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Optimal Synchronization of PSS and Statcom-Based Controller Using De Algorithm

Nishant Dhakre[1], Kapil Parkh[2], Raunak Jangid[3]
[1]M.tech Student, [2]Assistant Professor, Electrical Engineering, SITE, Nathdwara

Abstract: In this paper, synchronization of PSS and STATCOM-based controller has been applied for damping frequency oscillations and in improving power system stability. This optimal coordination has been successfully carried out by help of differential evolution algorithm. Simulation tests have been carried out on both SMIB and MMPS system for analyzing robustness of proposed controller. For MMPS system, Kundur's 4-machine 2-area transmission system has taken into consideration. Finally, performance of this algorithm is compared with other algorithms like BFOA and PSO algorithm.

Keywords: power system stabilizers, static synchronous compensators, differential evolution algorithm, single machine infinite-bus system, multi machine system.

I. INTRODUCTION

When several transmission networks are interconnected by weaker transmission lines, various frequency oscillations take place in power system. These oscillations may deplete within short period or sometimes they may sustain for a longer time. If these oscillations grow further due to absence of sufficient damping, then they may cause power system separation. At present, power system stabilizers are most commonly applied in different industries for frequency oscillations damping in transmission network. But in certain situations, only PSS is not enough for damping's illations in power system. Hence, it has to be synchronized in parallel with the suitable FACTS controller. In present case, PSS is coordinated with STATCOM-based controllers for damping oscillations in single machine infinite bus (SMIB) system and multi machine power system (MMPS). The static synchronous compensator (STATCOM) is very efficient member in FACTS family. In power system, the role of STATCOM is to balance bus voltage either by inserting or by absorbing reactive power. Also, it is very effective in enhancing stability of power system. There are several technical merits of STATCOM that involves fast convergence, less space necessity, easily replaceable and also can be easily communicated with active power sources like battery, fuel, etc. Both applied devices i.e. PSS and STATCOM are skilled of repressing low-frequency oscillations and also helps in extending power transfer limit.

In this paper, the difficulty of designing robust STATCOM controller for damping frequency oscillations is considered as an optimization problem and the differential evolution (DE) algorithm is applied for calculating optimized parameters of the controller. The effectiveness of proposed controller is analyzed through nonlinear type time domain simulation under various loading conditions.

The simulation result shows that DE algorithm is capable of achieving better performance as compared to bacteria foraging optimization algorithm.

II. SYSTEMMODEL

A. STATCOM overview & its control system

Static synchronous compensator (STATCOM) is generally a controlled reactive-power source and it provides voltage support by generation or absorption of reactive power at a common coupling point without the necessity of capacitor banks or external reactors. The functional block diagram representation of STATCOM is shown in figure1.

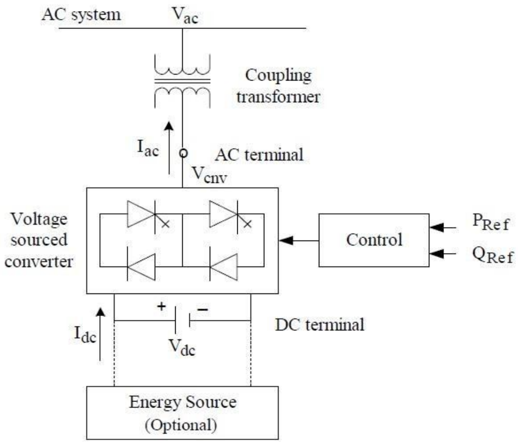

Fig. 1 Functional block diagram of STATCOM

In this arrangement, the basic functional block of static synchronous compensator is voltage source converter (VSC) which helps in converting input DC voltage into 3-phase output voltage at a fundamental frequency. Also, coupling transformer and DC capacitor are important parts of static synchronous compensators. In this diagram, P_{ref} and Q_{ref} are the references that indicates magnitude and phase angle respectively. The converter voltage V_{cnv} is very essential voltage which is required in exchanging desired active and reactive power between AC system and voltage source converter. For exchanging of reactive power, if STATCOM needs to operate strictly, then P_{ref} is set to zero position and there will be no requirement of external energy source. Here, respective converter VoltageV_{cnv} is in phase with AC voltage V_{ac} and practically there is no active power flow from or to voltage source converters.
If converter voltage is greater than AC voltage, then STATCOM controller supplies reactive power to AC system and in case if converter voltage is lower than AC system, then controller consumes reactive power. This device is so designed that magnitude of bus voltage can be maintained constant by controlling magnitude and/or phase shifting of VSC outputvoltage.

III. PROPOSED APPROACH

A. STATCOM based damping controller & PSS structures

For structure of STATCOM based damping controller, lead- lag arrangement is chosen in this paper. This structure is mainly comprises of gain block, signal washout block, and a two stage lead-lag phase compensation block as shown in figure2.

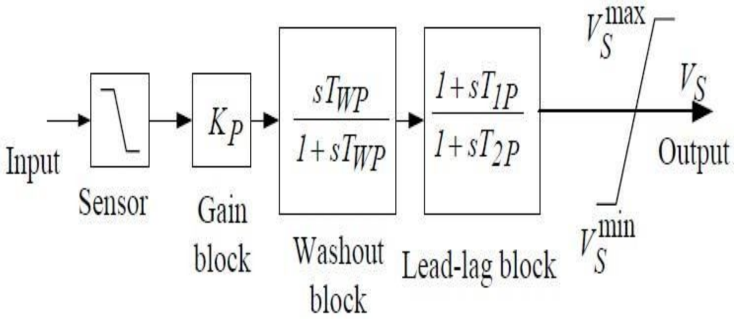

Fig. 2 STATCOM based controller

Third block of this controller provides appropriate phase-lead characteristics for lagging phase compensation between input and output control signals. Whereas second block i.e. signal washout block functions as high-pass filter which permit signals that are linked with input oscillations to pass unaffected. In absence of this block, steady changes in input signals can easily modify the output signals. By considering this context, it can be said that washout time period is not critical and may exists in the range of 1 to 20 seconds. The washout time constants and other time constants T_{2S} and T_{4S} are usually pre-specified for the structure shown in the figure 3. The washout time constant, T_{WS} = 10 sec and $T_{2S} = T_{4S}$= 0.3 sec have been assumed for this paper. The unknown parameterswhich needs to be calculated are T_{1S} , T_{3S} and controller gain K_S.

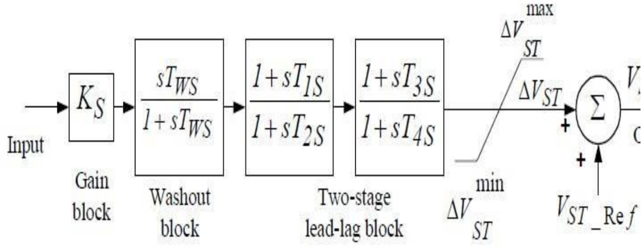

Fig. 3 Power System Stabilizer

B. Problem Formulation

The main purpose of designing PSS and STATCOM-based damping controller is to minimize oscillations of power system after larger disturbances so as to improve power system stability. In this paper, integral time absolute error of speed deviation is taken as basic prime function for single machine infinite bus systems. The block of power system stabilizer in SIM power systems is basically applied to add damping f$_n$or rotor oscillations in synchronous machines. The output signal of PSS is applied as an additional input for excitation block of this system.

IV. DIFFERENTIAL EVOLUTIONALGORITHM

The proposed algorithm is basically a population-based optimization technique. It is mainly characterized by its simplicity, strength and quick convergence. Since it is an evolutionary algorithm, it is utmost suitable in solving nonlinear zed and no differentiable problems. The main conception of such technique chiefly depends on generating variant vector solution on which the decision will be made to choose among the best solution (either parent or variant). The technique applied in this algorithm is to utilize the variation between randomly selected vectors for generating a new solution. The flowchart of differential evolution algorithm is shown in figure 4. Following are the steps required to perform the complete execution of differential evolution algorithm.

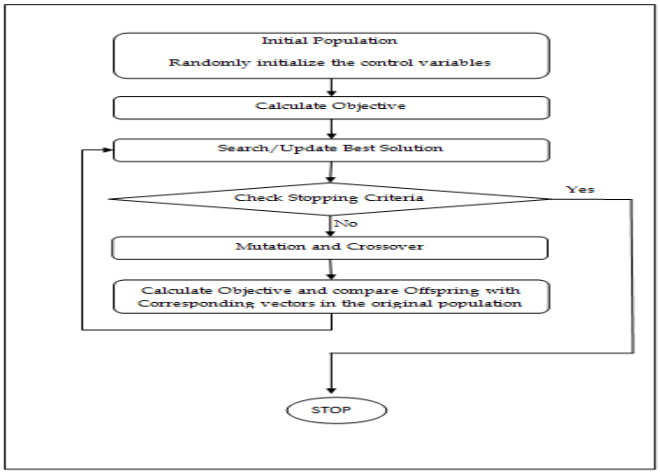

Fig. 4 DE algorithm

A. Initialization

This algorithm basically belongs from the category of the basics searching technique. It starts numbers of generations (NP) of candidate solutions () for creating population G^i, in which each solutions consist of some number of parameters x_{nj} based on dimension of the problem. Therefore for a population $G^i = [X_1, X_2, \ldots\ldots., XNP]$, i numbers of generation, and for population size of NP, the user solutions should be $X^i = [x_{n1}, x_{n2}, x_{n3}, \ldots\ldots\ldots\ldots.., x_{nj}]$ for n problem dimensions. This population mainly consists of NP solutions. In this technique, each vector x_i must be assigned in random manner. The range of corresponding control parameter is given below.

$$x_{i,j} = x_{j,min} + random\#(x_{j.max} - x_{j,min}) \quad (6)$$

First of all, objective value linked with each vector is evaluated. Then by comparing all these objective values, best or most optimal solution will be taken into account.

B. Mutation

For each and every generation (i), a mutant vector corresponding to every individual solution is generated by using the following formula:

$V_i(G+1) = X_{r1}(G) + F(X_{r2}(G) - X_{r3}(G))$ (7)In the above equation $X_{r1}^{(G)}$, $X_{r2}^{(G)}$, and $X_{r3}^{(G)}$ are respective vector solutions. All of these vectors are selected in the random manner from the present generation. Out of all these vectors, $X_{best}^{(G)}$ is the perfect suitable value. In this equation F denotes the mutation constant and it is very important for controlling the speed of convergence

C. Crossover

The crossover operation is also very essential for DE algorithm as it helps in settling the perturbing generated solutions and diversity improvement. The crossover factor (CR) is useful in producing the parameters of the mutant vector in the initial population and then its corresponding vector i is copied to its trial solution. After that the randomly generated number in the range of [1,0] is compared with that of the crossover factor. If that generated number is less than or equal to CR, the parameter of the mutant vector will be taken into consideration. But if it is greater than CR factor, then it will be taken from the parent. However if the value of CR equals to zero, then each and every parameters of the trial vector will be copied from parent vector excluding generated number of trial vector. This generated number will then be set accordingly equal to the corresponding parameter of mutant vector. But contradictory to that, if value of CR factor sets equal to 1, then all parameters of mutant vector will be copied excluding randomly chosen value of trial vector since its value is set accordingly equal to the corresponding parameter of parentvector.

D. Selection

After completing crossover operation, best objective function and resultant solution will be selected by comparing objective value of old solutions in the population with their corresponding objective value of trial solution.

E. Stopping Criteria

Once the maximum value of iterations arrives at predefined number, the stopping criteria have been taken into consideration. The optimal solution can be achieved during this period. This technique is then optimally implemented in which controller parameters are obtained using DE algorithm.

V. RESULTS &DISCUSSIONS

For conducting simulation over SMIB and MMPS system, the sim power toolbox is applied for design and analysis of power system. This toolbox is very useful for simulation. This toolbox consists of power library which contains different blocks such as AC/DC machines, generators, power electronics, electric drives, transmission lines, transformers, etc.

A. Single-machine infinite bus power system

Fig. 5 shows the single machine infinite bus system implemented by the PSS and STATCOM-based controller. The various components connected in this system are hydraulic unit, step-up transformer, STATCOM, etc. The ratings of different components are as follows:

1) Hydraulic unit rating: 500 MVA, 13.8 kV, 60Hz.
2) Step-up transformer: 3-Φ, 13.8/500kV
3) STATCOM: 100MVA
4) Transmission line: Double circuit type, 300 kmlong.

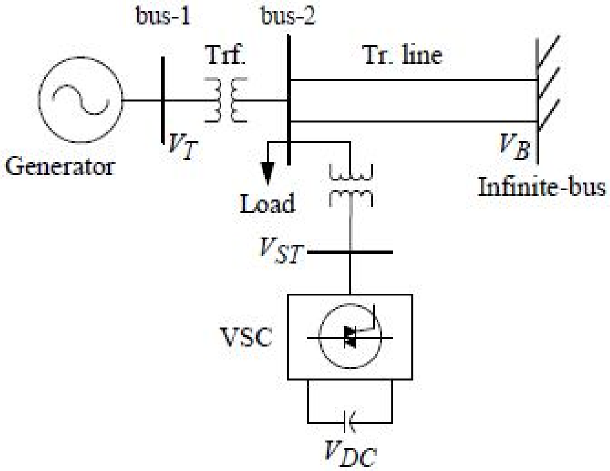

Fig. 5 Single-machine infinite-bus power systemwith STATCOM

As per diagram, the generator is connected with hydraulic turbine &governor (HTG), excitation system and PSS. The HTG system consists of non-linear type hydraulic turbine model, PID governor system and servo motor. The excitation system is made up of a voltage regulator and DC exciter.

Table 1. DE optimized for single-machine infinite-bus power system

STATCOM Base Controller		
K	T_1	T_3
50	0.436	0.1596

The convergence of objective function for SMIB system is shown in figure 6.

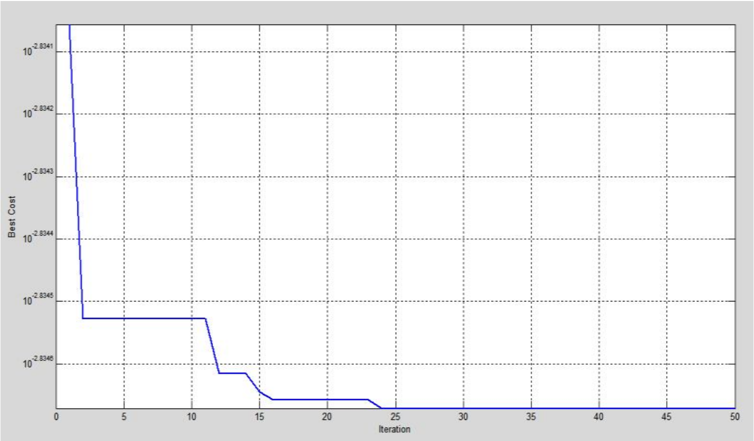

Fig. 6 Fitness function convergence for SMIB power system

B. Simulation Results for SMIB system

The simulation results of SMIB system under various loading conditions are presented below. This model is simulated with CPSS and STATCOM controller (tuned by DE) and without STATCOM controller. The responses of both these conditions are monitored to test the effectiveness and robustness of the proposed controller and its performance over wide range of operating conditions for different types of faults. The simulation studies are carried out in SMIB system and we obtain various graphs of power angle deviation, speed deviation, terminal voltage deviation, reference voltage deviation, stabilizing signal deviation at different loading conditions.

1) *Case 1: Nominal Loading:* The effectiveness of DE tuned STATCOM controller is analyzed on nominal loading conditions (Pe = 0.8 pu). A 3-Φ, 5-cycle fault is created at middle of the transmission line as shown in figure 7 at t = 1 sec. The faulty line is made tripped in order to clear the fault and is automatically reclosed after every 5 cycles. The originality of the system condition is regained after every fault clearance. The system response under this fault and in such loading conditions is shown in figure 7(a) to figure7(e).

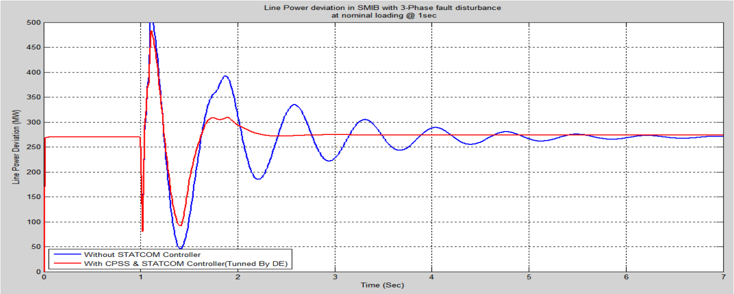

Fig. 7(a) Power angle response for five-cycle three-phase fault disturbance at middleof transmission line

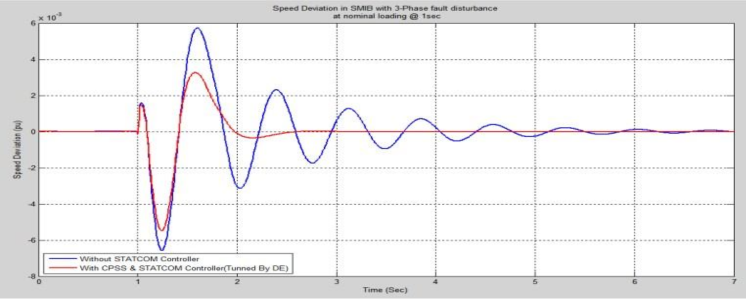

Fig. 7(b) Speed deviation response for five-cycle three-phase fault disturbance atmiddle of transmission line

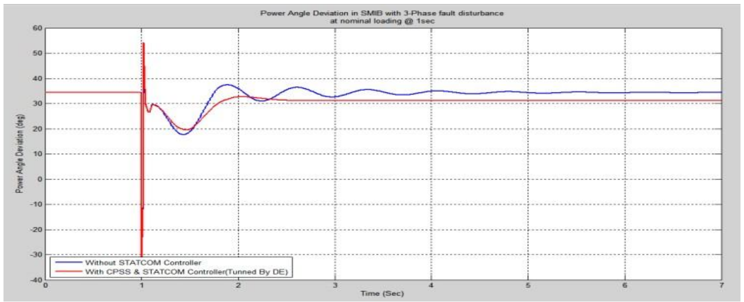

Fig. 7(c) Line power deviation for five-cycle three-phase fault disturbance atmiddle of transmission line

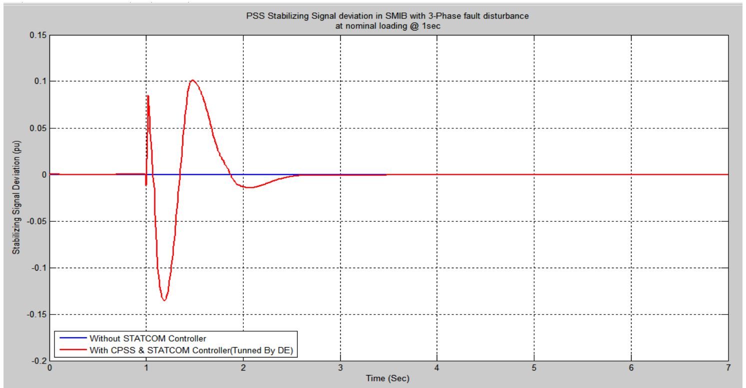

Fig. 7(d) Stabilizing signal of PSS for five-cycle three-phase fault disturbance at middle of transmission line

2) *Case 2: Light Loading:* The effectiveness of DE optimized STATCOM controller for oscillation damping and stability enhancement is initially analyzed on light loading condition (Pe = 0.5 pu). A 3-Φ, 5-cycle fault is created at t = 1 sec. as shown in figure 8. The faulty line is tripped for fault clearance and is automatically reclosed after 5 cycles. The original system is regained after each fault clearance. The system response under this fault is shown in figure 8.

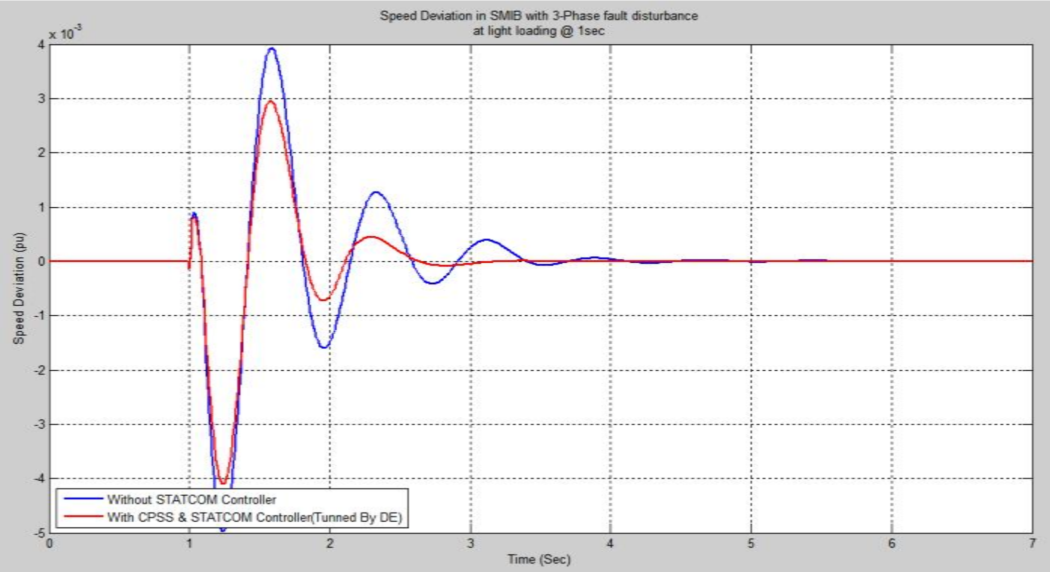

Fig. 8 Speed deviation response at light loading for five-cycle fault at bus2

3) *Case 3: Heavy Loading:* The effectiveness of DE optimized STATCOM controller for oscillation damping and stability enhancement is then analyzed on heavy loading condition (Pe = 1.0 pu). A 3-Φ, 5-cycle fault is created at t = 1 sec. as shown in figure 9. The faulty line is tripped for fault clearance and is automatically reclosed after 5 cycles. The original system is regained after each fault clearance. The system response under this fault is shown in figure 9.

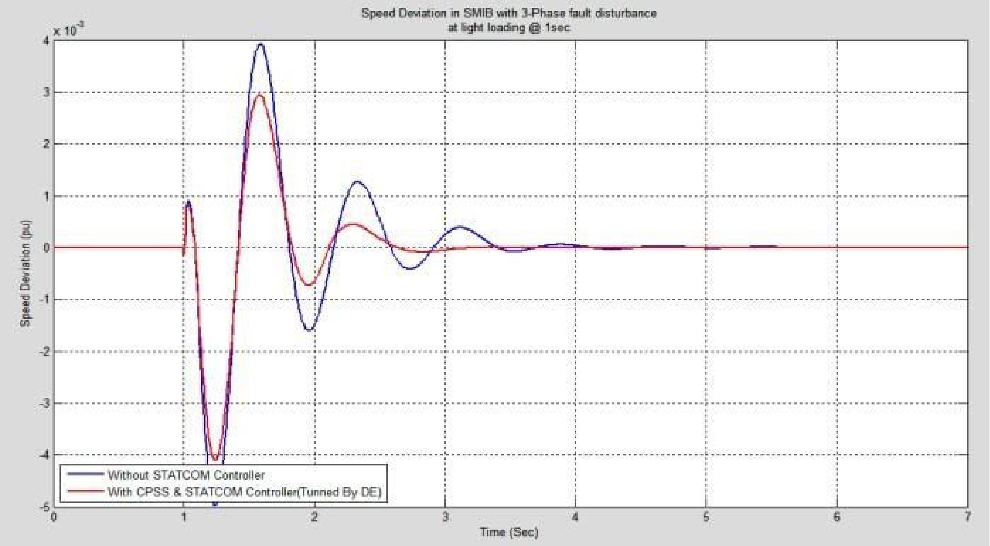

Fig. 9 Speed deviation response at heavy loading for five-cycle fault at bus2

C. Multimachine System

The design issue is further extended to 2-area system in Kundur’s four area system as shown in figure 10. This system comprises of four machines which are divided into two areas. G1 is connected to bus 1 and G2 is connected to bus 2 in area 1 and machine G3 is connected to bus 3 and machine G4 is connected to bus 4 in area2. The STATCOM is connected at bus 8 for improving system performance.

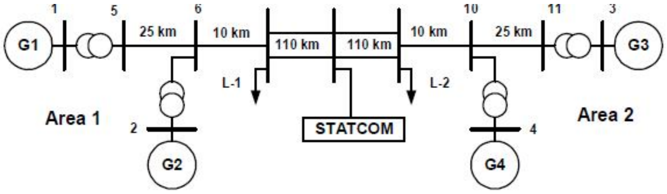

Fig. 10 Four-machine two-area system with STATCOM

DE based optimized parameters of STATCOM-based controller and PSS for four-machine two-area system is shown in table 2.

Table 2 DE optimized parameters of STATCOM-based controller and PSS for four-machine two area system

Controller/ Parameters	STATCOM	PSS1	PSS2	PSS3	PSS4
Gain	269.1373	5.3349	4.0771	6.0378	5.9520
Time Constant	1	0.0389	0.0169	0.0469	0.1
	1	1.3135	1.8349	1.5855	2

The convergence of fitness function for a Multimachine power system is shown in figure 11 for coordinated design of PSS and STATCOM.

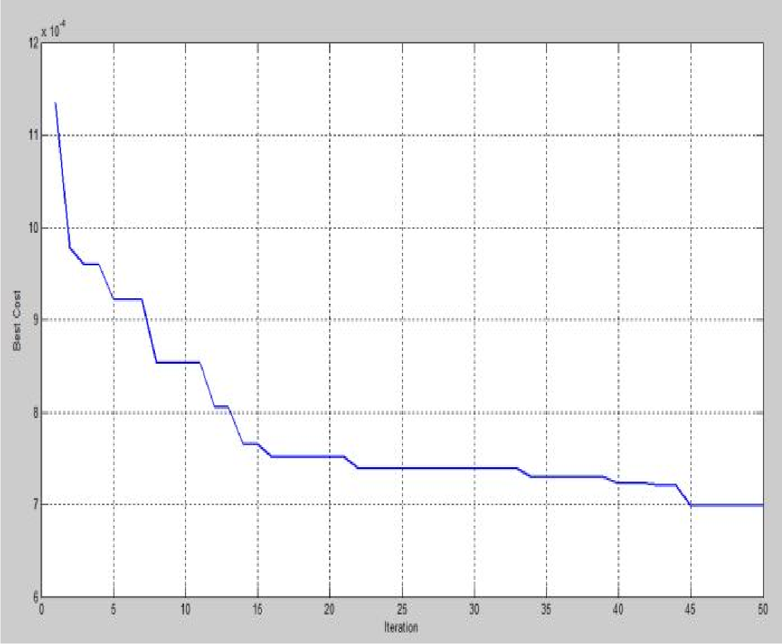

Fig.11 Convergence of fitness function for multi-machine power system

D.Simulation Results for MMPS system

The simulations of Multi machine system are carried out considering local modes and inter area modes of oscillations. Figure 12 and figure 13 shows an inter-area and local mode of oscillation. The graphs are plotted under two conditions. First condition is without STATCOM and PSS controller and second condition is with STATCOM and PSS controller (tuned by DE). DE algorithm gives optimized values and damped out oscillation under both modes of oscillation in MMPS system.

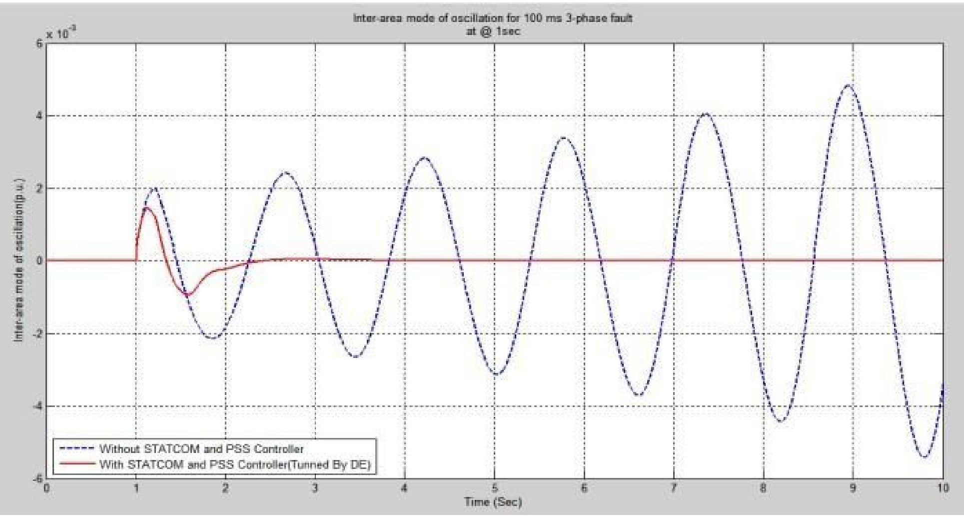

Fig. 12 Inter-area mode of oscillation

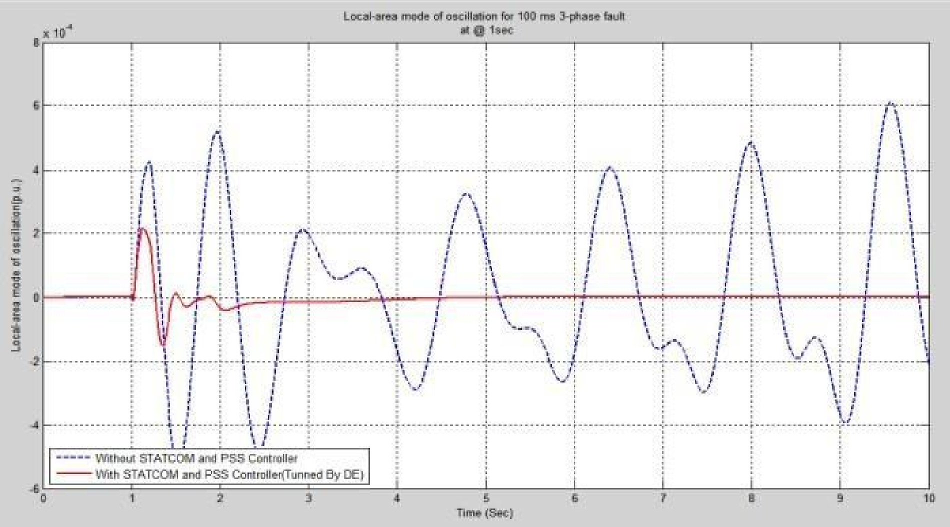

Fig.13 Local mode of oscillation

VI. CONCLUSION

In this paper, optimized parameters of static synchronous compensators (STATCOM) based damping controllers and PSS has been synchronized for damping low frequency oscillations in single machine infinite bus system (SMIB) and multi machine power system (MMPS). This synchronization is basically applied for improving stability performance of the power system. For controller design, nonlinear simulation based objective function has been considered and differential evolution (DE) algorithm is applied for optimized tuning of controller parameters and PSS. The frequency oscillations are effectively damped for various loading conditions in SMIB system whereas inter-area andlocal-areamodes of oscillations are effectively damped in MMPS system using this algorithm. Simulation results show the effectiveness and robustness of proposed algorithm over other algorithms such as bacteria foraging optimization algorithm.

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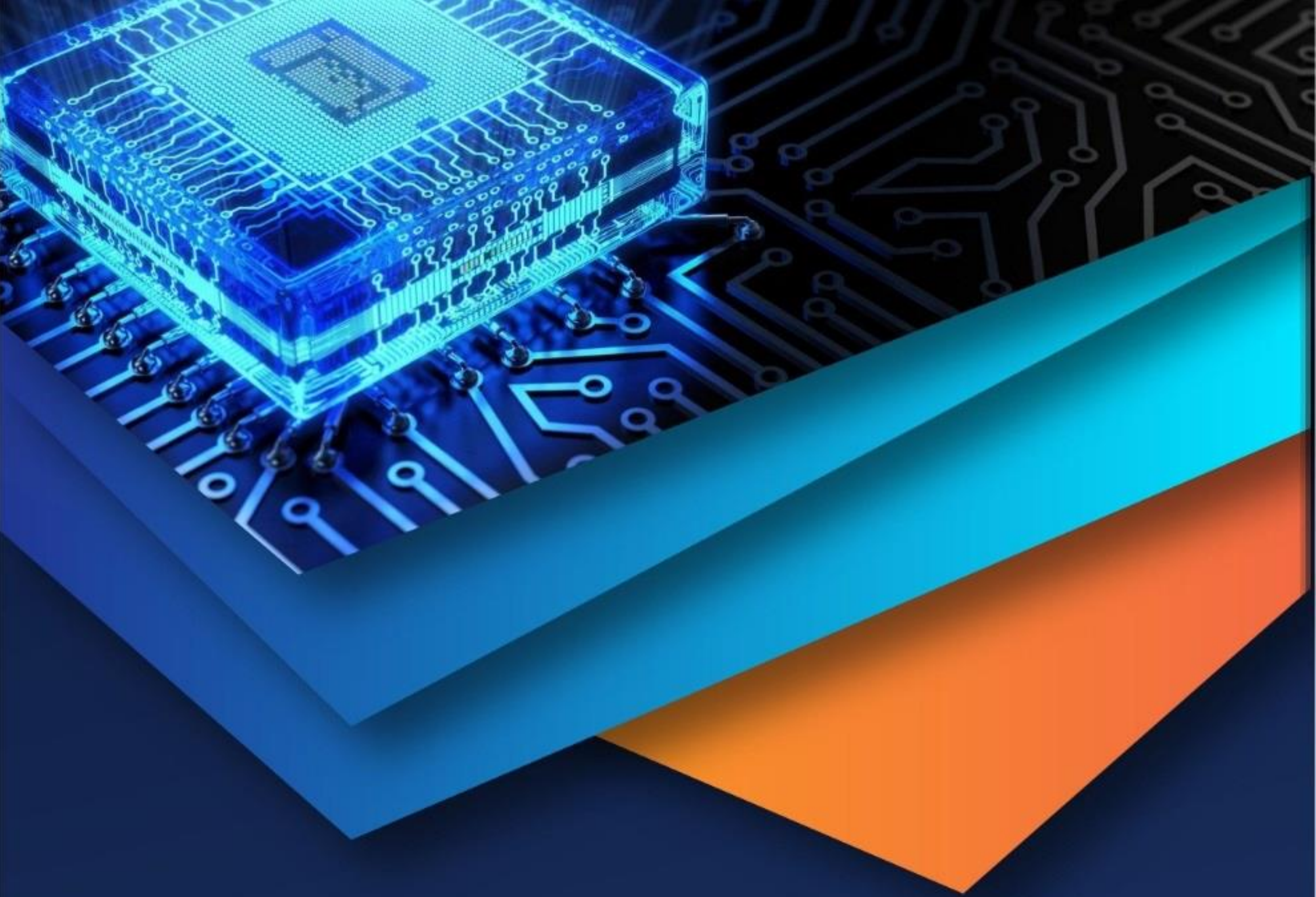

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