capability of existing power transmission systems at a lower investment cost and with a shorter installation time compared to the building new, additional lines. This is due to the inherent ability of series capacitors to achieve. Results for optimization of total cost with and without TCSC installation by considering the limits on generator real and reactive power outputs, bus voltages and transformer tapings have been obtained.

Keywords: Particle Swarm Optimization (PSO), Optimal Power Flow (OPF), FACTS, TCSC, Power System

I. INTRODUCTION

The increasing industrialization, urbanization of the life style has lead to increasing dependency on the electrical energy. This has resulted into rapid growth has resulted into few uncertainties. Power disruptions and individual power outages are one of the major problems and effect the economy of any country. Recent development of power electronics introduces the use of Flexible AC Transmission System (FACTS) controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this unique feature of FACTS can be exploited to improve the stability of power system. TCSC is one of the important members of FACTS family that is increasingly applied by the utilities in modern power system with long transmission lines. Optimal Power Flow (OPF) is an important optimizing tool for modern power system operation and planning which helps to maintain the economy of the power system [1, 2].Particle Swarm Optimization (PSO) is an optimization tool and it is a stochastic, population-based search and optimization algorithm for problem solving. Particle Swarm Optimization (PSO) technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling. The Particle swarm optimization (PSO) is becoming very popular because of its simplicity of implementation. . As compared with other optimization methods, it is faster and more efficient. To obtain performance of TCSC, PSO is included in Optimal Power Flow (OPF) technique. OPF seeks to optimize a certain objective, subject to the network power flow constraints and system and equipment operating limits [3-5].

In present work, Section 2 deals with general problem formulation for Optimization problem. In Section 3, Particle Swarm Optimization algorithm and its application to OPF is discussed in detail. Section 4 deals with Thyristor Control Series Compensator (TCSC) installation in power system and finally in Section 5 the results obtained and comparison graphs for IEEE 30 bus system without and with TCSC are presented.

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II. PROBLEM FORMULATION

The standard OPF problem can be formulated as a constrained optimization problem mathematically as follows:
Minimize$f(x)$
Subjected to $g(x) = 0$
$h(x) \leq 0$ (1)
where $f(x)$ is the objective function, $g(x)$ represents the equality constraints, $h(x)$ represents the inequality constraints and x is the vector of the control variables such as generator real power Pg, generator voltages Vg, transformer tap setting T.

A. *Objective Function*

The most commonly used objective in the OPF problem formulation is the minimization of the total operation cost of the fuel consumed for producing electric power within a schedule time interval (one hour). The individual costs of each generating unit is assumed to be function of only real power generation and are represented by quadratic curves of second order[4].

$$F(x) = \sum_{i=1}^{ng}(a_i + b_i Pg_i + c_i Pg_i^2) \quad \$/h \tag{2}$$

Wherea_i, b_i and c_i are the cost coefficients of generator at bus .
The objective of OPF can be changed to maximization of fitness correspondingly as follows:
Maximize

$$fitness = 1/F \tag{3}$$

B. *Types of constraints*

The above power generation equation can be subjected to two types of constraints.

1) *Equality Constraints:*

The equality constraints are the power flow equations describing bus injected active and reactive powers of the $i\ th$ bus. The active and reactive power injections at ith bus are defined in the following equation:

$$P_i = Pg_i - Pd_i = \sum_{j=1}^{nb} V_i V_j (g_{ij} Cos\theta_{ij} + b_{ij} Sin\theta_{ij}) \tag{4}$$

$$Q_i = Qg_i - Qd_i = \sum_{j=1}^{nb} V_i V_j (g_{ij} Cos\theta_{ij} - b_{ij} Sin\theta_{ij}) \tag{5}$$

Where
$Pg_i$is the active power generation at bus i;
Qg_i Is the reactive power generation at bus$i$;
$Pd_i$is the real power demands at bus i
$Qd_i$is the reactive power generation at bus i;
V_i,V_j, the voltage magnitude at bus *i*, *j*, respectively; θ_{ij} is the admittance angle, b_{ij} and g_{ij} are the real and imaginary parts of the admittance and nb is the total number of buses.

2) *Inequality constraints:*

The inequality constraints on the problem variables considered include:

- Upper and lower bounds on the active generations at generator buses
  $Pg_i^{min} \leq Pg_i \leq Pg_i^{max}$, $i = 1\ to\ ng$.
- Upper and lower bounds on the reactive generations at generator buses
  $Qg_i^{min} \leq Qg_i \leq Qg_i^{max}$,$i = 1\ to\ ng$
- reactive power injections due to capacitor banks
  $Q_{Ci}^{\min} \leq Q_{Ci} \leq Q_{Ci}^{\max}, i = 1, \ldots, cs$
- Upper and lower bounds on the voltage magnitudes at all the buses.
  $V_i^{min} \leq V_i \leq V_i^{max}$, $i = 1\ to\ nb$
- Upper and lower bounds on the tap changes of linear tap changing transformers
  $T_i^{min} \leq T_i \leq T_i^{max}$, $i = 1\ to\ nb$
- Voltage stability index:
  $L_j \leq L_j^{max}$, j=1,….,NL

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- TCSC constraint:

  $X_{TCSC\,i}^{\min} \le X_{TCSC\,i} \le X_{TCSC\,i}^{\max}$

  $i = 1,2,..., n_{TCSC}$

- transmission lines loading

  $S_i \le S_i^{\max}, i = 1,\ldots,nl$

III.PARTICLE SWARM OPTIMIZATION IN OPTIMAL POWER FLOW

The most commonly used objective in the OPF [5] problem formulation is the minimization of the total operation cost of the fuel consumed. Figure 1 shows the search mechanism of PSO. Each particle moves from the current position to the next one according to the present values. Generally, the fitness function is same the objective functions. The local best of other particles in the population should be changed if the present fitness function value is better than the previous. Repeat the new searching points until the maximum number of generations reached. 150 generations are set in this paper as the stopping criteria.

The particles continue flying and seeking solution and hence the algorithm continues until a pre-specified numbers of maximum iterations are exceeded or exit criteria are met. The accuracy and rate of convergence of the algorithm depends on the appropriate choice of particle size, maximum velocity of particles and inertia weight. However, no specific guideline is available to select the particle size. Moreover, it also varies from problem to problem. As a result, one has to choose it by trial and error. The maximum velocity of individual particles should be chosen very judiciously. If the maximum velocity is too high, the particles may fly past the best solution without discovering it and if it is too low particles may fail to explore sufficiently beyond local solutions.

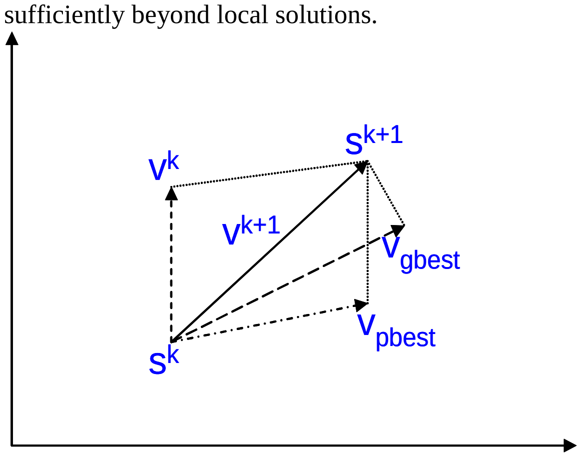

Figure 1: Concept of modification of a searching point by PSO

In figure 1, it shows the concept of modification of PSO. Each particle moves from the current position to the next one according to the present values. Generally, the fitness function is same the objective functions. The local best of other particles in the population should be changed if the present fitness function value is better than the previous.

S^k: Current searching point
S^{k+1}: Modified searching point
V^k: Current Velocity
V^{k+1}: Modified Velocity
V_{pbest} : Velocity based on pbest
V_{gbest} : Velocity based on gbest

Each position and velocity in the N dimensional space such as position $X_i = (x_{i1}, x_{i2}, x_{i3}, \ldots\ldots x_{in})$ and velocity $V_i = (v_{i1}, v_{i2}, v_{i3}, \ldots\ldots v_{in})$ Each particle is then flown over the search space in order its flying velocity and direction according to its own flying experience as well as that of its neighbors. Positions of the particles (tentative

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solutions) are evaluated at the end of every iteration relative to an objective or fitness value. Particles are assumed to retain memory of the best positions they have achieved in course of flying and share this information among the rest. The collective best positions of all the particles taken together is termed as the global best position given as $gbest = (gb_1, gb_2, gb_3, \ldots .. gb_n)$ and the best position achieved by the individual particle is termed as the local best or position best and for the i_{th} particle given as $p_{best} = (p_{i1}, p_{i2}, p_{i3}, \ldots .. p_{in})$ .Particles use both of these information to update their positions and velocities as given in the following equations:

$$v_i^{(t+1)} = w_i . v_i^{(t)} + c_1 . r_1 . (x_{gbest}^{(t)} - x_i^{(t)}) + c_2 . r_2 . (x_{ipbest}^{(t)} - x_i^{(t)}) \quad (6)$$

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)} \quad (7)$$

Where:
t: pointer of iterations (generations).
w_i: Inertia weight factor.
c_1, c_2: acceleration constant.
r_1, r_2 : uniform random value in the range (0,1).
$v_i^{(t)}$: Velocity of particle i at iteration t.
$x_i^{(t)}$: Current position of particle i at iteration t
$x_{ipbest}^{(t)}$: Previous best position of particle i at iteration t.
$x_{gbest}^{(t)}$: Best position among all individuals in the population at iteration t.
$v_i^{(t+1)}$: New velocity of particle i.
$x_i^{(t+1)}$: New position of particle i.

A. PSO Algorithm:

The step by step procedure of PSO algorithm as follows

1. Initialize a population of particles with random values and velocities within the d-dimensional search space. Initialize the maximum allowable velocity magnitude of any particleV^{max} . Evaluate the fitness of each particle and assign the particle's position to pbest fitness. Identify the best among the p-best as g-best.
2. Change the velocity and position of the particle according to the following equations.

$$V_i^{l+1} = wV_i^l + C_1 * r_1 (pbest^l - X_i^l) + C_2 * r_2 (gbest^l - X_i^l) \quad (8)$$

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)} \quad (9)$$

3. For each particle, evaluate the fitness, if all decisions variables are within the search ranges.
4. Compare the particle's fitness evaluation with its previous p-best. If the current value is better than the previous p-best location equal to the current location in the d-dimensional search space.
5. Compare the best current fitness evaluation with the population g-best. If the current value is better than population g-best, then reset the g-best to the current best position and the fitness value to current fitness value.
6. Repeat steps 2-5 until a stopping criterion, such as sufficiently good g-best fitness or a maximum number of iterations is met.

B. Algorithm application to OPF:

The PSO algorithm applied to OPF can be described in the following steps.
Step 1: Input parameters of system, and specify the lower and upper boundaries of each control variable.
Step 2: The particles are randomly generated between the maximum and minimum operating limits of the generators.
Step 3: Calculate the value of each particle using objective function.
Step 4: Evaluate the fitness value of objective function of each particle using (3). x_{ibest} Is set as the i th particle's initial position; x_{gbest} is set as the best one of x_{ibest} . The current evolution is t =1.
Step 5: Initialize learning factorsc_1, c_2, inertia weight w_i and the initial velocityv_1.
Step 6: Modify the velocity v of each particle according to (8).

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Step 7: Modify the position of each particle according to (9). If a particle violates its position limits in any dimension, set its position at proper limits. Calculate each particle's new fitness; if it is better than the previous x_{gbest} , the current value is set to be x_{gbest} .
Step 8: To each particles of the population, employ the Newton-Raphson method to calculate power flow and the transmission loss.
Step 9: Update the time counter $t = t + 1$.
Step 10: If one of the stopping criteria is satisfied then go to step 11. Otherwise go to step 6.
Step 11: The particle that generates the latest p_{gbest} is the global optimum

C. Voltage Stability Index (L-index) Computation:
The voltage stability L-index [6] is a good voltage stability indicator with its value change between zero (no load) and one (voltage collapse). Moreover, it can be used as a quantitative measure to estimate the voltage stability margin against the operating point. For a given system operating condition, using the load flow (state estimation) results, the voltage stability L -index is computed as given in equation

$$L_j = \left|1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j}\right| \qquad (10)$$

$$j = g + 1, \dots \dots, n$$

IV. POWER FLOW INCLUDING FACTS CONTROLLERS

Thyristor Controlled Series Compensation (TCSC) is as shown in figure 2. In There have been significant activities and achievement in the research and application of flexible AC transmission systems (FACTS). Thyristor Controlled Series Compensation (TCSC) is an important device in the FACTS family. It can have various roles in the operation and control of power systems, such as scheduling power flow; decreasing unsymmetrical components; reducing net loss; providing voltage support; limiting short-circuit currents; mitigating sub synchronous resonance (SSR); damping the power oscillation and enhancing-transient stability. TCSC controls the active power transmitted by varying the effective line reactance by connecting a variable reactance in series with line [7].

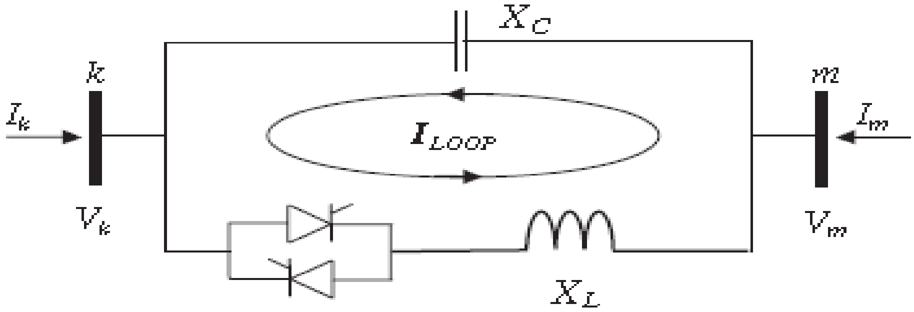

Figure 2: Thyristor Control Series Compensator

In fig 2, it shows the equivalent circuit of a thyristor controlled series compensation (TCSC).

The transfer admittance matrix of the variable series compensator is given by

$$\begin{bmatrix} I_k \\ I_m \end{bmatrix} = \begin{bmatrix} jB_{kk} & jB_{km} \\ jB_{mk} & jB_{mm} \end{bmatrix} \begin{bmatrix} V_k \\ V_m \end{bmatrix} \qquad (11)$$

For inductive operation we have

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$$\left.\begin{aligned} B_{kk} &= B_{mm} = -\frac{1}{X_{TCSC}}, \\ B_{km} &= B_{mk} = \frac{1}{X_{TCSC}} \end{aligned}\right\} \tag{12}$$

And for capacitive operation the signs are reversed.
The active and reactive power equations at bus k are

$$P_k = V_k V_m \sin(\theta_k - \theta_m) \tag{13}$$

$$Q_k = -V_k^2 B_{kk} - V_k V_m B_{km} \cos(\theta_k - \theta_m) \tag{14}$$

For the power equations at bus m, the subscripts k and m are exchanged in above equations.
The state variable X_{TCSC} of the series controller is updated at the end of each iterative step according to

$$X_{TCSC}^{(i)} = X_{TCSC}^{(i-1)} + \left(\frac{\Delta X_{TCSC}}{X_{TCSC}}\right)^{(i)} X_{TCSC}^{(i-1)} \tag{15}$$

V. RESULTS AND DISCUSSION

The research work carried out broadly touches upon the aspects of power system operation and analysis for obtaining reduced operating costs, reduction in power loss and improved voltage stability of the system.The major contributions of the thesis is the investigation on the performance of FACTS device. The Particle Swarm Optimization (PSO) technique has been applied to the OPF problems and has been compared with other OPF techniques reported in the literature. A PSO technique has been developed for TCSC facts device, in which performance with TCSC device exhibits best results compared to without TCSC device.

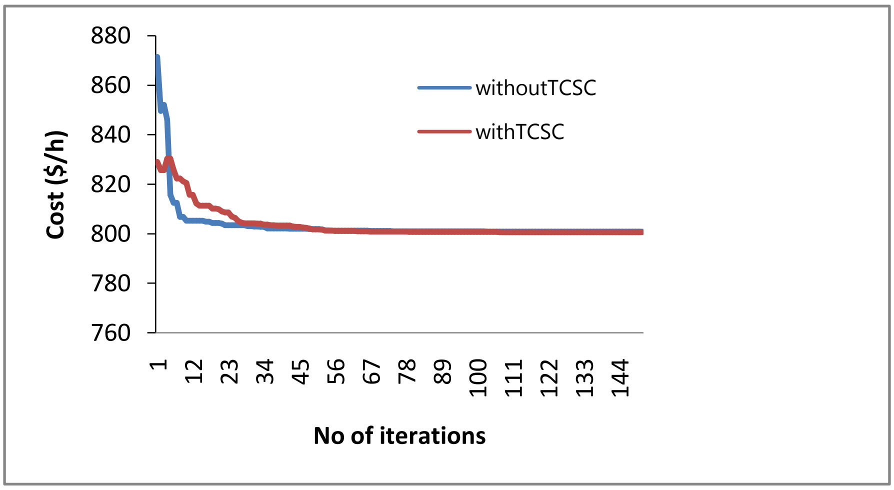

Fig. 3 Cost Curve

In the fig 3, it shows the graph of cost vs. no .of iterations. In Y-axis cost is in $/h. From the above graph it is clear that the cost becomes low on using TCSC (red line) when compared to the cost without TCSC.

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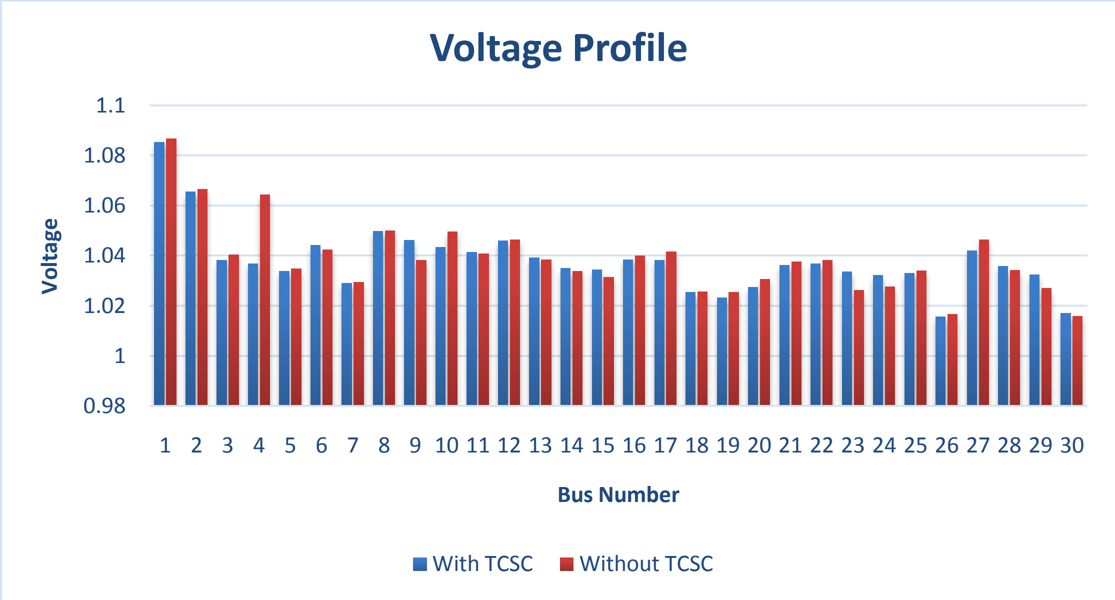

Fig. 4 Voltage Profile Vs Bus number

In the fig 4, it shows the graph of voltage Vs bus no. Inserting TCSC (red line) at 27th bus, voltage profile increases when compared to the voltage profile without TCSC (blue line).

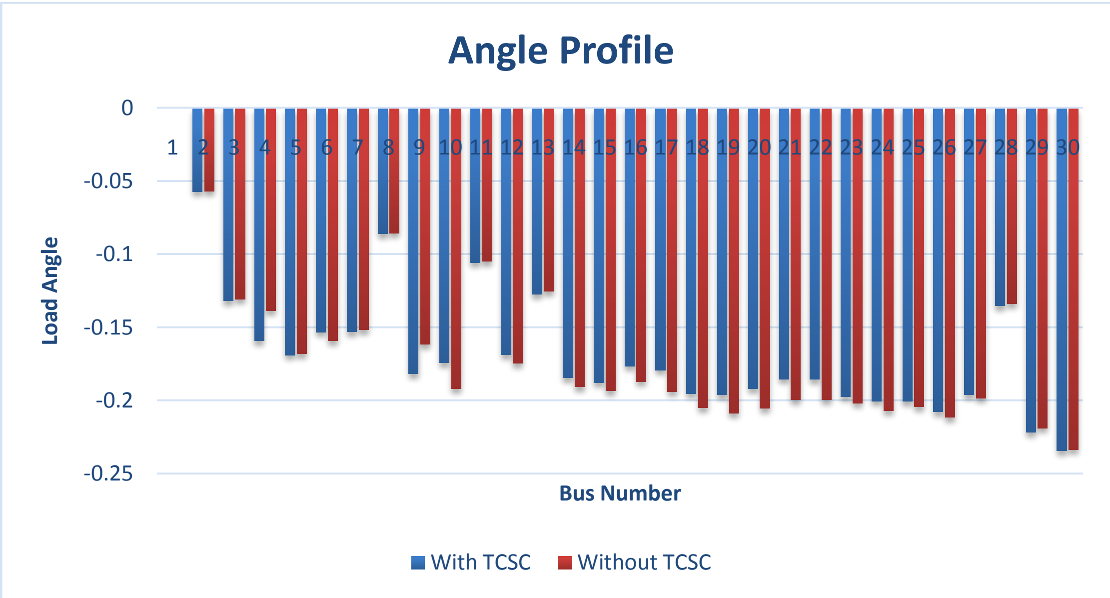

Fig. 5 Load Angle Vs Bus number

In the fig 5, it shows the graph of load angle Vs bus no. Inserting TCSC (red line) at 27th bus, load angle was improved when compared to the load angle without TCSC (blue line).

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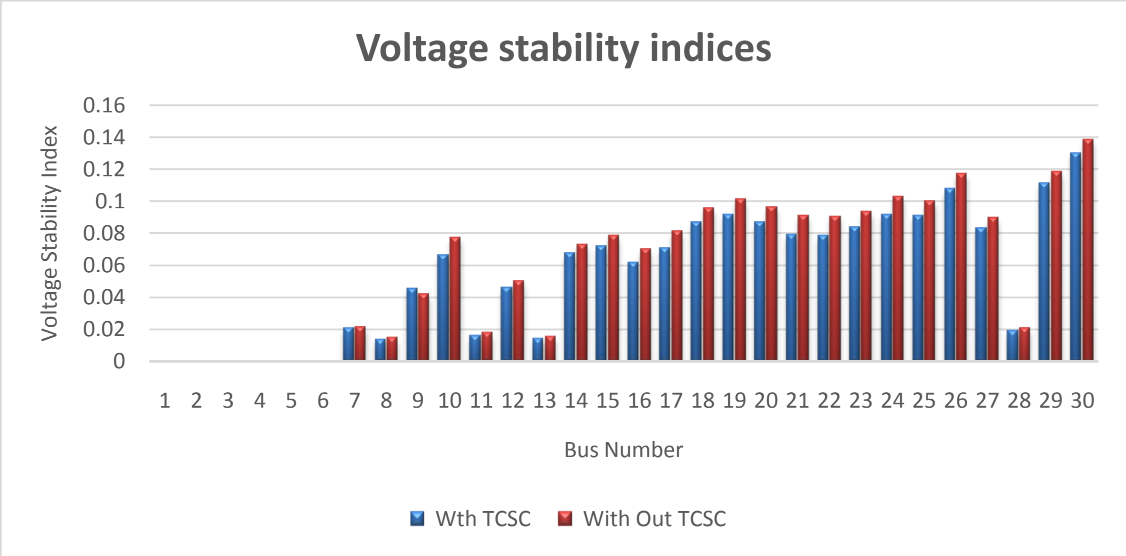

Fig. 6 Voltage Stability indices Vs Bus number

In the fig 6, it shows the graph of voltage stability index Vs bus no. Inserting TCSC (red line) at 27th bus, voltage stability index was improved when compared to voltage stability index without TCSC (blue line).

Table 1: Parameters difference with and without TCSC for IEEE 30-bus system

Parameter	**Without TCSC**	**With TCSC**
Total cost ($/hr)	800.5671	8000.4608
P loss (pu)	0.0908	0.0900
Ljmax	0.1301	0.1273
CPU time (Sec)	53.8600	44.1220

Table 2.Comparision Results for different parameters with and without TCSC for IEEE 30-bus system

Parameter	**Min Limit**	**Max Limit**	**Without TCSC**	**With TCSC**
PG1	0.5	2.0	1.7719	1.7748
PG2	0.2	2.8	0.4833	0.4888
PG3	0.1	0.35	0.2129	0.2080
PG4	0.1	0.3	0.1211	0.1183
PG5	0.15	0.5	0.2147	0.2147
PG6	0.12	0.4	0.1200	0.1202

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VG1	0.95	1.10	1.0830	1.0854
VG2	0.95	1.10	1.0641	1.0656
VG3	0.95	1.10	1.0279	1.0382
VG4	0.95	1.10	1.0384	1.0369
VG5	0.95	1.10	1.0176	1.0338
VG6	0.95	1.10	1.0477	1.0442
Tap - 1	0.9	1.10	1.100	1.0114
Tap - 2	0.9	1.10	0.9370	1.0187
Tap - 3	0.9	1.10	0.9634	0.9651
Tap - 4	0.9	1.10	0.9761	0.9831
Q_{C10}	0	0.10	0.0783	0.0993
Q_{C12}	0	0.10	0.000	0.000
Q_{C15}	0	0.10	0.0629	0.0264
Q_{C17}	0	0.10	0.0518	0.0276
Q_{C20}	0	0.10	0.0785	0.0666
Q_{C21}	0	0.10	0.0386	0.0693
Q_{C23}	0	0.10	0.0429	0.0337
Q_{C24}	0	0.10	0.0260	0.0415
Q_{C29}	0	0.10	0.0260	0.0336

VI. CONCLUSION

TCSC was installed in the IEEE 30 bus system and the stabilized voltages and reduction MVA loading of the transmission lines has been observed. PSO technique was employed as it possesses advantages of modelling flexibility, sure and fast convergence, less computational time over other heuristic methods. In this research work, Particle Swarm Optimization (PSO) technique was used effectively to solve the OPF problem. The performance of the system has been analyzed by comparing the cost of generation, real power loss, improvement of voltage profiles, voltage angles and improvement of voltage stability L-index.

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BIOGRAPHY

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In the fig 2, it shows the graph of throughput of received bits Vs Maximal end to end delay. End to end delay is the time taken by a packet to travel from source to reach destination.