International Journal of Research & Development Organisation

ISSN-4567-7860

JOURNAL OF ELECTRICAL AND ELECTRONINS ENGINEERING

PSO based Optimal Power Flow for Optimal Placement and Sizing of Static VAR Compensator

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Abstract— In recent years, the transmission lines are stressed heavily, hence there is a risk with leads to voltage instability in the power system. Hence it is difficult to operate the power system in order to maintain stable power supply. It will leads to major problems like voltage instability and power losses. Flexible AC Transmission System (FACTS) has been implemented in power system to overcome such problems. By placing these devices in suitable location, optimal power flow can be obtained. In this paper, Particle Swarm Optimization (PSO) is used to optimize the location of the FACTS devices as a shunt controller, Static VAR Compensator (SVC) is been taken under consideration for this paper. PSO is an iterative procedure solving multi objective optimization problems to obtain an optimal solution. Hear IEEE 14 bus system is considered for finding the optimal location and rating of SVC using PSO.

Keywords—Particle Swarm Optimization (PSO), Direct Load Flow (DLF) Method, voltage stability index, Static VAR Compensator (SVC).

I. INTRODUCTION

Flexible AC Transmission System (FACTS) [1] play a crucial role in power system, to increase the system transmission, flexibility and power flow control. FACTS devices are power electronic devices that have the ability to control various electrical parameters in transmission circuits, controls both in steady state power flow and dynamic stability. These devices involve Static VAR Compensator (SVC), Unified Power Flow Controller (UPFC), Thyristor Controlled Series Compensator (TCSC), Static Compensator (STATCOM) etc. Shunt FACTS devices are the most widely used in power networks is SVC due to its comparatively low cost and fair performance in system intensification [2]. It is a shunt-connected Static VAR Generator or absorber, the output is adjusted to exchange capacitive or inductive current so as to provide voltage support. When it is installed in a proper location, it also reduces power losses.

To solve optimization problems, Evolutionary Algorithms (EAs) have been widely used. To obtain the optimal location of SVC in the power system, many methods have been investigated. Different techniques such as Genetic Algorithm (GA), Simulated Annealing (SA), Artificial Immune system (AIS) and Particle Swarm Optimization (PSO) etc are some examples. In this paper, PSO is proposed to solve optimization problems in the transmission system. PSO is used to decide the position, types and sizes of VAR sources and their settings at different loading conditions. The equipment cost, the installation cost and the total cost of energy loss over the life of the VAR sources, can be reduced considering operational constraints. PSO is applied to obtain the best location of only one SVC with in a power system in which the objective function is defined for reducing power loss, voltage difference and cost. PSO technique is used to reduce the total loss and improve the voltage magnitude in a power system by determining the optimal placement of SVC.

MODELING OF SVC

Early SVC was used for power flow inspection, treats the SVC as a generator supporting an inductive reactance when operated within the limits. The SVC voltage regulation characteristics [3] are represented, i.e., SVC's slope as X_{st}. that the SVC slopes is assumed to be zero for voltage regulation for simpler representation. Till the SVC is operating within the limits, this assumption possibly tolerable, but may lead to entire errors if the SVC [4] is operating close to its reactive boundary. This is shown in Fig. 2. An upper characteristic of the system is considered for light load conditions. The generator will fail within its minimum reactive boundary if the slope is zero, point A. However, if the SVC slope considered, the generator operates fair enough within the limits, point B. The SVC characteristics can be represented by making the generator connected to an auxiliary bus coupled to the voltage bus with more value by an inductive reactance which is equal to the slope on the SVC [4]. The voltage bus with higher value is taken as a PQ-type, whereas the auxiliary bus is represented as a PV-type bus. The generator becomes invalid, if it is operated outside the limits. In that case, it is necessary to change the SVC value to a fixed reactive susceptance. This combined generator susceptance type gives fair results [5].

However, different numbers of buses are required for both the representations. The generator uses two or three buses, while the susceptance which is fixed makes use of only one bus. It may require the re-dimensioning and Jacobean reordering during the iterative solution, while processing the load flow analysis. It is also mandatory to verify whether the SVC can return to operate within the limits or not.

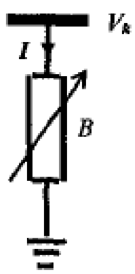

Fig.1 : Variable Shunt-Susceptance Model

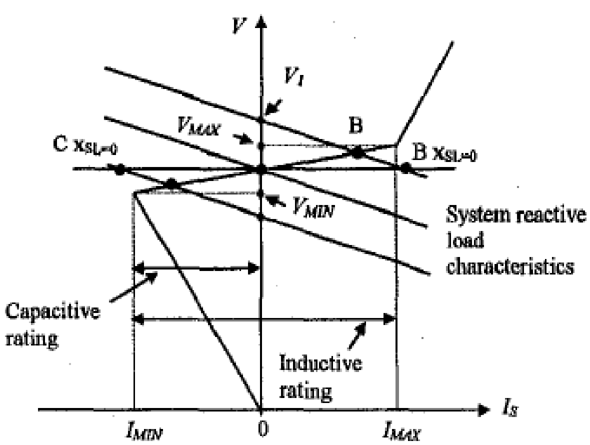

Fig.2: Voltage-Current Characteristics of SVC

It should be noted that the operation exceeding the limits, the SVC requires to be modeled as a susceptance but not as a generator set at its violated limit $Q_{voilated}$. If we ignore this point, it will result to inappropriate results. The product of the fixed susceptance, B_{fixed} and the nodal voltage magnitude V_k gives amount of reactive power drawn by the SVC. .As V_k is a function of network operating constraint, the reactive power drawn by the fixed susceptance model may change from the reactive power drawn by the generator model, i.e. (1)

$$Q_{Voilated} \neq -B_{Fixed}V_K^2 \quad (1)$$

SVC LOAD FLOWS

To extract the SVC's non-linear power equations and the linear equations required by Newton's load flow method, the circuit in Fig. 1 is used [7]. For the variable shunt compensator, the transfer admittance equation is given by (2),

$$Isvs = j\,B_{svc}\,Vk \quad (2)$$

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

And the reactive Power equation is (3),

$$Q_K = -V_K^2 B_{SVC} \quad (3)$$

SVC is a shunt connected device, which contains 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 immediate reactive power and voltage regulation comfort [3]. The SVC basic type is shown in Fig 1.

The active and reactive power flow equations of SVC are given in (4) and (5).

$$P_{Gi} - P_{Di} = V_i \sum_{k=1}^{x} \left[V_k \left[G_{ik}\cos(\theta_i - \theta_k) + B_{ik}\sin(\theta_i - \theta_k) \right] \right] \quad (4)$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{k=1}^{x} \left[V_k \left[G_{ik}\sin(\theta_i - \theta_k) + B_{ik}\cos(\theta_i - \theta_k) \right] \right] \quad (5)$$

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

II. PROBLEM FORMATION

A multi-objective optimization problem composed of objective functions with equality and inequality constraints, which are to be optimized. The equality constraints mean the typical load flow equations and the inequality constraints mean the operating limits of the SVC [7]. Here, a problem with an objective function is formulated on the reduction in cost of generation. Results can be made better by minimizing the objective function and to satisfy the constraints.

Generators fuel cost, F ($/MWhr)

Representing the objective function for minimization of generation can be represented in the equation below (6)

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

n - The number of generators.
P_{Gi}- ith generator generated power.
a_i- Cost coefficient of ith generator ($/MWh2)
b_i- Cost coefficient of ith generator ($/Mwah)
c_i- Cost coefficient of ith generator

III. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

PSO is a stochastic evolutionary computing algorithm that is generally used for optimization and search problems. This method is based on a population and the interaction of different members of the population. The PSO algorithm was first described by Kennedy and Eberhart and draws its inspiration from the movement of organisms such as a flock of birds or a school of fish. In a PSO, each probable solution is called a particle. The fitness of these particles is defined by the cost function. The number of particles is randomly chosen at the start of the problem. Initially each particle has a random velocity in the problem search space. In every iteration the fitness of the particles are calculated according to a pre-defined cost function. Based on these calculations the best fit particle is updated. Each of the particles has the capability to remember its best positions and also that of its neighbors. At the end of every iteration the particles updates their velocities in order to move towards the local and global best positions [6].The PSO algorithm [9] consists updating the velocities and positions of the particle, respectively as follows in Equations (7) and (8).

$$v_{k+1}^{i} = wv_{k}^{i} + c_1 r_1 (p_{best}^{i} - x_{k}^{i}) + c_2 r_2 (gbest_k - x_{k}^{i}) \quad (7)$$

$$x_{k+1}^{i} = x_{k}^{i} + v_{k+1}^{i} \quad (8)$$

Where V^i_K is the velocity of ith particle at the kth iteration, X^i_k (position) is current solution of the ith particle, r1 andr2 are random numbers generated uniformly between 0 and 1,c1 is the self-confidence factor and c2 is the swarm confidence factor. Usually c1 and c2 are in the range from 1.5 to 2.5.

Implementation of PSO Algorithm

The optimal placement and sizing of SVC problem will minimize the real power loss using PSO-based approach takes the following steps [10]:
Step 1: Get the Input. The input data are line (Line Impedance) and bus data (Load Power i.e., Real Power and Reactive Power) and bus voltage limits.
Step 2: Based on Direct Load Flow Method loss is calculated using distribution load flow.
Step3: Set the generation counter k = 0.
Step4: With random positions and velocities, randomly generate an initial population.
Step 5: Set the bus count C=2.
Step 6: For each particle calculate the total cost of generation using equation (6).
Step 7: Check the bus voltage limits. Exceeding the limit implies particle is infeasible.
Step 8: Objective value is compared with the individual best for each particle. If the value is less than Pbest, set this value as the current Pbest, and update the corresponding particle position.
Step 9: The particle associated with the minimum individual best Pbest is chosen, and updated this Pbest as the present overall best i.e. Gbest.
Step 10: equation (7) and (8) are the velocity and position of particle respectively are calculated and updated.
Step 11: If the count of the bus reaches the maximum limit, go to step12. Else, set bus count C=C+1, and get back to step 6.
Step 12: If the generator bus number reaches to maximum, go to Step 13. Otherwise, set generation index K=K+1, and get back to step 4.
Step 13: Optimal solutions is obtained.

The solutions include the optimal location and size of SVC in transmission system [11]. The total real power loss is minimized according to corresponding fitness values of solutions with respect to the PSO [12].

IV. RESULTS AND DISCUSSIONS

For IEEE 14 bus system, analyses are made by comparing the voltage profiles with and without SVC along with and without PSO algorithm. The SVC is located optimally at bus no 9 such that the voltage instability and power losses are greatly reduced [8]. The table below shows the explanation of the above statement.

TABLE I. COMPARISON OF BUS VOLTAGES FOR 14 BUS SYSTEM USING OPF WITHOUT AND WITH SVC

Bus no.	without SVC	with SVC at bus 9
1	1.0600	1.0600
2	1.0450	1.0450
3	0.9705	0.9717
4	0.9880	0.9903
5	0.9984	1.0003

6	0.9661	0.9709
7	0.9434	0.9493
8	0.9434	0.9493
9	0.9919	1.0000
10	0.9966	1.0041
11	0.9887	0.9949
12	0.9713	0.9765
13	0.9558	0.9612
14	0.9567	0.9638

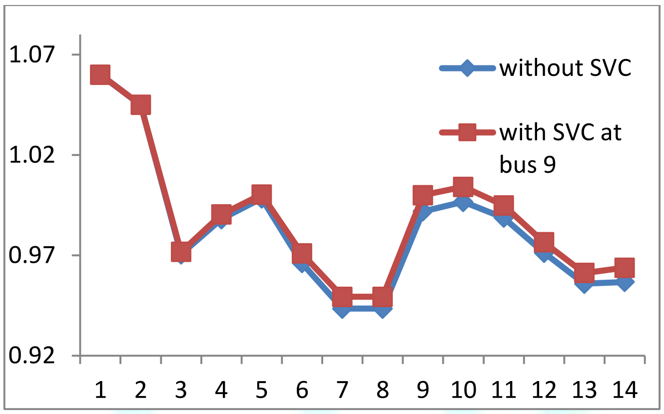

Fig 3.Voltage magnitude

TABLE II.COMPARISON OF BUS VOLTAGES FOR 14 BUS SYSTEM USING PSO-OPF WITHOUT AND WITH SVC

Bus no.	PSO without SVC	PSO with SVC at bus 9
1	1.0600	1.0600
2	1.0250	1.0350
3	0.9502	0.9679
4	0.9699	0.9932
5	0.9820	1.0020
6	0.9477	0.9650
7	0.9251	0.9511
8	0.9251	0.9511
9	0.9724	1.0000
10	0.9773	1.0034
11	0.9695	0.9920
12	0.9520	0.9703
13	0.9367	0.9564
14	0.9369	0.9616

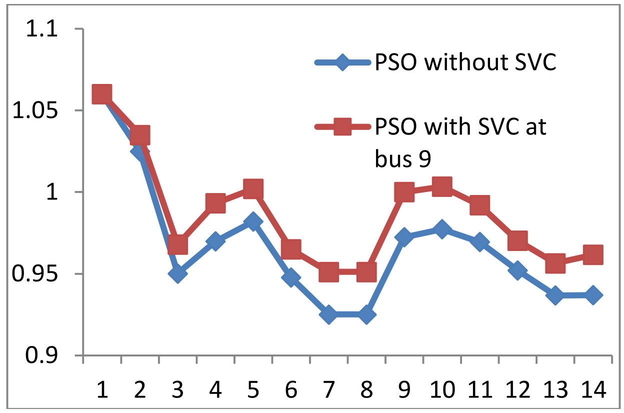

Fig 4.Voltage magnitude using PSO

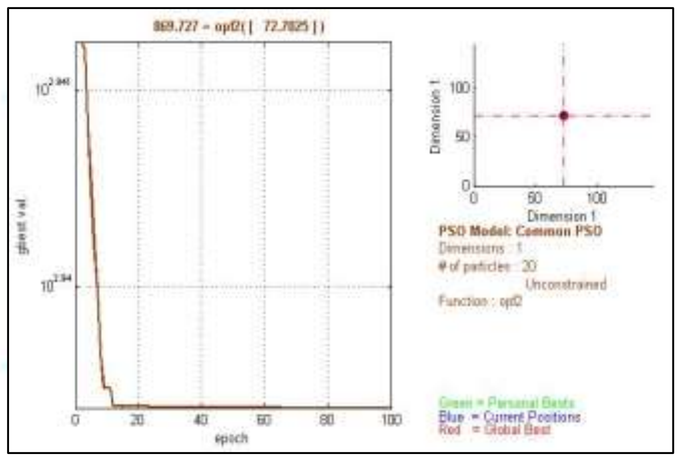

Fig 5.PSO without SVC

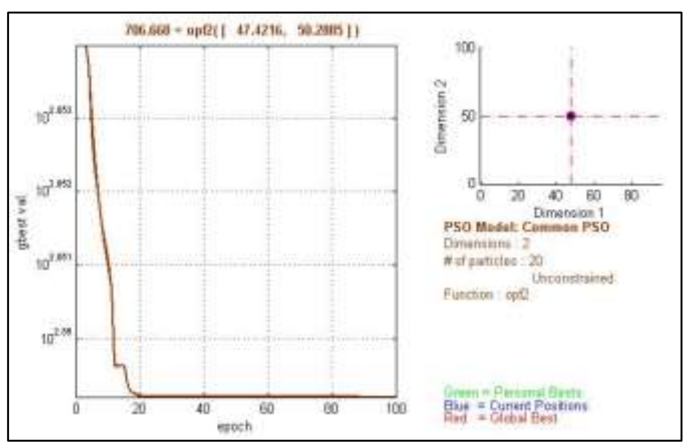

Fig 6.PSO with SVC

TABLE III.LOSSES, SVC SIZE& COST

	P_{LOSSES}	SIIZE OF SVC	COST
PSO	13.4021	-	86.727
PSO WITH SVC	9.5358	50.2851	706.668

V. CONCLUSION

The results show that incorporating the SVC in the IEEE 14 bus system can reduce the total active power losses and improve the voltage profile of the system. We clearly understand from the values that PSO aides in the optimal placement of SVC. In addition, the cost reduction is also analysed and seen that cost is quite reasonable.

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