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OPTIMAL PLACEMENT OF TCSC USING WIPSO

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ABSTRACT

Modern power systems are heavily loaded and are being operated in ways not originally envisioned. Flexible AC Transmission System (FACTS) devices play a vital role in improving the static as well as dynamic performance of the power systems. FACTS devices are multi-functional control devices which can be used to effectively control the power distribution and the power transfer capability, to reduce active power losses, to improve stabilities of the power network, to decrease the cost of power production and to fulfill the other control requirements by controlling the power flow in the network. FACTS devices are based on solid-state control and so are capable of control actions at far higher speed. However the location and rating of the FACTS devices play a major role in deciding the extent to which the objective of improving the system performance is achieved in a cost effective manner. In this work an objective function comprising of cost, line loadings and load voltage deviations is proposed to tap maximum benefits out of their installation and the weights assigned to them decide the relative importance. WIPSO (Weight Improved PSO) technique is applied for solving the problem and the effectiveness of the proposed method is tested on IEEE 14, 30 and 57 bus systems using MATAB. The results of the proposed technique are compared with the results obtained through the application of PSO algorithm for the same objective function.

Keywords: FACTS devices, thyristor controlled series capacitor (TCSC), particle swarm optimization (PSO),weight improved PSO (WIPSO), security enhancement.

INTRODUCTION

The secure and reliable operation of power systems has become an important issue in today's large and highly complex interconnected systems. So it becomes essential to improve the electric power utilization while maintaining the reliability and security. Due to increase in load demand, the magnitude of the power flows in some of the transmission lines are well above their normal limits and in some other lines, it is below their normal. As a result of this uneven load distribution the voltage profile of the system gets deteriorated which poses a threat for the security of the system. Considering the factors such as ever increasing load demand, economical and technical constraints involved in setting up new power generation facilities and limitations faced in purchasing right of ways to realize new transmission corridors, it becomes highly essential to utilize the existing generation and transmission facilities in the most efficient manner. To achieve this, FACTS controllers are found to be an effective alternative for the complex task of building up new transmission corridors [1].

FACTS (Flexible Alternating Current Transmission System) is a concept introduced by N.G.Hingorani [2]. FACTS devices are multi-functional control devices which can be used to effectively control the power distribution and the power transfer capability, to improve the voltage profile, to reduce line loadings, to reduce active power losses, to provide reactive power support, to improve stabilities of the power network and also to decrease the cost of power production. Controlling the power flow in an electric power system without generation rescheduling or topological changes can improve the performance of system considerably [3]. To achieve the maximum benefits through the installation of FACTS devices, it is highly important to determine the optimal location and suitable ratings of the devices in the power system [4].

TCSC (Thyristor Controlled Series Capacitor) is a type of series compensator that can provide many benefits for a power system including control of power flow in the line damping power oscillations and mitigating sub synchronous resonance [5]. TCSC is a variable impedance type series compensator. It consists of a series compensating capacitor shunted by a thyristor controlled reactor. By controlling the firing angle of thyristor, TCSC can change the line reactance smoothly and rapidly. TCSC has one of the two possible characteristics either capacitive or inductive, thereby increasing or decreasing the reactance of the line X_l [6]. Moreover to avoid the over compensation of the line, the maximum values of capacitance and inductance are fixed at $-0.8X_l$ and $0.2X_l$ [7]. World's first 3 phase, 2*165 MVAR, TCSC was installed in 1992 in Kayenta substation, Arizona. It raised the transmission capacity of transmission line by 30% and effectively damped electromechanical power oscillations [8]. Optimal placement of TCSC is essential to tap the maximum benefits in terms of system performance and cost effectiveness.

A loss sensitivity index with respect to the control parameters of FACTS devices has been suggested

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and with the computed loss sensitivity index, the FACTS devices are placed on the most sensitive bus or line [9]. Fuzzy based approach for the optimal placement of FACTS device for enhancing the system security under normal and network contingencies has been discussed in [10]. The optimal location of a given number of FACTS devices is a problem of combinatorial analysis. To solve such kind of problems, heuristic methods can be used [11]. They permit to obtain acceptable solutions within a limited computation time. The application of Genetic Algorithm for the optimal location of multi type FACTS devices in order to maximize the system loadability is analysed in [12]. A Differential Evolution based algorithm to decide the optimal location and device rating has been suggested in [13] with an objective of enhancing the system security under single line contingencies. The Particle Swarm Optimization (PSO) is applied for the optimal location of FACTS devices to achieve minimum cost of installation and to improve system loadability, by considering thermal limit for the lines and bus voltage limit for the load buses as constraints [14]. Sensitivity analysis approach for finding the optimal location and PSO for the optimal parameter setting of TCSC has been suggested in [15] so as to maximize the loadability. A novel Weight Improved PSO method based on the improved function of weight parameter is applied for solving Economic load dispatch problems [16].

As bus voltage deviations on the load buses are also considered as appropriate indices that reflect the system security, these voltage deviations along with the cost of installation of the devices and the line loading are used to formulate the objective function that is to be minimized and the WIPSO technique is used to solve the problem in this work.

PROBLEM FORMULATION

Objective of the optimization

As the cost of the FACTS devices, especially TCSC is high, in order to achieve the maximum benefit, the devices are to be installed at the optimal locations. Minimizing the cost of installation of the TCSC is chosen as the primary objective and the objective function is augmented with two indices, one for the load voltage deviation and the other for line loading thereby making it a comprehensive one, whose minimization leads to a cost effective, security oriented solution.

The objective function is formulated as

$$MinF = W_1[C_{TCSC} * S] + W_2[LVD] + W_3[LL] \quad (1)$$

F is the objective function;

C_{TCSC} = Cost of TCSC device in US $/KVar;

S = Operating range of TCSC;

LVD = Load voltage deviation;

LL = Line loading;

W_1, W_2 and W_3 are the weight factors.

(i) Cost (C_{TCSC})

The first term of the objective function C_{TCSC} presents the installation cost of TCSC device in the network, which is given by the following equation.

$$C_{TCSC} = 0.0015s^2 - 0.7130s + 153.75 \quad (2)$$

(ii) Load voltage deviation (LVD)

Excessive high or low voltages can lead to an unacceptable service quality and can create voltage instability problems. TCSC's connected at appropriate locations play a leading role in improving voltage profile thereby avoiding voltage collapse in the power system. The second term represents the load voltage deviations in order to avoid the unsatisfactory voltage profiles on load buses.

$$LVD = \sum_{m=1}^{nb} \left(\frac{V_{mref} - V_m}{V_{mref}} \right)^n \quad (3)$$

V_m = Voltage magnitude at bus m

V_{mref} = Nominal voltage at bus m and is considered as 1.0 pu.

m = Load buses, where V_m is less than V_{mref} .

(iii) Line loading (LL)

TCSC is located in order to remove the overloads and to distribute the load flows uniformly. To achieve this, line loading is considered as the third term in the objective function.

$$LL = \sum_{l=1}^{nl} \left(\frac{S_l}{S_{l\max}} \right)^n \quad (4)$$

S_l = Apparent power in the line l.

$S_{l\max}$ = Apparent power rating of line l.

The optimization variables

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The optimization variables considered in this work are

(a) The number of TCSC devices to be installed is taken as the first variable.

(b) TCSC location is considered as the second variable to be optimized. TCSC's are not installed in the lines where the transformers exist.

(c) The reactance of the TCSC is considered as the third variable.

Modelling of TCSC device

TCSC is a series compensator. It consists of a series compensating capacitor shunted by a thyristor controlled reactor as shown in Figure-1.With TCSC the power flow control can be achieved by varying the overall lines effective series transmission impedance. The TCSC is modelled as a variable reactance as shown in Figure-2.

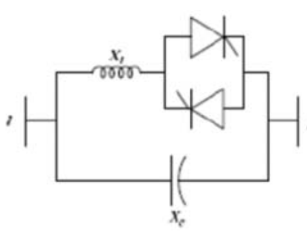

Figure-1.

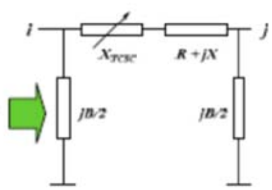

Figure-2.

The working range of TCSC is considered as follows.

$$-0.8X_l \le X_{TCSC} \le 0.2X_l \quad (5)$$

X_{TCSC} is the reactance added to the line by placing TCSC.

X_l is the overall line reactance.

Overview of PSO technique

Particle swarm optimization is a heuristic search technique developed by Eberhart and Kennedy [16] based on the concept of swarm intelligence exhibited by the flock of birds, school of fish etc in which each member of the group adjusts its behavior based upon its own experience and the experience of the swarm. .This sort of social behavior is used to simulate the problem solving environment in which a swarm is randomly generated in terms of solution variables of the problem. The individuals in a swarm are called particles. After generating the swarm, the fitness values of the particles P_{best} are evaluated and compared against the values obtained from the previous iteration. The particles with the best values of fitness function in the next generation P_{best} are retained. G_{best} is the best value attained so far by the swarm of particles. In each iteration, G_{best} of the current swam is compared with the G_{best} of the previous iteration and whichever is lower is retained along with the corresponding particle.

The position update of particles is carried out through the expression (6) and the velocity is calculated using (7).

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \quad (6)$$

$$V_{id}^{K+1} = WV_{id}^{K} + c_1 r_1 \left(P_{bestid}^{k} - X_{id}^{k}\right) + c_2 r_2 \left(G_{bestid}^{k} - X_{id}^{k}\right) \quad (7)$$

The inertia weight in (7) is calculated using the following expression.

$$W = W_{\max} - \frac{W_{\max} - W_{\min}}{iter_{\max}} * iter \quad (8)$$

This iterative procedure is repeated till a specified number of swarm are generated or until a predefined amount of time has elapsed or until there is no considerable difference between the outcomes of any two subsequent iterations.

V_{id}^{k+1} = Velocity of the i^{th} individual at $(k+1)^{th}$ iteration.

V_{id}^{k} = Velocity of the i^{th} individual at k^{th} iteration

X_{id}^{k} = Position of the i^{th} individual at k^{th} iteration.

X_{id}^{k+1} = Position of the i^{th} individual at $(k+1)^{th}$ iteration.

$P_{best\ id}$ = Best position of the i^{th} individual.

$G_{best\ id}$ = Best position among the individuals.

$r_{1,}\ r_2$ = Random numbers distributed within the interval [0, 1]

c_1 = Cognitive factor

c_2 = Social factor

W = Inertia weight

$W_{\max}$ =Initial value of inertia weight

$W_{\min}$ = Final value of inertia weight

$iter_{\max}$ = Maximum number of iterations

$iter$ = Current iteration number

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$d = 1,2,.....D$, D is the number of members in a particle.

$i = 1,2,.......m$, m is the size of the swarm.

WIPSO-Weight improved PSO technique

WIPSO is based on the improved weight parameter function. For getting the better global solution, the traditional PSO algorithm is improved by adjusting the inertia weight, cognitive and social factors.

The velocity of an individual i of WIPSO is given by

$$V_{id}^{K+1} = W_{new} V_{id}^{K} + c_1 r_1 \left(P_{bestid}^{k} - X_{id}^{k}\right) + c_2 r_2 \left(G_{bestid}^{k} - X_{id}^{k}\right) \quad (9)$$

Where,

$$W = W_{\max} - \frac{W_{\max} - W_{\min}}{iter_{\max}} \times iter \quad (10)$$

$$W_{new} = W_{\min} + W \times r_3 \quad (11)$$

$$c_1 = c_{1\max} - \frac{c_{1\max} - c_{1\min}}{iter_{\max}} \times iter \quad (12)$$

$$c_2 = c_{2\max} - \frac{c_{2\max} - c_{2\min}}{iter_{\max}} \times iter \quad (13)$$

r_3 = Random number distributed within the interval [0, 1]

$W_{\max}$ = Initial value of inertia weight.

$W_{\min}$ = Final value of inertia weight.

$c_{1\min}$ = Initial value of cognitive factor.

$c_{1\max}$ = Final value of cognitive factor.

$c_{2\min}$ = Initial value of social factor.

$c_{2\max}$ = Final value of social factor.

$iter_{\max}$ = Maximum number of iterations.

$iter$ = Current iteration number.

5. ALGORITHM

The algorithm of the proposed work is explained below.

Step 1: The system data and the load factor are initialized.

Step 2: WIPSO parameters such as the size of swarm m, the number of variables to be optimized, limits of each variable in the particle, c_1 and c_2, $C_{1\min}$ and $C_{1\max}$, $C_{2\min}$ and $C_{2\max}$, $iter_{\max}$, $W_{\min}$ and $W_{\max}$, D, velocity limits, P_{best} and G_{best} are initialized.

Step 3: An initial population is randomly generated considering the variables to be optimized. [The number of TCSCs, location of TCSC, parameter setting of TCSC]

Step 4: For each particle i [i = 1, 2,…..m] in the population, the objective function is evaluated.

Step 5: The objective function value of each particle is compared with the corresponding P_{best} of previous iteration and P_{best} of each particle is updated.

Step 6: G_{best} is identified, then compared with the G_{best} in the previous iteration and it is updated.

Step 7: A new population is created by updating the velocity and position of the particle.

Step 8: If stopping criterion is satisfied, the best individual is identified; else steps from 4 are repeated.

Step 9: The steps from 2 to 8 are repeated for different load factors.

SIMULATED RESULTS

The proposed method has been tested on standard IEEE 14 bus, 30 bus and 57 bus test systems. To study the effect of the installation of TCSC on load bus voltages and line loadings under overload conditions, the loads on the system were increased in a step by step manner; the real and reactive power loads connected at various load buses were increased keeping the load power factor constant. The maximum number of FACTS devices is limited to 2 on a 14 bus system, 3 on a 30 bus system and 5 on a 57 bus system.

The Tables 1, 5 and 9 show the location of TCSC's for 14, 30 and 57 bus systems obtained using PSO algorithm. Similarly the Tables 2, 6 and 10 show the location of TCSC's for 14, 30 and 57 bus systems obtained using WIPSO algorithm. The Tables 3, 7 and 11 show variation in line loading before and after the placement of TCSC using PSO and WIPSO algorithms for 14, 30 and 57 bus systems. The Tables 4, 8 and 12 show variation in load voltage deviation before and after the placement of TCSC using PSO and WIPSO algorithms for 14, 30 and 57 bus systems.

From the tabulated results, it has been observed that there is a significant reduction in the line loadings and load voltage deviations when TCSC's are connected at optimal locations using WIPSO algorithm.

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A. Case I: 14 bus system

PSO

Table-1. TCSC location.

	Load factor	1	1.1	1.2	1.3	1.4	1.5
Line number	TCSC 1	12	12	4	12	6	12
Line number	TCSC 2	19	19	18	19	10	19

WIPSO

Table-2. TCSC location.

	Load factor	1	1.1	1.2	1.3	1.4	1.5
Line number	TCSC 1	4	5	5	6	6	6
Line number	TCSC 2	18	18	18	10	11	11

Table-3. Line loading for different load factors.

Load factor	1	1.1	1.2	1.3	1.4	1.5
Without TCSC	17.5892	19.2093	20.9319	22.4464	24.0519	25.7766
With TCSC (PSO)	17.3907	19.0305	20.6862	22.3651	23.3228	25.0535
With TCSC (WIPSO)	17.3811	18.9871	20.6228	22.3334	23.2014	24.5716

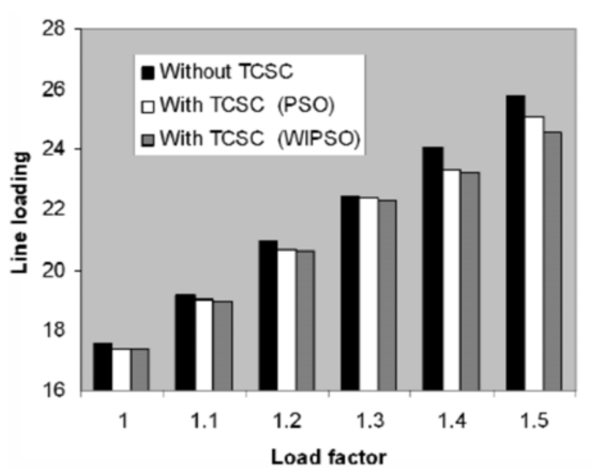

Figure-3. Line loading Vs percentage of load.

Table-4. Load voltage deviation for different load factors.

Load factor	1	1.1	1.2	1.3	1.4	1.5
Without TCSC	0.3509	0.3696	0.4075	0.4875	0.5689	0.5922
With TCSC (PSO)	0.2884	0.3079	0.3275	0.3479	0.3801	0.4024
With TCSC (WIPSO)	0.2877	0.2949	0.3146	0.3351	0.3799	0.3992

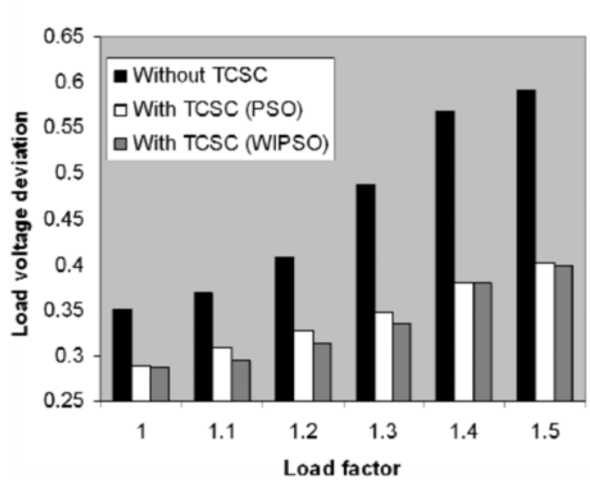

Figure-4. Load voltage deviation Vs percentage of load.

B. Case II: 30 bus system

PSO

Table-5. TCSC location.

	Load factor	1	1.1	1.2	1.3	1.4	1.5
Line number	TCSC 1	9	15	9	9	9	9
Line number	TCSC 2	25	28	25	21	21	21
Line number	TCSC 3	37	30	37	30	30	30

WIPSO

Table-6. TCSC location.

	Load factor	1	1.1	1.2	1.3	1.4	1.5
Line number	TCSC 1	15	9	9	9	15	28
Line number	TCSC 2	28	21	25	21	28	29
Line number	TCSC 3	30	30	37	30	30	33

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Table-7. Line loading for different load factors.

Load factor	1	1.1	1.2	1.3	1.4	1.5
Without TCSC	14.5592	16.2116	17.9504	19.7258	21.5352	23.1761
With TCSC (PSO)	14.5522	16.1973	17.9397	19.7155	21.5319	23.1159
With TCSC (WIPSO)	14.5457	16.1921	17.9054	19.6876	21.4897	23.1062

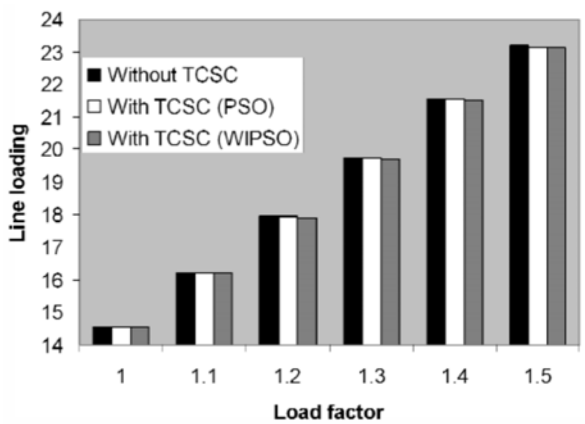

Figure-5. Line loading Vs percentage of load.

Table-8. Load voltage deviation for different load factors.

Load factor	1	1.1	1.2	1.3	1.4	1.5
Without TCSC	0.6967	0.6974	0.7145	0.7342	0.7548	0.7834
With TCSC (PSO)	0.6965	0.6973	0.7128	0.7335	0.7529	0.7578
With TCSC (WIPSO)	0.6962	0.6968	0.7075	0.7302	0.7489	0.7568

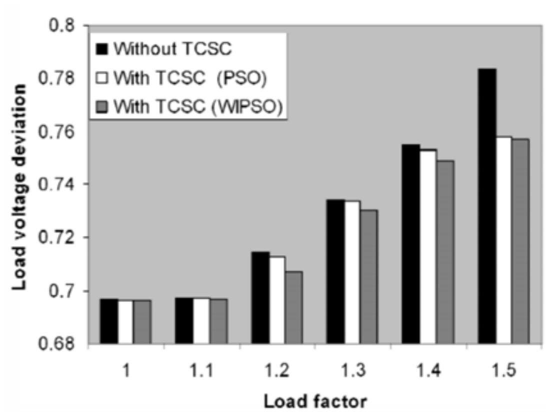

Figure-6. Load voltage deviation Vs percentage of load.

Case III: 57 bus system

PSO

Table-9. TCSC location.

	Load factor	1	1.1	1.2	1.3	1.4	1.5
Line number	TCSC 1	23	14	18	18	18	18
Line number	TCSC 2	27	33	49	49	49	49
Line number	TCSC 3	35	37	73	73	73	73
Line number	TCSC 4	45	45	74	74	74	74
Line number	TCSC 5	63	66	78	78	78	78

WIPSO

Table-10. TCSC location.

	Load factor	1	1.1	1.2	1.3	1.4	1.5
Line number	TCSC 1	14	14	14	14	14	14
Line number	TCSC 2	21	33	21	33	15	15
Line number	TCSC 3	45	37	45	37	23	23
Line number	TCSC 4	74	45	74	45	38	38
Line number	TCSC 5	77	66	77	66	67	67

Table-11. Line loading for different load factors.

Load factor	1	1.1	1.2	1.3	1.4	1.5
Without TCSC	53.3300	61.2900	70.0100	79.8600	92.0100	105.1600
With TCSC (PSO)	53.2600	61.2300	69.9200	79.6600	91.5900	104.2300
With TCSC (WIPSO)	52.9961	61.1558	69.8170	79.5603	91.4201	104.1644

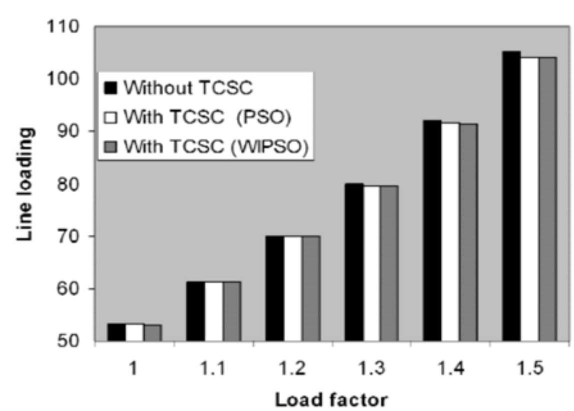

Figure-7. Line loading Vs percentage of load.

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Table-12. Load voltage deviation for different load factors.

Load factor	1	1.1	1.2	1.3	1.4	1.5
Without TCSC	3.8800	4.1600	4.4600	4.4600	5.9700	6.8800
With TCSC (PSO)	3.8600	4.1600	4.4500	4.4600	5.6500	6.7800
With TCSC (WIPSO)	3.7701	4.1927	4.4395	4.3262	5.5887	6.7155

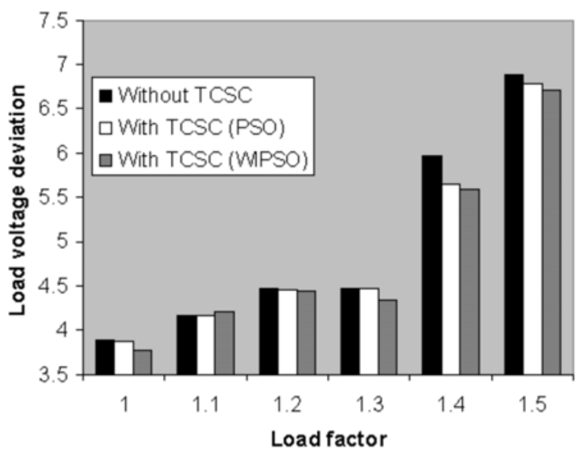

Figure-8. Load voltage deviation Vs percentage of load.

As line loadings form a part of the objective function, overload conditions were simulated by simultaneously varying the real and reactive powers on the load buses keeping the load power factor constant. Minimizing the installation cost of the devices forms the other objective and this is achieved by optimally sizing and placing the devices. Under over loaded conditions, the increased voltage drops on transmission lines result in unsatisfactory voltage profile. So, reduction in the deviation of load voltages has been made as a third objective.

Line loadings and load voltage deviations under different load conditions are shown from Figure 3 – 8 for 14, 30 and 57 bus systems. These variations are shown in the form of bar charts for three different cases namely when the system is operated without TCSC and when the device placement is carried out through PSO and WIPSO techniques. It has been observed that line loadings and the load voltage deviations are reduced when the system is operated with TCSCs at optimum locations. There is a significant improvement in the performance of the system when the device placement is done through WIPSO algorithm.

CONCLUSIONS

WIPSO (Weight Improved PSO) technique has been applied for the security enhancement of power systems. Though TCSCs can be placed at any feasible location in the power system, their locations and ratings are to be fixed optimally as they turn out to be costlier than the conventional compensating devices. Here the problem of device placement is guided through the WIPSO algorithm which gives the solution for the comprehensive objective function consisting of cost of the device, load voltage deviations and line loadings. The proposed method yields an efficient solution when compared to PSO and considerably reduces load voltage deviations and relieve the lines off their over loads under various load conditions.

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