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A Hybrid Particle Swarm Optimization Approach for Design Power System Stabilizer

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***Abstract*— The swarm intelligence techniques have invited interest of researchers in recent years. Present work is the effort to investigate all the aspects of biologically inspired algorithm with multilayer Swarm optimization .Multi layer swarm optimization Algorithm exhibits its ability to solve the optimization and design problem. Design of Power System stabilizer (PSS) for modern power system has its importance for improving the stability of the system.**

The work presented in this paper is related with the design of PSS parameters with help of swarm intelligence technique. Hybrid Particle Swarm Optimization (HPSO) method is used and applied to find the parameters for PSS at Single machine infinite bus system. System performance is judged with the Particle swarm optimization and Algorithm tuned PSS for different cases of loading conditions. The system is tested for light medium and heavy loading. The efficacy of the stabilizer is tested on a single machine infinite bus bar system.

***Index Terms*—Particle Swarm Optimization, PSS, Small signal stability, Single Machine infinite bus system, Hybrid Particle swarm optimization, Hierarchical structure poly-particle swarm optimization.**

I. Introduction

Recent years demand of the power has been increased from domestic and industrial purposes in all around the world. Interconnection of the two systems are required to meet this demand ,generally operating conditions are very stressed at high load centers and tie lines are operated at maximum capacity. The stability of the interconnected system is mainly characterized by two subclasses small signal stability and transient stability. Small signal stability is the one of major concerns in the power system it provides valuable information about the inherent dynamic characteristics of the power system and help in the design. The interconnected power systems are complex and exhibit non linearity for wide range of operating conditions .operating conditions of a power system are continually changing due to following reasons:

- Changing in Load Patterns
- Variation in generation
- Transmission topology
- Line switching

This work addresses a special requirement of Power system stabilizer (PSS) for excitation control.

The basic function of PSS is to extend stability limits which are characterized by lightly damped oscillations of frequency [1].PSS is a control device which increase not only the stability limit and thereby extend the power transfer capability by mitigating the low frequency oscillations associated with the electromechanical modes.PSS is used to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s) [1][2].

Conventional Power system stabilizers are designed using the theory of phase compensation in the frequency domain and are introduced as a lead lag compensator. Recent years artificial intelligent techniques contribute majorly to solve the optimization problems and design algorithms. Researchers have come forward with new evolutionary techniques like Trajectory Search Algorithm, µ synthesis [3][4] .Particle swarm optimization algorithm[7] is modified by Lin Lu,Qi Luo ,Jun-yong,Liu and Chuan Long [8] this algorithm is termed as hierarchical structure poly-particle swarm optimization (HSPPSO).A structure which contains hierarchy tested on various functions and give good convergence.Further in this work the HPSO algorithm is applied for design and tune the stabilizer constants. The work presented here is related with Power system stabilizer design, The efficacy of this stabilizer is tested on single machine infinite bus system.

II. Modeling of SMIB

The oscillatory period is divided into a transient period and steady state period. Interest of this work to investigate the response towards the small changes. Following are the assumptions

- Stator winding is neglected
- Balancing conditions are assumed and saturation effects are neglected.
- Damper winding effect is neglected

The classical generator model is constituted by the following equations from [1] [2].

$$\Delta T_e = \frac{\partial T_e}{\partial \delta}\ \Delta\delta = E' E_b / X_T\ \cos\delta_0 (\Delta\delta) \quad (1)$$

$$p\Delta\omega_r = \frac{1}{2H}\left(T_m - T_e - K_D \Delta\omega_r\right) \quad (2)$$

$$p\delta = \omega_0 \Delta\omega_r \quad (3)$$

$$p\Delta\omega_r = \frac{1}{2H}\left(\Delta T_m - K_s\Delta\delta - K_D \Delta\omega_r\right) \quad (4)$$

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$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_r\\ \Delta\delta\end{bmatrix} = \begin{bmatrix}\frac{-K_D}{2H} & \frac{-K_s}{2H}\\ \omega_0 & 0\end{bmatrix}\begin{bmatrix}\Delta\omega_r\\ \Delta\delta\end{bmatrix} + \begin{bmatrix}1/2H\\ 0\end{bmatrix}\Delta T_m \quad (5)$$

Where

K_D=Damping torque coefficient

K_s=Synchronizing coefficient

H=Inertia Constant
ω_0 = rated speed

$\Delta\omega_r$=deviation in speed in p.u

E'=voltage behind X_d '

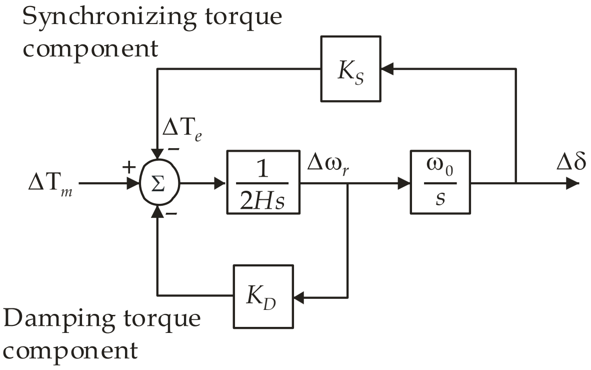


Fig 2.1 Single Machine to infinite bus System

PSS is a device which provides additional supplementary control loops to the automatic voltage regulator system. the main idea behind the stabilization is to investigate the system states i.e. if it is in steady state the voltage controller should be driven by the voltage error however in the case of any small perturbations of load or in transient state (when rotor undergoes the swing) the task of PSS is to generate the additional signal which compensates for the Δv oscillation and provides a damping component that is in phase with Δω Fig.2.2 is the block diagram representation given by Kundur [1] for the single machine infinite bus system with PSS and AVR.

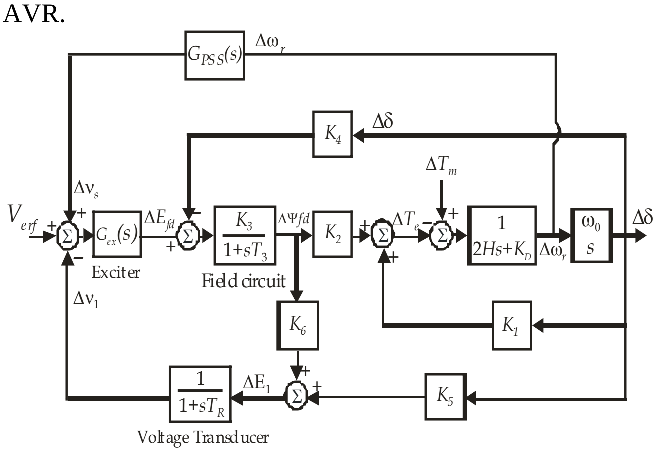


Fig.2.2 Block Diagram for SMIB with PSS

A. *Structure of PSS*

A widely speed based conventional PSS Fig 2.3 is considered for this work [5] [6] .the supplementary stabilizing signal is considered is one proportional to the speed. further structure consist of a block with gain washout filter which essentially is a high pass filter .The washout filter is used to reset the steady state offset in output of the PSS the time constant for this filter is Tw and its high enough to allow signals associated with oscillations in input signal to pass unchanged[8] [9].The Lead Lag block present in the system provides phase lead compensation for the phase lag that is introduced in the circuit between the input of exciter and electrical torque in other words this block provides the appropriate phase lag between input and output . The required phase lag can be obtain by lead lag block even if the denominator portion consisting of fixed lag angle .the values for those taken as T2=0.05 T4=0.01and tuning of T1 and T3 are undertaken to achieve the net phase lead required by the system[9].

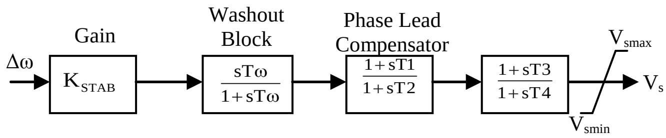


Fig. 2 .3 Structure of power system stabilizer

$$U_i = K_s\frac{sT_W}{1+sT_W}\left[\frac{(1+sT_1)\ (1+sT_3)}{(1+sT_2)\ \ (1+sT_4)}\right]\ \Delta\omega_i(s) \quad (6)$$

B. *Problem Formulation*

From SMIB Eigen value of the generator is computed which is shown in TABLE I for different case of damping factor. The real component of the eigenvalue gives the damping, and the imaginary component gives the frequency of oscillation. A negative real part represents a damped oscillation whereas a positive real part represents oscillation of increasing amplitude [11].

$$\lambda = \sigma \pm j\ \omega \quad (7)$$

Damping ratio ζ is given by the equation (8)

$$\zeta = \frac{-\sigma}{\sqrt{\sigma^2-\omega^2}} \quad (8)$$

The objective of PSS design is to minimize the power system oscillations after a disturbance so as to improve the power system stability [9] [10]. Further objective function for this work is given as

$$J = \min \zeta \quad (9)$$

With constraints

$$K_i^{min} \le K_i \le K_i^{min}$$
$$T_{1i}^{min} \le T_{1i} \le T_{1i}^{min}$$
$$T_{3i}^{min} \le T_{3i} \le T_{3i}^{min}$$

In case of above lead-lag structured PSS, the sensor and the Washout time constants are usually specified. In the present study, washout time constant *Tw* =10s are used. Also, in lead-lag structured controllers the denominator time constants are usually specified [9]-[13]. In the present study, *T2* =0.05, *T4* = 0.1 s are used. The controller gain K_s and the time constants *T1*, and *T3* are to be determined.

III. Improved Particle Swarm Optimization

PSO is a kind of heuristic optimization algorithms. It is motivated from simulating certain simplified animal social behaviors such as bird flocking, and is first proposed by

Kennedy and Eberhart in 1995 [5].It is an iterative, population-based method. The particles are described by their two instinct properties: position and velocity. The position of each particle represents a point in the parameter space, which a possible solution of the optimization problem and the velocity is used to change the position.

$$v_{ij}^{k+1} = \omega . v_{ij}^{k} + c_1 r_1 (P_{ij} - x_{ij}^{k}) + c_2 r_2 (P_{gj} - x_{ij}^{k}) \quad (3.1)$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \quad (3.2)$$

$$i = 1,2,3 \ldots\ldots\ldots N_p \qquad j = 1,2,3 \ldots\ldots\ldots N_D$$

Where *Np* is the number of particles in the population; *Nd* is the number of variables of the problem (i.e. dimension of a particle); v_{ij}^{k} is the *jth* coordinate component of the velocity of the *ith* particle at iteration *k*; P_{ij} is the *jth* coordinate component of the best position recorded by the *ith* particle during the previous iterations; P_{gj} is the *jth* coordinate component of the best position of the global best particle in the swarm, which is marked by *g*; x_{ij}^{k} is the *jth* coordinate component of the current position of particle *i* at the *kth* iteration; ω is the inertia weight, $c1$, $c2$ are the acceleration coefficients, $r1$, $r2$ are the uniformly distributed random values between 0 and 1.

Multi Layer Particle swarm optimization is used to find the various parameters of PSS following is the algorithm which is used to carry out desired values of coefficients

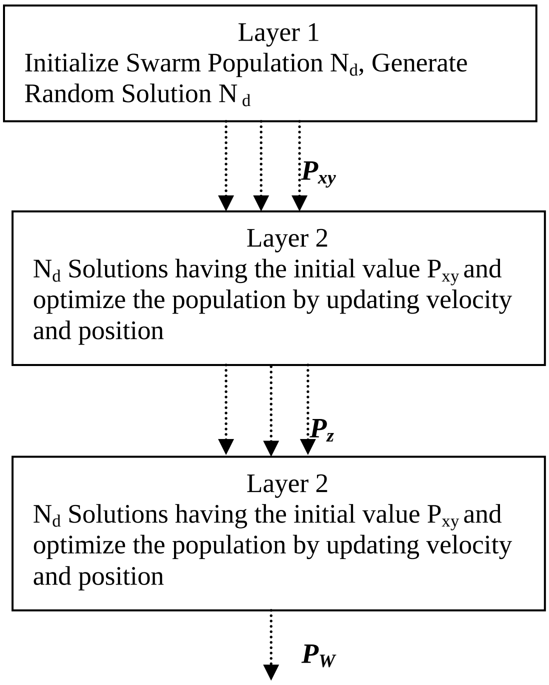


Fig 3.1 Structure of HPSO

Step1. Initialize Swarm Population, Scale and parameters for each layers, inertia weight, learning factor, Correction factors and largest iteration no.

Step2. The whole population of Swarm is divided into three Layers. Swarm Population of first layer first generate random solutions. The values of these are considered as the adaptive values. The most suitable optimum value is assigned as a current optimum solution P_{xy}.

Step3. Second Layer accepts the optimum solutions which is equal to swarm size from the first layer Pxy. These values are considered as the initial values for the swarm population. Updation of velocity and position according to following equation 3.3

$$v_{ij}^{k+1} = \omega . v_{ij}^{k} + c_1 r_1 (P_{ij}^{k} - x_{ij}^{k}) + c_2 r_2 (P_{xy}^{k} - x_{ij}^{k})$$

If $v_{ij}^{k+1} > V_{max}$, $V_{k+1}^{ij} = V_{max}$

If $v_{ij}^{k+1} < V_{min}$, $V_{k+1}^{ij} = V_{min}$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \quad (3.3)$$

Step4. The current optimum solution is obtained from the layer and the value which is most optimum is assigned to the whole population. Suppose this value is Pz. Now these adaptive values of particle and compares with current individual extremum which is transferred to third layer

Step5. Further the velocities and positions are updated by 3.4

$$v_{ij}^{k+1} = \omega . v_{ij}^{k} + c_1 r_1 (P_{ij}^{k} - x_{ij}^{k}) + c_2 r_2 (P_{xy}^{k} - x_{ij}^{k}) + c_3 r_3 (P_{z}^{k} - x_{ij}^{k})$$

If $v_{ij}^{k+1} > V_{max}$, $V_{k+1}^{ij} = V_{max}$

If $v_{ij}^{k+1} < V_{min}$, $V_{k+1}^{ij} = V_{min}$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1} \quad (3.4)$$

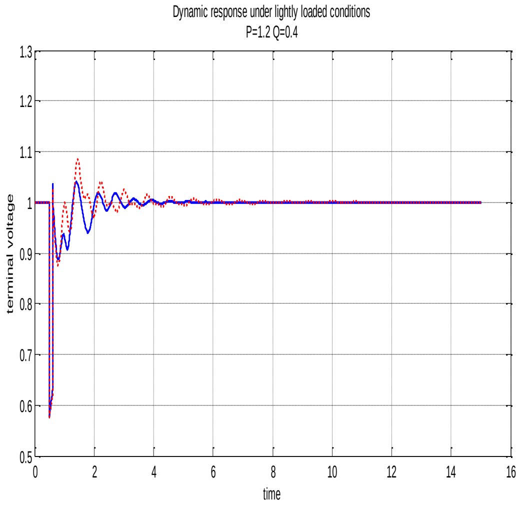
Step6. Evaluate end condition of iteration; if sustainable then out put the result Pw.

IV. Simulation and Results

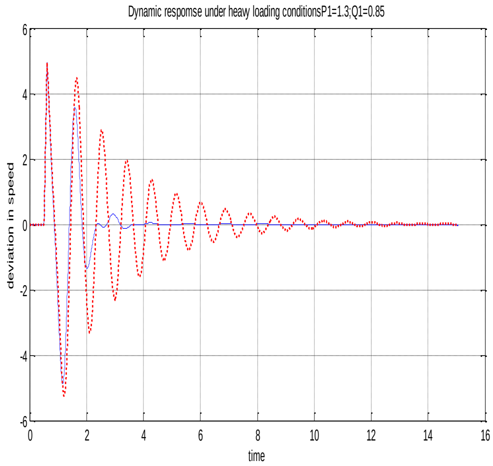
The performance results of the SMIB system as discussed by Kundur [1] with power system stabilizer control generator terminal voltage and voltage of the bus next to the generator. This work investigated under different loading conditions named as heavy, medium and light loading condition .The data for these conditions are given in Table I when three phase fault at infinite bus at 0.1 sec. All the data SMIB is taken from [1] .Response are shown in fig 4.1.Table II shows the calculated values of K and T1 and T3 for PSO and HPSO the values of J is obtained and these values are shown in Table IV .The different eigenvalues for loading conditions when PSS is corporate on SMIB is shown in Table III.

TABLE I Generator Opreating Conditions (P.U.)

Loading	P	Q
Heavy	1.2	0.85
	1.3	0.86
Medium	0.8	0.6
	0.7	0.5
Light	0.5	0.2
	0.5	0.4



(a)



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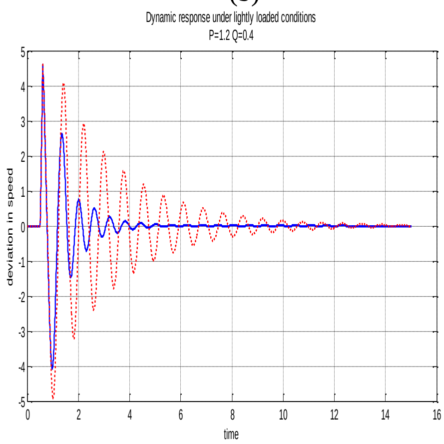

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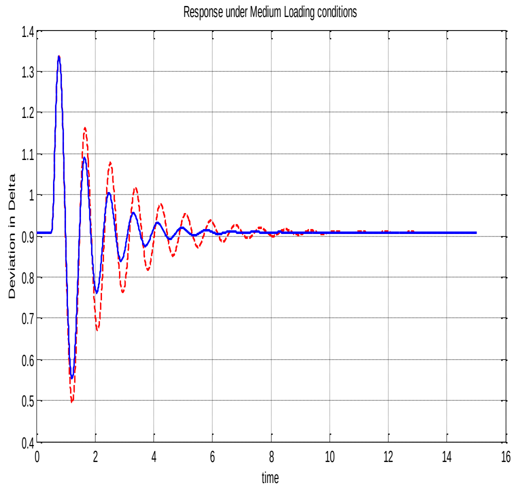

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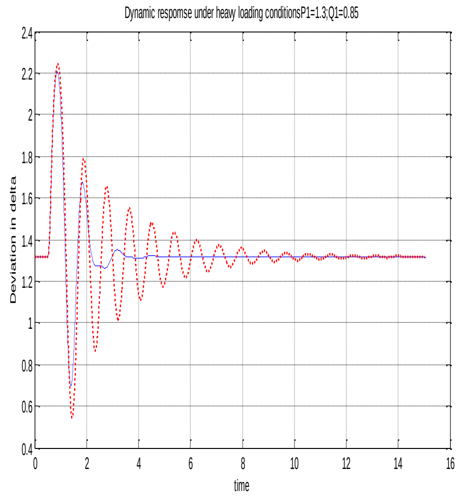
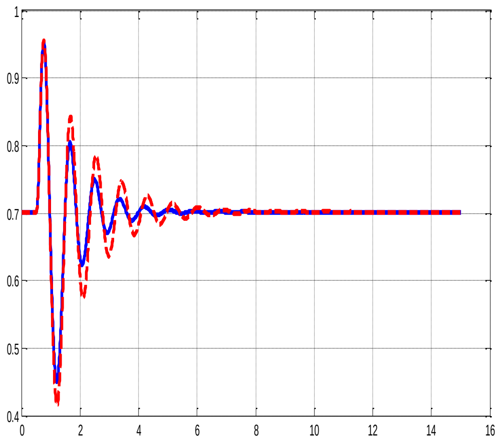


(e)



(f)

Fig 4.1 For operating conditions Noiminal Heavy and Light Loading given in Table I the reposnses are shown .The reponses for lightly loaded conditions similarly for heavy loading conditions and for nominal loading conditions.The reponses are for speed deviation vs time, voltage (terminal) deviation with time and Delta deviation vs time the Solid part(------) shows the reponse of the new multilayer particle swarm optimization and dotted line(- - - -) shows the repsponse of the PSO

TABLE II OPTIMAL PSSS PARAMETERS WITH PSO AND HSPPSO

Method	K	T1	T2	T3	T4
PSO	12.04	0.1821	0.05	0.276	0.1
HPSO	14.39	.16	0.05	0.1056	0.1

TABLE III EIGENVALUES OF ELECTROMECHANICAL MODE WITH PSSS

Nominal	Heavy	Light
-1.8692±j6.1010 -1.9235±j6.0841 -1.811±j6.118 -1.859±j6.1039	-1.5513±j6.1895 -2.634±j5.8119 -1.3802±j6.2299 -1.2927±j6.248	-0.5816±j6.3544 -0.9467±j6.313 -3.4760±j5.315 -3.6325±j5.2461

V. CONCLUSION

This paper is a systematic procedure for simultaneous tuning of power system stabilizer in SMIB. This work has an objective to solve the controller design problem objective function is developed [9] and system is tested for PSO and HPSO both algorithm searches optimal parameter for controller further it is tested for robustness .Figure of Demerit performance indices is defined as (5.1).Overshoot and Undershoot from the rotor angle deviation curve is calculated further FOD is calculated and shown in Table IV.

$$FOD= (1000*OS^2) + (1000*US^2) + (Ts)^2 \qquad (5.1)$$

TABLE IV OBJECTIVE FUNCTIONS AND FOD CALCULATION FOR ALL OPERATING CONDITIONS AND FOR PSO AND HSPPSO

Loading conditions	J (HPSO)	J(PSO)	FOD	
Nominal	0.2837	0.2928	**114.23**	132
	0.2913	0.3017	**107.18**	128.2
Heavy	.2162	.2430	**113.91**	133.7
	.2025	.4126	**98.09**	99.07
Light	.5445	0.0911	**153.47**	157.23
	.5692	0.14837	**157.89**	159.47

It is to be mention here the as the value of this indices will be low the controller to more robust and more effective .controller is tested for three phase fault at generator terminal at 0.1 s. The simulation results for this controller shown in *Fig4.1*and it shows that when compared it shows better robustness and effective in damping the modal oscillations.

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