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Damping Power System Oscillations in Single-Machine Infinite-Bus Power System Using a PSO based STATCOM

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ABSTRACT: Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. Flexible ac transmission system (FACTS) devices are found to be very effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. Flexible AC Transmission System (FACTS) such as Static Synchronous Compensator (STATCOM) and Static VAR Compensator (SVC), employ the latest technology of power electronic switching devices in electric power transmission systems to control voltage and power flow. A static synchronous compensator (STATCOM) is a shunt device of the flexible AC transmission systems (FACTS) family. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from power system. When system voltage is low, STATCOM generates reactive power and when system voltage is high it absorbs reactive power. In this work STATCOM controller i.e. based on particle swarm optimization algorithm is proposed in single machine system. Proposed controller is implemented under MATLAB/SIMULNK environment.

I. INTRODUCTION

It is becoming increasingly important to fully utilize the existing transmission facilities satisfying constraints of environmental legislation, right-of-way issues, cost of construction of new lines and deregulation policies that have recently introduced in the power market .But this increase in load demand on power system is a threat to transient stability limit so we need some methods to improve the transient stability limit. Control by changing the network parameters is an effective method of improving transient stability. In the late 1980s the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS). The two main objectives of FACTS are to increase the transmission capacity of existing system and control power flow over designated transmission routes.

Flexible AC Transmission System (FACTS) controllers due to their rapid response are suitable to control transient stability as they can bring quick changes in the network parameters. Transient stability control involves changing the control variables such that the system state enters in stable region after a large disturbance

Stability of power systems has been and continues to be of major concern in system operation. This arises from the fact that in steady state (under normal conditions) the average electrical speed of all the generators must remain the same anywhere in the system. This is termed as the synchronous operation of a system. Any disturbance small or large can affect the synchronous operation.

II.STATIC SYNCHRONOUSCOMPENSATOR (STATCOM)

"A Static synchronous compensator is a shunt-connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage"[1].

The concept of STATCOM was proposed by Gyugyi in 1976. Power Converter employed in the STATCOM mainly of two types i.e. is Voltage Source Converter and Current Source Converter. In Current source Converter direct current always has one polarity and the power reversal takes place through reversal of dc voltage polarity while In Voltage Source Converter dc voltage always has one polarity, and the power reversal takes place through reversal of dc current polarity.

The power semiconductor devices used in current source converter requires bidirectional voltage blocking capability and for achieving this Characteristic an additional diode must be connected in series with a semiconductor switch which increased the system cost and its becomes costlier as compared to voltage source converter moreover Voltage source converter can operate on higher efficiency in high power applications. Because of the above reasons Voltage source converter is Preferred over Current source converter and now these days it act as a basic electronic block of a STATCOM that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle [1].

STATCOM is made up of a coupling transformer, a VSC and adc energy storage device. STATCOM is capable of exchanging reactive power with the transmission line because of its small energy storage device i.e. small dc capacitor, if this dc capacitor rise replaced with dc storage battery or other dc voltage source, the controller can exchange real and reactive power with the transmission system, extending its region of operation from two to four quadrants. A functional model of a STATCOM is shown inFigure1.

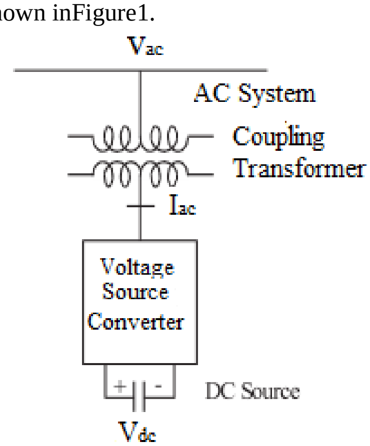

Fig. 1. Functional model of STATCOM.

III. MAJOR ADVANTAGES OF STATCOM OVER SVC

In STATCOM, maximum inductive or capacitive current can be maintained independently of the ac system voltage and the maximum VAR generation or absorption changes linearly with ac system voltage while in SVC maximum inductive or capacitive current decreases linearly with system ac voltage and maximum VAR output decreases with the square of voltage. i.e. why STATCOM is better than SVC in providing voltage support under large disturbances.

(i) STATCOM is more effective than SVC in improving transient stability of system because of its ability to maintain full capacitive output current at low system voltage.

(ii) Response time is better than SVC.

(iii) Active power control is possible in STATCOM

(iv) Installation space requirement of STATCOM is lesser as compared to SVC [1].

VI.SINGLE MACHINE INFINITE BUS SYSTEM

In this study the single machine infinite bus system which is shown in Figure 2 is used for this stability study.

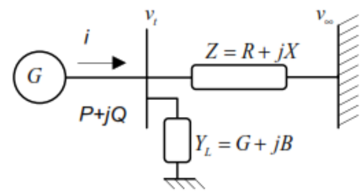

Fig.2. Single machine infinite bus system.

The STATCOM is going to be implemented to this system to check and enhance its stability. In this study the third order, nonlinear model of synchronous machine is enough for stability study, however, in case of transients stability consideration the higher order of synchronies machine is required.

IV. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization is an algorithm developed by Kennedy and Eberhart [22] that simulates the social behaviors of bird flocking or fish schooling and the methods by which they find roosting places, foods sources or other suitable habitat.

PSO is inspired firstly by general artificial life, the same as bird flocking, fish schooling and social interaction behaviour of human and secondly by random search methods of evolutionary algorithm [22]. Animals, especially birds, fishes etc. always travel in a group without colliding, each member follows its group, adjust its position and velocity using the group information, because it reduces individual's effort for search of food, shelter etc.

Fig. 3 shows the velocity and position updates of a particle for a two dimensional parameter space. The computational flow chart of PSO is shown in Fig.4.

In the basic PSO technique, suppose that the search space is d-dimensional,

(i) Each member is called *particle*, and each particle (i-th particle) is represented by d-dimensional vector and described as $Xi = [x_{i1},x_{i2},\ldots\ldots,x_{id}]$.

(ii) The set of n particle in the swarm are called *population* and described as $pop = [X_1,X_2,\ldots.,X_n]$. (iii) The best previous position for each particle (the position giving the best fitness value) is called *particle best* and described as $PBi=[\, pb_{i1},\, pb_{i2}\ldots.,pb_{id}\,]$.

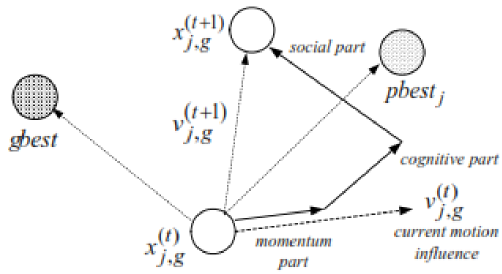

Fig. 3 Description of velocity and position updates in particle swarm optimization technique

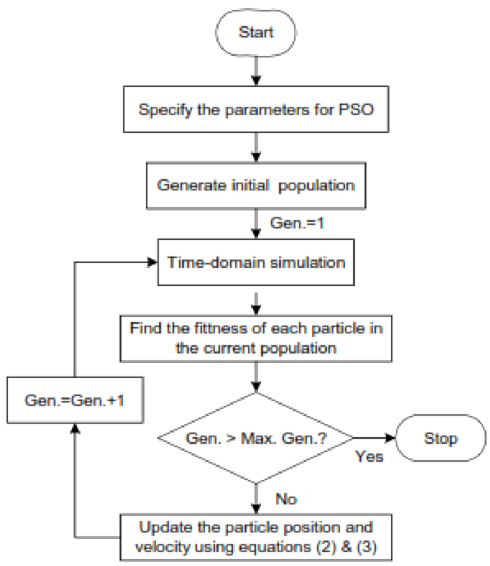

Fig. 4 Flowchart of particle swarm optimization algorithm

(iv) The best position among all of the particle best position achieved so far is called *global best* and described as $GB=[gb_1, gb_2, \ldots, gb_d]$.

At iteration k the velocity for d-dimension of i particle is updated by: w is the inertia weight, c_1 and c are the acceleration constants, and r_1 and r_2 are two random values in range [0,1].

The i-particle position is updated by

$x_{id}^{k+1}= x_{id}^{k} +v_{id}^{k+1}$...(1)

For binary discrete search space, Kennedy and Eberhart have adapted the PSO to search in binary spaces, by applying a sigmoid transformation to the velocity component Eqn. (2) to squash the velocities into a range [0,1], and force the component values of the locations of particles to be 0's or 1's.

The equation for updating positions Eqn. (1) is then replaced by Eqn. (3).

(v) The rate of position change for each particle is called *the particle velocity* and described as

$Vi = [v_{i1},v_{i2},\ldots, v]$.

$\mathrm{Sigmoid}(v_{id}^{k})=1/(1+\exp(-v_{id}^{k}))$ ...(2)

$x_{id}^{k}=\{1$, if rand <sigmoid(v_{id}^{k}) ...(3)
0, otherwise

V. ADVANTAGES OF EVOLUTIONARY METHODS

-Simple constraint handling
-Capable of producing solutions for problems where classical mathematical methods fail
-Do not depend on initial guess
-Parallel search through a population rather than from a single point

Evolutionary techniques have some very attractive features due to which they are gaining over traditional methods of optimization, particularly for real world problems. These techniques can be integrated to create hybrid evo. Techniques which are likely to perform better

VI.HEFFRON AND PHILLIPS MODEL

This diagram was developed by Heffron and Phillips [Heffron and Phillips, 1952] to represent the dynamics of a single synchronous generator connected to the grid through a line. The simple electromechanical generator model with mechanical swing and field flux dynamics was used. The dynamics of the voltage regulator was represented as a transfer function block EXC(s).

De Mello and Concordia adopted this model in their paper [de Mello and Concordia, 1969] to develop an understanding of the mechanism of oscillations in terms of damping and synchronizing torque. The parameters K_1 - K_6 in Figure 5are constants for a particular operating point but vary with the power output and the strength of the electrical network connecting the machine to the infinite bus.

STATCOM controller plays a main roll in stability control in condition of fault when rotor is deviated and power angle is deviate. Controllers have gain values which have to be optimized because improper gain may take much time to control the stability. For the analysis of SMIB we here taking Heffron Phillips system as shown in Fig. 5.After STATCOM is installed in SMIB Heffron Phillip model as shown below:

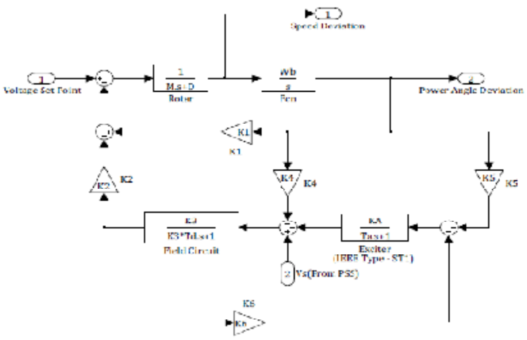

Fig. 5. Heffron and Phillips, Model for SMIB system.

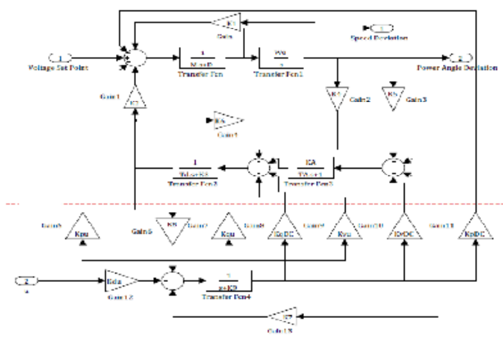

Fig. 6. SMIB with Installed STATCOM.

To solve the problem we are optimizing the parameters of STATCOM. For this we deriving an objective function to control speed deviation of Single machine system and on this objective function we applying particle swarm optimization algorithm to get optimized parameter to provide stability to the system.For the study of single machine infinite bus system a Heffron Phillips model can be obtained by linearizing the system equations around an operating condition. The obtained Hefffron model is as in figure and the parameters are K_1 = 0.5320, K_2 = 0.7858, K_3 = 0.4494, K_4 = 1.0184,K_5 = -0.0597, K_6 = 0.5746, K_A = 20, M = 7.

VII. OBJECTIVE FUNCTION

In this study, an Integral of absolute Error (IAE) of the speed deviation as the objective functions for SMIB system, which can be expressed as follows:

$$J = \int_0^{t_s} |\Delta \omega| dt$$

$$J = \sum_{t=0}^{t_s} |\Delta \omega| \quad \ldots (4)$$

In the above equations, Δω denotes the rotor speed deviation for a set of controller parameters X. Here X represents the parameters to be optimized. A total of 5 parameters of controller have been tuned to get the optimal response. The time range of the simulation is t_S.It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots under different operating condition. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameters bounds.

Minimize J Subject to:

$$K_T^{\min} \le K_T \le K_T^{\max}$$

$$T_i^{\min} \le T_i \le T_i^{\max} \quad \text{forI} = 1,2,3,4\ldots(5)$$

The time-domain simulation of the nonlinear system model was performed for the simulation period. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots. i. Small step increase in reference Voltage setting (ΔV_{ref}=0.05p.u.) is the operating case we analyse.

VIII. SIMULATION RESULT

The behaviour of the proposed PSO based designed STATCOM under faulty conditions is verified by applying the small perturbation for SMIB. System responses in the form of Speed Deviation, power angle deviation voltage deviation & electrical torque are plotted. It can be seen that the system without PSS is highly oscillatory.

PSO based STATCOM tuned are able to damp the oscillations reasonably well and stabilize the system at faulty conditions. System is more stable in this case, following any disturbance. PSO based PSS improve its dynamic stability considerably. The proposed PSO based STATCOM is effectual and achieves good system damping characteristics.

These simulation have been carried out on program has been coded in MATLAB and the performance of the algorithms have been obtained by using MATLAB 7.10.a on a core 2 duo, 2 GHz, 2.99 GB RAM.

CASE: Small step increase in reference Voltage setting (▲V_{ref}=0.05p.u.)

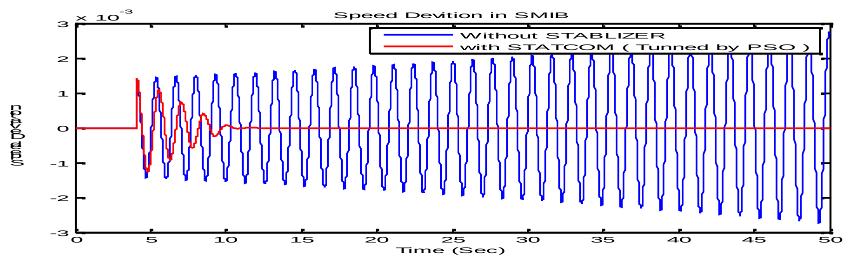

Fig.7. Speed Deviation without STATCOM & with PSO based STATCOM fault at t=5 sec.

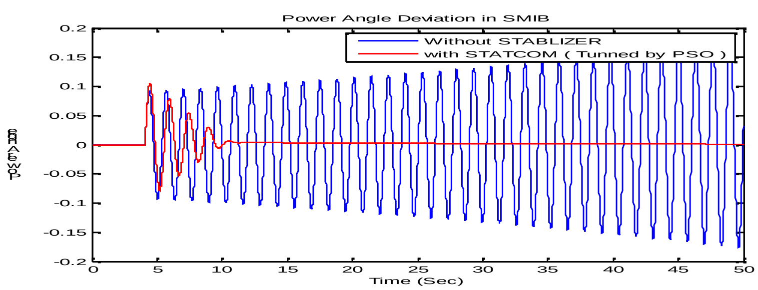

Fig. 8. Power Angle without STATCOM & with PSO based STATCOM fault at t=5 sec.

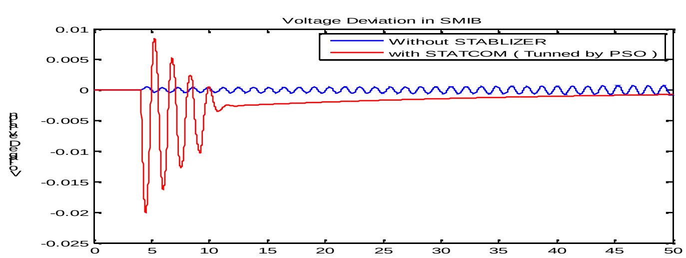

Fig. 9. Voltage Deviation without STATCOM & with PSO based STATCOM fault at t=5 sec.

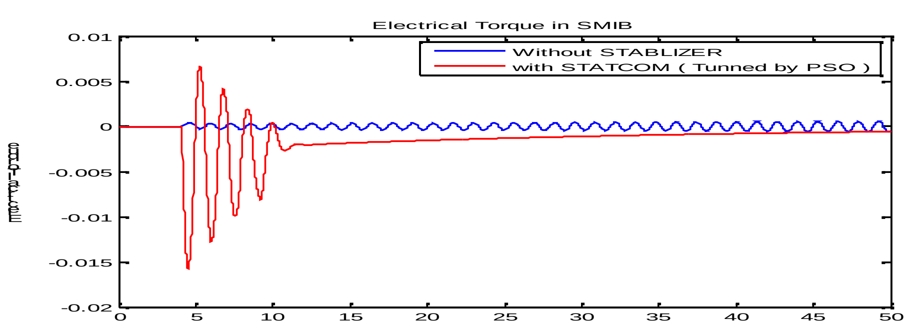

Fig. 10. Electrical torque without STATCOM & with PSO based STATCOM fault at t=5 sec.

IX. RESULT

Average cumulative change in value of the fitness function over 50 generations less than 1e-006 and constraint violation less than 1e-006, after 137 generations.

Final best point: [4.6367 0.99999 0.56909 0.99952 0.010004]

Kw =4.6367	T_1 = 1.0000	T_2 = 0.5691	T_3 =0.9995	T_4 = 0.0100

X. CONCLUSION

In this paper the power system stability enhancements by damping controller to the STATCOM AC voltage control loop was added to improve STATCOM power oscillation damping. The tuning parameters of the proposed stabilizer were optimized using PSO. The proposed stabilizers have been applied and tested on power system under small disturbance. The nonlinear time domain simulation results show the robustness of the proposed controller and its ability to provide good damping of low frequency oscillation and enhance the overall power system stability.

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