Loss Minimization and Voltage Profile Improvement Incorporating Multiple SVC using PSO Algorithm

A. Subramanian	G. Ravi	D. Arun Gopal
Department of Elec & Elect	Department of Elec & Elect	Student
V.R.S.college of Engg &Tech	Pondicherry engineering college	V.R.S. college of Engg & Tech
Tamil Nadu	Puducherry	Tamil Nadu

ABSTRACT
Relieving the power system from the effects of heavy losses and higher voltage magnitude deviations is very important to improve the voltage profile at the load buses. In this paper, multiple FACTS devices with the view to minimize load voltage magnitude deviations and network losses using particle swarm optimization have been presented. The strategy uses multiple static VAR compensators and offers optimal locations for placement of the devices and parameters. Test results on IEEE 30 bus system with and without FACTS device reveals the superiority of the algorithm and operation of SVC in power system.

General Terms
FACTS Flexible AC transmission system

FSQV Full sum QV

g_k Conductance of transmission line k

nb Load buses

nl Transmission lines

P_{loss} System real power loss

PSO Particle swarm optimization

SVC Static VAR compensator

UPFC Unified Power Flow Controller

V_{di} Voltage magnitude deviation at bus i

V_j,V_{ref} Voltage magnitude at j and reference buses respectively

w1, w2 Weight constants

λ Load factor

S_{nb} Size of the SVC at load bus

Keywords
PSO, FSQV, FACTS devices, SVC, Voltage Stability,

1. INTRODUCTION
Power system at present day is meeting different problems in maintaining voltage stability due to many reasons such as environmental, political, increased population, unscheduled loading etc. These problems can cause higher losses of about 5-13% of the generated power [1]. In addition the load bus voltage should be within the tolerance for safety operation and to provide quality power to the consumers.

Recent developments in power electronic devices have introduced flexible AC transmission systems (FACTS) that include Thyristor controlled series compensator (TCSC), Static VAR compensator (SVC), Unified Power Flow controller (UPFC) etc. These devices can facilitate the control of power flow, improve the power transfer, increases the reactive reserve capacity, and reduce the voltage magnitude deviations at the load buses by providing flexibility to the operation of power systems. However the decision on the size and the location are of great significance in obtaining the benefits of FACTS devices [2-3].

The placement of FACTS devices can be described as an optimization problem with an objective of minimizing system losses, voltage magnitude deviations, improving the reactive power reserve and cost minimization. The constraints may include power flow and security limits under normal, contingent and congestion conditions. FACTS placement problem may be a non-linear and non-convex problem and becomes the most challenging optimization problem in power system.

Numerous methods are available to solve the optimization problems and optimal placement of FACTS devices in power systems, for improving the voltage stability, minimizing the losses and to reduce the voltage magnitude deviations. An operation strategy has been suggested for voltage profile improvement in [4]. New challenging methods have been discussed for voltage stability in [5]. Neural network has been proposed in [6] for voltage stability improvement. Real and reactive power loss reduction with reactive power reserve has been explained in [7] by the optimal placement of single FACTS device, SVC using PSO. The way to manage the reactive power reserve in the power system has been elaborated in [8], the author explained that 20% of reserve can be made to be available in the power system by the placement of suitable devices. A literature survey has been made for the prevention of voltage instability by proper usage and placement of FACTS devices in the power system in [9]. FACTS device placement for congestion relief and voltage stability problem has been proposed in [10]. Bacteria foraging based algorithm has been used in [11] for real power loss and voltage stability limit improvement. PSO algorithm has been applied in [12] for the reactive power and voltage control with the consideration of voltage profile improvement using multiple TCSC.

Solution techniques for optimization may be classified as conventional methods, intelligent global search methods, neural network, fuzzy set applications, neuro-fuzzy methods etc. The conventional methods include linear programming and non-linear programming. The intelligent search based methods uses GA, simulated annealing, evolutionary programming, ant colony algorithm, bee colony algorithm, tabu search and PSO. Particle swarm optimization is the simplest, robust and easiest algorithm to apply over other methods. The fundamental concepts and social behavior of swarming has been brought out in [13]. In [14] the performance of PSO and GA in FACTS controller design has been compared and the significance of PSO are outlined. A Particle swarm optimization approach has been used in [15] for the design of PID controller to control the voltage automatically. Particle swarm optimization tool has been handled in [16] for the placement of multiple type FACTS devices in power system in view of enhancing maximum loadabilty point.

Different types of line and bus stability indices are used to ascertain the maximum voltage stability point of the line and bus of the power system. Voltage stability index determines how far the system is from voltage collapse. A study has been established in [17] on various indices to show the suitability of the index in determining the maximum loadabiltiy point or voltage collapse point. In this paper an index to determine the maximum loadability point has been used based on the system reactive power and bus voltages known as Full sum QV (FSQV) from [18]. The main problem is that the voltage on its own is often a poor indicator of voltage instability. But FSQV considers reactive power with bus voltage. Based on index, predefined protective measures at the most critical buses can be executed. In the proposed method multiple SVC has been placed using the PSO algorithm with the FSQV index to minimize the system losses and to reduce the voltage magnitude deviations.

2. STATIC VAR COMPENSATOR

Static VAR compensator (SVC) is a simplest, low cost FACTS device which is connected in shunt at load buses as a VAR generator or absorber, whose output is adjusted to enhance capacitive or inductive currents so as to control specific parameters of electric power system, typically a bus voltage. The performance characteristics and construction are detailed in [2].SVC can be used as susceptance model to adjust the susceptance of the transmission line and as VAR compensator to control the reactive power of the buses. For the connection of steady state model of SVC in a particular load bus ‘i’ then the exchanged reactive power at that bus is $Q_i = Q_{svc}$. The equivalent circuit of the SVC is shown in figure 1.

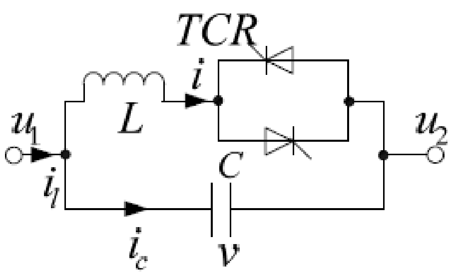

Fig 1: Equivalent circuit of SVC

3. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is one of the best and simplest optimization technique and algorithm used in the field of power system optimization especially for the placement of FACTS devices. It is first proposed by Kennedy and Eberhart in 1985 [13]. The main idea of the PSO is based on the food searching behavior of birds and schooling of fishes. It is a population based algorithm as the other type of GA and ant colony algorithms.

In PSO the objective is imported on the particle and they are made to randomly move in the search space with a velocity. In each and every iteration the position and velocity of each particle is updated form its own memory, using the equations (1, 2), and best particle (pbest) is selected from the particles. The global best particle (gbest) is selected at the end of the iteration from the pbest particle, which is the optimal size and location; parameters of the SVC are tabulated in table 1.

$$v_{j,g}^{(t+1)} = w \times v_{j,g}^{(t)} + c_1 \times r_1() \times \left(Pbest_{j,g} - x_{j,g}^{(t)}\right) + c_2 \times r_2() \times \left(gbest_g - x_{j,g}^{(t)}\right) \quad (1)$$

$$x_{j,g}^{(t+1)} = x_{j,g}^{(t)} + v_{j,g}^{(t+1)} \quad (2)$$

The various steps involved in the operation of PSO algorithm have been given through the flow chart as in figure 2.

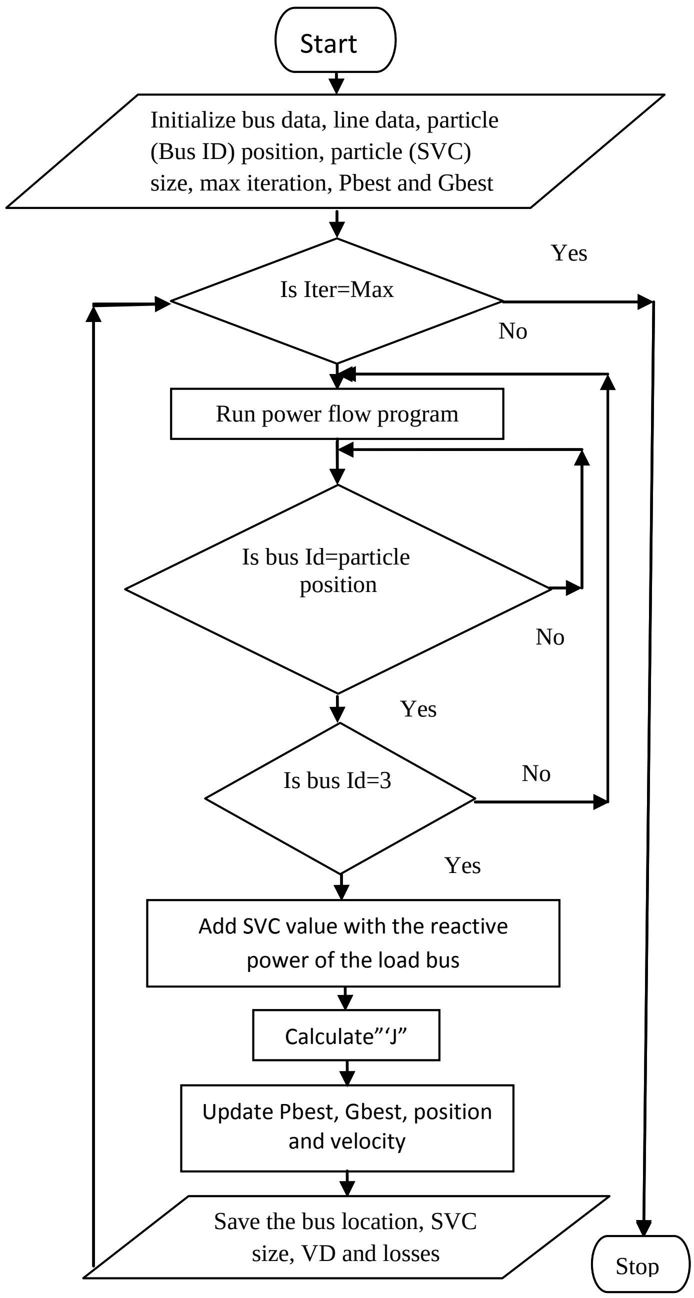

Fig 2: Flowchart for PSO algorithm

Table 1: Parameters of PSO

S.no	Parameter	Optimal value
1	Number of particles	20
2	Inertia weight	0.7
3	Individual acceleration constant	2.5
4	Social acceleration constant	2.0
5	No of iterations	500
6	Velocity bounds	{-2,7}
7	$Rand_1$	0.3
8	$Rand_2$	0.2

4. PROBLEM FORMULATION

The FACTS devices should be installed at the best possible locations with optimal parameter settings in order to minimize the load voltage magnitude deviations and real power losses. The FACTS placement problem is formulated as an optimization problem in reducing voltage magnitude deviations and real power losses as a bi- objective function.

$$\text{Minimize } \varphi = w_1 \sum_{i=1}^{n} V_{di} + w_2 P_{loss} \quad (3)$$

$$V_{di} = \sum_{i=1}^{nb} \sqrt{(V_i - V_{ref})^2} \quad (4)$$

$$P_{loss} = \sum_{k=1}^{nl} g_k \left(V_i^2 + V_j^2 - 2V_iV_j \cos\theta_{ij}\right) \quad (5)$$

where w_1 and w_2 are the weight constants,

Maximum loadability index

$$FSQV = \sum_{j=1}^{nb} \frac{\partial Q_i}{\partial V_i} \quad (6)$$

Subject to

FACTS device constraints

$$-100 \text{ MVAR} \leq Q_{svc} \leq +100 \text{ MVAR} \quad (7)$$

Power flow constraint

$$P_i = V_i \sum_{j=1}^{N} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}\right) = 0 \quad (8)$$

$$Q_i = V_i \sum_{j=1}^{N} V_j \left(G_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}\right) = 0 \quad (9)$$

where 'i' and 'j' are buses and N=number of buses

Voltage Constraints

$$V_i^{min} \leq V_i \leq V_i^{max}; \boldsymbol{i} \in \boldsymbol{N_b} \quad (10)$$

Generator reactive power capability limit

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in Ng \quad (11)$$

Transmission line flow limit

$$S_i \leq S_i^{max}; i \in Nl \quad (12)$$

5. SIMULATION and RESULT

The proposed PSO based strategy is tested on IEEE 30 bus test systems under two conditions. NR technique [19] is used to carry out the load flow during the optimization process.

1. With FACTS device
2. Without FACTS device.

The real power losses, voltage magnitude deviations, FSQV and SVC size under with FACTS device and without FACTS device are shown in table 2 for different load factor. It is clear from the table that the real power losses are lesser in amount for the installations of FACTS devices at the load buses 4 and 29 over the without FACTS device condition, and the real power losses are given in MW. The voltage magnitude deviations are less in with FACTS device case over the without FACTS device under all load factor. This is mainly because of the proper location of SVC at 4th and 29th buses of the IEEE 30 bus system and its reactive power exchange with the system. From the result, it is now clear that the buses 4 and 29 are vulnerable buses in the system. The FSQV value is high in the with FACTS device condition over without FACTS device case which is shown in figure 6, this is because the voltage magnitude deviations is less and reactive power support at the load buses are increased. Table 3 shows the voltage profile at different buses of the system under with FACTS device, and without FACTS device. Voltage profile is within the limit in the with FACTS device system than the other case. Figures-3, 4 and 5 shows the comparison of voltage profile at the buses of the system under different load factor for with and without FACTS device.

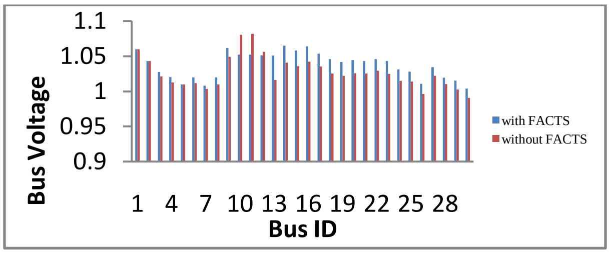

Fig 3: Voltage profile under λ =1.0

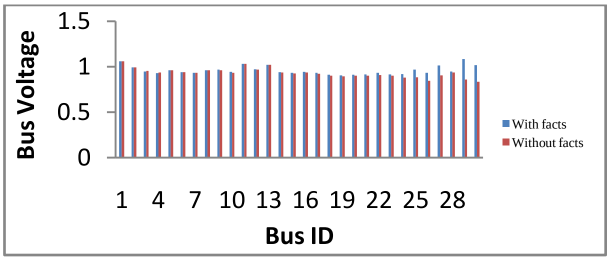

Fig 4: Voltage profile under λ=1.8

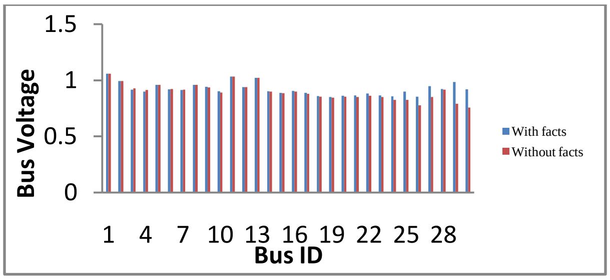

Fig 5: Voltage profile under λ =2.6

Table 2: Voltage deviation, real power losses, FSQV and SVC size

LF	Real power losses (MW)		Voltage deviation (V)		FSQV		S_{nb} (MVAR)	
	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS	S_{nb-} - 1	S_{nb} - 2
1.0	82.7612	86.2112	0.5391	0.6119	1252.3917	1246.1814	13	-9
1.4	130.4547	133.3663	0.7308	0.9557	1154.1495	1124.8352	49	-2
1.8	139.2126	145.5298	1.5342	2.1579	1056.6012	1033.5486	-35	39
2.2	139.5857	148.6528	2.4734	3.1819	982.3436	967.8424	-45	29
2.6	141.6757	153.6965	4.2743	4.7220	912.7162	877.4335	89	-1
2.78	142.3478	--	4.7398	--	897.4187	--	19	-11

Table 3: Voltage profile at different busses under with and without FACTS conditions

Bus no.	**λ** =1.0		**λ** =1.4		**λ** =1.8		**λ** =2.2		**λ** =2.6	
	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS
1	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600	1.0600
2	1.0430	1.0430	1.0130	1.0130	0.9930	0.9930	0.9930	0.9930	0.9930	0.9930
3	1.0276	1.0213	1.0021	0.9842	0.9472	0.9547	0.9175	0.9290	0.9229	0.8910
4	**1.0202**	**1.0124**	**0.9914**	**0.9692**	**0.9280**	**0.9373**	**0.8981**	**0.8924**	**0.9151**	**0.8761**
5	1.0100	1.0100	0.9600	0.9600	0.9600	0.9600	0.9600	0.9600	0.9600	0.9600
6	1.0199	1.0116	0.9788	0.9658	0.9403	0.9401	0.9205	0.9227	0.9136	0.8973
7	1.0082	1.0032	0.9590	0.9512	0.9315	0.9314	0.9149	0.9162	0.9057	0.8957
8	1.0200	1.0100	0.9800	0.9700	0.9600	0.9600	0.9600	0.9600	0.9600	0.9600
9	1.0616	1.0489	1.0130	1.0005	0.9688	0.9627	0.9411	0.9370	0.9122	0.8995
10	**1.0520**	**1.0803**	0.9960	0.9828	0.9440	0.9319	0.9009	0.8918	0.8507	0.8341
11	**1.0520**	**1.0820**	**1.0620**	**1.0520**	1.0320	1.0320	1.0320	1.0320	1.0320	1.0320
12	1.0513	1.0561	**1.0271**	**1.0124**	0.9702	0.9677	0.9400	0.9399	0.9169	0.8996
13	1.0510	1.0160	**1.0610**	**1.0510**	1.0210	1.0210	1.0210	1.0210	1.0210	1.0210
14	1.0648	1.0408	1.0032	0.9886	0.9410	0.9359	0.9009	0.8984	0.8638	0.8456
15	1.0583	1.0359	0.9945	0.9801	0.9327	0.9250	0.8888	0.8838	0.8439	0.8256
16	**1.0638**	**1.0422**	1.0034	0.9892	0.9446	0.9379	0.9048	0.9008	0.8657	0.8482
17	**1.0536**	**1.0355**	0.9904	0.9768	0.9334	0.9229	0.8883	0.8806	0.8380	0.8208
18	**1.0459**	**1.0253**	0.9770	0.9627	0.9117	0.9021	0.8604	0.8537	0.8045	0.7858
19	**1.0416**	**1.0221**	0.9713	0.9572	0.9057	0.8951	0.8521	0.8444	0.7921	0.7734
20	1.0445	1.0259	0.9763	0.9624	0.9136	0.9026	0.8621	0.8540	0.8038	0.7856
21	1.0429	1.0251	**0.9745**	**0.9609**	0.9166	0.9014	0.8643	0.8523	0.8008	0.7827
22	1.0458	1.0293	**0.9794**	**0.9666**	0.9331	0.9101	0.8819	0.8631	0.8123	0.7948
23	1.0430	1.0248	**0.9743**	**0.9607**	0.9170	0.9009	0.8645	0.8517	0.8000	0.7819
24	1.0313	1.0146	**0.9573**	**0.9449**	**0.9177**	**0.8809**	0.8560	0.8248	0.7611	0.7424
25	1.0281	1.0139	0.9535	0.9441	**0.9676**	**0.8834**	0.8991	0.8266	0.7541	0.7358
26	**1.0108**	**0.9962**	0.9268	0.9171	**0.9335**	**0.8457**	0.8534	0.7763	0.6868	0.6663
27	1.0346	1.0221	0.9641	0.9567	**1.0154**	**0.9034**	**0.9484**	**0.8524**	0.7832	0.7662
28	1.0192	1.0101	0.9739	0.9620	**0.9460**	**0.9349**	**0.9234**	**0.9155**	0.8994	0.8860
29	**1.0152**	**1.0023**	**0.9272**	**0.9260**	**1.0846**	**0.8597**	**0.9853**	**0.7925**	**0.6933**	**0.6774**
30	1.0039	0.9908	0.9123	0.9082	**1.0184**	**0.8345**	**0.9199**	**0.7581**	0.6457	0.6261

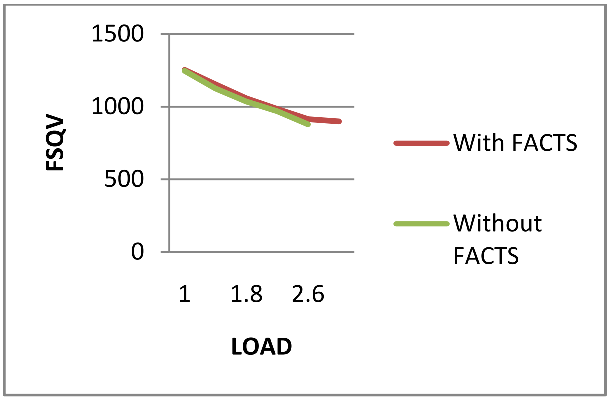

Fig 6: FSQV Vs Load

6. CONCLUSION

PSO optimization method is a natural based simple, easy to handle optimization algorithm, and suitable for optimization of power system parameters such as real power losses and voltage magnitude deviations by optimally selecting the location and size of SVC. From the result it is clear that the losses and voltage magnitude deviations are very much reduced in the with FACTS device case over the without FACTS device. The maximum loadability index FSQV is a good index in determining the maximum loadablility point and/or to indicate the voltage collapse point of the system, and suitable for practical implementation.

7. BIBILOGRAPHY

Dr. G. Ravi received B.E. degree in Electrical and Electronics Engineering from Mysore University in 1992, M.E. degree from Annamalai University in 1994 and Ph.D (Engg) from Jadavpur University in 2005. At present he is working as Associate Professor in Electrical and Electronics Engineering department at Pondicherry Engineering College which is affiliated to Pondicherry central University Puducherry. His research area includes electrical machines, power system operation, planning, optimization and soft computing techniques.

A. Subramanian received B.E. degree in Electrical and Electronics Engineering from Annamalai University in 1995. M.Tech., degree from Pondicherry Engineering College in 2004 and now pursuing Ph.D (Engg) at Anna University Trichirapalli, Trichy. At present he is working as professor in Electrical and Electronics Engineering department at V.R.S. College of Engineering and Technology Arasur, Tamil Nadu. His field of interest are power system reactive power reserve management, voltage stability and optimization techniques.

D. Arun Gopal is a B. E. student of Electrical and Electronics Engineering department at V.R.S. College of Engineering and Technology Arasur, Tamil Nadu. His areas of interest are Power system operation and optimization techniques, Electrical machines, Renewable energy resources.

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