

# Application of Soft Computing Technique to Avoid Voltage Collapse in Power System

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**Abstract**—In the present heavy load scenario, due to the presence of many small scale and large scale industries, the operation of power system network to maintain stable power supply becomes complicated. It will lead to have major problems such as voltage instability and voltage collapse in the power system. To overcome these difficulties, Flexible AC Transmission System (FACTS) have been proposed and implemented in power system. By placing these devices in suitable location will give effective results. In this paper, the optimal location and the ratings of FACTS devices are determined using evolutionary algorithm. The main objective function is to find the optimal location and ratings of FACTS devices to minimize the losses in the power system and also to minimize the cost of the generators and to enhance the voltage stability. FACTS devices such as Thyristor Controlled Series Capacitor (TCSC) and Static VAR Compensator (SVC) are considered in this paper. Evolutionary algorithm such as Genetic Algorithm (GA) is a population based search method used for solving multi objective optimization problems that are capable of searching for multiple solutions concurrently in a single run and provide an optimal solution. Genetic Algorithm is used to find the optimal location and rating values of Static VAR Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC) to reduce the cost of generators, to enhance the voltage stability and also to reduce the power losses in the power system. It is observed from the results that the voltages stability margin is improved, voltage profile of the power system is increased and real power losses also reduced by optimally locating the devices in the power system. IEEE 14 bus and IEEE 30 bus systems are used to demonstrate the effectiveness of the proposed algorithm.

**Keyword**-Voltage stability, Voltage collapse, SVC, TCSC, GA

## I. INTRODUCTION

Power system networks are widely interconnected and operated under heavily stressed conditions due to increase in power demand. In some cases, the generating station is far away from the load centre and it is a critical task to transmit the power over longer distance to huge loads and this will cause more real power losses and voltage instability as in [1-3]. Voltage stability is defined as the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial operating condition. In recent years, voltage instability has been responsible for several major network collapses. Several incidences of voltage collapse have been reported, in different parts of the country as in [4]. Recent developments in power electronics introduced several control devices such as FACTS (Flexible AC Transmission System). Insertion of FACTS devices in transmission line will provide many advantages. The phase angle, the voltage magnitude and line impedances of the transmission line are the three main parameters that can be controlled by FACTS devices in an effective manner as in [5].

Genetic Algorithm was first developed by John Holland, University of Michigan in 1970's. It can able to solve multi objective optimization problems and gives optimal solution by iterations, which maintains a constant size population of candidate solutions. During each iteration, three genetic operators such as selection, crossover, and mutation are performed to generate new population and chromosomes of the new population are evaluated via the value of the fitness. Based on these genetic operators and the evaluations, the better new populations of candidate solution are formed from the old population. If the search goal has not been achieved, again GA creates offspring strings through three operators and the process is continued until the search goal is achieved as in [6].

Soft computing techniques can be used to solve multi objective optimization problem efficiently and effectively. FACTS devices can be located optimally by soft computing techniques such as Genetic Algorithm (GA) as in [7]. The location and the parameter settings of SVC and TCSC can be optimized and the system performance can be enhanced as in [8-10]. This paper investigates the detailed application of GA to find the optimal location and ratings of TCSC and SVC to enhance the voltage stability and reduce the power losses and the power generation cost.

## II. PROBLEM FORMULATION

In this paper, the problem is formulated which includes the minimization of voltage stability index, generation cost and real power loss. A multi-objective optimization problem consists of multiple objectives to be optimized simultaneously with the various equality and inequality constraints. Better results can be obtained by minimizing the objective function and satisfying all the constraints as in [11].

### A. Voltage stability index

Voltage stability is an important problem to electric power system. An indicator L-index is used to evaluate voltage stability at each bus of the system as in [12]. L index at load bus j can be expressed as given in equation (1).

$$L_j = |L_j| = \left| 1 - \frac{\sum_{i \in \alpha_G} C_{ij} V_i}{V_j} \right| \quad j \in \alpha_L \quad (1)$$

where

$\alpha_L$  = set of load buses

$\alpha_G$  = set of generator buses

$V_j$  = complex voltage at load bus j

$V_i$  = complex voltage at generator bus i

$C_{ji}$  = Elements of matrix C which can be determined using equation (2)

$$[C] = -[Y_{LL}]^{-1}[Y_{LG}] \quad (2)$$

Matrices  $[Y_{LL}]$  and  $[Y_{LG}]$  can be found using equation (3).

$$\begin{bmatrix} I_L \\ I_G \end{bmatrix} = \begin{bmatrix} Y_{LL} & Y_{LG} \\ Y_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} V_L \\ V_G \end{bmatrix} \quad (3)$$

The objective function considering minimization of voltage stability index can be represented as given in equation (4).

$$F_1 = L_{\max} = \max(L_j) \quad j \in \alpha_L \quad (4)$$

### B. Fuel Cost of generators

The objective function considering minimization of generation cost as in [13] can be represented as given in equation (5).

$$F_2 = F(P_G) = \sum_{i=1}^n a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad (5)$$

where

n is the number of generators

$P_{Gi}$  is generated power of  $i^{\text{th}}$  generator

$a_i$  is Cost coefficient of  $i^{\text{th}}$  generator (\$/MWh<sup>2</sup>)

$b_i$  is Cost coefficient of  $i^{\text{th}}$  generator (\$/MWh)

$c_i$  is Cost coefficient of  $i^{\text{th}}$  generator

### C. Power loss

The objective function considering minimization of real power loss as in [14] can be represented as given in equation (6).

$$F_3 = P_{\text{loss}} = \sum_{i=1}^{N_L} g_{i,j} (V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)) \quad (6)$$

where

$V_i$  is the voltage magnitude at bus

$g_{i,j}$  is the conductance of line i-j

$\delta_i$  is the voltage angle at bus i

$N_L$  is the total number of transmission lines

### D. Fitness function

Considering all the objective functions, the fitness function is expressed as given in equation (7).

$$F = h_1 F_1 + h_2 F_2 + h_3 F_3 \quad (7)$$

where  $h_1$ ,  $h_2$  and  $h_3$  are weighting factor of voltage stability index objective function, weighting factor of fuel cost objective function, weighting factor of power loss objective function respectively as in [15].

$$h_1 + h_2 + h_3 = 1 \quad (8)$$

The coefficients  $h_1$ ,  $h_2$  and  $h_3$  are optimized by trial and error method to 0.35, 0.3 and 0.35 by satisfying equation (8).

### III. FACTS DEVICE

The concept of FACTS controllers was first defined by Hingorani in 1988. FACTS devices have the ability to control the various electrical parameters such as the phase angle, the voltage magnitude at chosen buses and line impedances of transmission system. Introduction of FACTS devices will provide advantages such as power flow control, managing blackouts, enhancing voltage stability, limiting short circuit currents as in [16-17]. FACTS can be classified into four categories namely series, shunt, combined series-series and combined series-shunt controllers. This paper deals with a series controller (TCSC) and a shunt controller (SVC).

#### A. Power flow modelling of SVC

Static Var Compensator (SVC) behaves like a shunt connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. It is extensively to provide fast reactive power and voltage regulation support. The basic model of SVC is shown in Fig.1.

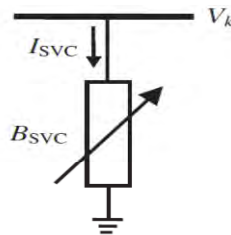


Fig. 1. Basic SVC model

The SVC can be inserted in the bus or at the midpoint of the transmission line. The current drawn by the SVC is given in (9).

$$I_{SVC} = jB_{SVC}V_k \tag{9}$$

The reactive power drawn by the SVC, which is also the reactive power injected at bus k, is given in (10).

$$Q_{SVC} = Q_k = -V_k^2 B_{SVC} \tag{10}$$

where  $B_{SVC}$  is the susceptance of SVC and  $V_k$  is the voltage at bus k.

The range of reactive power generation of SVC is limited between -25 MVAR and +25 MVAR.

#### B. Power flow modelling of TCSC

Thyristor-controlled series compensators (TCSC) is a series connected FACTS device. It reduces the power flow in heavily loaded line by controlling the power flow in the network. It is able to minimize the power loss of the systems. The basic model of TCSC is shown in Fig.2.

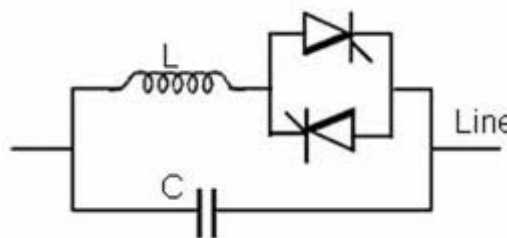


Fig. 2. Basic model of TCSC

In this FACTS device, a capacitor is inserted in series with the transmission line to be compensated and a Thyristor Controlled Reactor (TCR) is connected in parallel with the capacitor. Net reactance of the transmission line can be found by (12) and the rated value of TCSC can be found by (13).

$$X_{ij} = X_{Line} + X_{TCSC} \tag{12}$$

$$X_{TCSC} = X_C - \frac{X_C^2}{(X_C - X_L)} \frac{2\beta + \sin 2\beta}{\pi} + \frac{4X_C^2}{(X_C - X_L)} \frac{\cos^2 \beta (k \tan \beta - \tan \beta)}{(k^2 - 1)\pi} \tag{13}$$

where

$X_{Line}$  is the reactance of the transmission line i-j.

$X_C$  is the nominal reactance of the fixed capacitor

$X_L$  is the nominal reactance of the TCR

$\beta$  is the angle of advance which is equal to  $\pi-\alpha$ ;  $k = \sqrt{\frac{X_C}{X_L}}$

The range of TCSC reactance is limited between  $-50\% X_L$  and  $+50\% X_L$ .

#### IV. GENETIC ALGORITHM

In the artificial intelligence, GA is a search heuristic that mimics the process of natural selection which was developed by John Holland in 1970, university of Michigan. This method is an iterative procedure used to generate optimal solutions for multi objective problem based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions.

At each step of iteration, the genetic algorithm selects individuals at random from the current population to be parents and uses them produce the children for the next generation. Over successive generations, the population gives an optimal solution. The GA can be used to solve a variety of optimization problems including problems in which the objective function is discontinuous, non differentiable, stochastic, or highly nonlinear. Main components of GA are initialization, selection, crossover, mutation and termination as in [18-19].

##### A. Steps in GA

The steps that are to be followed for the placement of SVC and TCSC in GA are:

Step 1: Create an initial population

Step 2: Run power flow program.

Step 3: Evaluate fitness value of all the individuals.

Step 4: Select a new population from the old population based on the fitness of the individuals as given by the evaluation function.

Step5: Apply genetic operators (crossover and mutation) to members of the population to create new solutions.

Step6: Evaluate the fitness value of new chromosomes and insert them into the population.

Step7: If time is up, stop and return the best individual if not, go to step 4.

#### V. RESULTS AND DISCUSSION

The proposed algorithm was tested on IEEE 14 bus and IEEE 30 bus systems as in [20-21] and the results were obtained. In which the optimal location and ratings of SVC and TCSC were found and the objectives such as fuel cost of generation, voltage stability index and power losses were minimized using GA technique. The parameters used for this technique is shown in Table I. This proves that the GA is more efficient than the conventional method.

TABLE I  
GA Parameters

Population	20
Crossover fraction	0.8
Selection function	Stochastic uniform
Elite count	2
Crossover function	Scattered

##### A. IEEE 14 bus system

It contains 20 transmission lines. The test system consists of 5 generator buses (bus no.1, 2, 3, 6 and 8), 9 load buses (bus no. 4, 5, 7, 9, 10, 11, 12, 13 and 14) and 20 transmission lines. The total system demand is 259 MW. Optimal location and rating of SVC and TCSC have been found for IEEE 14 bus using GA technique and it is shown in Table II. GA convergence characteristics of IEEE 14 bus system for SVC and for TCSC are shown in Fig.3-4.

TABLE II  
Optimal Location and Rating of SVC and TCSC for IEEE 14 bus using GA

SVC		TCSC	
Location	Rating	Location	Rating
Bus 4	0.1894	Line 9-14	23% of line reactance

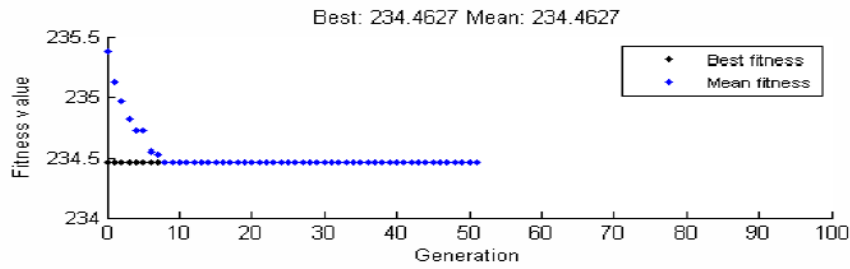


Fig. 3. GA convergence characteristics of IEEE 14 bus system for SVC

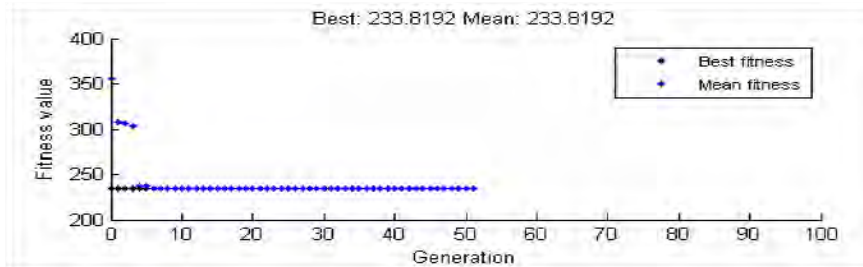


Fig. 4. GA convergence characteristics of IEEE 14 bus system for TCSC

Bus 4 is identified as optimal location of SVC using GA and susceptance rating of SVC is 0.1894 p.u. Voltage profile is increased at all the buses and voltage stability index is decreased from 0.0783 to 0.0772, real power loss is reduced by 0.0946 MW and generator cost is reduced by 0.5611 \$/Hour. Line 9-14 is identified as optimal location of TCSC and reactance rating of TCSC is 23% of line reactance. Voltage profile is increased at all the buses and voltage stability index is decreased from 0.0783 to 0.0732, real power loss is reduced by 2.0378 MW and generator cost is reduced by 0.2278 \$/Hour. Real power loss is reduced with TCSC is more than SVC. Voltage profile of IEEE 14 bus system without FACTS device is compared with SVC and TCSC and it is shown in Fig.5.

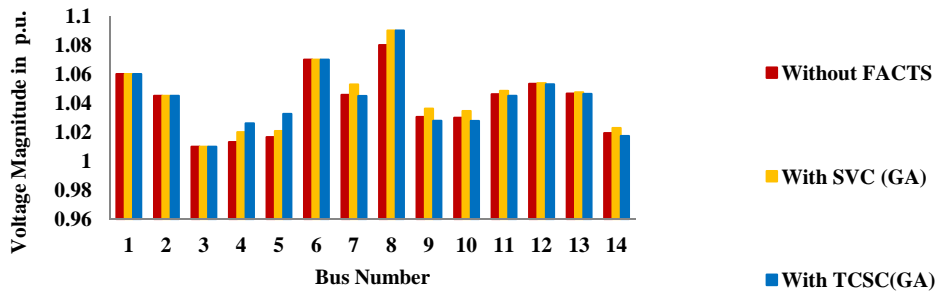


Fig. 5. Voltage profile of IEEE 14 bus system

Similarly voltage stability index, real power loss, generator cost and total objective function of IEEE 14 bus system without FACTS device is compared with SVC and TCSC and it is shown in Fig. 6-9.

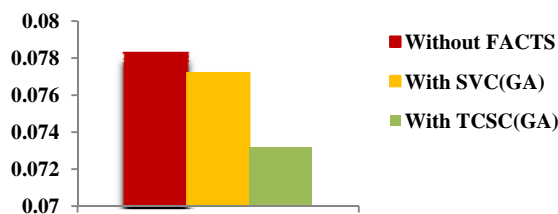


Fig. 6. Comparison of voltage stability index of IEEE 14 bus system

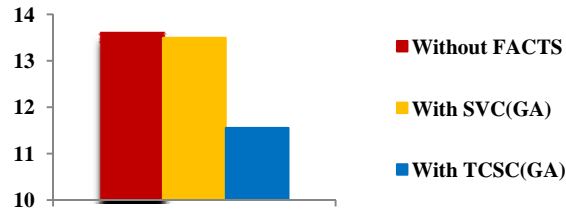


Fig. 7. Comparison of real power loss of IEEE 14 bus system

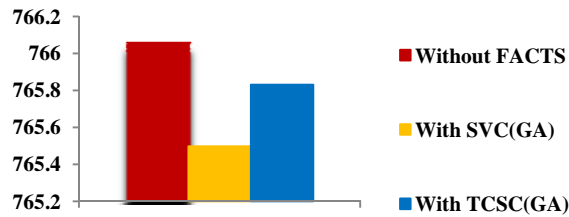


Fig. 8. Comparison of generator cost of IEEE 14 bus system

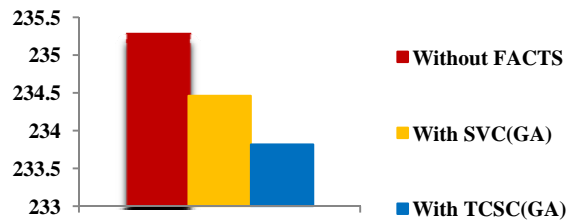


Fig. 9. Comparison of total objective function of IEEE 14 bus system

**B. IEEE 30 bus system**

The test system consists of 6 generator buses (bus no. 1, 2, 5, 8, 11 and 13), 24 load buses (bus no. 3, 4, 6, 7, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30) and 41 transmission lines. The total system demand is 283.4 MW. Optimal location and rating of SVC and TCSC have been found for IEEE 30 bus using GA technique and it is shown in Table III. GA convergence characteristics of IEEE 30 bus system for SVC and for TCSC are shown in Fig.10-11.

TABLE III  
Optimal Location and Rating of SVC and TCSC for IEEE 30 bus using GA

SVC		TCSC	
Location	Rating	Location	Rating
Bus 29	0.0981	Line 28-27	16% of line reactance

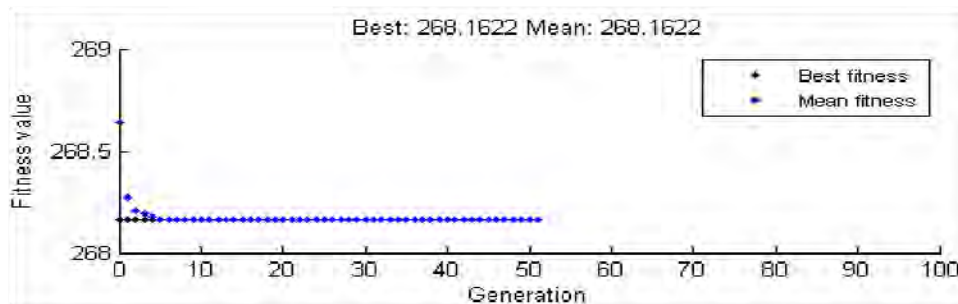


Fig. 10. GA convergence characteristics of IEEE 30 bus system for SVC

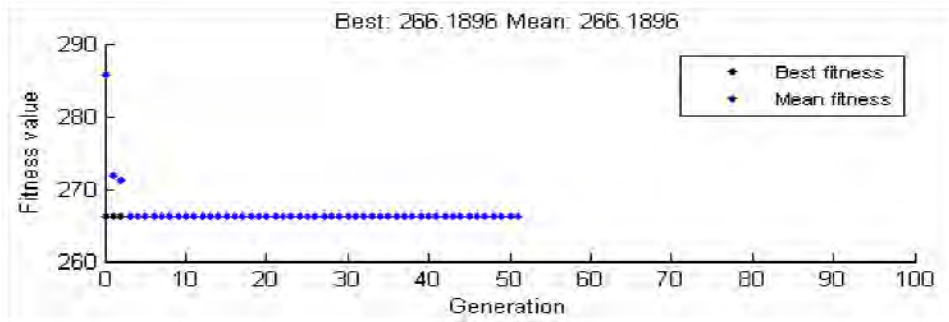


Fig. 11. GA convergence characteristics of IEEE 30 bus system for TCSC

Bus 29 is identified as optimal location of SVC using GA and susceptance rating of SVC is 0.0981 p.u. Voltage profile is increased at all the buses and voltage stability index is decreased from 0.1363 to 0.1342, real power loss is reduced by 0.0218 MW and generator cost is reduced by 0.0864 \$/Hour. Line 28-27 is identified as optimal location of TCSC and reactance rating of TCSC is 16% of line reactance. Voltage profile is increased at all the buses and voltage stability index is decreased from 0.1363 to 0.1275, real power loss is reduced by 5.5865 MW and generator cost is reduced by 0.1727 \$/Hour. Real power loss is reduced with TCSC is more than SVC. Voltage profile of IEEE 30 bus system without FACTS device is compared with SVC and TCSC and it is shown in Fig.12.

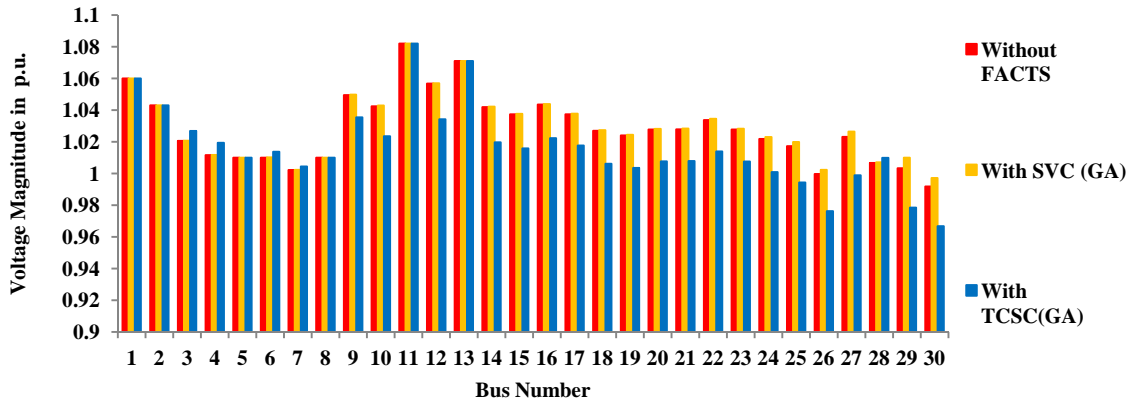


Fig. 12. Voltage profile of IEEE 30 bus system

Similarly voltage stability index, real power loss, generator cost and total objective function of IEEE 30 bus system without FACTS device is compared with SVC and TCSC and it is shown in Fig. 13-16.

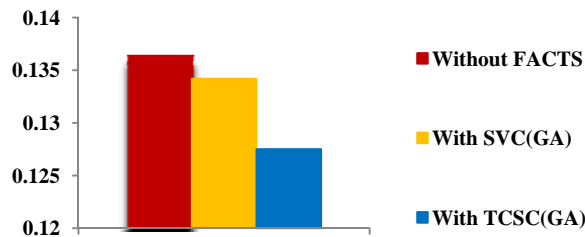


Fig. 13. Comparison of voltage stability index of IEEE 30 bus system

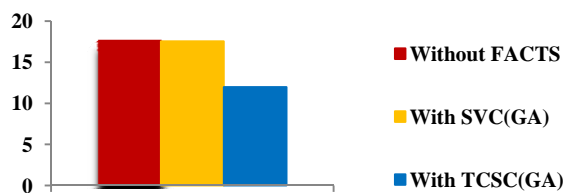


Fig. 14. Comparison of real power loss of IEEE 30 bus system

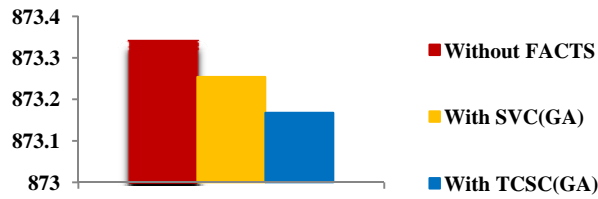


Fig. 15. Comparison of generator cost of IEEE 30 bus system

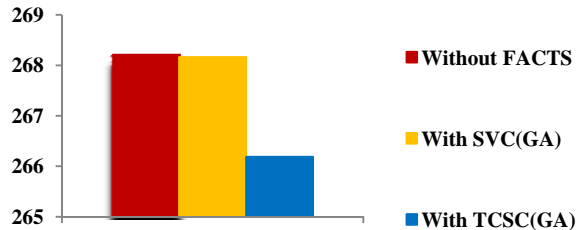


Fig. 16. Comparison of total objective function of IEEE 30 bus system

## VI. CONCLUSION

This paper made an attempt to find the optimal location and size of SVC and TCSC devices to avoid voltage instability and voltage collapse. Multi-objective optimization problem consists of multiple objectives such as minimization of voltage stability index, cost of generating unit and real power loss has been considered and GA is used to give optimization results. Simulations were performed on IEEE 14 bus and IEEE 30 bus systems. It is observed that the voltages stability margin is improved, voltage profile of the power system is increased, real power loss and cost of generating unit are also reduced by optimally locating SVC and TCSC devices in the power system. Results of both power system with SVC and TCSC devices and without FACTS devices are compared. SVC improves voltage profile better than TCSC and TCSC reduces real power loss than SVC. Results of power system with SVC and TCSC devices are better than that of normal system without FACTS devices.

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