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Investigation Of Security Enhancement With The Implementation Of Facts Devices Under Single Line Contingencies

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ABSTRACT

FACTS technology opens a new platform to rethink and re-engineer the future power systems and has arisen as an appealing solution for boosting performance of existing transmission assets. Flexible Alternating Current Transmission System is an idea which assists to modulate and reverse the power flow through the transmission lines, in a quick, accurate and precise manner. Applications of FACTS devices not only improve the system performance, but also provide more flexibility to the network operation. Increasingly over any of the astounding events like abrupt increase in system loading or contingency, may decline the bus voltages unexpectedly and subsequently threatening the system security. It is essential to have an investigation ahead and trace the locations and type of FACTS device, so as to defeat and overcome the conditions threatening the system security. System loadability and voltage stability have been treated as good indicators of power system security. This work shows examination and subsequently the impact of placement of different FACTS devices under single line contingency conditions. The optimal placement of multi type FACTS devices has been carried out using various heuristic search techniques like PSO,WIPSO, BBO & LOA techniques are compared and the outcomes are investigated.

Key words: Security enhancement, Optimal FACTS device placement, TCSC, SVC UPFC placement.

1.INTRODUCTION

Day by day increase in load demand makes the power system increasingly unpredictable and less secure to work. Because of the dynamic ever increasing load demand, power flows in some of the transmission lines are well above their normal limits, while some of the lines are not loaded up to their full capacity. As an outcome of this uneven load distribution the voltage profile of the power system gets decayed, which represents a risk for the security of the system. To defeat these issues and to expand the dependability, some new power generation facilities can be added to the power grid. This increases the generation cost of the electricity.

A substitute method to expand the system reliability with the same generation is to increase the transmission capability. So it very well may be seen as, with less transmission line ability, more generation resources are required. This demonstrates, it winds up fundamental to grow the transmission grid capability which is which is the back bone for power generation. Over recent decades it is demonstrated that building new transmission lines had turned out to be incredibly troublesome, costly and tedious [1].

Due to these economical and technical constraints involved in setting up new generation resources and limitations faced in purchasing right of ways to realize new transmission corridors, it is essential to utilize the existing transmission lines in an efficient manner. Most interesting technology - FACTS technology, has emerged as an effective alternative solution for the complex task of building up new transmission corridors. FACTS controllers take care of specialized issues in interconnected power systems and can also improve the synchronous operation of the interconnections and influence the load flow conditions.

1.1 TYPES OF FACTS DEVICES AND RELATED CONTROL PARAMETERS

FACTS devices are basically categorized into four types based on their connection; series, shunt, combined series-shunt and series-series type. Series controllers comprise of capacitors or reactors which introduce voltage in series with the line. They are basically variable impedance devices and their significant assignment is to reduce the inductivity of the transmission line. They supply or consume variable reactive power. Shunt controllers comprise of variable impedance devices like capacitors or reactors which introduce current into the system at the point of interconnection and their major undertaking is to reduce the capacitivity of the transmission line. The injected current is in phase with the line voltage. Combined series-shunt controllers introduce current in series using the series component and voltage in shunt using the shunt component. Combined series-series controllers consist of a combination of series controllers with each controller providing series compensation and also transfers real power along the line.

Thyristor controlled Series Compensator (TCSC) comes under the first category, which is connected in series with the branches. The second category devices like Static VAR Compensator (SVC) and STAtic synchronous COMpensator (STATCOM) are connected in shunt with the buses. The third category includes devices like Unified Power Flow Controller (UPFC) which have both series-connected and shunt-connected components, which are called as combined series-shunt devices. Inter Line Power Controller (IPFC) comes under the fourth category of FACTS devices.

The type of FACTS device to be installed is determined based on the requirement. The point of integration of the FACTS device to the system depends upon the type of device. It is desirable to install series controllers to maximize the system loadability, shunt controllers for voltage support and combined series–shunt controllers to satisfy both the objectives [2]. Proper selection and installation of FACTS devices is necessary to enhance system security under normal and network contingencies [3].

1.2 BREIF SURVEY OF LITERATURE

Many researchers had carried out their work on the optimal location of FACTS devices to achieve different objectives using various techniques [4], as effectiveness of the FACTS devices mainly depends on their location and rating. Optimal placement of FACTS devices is essential to tap the maximum benefits in terms of system performance and cost effectiveness [5].

The most common objectives considered in literature for the installation of FACTS devices are voltage stability enhancement [6][7], voltage collapse avoidance [5], loadability enhancement [8][9], voltage sag mitigation [10], transmission loss reduction [11][12], voltage profile improvement [13], generation fuel cost reduction [14], efficient damping of power swings [15], relieving congestion [16][17], Available Transfer Capability (ATC) improvement [18] [19] and dynamic stability enhancement [20].

Bekri and Fellah [6], carried out voltage stability assessment in an IEEE 6-bus test system with the placement of SVC and TCSC. Phadke et al.[7], recommended a strategy using Fuzzy logic and Real coded Genetic Algorithm (RGA) for placement and sizing of shunt FACTS controller. Aghaei et al.[5], resolved the optimal location of TCSC and SVC with upgraded security margin against voltage collapse. Nagalakshmi and Kamaraj [8] , achieved the enhancement in system loadability by the optimal location and control of TCSC in transmission system using PSO and DE techniques. Alamelu et al. [9], developed an objective of optimal placement of UPFC to minimize generation and UPFC installation cost, so as to maximize loadability limit of the power system using evolutionary algorithms. Goswami et al.[10], examined the impact of equipment sensitivity by the optimal placement of FACTS devices for voltage sag mitigation. The authors had projected the placement of mitigation devices considering maximum number of voltage sags, maximum number of process trips or the maximum financial losses reported.

Ghamgeen et al.[11][12], determined the optimal location and parameter setting of TCSC for minimizing active power losses in the power network using GA and DE techniques, and compared their performances in minimizing the target. Reza et al.[13], defined a multi-criterion objective function to enhance the voltage stability, improve the voltage profile, minimize power loss and total cost for locating and sizing shunt reactive power compensators in a transmission system using Novel Global Harmony Search algorithm (NGHS). Basu [14], exhibited the optimal placement of TCSC and TCPST to minimize the generator fuel cost subject to power balance constraints, active and reactive power generation limits, voltage limits, transmission line limits and FACTS parameters limits, using DE technique.

Mondal et al.[15], determined the location and parameter optimization of SVC and TCSC, to mitigate small signal oscillations in a multi-machine power system using PSO technique. Wibowo et al.[16], resolved the optimal location and capacity of multiple FACTS devices to relieve congestion considering voltage stability in deregulated electricity market using PSO technique. Javaheri and Goldoost [17], solved the problem of locating TCSC for congestion management and enhanced system security in restructured power system using DC power flow sensitivity factors and Harmony Search Algorithm (HSA).

Farahmand et al.[18], investigated the optimal installation of TCSC and SVC to enhance ATC, voltage profile and minimize active power losses using Hybrid Mutation PSO technique. Nireekshana et al.[19], examined the optimal placement of SVC and TCSC to maximize the power transfer during normal and contingencies using RGA algorithm. Vijay Kumar and Srikanth [20], developed a hybrid technique for deciding the optimal location and size of UPFC, so as to improve the dynamic stability.

There are several methods and approaches in the literature, to solve the optimization problem of FACTS. Some Common heuristic search techniques to determine the optimal location of FACTS devices in the power system, reported in literature are Genetic Algorithm (GA), Simulated Annealing (SA), Tabu search (TA), Immune Algorithm (IA), Particle Swarm Optimization (PSO), Differential Evolution (DE), Harmony Search Algorithm (HSA), Ant Colony Algorithm (ACO), Cuckoo Search (CS), Artificial Bees Colony (ABC) algorithm, Gravitational Search Algorithm (GSA) and BAT algorithm.

Literature review says that the optimal allocation of FACTS devices has been analyzed based on numerous goals. It is worth noticed that each of the said objective upgrades the power system network operation. Only few papers deal with security enhancement objective and among those, limited papers had focused to achieve the goal of enhancing system loadability and improving voltage profile together. Also the optimal placement study is mostly analysed under normal operating condition of power system. Since power systems are subjected to abnormalities, it becomes essential to predict the worst condition and locations that require supportive devices. So in the paper, a resourceful method is anticipated for the optimization of multi-type FACTS devices under (nl-1) possible single line contingency conditions.

Three types of FACTS devices namely a series compensator - TCSC, a shunt compensator - SVC and combined series shunt compensator - UPFC are considered for the analysis. The impact of installing TCSC, SVC, TCSC-SVC and UPFC in minimizing the formulated objective has been analysed in enhancing security, under nl-1 contingency conditions. Best possible determination and establishment of FACTS devices is vital to improve system security under normal and abnormal state of power systems. To determine the best possible locations and size of the above FACTS devices heuristic techniques are implemented.

2. PROBLEM FORMULATION

The target of this paper is to analyze the effect of optimal placement of various FACTS devices using heuristic search techniques, so as to enhance the security of the power system by eliminating or minimizing overloaded lines and bus voltage limit violations under single line contingency conditions. To incorporate these objectives, an equation is formulated by including the terms; Line Loadings, Load Voltage Deviations and Cost of the device. The minimization of the proposed objective function is expected to lead to a cost effective security oriented device placement.

The objective function is formulated as

$$\text{Min F} = W_1\left[C_{FACTS} * S\right] + W_2\left[\sum_{m=1}^{nb}\left(\frac{V_{mref} - V_m}{V_{mref}}\right)^n\right] + W_3\left[\sum_{l=1}^{nl}\left(\frac{S_l}{S_{l\max}}\right)^n\right]$$

(1)

Whereas W_1, W_2 & W_3 are designated weight factors that decides the contribution of each term in achieving the framed objective. $W_1 = 0.2$, $W_2 = 0.4$ & $W_3 = 0.4$ are the considered values in the proposed method of optimal placement. Here the objective of minimizing load voltage deviations and line loading are given preference when compared to cost of the device, because the main objective of the work focuses on the security enhancement of the power system. The exponent n is considered as 4 in order to give more importance to high level of voltage variations and overloads.

where,

F	Objective function
C_{FACTS}	Cost of FACTS device in US $/ Kvar
S	Operating range of device
V_m	Voltage magnitude at bus m
V_{mref}	Reference voltage at bus m
nb	Number of buses
m	Load buses, where V_m is less than or greater than V_{mref}
S_l	Line l apparent power
$S_{l\max}$	Line l apparent power rating
nl	Number of lines

$W_1, W_2 \& W_3$ Weight factors

The first term of the objective function considered is the cost function. The cost function for installation of FACTS devices is taken from the Siemens data base. The second term of the objective function represents the load voltage deviations so as to prevent the under or over voltages at network buses. In order to remove the overloads and to distribute the power flows uniformly line loading is considered as the third term in the objective function. Operating range S of the FACTS device is defined by the equation (2).

$$S = |Q_2| - |Q_1| \tag{2}$$

Where Q_2 is the reactive power flow in line after installing FACTS device in MVAR and Q_1 the reactive power flow in line before installing FACTS device in MVAR.

TCSC is modeled as a variable reactance with the maximum value of the capacitance fixed at -0.8 and the inductance at 0.2. Hence the working range of TCSC is considered as in equation (3).

$$-0.8X_l \le X_{TCSC} \le 0.2X_l \tag{3}$$

SVC is modeled as an ideal reactive power injection at bus i with the reactive power limited as in equation (4)

$$-100MVAR \le Q_{SVC} \le 100MVAR \tag{4}$$

UPFC is modeled as two coordinated synchronous voltage sources, a series voltage source with magnitude V_{CR} & angle θ_{CR} and a shunt voltage source with magnitude V_{VR} & angle θ_{VR} given by equations (5) - (8)

$$V_{CR} : V_{CR\min} \le V_{CR} \le V_{CR\max} \tag{5}$$

$$\theta_{CR} : 0 \le \theta_{CR} \le 2\pi \tag{6}$$

$$V_{VR} : V_{VR\min} \le V_{VR} \le V_{VR\max} \tag{7}$$

$$\theta_{VR} : 0 \le \theta_{VR} \le 2\pi \tag{8}$$

3. OPTIMIZATION TECHNIQUES

The literature survey depicts that various heuristic search techniques are employed effectively in the problem of optimization. In the proposed work, PSO technique is chosen to compare the results of recently introduced BBO and LOA techniques. Over the last decade, it is observed that PSO algorithms have been successfully deployed in power system optimizations studies [21], so to validate the application of the recently introduced BBO and LOA techniques in the optimization of the proposed objective, the results are compared with the results of PSO and WIPSO techniques.

Biogeography based optimization (BBO) is a new type of heuristic search algorithm based on the species behaviour developed by Dan Simon [22]. BBO is a population based algorithm, which uses the immigration and emigration behaviour of the species based on various natural factors [23]. Application of BBO to solve the economic dispatch problem is described in [24] where it has been proved that BBO gives a solution which is comparable with evolutionary programming and differential evolution techniques. Lion Optimization Algorithm (LOA) is a recently introduced optimization technique based on simulation of the solitary and cooperative behaviours of lions such as prey capturing, mating, territorial marking, defense and the other behaviours [25]. To exhibit the validity of the proposed techniques, simulations are carried out on IEEE-14 bus and IEEE-30 bus systems.

To exhibit the validity of the proposed techniques, simulations are carried out on IEEE-14 bus and IEEE-30 bus systems. The acquired results indicate that LOA gives better performance when contrasted with BBO, WIPSO and PSO techniques. The obtained results analysis reveals the impact of TCSC, SVC, TCSC-SVC and UPFC in minimizing the formulated objective and consequently upgrading system security.

4. CASE STUDY

The work considers the placement of three types of devices namely

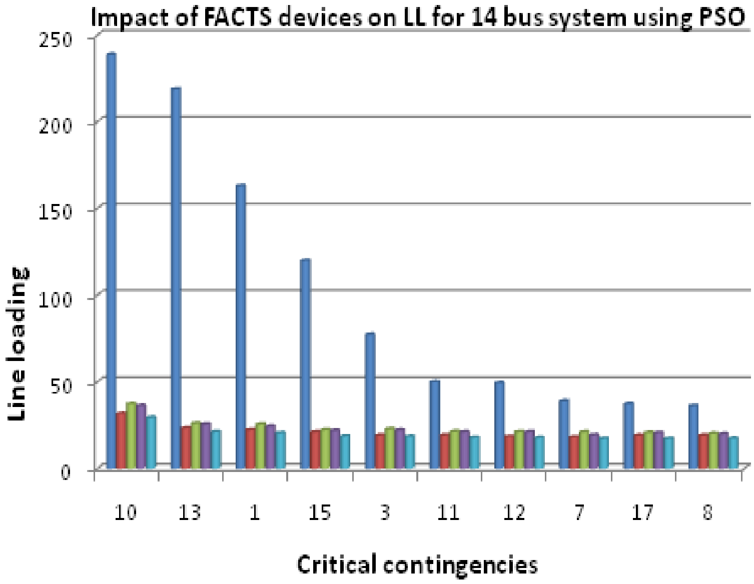
1. Series compensator–TCSC
2. Shunt compensator –SVC
3. Combined series shunt compensator –The work tries to implement combined series–shunt compensator with 2 configurations.
   (i) With combined TCSC & SVC installation, without considering series and shunt coordination in their placement.
   (ii) With UPFC installation, considering series and shunt coordination in the device placement.

The study has been carried out to give idea about the impact of device placement based on their type and to help the transmission line planners to choose the optimal device for required objective.

4.1 EFFECT OF FACTS DEVICES ON LINE LOADING UNDER SINGLE LINE CONTINGENCIES

The effect of the installation of TCSC, SVC, combined TCSC-SVC & UPFC in minimizing line loading using PSO, WIPSO, BBO and LOA techniques under varying system load and single line contingencies is studied.

Figure 1 to 4 demonstrate the impact of placement of FACTS devices in minimizing the line loading on IEEE-14 and IEEE-30 bus systems for single line contingencies using PSO, WIPSO, BBO & LOA techniques.



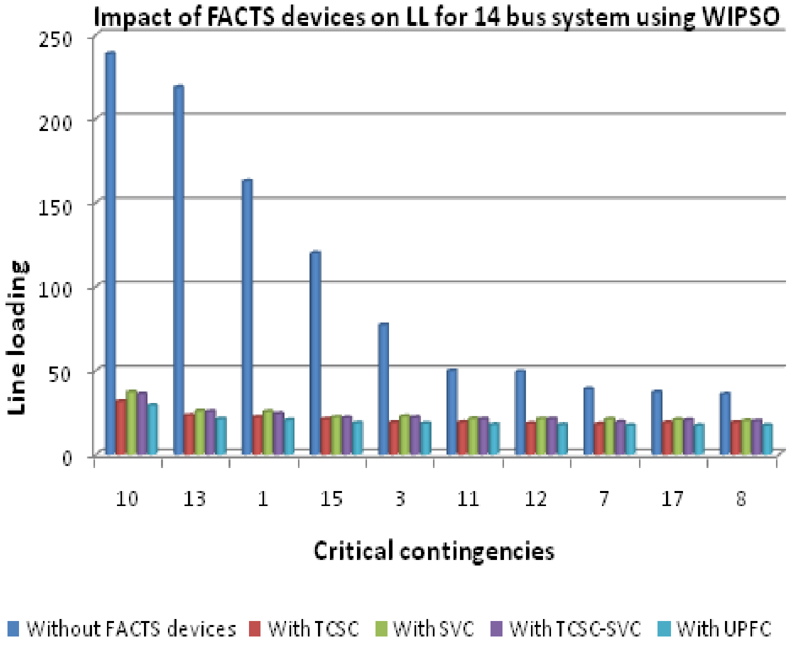
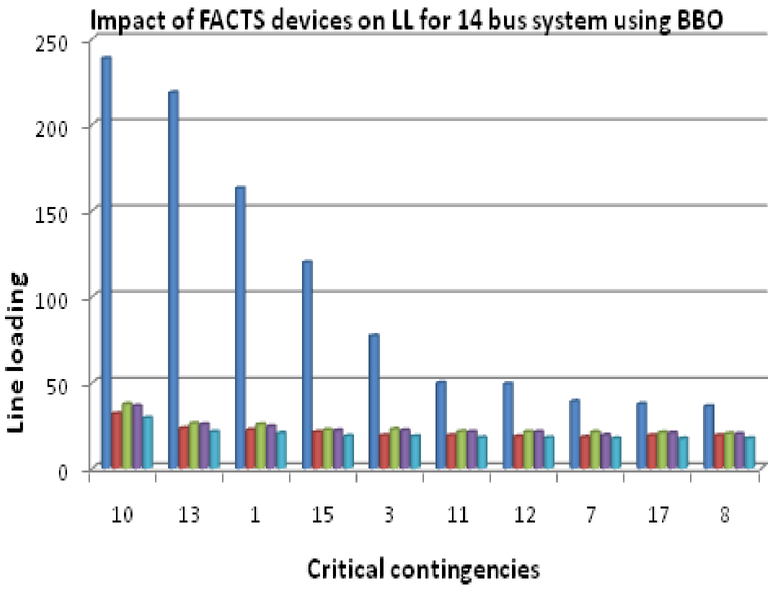


Fig.1 Effect of FACTS devices on LL under single line contingency for 14 bus system using PSO-WIPSO techniques



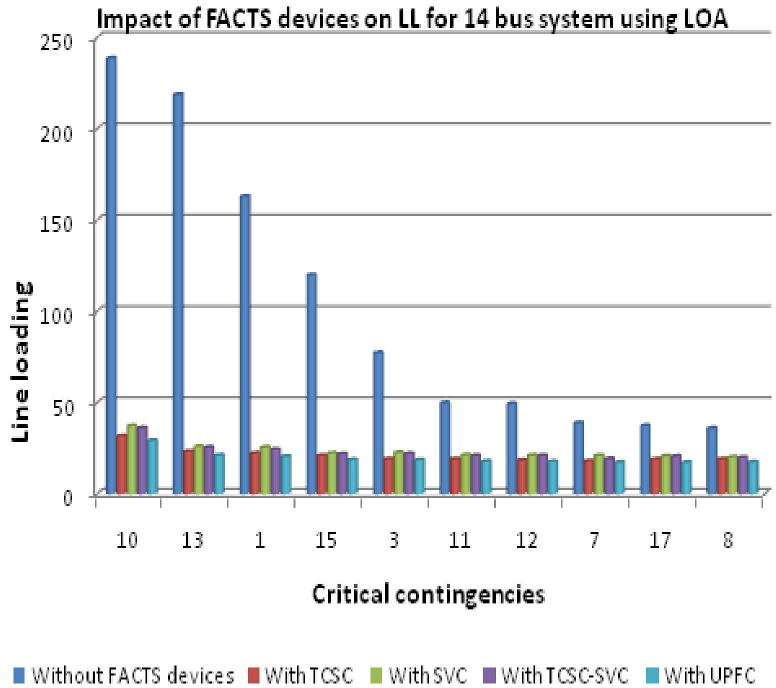


Fig.2 Effect of FACTS devices on LL under single line contingency for 14 bus system using BBO-LOA techniques

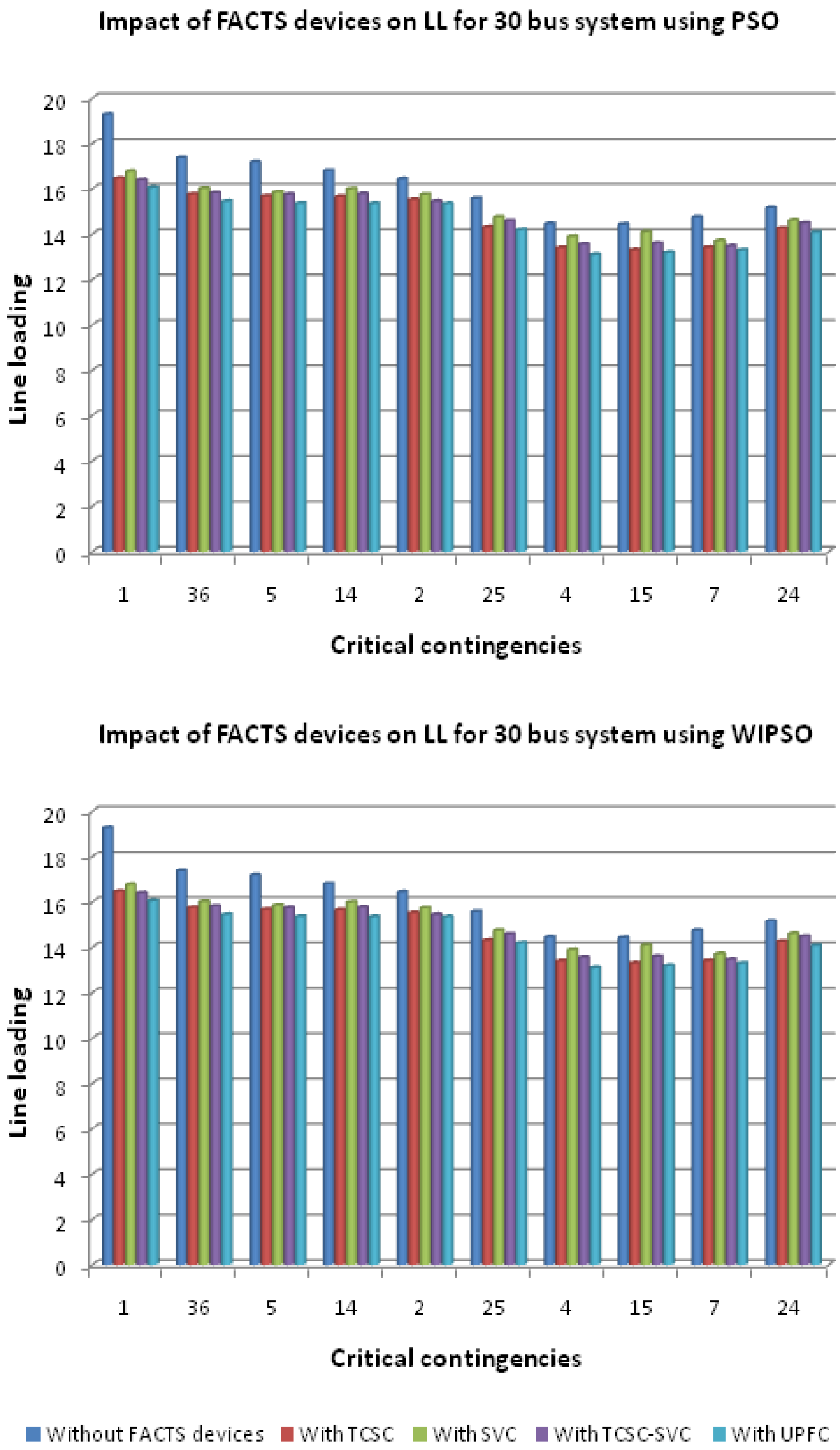


Fig.3 Effect of FACTS devices on LL under single line contingency for 30 bus system using PSO-WIPSO techniques

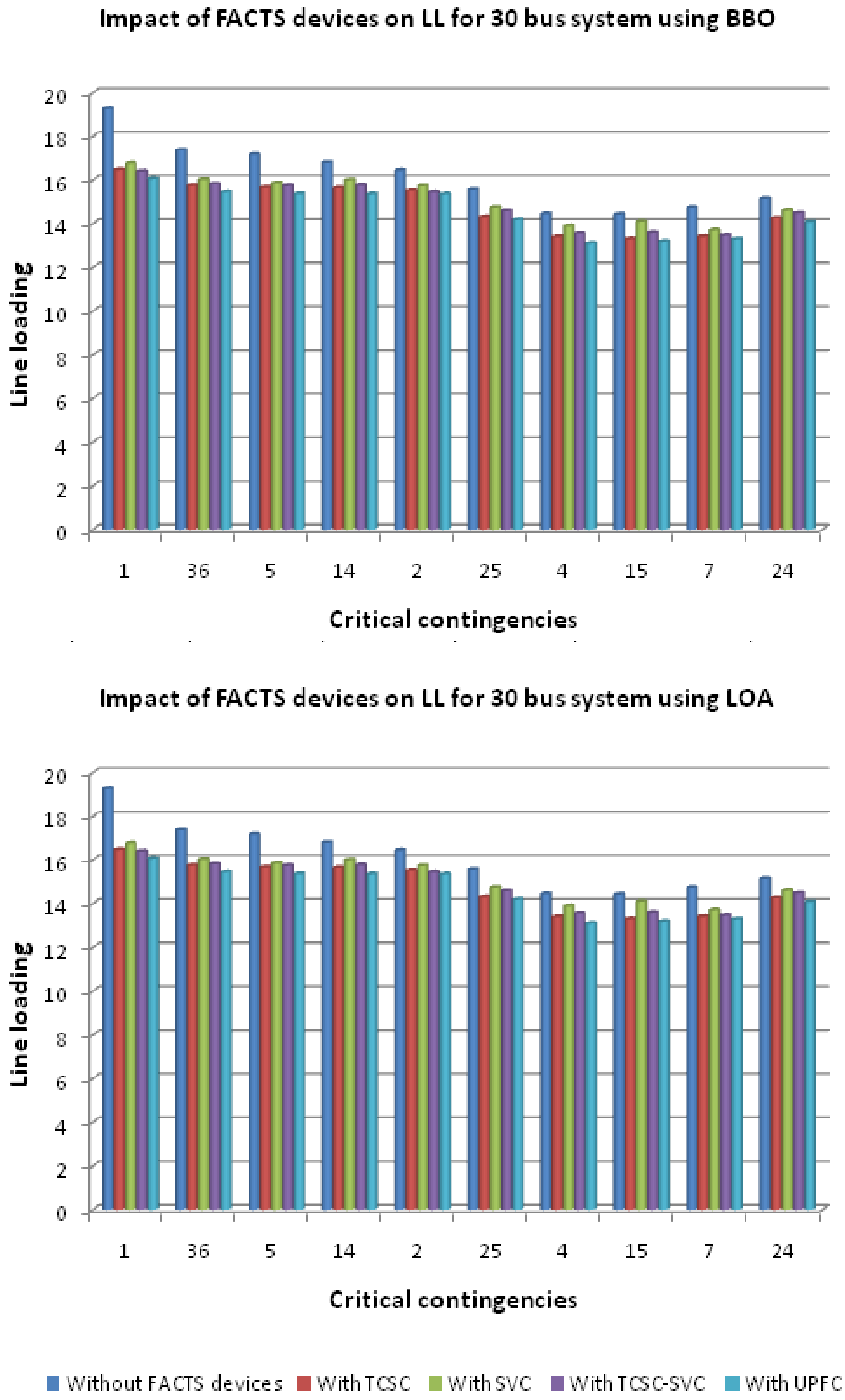


Fig.4 Effect of FACTS devices on LL under single line contingency for 30 bus system using BBO-LOA techniques

Figures 1 – 4 clearly depict the minimization of line loading with the optimal placement of various FACTS devices, when compared with line loading without FACTS devices. This shows that the system security is enhanced after the placement of FACTS devices. Optimal placement of UPFC minimizes the overall line loading and gives excellent security enhancement when compared with other FACTS devices. Likewise the optimal placement of TCSC gives relatively good performance comparable with UPFC in minimizing line loading.

4.2 EFFECT OF FACTS DEVICES ON LOAD VOLTAGE DEVIATION UNDER SINGLE LINE CONTINGENCIES

Figures 5 – 8, exhibit the effect of placement of FACTS devices in minimizing the load voltage deviation on IEEE-14 and IEEE-30 bus systems for single line contingencies using PSO, WIPSO, BBO & LOA techniques.

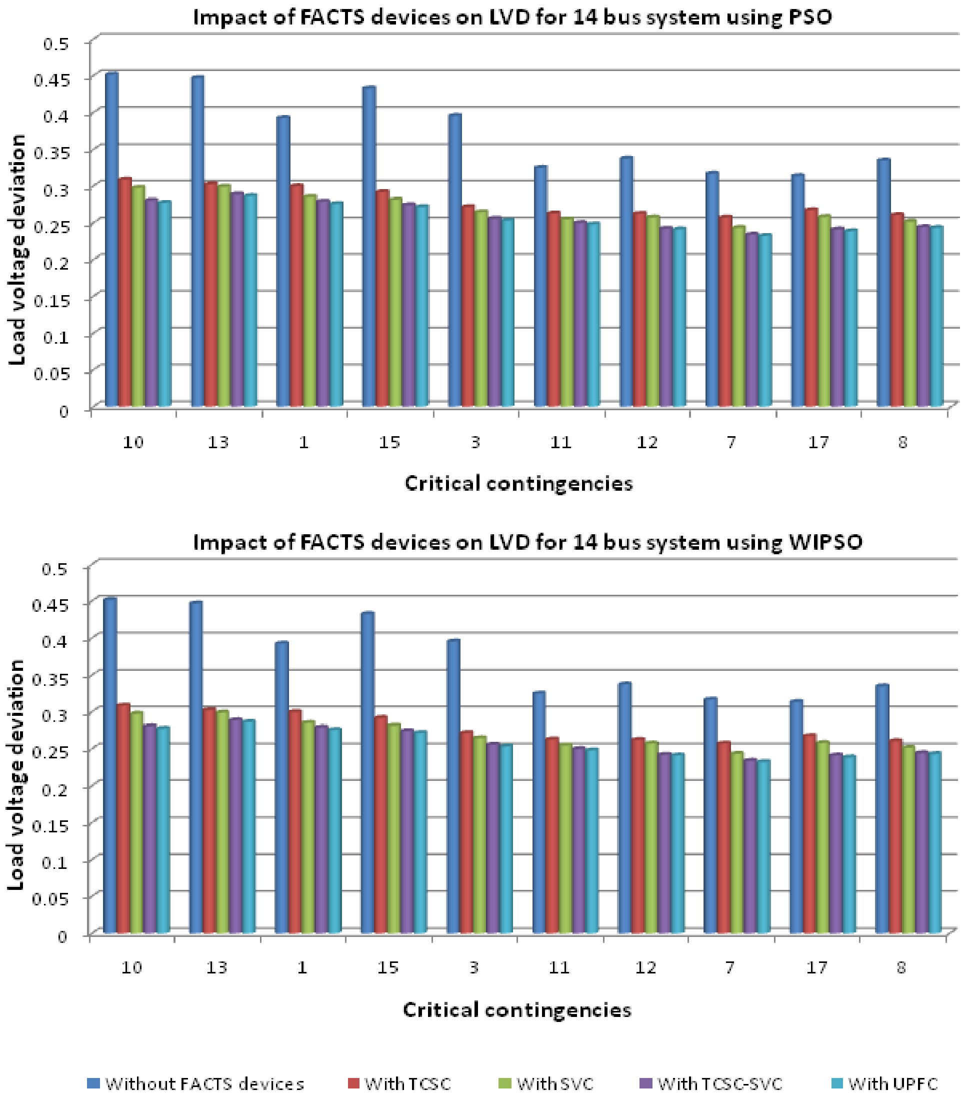


Fig.5 Effect of FACTS devices on LVD under single line contingency for 14 bus system using PSO-WIPSO techniques

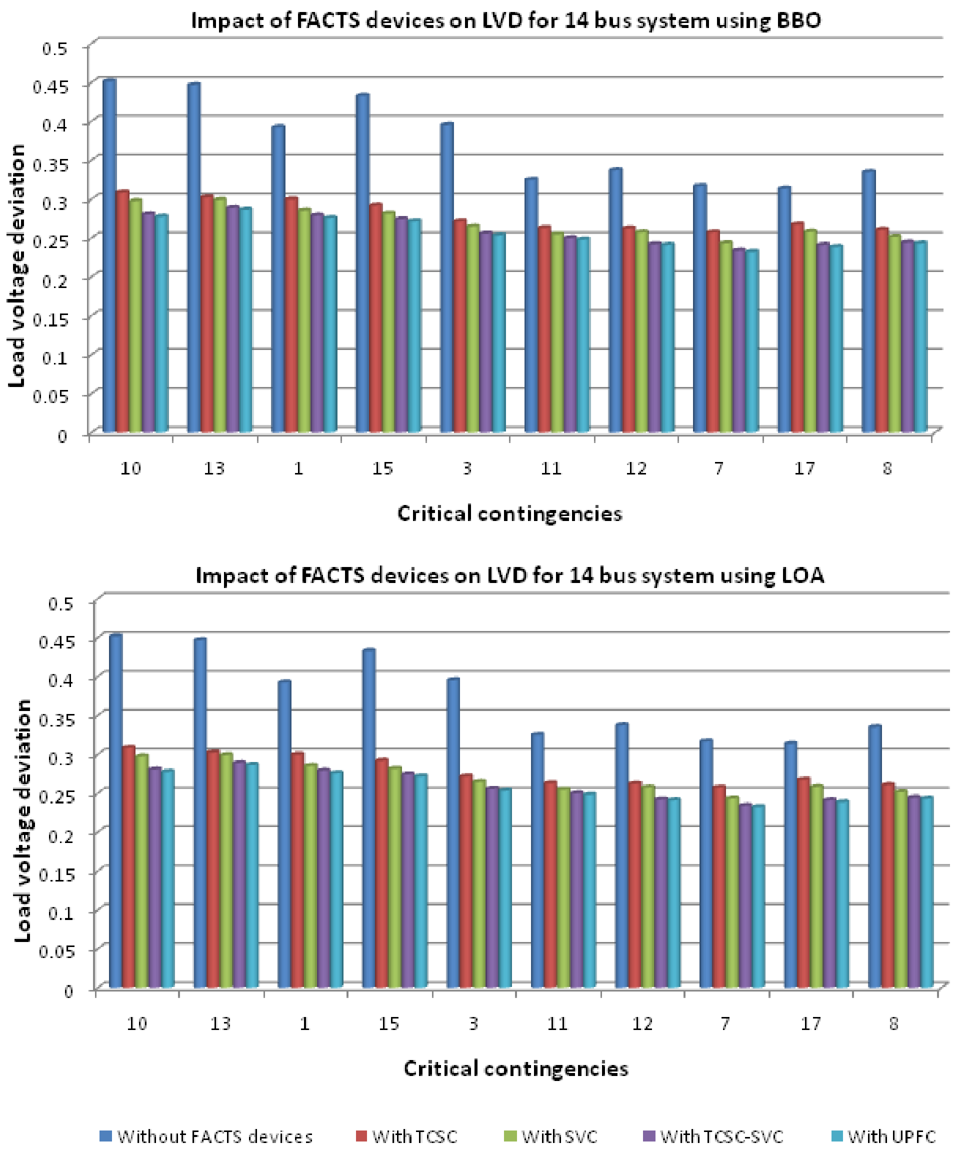
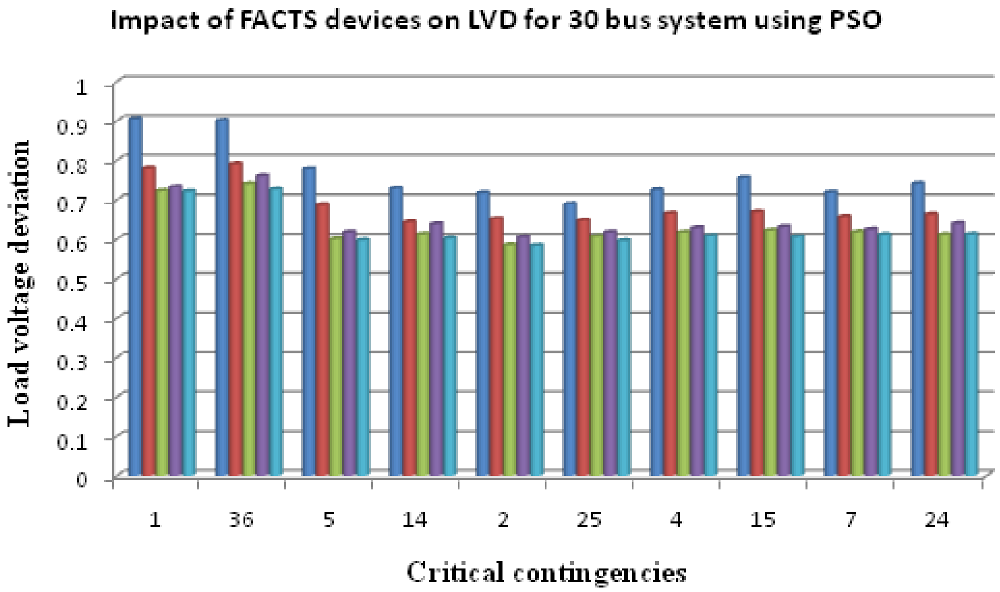


Fig.6 Effect of FACTS devices on LVD under single line contingency for 14 bus system using BBO-LOA techniques



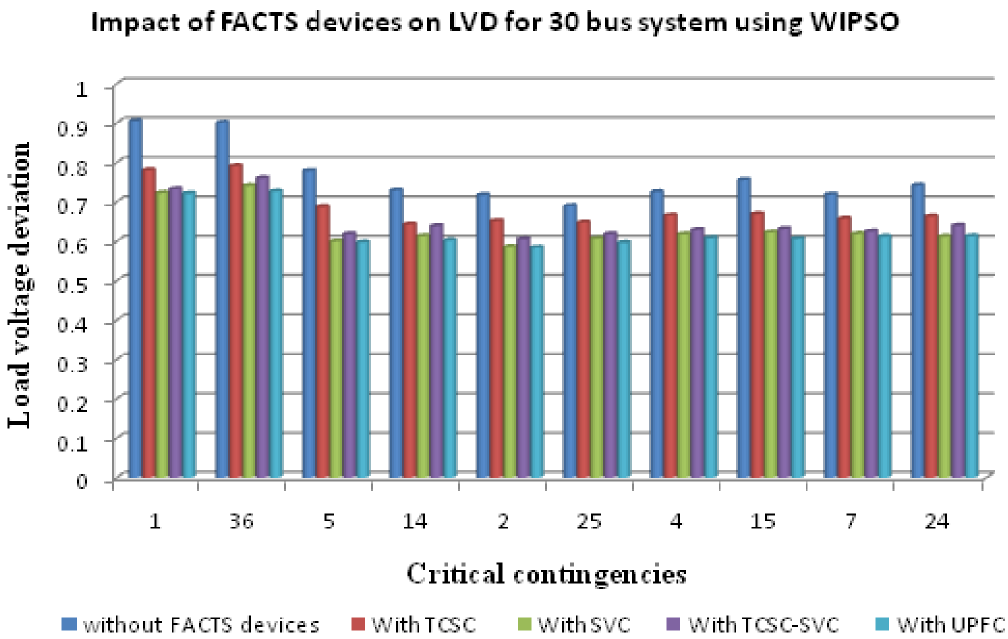


Fig.7 Effect of FACTS devices on LVD under single line contingency for 30 bus system using PSO-WIPSO techniques

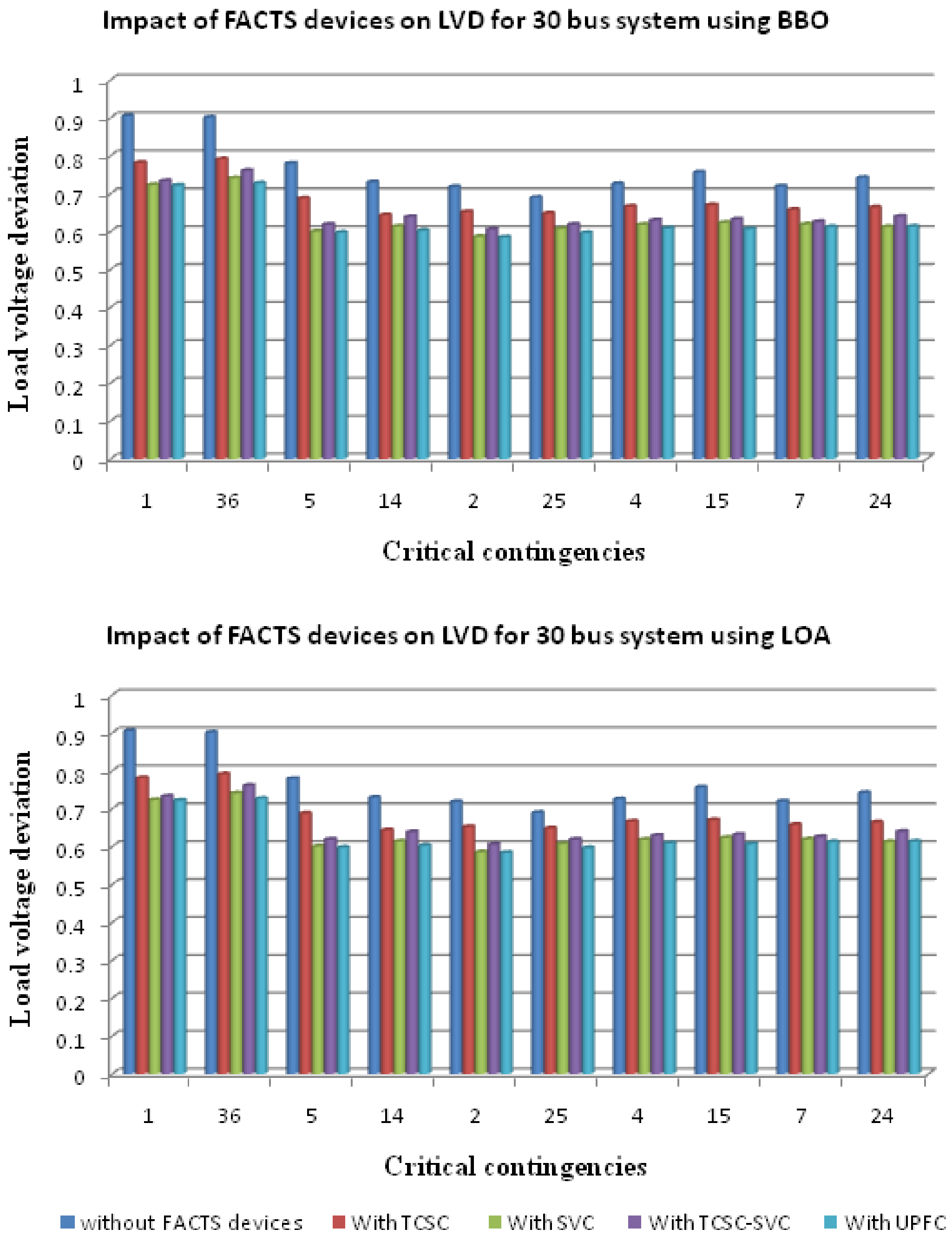


Fig.8 Effect of FACTS devices on LVD under single line contingency for 30 bus system using BBO-LOA techniques

Figures 5 – 8, demonstrates the effect of placement of FACTS devices in load voltage deviation using PSO, WIPSO, BBO & LOA strategies. The bar chart representation reveals that load voltage profile improves significantly with the optimal placement of various FACTS devices. This shows the enhancement of system security under the abnormal loading conditions after the placement of FACTS devices. Even though all FACTS devices improve profile voltage, the performance of UPFC is highly efficient in minimizing the load voltage deviation. Further analysis shows next to UPFC, SVC also plays its role in improving the voltage profile.

5. CONCLUSION

This paper investigates and proposes new solution techniques for the optimal placement of FACTS devices, for the enhancement of system security under single line contingencies. The effectiveness of the optimal installation of TCSC, SVC, combined TCSC-SVC and UPFC in upgrading the security of power systems, in terms of minimizing the line loading and load voltage deviations are examined. The developed algorithms for the optimal placement of various FACTS devices is validated by conducting case studies on standard IEEE test systems. The pictorial representation of bar charts clearly depicts the variation of system performance in terms of line loading and load voltage deviation, before and after placement of FACTS devices. Also it reveals the effect of system enhancement after the incorporation of TCSC, SVC, combined TCSC-SVC & UPFC under single line contingency conditions. The bar charts plotted demonstrate that the UPFC establishment viably upgrades the system security by minimizing both the line loading and load voltage deviation. Additionally it is visualized that TCSC efficiently minimizes line loading, SVC efficiently improves voltage profile and the combined placement of TCSC-SVC shows reasonably good improvement in minimizing both line loading and load voltage deviations which is comparable with UPFC.

The study shows after the optimal FACTS device placement, both the load bus voltage deviations and line loadings are minimized hence enhancing the system security. Further analysis reveals that LOA technique shows best performance contrasted with PSO, WIPSO and BBO strategies. Henceforth the proposed technique based on LOA optimization, yields an efficient solution which considerably reduces load voltage deviations and relieves the lines off their over loads under various loading conditions and under critical contingency conditions.

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