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APPLICATION OF HYBRID PSOGA FOR OPTIMAL LOCATION OF SVC TO IMPROVE VOLTAGE STABILITY OF POWER SYSTEM

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Abstract—Due to huge increase in power demand, modern power system networks are being operated under highly stressed conditions. This has resulted into the difficulty in meeting reactive power requirement and maintaining the bus voltage within acceptable limits. Voltage instability in the system occurs in the form of a progressive decay in voltage magnitude at some of the buses. The problems of voltage instability and voltage collapse are the major concerns in the operation of power system. It is very important to do the power system analysis with respect to voltage stability. Flexible AC Transmission System (FACTS) device in a power system improves the stability, enhances the voltage stability margin and reduces the power losses. Identification of location of FACTS device in the power system is very important task. Research is carried out to investigate application of Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and hybrid PSOGA to find optimal location and rated value of SVC device to minimize the voltage stability index, total power loss, load voltage deviation, cost of generation and cost of FACTS device to improve voltage stability in the power system. Optimal location and rated value of SVC device have been found for different loading scenario using PSO, GA and PSOGA. It is observed from the results that the voltages stability margin is improved, voltage profile of the power system is increased, load voltage deviation is reduced and real power losses also reduced by optimally locating SVC device in the power system. The proposed algorithm is verified with IEEE 14 bus and 30 bus power systems

Keywords—*Voltage stability analysis, Voltage collapse, SVC, PSO, GA, Hybrid PSOGA.*

I.   INTRODUCTION

Modern power system networks are being operated under highly stressed conditions due to continuous increase in power demand. This has been imposed the threat of maintaining the required bus voltage, and thus the systems have been facing voltage instability problem. 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. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing voltage instability is the inability of the power system to meet the demand for reactive power as in [1] and [2]. Voltage Collapse Proximity Indicator (VCPI), L-index, the minimum singular value of power flow Jacobian matrix, the loading margin, minimum eigen value of reduced Jacobian Matrix etc. are some of the voltage stability indices defined to find the locations for the FACTS devices.

FACTS have made the power systems operation more flexible and secure. They have the ability to

control, in a fast and effective manner, it is also possible to control the phase angle, the voltage magnitude at chosen buses and/or line impedances of transmission system as in [3] and [4]. FACTS controllers enhance the voltage profile and the

loadability margin of power systems as in [5] and [6]. FACTS devices can be modeled and used for power flow analysis as in [7] and [8]

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr.Eberhart and Dr.Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. The main idea is based on the food-searching behavior of birds as in [9]. It is observed that they take into consideration of the globallevel of information to determine their direction. The global and local best positions are computed at each iteration and the output is the new direction of search. Once this direction is detected, it is followed by the cluster of birds.

The optimal location of SVC can be found using PSO in order to improve the voltage stability margin, minimize load voltage deviation and reduce power loss as in [10]. Simultaneous application of particle swarm optimization (PSO) and continuation power flow (CPF) to improve voltage profile, minimize power system total losses, and maximize system loadability with respect to the size of STATCOM can be made as in [11].

Genetic Algorithm is initially developed by John Holland, University of Michigan during 1970's, it is an iterative procedure, which maintains a constant size population of candidate solutions. During each iteration step, three genetic operators such as reproduction, 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. 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.

Genetic algorithm is used to optimize the various process parameters involved of FACTS devices in a power system. The various parameters taken into consideration are the location of the device, their type, and their rated value of the devices as in [12]. Multi-type FACTS devices can be placed in optimal location to improve security margins and reduce losses in the network as in [13]. GA can be applied to find optimal location of SVC to increase the power transfer capability and to reduce the generation costs as in [14].

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. GA and PSO algorithms are implemented for optimal location of SVC using MATLAB software as in [15].

This paper deals with the applications of PSO, GA and hybrid PSOGA to find optimal location and rating of SVC to minimize the voltage stability index, total power loss, load voltage deviation, cost of generation and cost of FACTS device to improve voltage stability in the power system.

II. PROBLEM FORMULATION

In the present work, the multi-objective function is formulated to find optimal location and size of SVC device by minimizing certain objective functions subject to satisfying some network constraints. The multi-objective functions can be written as in [18]:

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. The indicator value varies between 0 (no load case) and 1 (voltage collapse) as in [16] and [17]. L index at load bus j can be expressed as given in (1).

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

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

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

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

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

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

$$F_1 = \text{Voltage Stability Index} = L_{max} \quad (4)$$

where $L_{max} = \max (L_j) \quad j \square \alpha_L$

B. Fuel Cost

The objective function considering minimization of generation cost can be represented as given in (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 ith generator
a_i is Cost coefficient of ith generator ($/MWh^2)
b_i is Cost coefficient of ith generator ($/MWh)
c_i is Cost coefficient of ith generator

C. Power loss

The objective of real power loss minimization is done by selecting the best combination of variables, which minimizes the total real power loss of the network simultaneously satisfying all the network constraints. Mathematically it can be expressed as given in (6).

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

Where

V_i is the voltage magnitude at bus
$g_{i,j}$ is the conductance of line i-j
δ_i is the voltage angle at bus i
N_L is the total number of transmission lines

D. Voltage Deviation

To have a good voltage performance, the voltage deviation at each load bus must be made as small as possible. The voltage deviation (VD) to be minimized is given in (7).

$$F_4 = VD = \sum_{i=1}^{nPQ} (|V_i - 1|)^2 \quad (7)$$

where V_i is the voltage magnitude at load bus i.

E. Cost of FACTS device

The objective function considering minimization of cost of SVC device as in [19] can be represented as in (8).

$$F5 = C_{SVC} = 0.0003S2 - 0.305S + 127.38 \quad (8)$$

where

C_{SVC} is cost of SVC in $/VAR
S is operating range of SVC in MVAR and it can be found using (9).

$$S = |Q_2 - Q_1| \quad (9)$$

Q_1 is MVAR flow before placing FACTS device.
Q_2 is MVAR flow after placing FACTS device.

F. Power balance constraints

The total power generated by the units must be equal to the sum of total load demand and total real power loss in the transmission lines. Hence the equality constraints are given in (10) and (11).

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i| |V_j| |Y_{ji}| \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (10)$$

$$- \quad - \qquad\qquad - \ - \qquad (11)$$

where$P_{Gi}$is the real power generation at bus i

$Q_{Gi}$is the reactive power generation at bus i

$P_{Di}$is the real power demand at bus i

$Q_{Di}$is the reactive power demand at bus i

N is the total number of buses

$\theta_{i,j}$is the angle of bus admittance element i,j

$Y_{i,j}$is the magnitude of bus admittance element i,j

G. Inequality Constraints

The real power output of generating units, generator reactive power, voltages of all PV buses, transformer tap positions, bus voltage magnitudes of all PQ buses and power flow in the transmission line must be restricted within their respective lower and upper bounds (inequality constraints).

H. Fitness function

Considering all the objective functions from (1)-(8) the fitness function is expressed asgiven in (12).

Fitness function = $h_1 F_1 + h_2 F_2 + h_3 F_3 + h_4 F_4 + h_5 F_5$(12)

where $h_1,$ $h_2,$ $h_3,$ h_4 and h_5 are weighting factor of voltage stability index minimization objective function, weighting factor of fuel cost minimization objective function, weighting factor of loss minimization objective function, weighting factor of voltage deviation minimization objective function and weighting factor of FACTS cost minimization objective function respectively.

$$h_1+h_2+h_3+h_4+h_5=1$$
$$(13)$$

The coefficients $h_1,$ $h_2,$ $h_3,$ h_4 and $h_5$are optimized by trial and error method to 0.2, 0.1, 0.5, 0.1 and 0.1 by satisfying (13).

III. FACTS DEVICE

FACTS devices have the ability to control the phase angle, the voltage magnitude at chosen buses and line impedances of transmission system. In order to meet the growing power demand, utilities have an interest in better utilization of available power system capacities, existing generation and existing power transmission network, instead of building new transmission lines and expanding substations. .

A. Power flow modelling of SVC

SVC is a shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage). It is modeled as an ideal reactive power injection at the load ends as in [8].
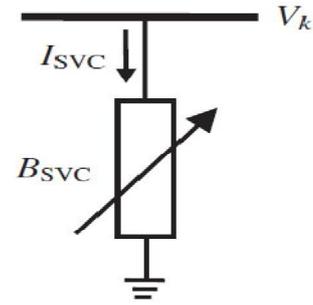
.Fig. 1: Variable shunt susceptance model

The current drawn by the SVC is given in (14).

$$I_{SVC} = jB_{SVC}V_k(14)$$

The reactive power drawn by the SVC, which is also the reactive power injected at bus k, is given in (15).

$$Q_{SVC} = Q_k = -V_K^2 B_{SVC}(15)$$

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

IV. PARTICLE SWARM OPTIMIZATION

PSO was proposed by James Kennedy and R. C. Eberhart in 1995, inspired by social behavior of organisms such as bird flocking and fish schooling. PSO as an optimization tool, provides a population based search procedure in which individuals called particles change their position (state) with time as in [9].

A. Mathematical model of PSO

The swarm of particles initialized with a population of random candidate solutions move through the d-dimension problem space to search the new solutions. The fitness, f, can be calculated. Each particle has a position and a velocity. After every iteration the best position among the swarm so is stored.

$$(16)$$

$$(17)$$

Inertia weight w is calculated using equation (23).

$$- \quad \overline{\qquad\qquad}$$

$$(18)$$

where

V_i^k: Velocity of i^{th}particle at kth iteration;

V_i^{k+1}: Velocity of i^{th}particle at $(k+1)^{th}$ iteration

S_i^k: Current position of particle i at k^{th} iteration

S_i^{k+1}: Current position of particle i at $(k+1)^{th}$ iteration

$P_{best\ i}$: Best position of i^{th}particle

$G_{best\ i:}$ Best position among the particles (group best)

$c_1:$Coefficient of the self-recognition component,

c_2: Coefficient of the social component

$c_1+c_2 = 4$

$rand_1$ and $rand_2$ are the random numbers usually chosen between [0, 1]

w: Inertia weight,

w_{max}: Initial value of inertia weight;

w_{min}: Final value of inertia weight;

iter: Current iteration number;

iterw$_{max}$: Maximum iteration number

B. Proposed Algorithm for PSO

The proposed algorithm for the optimal placement of SVC device using PSO is given below:

Step 1: Initialize velocity, Pbest, Gbest, No.of particles and maximum iteration.

Step 2: For each particle initialize SVC size and location of SVC.

Step 3: Check whether maximum iteration is reached, if yes then obtain the optimum location and rating of SVC.

Step 4: Run power flow program and compute objective function

Step 5: For each particle determine and store Pbest

Step 6: For each particle determine and store Gbest

Step 7: Update velocity and position using equations (16)-(18).

Step 8: If feasibility solution is obtained then goto step

3. Otherwise relocate particle to feasible position of search space.

V. GENETIC ALGORITHM (GA)

GA is an evolutionary computing method in the area of artificial intelligence. It is a stochastic global search and optimization method that is based on concepts from natural genetics and the Darwinian survival-of-the-fittest code. Genetics is usually used to reach to a near global optimum solution. In each iteration of GA, a new set of string (.i.e. chromosomes) with improved fitness is produced using genetic operators (i.e. selection crossover and mutation). Main components of GA Algorithm are initialization, selection, crossover, mutation and termination as in [12].

A. Proposed Algorithm for GA

The proposed algorithm for the optimal placement of SVC device using GA is given below:

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

Step 5: Applygenetic operators (mutation and crossover) to members of the population to create new solutions.

Step 6: Evaluate the fitness value of new chromosomes and insert them into the population.

Step 7: If time is up, stop and return the best individual if not, go to step 4.

VI. HYBRID PSOGA

Hybrid PSOGA algorithm combines the standard velocity and position update rules of PSOs with the ideas of selection and crossover from GAs. The algorithm is designed so that the PSO performs a global search and the GA performs a local search.

A. Proposed Algorithm for hybrid PSOGA

The proposed algorithm for the optimal placement of SVC device using GA is given below:

Step 1: Initialize velocity, Pbest, Gbest, No.of particles and maximum iteration.

Step 2: For each particle initialize SVC size and location of SVC.

Step 3: Check whether maximum iteration is reached, if yes then obtain the optimum location and rating of SVC.

Step 4: Run power flow program and compute objective function

Step 5: For each particle determine and store Pbest

Step 6: For each particle determine and store Gbest

Step 7: Update velocity and position using equations (21)-(23).

Step 8: If feasibility solution is obtained then goto step

3. Otherwise relocate particle to feasible position of search space.

Step 9: Create an initial population

Step 10: Run power flow program

Step 11 Evaluate fitness value of all the individuals.

Step 12: Select a new population from the old population based on the fitness of the individuals as given by the evaluation function

Step 13:Apply genetic operators (mutation and crossover) to members of the population to create new solutions.

Step 14: Evaluate the fitness value of new chromosomes and insert them into the population.

Step 15: If time is up, stop and return the best individual if not, go to step 12.

VII. RESULTS AND DISCUSSION

The solutions for optimal location of SVC device to minimize the objective function for IEEE 14 bus, IEEE 30 bus systems were obtained and discussed below. The test system data used as in [20].The location, setting of SVC device, optimal objective function value, voltage profile and total real power losses of power system are obtained using the PSO, GA and PSOGA techniques.The parameters used for GA and PSO techniques are shown in Table 1. The proposed PSO and GA is tested on standard IEEE 14 bus, IEEE 30 bus systems.

Table 1: GA and PSO parameters

GA	PSO

Population	20	Population	10
Crossover fraction	0.8	C1	2.5
Selection function	Stochastic uniform	C2	1.5
Elite count	2	Wmax	0.9
Crossover function	Scattered	Wmin	0.4

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. Comparison of voltage profile and Comparison of real power loss of IEEE 14 Bus system for normal loading condition are shown in Fig. 2 and Fig. 3 respectively.Optimal location and rating of SVC have been found for different load scenario for IEEE 14 bus using GA, PSO and PSOGA techniques and it is shown in Table 2.

In conventional method, Voltage stability index (L index) is evaluated at all the load buses of IEEE 14 Bus system. The load bus with highest value of L index is considered as weakest bus.Using L index method bus 14 is identified as the best location for SVC and susceptance rating of SVC is 0.01p.u.Voltage profile is increased at all the load buses and real power loss is reduced by 0.133 MW.

Table 2: Optimal location and rating of SVC for IEEE 14Bus using GA, PSO and PSOGA

loading condition	GA		PSO		PSOGA	
	Location	Rating	Location	Rating	Location	Rating
Normal loading	10	0.0086	11	0.1843	9	0.1103

Bus 10 is identified as optimal location of SVC using GA and susceptance rating of SVC is 0.0086 p.u. Voltage profile is increased at all the buses and real power loss is reduced by 0.15 MW.Bus 11 is identified as optimal location of SVC using PSO and susceptance rating of SVC is 0.1843 p.u. Voltage profile is increased at all the buses and real power loss is reduced by 0.058 MW.Bus 9 is identified as optimal location of SVC using hybrid PSOGA and susceptance rating of SVC is 0.1103 p.u. Voltage profile is increased at all the buses and real power loss is reduced by 0.174 MW.
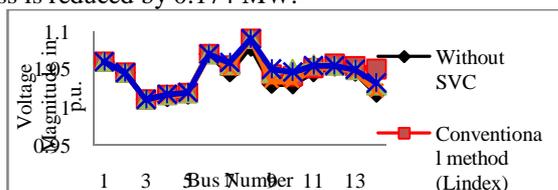

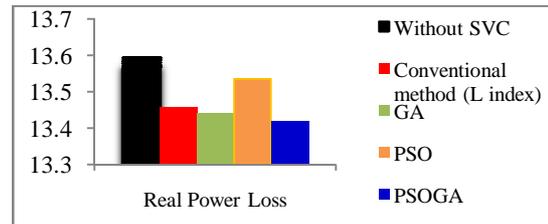Fig. 2: Voltage profile of IEEE 14 Bus system for normal loading condition

Fig. 3: Comparison of real power loss of IEEE 14 Bus system for normal loading condition

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. Comparison of voltage profile and Comparison of real power loss of IEEE 30 Bus system for for normal loading condition are shown in Fig. 4 and Fig.5 respectively.Optimal location and rating of SVC have been found for different load scenario for IEEE 30 bus using GA, PSOand PSOGA techniques and it is shown in Table 3.

In conventional method, Voltage stability index (L index) is evaluated at all the load buses of IEEE 30 Bus system, SVC located at the load bus, which is having high value of L index. Using L index method bus 30 is identified as the best location for SVC and susceptance rating of SVC is 0.01p.u.Voltage profile is increased at all the load buses and real power loss is reduced by 0.012 MW.

Bus 24 is identified as optimal location of SVC using GA and susceptance rating of SVC is 0.0692 p.u. and voltage profile is increased at all the buses and real power loss is reduced by 0.057 MW. Bus 17 is identified as optimal location of SVC using PSO and susceptance rating of SVC is -0.1189 p.u. and voltage profile is increased at all the buses and 0.044 MW reduces real power loss.Bus 25 is identified as optimal location of SVC using hybrid PSOGA and susceptance rating of SVC is 0.0740 p.u. and voltage profile is increased at all the buses and 0.063 MW reduces real power loss.

Table 3: Optimal location and rating of SVCfor IEEE 30 Bus using GA, PSO and PSOGA

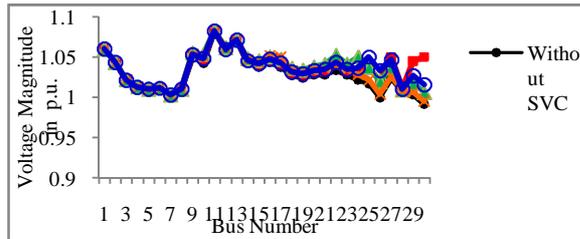| loading condition	GA		PSO		PSOGA	
	Location	Rating	Location	Rating	Location	Rating
Normal loading	24	0.0692	17	-0.1189	25	0.074

Fig. 4: Voltage profile of IEEE 30 Bus system for normal loading condition
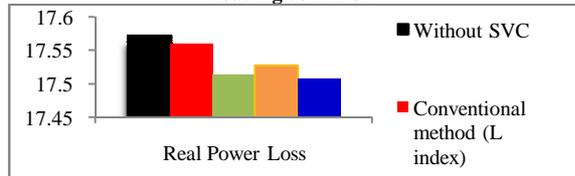

Fig. 5: Comparison of real power loss of IEEE 30 Bus system for normal loading condition

VIII. CONCLUSION

This paper made an attempt to find the optimal location and size of SVC device for decreasing voltage stability index, power loss, voltage deviation, cost of generating unit and cost of SVC device using PSO, GA and PSOGA for different loading condition.Simulations were performed on IEEE 14, 30 bus systems. It is observed that thevoltages stability margin is improved, voltage profile of the power system is increased, load voltage deviation is reduced and real power losses also reduced by optimally locating SVC device in the power system.Hybrid PSOGA results are better than that of GA,PSO and conventional method.

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