Journal of Engineering and
Technology (JET)
Vol.1, Issue 1 Dec 2011 1-27
© TJPRC Pvt. Ltd.,

MULTI-OBJECTIVE VAR PLANNING WITH SVC USING PARTICLE SWARM OPTIMIZATION TECHNIQUES IN POWER SYSTEM NETWORKS

Mr.Bindeshwar Singh, **K.S. Verma**, Member, IEEE,
Mr.Deependra Singh, Member, IEEE **and** Mr.**S.N. Singh**, Senior Member, IEEE

ABSTRACT

This paper presents a novel muti-objective evolutionary computational approach such as Particle Swarm Optimization (PSO) technique proposed for optimal placement of Static Var Compensator (SVC) form the different performance parameters of power systems viewpoint such as minimize the active power losses and cost of system, improve the voltage profile, increase the loadability of systems, and provide the reactive power support in emergency case such fault occur or suddenly change in field excitation of alternators, or suddenly load increased in power systems. The proposed technique such as PSO is also applicable for optimal placement of other FACTS controllers such as TCSC, SSSC, STATCOM, UPFC, GUPFC, and IPFC in similar fashion from different performance parameters viewpoints. Simulations are proposed to performed in the next paper on IEEE-9, and IEEE-59, and IEEE-14 bus systems for optimal location of FACTS devices and the results obtained are encouraging and will be useful in electrical restructuring.

Index Terms - Flexible AC Transmission Systems (FACTS), FACTS Controllers, SVC, Particle Swarm Optimization (PSO) technique, Power Systems.

NOMENCLATURE

v_i^k	Velocity of agent i at kth iteration
v_i^{k+1}	Velocity of agent i at (k+1)th iteration
w	The inertia weight
$c_1 \& c_2$	Individual and social acceleration Constants (0 to 3)
$rand_1 \& rand_2$	Random numbers (0 to 1)
s_i^k	Current position of agent i at kth iteration
s_i^{k+1}	Current position of agent i at (k+1)th iteration
$pbest_i$	Particle best of agent i
$gbest$	Global best of the group
$iter_{\max}$	Maximum iteration number
$iter$	Current iteration number

1. INTRODUCTION

In the past decade, the problem of reactive power control for improving economy and security of power system operation has received much attention. Generally, the load bus voltages can be maintained within their permissible limits by reallocating reactive power generations in the system. This can achieve by adjusting transformer taps, generator voltages, and switchable VAR sources. In addition, the system losses can be minimized via redistribution of reactive power in the system. Therefore, the problem of the reactive power dispatch can be optimized to improve the voltage profile and minimize the system losses as well. Several methods to solve the optimal reactive power dispatch problem have been proposed in the open literatures.

With the worldwide restructuring and deregulation of power systems, sufficient transmission capacity and reliable operation have become more valuable to both system planners and operators. Building new constructions to enhance the loadability of a network is very expensive and many constraints have to be satisfied. As a result, there is a significantly increased potential for the application of FACTS devices due to their important role in power system security enhancement. Among the FACTS devices, Static VAr Compensators (SVCs) are widely used around the world both for their capabilities and for their low maintenance costs. Although investment cost of SVCs are expensive but maintenance costs are low since the devices have no moving parts and repairs are minimal.

SVC is a first generation FACTS device. SVCs are extensively employed in power system since 1970s. They are applied by utilities in transmission applications for several purposes. The primary purpose is usually the rapid control of voltage at weak nodes in power system networks. SVCs are also used for:

- Increasing power transfer capacity in long lines.
- Stability improvement (both transient and dynamic) with fast acting voltage regulation.
- Damping of low power frequency oscillations (corresponding to electro-mechanical modes).
- Damping of sub-synchronous oscillations (due to torsional modes).
- Control of dynamic overvoltages.

Basic Optimal FACTS Allocation problem has been solved by various optimization techniques and different objective functions. In general optimal FACTS allocation problem is to determine the optimal size and location of new installed FACTS devices in order to optimize a specific objective function while considering variety of operating constraints. The main presented objective functions are system loadability maximization, minimization of overall operation cost, minimization of installation cost and congestion management.

Voltage collapse and other instability problems can be related to the system's inability to meet VAr demands. Efforts have been made to find the ways to assure the security of the system in terms of voltage stability. Flexible AC transmission system (FACTS) devices are good choice to improve the voltage profile in a power system, which operates near the steady-state stability limit and may result in voltage instability. Taking advantages of the FACTS devices depends greatly on how these devices are placed in the power system, namely on their location and size.

In the literature a tool has been reported, which is based on the determination of critical modes known as modal analysis. Modal analysis has been used in locating SVC and other shunt compensators to avoid voltage instability [1]. However, this method meets difficulties in placing the devices optimally.

Over the last decades there has been a growing interest in algorithms inspired from the observation of natural phenomena [2]-[5].

Due to many good features of genetic algorithm (GA), GA has been widely applied in different applications. Study on the use of GA is also carried out by researches to seek the optimal location of FACTS devices in power systems and other optimization problems [6]-[7].

In 1995, Kennedy and Eberhart introduced the Particle Swarm Optimization (PSO) method as an evolutionary computation technique [30]. The original version of the PSO operates in continuous space [9] and was extended to operate on discrete binary variables [10]. The PSO has been shown to be very effective for static and dynamic optimization problems. For the first time, the PSO is applied in power systems in 1999 [11], and has been successfully applied to various problems [12]-[15]. In spite of the importance of FACTS devices in power system stability, however, only few application of PSO on FACTS devices can be found in [16].

This paper is organized as follows: Section II discusses the fundamentals and mathematical model of SVC. Section III presents the particle swarm optimization (PSO) technique for optimal location of SVC in power systems. Section IV presents the problem formulation of this work. Section V presents the results and discussion of the problem. Section VI presents the conclusions of the paper.

2. MATHEMATICAL MODEL OF SVC

A. Mathematical model of SVC

Static Var Compensator (SVC) as in [17] is one of the simple controllers based on Power Electronics and other static devices known as FACTS (Flexible AC Transmission Systems) Controllers which could be used to increase the capacity and the flexibility of a transmission network. The electric power quality at the low voltage level is affected, in great deal, by the disturbance due to switching actions or faults that happens in the power system at the middle and low voltage levels. SVC is one of the best devices to improve the voltages profile by providing the necessary reactive power in the load buses. Claudio et al. [10] proposed the steady state models of SVC and TCSC for the voltage collapse point improvement problem.

In this the modeling of the devices and selecting the ranges are found difficult. C.J.Parkar in [18] used many devices to achieve reactive power reserve, it increased the installation cost.. FACTS devices based on thyristor controlled reactor (TCR) such as static var compensators (SVC) and thyristor controlled series capacitor (TCSC) are being used by several electric utilities to compensate their system [19]. SVC is more suited in reactive power adjustment when connected in the load buses than in the lines with the susceptance property. The basic structure of SVC is shown in figure1 (a).In the steady state model if an

SVC is connected to a particular bus „i then the injected power at that bus is given by:

$$Q_i = Q_{SVC} \tag{1}$$

The work carried out the authors in [20] used PSO and GA for multi-objective VAr planning by SVC. It was revealed that both algorithms show the same bus for the placement of SVC but with different MVAr size.

Static VAR Compensator (SVC) is a shunt connected FACTS controller whose main functionality is to regulate the voltage at a given bus by controlling its equivalent reactance. Basically it consists of a fixed capacitor (FC) and a thyristor controlled reactor (TCR). Generally they are two configurations of the SVC is presented in [8]-[29].

SVC total susceptance model. A changing susceptance Bsvc represents the fundamental frequency equivalent susceptance of all shunt modules making up the SVC as shown in Fig. 1(a).

SVC firing angle model. The equivalent reactance XSVC, which is function of a changing firing angle α, is made up of the parallel combination of a thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive reactance as shown in Fig. 1 (b). This model provides information on the SVC firing angle required to achieve a given level of compensation. The SVC block diagram for state-equation of SVC is shown in Fig.1 (c).

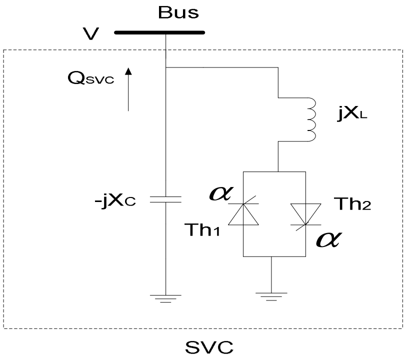

Figure 1 (a) : SVC firing angle model

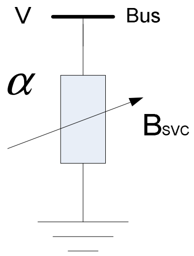

Figure 1 (b) : SVC total susceptance model

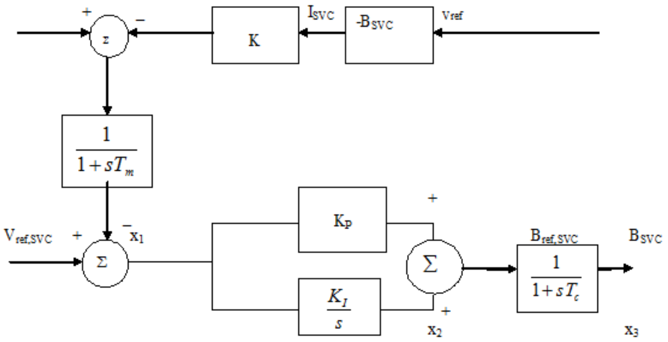

Figure 1 (c) : SVC block diagram

Figure 2 shows the steady-state and dynamic voltage-current characteristics of the SVC. In the active control range, current/susceptance and reactive power is varied to regulate voltage according to a slope (droop) characteristic. The slope value depends on the desired voltage regulation, the desired sharing of reactive power production between various sources, and other needs of the system. The slope is typically1-5%. At the capacitive limit, the SVC becomes a shunt capacitor. At the inductive limit, the SVC becomes a shunt reactor (the current or reactive power may also be limited).

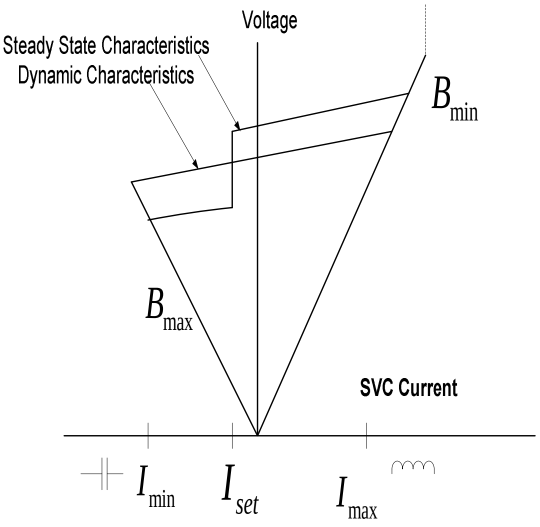

Figure 2 : Steady-state and dynamic voltage/current Characteristics of the SVC

The SVC firing angle model is implemented in this paper. Thus, the model can be developed with respect to a sinusoidal voltage, differential and algebraic equations can be written as

$$I_{SVC} = -jB_{SVC}V_k \tag{2}$$

The fundamental frequency TCR equivalent reactance X_{TCR}

$$X_{TCR} = \frac{\pi X_L}{\sigma - \sin\sigma} \tag{3}$$

Where $\sigma = 2(\pi - \alpha), X_L = \omega L$

And in terms of firing angle

$$X_{TCR} = \frac{\pi X_L}{2(\pi - \alpha) + \sin 2\alpha} \tag{4}$$

σ and α are conduction and firing angles respectively.

At $\alpha = 90^0$, TCR conducts fully and the equivalent reactance XTCR becomes XL, while at $\alpha = 180^0$, TCR is blocked and its equivalent reactance becomes infinite.

The SVC effective reactance X_{SVC} is determined by the parallel combination of X_C and X_{TCR}

$$X_{SVC}(\alpha) = \frac{\pi X_C X_L}{X_C[2(\pi - \alpha) + \sin 2\alpha] - \pi X_L} \tag{5}$$

Where $X_C = {}^{1}\!/_{\omega C}$

$$Q_k = -V_k^{\ 2}\left\{\frac{X_C[2(\pi - \alpha) + \sin 2\alpha]}{\pi X_C X_L}\right\} \tag{6}$$

The SVC equivalent reactance is given above equation. It is shown in Fig. that the SVC equivalent susceptance $(B_{SVC} = -1/X_{SVC})$ profile, as function of firing angle, does not present discontinuities, i.e., B_{SVC} varies in a continuous, smooth fashion in both operative regions. Hence, linearization of the SVC power flow equations, based on B_{SVC} with respect to firing angle, will exhibit a better numerical behavior than the linearized model based on X_{SVC}. Fig.3. shows the SVC equivalent susceptance profile.

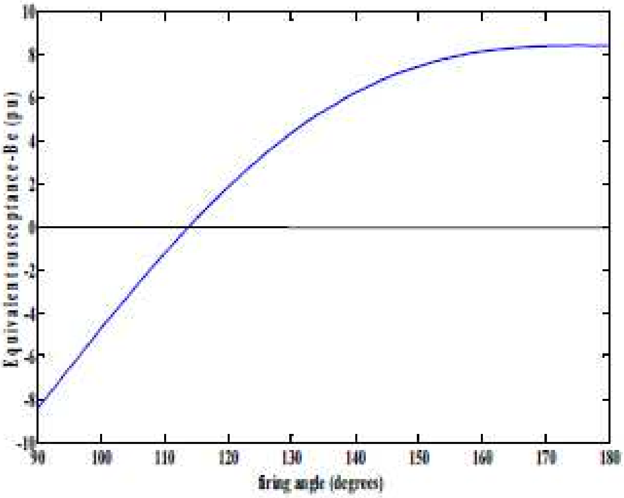

Figure 3 : SVC equivalent susceptance profile

The initialization of the SVC variables based on the initial values of ac variables and the characteristic of the equivalent susceptance (Fig.), thus the impedance is initialized at the resonance point $X_{TCR} = X_C$, i.e. Q_{SVC} =0, corresponding to firing angle $\alpha = 115^0$, for chosen parameters of L and C i.e. $X_L = 0.1134\Omega$ and $X_C = 0.2267\Omega$.

B. Proposed SVC power flow model

The proposed model takes firing angle as the state variable in power flow formulation. From above equation the SVC linearized power flow equation can be written as

$$\begin{bmatrix} \nabla P_k \\ \nabla Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2V_k^{\ 2}}{\pi X_L}[\cos 2\alpha - 1] \end{bmatrix}^{(i)} \begin{bmatrix} \nabla \theta_k \\ \nabla \alpha \end{bmatrix}^{(i)} \tag{7}$$

At the end of iteration i, the variable firing angle α is updated according to

$$\alpha^{(i)} = \alpha^{(i-1)} + \nabla\alpha^{(i)} \tag{8}$$

3. PARTICLE SWARM OPTIMIZATION (PSO) TECHNIQUES

The Particle Swarm Optimizer is a population based optimization method first introduced by Kennedy and Eberhart [30] in 1995, and was inspired by the social behavior of bird flocking and fish schooling. PSO is one of evolutionary computational (EC) techniques [30]. PSO is one of the PSO has been developed through simulation of simplified social models.

The following variants of PSO technique are given as follows:

- Discrete PSO: can handle discrete binary variables.
- MINLP PSO: can handle both discrete binary and continuous variables.
- Hybrid PSO: Utilizes basic mechanism of PSO and the natural selection mechanism, which is usually utilized by EC methods such as GAs.

The features of the method are as follows:

a) The method is based on researches about swarms such a fish schooling and a flock of birds.
b) It is based on a simple concept. Therefore, the computation time is short and it requires few memories.
c) It was originally developed for nonlinear optimization problems with continuous variables. However, it is easily expand to treat problems with discrete variables. Therefore, it is applicable to a MINLP with both continuous and discrete variables.

The features of the searching procedure can be summarized as follows [31]:

- Initial positions of pbest and gbest are different. However, using the different direction of pbest and gbest, all agents gradually get close to the global optimum.

- The modified value of the agent position is continuous. However, the method can be applied to the continuous and discrete problem using grids and its velocity.
- There are no inconsistencies in searching procedures even if continuous and discrete state variables are utilized with continuous grid positions and velocities. The modified velocity and position of each particle can be calculated using the current velocity and the distances from the pbestj,g to gbestg as shown in the following formulas [32]:

Fig.4. shows the Procedure of selection of *pbest.*

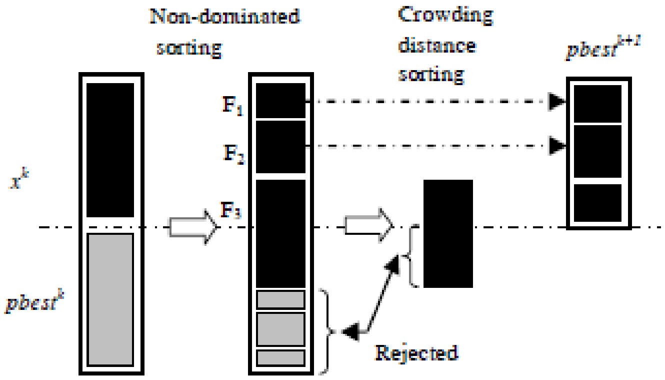

Figure 4 : Procedure of selection of *pbest*

The concept of modification of a searching point by PSO is shown in Fig.5.

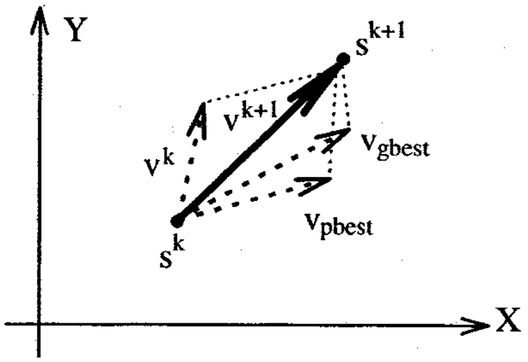

Figure 5 : Concept of modification of a searching point by PSO

Basically, the PSO was developed through simulation of birds flocking in two-dimensional space. The position of each bird (called agent) is represented by a point in the X-Y coordinates, and the velocity is similarly defined. Bird flocking is assumed to optimize a certain objective function. Each agent knows its best value so far (pbest) and its current position. This information is an analogy of personal experience of an agent. Morever, each agent knows the best value so far in the group (gbest) among pbests of all agents. This information is an analogy of an agent knowing how other agents around it have performed. Each agent tries to modify its position using the concept of velocity. The velocity of each agent can be updated by the following equation:

$$v_i^{k+1} = w * v_i^k + c_1 * rand_1 * (pbest_i - s_i^k) + c_2 * rand_2 * (gbest - s_i^k) \qquad (9)$$

Where

v_i^k = the velocity of agent i at iteration k,

w = weighting function,

c_1 and c_2 = are weighting factors,

$rand_1$ and $rand_2$ = are random numbers between 0 and 1,

s_i^k = the current position of agent i at kth iteration

s_i^{k+1} = the current position of agent i at (k+1)th iteration

v_i^k = the velocity of agent i at kth iteration

v_i^{k+1} = the velocity of agent i at (k+1)th iteration

$pbest_i$ = the particle best of agent i

$gbest$ = the global best of the group

The following weighting function is usually used in above equation:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{10}$$

Where

$w_{\max}$ = the initial weight

$w_{\min}$ = the final weight

$iter_{\max}$ = the maximum iteration number

$iter$ = the current iteration number.

Using the previous equations, a certain velocity, which gradually brings the agents close to pbest and gbest, can be calculated. The current position (search point in the solution space) can be modified by the following equation:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{11}$$

The model using (9) is called gbest model. The model (10) in (9) is called inertia weights approach (IWA). The parameters of PSO techniques are given in Table 1.

Table 1 : Parameters of Particle Swarm Optimization Techniques

Parameters	**PSO**
Population Size	50
Number of Particles	10
Inertia Weight (Weighing Factor), w	Linearly decreased
c_1 (Acceleration Constant)	1.4
c_2 (Acceleration Constant)	1.4
No. of Iterations	100
rand1	0.3
rand2	0.2
$w_{\max}$ (Initial Weight)	1.3
$w_{\min}$ (Final Weight)	1.4
$iter_{\max}$ (maximum iteration number)	50
$iter$ (current iteration number)	20

The velocity of the particle is modified by using (9) and the position is modified by using (11). The inertia weight factor is modified according to (10) to enable quick convergence. Implementation of an optimization problem of PSO is realized within the evolutionary process of a fitness function. The fitness function adopted is given as:

$$fitness = \frac{1}{objective + penalty} \tag{12}$$

where objective function is the generation cost and the penalty is the bus voltage angle. Penalty cost has been added to discourage solutions which violate the binding constraints. Finally, the penalty factor is tended to zero. The PSO algorithm or flowchart to find the optimal location of FACTS devices shown in Fig. 6.

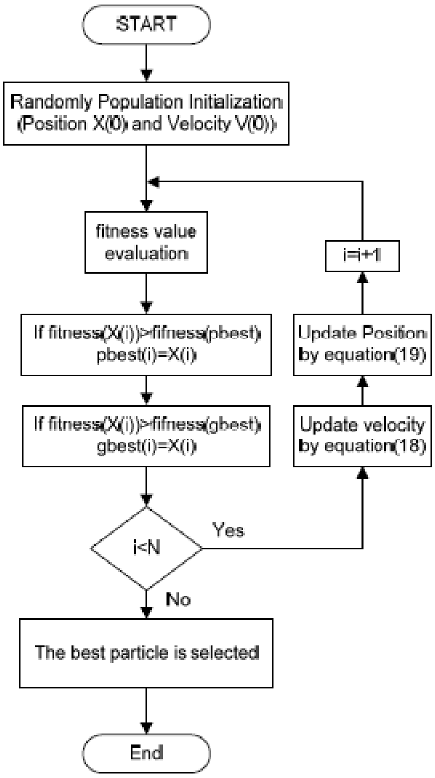

Figure 6 : Flowchart of the PSO algorithm

The step by step algorithm for the proposed optimal placement of FACTS devices is given below:

Step 1. The number of devices to be placed, type of FACTS device to be used in the case of single type of FACTS device and the initial load factor are declared.

Step 2. In case of multi type of FACTS devices, type of device is also taken as a variable.

Step 3. The initial population of individuals is created satisfying the FACTS device's constraints given by (6) and (7) and also it is verified that only one device is placed in each line.

Step 4. For each individual in the population, the fitness function given by (1) is evaluated after running load flow.

Step 5. The velocity is updated by (10) and new population is created by (11).

Step 6. If maximum iteration number is reached, then go to next step else go to step 4.

Step 7. If the final best individual obtained satisfies the condition J=1, which means that the line flow and bus voltage are within their maximum and minimum limits, and then it is stored with its cost of installation and settings. Increase the load factor and go to step 3, else go to next step.

Step 8. Print the previous best individual's cost of installation and its settings.

Step 9. Stop.

4. PROBLEM FOMULATION

The VAr planning problem using SVC can be formulated by considering a number of different objective functions, i.e., multi-objective functions. They include in this paper reduction of the active or real power loss, reduction of load voltage deviation, reduction of the cost function of SVC, increased the loadability of systems or static voltage stability margin (SVSM).

A. Multi-objective Functions

The goal is that to find the best SVC location and the level of compensation, which would result in the increase of system VAr margin. System VAr margin can be evaluated by stressing the system gradually from an initial operating state until the state of critical voltage stability is reached. This can be done by increasing all loads gradually close to the point of voltage collapse. Increasing system VAr margin could be achieved by placing SVC considering the following objective functions:

a*) Active or real power loss*: The total power loss to be minimized is as follows:

$$P_{Loss} = Min\left\{\sum_{k=1}^{nl} g_k\left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right]\right\} \tag{13}$$

Where

nl = the number of transmission line

g_k = the conductance of k^{th} transmission line

$V_i\angle\delta_i$ and $V_j\angle\delta_j$ = are the voltages at the end buses i and j of the k^{th} transmission line, respectively.

***b) Maximum load Voltage deviation*:** To have a good voltage performance (to keep the voltage between 0.95-1.05 per unit), the voltage deviation at each load bus must be made as small as possible. The voltage deviation to be minimized is as follows:

$$LVD = Min\left\{\sum_{k=1}^{NL}\left|V_k - V_k^{ref}\right|\right\} \tag{14}$$

Where

NL = the number of load buses

V_k^{ref} = the pre-specified reference value of voltage magnitude at the k^{th} load bus

V_k^{ref} is usually set to 1.0 pu.

c) Cost Function of SVC

The SVC is modeled as a variable reactive power connected to a bus in a system. The effect of SVC is incorporated in power flow problem as reactive power generation/absorption. The range of reactive power generation is limited between maximum and minimum values of -100 MVAR to +100 MVAR to keep the size minimum for reducing the cost of SVC. The reactive power generated by SVC is given by:

$$Q_{SVC}^{\min} \leq Q_{SVC} \leq Q_{SVC}^{max} \tag{15}$$

According to [20], the costs function for SVC in term of (US$/kVAr) is given by the following equation:

$$C = 0.0003Q^2 - 0.3051Q + 127.38 \tag{16}$$

Where Q is MVAr size of SVC.

d) Loadability of systems

e) Static Voltage Stability Margin (SVSM)

Static Voltage stability Margin (SVSM) or loading margin is the most widely accepted index for proximity of voltage collapse. The *SVSM* is calculated using Power System Analysis Toolbox (PSAT) [24]. *SVSM* is defined as the largest load change that the power system may sustain at a bus or collective of buses from a well defined operating point (base case). The maximization of *SVSM* can be presented as follows:

$$\max\{\lambda\} \tag{17}$$

Where, λ is the *SVSM* or the loading margin.

B. Problem Constraints

a) Equality Constraints

These constraints represent typical load flow equations as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j) \right] = 0$$
$$i = 1, 2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, NB. \qquad (18)\ \&\ (19)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j) \right] = 0$$
$$i = 1, 2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots, NB.$$

Where NB is the number of buses; P_G and Q_G are the generator real reactive power, respectively; P_D and Q_D are the load real reactive power, respectively; G_{ij} and B_{ij} are the transfer conductance and susceptance between bus i and j, respectively.

b) Inequality Constraints

These constraints represent the system operating constraints as follows:

1) Generation Constraints

Generator voltages V_G and reactive power output Q_G are restricted by their lower and upper limits as follows:

$$V_{G_i}^{\min} \le V_{G_i} \le V_{G_i}^{\max}$$
$$i = 1, 2, \ldots\ldots\ldots, NG.$$
$$Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max}$$
$$i = 1, 2, \ldots\ldots\ldots, NG \qquad (20)\ \&\ (21)$$

Where NG is the number of generators.

Transformer Constraints

Transformer tap T settings are bounded as follows:

$$T_i^{\min} \le T_i \le T_i^{\max}$$
$$i = 1, 2, \ldots\ldots\ldots\ldots\ldots, NT. \qquad (22)$$

Where NG is the number of generators.

Switchable VAR Constraints

Switchable VAR compensations QC are restricted by their limits as follows:

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}$$
$$i = 1, 2, \ldots\ldots\ldots\ldots\ldots, NC. \qquad (23)$$

Where NC is the number of switchable VAR sources.

Security Constraints

These include the constraints of voltages at load buses VL and transmission line loadings S1 as follows:

$$V_{Li}^{\min} \le V_{Li} \le V_{Li}^{\max}$$
$$i = 1, 2, \ldots\ldots\ldots\ldots\ldots, NL.$$
$$S_{1_i} \le S_{1_i}^{\max}$$
$$i = 1, 2, \ldots\ldots\ldots\ldots\ldots\ldots, n1 \qquad (24)\ \&\ (25)$$

Multi-Objective functions Optimization

The goal of voltage stability improvement under contingency condition is to minimize the active power losses and voltage deviation by optimal positioning of SVC and its corresponding parameter. Aggregating the objectives and constraints, the problem can be mathematically formulated as a non-linear constraints multi-objective optimization problem as follows [33]:

$$Minimize\left[P_L(x,u), VD(x,u)\right]$$

Subjected to:

$$g(x,u) = 0$$

$$h(x,u) \le 0$$

Where x is the vector of dependent variables consisting of load bus voltages VL, generator reactive power outputs QG, and transmission line loadings S1. Hence, x can be expressed as follows:

$$x^T = \left[V_{L_1},......,V_{L_{NL}};Q_{G_1},.......,Q_{G_{NG}};S_{1_1},.......,S_{1_{nl}}\right]$$

The u is the vector of control variable consisting of generator voltages VG, transmission tap settings T, and shunt VAR compensations QC. Hence, u can be expressed as follows:

$$u^T = \left[V_{G_1},......,V_{G_{NG}};T_1,.......,T_{NT};Q_{c_1},.......,Q_{c_{NC}}\right]$$

g is the equality constraints.

h is the inequality constraints.

Hence, the multi-objective function also can be expressed as follows:

$$\min\ f = P_{Loss} + \lambda_1 LVD + \lambda_2 C + \lambda_3 L + \lambda_4 SVSM$$

Where

$$P_L = \sum\left[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)\right]Y_{ij}\cos\varphi_{ij}$$

$$VD = \overset{\max}{k \in \Omega}\left|V_k - V_{refk}\right|$$

$$C = 0.0003Q^2 - 0.3051Q + 127.38$$

$$L = 0.0003Q^2 - 0.3051Q + 127.38$$

$$SVSM = 0.0003Q^2 - 0.3051Q + 127.38$$

$\lambda_1, \lambda_2, \lambda_3, \lambda_4 =$ Penalty factors to give equal weightage for losses voltage deviation, cost of SVC, and Loadability of system.

Subjected to

Equality constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{N_B} V_i V_j Y_{ij} \cos(\delta_{ij} + \gamma_j - \gamma_i) = 0$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{N_B} V_i V_j Y_{ij} \sin(\delta_{ij} + \gamma_j - \gamma_i) = 0$$

Inequality constraints

$$Q_{sh}^{\min} \le Q_{sh} \le Q_{sh}^{\max}$$

$$V_i^{\min} \le V_i \le V_i^{\max}$$

There are a number of approaches to solve the multi-objective optimization problem. Since SVC placement according to the multi-objective functions is difficult with an analytical method, a PSO technique is proposed in this paper to achieve a tradeoff between the objective functions.

5. RESULTS AND DISCUSSIONS

6. CONCLUSIONS

In this paper presents the optimal placement techniques for SVC form different performance parameter of systems viewpoints such as improve the voltage profile, reduce active power losses, reduce the voltage deviation and cost of systems, increase the loadability of systems. The proposed technique also applicable for optimal placement of other FACTS controllers such as TCSC, SSSC, STATCOM, UPFC, GUPFC, IPFC in similar fashion.

ACKNOWLEDGMENT

The authors would like to thanks Dr. S. C. Srivastava, and Dr. S. N. Singh, Indian Institute of Technology, Kanpur, U.P., India, for their valuables suggestions regarding optimal placement techniques for FACTS controllers form different performance parameter of systems viewpoints such as improve the voltage profile, reduce active power losses, reduce the voltage deviation and cost of systems, increase the loadability of systems.

REFERENCES

1. P. Kundur, Power System Stability and Control, Mc Graw-Hill: New York, 1994.
2. K. Y.Lee and M. A. El-Sharkawi (Editors), “Tutorial on modern heuristic optimization techniques with applications to power systems IEEE Power Engineering Society,” IEEE Catalog Number 02TP160, Piscataway, NJ, 2002.
3. K. Y.Lee and M. A. El-Sharkawi (Editors), “A tutorial course on evolutionary computation techniques for power system optimization,” IFAC Symposium on Power Plants and Power System Control, Seoul, Korea, 2003.
4. K. Y.Lee (Editor), “Tutorial on intelligent optimization and control of power systems,” the 13th International Conference on Intelligent Systems Application to Power Systems, Arlington, VA, 2005.
5. J. G. Vlachogiannis, N. D. Hatziargyriou, and K.Y. Lee, “Ant Colony System Based Algorithm for Constrained Load Flow Problem,” IEEE Trans. Power Syst., Vol. 20, No. 3, pp. 1241-1249, August 2005.
6. S. Gerbex, R. Cherkaoui and A.J. Germond, “Optimal location of multitype FACTS devices in a power system by means of genetic algorithms,” IEEE Trans. Power Syst., Vol. 16, No. 3, pp. 537–544, August 2001.

7. K. Y. Lee, X. Bai, and Y. M. Park, “Optimization Method for Reactive Power Planning Using a Genetic Algorithm,” IEEE Trans. Power Syst., Vol. 10, No. 4, pp. 1843-1850, November 1995.
8. Kundur P., “Inter-area Oscillations in Power System,” IEEE Power Engineering Society, pp. 13-16, October 1994.
9. Kazemi, and B. Badrzadeh, “Modeling and Simulation of SVC and TCSC to Study Their Limits on Maximum Loadalibility Point,” Electrical Power & Energy Systems, Vol. 26, pp. 619-626, 2004.
10. Claudio A. Canizares, and Zeno T. Faur, “ Analysis of SVC and TCSC Controllers in Voltage Collapse,” IEEE Trans on Power Systems, Vol. 14, No. 1, February 1999.
11. Y. Mansour, W. Xu. F. Alvarado, and C. Rinzin, “SVC Placement Using Critical Modes of Voltage Stability,” IEEE Trans. on Power Systems, Vol. 9, pp. 757-762, May 1994.
12. Cigre Working Group, “Modeling of Static VAR Systems for Systems Analysis,” Electra, Vol. 51, pp.45-74, 1977.
13. Malihe M. Farsangi, Hossein Mezamabadi-pour, “Placement of SVCs and Selection of Stabilizing Signals in Power Systems, “IEEE Trans. on Power Systems, Vol. 22, No. 3, August 2007.
14. K. Sharma, A. Ghosh, and R. K. Verma, “A Novel Placement Strategy for FACTS Controllers”, IEEE Trans. on Power Delivery, Vol. 18, No.3, July 2003.
15. N. Martins and L. T. G. Lima, “Determination of Suitable Locations for Power System Stabilizers and Static Var Compensators for Damping Electro-mechanical Oscillation in large Scale Power Systems,” IEEE Trans. on Power Systems, Vol. 5, No.4, pp. 1455-1469, November 1990.
16. M. K. Verma, and S. C. Srivastava, “Optimal Placement of SVC for Static and Dynamic Voltage Security Enhancement,” International Journal of Emerging Electric Power Systems, Vol.2, issue-2, 2005.

17. Narain G.Hingorani**,** L.Gyugyi “Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems”.IEEE Press, 2000, ISBN0-7803- 345508.
18. C.J.Parker I.F. Morrison, D**.** Sutanto “Application of an Optimisation Method for Determining the Reactive Margin from Voltage Collapse in Reactive Power Planning” IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996 1473.
19. Yakout Mansour Wilsun Xu Fernando Alvarado Chhewang Rinzin B.C” SVC Placement using critical modes of Voltage instability”. IEEE Transactions on Power Systems. Vol. 9. No. 2. May 1994, pp. 757-764.
20. M. M. Farsangi, H. Nezamabadi-Pour and K. Y. Lee, “Multi-objective VAr Planning with SVC for a Large Power System Using PSO and GA,” *Proc. 2006 IEEE PES Power Systems Conference and Exposition (PSCE),* Atlanta, USA,. 29Oct-1Nov, 2006.
21. J.G. Singh, S. N. Singh, and S. C. Srivastava, “Placement of FACTS Controllers for Enhancing Power System Loadability”, IEEE Trans. on Power Delivery, Vol. 12, No.3, July 2006.
22. R. K. Verma, “Control of Static VAR systems for Improvement of Dynamic Stability and Damping of Torsional Oscillations,” Ph. D. Thesis, IIT Kanpur, April 1998
23. Roberto Mingues, Federico Milano, Rafael Zarate-Minano, and Antonio J. Conejo, “Optimal Network Placement of SVC Devices,” IEEE Trans. on Power Systems, Vol.22, No.4, November 2007.
24. S. Chang, and J. S. Huang, “Optimal SVC Placement for Voltage Stability Reinforcements,” Electric Power System Research, Vol.42, pp.165-172, 1997.
25. R. M. Hamouda, M. R. Iravani, and R. Hacham, “Coordinated Static VAR Compensators for Damping Power System Oscillations,” IEEE Trans. on Power Systems, Vol. PWRS-2, No.4, November 1987.

26. Yuan-Lin Chen, “Weak Bus-Oriented Optimal Multi-Objective VAR Planning,” IEEE Trans on Power Systems, Vol. 11, No.4, November 1996.
27. Ying-Yi Hong, and Chen-Ching Liu, “A heuristic and Algorithmic Approach to VAR Planning,” IEEE Trans on Power Systems, Vol. 7, No.2, May 1992.
28. Y. Chang, “Design of HVDC and SVC Coordinate Damping Controller Based on Wide Area Signal,” International Journal of Emerging Electric Power Systems, Vol. 7, Issue 4, 2006.
29. P. Gupta, “Voltage Stability Margin Enhancement using FACTS controllers,” Ph. D. Thesis, IIT Kanpur, October, 2000.
30. J. Kennedy, and R.Eberhart, “Particle Swarm Optimization,” in Proc. 1995 IEEE Int. Conf. Neural Networks (ICNN’95), Vol. IV, pp. 1942-1948, 1995.
31. Sidhartha Panda ,Narayana Prasad Padhy“Comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design ” Applied Soft Computing 8 (2008) 1418–1427.
32. Z.LGaing, “A particle swarm optimization approach for Optimum design of PID Controller in AVR system” IEEE Trans. Energy Conv. 9 (2) (2004) 84–391.
33. M .A. Abido, and J.M. Bakhashwain, “Optimal VAR dispatch using a multi-objective evolutionary algorithm,” Electrical Power & Energy Systems, Vol. 27, 2005, pp.13-20.