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Voltage Stability Enhancement by Coordination of SVC and TCSC Using Particle Swarm Optimization

Maulik Pandya[1] **and J. G. Jamnani**[2]
[1]Research Scholar, [2]Associate Professor
[1]Department of Engineering & Technology, Kadi Sarva Vishwavidhyalaya, Gandhi Nagar, Gujarat, India
[2]Department of Electrical Engineering, Pandit Deendayal Petroleum University, Gandhi Nagar, Gujarat, India
E-Mail: mcpandya_ee@ldrp.ac.in, jg.jamnani@sot.pdpu.ac.in

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***Abstract* - The Flexible AC Transmission System (FATCS) plays a vital role in power system performance enhancement. They attributes to accomplish faster and having answers for many issues in power system study. With regards to this, a particles warm optimization (PSO) algorithm is implemented so that to design the coordinated parameters of static VAR compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC). Transient stability of a power system is based on the generator relative rotor angles obtained from time domain simulations outputs. A self-sufficient model of IEEE fourteen bus systems has been given with full detail and voltage stability analysis is done by considering load changing at a bus. PSO applied here is built on searching the values of L and C of SVC, then one can achieve desired and fine coordination. PSO is available with few modification, as change in PSO range & number, difference in selection criteria technique, control technique etc, with due respect to normalize PSO. The results are compared and found that coordination of FACTS devices with each other promises the efficiency of the suggested method for revamping Power flows. When function of TCSC is impelled by some curb, adjustable SVC can supply additional support to upgrade the gross performance.**

***Keywords:* Static Var compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Particle Swarm Optimization (PSO), Coordination**

I. INTRODUCTION

Flexible ac transmission system controllers have ability to extend the power transfer capability and also to enhance the stability within given limits, along with improvements in power system operation [1]. Voltage stability has been seen as a steady state problem involving static power flow studies for analysis. The voltage at various buses, the flow of active and reactive power, etc. keep on changing. It can be interpreted that the FACTS controller will normally be furnished with higher order controllers like power swing damping controller, Sub Synchronous Resonance (SSR) damping controller etc. Still to enlarge the awareness, the FACTS controllers are presumed to be furnished with basic PI controller only [2]. For improvement in operation of power system kind of interaction can occur amongst different types of FACTS controllers, which may include the interaction of stabilizers and High voltage DC (HVDC) controllers, too. It is categorized on the base of different values of frequency. The label coordination doesn't mean a centralized control; in lieu, it is recognized that the tuning of the FACTS controllers will be done together for ensuring the promising, pragmatic improvement of the overall control scheme. It is suggested that the each controller rests mainly with measure of current useable quantity. It will act separately on connected FACTS devices.

The TCSC is a prime element of FACTS (Flexible AC Transmission Systems) devices. With the firing control of the thyristor, it can change its apparent reactance smoothly and rapidly [3].The TCSC is able to directly schedule power flow along required trails and allow the network to run near to the line limits [4]. The SVC is a shunt compensation component. It is actually drafted for voltage maintenance in power structures. Ample as the TCSC, the SVC is also capable of flexible adjustment. In conventional methods, when performance of power system is normally linear, it is designed and engaged cautiously. On the event of large deviation, power system operating point alters substantially. Nevertheless, in such conditions, nonlinearities of power system have substantial effects and linear methods can't be capable of endure its stability.

Therefore, it is necessary to consider the effect of nonlinearities of power system [4]. Now a time, intelligent optimization algorithm is being widely used to design power system stabilizers. With this all circumstances, tabu search algorithm [6], genetic algorithm [7], simulate annealing, bacterial foraging algorithm (BFA) and small population based PSO are applied as intelligent algorithms for one to one coordination of stabilizer in power system. In number of literatures numerous researchers suggested for coordination betwixt Power system stabilizer and FACTS devices for encircling the vigorous presentation of the power network. In [8], global tuning method for PSS and FACTS devices by a terminology forced no dimensional optimization algorithm is suggested. The integral of squared error process is utilised for global attuning in the stabilizers by taking the multi machine power area containing SVC and TCSC besides PSS to manifest the efficient and hardiness of the proposed tuning method is also considered. In [5] combined performance of SVC-TCSC along with UPFC has been simulated under EUROSTAG environment for Voltage stability improvement. Power transfer capability enhancement with IEEE-118 bus system by four types of FACTS controllers has been presented in [16]. Hybrid Particle swarm optimization was used for the same.

Recently, quasi-oppositional chemical reaction optimization [17] was used for optimal reactive power dispatch problem for multi FACTS device.non-linear control scheme for Thyristor Controlled Series Capacitors (TCSC) has been presented [18] to analyze transient stability of a multi machine power system with non-linear control scheme. To increase the transmission capacity and enhancement of the power system stability, UPFC was proposed in [19]. There is simultaneous application of thyristor controlled series capacitor based damping controller and power system stabilizer for stability improvement of dynamic power system in [20].Voltage stability assessment with appropriate representation of SVC and TCSC is investigated and compared in the IEEE 6-bus system [21].

II. SVC AND TCSC

According to IEEE definition, SVC, known as a shunt connected static var generator; capable of stepless adjustment of reactive power over an unlimited range i.e. lagging or leading without any time delay. In its basic form it comprises of fixed capacitor bank and switched reactor bank in parallel. A duet of reverse poled thyristors is attached in sequence with a confirmed inductor to frame a Thyristor Controlled Reactor (TCR) module. When the thyristors, connected in succession with a capacitor they will pattern Thyristor Switched Capacitor module. These will draw reactive power from the line and thereby regulating voltage, improve both steady-state and dynamic stability and reduce voltage flicker. Hence it will drastically improve the voltage profile [22].

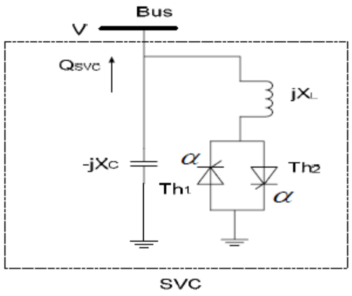

Fig. 1 SVC firing angle mode

Their primary purpose is to supply a fast-acting, precise, and adjustable amount of reactive power to the system to which they are connected. SVCs achieve this by switching in or out one or more thyristor-switched capacitors (TSCs), and by adjusting the firing angle of a thyristor-controlled reactor (TCR). Some SVCs also comprise a number of fixed capacitors (FCs) which supply a steady amount of reactive power.One of the firing angle mode is as per Fig. 1. SVCs can be used for voltage compensation at the receiver end of ac transmission lines, thus replacing banks of shunt capacitors. When used for this purpose, SVCs offer a number of advantages over banks of shunt capacitors, such as much tighter control of the voltage compensation at the receiver end of the ac transmission line and increased line stability during load variations.

The fundamental arrangement the TCSC is as per Fig. 2. The structure comprises of a Thyristor controlled reactor (TCR), a parallel capacitor and a Metal Oxide Varistor (MOV). In the same, one may found restriction in limit of firing angles, safety measure of voltage in MOV as well as the harmonic current(I), resting on line current. Consequently, the span of Reactance is further little. Potential of TCSC may be elucidated with regard to their reactance against the line current.

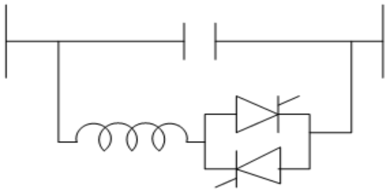

Fig. 2 Layout of TCSC

TCSC will react as an inductive or capacitive compensator by reshaping its equivalent reactance XTCSC of transmission line [9]. Its value is maintained within definite capacitive reactance span, while supplying damping to power structure. In the transient process, this controls line power flow by rapidly changing equivalent reactance. The TCSC furnishes muscular meaning of commanding and enlarging power transferral level of the system by differing the noticeable impedance of a determined transmission line. A TCSC is exploited in a drafted way for contingency to escalate power system stability [10].

III. PARTICLE SWARM OPTIMIZATION

A. Primary Goal

Particle swarm optimization is a robust technical optimization technique based on the movement and intelligence of swarms.PSO applies the concept of social interaction to problem solving. It was polished in 1995 by James Kennedy (social-psychologist) and Russell Eberhart (electrical engineer) [11]. PSO arrives with compliant & smooth adjusted mechanics to increase the global and local expedition capacity. It is applying a various agents (particles) which represent a swarm travelling in the search margin, focusing for the best solution. Each particle is viewed as a spot in an N-dimensional space, which calibrates its “flying” in fulfilment of its own flying occurrence besides the “flying” occurrence of additional agents. The agents in the optimization formulation contribute its data with one and all & run so as to approach the foremost flight for detecting optimal result by number of iterations. In particular iteration, agents will revise belonging velocity and position with operating given equation

$$\mathrm{Vi}^{k+1} = \mathrm{wv}_{\mathrm{i}}^{\mathrm{k}} + \mathrm{c}_{1\ \mathrm{rand}_{1(\ldots)}\times}\left(\mathrm{P}_{\mathrm{best}-\mathrm{s}_{\mathrm{i}}^{\mathrm{k}}}\right) + \mathrm{c}_{2\ \mathrm{rand}_{2(\ldots)}\times}\left(\mathrm{g}_{\mathrm{best}-\mathrm{s}_{\mathrm{i}}^{\mathrm{k}}}\right) \qquad (1)$$

where,

Vik - Velocity of agent I at iteration k,

W - Weighting function,
Ci - Weighting factor,
r and uniformly distributed number b/w 0 and 1,
ik current position of agent I at iteration k,
Pbes personal best position of agent I,
gbest - global best of the group.

$$W = \frac{W_{max} - \left[(W_{max} - W_{min}) \times iter\right]}{max_{iter}} \qquad (2)$$

where,
wMax, wMin - Max. & Min. Inertia weight,
maxiter - maximum iteration number,
iter - current iteration number.

Equation (2) is normally utilized in (1)

The PSO iteration is carried out to obtain the smooth voltage profile according to the algorithm of it, as shown in fig.3. The optimization issue considered in this occasion is to curtail the cost. Target in this optimization issue is to operate as a fitness function in the problem.

B. Why PSO?

With the perspective of advancement, functioning of the PSO is wagerer with respect to Genetic Algorithm [12] & then it was found that PSO appears with its terminal parameter data in very lesser number of generations than the GA. With balancing to GA, PSO was gentle to enact and it comprises of very less variables to adapt [13]. All agents in process are kept as a fellow of society through the course of procedure. PSO is the sole algorism that will not execute the existence of the fittest. In Evolutionary Programming (EP), balance betwixt the global and local search should be managed with the strategy variable, while in PSO the poise will accomplish by the inertial weight factor (w). Apart from all, PSO came with many variants like discrete PSO, MINLP PSO, and Hybrid PSO etc. Ordinary PSO have disadvantage of the short of convergence directed to global optima.

TABLE I PSO PARAMETERS

No. of Particles	10
Max. Inertia weight	0.9
Min. Inertia weight	0.4
C1, C2	0.5, 3.5
No. of Iterations	10

IV. PROPOSED APPROACH

To examine the problem, standard IEEE 14-bus system as shown in Fig.4 is depicted. It is a one line diagram representation. System parameters related to transmission lines, transformers, synchronous generators etc is according to [14]. The placement of two of the FACTS devices is decided on Load flow analysis of this particular bus system. Normally, Real rating of the SVC and TCSC can be determined by various sizing methods [15]. Load flow analysis is required to know the total amount of real and reactive power flow in the system. It will help to find out power flow pattern through system, so one can assess the voltage stability. Result of the same is in Appendix A and B. As voltages of all networks are to be within specified limits [5], we will illustrate the voltage instability by considering various loading condition. Initially, there is a load change up to 15% has been applied at different Bus. On preliminary observations, having identified weakest Bus of the system, selection of FACTS device is possible. Accordingly SVC is placed at Bus-9 and TCSC is connected in series betwixt line 9 and 14.

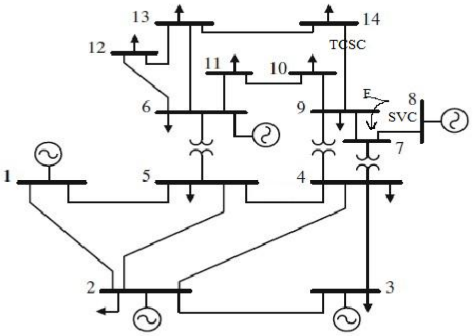

Fig. 4 IEEE-14 bus system with FACTS device

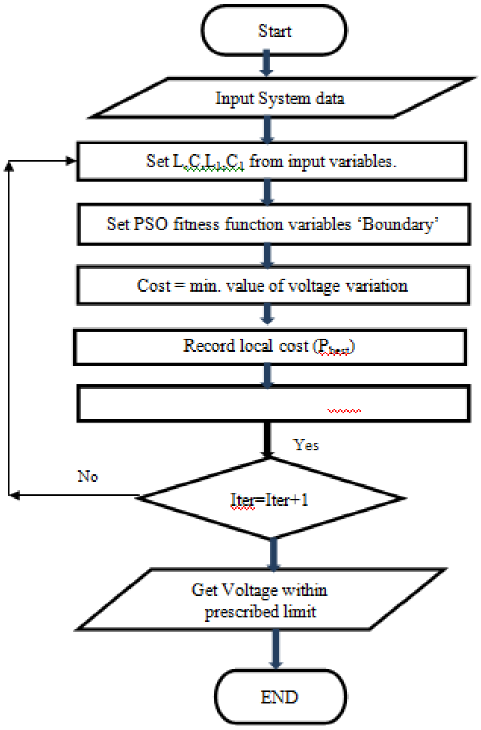

Fig. 3 Algorithm of PSO

As voltage is to be within permissible limits, we have developed a PSO algorithm. According to algorithm of fig. 3, we will initialize with Function Variables i.e. L, C, L1 and C1.Then will Set PSO Fitness Function Variables' Boundary. Generate Different Variables Combination Sets within Boundary which is equal to number of Population

Size. In One Iteration, will Set 1st Variables Combination and will give to PSO Fitness Function. It will give us its return Cost value (which is equal to minimum value of voltage variation or voltage). Here, value of voltage is to be maintained between 0.95 pu to 1.05 pu [5]. Then Save Input Variable Combination and return Cost value. Repeat the same procedure with other Variable Combinations. After Completion of All Variable Combinations, will find better Cost. From all better Cost, will find Local Cost (Pbest). Regenerate 2nd Variables Combination Sets from last Global & local Parameters. Repeat PSO function for Remaining iteration. At Completion of each iteration will get Global cost (Gbest) (which is value of voltage within prescribed limit) from previous Global Cost and Current Local Cost. After Completion of all Iteration we get Final Global Cost.

V. RESULTS AND DISCUSSION

While investigating the problem, PSO algorism is exploited for navigation of datas of SVC and TCSC controller co-ordinately with help of eq. (1). In accordance with the present procedure, simulation is put through the multi machine system in MATLAB with toolbox. PSO [11] used here is built on searching the values of L and C of SVC and TCSC, then one can achieve desired and fine coordination. PSO taken here is available with few modification, as change in PSO range & number, difference in selection criteria technique, control technique etc, with due respect to normalize PSO. Accordingly, in PSO algorithm, initially we have to Set L, C, L1, C1 from input variables. Procedure of the same has been discussed in section 4.

To understand the behaviour of network, we have made a change in load at time from 5% to 20% at Bus-9 and Bus-14. While doing this we have observed change in voltage values, which is not in prescribed limit and network loses its stability in terms of voltage. Voltage level at Bus-9 has been reduced to 0.93 pu after 15% of change in load, which will be then 0.965 pu after application of coordination of SVC-TCSC.As a result, according to fig. (5) and (6), an enhancement in level of voltage at Bus-9 and Bus-14has been observed with the action of SVC-TCSC interaction.

Similarly, to see the effect of load change, we have changed a power factor of a load at various buses, too. At Bus-9, 10, 13 and 14, power factor of a total load has been reduced, which has given us a value of voltage, which is not acceptable. Hence with help of coordination of SVC and TCSC, achieved voltage within limit. Results are shown in table II. Similar to previous case, fig. (7) and (8) validates the result and voltage stability. The important thing here is that SVC-TSCS coordination has better result than alone TCSC or SVC. On the same note, for the reactive power flow, it encountered a small decrease too, by using coordinated control. The amount of active and reactive power can be also controlled.

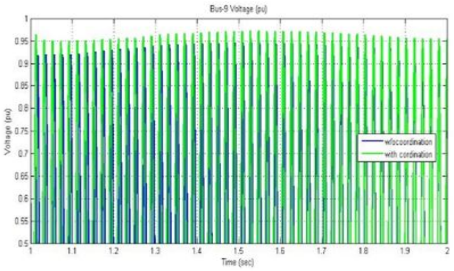

Fig. 5 Bus-9 voltage (pu)

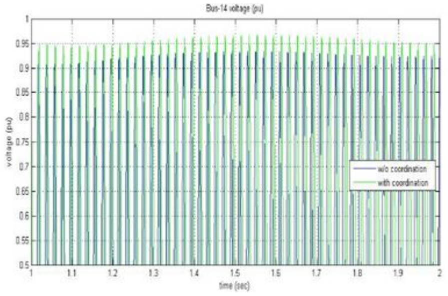

Fig. 6 Bus-14 voltage (pu)

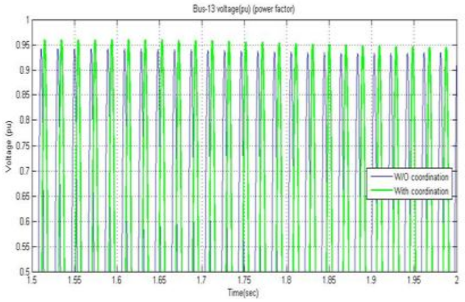

Fig. 7 Bus-13voltage (pu) (pf changed)

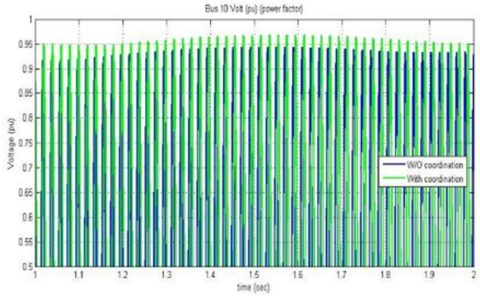

Fig. 8 Bus-10 voltage (pu) (pf changed)

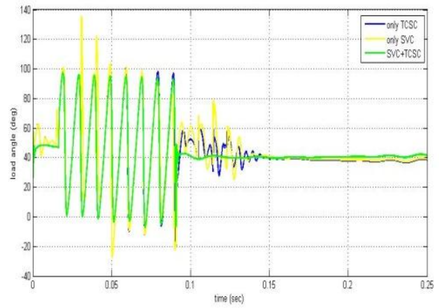

Fig. 9 Load angle at Bus-8

TABLE I VOLTAGE MAGNITUDE (PU) WHEN LOAD CHANGES

Load Changed at Bus-9	**Voltage at Bus-9**	**Voltage at Bus-13**	**Voltage at Bus-14**
Without FACTS	0.93	0.94	0.925
With coordination	0.965	0.961	0.96
Load Changed at Bus-14	Voltage at Bus-9	Voltage at Bus-13	Voltage at Bus-14
Without FACTS	0.941	0.94	0.93
With coordination	0.965	0.96	0.95

TABLE II VOLTAGE MAGNITUDE (PU) WHEN POWER FACTOR CHANGES

Bus No	**Power Factor (original)**	**Power factor (load changed)**	**Bus Voltage (pu)**	**Bus Voltage (with coordination)**
9	0.87	0.79	0.925	0.955
10	1.07	0.81	0.935	0.965
13	0.91	0.75	0.93	0.96
14	0.94	0.85	0.92	0.96

TABLE III LOAD FLOW DATA

Bus No	**Bus Voltage (pu)**
1	1.01
2	0.992
3	0.984
4	0.976
5	0.981
6	0.984
7	0.976
8	0.995
9	0.962
10	0.965
11	0.975
12	0.973
13	0.97
14	0.96

TABLE IV POWER FLOW (SIMULATION)

Bus No	**P (MW) (GEN)**	**Q (MVAr) (GEN)**	**P (MW) LOAD**	**Q (MVAr) LOAD**
1	352.16	-27.511	0	0
2	40	96.484	30.38	17.78
3	0	60.62	131.8	26.6
4	0	0	66.9	5.6
5	0	0	10.64	2.24
6	0	46.15	15.68	10.5
7	0	0	0	0
8	0	30	0	0
9	0	0	41.3	23.5
10	0	0	12.6	8.1
11	0	0	4.9	2.5
12	0	0	8.5	2.2
13	0	0	18.9	8.12
14	0	0	20.86	7

As we were interested to the evolution of Bus voltage and hence voltage stability, have also checked variation in load angle. Fig (9) shows load angle of generator at Bus-8 has been changed, when load changed at Bus-9 and gets more stable when coordination has been applied.

VI. CONCLUSION

This paper furnishes a crisp thought on outcome of coordination. Their separate donation in direction to the improvement of voltage magnitude which have experimented on a 14 bus system. The composite, SVC and TCSC has been examined, as a multi type FACTS device effect, for preservation of the voltage profile. This approach can be supported by identifying the proper location of the FACTS. The heart of the paper was SVC-TCSC combination, which have given dynamic performance under various loading condition. On the other hand, parameters like active power, reactive power (limit) and damping of oscillations can also be verified, by same coordination and with interaction of SVC & TCSC. In conclusion, appropriate coordination of FACTS devices can fruitfully refine the performance of power system.

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