

Enhancement of Voltage Stability by SVC and TCSC Using Genetic Algorithm

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ABSTRACT— In the recent days, power demand is more than the generation due to huge loads. Hence it is difficult to operate the power system in order to maintain stable power supply. It will lead to major problems like voltage instability and power losses. To overcome these problems, Flexible AC Transmission System (FACTS) have been implemented in power system. Effective results can be obtained by placing these devices in suitable location. In this paper, the location and the ratings of FACTS devices are optimized using Genetic Algorithm (GA). The main objective is to optimize the location and ratings of FACTS devices by considering the three objectives such as the minimization of Voltage Stability Index (VSI), minimization of power losses and minimization of generation cost. Thyristor controlled series capacitor (TCSC) and Static VAR Compensator (SVC) are considered for this project. Genetic Algorithm (GA) is an iterative method used to provide an optimal solution by solving multi objective optimization problems. The locations and ratings of SVC and TCSC are optimized in IEEE 14 bus and IEEE 30 bus systems using GA. Simulations are done by using MATLAB software. It is clear from the results that the voltage stability is enhanced well and also there is a reduction in power loss by GA when compared with the conventional method.

KEYWORDS— voltage stability index; SVC; TCSC; GA.

Due to increase in power demand, many power systems

are generated and are widely interconnected. As the power transfer grow, it is more complex to maintain voltage at all buses in the power system. Due to some of the reasons like the generating station is locating far away from the load centre, inability to meet the reactive power demand, sudden system condition will lead to voltage instability and losses. Introduction of FACTS devices in suitable location will provide power flow control, reactive power demand, etc. Conventional methods are not suited for multiobjective optimization. Out of many EA techniques GA is used for optimizing the locations of SVC and TCSC because GA is efficient than the conventional method. It can able to provide optimal solution by iterations using genetic operators. Reactive power demand is the main cause for voltage instability as in [1]. The voltage magnitude, phase angle and line impedance of the transmission line as in [2] and [3]. FACTS devices can able to provide control flow, enhance voltage profile as in [4]. FACTS devices are able to enhance the performance of power system as in [5]. FACTS devices can be optimally located by GA and thus voltage stability and static security margin can be increased as in [6]. GA can be optimize the location, type and the rated value of the devices as in [7]. SVC is optimally located by GA with Particle Swarm Optimization to reduce the generation cost and to increase the power transfer capacity which proves that

GA is efficient with other algorithm as in [8]. Multitype FACTS devices are optimally located to reduce losses and to increase the security margin by GA as in [9]. FACTS devices are used to solve the optimal power flow problems by placing it in an optimal location as in [10], [11], [12] and [14]. TCSC can able to do congestion management when their location and ratings are optimized as in [15] and [18]. The location and ratings of FACTS devices were optimized by GA and the system loadability and minimization of power losses as in [17]. The location and the control variable settings of TCSC are optimized and the system performance was enhanced and the powerflow in a transmission line was improved as in [19]. From the overview of literature survey, it is clear that FACTS devices has provided versatile benefits and the system performance can be improved drastically when compared without FACTS devices in the system. This paper gives the application of GA to find the location and ratings of TCSC and SVC optimally to enhance the voltage stability, reduce the power losses and the generation cost than the conventional methods.

II. PROBLEM FORMULATION

A multi-objective optimization problem consists of multiple objective functions with equality and inequality constraints to be optimized. The equality constraints represents the typical load flow equations. The inequality constraints represent the operating limits of the TCSC and SVC. Here, a problem with three objective functions is formulated which include the minimization of VSI, minimization of real power loss and minimization of generation cost. Better results can be obtained by minimizing all the objective function and to satisfy all the constraints.

A. Voltage stability index, F_1 (Constant)

Voltage stability is an important problem to power system. Voltage stability is evaluated at each bus of the system by an indicator, L - index. At load bus j, L - index can be expressed as given in (1).

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

where

α_L - set of load buses

α_G - set of generator buses

V_j - complex voltage at load bus j

V_i - complex voltage at generator bus i

C_{ij} - Elements of matrix C which can be determined using (2)

$$[C] = -[Y_{LL}]^{-1}[Y_{LG}] \tag{2}$$

Sub matrices of Y bus matrix are $[Y_{LL}]$ and $[Y_{LG}]$ and it can be found using (3).

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

The first objective function considering the minimization of Voltage Stability Index can be represented as given in (4).

$$F_1 = \text{Voltage Stability Index} = L_{\max}$$

B. Power loss, F_2 (MW)

The second objective function considering the minimization of real power loss can be expressed as given in (5).

$$F_2 = P_{\text{loss}} = \sum_{i=1}^{N_L} g_{i,j} (V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)) \tag{5}$$

Where

V_i - the voltage magnitude at bus

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

δ_i - the voltage angle at bus i

N_L - the total number of transmission lines

C. Fuel Cost of generators, F_3 (\$/MWhr)

The third objective function considering minimization of cost of generation can be represented as given in (6).

$$F_3 = \min F(P_n) = \sum_{i=1}^n a_i P_{Gi}^2 + b_i P_{Gi} + c_i \tag{6}$$

where

n - the number of generators

P_{Gi} - generated power of ith generator

a_i - Cost coefficient of ith generator (\$/MWh²)

b_i - Cost coefficient of ith generator (\$/MWh)

c_i - Cost coefficient of ith generator

D. Fitness function

Considering all the three objective functions from (1)-(6) the Fitness Function (FF) is expressed as given in (7).

$$\text{Fitness function, } F = h_1 F_1 + h_2 F_2 + h_3 F_3 \tag{7}$$

where h_1 , h_2 and h_3 are weighting factor of minimization of VSI objective function, weighting factor of power loss minimization objective function, weighting factor of generation cost minimization objective function.

$$h_1 + h_2 + h_3 = 1$$

(8)

where h_1 , h_2 and h_3 are coefficients. By trial and error method, they are optimized to 0.3, 0.3 and 0.4 for SVC and 0.35, 0.35, 0.3 for TCSC by satisfying (8).

III. FACTS DEVICE

In 1988, Hingorani defined the FACTS concept. FACTS devices can able to control the various electrical parameters such as the voltage magnitude at chosen buses, the phase angle and line impedances of transmission line. They will provide advantages such as control of power flow, avoiding blackouts, improving voltage stability, limiting short circuit currents, etc; The four categories of FACTS namely series, shunt, series-series and combined series shunt controllers. A series controller (TCSC) and a shunt controller (SVC) are deal in this paper.

A. Power flow modelling of SVC

A shunt connected device, SVC which consists of a Thyristor Controlled Rectifier (TCR) in parallel with a bank of capacitor. It regulates the voltage magnitude at which it is connected by either generating or absorbing the reactive power. It is mainly used to provide fast reactive power and voltage regulation support. The basic SVC model is shown in Fig 1.

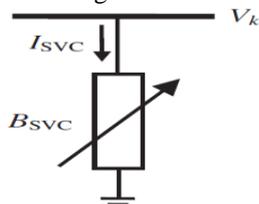


Fig 1. Basic model of SVC

The current drawn by the SVC is given in (9).

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

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

The active and reactive power flow equations of SVC is given in (10) and (11).

$$P_{Gi} - P_{Di} = V_i \sum_{k=1}^n [V_k [G_{ik} \cos(\theta_i - \theta_k) + B_{ik} \sin(\theta_i - \theta_k)]] \tag{10}$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{k=1}^n [V_k [G_{ik} \sin(\theta_i - \theta_k) + B_{ik} \cos(\theta_i - \theta_k)]] \tag{11}$$

Where G_{ik} is the conductance and the susceptance B_{ik} are between bus i and j respectively.

B. Power flow modelling of TCSC

TCSC is a series connected FACTS device in which a capacitor is connected in series with the transmission line and a parallel connection of thyristor-controlled inductor with the capacitor. The power flows in heavily loaded line can be reduced by TCSC through power flow control in the network.

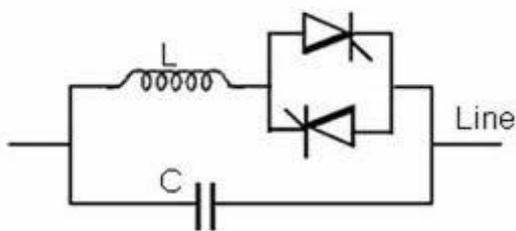


Fig 2. Basic model of TCSC

The rated value of TCSC where the it is located is given by (12).

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

where X_{Line} - the reactance of the transmission line.

The power flow equations of TCSC are as given by (13) and (14)

$$P_{ij} = V_i^2 g_{ij} - V_i V_j (g_{ij} \cos_{ij} + b_{ij} \sin_{ij}) \tag{13}$$

$$Q_{ij} = V_i^2 b_{ij} - V_i V_j (g_{ij} \sin_{ij} + b_{ij} \cos_{ij}) \tag{14}$$

Where V_i and V_j are voltages of i^{th} and j^{th} bus respectively.

IV. GENETIC ALGORITHM

GA is a search heuristic method based on the Darwinian theory of the fittest which was developed by John Holland in 1970. It is an iterative procedure used to provide optimal solutions by solving multiobjective optimization problems.

At each step of iteration, the individuals are selected randomly from the current population to be parents and the next generation is formed by those parents. Optimal solution can be obtained in repeated iterations. GA can be used to solve to optimization problems with a variety of objective functions even it is highly non-linear, nondifferentiable or discontinuous,. New generation can be obtained through the genetic operators.

COMPONENTS OF GA

The major components of GA are required to create the new generation from the current population as follows:

a) Initial population

GA starts with a large group of randomly selected chromosomes knows as initial population. The initial population is created by using the following parameters: N_{FACTS} , $N_{location}$, N_{types} represents the the number of FACTS devices, the possible location of the devices, the types of devices respectively.

b) Selection

Selection selects the parents with high fitness from the current population and insert them in a mating pool to create new offsprings. Some of the selection procedures are stochastic, uniform, remainder, roulette wheel, Tournament, rank selection, steady state selection, etc.

c) Crossover

Crossover plays a major role in convergence speed of GA. After selecting the parents with higher fitness, select an appropriate site to perform recombination process and the contents to the right of the site is exchanged. Some of the crossover schemes are scattered, Intermediate, arithmetic, single point, multipoint or uniform crossover have been used.

c) Mutation

Mutation operator prevents the premature stopping of the algorithm. It changes a random bit value in a chosen string involves flipping it, changing 0 to 1 and vice versa with a low probability. Gaussian, uniform, adaptive feasible are some of the options of mutations. Mutation probability specifies how often parts of chromosomes will be mutated.

A. STEPS IN GA

SVC and TCSC are to be placed in IEEE 14 bus and IEEE 30 bus systems by GA, the following steps are to be followed :

Step 1: Initially create a population

$$(N_{FACTS}, N_{type}, N_{location}, N_{rated}, N_{ind})$$

Step 2: Perform power flow program.

- Step 3: For all the individuals fitness values are evaluated.
- Step 4: Based on the fitness values, a new population has been selected from the old population based on the evaluation function as given.
- Step5: Genetic operators (crossover and mutation) applied to the population that has been selected to create new solutions.
- Step6: Fitness value is evaluated for new chromosomes and use them into the population.
- Step7: If it exceeds the time, stop the process and provide the best Individual if not, proceed from step 4.

V. RESULTS AND DISCUSSION

IEEE 14 bus and IEEE 30 bus systems was used for the tests by GA and the results were obtained. In which the location and ratings of SVC and TCSC were optimized and the objectives such as VSI, power losses and generation cost were minimized. The parameters used by GA 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

IEEE 14 bus system consists of five generator buses (bus no.1,2,3,6 and8), nine load buses (bus no.4,5,7,9,10,11,12,13 and 14) and 20 transmission lines.

1. Optimal location and rating of SVC and TCSC in IEEE 14 bus system

For each chromosome in the population, location of SVC and TCSC device is initialized. Fitness function evaluated for each chromosome considering minimization of voltage stability index, the total real power loss and minimization of the cost of generation. The optimal location of SVC in IEEE 14 system is identified as 10 and susceptance rating is optimized as 0.0086 p.u. by GA by considering all the three mentioned objection. The optimal location of TCSC in IEEE 14 system is identified as line 17 using GA by considering all the objective functions. Hence TCSC is placed between bus number 9 and bus number 14.

B. IEEE 30 BUS SYSTEM

IEEE 30 bus system consists of six 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.

1. Optimal location and rating of SVC and TCSC in IEEE 30 bus system

The optimal location of SVC in IEEE 14 system is identified as 24 and susceptance rating is optimized as 0.0692 p.u. by GA by considering all the three mentioned objectives. The optimal location of TCSC in IEEE 30 system is identified as line 36 using GA by considering all the objective functions. Hence TCSC is placed between bus number 28 and bus number 27.

A. COMPARISON OF VOLTAGE Profile in IEEE 14 BUS AND IEEE 30 BUS SYSTEMS

The enhancement of voltage stability in IEEE 14 bus system is shown in Fig 2. It is observed that voltage profile by GA is enhanced well when compared with the conventional method.

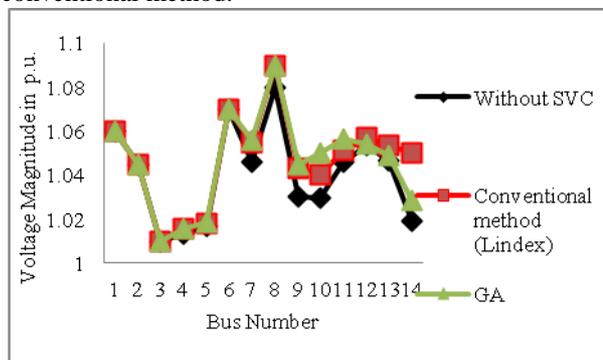


Fig 2. comparison of voltage profile in IEEE 14 bus System

The enhancement of voltage stability in IEEE 30 bus system is shown in Fig 3. The voltage magnitude is increased at all buses of IEEE 30 bus system.

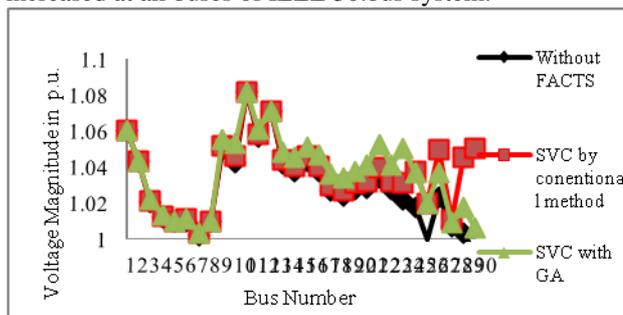


Fig 3. comparison of voltage profile in IEEE 30 bus system

A. COMPARISON OF OBJECTIVE FUNCTIONS IN IEEE 14 BUS SYSTEM

The comparison of minimization of VSI, minimization of real power loss and minimization of generation cost are shown in Fig 4 - Fig 6.

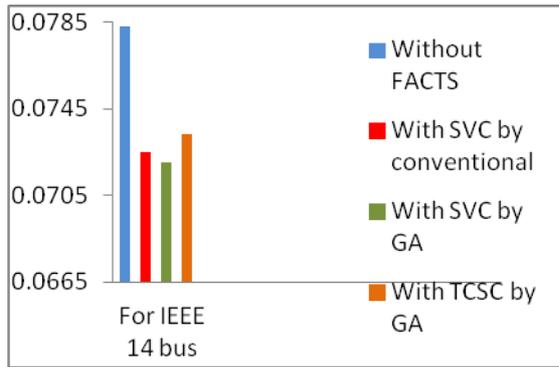


Fig 4. Comparison of VSI

When SVC and TCSC placed by GA, power loss is reduced by 0.15 MW and 1.6082 MW respectively and fuel cost is reduced by 0.5908 \$/MWhr and 0.5228 \$/MWhr. It proves that GA is more efficient in minimizing the objective functions when compared with the conventional method.

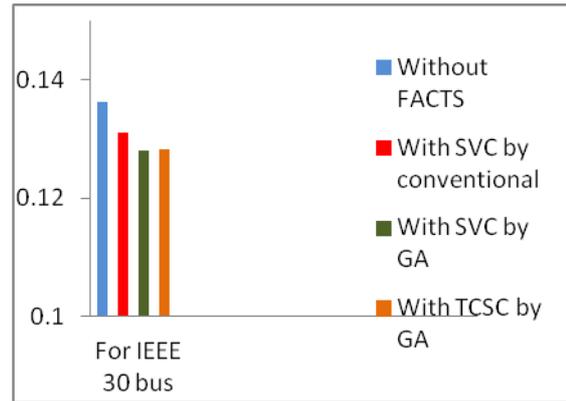


Fig 7. Comparison of VSI

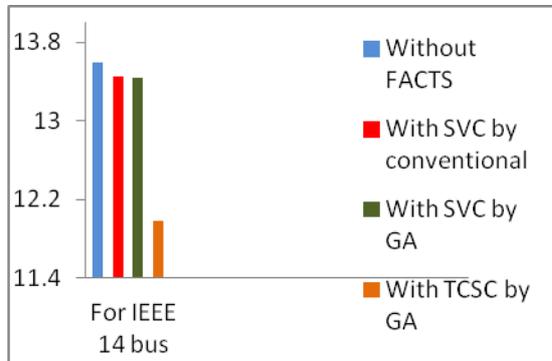


Fig 5. Comparison of real power loss

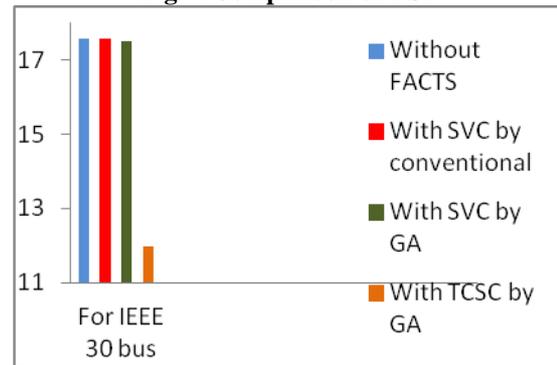


Fig 8. Comparison of real power loss

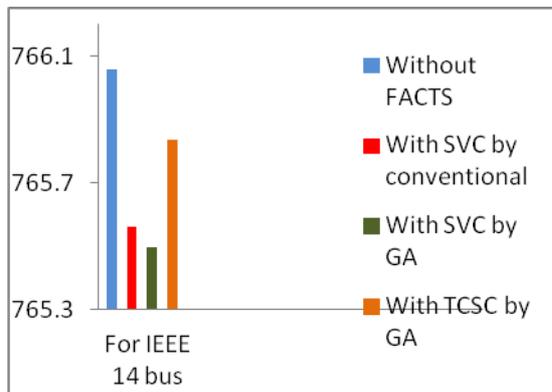


Fig 6. Comparison of generation cost

A. COMPARISON OF OBJECTIVE FUNCTIONS IN IEEE 30 BUS SYSTEM

The comparison of minimization of VSI, Power loss and generation cost are shown in Fig 7 - Fig 9. When SVC and TCSC placed by GA, power loss is reduced by 0.057 MW and 5.5862 MW respectively and fuel cost is reduced by 0.2254 \$/MWhr and 0.0564 \$/MWhr. It proves that GA is more efficient in minimizing the objective functions when compared with the conventional method.

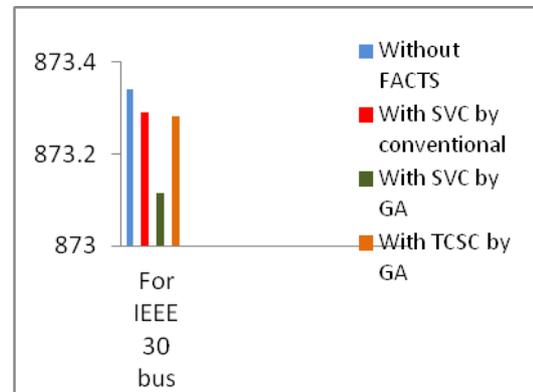


Fig 9. Comparison of generation cost

V. CONCLUSION

Recently power losses and voltage instability problems are the major problems in power system and generation cost also goes high. FACTS concept made a revolution in power system which overcomes all the problems. Many techniques are used to optimize the location of FACTS devices. GA belongs to a class of Evolutionary Algorithms is used as an optimization technique in this project. The location and ratings of SVC and TCSC are optimally identified by GA and compared with the conventional, NR method. The results shows that voltage profile is enhanced at all buses and

power losses are considerably decreased by considering the objectives such as minimization of VSI, minimization of power losses and minimization of generation cost. Thus it proves that the efficiency of GA is better than the conventional method.

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