Improvement of Voltage Stability by Optimal Placement and Sizing of Static Var Compensator using Particle Swarm Optimization

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Abstract— **In this paper, Particle Swarm optimization (PSO) algorithm is used to determine the optimal placement and size of Static Var Compensator in transmission network. The objective function is defined to minimize voltage deviation and power loss and combination of voltage deviation and Power loss. The results are tested on IEEE 5 bus and 14 bus system with the help of MATLAB. Optimal placement of SVC is verified by voltage sensitivity method. Optimal sizing of SVC is verified by Power World Simulator.**

Keywords— *Static Var compensator, Voltage Deviation, Power loss, Particle swarm optimization algorithm (PSO)*

I. INTRODUCTION

Today, Electricity demand is increased as number of industries is increasing day by day. Electricity consumption is becoming high in commercial and residential areas also. The electric utilities are suffering from different government policies, electricity theft and loss of generation. High consumption of electricity causes increase in number of transmission line in power network, which results in complex power system. Hence, utilization of electrical power is more as compare to generation. Result is, Power systems are running closer to stability. Voltage stability is defined as ability of power system to maintain acceptable voltages at all buses in normal as well as after being subjected to disturbance [1]. The voltage instability may occur when a power system is heavily loaded in transmission line and lacks in local reactive power sources [2].

The reactive power sources are power electronic devices known as Flexible alternative current transmission system (FACTS) which helps in preventing voltage instability [3].Facts devices include Static var Compensator (SVC), Thyristor controlled series compensator (TCSC), unified power flow controller (UPFC) etc [4][5]. Several methods like genetic algorithm (GA), reactive power spot price index (QSPI), simulated annealing (SA), artificial immune system (AIS) are used for optimal placement of Static Var compensator. In [6], considering more critical contingencies, GA is applied for minimizing real power loss, voltage deviation and rating of SVC for optimal placement of

SVC. In [7], Optimal placement of SVC is done using QSPI technique which explains optimal placement of SVC reduces real and reactive power spot prices, real power loss, generation cost etc. In [8], simulated annealing technique is used for optimal location to install VAR Sources. It also finds the type and sizes of VAR sources as well as setting of VAR sources at different loading condition. In [9], optimal placement of SVC is done by maximizing loading where non-linear programming problem is used which include binary decisions for actual placement of SVC. In [10], optimal location of three SVC's were identified through Particle Swarm Optimization (PSO) where Voltage Stability Index (VSI) is used as the main objective function. Minimum value of VSI at particular bus shows optimal bus for SVC placement.

After reviewing above papers, it clears the idea that there are many modern methods which are used for optimal placement of SVC. In this paper, optimal placement of SVC is done with the help of one of the modern method like PSO. This paper also include optimal sizing of SVC.As SVC is costly, its size is also important. Hence this paper determines optimal placement and sizing of SVC. Second part of this paper shows information related to SVC. Third part of this paper shows basics of PSO and its algorithm. Fourth part of this paper comprises of problem formulation where voltage deviation (VD) and power (real and reactive both power) loss are used as two main objective function. Minimized value of VD, Power loss and VD+Ploss with different sizes of SVC are found out. Fifth part of this paper shows simulation results. At particular bus minimum VD and minimum power loss and minimum size of SVC, Minimum VD +Ploss these four criterions helps in finding optimal placement of SVC.

II. STATIC VAR COMPENSATOR

Static Var Compensator is shunt connected FACTS device. Means it is installed in parallel with a bus. This device is able to generate or absorb reactive power at location where it is placed .SVC is made up of mechanically switched reactor, Thyristor controlled reactor (TCR), Thyristor Switched Capacitor (TSC), Harmonic Filter and mechanically switched capacitor. If load is capacitive, TCR consume VARs and lower system voltage. If load is inductive, capacitor

banks are switched on to supply VARs and higher system voltage. Hence, SVC consumes or supply reactive power to compensate voltage. The equivalent diagram of SVC having fixed capacitor FC with TCR is shown in Fig.1.This combination provides a fast variable source of reactive power.
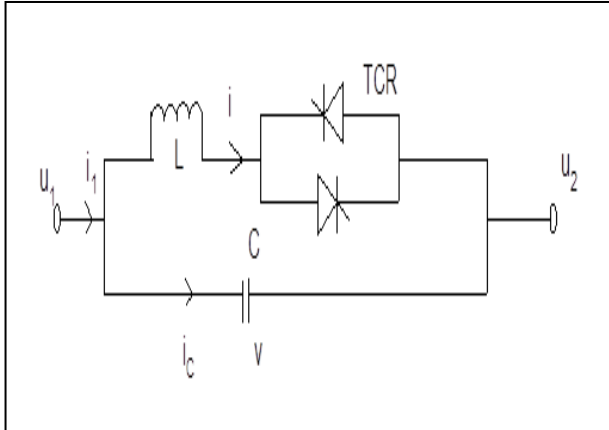

Fig 1: Equivalent Circuit of SVC

III. BASIC CONCEPT OF PARTICLE SWARM OPTIMIZATION

The PSO is based on the behavior of colony of living things like colony or swarm of insects such as ants, bees, termites, wasps. PSO is inspired by a flock of birds and fish schooling [11], [12]. PSO is population based algorithm. The word "Particle" denotes a bird in a flock or bee in a colony." Swarm" means moving particles which have certain velocity. "Optimization" means obtaining best results from given circumstances.

The PSO algorithm was originally proposed by Kennedy and Eberhart in 1995.They proposed an algorithm where each particle is located randomly in space. Particle is assumed to have two characteristics a) Position b) Velocity.

Each particle wonders around in the space and remembers its best position .This individual best position (obtained by using its own knowledge) is called "Pbest". Particle achieve best position in a group (obtained by sharing knowledge among a group) is called "Gbest". Individuals or particles in swarm, approach the optimum through its current velocity, earlier experience and the knowledge of its neighbors [13].The formulae used to find modified position and velocity are shown in equation (1) and (2).

$$Xi(t) = Xi(t-1) + Vi(t) \tag{1}$$

$$Vi(t) = w*Vi(t-1) + \Phi1*rnd1*(Pi - Xi(t-1)) \\ + \Phi2*rnd2*(Pg - Xi(t-1)) \tag{2}$$

$$Vi(t) = Inertia + Cognitive + Social. \tag{3}$$

Where ,

Xi (t)	=	New particle position
Xi (t-1)	=	Previous position
Vi (t)	=	New particle Velocity
Vi (t-1)	=	Previous Velocity
w	=	Inertia Weight
Φ1 & Φ2	=	Two positive numbers

Pi	=	Individual best position (Pbest)
Pg	=	Global best position
rnd1 & rnd2	=	Two random numbers in the range of (0,1)

Equation (3) shows three components.

First component shows the term inertia which develop the tendency of the particle to carry on in the similar direction in which it was moving.[14]shows, inertia weight is used in original version of PSO to equilibrium the local and global search during the optimization process.

Second component shows the linear pull towards the best position found by the given particle. This component is known as "self-knowledge".

Third component shows linear pull towards the position found by any particle .This component is known as "group knowledge.

A. PSO Algorithm:

Consider an objective function which has to maximize or minimize.
Suppose Minimize
Take minimize function to be F(X).
With $X^l \leq X \leq X^u$
Where ,

$X^l \longrightarrow$ Lower limits of X
$X^u \longrightarrow$ Upper limits of X

Here F(X) is given in equation 5 and 6.
Initial SVC size used in PSO algorithm is given in table below.

Table 1: Initial SVC Size

Sr.No.(j)	SVC Size (p.u)
1	0.16
2	0.22
3	0.33
4	0.25
5	0.4
6	0.028
7	0.37
8	0.38
9	0.19
10	0.125

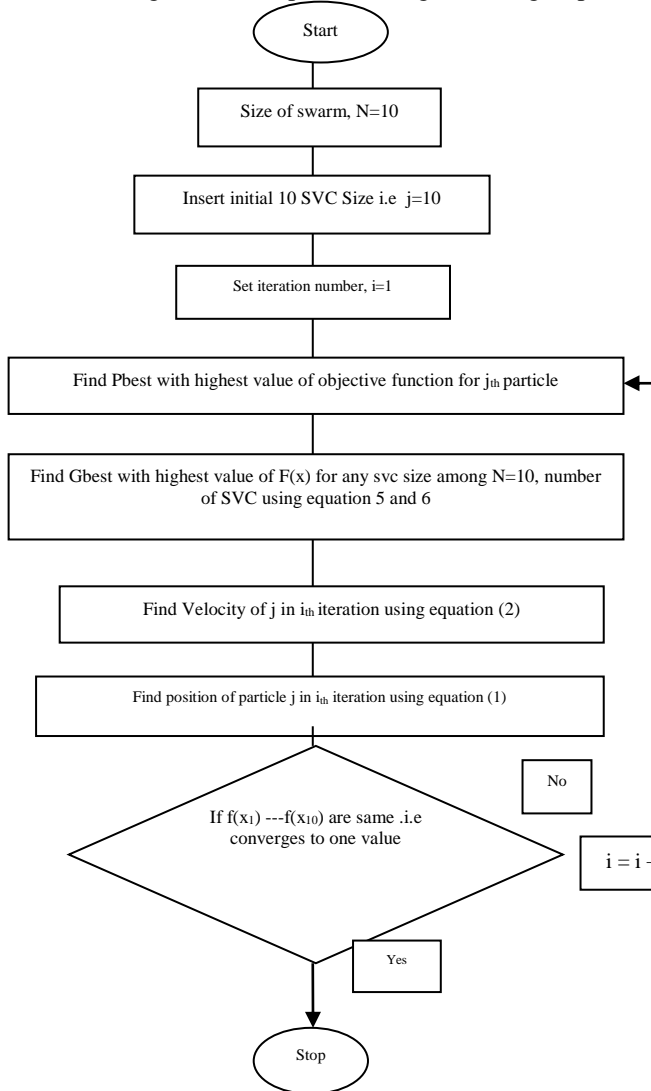The PSO algorithm is explained using following steps:

Fig 2: PSO Algorithm flowchart

B. PSO Parameters:

Studies on PSO shows that, the particles diverge from its required position i.e go to infinity called explosion. Hence to control this explosion inertia weight 'w' is used. Value of 'w' gradually reduces over time. Φ_1 and Φ_2 are called acceleration constant .They controls the travelling of each particle towards its individual best and global best position. Small value of them limits movement of particle while large value may cause particles to diverge [15]. Hence it is necessary to define the values of these particles accurately. Table 1 Shows, PSO parameters used in this paper.

Table 2: PSO parameters

Parameters	PSO
Population Size	**10**
Inertia weight	0.9-0.4
Constant Φ_1	1.4
Constant Φ_2	1.4
No. of Iterations	20

C. Problem Formulation:

The aim of optimization problem is to minimize voltage deviation and power loss.
In particle swarm optimization, objective function is given as follows,

$$F = F1+F2 = VD + Ploss \qquad (4)$$

Where,

VD = Voltage deviation

Ploss = Network real power loss

$$F1 = VD = (\ |\ Vi - Vref\ |\ /\ Npq\ ) \qquad (5)$$

Where,

Vdev = Voltage Deviation

Vref = load bus reference voltage value =1

Vi = load bus voltage

Npq = load bus number

Subject to 0.95 < Vm (per unit) <1.1.

$$F2 = Ploss = \Sigma\ g_k\ [V_{i2} + V_{j2} - 2\ Vi\ V_j \cos \theta_{ij}\ ] \qquad (6)$$
Where,

g_k = Conductance

V_i = Sending end voltage

V_j = Receiving end voltage

θ_{ij} = Angle between V_i and V_j

IV.SIMULATION RESULT

A. Particle Swarm Optimization
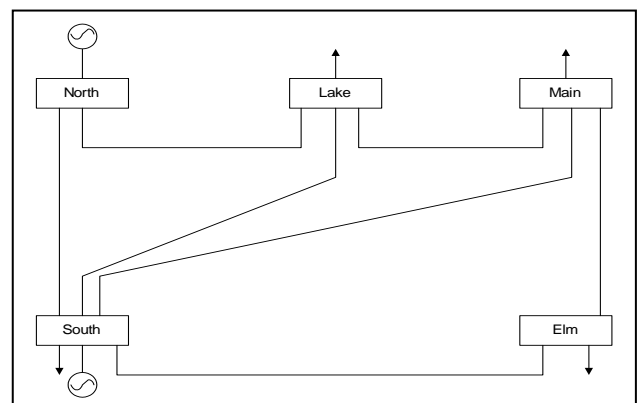
IEEE - 5 bus system shown in Fig 3.

Fig 3: IEEE 5 bus system

IEEE 5 bus data is taken from [16]. Matlab programming with SVC and without SVC are taken from [17]. Matlab programming for

PSO is taken from [18].Results are tested not including SVC, including SVC and with PSO.

Table No 3 shows, load buses where SVC is connected. For load buses SVC size , total Voltage deviation , power loss and combination of total voltage deviation and power loss is given .

Table 3: Results with SVC and PSO

Bus no	SVC size in p.u	Min VD (p.u)	Ploss (p.u)	Min VD+Ploss (p.u)
2	0.6540	0.4843	0.069	0.5533
3	1.6594	0.1032	0.063	0.1662
4	1.5021	0.0598	0.061	0.1208
5	3.0116	0.2491	0.067	0.3161

As shown in table no.3,VD , Ploss and VD + Ploss are minimum at bus number 4.SVC size is minimum at bus number 2 but VD, Ploss, VD + Ploss values are more as compare to bus number 4.Another minimum size is 1.5021 at bus number 4. This also explained in Fig.3, where 'bus number' is scale on X-axis. On Y-axis SVC size (p.u), Min VD (p.u), Ploss (p.u) and VD + Ploss (p.u) are shown Which shows, optimal placement of SVC is at bus number 4 and optimal size of SVC is 1.5021(p.u) for IEEE 5 bus system.
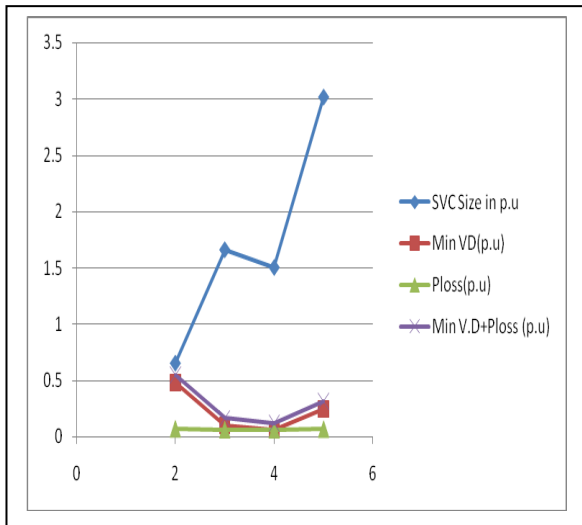

Fig 4: 'Bus no.' Vs 'SVC Size, Minimum Voltage Deviation (p.u) and Ploss (p.u), VD+Ploss (p.u)'for IEEE 5 bus System
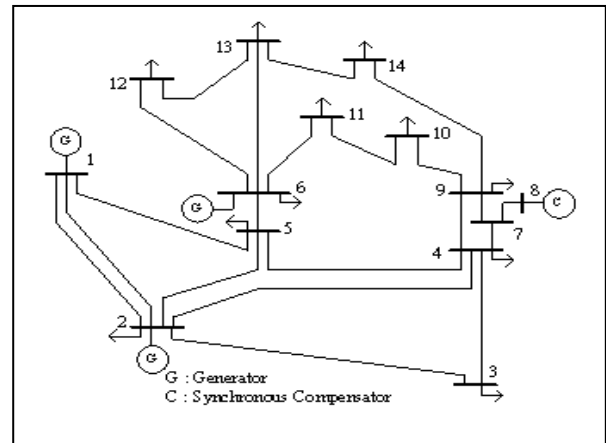
IEEE-14 bus test system (shown in Fig-5).

Fig 5: IEEE 14 Bus System

The program is run for different load buses of the IEEE 14 bus and results are shown in table 4 given below.

Table 4:Results with SVC and PSO for IEEE 14 bus system.

Bus no	VD(p.u)	Svc size	Ploss	VD+Poss
4	0.0091	1	0.1891	0.1982
5	0.0103	1	0.1884	0.1988
6	0.0099	0.16	0.1894	0.1992
9	0.018	1	0.1985	0.2165
10	0.0291	1	0.227	0.2561
11	0.0232	1	0.2508	0.274
12	0.0256	0.88	0.2991	0.3247
13	0.0109	0.86	0.235	0.2459
14	0.0445	0.92	0.2894	0.3339

As shown in table no. 4, VD, Ploss and VD + Ploss are minimum at bus number 5. Svc size is minimum at bus number 6 but other values are high as compare to bus number 5.The same idea is explained by fig 6.On X axis 'bus number' is scaled . On Y-axis SVC size(p.u), Min VD(p.u), Ploss(p.u) and VD+Ploss (p.u) are shown Which shows, optimal placement and size of SVC is at bus number 9 and optimal size of SVC is 0.16 (p.u).
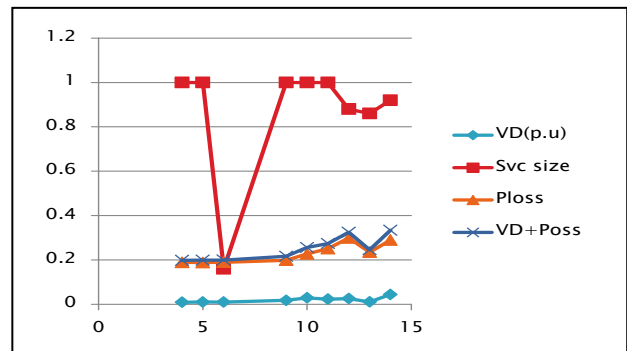

Fig 6: 'Bus no.' Vs 'SVC Size, Minimum Voltage Deviation (p.u) and Ploss (p.u), VD+Ploss(p.u)'for IEEE 14 bus System

B. Voltage Sensitivity:

Optimal placement of SVC is done by another approach i.e using Voltage sensitivity method.

Voltage sensitivity is given by formula,

$$VSF = \frac{VM \text{ with } SVC - VM \text{ without } SVC}{VM \text{ with } SVC}$$

(6)

Where VSF = Voltage sensitivity factor
        VM = Voltage magnitude of bus
The bus where voltage sensitivity factor is highest that bus is best for placement of SVC.

Table 5: .Average of Voltage sensitivity for IEEE 5 bus system

Bus Number	Average of voltage sensitivity
3	-0.0093
4	0.02845
5	0.02664

Average of Voltage sensitivity for IEEE 5 bus system is highest at bus number 4 shows optimal place for SVC.

Table: 6: Average of Voltage sensitivity for IEEE 14 bus system

Bus Number	Average of voltage sensitivity
4	-0.00974
5	-0.00804
6	0.000309
9	-0.02939
10	-0.03097
11	-0.02279
12	-0.017
13	-0.01648
14	-0.0323

Average of Voltage sensitivity for IEEE 14 bus system is highest at bus number 6 shows optimal place for SVC.

C.Power World Simulator

C.1 IEEE 5 bus diagram without SVC and with SVC:
Optimal size of SVC is verified by Power World Simulator. IEEE 5 bus system is shown in fig.7 & 8.Where, Without SVC p.u voltages at the buses are less as compared to With SVC of size 1.p.u connected at bus number 4.
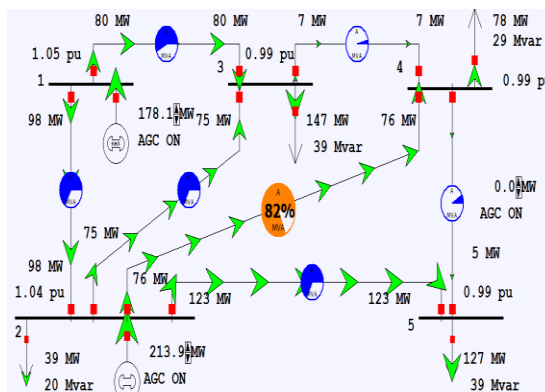

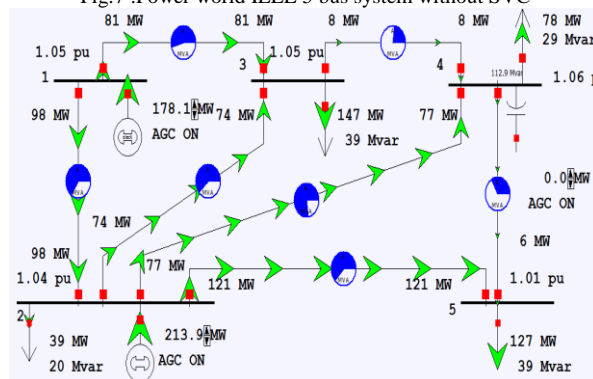Fig.7 :Power world IEEE 5 bus system without SVC

Fig.8:Power world IEEE 5 bus system with SVC at bus 4

Table7: IEEE 5 bus result with 1.5 sizes of SVC with Power World Simulator

Bus number	VD (p.u)
3	0.0062
4	0.0053
5	0.0105

C.2 IEEE 14 bus diagram without SVC and with SVC
IEEE 14 bus system is shown in fig. Without SVC p.u voltages at the buses are less as compared to With SVC of size p.u connected at bus number 6.
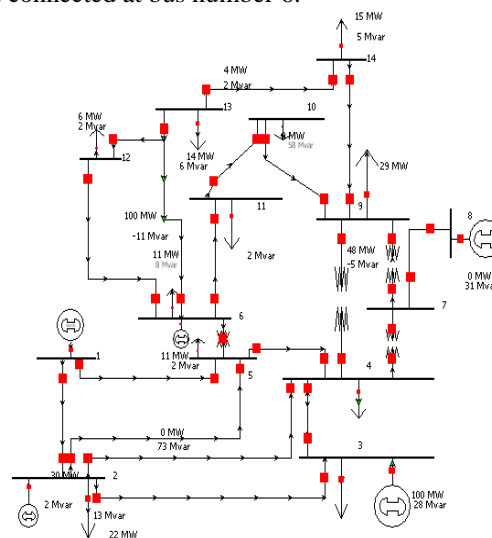

Fig. 9: Power world IEEE 14 bus system without SVC

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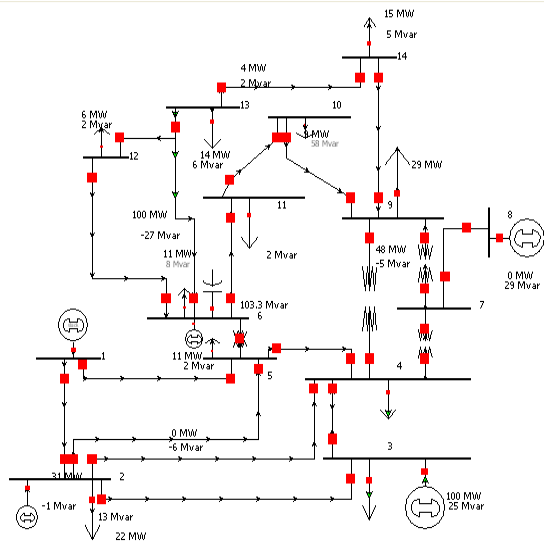

Fig.10 Power world IEEE 14 bus system with SVC at bus number 6

Table 7: IEEE 14 bus result with 0.16 (p.u) sizes of SVC with Power World Simulator

Bus number	VD(p.u)
4	0.000303
5	0.000303
6	0.000288
9	0.00159
10	0.004562
11	0.00256
12	0.006456
13	0.0052
14	0.002872

V. CONCLUSION:

The result obtained from the IEEE 5 bus and 14 bus system test shows that the PSO algorithm is very efficient in finding minimum SVC size, voltage deviation and power loss ,Voltage deviation +Ploss (p.u).Hence optimal placement of SVC in IEEE 5 bus system is at bus number 4. And optimal size of SVC is1.5021 p.u. Similarly in IEEE 14 bus system, optimal placement of SVC is bus number 6 and optimal size of SVC is 0.16 p.u. optimal placement is justified by voltage sensitivity method and optimal sizing is justified by Power world simulator.