Supression of Low Frequency Oscillations Using Hybrid Optimization Techniques

Mohit Bhagat[1], Baljit Singh[2]
Department of Electrical Engineering[1, 2],D.A.V institute of Engineering & Technology , jalandhar[1, 2]
Email:mohitbhagat47@gmail.com [1] ,singh_baljit82@yahoo.com [2]

Abstract- Low frequency oscillations in the interconnected power system are observed all around the world. This Paper considers the stabilization of synchronous machines in the interconnected system via PID. The PID parameters are tuned using hybrid Firefly Algorithm (FFA) by adding Particle Swarm Optimization (PSO). The tuning of the PID parameters is formulated with objective function. The Firefly and PSO Algorithm which has been found robust in solving these kinds of optimization problems is selected as a tool to find the optimum solution. Simulation results indicate that the applied hybrid technique is effective and efficient. Also, a comparison study is introduced when using classical PID, only firefly optimization and when using hybrid firefly-particle swarm optimization. The results show that using the proposed hybrid control is capable of guaranteeing the stability and performance of the power system better than the PID-PSS based classical PID and FFA only.

Keywords: PSS, PID, Firefly Algorithm, Particle Swarm Optimization, Hybrid FFA-PSO Algorithm

1. INTRODUCTION

The disturbances occurring in power system because of changes in load include electro mechanical oscillations of electrical generators. These oscillations are also called power swings and these must be effectively damped to maintain the system stability. Electromechanical oscillations can be classified in two main categories (i) Local Plant Mode Oscillations**:** One type is associated with units at a generating station swinging with respect to the rest of the power system. Such oscillations are referred to as 'local plant mode oscillations'. The frequencies of these oscillations are typically in the range 0.8Hz to 2.0 Hz., (ii) Inter-area Oscillations: The second type of oscillation is associated with the swinging of many machines in one part of the system against machines in other parts. These are referred to as 'interarea mode' oscillations and have frequencies in the range 0.1 to 0.7 Hz. The stability criterion with respect to synchronous machine equilibrium has been presented. The perturbations weak damping may be caused by adverse operating conditions. Inter-Area oscillations are associated with the swinging of machines in one part of the system against machines in other regions, this problem can occur when these machines are interconnected with weak tie lines. Automatic Voltage Regulator (AVR) may help to improve the steady state stability of systems, but are not as useful for maintaining stability during transient conditions. The addition controller is required in the AVR control loop provides the means to damp these oscillations [16]. The added AVR and PSS are designed to act upon local measurements such as bus voltage, generator shaft speed, or the rotor angle of the associated machine. PSS can provide supplementary control signal to the excitation system and or the speed governor system of the electric generating unit to damp these oscillations. Due to their flexibility, easy implementations and low cost, PSS have extensively studied and successfully used. When a power system under normal load condition suffers a perturbation there is synchronous machine voltage angle rearrangement. If for each perturbation that occurs, an unbalance is crated between the system generation and the load a new operation point will be established and consequently there will be voltage angle adjustments. The system adjustment to its new operation condition is called "transient period" and the system behavior during this period is called "dynamic performance" [2]. It is observed by adding additional controller named PID in the AVR system with PSS is very effective to damp oscillations during the system is subjected under large perturbations or transient period[4]. Despite the potential of the modern control techniques with different structure, Proportional Integral Derivative (PID) type controller is still widely used for AVR system [2]. Industrial implementations of PID controllers in AVR systems show that the appropriate selection of PID controller parameters results in satisfactory performance during system upsets. Thus, the optimal tuning of a PID gains is required to get the desired level of robust performance. Since optimal setting of PID controller gains is a multimodal optimization problem and more complex due to nonlinearity and time-variability of real world power system operation. Therefore, the traditional techniques are not completely systemic and most of them occasionally yield poor performance in practice, so they are not suitable for such a problem.

Recently metaheuristic approaches, have received increased attention from researchers dealing with the AVR control problems. In order to obtain an optimal PID controller for an AVR, Mukherjee and Ghoshal presented a craziness based particle swarm optimization (CRPSO) and binary coded genetic algorithm (GA) [5]. Ching-Chang suggested a real-valued genetic algorithm (RGA) and a particle swarm optimization (PSO) to design PID controller for AVR system [6].

2. POWER SYTEM STABILIZER

Power System stabilizers (PSS) were developed to aid in damping via modulation of excitation system of generators. The action of a PSS is to extend the angular stability limits of power system by providing supplemental damping to the oscillation of synchronous machines rotors through the generator excitation. To provide damping, stabilizers must produce a component of electrical torque on the rotor which is in phase with the speed variations. However, power system instabilities can arise in certain circumstances due to negative damping effects of the PSS on the rotor. The reasons for this is that PSS are tuned around a steady-state operating point their damping effect is only valid for small excursions around this operating point. During severe disturbances, a PSS may actually cause the generator under its control to lose synchronism [2,4,9].

A. Structure of PSS

The Block Diagram of the PSS is shown below in Fig 1. It consists of signal washout block, phase compensation block and a gain block.

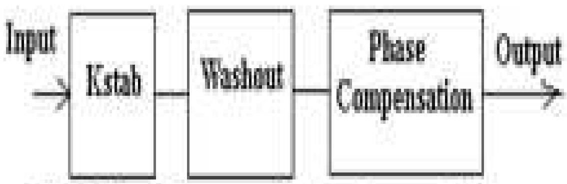

Fig. 1 Block diagram of Power System Stabilizer

1) Gain Block

The stabilizer gain Kstab determines the amount of damping introduced by PSS. Ideally the gain should be set at a value corresponding to maximum damping, however it is often limited by other considerations.

2) Washout circuit

The signal washout block serves as a high-pass filter, with the time constant Tw high enough to allow signal associated with oscillations in w_r to pass unchanged. Without it steady changes in speed would modify the terminal voltage. It allows the PSS to respond only to changes in speed. From the viewpoint of the washout function, the value of Tw is not critical and may be in the range of 1 to 20 seconds. The main consideration is that it be long enough to pass stabilizing signal at the frequencies of interest unchanged, but not so long that it leads to undesirable generator voltage excursions during system islanding conditions.

3) Phase Compensation Block

The phase compensation block provides tha appropriate phase-lead characteristic to compensate for the phase lag between the exciter input and the generator electrical torque. The figure shows a single first order block. In practice, two or more first-order blocks may be used to achieve the desired phase compensation. Normally the frequency range of interest of 0.1 to 2.0 Hz, and the phase lead network should provide compensation over this entire lead network should provide compensation over this entire frequency range.

4) Input Signal

The input signals that have been identified as valuable include deviations in the rotor speed (Δω), the frequency (Δf), the electrical power (ΔPe) and the accelerating power (ΔPa). Since the main action of the PSS is to control the rotor oscillations, the input signal of rotor speed has been the most frequently advocated in the literature.

3. PID CONTROLLER

The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin and increases the system order by one and reduces the steady-state error due to a step function to zero. The PID controller transfer function is done by [2]

$$G_{PID}(s) = k_p + \frac{ki}{s} + k_{Ds} \qquad (1)$$

Where k_p, k_i, k_d are gain for proportional, derivative and integral controller respectively.
Based on the three-term PID controller, there may be derived a number of other controller. The majority of the industrial control elements are o P or PI type. These controllers are derived from PID controller.

4. FIREFLY ALGORITHM

Firefly Algorithm is a nature inspired algorithm, which is based on the Flashing Light of Fireflies. In fact, the algorithm has three particular idealized rules which are based in real on some major flashing characteristics of real fireflies[14]. These are the following:

(1) All fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.
(2) The degree of the attractiveness of a firefly is proportional to its brightness which decreases as the distances from the other firefly increases.
(3) If there is no brighter or more attractive firefly then a particular one, then it will move randomly.

For an optimization problem, the flashing light is associated with the fitness function in order to obtain efficient optimal solutions.

When searching solutions the fireflies use three main procedures: attractiveness, movement and distance which are defined as follow [14,16]

- **Attractiveness:**

In the firefly algorithm, the form of attractiveness function of a firefly is given by the following monotonically decreasing function

$\beta(r) = \beta_0 * exp(-\gamma r_{ij}^{m})$ with m≥1 (2)

Where, r is the gap between two fireflies.

β_0 is the attractiveness in the starting when distance r=0

γ is an absorption coefficient which controls the decrease of light intensity.

- **Distance:**

The distance between two fireflies i & j, at positions x_i *and* x_j.it can be defined as a Cartesian.

$$r_{ij} = \| x_i - x_{ji} \| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (3)$$

Where $x_{i,k}$ is the Kth component of the spatial coordinate x_i of the ith firefly and d is the number of dimensions we have, for d=2 , we have

$$r_{ij} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} \quad (4)$$

However, the calculation of a distance r can also be defined using other distance metrics, based on the nature of problem, such as manhattan distance.

- **Movement:**

The movement of the firefly *i* which is attracted by a more attractive. Firefly *j* is given by is given by:

$$x_i = x_i + \beta_0 * \exp(-\gamma r_{ij}^2) \; * \; (x_j - x_i) \; + \; \alpha * \; (rand - \tfrac{1}{2}) \quad (5)$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies and third term is used for the random movement of fireflies in case there are no brighter ones. The coefficient α is a randomization parameter determined by the problem of interest. Rand is a random number generator uniformly in the distributed space [0,1].

5. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization is a population based stochastic optimization method. It explores for the optimal solution from a population of moving particles, based on a fitness function. Each particle represents a potential answer and has a position (X_i^k) and a velocity (V_i^k) in the problem space. Each particle keeps a record of its individual best position(P_i^k), which is associated with the best fitness is has achieved thus far, at any step in the solution. This value is known as p_{best}. Moreover, the optimum position between all the particles obtained so far in the swarm is stored as a global best position (P_g^k). This location is called gbest. The velocity of particle and its new position will be updated according to the following equations and fig 2:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (6)$$

V_i^{k+1}=
w□□V_i^k□□c_1□ r_1 ∗□P_i^k□X_i^k□□□c_1□r_1□□P_g^k□X_i^k□□

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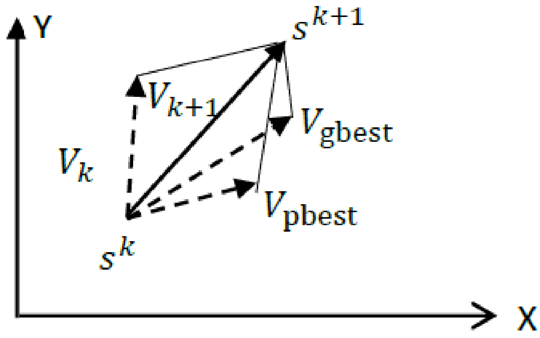


Fig 2: Position update of particle in PSO

where *w* is an inertia weight that controls a particle's exploration during a search, c_1 and c_2 are positive numbers explaining the weight toward the individual best and the swarm best positions respectively, r_1 and r_2 are uniformly distributed random number in (0, 1), and *N* is the number of particles in the swarm. The inertia weighting function in Eq.7 is usually calculated using following equation:

$$w = w_{max} - (w_{max} - w_{min}) * \frac{K}{G} \quad (8)$$

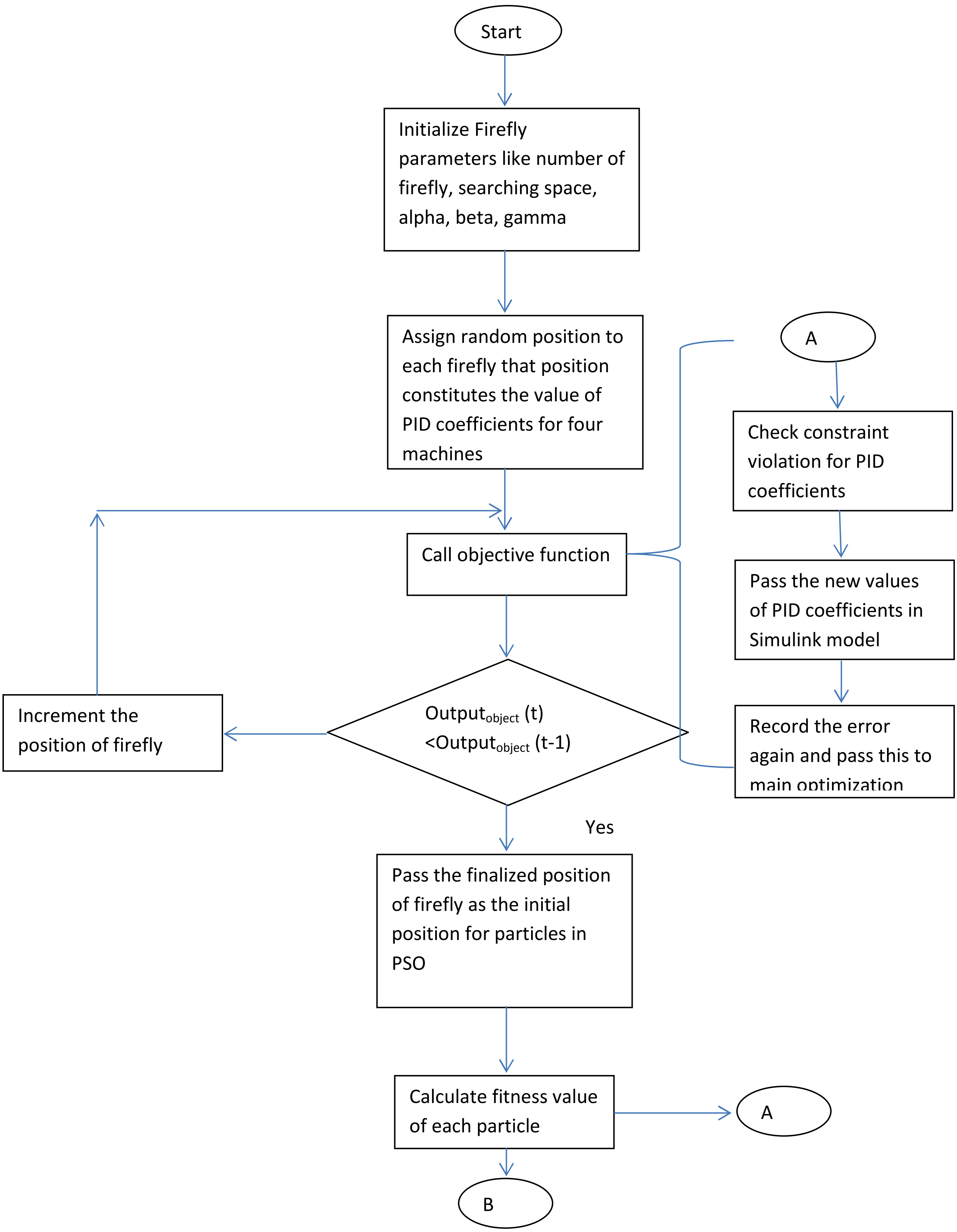
where w_{max} and w_{min} are maximum and minimum value of *w*, *G* is the maximum number of iteration of *K* is the current iteration number. The first term in Eq.(7) enables each particle to perform a global search by exploring a new search space. The last two terms in Eq. (7) enable each particle to perform a local search around its individual best position and the swarm best position[15].

6. HYBRID ALGORITHM

A new approach called Hybrid Firefly Swarm algorithm (HFS) is proposed using Firefly (FA) and Particle swarm optimization (PSO) algorithm. Hybridization is carried out either sequentially or parallel. Sequential hybridization is carried out by
passing the output of one algorithm to other as input in a pipeline fashion. In this work, Sequential hybridization is performed by passing the best ten optimum values of the Firefly algorithm (FFA) as the initial population to the Particle swarm optimization (PSO) algorithm. The need for hybridization is that search space of the FA algorithm is refined to achieve a better solution using PSO. The PSO algorithm is fast in convergence to a best solution and FFA always finds a global optimum is less number of iterations. To further exploit the search space of FFA, it is hybridized with the PSO. Fig 3 shown for the hybrid optimization flowchart.

7. IMPLEMENTATION OF HYBRID-PID CONTORLLER

Consider a Four-machine two-area system shown in Fig.3. For the purpose of comparison, the performance of PSS designed using the conventional parameters setting method and the proposed FFA-PSO tuning approach considering Low Frequency Oscillations are investigated in four operating condition. A same three-phase short-circuit fault lasting for 0.1 second is set in the AC line between. In this paper, a PID controller is tuned with FFA-PSO was proposed to improve the dynamic in the Kundur's model.



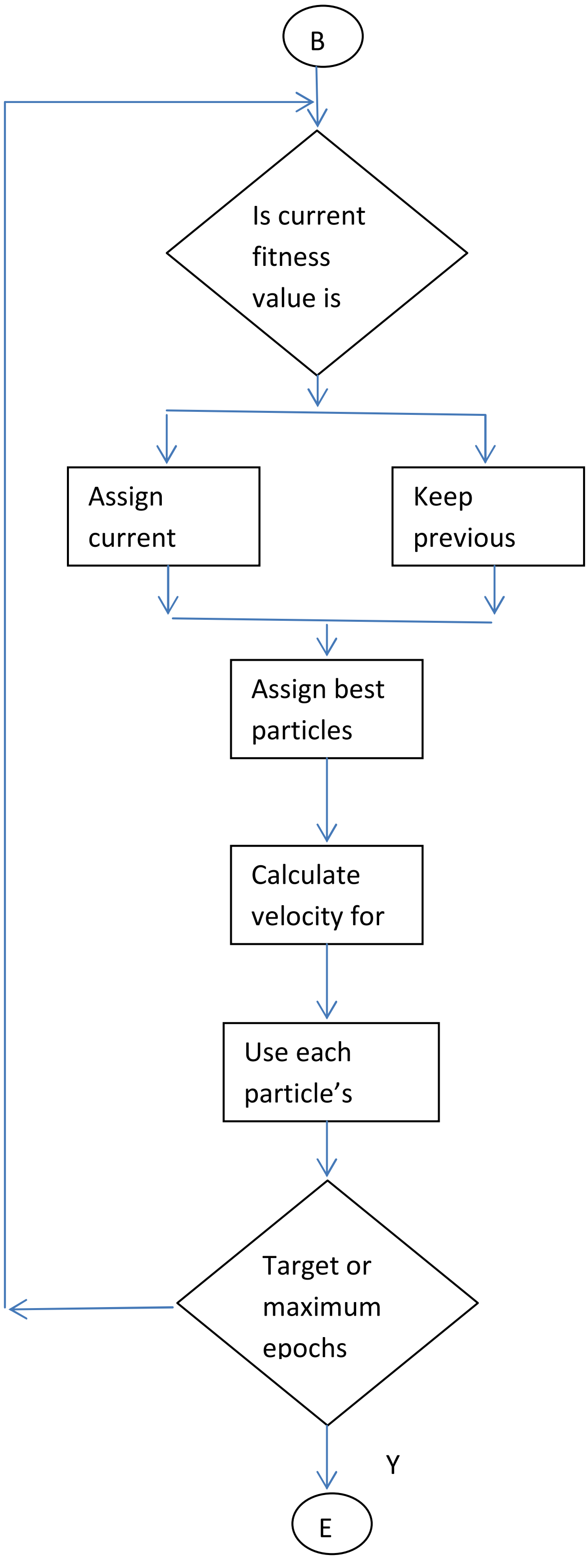


Fig: 3 Flow chart of Hybrid FFA-PSO

A same three-phase short-circuit fault lasting for 0.1 seconds is set in the AC line. Fig 4 shows system for the two area four machine kundur's model, each area have 900 MVA generating units equipped with fast static exciters. All two generating units represented by the dynamic model1. The machine and the exciter data used in the study are taken from Kundur book of power

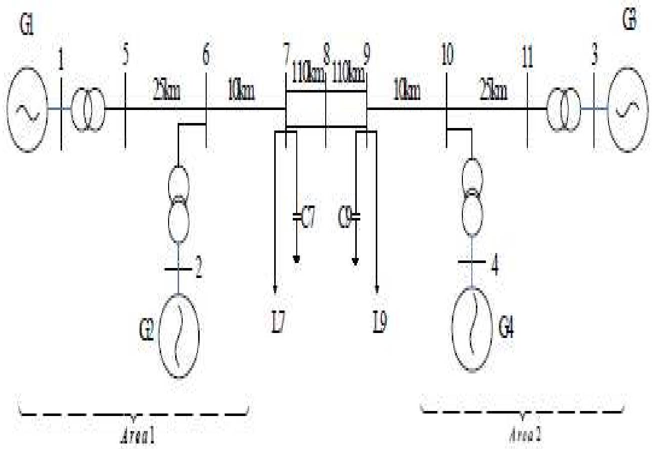


Fig 4: Two area Four Machine System

system stability & control. In this system area 2 is weak system area because load connected to area 2 is greater than the capacity of generator of area 2 so excessive power fed by area 1.

7.1 FITNESS FUNCTION

To improve the transient response of an AVR system, the main goal of the proposed Hybrid FFA-PSO controller is demonstrating to adjust optimally as fast as possible the PID controller parameters by minimization of predetermined fitness function. A Hybrid FFA-PSO scheme has been used for the optimization of PID-PSS parameters just like any other optimization problem, a cost or a fitness function needs to be formulated for the optimal PID-PSS design. The objective in the optimal PID-PSS design is to maximize damping. In time domain, the fitness function can be formed by different performance specifications such as integral of time multiplied by absolute error value (ITAE), rise time, settling time, overshoot and steady state error must be minimized. The fitness function is give by

$$F = ITAE \int_0^{\infty} (\Delta\omega)^2 \, dt \qquad (9)$$

where $\Delta\omega$ is the Rotor speed deviation of the generator obtained from time domain simulation. Therefore, the design problem can be formulated as the following optimization problem.
Minimize F
Subject to

$$X^{min} \leq X \leq X^{max} \qquad (10)$$

Where X is vector, which consist of the parameters of the PID-PSS.

The proposed approach employs FFA-PSO to solve this optimization problem and search for the optimal set of PID-PSS parameters.

8. SIMULATION RESULTS

The proposed approach is implemented on Kundur's Model in which model is run in four different cases. Results of the four Machines are shown in following figure. However, there is no formal methodology to solve the problem because different performance of the approach.

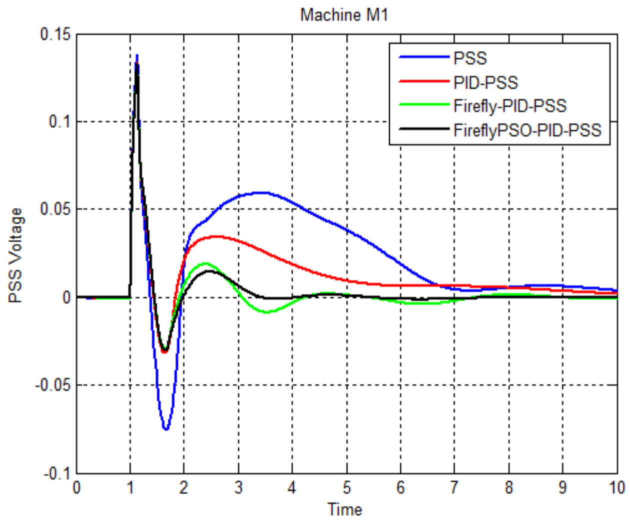


Fig:5 Result of Machine 1

Table: 5.1 For machine 1

	First Peak (F)	Settling Time (S)
With PSS Only	0.059	9.9
With PID-PSS	0.035	5.6
With FireFly-PID-PSS	0.019	4.2
With Firefly-PSO-PID-PSS	0.14	3.3

Result shown for machine 2 in fig 6 followed by table 6.1

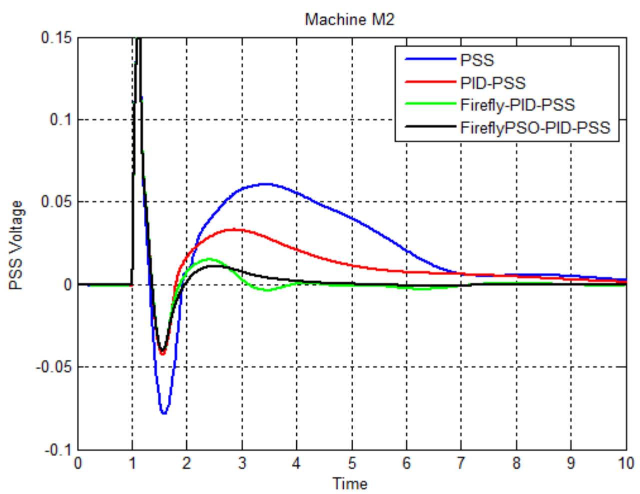


Fig: 6 Result of Machine 2

Table: 6.1 For machine 2

	First Peak (F)	Settling Time (S)
With PSS Only	0.0605	9.8
With PID-PSS	0.035	7.2
With FireFly-PID-PSS	0.015	4.5
With Firefly-PSO-PID-PSS	0.14	3.8

Result shown for Machine 3 in figure 7 followed by table 7.1

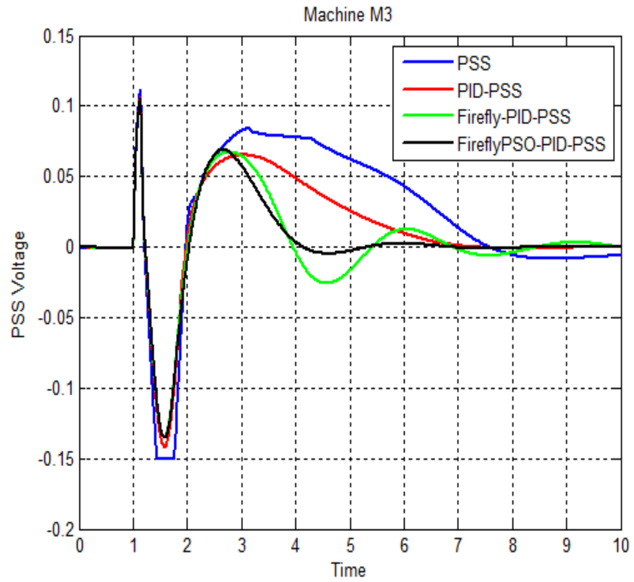


Fig: 7 Result of Machine 3

Table: 7.1 For machine 3

	First Peak (F)	Settling Time (S)
With PSS Only	0.0845	7.65
With PID-PSS	0.069	7.7
With FireFly-PID-PSS	0.067	6.92
With Firefly-PSO-PID-PSS	0.065	4.8

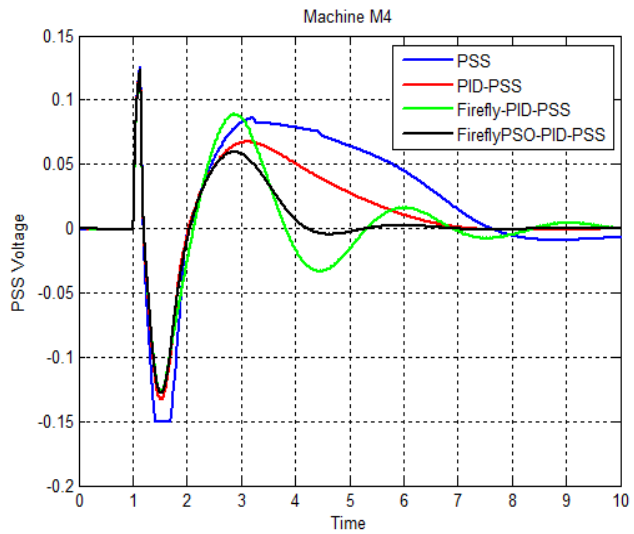


Fig: 8 Result of Machine 4

Table: 8.1 For Machine 4

	First Peak (F)	Settling Time (S)
With PSS Only	0.082	7.68
With PID-PSS	0.068	7.5
With FireFly-PID-PSS	0.885	8.4
With Firefly-PSO-PID-PSS	0.058	5.3

9. CONCLUSION

In this paper, the design of a PID power system stabilizer using hybrid FFA-PSO had been investigated. The design was applied to a typical Kundur's model two area four machine system. The simulation results of the system for the deviations in the rotor speed demonstrated that the designed optimal PID-PSS based proposed hybrid FFA-PSO optimization method is capable of guaranteeing the stability and performance of the power system better that the PID controllers and PID-PSS based Firefly only.

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