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Frequency Oscillation & Power Oscillation Damping Controlled by PSO Tuned SSSC Controller

Sandeep Kumar Mali[1], Kapil Parkh[2], Raunak Jangid[3]
[1]M.Tech Student, Power System, [2,3] Assistant Professor,SITE Nathdwara

Abstract: Today's modern interconnected power system is requiring operating stability consideration. Reliability and stability is key issue of modern power system .power and frequency oscillation damping mechanism is requiring progressing the reliability. Facts devise that can control the power system stability in very fast time, are becoming in style. But facts controller capability can be seen in a major fault present when nonlinear models of facts devise and power system equipment are applied. To understand this purpose, the model of multi-machine power system with facts controller is developed in matlab/simulink using sim power system (sps) blockiest. Among the facts device, static synchronous series compensator (sssc) due to high speed changes its reactance characteristic inductive to capacitive, is effective power flow controller. Tuning process of controller parameter can be performed using different method. The optimal parameters for the proposed controller are obtained using particle swarm optimization (pso).in this paper firstly pod controller is used to power oscillation damping. But in this station, frequency oscillation dos not has proper damping situation. So fod controller that is tuned using pso is using that cause to damp out frequency oscillation properly and power oscillation damping has suitable situation.pod and fod damping controller is evaluated under various operating conditions viz. 3 cycle for various disturbances like 3-phase, l-l, l-l-g, l-g fault with the objective of minimizing the frequency oscillation & power oscillation damping . The simulation results presented through various graphs validated that pso optimized sssc damping controller reduces frequency oscillation properly the and therefore enhances the system stability.
Keywords: pso,pod,fod,sssc,facts

I. INTRODUCTION

In today's highly complex and interconnected power systems, there is a great need to improve current utilization while ensuring reliability and safety. While the power supply in some of the

transmission lines is well below its normal limits, other lines are overloaded, which overall has an effect on the deterioration of the voltage profiles and reduces system stability and safety. Because of all this, it becomes more important to control the power flow along the transmission lines to meet the current transmission requirements. On the other hand, the rapid development of semiconductor technology has introduced a number of electronic power devices that have made FACTS a promising model for future power supply systems. The power flow is a function of the impedance of the transmission line, the amplitude of the transmit and receive end voltages, and the phase angle between the voltages. By controlling one or a combination of the power flow arrangements, it is possible to control the active power flow as well as the reactive current in the transmission line. FACTS technology opens up new possibilities to control power and improve the usable capacity of existing, new and improved lines. The possibility that the current and thus the power can be controlled by a line makes it possible to increase the capacity of the existing lines. These capabilities are the result of the ability of FACTS controllers to control contiguous parameters that govern the operation of transmission systems including serial impedance, shunt impedance, current, voltage, phase angle, and attenuation of oscillations. With FACTS technology such as SVC, STATCOM, SSSC, UPFC etc., bus voltages, line impedances and phase angles in the power grid can be adjusted quickly and flexibly. Therefore, FACTS can facilitate power flow control, improve power transfer capacity, lower production costs, and improve the safety and stability of the energy system. In previous work, we focused on the localization and dimensioning of the different types of FACTS devices to maximize power transfer taking into account variable load networks. The Static Synchronous Series Compensator (SSSC) is one of the most widely used FACTS controllers that is installed in series with a line. The SSSC can effectively control power flow in one line because of its ability to change its inductive to capacitive reactance characteristics. The use of the SSSC controller for frequency stabilization, stability enhancement and power swing damping can be seen in many references. The effect of the mode of operation, ie inductive or capacitive and the degree of compensation by the SSSC on stability, has also been cited in many references.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Many of these proposals are based on small perturbation analyzes that require a linearization of the considered system. But the complex dynamics of the power system is not covered by linear methods mainly for major perturbations. This condition poses a problem in the tuning of the FACTS controller because the controllers that are tuned to perform for small signal conditions do not function satisfactorily for major disturbances. In addition to this, with linear single-phase models, the controller behavior can not be identified for unbalanced faults. Therefore, to solve this problem in this thesis we have considered three phase models of several components of the power system and SSSC controller.Power system utilities prefer the classic time-shift structured controller because it offers many benefits, such as easy dynamic modeling, inline tuning and minimal effort for development. A large number of standard conventional methods are available for the design problem of controllers such as modern control theory, eigenvalue assignment and mathematical programming. But these classic approaches have some problems as they consume a lot of time since the iterations are over, need a heavy computational burden and have a slow convergence. Conventional techniques also have possibilities that the search process can be limited to local minima and an optimal solution can not be obtained.In recent years, particle grain optimization (PSO) technology has been preferred by researchers for optimization problems. PSO is mainly a stochastic optimization algorithm of population quota. The PSO algorithm is influenced by the social behavior of the schooling of birds in flocking birds. PSO is similar to the genetic algorithm (GA) in many aspects like the initialization of the population and the search for the optimal solution by updating the population. But PSO does not use evolutionary operators like the mutation and the crossover that are used by GA. PSO offers many advantages over GA as a simple algorithm - can be easily implemented and it uses few parameters. In the present thesis work PSO is used for optimization of SSSC-based controller parameters.

II. FOD, POD CONTROLLERS

The voltage reference supplied by the SSSC is normally set by a POD (Power Oscillation Damping) controller whose output is connected to the input Vqref of the SSSC. The POD controller consists of a general gain, a low-pass filter, a high-pass filter, a line compensator and an output limiter. The input of the POD controller is the supply of L2 The POD structure is shown in fig.1

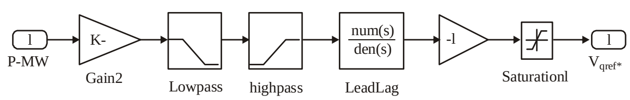

Fig. 1 POD Controller Structure

But the POD controller as shown in later sections cannot capture frequency oscillation. Therefore, FOD controller is another suggestion to adjust V

Its structure consists of a gain block with KS gain, a signal wash block and a two-stage phase compensation block, as shown in FIG. From the viewpoint of the washing function, the value of tw is not critical and can be in the range of 1 to 20 seconds. The phase compensation blocks (time constants t1, t2 and t3, t4) compensate for the phase delay between the input signals and the output signals. The inputs of the FOD controller are the speed deviations of Zone 1 and Zone 2 as shown in Figure 2

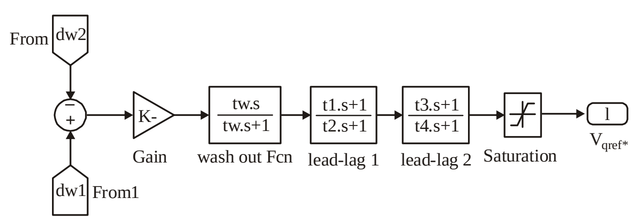

Fig.2 FOD Controller Structure

FOD controller can damp out frequency oscillation, but cause power oscillation damp later than POD controller. So it is necessary reconciliation between FOD and POD performance.

III. PROBLEM FORMULATION

The minimization of one or all of the above deviations could be chosen as the target. In the FOD control, an absolute integer time error of the speed deviations as an objective function is expressed as follows:

$$FT = \int_{t=0}^{t=t_{sim}} [|w_1 - w_2|].tdt = \int_{t=0}^{t=tsim} [|\Delta w|].tdt \qquad (1)$$

FT= Fitness Function

w_1=Area1 speed ,rad/s

w_2= Area2 speed ,rad/s

Δw= Speed difference, rad/s

t_{sim}= Simulation time,s

Minimize J subjected to

$$K^{min} \leq K \leq K^{max} \quad (2)$$

$$T_1^{min} \leq T_1 \leq T_1^{max} \quad (3)$$

$$T_3^{min} \leq T_3 \leq T_3^{max} \quad (4)$$

The above mentioned parameters of SSSC damping controller are optimized using PSO algorithm.

IV. THE POWER SYSTEM UNDER STUDY

A. Power System Characterize

For the construction and optimization of the SSSC-based damping controller, a two-machine system with SSSC in Fig. 3 applies. The system consists of two generators, which are subdivided into two subsystems and are interconnected via intertie. Area 1 has a rating of 2100 MVA consisting of 6 machines of 350 MVA. Area 2 has a rating of 1400 MVA consisting of 4 machines of 350 MVA. The load center has about 2200 MW of consuming capacity modeled with a dynamic load model where the active and reactive power absorbed by the load is a function of the system voltage.

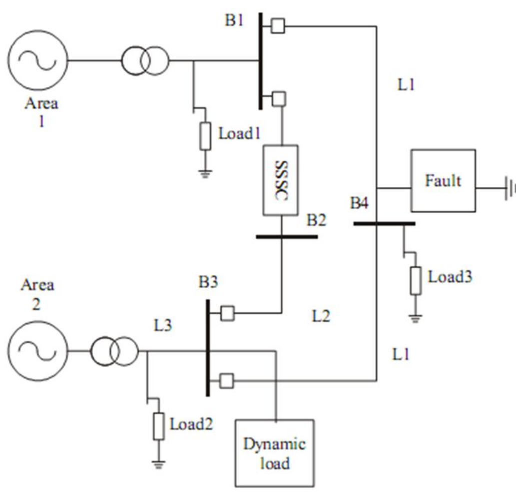

Fig. 3 : Two Machine Power System with SSSC

The area 1 is connected to this load by two paths. L2 is 280 km and L1 is 150 km. The area 2 is also connected to the load by a 50 km line (L3). When the SSSC is bypass, the power flow towards the load center is as follow: 664 MW flow on L2, 563 MW flow on L1. The SSSC which is located at B1 is in series with line L2. Fault box is used to implementation three phase short circuit condition. Since the mentioned fault is the worst fault. Type, if a controller can damp out the power and frequency oscillation, the controller is proper in present of other fault. Therefore three phase short circuit is used in simulation process.

B. Overview of SSSC and its Control System

The synchronous voltage source (SVS)-based series compensator, called SSSC was proposed by Gyugyi in 1989 within the concept of using converter-based technology uniformly for shunt and series compensation as well as for transmission angle control. The concept of using the SVS for series reactive compensation is based on the fact that SVS injects an ac voltage with the controllable magnitude and angle into the transmission line by being independent of the line current so it can rapidly change the effective reactance between the two ends of the transmission line and the power flow, whereas the compensating voltage is dependent on the line current in the series capacitor compensation case . The injected voltage (Vq) is in quadrature with the line current I, and emulates an inductive or a capacitive reactance so as to influence the power flow in the transmission lines . Power transmission without SSSC is expressed in 5.

$$p = \frac{v^2}{x_L}\sin(\delta) \tag{5}$$

$$p = \frac{v^2}{x_L}\sin(\delta) + \frac{v}{x_L}v_{sssc}(\varepsilon)\cos(\frac{\delta}{2}) \tag{6}$$

p=Transmission active power(pu or K/MW)
v=Line Voltage(pu or k volts)
xL=Line reactance(pu or ohm)
δ= Load angle
vsssc= SSSC injected voltage
ε= Chosen Control Parameter
Additional statement resulting from SSSC presentation can be negative or positive due to happened condition to stabilize power flow and frequency deviation. In other words, injected voltage changes the stability level. Supplementary description about SSSC structure and its control technique is brought in.

V. PARTICLE SWARM OPTIMIZATION TECHNIQUE

Particle Swarm Optimization Technique was developed in 1995 by James Kennedy (Social-Psychologist) and Russell Eberhart (Electrical Engineer) whose inspiration was social behavior of fish schooling or bird flocking. Each particle in search space adjusts its “flying” according to its own flying experience as well as the flying experience of other particles The PSO Uses a number of particles that constitute a swarm moving around in the search space looking for the best solution. PSO is a robust stochastic optimization technique based on the movement and intelligence of swarms.
In PSO, the current optimum particles and his potential solutions, known as particles, fly through problem space. The PSO technique conducts searches using a population of particles, corresponding to individuals. Each particle represents a candidate solution to problem at hand. In a PSO system particles change their positions by flying around in a multidimensional search space until a relatively unchanged position has been encountered or until computational limitations are exceed. In social science context, a PSO system combines a social only model and a cognition only model. The social only component suggested that individual ignore their own experiences and adjust their behavior according to their successful beliefs of individuals in the neighborhood. On the other hand, the cognition only component treats individuals as isolated beings.

A. The Advantages of PSO over other Traditional Optimization Techniques [Genetic Algorithms (GA)] can be Summarized as follows

1) PSO is a proportional based search algorithm. This property ensures PSO to be less susceptible to getting trapped on local minima
2) PSO uses payoff information to guide search in the problem space. Therefore PSO can easily deal with non-differentiable objective functions. Additionally, this property relieves PSO of assumptions and approximation, which are often required by traditional optimization methods
3) PSO uses probabilistic transition rule and non-deterministic rules. Hence, PSO is a kind of stochastic optimization algorithms that can search a complicated and uncertain area. This makes PSO more flexible and robust than conventional methods
4) Unlike GA and other heuristic algorithms, PSO has the flexibility to control the balance between the global and local exploration of search space.
5) The unique feature of PSO overcomes the premature convergence problem and enhances the search capability
6) The PSO system begins with a random solutions population and searches for optimal one via updating generations. Unlike GA has no evaluations operator like cross over and mutation
7) The advantages of the PSO over the GA are that there are few parameters to adjust and is easy to implement
8) PSO is successfully applied in many areas like: artificial neural networking training, function optimization, fuzzy system control

and the other areas where the GA can be applied.

9) Unlike the traditional methods, the solutions quality of proposed approach does not rely on the initial population. Starting anywhere in the search space the algorithms insure the convergence to the optimal solutions.

B. Operators of Particle Swarm Optimization

1) *Mutation:* Mutation operators are an integral part of evolutionary computation techniques, relenting loss of diversity in a population of solution, which allows a greater reason of the search space to be covered. Like evolutionary computation techniques, that state the lack of population diversity in PSO algorithms is understood to be factor in their convergence in local minima. Therefore the addition of a mutation operator to PSO should enhance its global search capability and thus improve its performance. Mutation operation have been added a PSO to improve its performance. The basic PSO approach typically converges rapidly during the initial search period and then slow. Then, checking the position of particles showed that the particles were very tightly clustered around a local optimum and the particle velocities were at most zero.
This phenomenon resulted in a slow convergence and trapped the whole swarm at a local optimum. Mutation operation is capable of overcoming this shortcoming. Mutation operation is an occasional random alternation of the Gbest string. This work integrates a PSO technique with a mutation operation providing background variation and occasionally introduces beneficial material in to the swarm to speed up convergence and escape local optimums.

2) *Crossover:* When particles are exploring the search space, if some particles find the current based position, the other will fly towards it. If the best position is a local optimum, particles cannot explore over again in the search space. In the condition, particles are lack of communication with each other, especially with the particles having better fitness, so that information cannot be share in the population. Therefore, the cross over operator defines the idea that the individual best position after updating crosses with the best one achieved according to fitness. Through crossover, there is a chance changing the global best position, and the algorithm may not be trapped in to local optima. On the other side, particles can make use of the other's advantage by sharing information mechanism. The crossover just is carried out in one dimension that is randomly selected. In the meantime, the fitness of the best position is compared with two offspring produced by cross over operator. Then, we choose better one as the individual best position.

3) *Recombination:* For evaluator algorithm, the merits of crossover have been an essential research topic. Instead of the rational two-parent re-combinatory chromosome reproduction there has been considerable discussion of multivalent crossover mechanisms. Work on multi-parental recombination techniques showed that n-parental inheritance can be advantageous. Based on previous research work develop a multi-parental recombination operator for constructing the offspring population. It has been discovered the linkage configuration in order to make good use of the obtained information, it specifically a new design of recombination operator. Use this recombination process to generate the next population. By repeating the process, construct a new population in which each particle is composed of the building blocks.

In a PSO system, particles change their positions by flying around in a multidimensional search space until computational limitations are exceeded. Concept of modification of a searching point by PSO is shown in fig. 4.

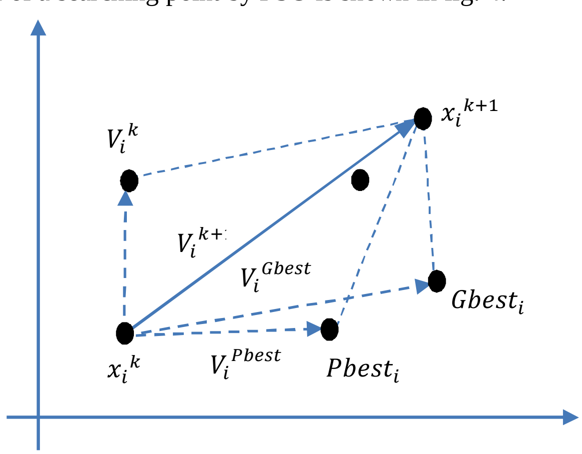

Fig. 4. Concept of Modification of a Searching Point by PSO

Where

xk : Current position,
xk+1 : Modified position,
Vk : Current velocity,
Vk+1 : Modified velocity,
V_i^{Pbest} : Velocity based on Pbest,
V_i^{Gbest} : Velocity based on Gbest

For each particle, at the current time step, a record is kept of the position, velocity and the best position found in the search space so far. Each particle tries to modify its position using the following information:

a) The current positions
b) The current velocities
c) The distance between the current position and Pbest
d) The distance between the current position and Gbest

C. PSO Flow Chart

The fig. 5 below shows the flow chart of PSO technique.

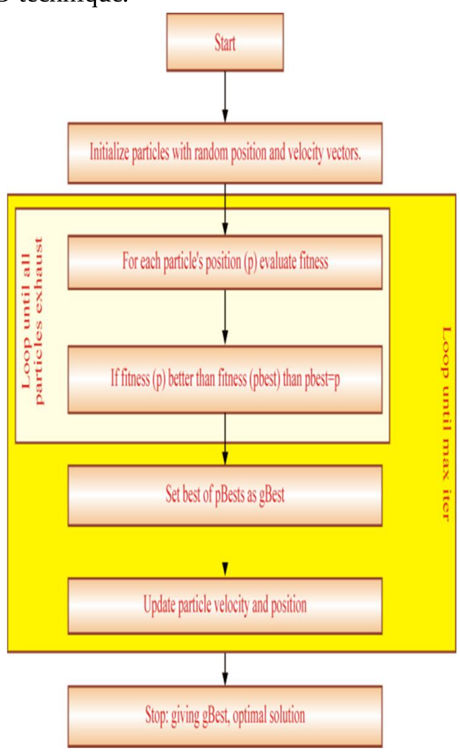

Fig. 5: Flow Diagram of Particle Swarm Optimization

D. Variant of PSO

The original PSO algorithm has undergone a number of changes. Most of these changes affect the way the velocity of a particle is updated. The many of the existing particle swarm optimization variants as:

1) Discrete PSO: Can handle discrete binary variables.
2) MINLP PSO: Can handle both discrete binary and continues variables.
3) Hybrid PSO: Utilize basic mechanism of PSO and the natural selection mechanism

VI. RESULT ANALYSIS & DISCUSSION OF PSO TUNED SSSC CONTROLLER IN MATLAB / SIMULINK

The models have been designed using simpower system toolbox of MATLAB / Simulink. SimPower system is a widely used MATLAB based design tool used by engineers & scientists to build models and for simulation.The Simpower system tool consists of models of various equipments like machines, governors, transformers, excitation system, FACTS devices and transmission lines. It

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also consists of a powergui block which is required for simulation of a model having simpower system blocks. The powergui block performs load flow & machine initialization.

VII. PROPOSED MATLAB/SIMULINK MODEL MULTIMACHINE SYSTEM WITH SSSC CONTROLLER

To design and optimize the SSSC-based damping controller, a two machine system with SSSC shown in Fig.6, is considered. The system consist of two generator divided in two subsystem and are connected via intertie. Area 1 has rating of 2100 MVA that consist of 6 machines of 350 MVA. Area 2 has rating of 1400 MVA that consist of 4 machines of 350 MVA. The load center has approximately 2200 MW consuming capacity that is modeled using a dynamic load model where the active and reactive power absorbed by the load is a function of the system voltage. The area 1 is connected to this load by two paths. L2 is 280 km and L1 is 150 km. The area 2 is also connected to the load by a 50 km line (L3). When the SSSC is bypass, the power flow towards the load center is as follow: 664 MW flow on L2, 563 MW flow on L1. The SSSC which is located at B1 is in series with line L2. Fault box is used to implementation three phase short circuit condition. Since the mentioned fault is the worst fault. Type, if a controller can damp out the power and frequency oscillation, the controller is proper in present of other fault. Therefore three phase short circuit is used in simulation process.

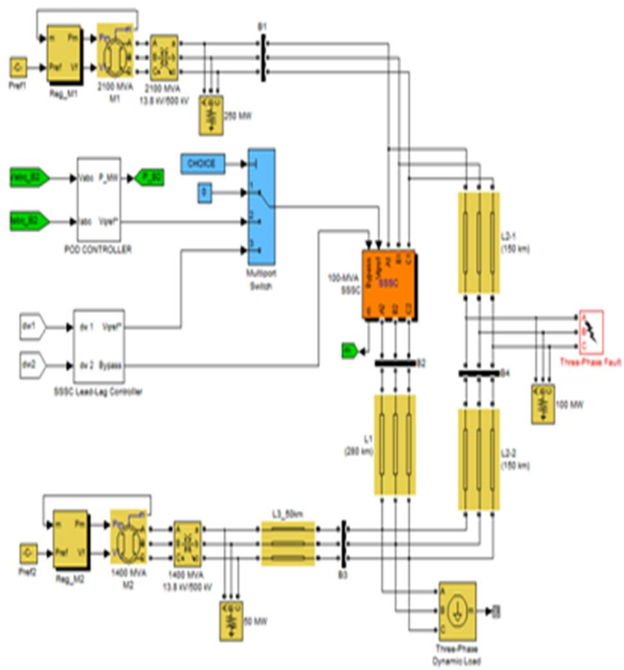

Fig. 6: MATLAB Model of Multimachine System with SSSC Controller

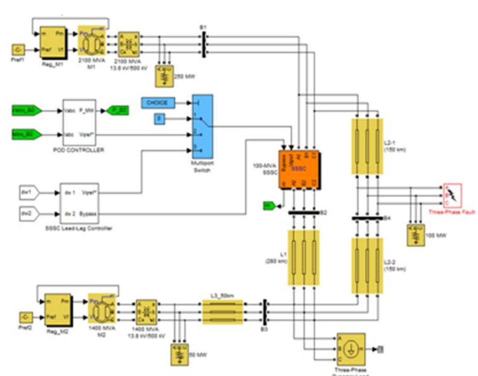

Fig.7 shows the convergence of objective function for gbest in multimachine system.

Volume 5 Issue V, May 2017
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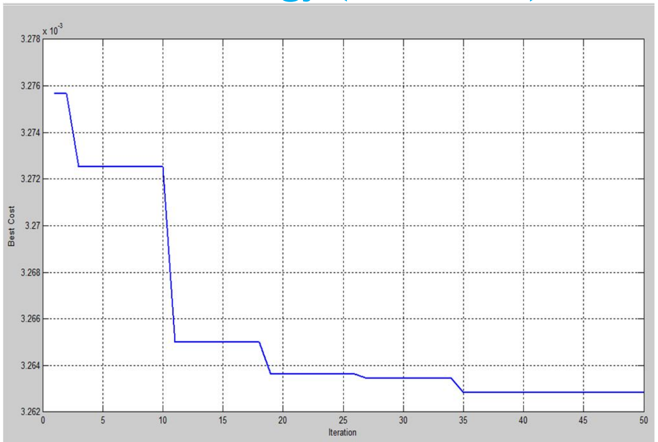

Fig. 7: Convergence of objective function for *gbest* in Multimachine System

A. Two Machine System with 3-Cylce Self Clearing 3-Phase Fault at Speed Deviation & Line Power Deviation

In fig. 8 to 5.9 shows inter –area mode of oscillation in two machine system with 3-cylce self clearing 3-phase fault at speed deviation & line power deviation without, with POD and FOD Controller presented . In speed deviation FOD controller is tuned using PSO is damped out frequency oscillation better than POD controller and in line power deviation The effectiveness of FOD controller to damp out power oscillation is investigated. But its ability in damping out power oscillation was not better than POD controller. POD controller is used to power oscillation damping.

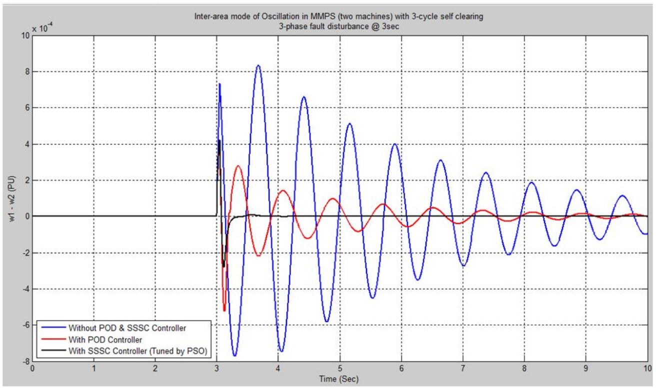

Fig.8 Response of Speed Deviation Flow for a 3-Cycle 3-Phase Fault at without, with POD and with FOD Controller

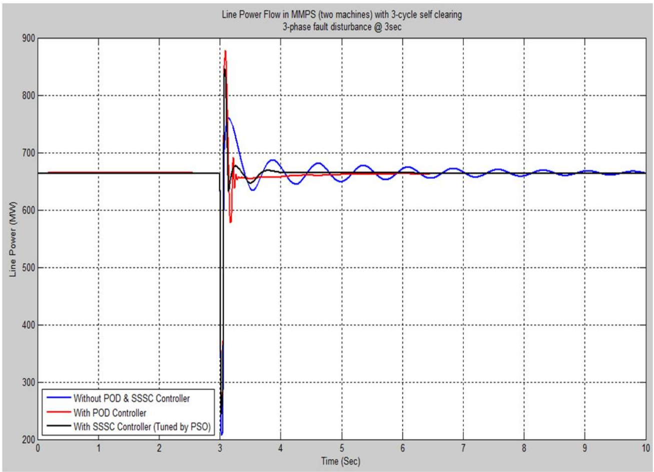

Fig.9 Response of Line Power Deviation Flow for a 3-Cycle 3-Phase Fault at without, with POD and with FOD Controller

Volume 5 Issue V, May 2017
ISSN: 2321-9653

B. Two Machine System with 3-Cylce Self Clearing L-G Fault at Speed Deviation & Line Power Deviation

In fig. 10 to 11 shows inter –area mode of oscillation in two machine system with 3-cylce self clearing L-G fault at speed deviation & line power deviation without, with POD and FOD Controller presented. FOD controller is tuned using PSO is damped out frequency oscillation better than POD controller. Therefore it can be concluded that the PSO tuned SSSC controller enhances the system stability and The effectiveness of FOD controller to damp out power oscillation is investigated. But its ability in damping out power oscillation was not better than POD controller. POD controller is used to power oscillation damping.

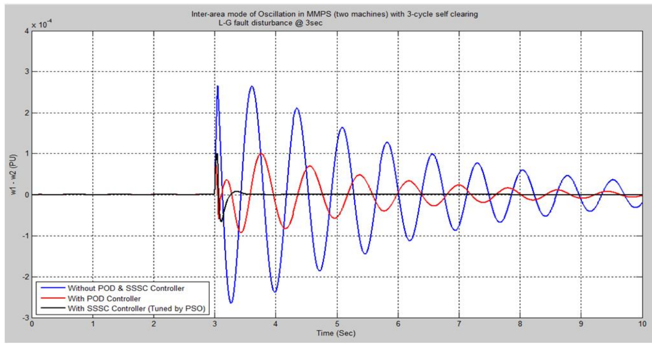

Fig.10 Response of speed Deviation Flow for a 3-Cycle L-G Fault at without, with POD and with FOD Controller

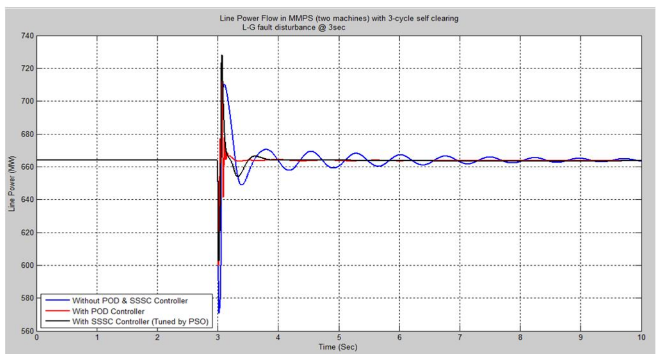

Fig.11 Response of Line Power Deviation Flow for a 3-Cycle L-G Fault at without, with POD and with FOD Controller

C. Two Machine System with 3-Cylce Self Clearing L-L Fault at Speed Deviation & Line Power Deviation

In fig.12 to 13 shows inter –area mode of oscillation in two machine system with 3-cylce self clearing L-L fault at speed deviation & line power deviation without, with POD and FOD Controller presented.The FOD controller damped out easily speed deviation and POD controller damped out line power deviation.

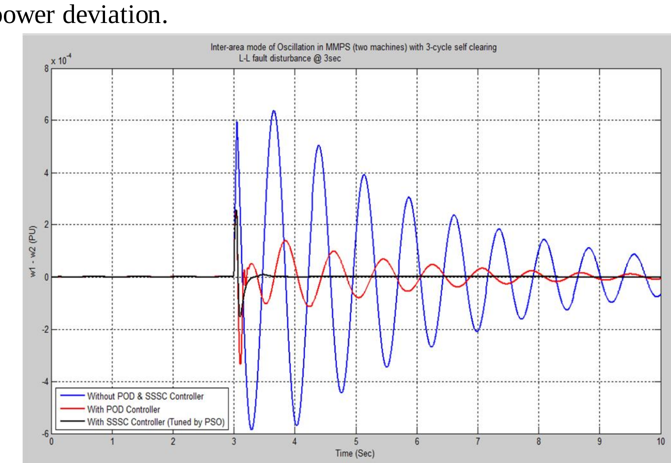

Fig.12 Response of Speed Deviation Flow for a 3-Cycle L-L Fault at without, with POD and with FOD Controller

Volume 5 Issue V, May 2017
ISSN: 2321-9653

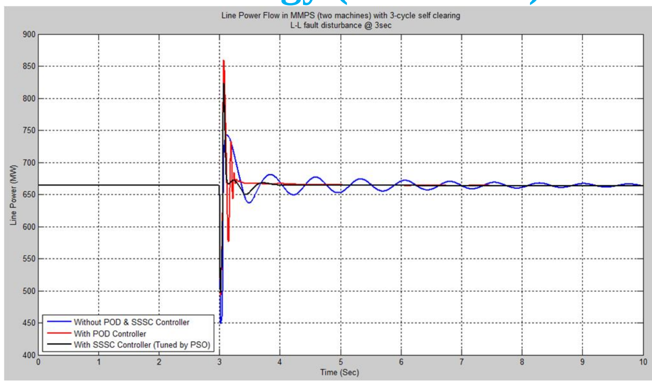

Fig.13 Response of Line Power Deviation Flow for a 3-Cycle L-L Fault at without, with POD and with FOD Controller

D. Two Machine System with 3-Cylce Self Clearing L-L-G Fault at Speed Deviation & Line Power Deviation

In fig.14 to 15 shows inter –area mode of oscillation in two machine system with 3-cylce self clearing 3-phase fault at speed deviation & line power deviation without, with POD and FOD Controller presented. The FOD controller damped out easily speed deviation and POD controller damped out line power deviation.

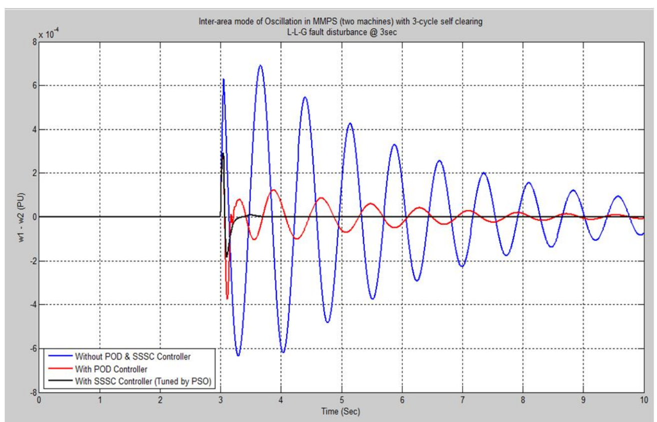

Fig.14 Response of Speed Deviation Flow for a 3-Cycle L-L-G Fault at without, with POD and with FOD Controller

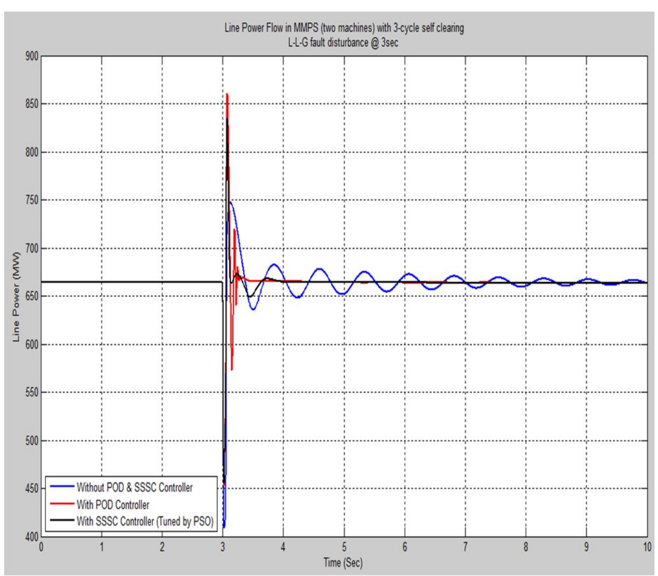

Fig.15 Response of Line Power Deviation Flow for a 3-Cycle L-L-G Fault at without, with POD and with FOD Controller

Volume 5 Issue V, May 2017
ISSN: 2321-9653

Table 1 Comparison Power and Frequency Oscillation Damping Time for 3 -cycle various Fault

S.N	Fault Status Controller	Fault	Damp Time for Frequency Oscillation (Settling time)	Damp Time for Power Oscillation (Settling Time)
1.	No POD	3-Phase	9.8778	6.1627
	POD		9.8562	3.5679
	FOD		3.5797	3.5905
2.	No POD	L--G	9.9711	8.3130
	POD		9.9515	3.2608
	FOD		3.4883	3.7709
3.	No POD	L-L	9.8330	8.3297
	POD		9.7178	3.4064
	FOD		3.5591	3.8092
4	No POD	L-L-G	9.8426	7.6219
	POD		9.7376	3.3626
	FOD		3.5667	3.7704

The table1 prove result validation at multimachine system. We tested result at various operating conditions viz. 3cylce for various disturbances like 3-phase, L-L, L-G, L-L-G. We get better result when we apply PSO tuned SSSC controller .So System shows good time response (less settling time) when we apply with PSO tuned SSSC controller.

VIII. CONCLUSION

In this paper, power system stability enhancement by PSO tuned SSSC controller is presented. An objective function based on simulation is developed to design lead-lag structured SSSC controller to achieve the oscillation damping two machine system.Then, the PSO optimization technique is implemented to search for the optimal controller parameters. .POD and FOD damping controller is evaluated under various operating conditions viz. 3 cycle for various disturbances like 3-phase, L-L, L-L-G, L-G fault with the objective of minimizing the frequency oscillation & power oscillation damping . The simulation results presented through various graphs validated that PSO optimized SSSC damping controller reduces frequency oscillation properly the and therefore enhances the system stability.FOD controller is damped out frequency oscillation better than POD controller but its ability in damping out power oscillation was not better than POD controller.

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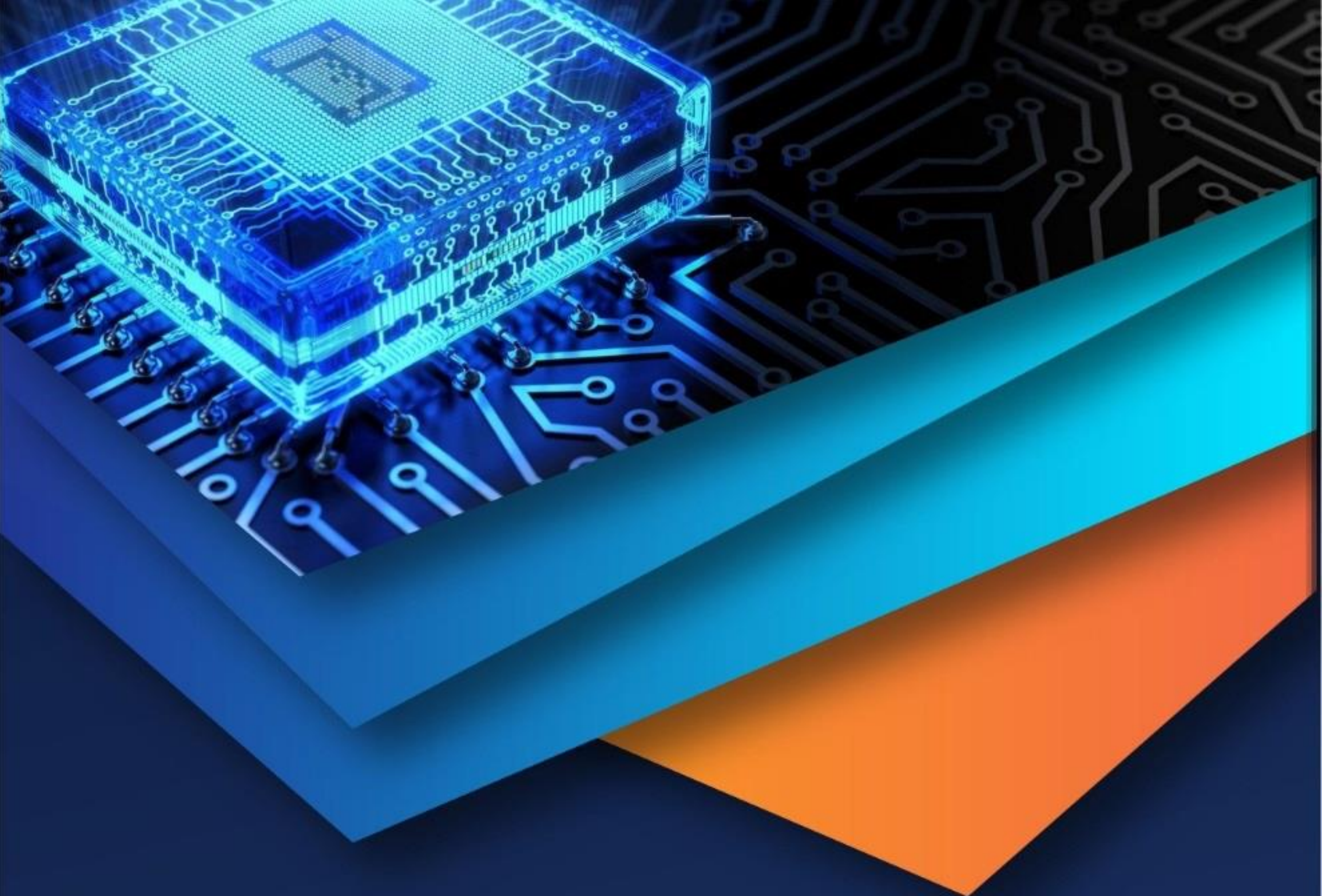

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