ISSN 2347 - 3983

Volume 1, No.2, October 2013

International Journal of Emerging Trends in Engineering Research

Available Online at http://warse.org/pdfs/2013/ijeter02122013.pdf

Optimal Placement of SVC with Cost Effective Function Using Particle Swarm Optimization

B Chandra sekhar[1] Prof Dr.N Visali[2]

[1] PG Scholar, EEE, JNTUACE Pulivendula, India, bandisekhar208@gmail.com

[2] Professor, EEE, JNTUACE Pulivendula, India, nvisali@gmail.com

ABSTACT

Present day power systems are being operated closer to their stability limits due to ever increasing load demand. In such a stressed condition, the system may enter into voltage instability problem and it has been found responsible for several line outages. At any point of time, a power system operating condition should be stable, meeting various operational criteria and it should also be secure in the event of any credible contingency. Insertion of FACTS devices is found to be highly effective in preventing voltage instability. A FACTS device in a power system improves the voltage stability, reduces the power loss and also improves the load ability of the system. Here SVC is used as a FACTS device and can be seen as a variable shunt reactance that adjusts automatically in response to changing system operative conditions. This paper proposes a Particle Swarm optimization (PSO) primarily based algorithmic program for the best location and setting of FACTS devices with cost effective function to boost voltage stability. Particle swarm optimisation technique optimizes the placement and setting of SVC. The effectiveness of the planned algorithmic program has been tested on IEEE-30 Bus standard test system.

Keywords — Power System, Optimization, Particle Swarm Optimization, SVC, Real Power Losses, cost function.

1.INTRODUCTION

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 load ability of a network is very expensive and many constraints have to be satisfied. It is expected that the secure, efficient and economical operation of power system will become more difficult because of more complex power flow in the future. As a result, the cost reduction and efficiency improvement are needed not only for the power plant operation but also for the power system operation. Voltage profile is improved by controlling the production, absorption and flow of reactive power throughout the network. Reactive power flows are minimized so as to reduce system losses. As a result, there is a significantly increased potential for the application of FACTS devices due to their important role.

Flexible AC transmission devices (FACTS) identifies the AC transmission incorporating with power electronics-based devices or alternative static controllers. FACTS devices will give management of one or a lot of AC transmission parameters (e.g. voltage magnitudes, phase of bus voltages) to reinforce controllability and increase power transfer capability[6]. Basic applications of FACTS devices, for instance, are increase of transmission capability, voltage management, power flow management, reactive power compensation, stability improvement [2].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 [3].

This paper focuses on the placement of SVC, for improving the voltage profile and reducing the real power losses. SVC is a shunt FACTS device which is designed to maintain the voltage profile in a power system under normal/contingency conditions. In practical power systems, all buses have different sensitivity to the power system security/stability, some buses are more and some are less. If SVC is allocated at more sensitive buses, it will effectively improve the voltage profile stability [1]. Reactive power designing or VAR designing is, therefore, a crucial issue in power systems. Reactive power designing deals with associate degree allocation of reactive power sources (or VAR sources) to permit the system to dependably operate, improve voltage profiles, decrease line losses, and proper system power factor. To realize such advantages, it's necessary to confirm the optimal numbers, locations, and sizes of selected power unit sources to be put in within the network.

Reactive power designing is a large scale combinatorial optimization drawback which is mathematically formulated with continuous and discrete variables as well as discontinuous, non-differentiable and non-linear equations. With such a feature of reactive power designing drawback, it is

very difficult or generally not possible to seek out the best solution by typical improvement algorithms. One economical technique, that has been tested as a robust tool to resolve this kind of drawback, is particle swarm optimization (PSO).In this work, a searching method is developed by supported PSO algorithm to work out the best reactive power designing and SVC served as VAR source. The best allocation of SVC device is examined on IEEE 30-bus system with completely different objective functions. The obtained best solutions and their related numerical results are mentioned.
Two models of SVC are usually implemented for load flow analysis of a power system [4]:

1.1 SVC Susceptance model:

A changing susceptance *BSVC* represents the fundamental frequency equivalent susceptance of all shunt modules making up the SVC. This model is an improved version of SVC models.

1.2 SVC Firing angle model:

The equivalent susceptance, **Beq** which is function of a changing firing angle, is made up of the parallel combination of thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive susceptance. This is a new and more advanced SVC representation. This model provides information on the SVC firing angle required to achieve a given level of compensation.

2.SVC EQUIVALENT SUSCEPTANCE MODEL

Enhancement of power electronics technology including control methods have made possible the development of fast SVC's in the early 1970's. The SVC consists of a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching circuits. From the operational point of view, the SVC can be considered as a variable shunt reactance that adjusts automatically according to the system operative conditions. Depending on the nature of the equivalent SVC's reactance, i.e., capacitive or inductive, the SVC draws either capacitive or inductive current from the network. Suitable control of this equivalent reactance allows voltage magnitude regulation at the SVC point of connection. The most popular configuration for continuously controlled SVC's is the combination of either fix capacitor and thyristor controlled reactor or thyristor switched capacitor and thyristor controlled reactor.

3. PROBLEM FORMULATION

3.1 Modelling of SVC

The SVC is a shunt type FACTS device defined as a shunt connected static volt-ampere generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the power system, usually the bus voltage [4]. The SVC will inject or absorb its reactive power (QSVC) at a selected bus. It injects reactive power into the system QSVC <0 and absorbs reactive power from the system if QSVC > 0[9]. The operating range of SVC is between -100MVar and 100MVar [7].
The SVC is modelled as a generator or absorber of reactive power as shown in Figure 1.

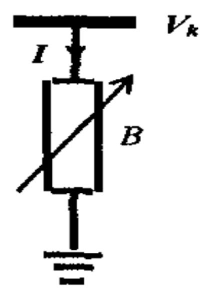

Figure 1: Variable susceptance model of SVC

The transfer admittance equation is

$$I_{svc}=j\,B_{svc}\,V_k \qquad (1)$$

The reactive power equation is

$$Q_k=-V^2_k\,B_{svc} \qquad (2)$$

In SVC susceptance model, the total susceptance Bsvc is taken to be the state variable, therefore the linearised equation of the SVC is given by

$$\begin{bmatrix}\Delta P_k\\ \Delta Q_k\end{bmatrix}=\begin{bmatrix}0 & 0\\ 0 & Q_k\end{bmatrix}\begin{bmatrix}\Delta\theta_k\\ \Delta B_{svc}/B_{svc}\end{bmatrix} \quad (3)$$

At the end of iteration i the variable shunt susceptance BSVC is updated according to

$$B_{svc}^{(i)}= B_{svc}^{(i-1)}+ (\Delta B_{svc}/B_{svc})^{(i)} B_{svc}^{(i-1)} \quad (4)$$

This changing susceptance value represents the total SVC susceptance which is necessary to maintain the nodal voltage magnitude .

3.2 Objective Function and Constraints

The goal of voltage stability improvement below contingency condition is to attenuate the active power losses and voltage deviation by best positioning of SVC with maximum total reduction in cost and its corresponding parameters.

Hence, the objective function can be expressed as:

Max TRC=((PL_2-PL_1)*8760*C*1000)-(D*(N_d*IC) (5)

Where,

TRC= Total reduction in cost in Rs.

PL_2=Real power loss with SVC in MW.

PL_1=Real power loss without SVC in MW.

D=Depreciation cost (0.1).

C=Cost per unit in Rs (5).

N_d=No of devices.

The cost of installation of SVC devices has been mathematically formulated and given by the following equation [12, 13]:

$$IC = C_{svc} \times S \times 1000 \quad (6)$$

IC =The installation cost of SVC devices in [Rs],
C_{svc}= The cost of SVC devices in [Rs/KVar].
Installation of SVC device can be calculated using the cost function given by [2, 6, 15].

$$CSVC = (0.0003s^2 - 0.3051s + 127.38)*55 \text{ (Rs/KVar)} \quad (7)$$

$$S = |Q_2 - Q_1|$$

where
S = Operating range of SVC in [MVar].
Q1 = Reactive power flow through the branch before SVC installation.
Q2 = Reactive power flow through the branch after SVC installation.
Subjected to the subsequent equality constraints

$$PGi - PLi = Ui\sum_{k=1}^{n}(Uk[Gik\cos(\theta i - \theta k) + Bik\sin(\theta i - \theta k)]) \quad (8)$$

$$QGi - QLi = Ui\sum_{k=1}^{n}(Uk[Gik\sin(\theta i - \theta k) - Bik\cos(\theta i - \theta k)]) \quad (9)$$

And the inequality constraints
Power flow limits: The apparent power that is transmitted through a branch one should not exceed a limit value, S1 max, that represents the thermal limit of the line or transformer in steady-state operation[4]:

$$Sl \leq Slmax \quad (10)$$

Bus voltages: For many reasons (stability, power quality, etc.), the bus voltages should be maintained around the nominal value:

$$Uimin \leq Ui \leq Uimax \quad (11)$$

4.IMPLEMENTATION OF PSO ALGORITHM

PSO is originally attributed to Kennedy, Eberhart and Shi and was first intended for simulating social behaviour, as a stylized representation of the movement of organisms in a bird flock or fish school. PSO is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best known position and is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. The fitness value is also stored[10]. This value is called Pbest. once a particle takes all the population as its topological neighbours, the simplest value could be a global best and is termed Gbest. when finding the two best values, the particle updates its velocity and positions with following equation (12) and (13).

4.1 Algorithm of Proposed Methodology

Step 1:Input line data, bus data, svc data, voltage limits, line limits and PSO settings.
Step 2: Establish the simplest location for svc placement by the calculation of total active power loss of the system and connect the svc to its specific bus.
Step 3: Calculate the base case power flow with the svc connected at the known bus.
Step 4: Randomly generate associate initial population (array) of particles with random positions and velocities on dimensions within the resolution area and Set the iteration counter i=0.
Step 5: For every particle, calculate and compare its objective operate worth with the individual best. If the target value is above Pbest, set this value as the current Pbest and record the corresponding particle position.
Step 6: Choose the particle related to the minimum individual best Pbest of all particles, and set the value of Pbest as the current overall Gbest.
Step 7: Update the velocity and position of particle using the velocity and position update equations.

$$V_i^{k+1} = W*V_i^{ki} + C_1*rand1*P_{best\ i} - S_i^k + C_2*rand2*G_{best} - S_i^k \quad (12)$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad (13)$$

Step 8: If the iteration number reaches the maximum limit, go to step 9. Else set iteration index i = i+1 and go back to step 5.
Step 9: Display the optimal solution to the target problem. The best position gives the location for svc resulting in minimum total active power loss for the system.
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
C1 = C2 = individual and social acceleration constants (0 to 3)
rand1=rand2=random numbers (0 to1)
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
itermax = Maximum iteration number
iter= Current iteration number
Pbest i= Particle best of agent i
Gbest= Global best of the group

4.2 Optimal Parameter Value

Table1: Optimal Value of PSO Parameters

Parameters	PSO values
Population size	15,20,30
Initial inertia weight	0.9
Final inertia weight	0.4
Constant,C1	2
Constant,C2	2
Number of iterations	100
Rand1	0 to 1
Rand2	0 to 1

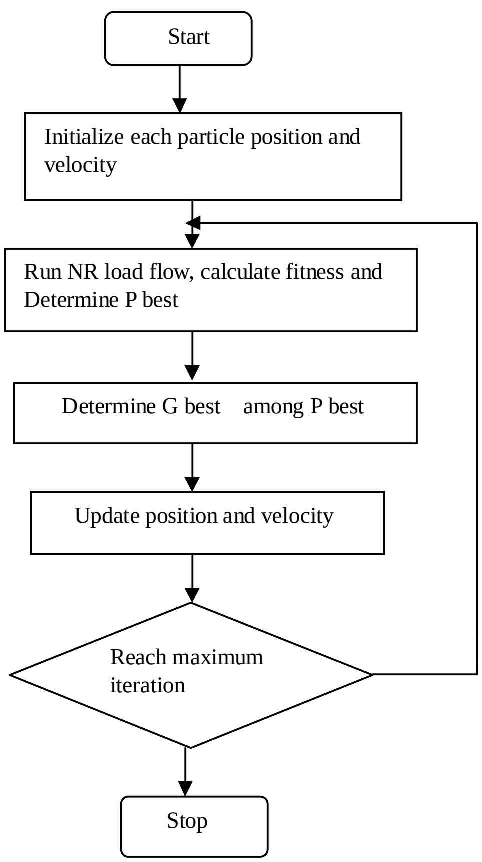

Figure 2: Flow Chart for the PSO Algorithm

5. RESULTS AND DISCUSSION

The effectiveness of proposed approach has been illustrated using the medium size IEEE 30 bus test system. The system line and bus data are given in [11]. The system has 6 generator buses, 24 load buses and 41 transmission lines. The possible location for installation of SVC device is only the 24 load buses. The primary objective of minimization of real power losses with cost effective function, subject to voltage limit and reactive power limit constraints. The base case without SVC bus voltage level is compared against the base case with SVC and the voltage profile is as given in Figure.3.The figure shows that optimal placement of SVC slightly adjusted the voltages of PQ buses and for minimising the losses. The figure clearly states that each one the bus voltages are at intervals within the set limits at minimum active power loss with SVC at optimum location, which is at24-bus.

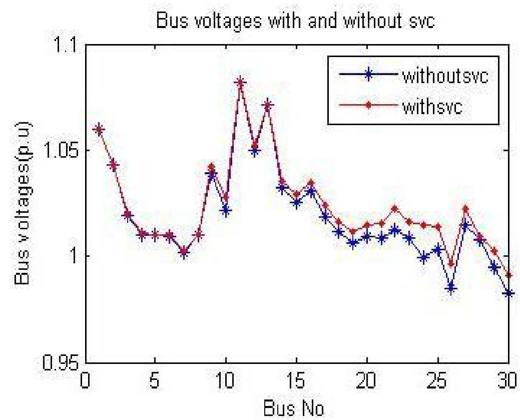

Figure 3.Typical voltage levels with and without svc

The active power loss and cost functions of the system with and without SVC is shown in Table 2. The losses are reduced when the SVC is optimally located. The investment cost and reduction in total cost are also shown in table 2.

Table 2: Active Power Loss and cost function without and with SVC

	Total Real Power losses in MW	Location of SVC	SVC Sizing (MVAR)	SVC investment cost in Rs	Overall system reduction cost in Rs
With out SVC	17.759	_	_	_	_
With SVC	17.616	24	7.025	6888.831	1.298638497e+006

6. CONCLUSION

This paper presents the application of PSO technique to reduce the total cost of the system by minimizing the real power losses and improve the voltage profile by optimal placement of SVC. The effectiveness of the proposed method was demonstrated using an IEEE 30 bus system. The settings of the PSO parameters are shown to be optimum for this kind of application and therefore the formula is ready to seek out the optimum solutions with a comparatively little variety of iterations and particles, so with an inexpensive machine effort. Results show that the real power loss and voltage violation have been greatly reduced after optimization using the proposed method. From the results it is concluded that the system performs better when the SVC is connected.

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