Stability Enhancement for Multi-machine Power System by Optimal PID Tuning of Power System Stabilizer using Particle Swarm Optimization

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Abstract: - This paper demonstrates the superior effectiveness of utilizing the artificial search technique to ascertain parameters optimization of power system stabilizer (PSS), contemplating proportional-integral-derivative controller (PID) for a multi-machine power system, compared to the customary Ziegler-Nichols method. As the PID - PSS parameters are also tuned by the Ziegler-Nichols method at the same operating point. Its effectiveness is presented using four machines power system. Acquire settings of PID - PSS which meliorate damping frequency of system are optimized by minimizing an objective function using Particle Swarm Optimization, an artificial search technique. The results convey eminent efficiency of the proposed PSO based PID controller.

Key-Words: - Power system stabilizer, PID tuning, Multi-machine power system, Particle Swarm Optimization, Artificial intelligent search technique

1 Introduction

Recently, electricity demands are increasingly in every electric utility around the world. Modern power system control requires a continuous balance between electrical generation and a varying load demand, while maintaining system frequency and voltage levels. The use of high performance excitation systems is essential for maintaining steady state and transient stability of modern synchronous generators and provides fast control of the terminal voltage.

It is well known that each generator in an interconnected power system is supported by two major control loops. These loops are: Automatic Generation Control (AGC) which is responsible for power balancing, and Automatic Voltage Regulator (AVR) which regulates the terminal voltage by controlling the excitation. Since the development of interconnection of electric power systems, there have been spontaneous system oscillations at low frequencies in the order of several cycles per seconds. These oscillations may cause operating constraints depending on their magnitude and location in system, and are classified as local mode oscillations that oscillate in the range 0.8 to 3 Hz, inter-machine mode oscillations that oscillate in the range 0.3 to 1 Hz , and inter-area mode oscillations that oscillate in the range 0.1 to 0.7 Hz. These slow oscillations could continue to grow causing system separation. It is well known that these oscillations are due to lack of sufficient damping of the slow mechanical modes of the systems. The desired additional damping is provided by a supplementary control loop known as Power System Stabilizer (PSS) [1].

A PSS stabilizer provides a supplementary control signal to the AVR loop for excitation control. This signal improves the transient behavior of the generator and provides a damping for the slow mode oscillations. This results in an enhancement of transient stability limit. The most commonly used PSS, referred to as conventional PSS(CPSS), is a fixed parameter analog type device with lead-lag compensation, wash out, and amplifier gains, which are limited and may lose effective damping robustness for overall operation. The conventional PSS is widely used in power systems, contributing to enhancing power system dynamic stability.

A PSS uses several local measurements and, perhaps, remote telemetries measurements to augment Stability by supplementary excitation control. A PSS has input signals from speed deviation ($\Delta\omega$), accelerating power (ΔP_a), actual generator speed deviation and reactive power (ΔP_g,

ΔQ_g) or current (ΔI_g).

Up to now, artificial intelligent techniques have been adopted to many applications in electrical power system[2–9]. Also, optimal tuning of PSSs have been considered study by many researcher using artificial intelligent techniques [10–13].

In this paper, the Particle Swarm Optimization (PSO) algorithm is practical to solve the optimal PID tuning for PSS. A description of PSO is presented in Section 2. Then a description of power system for this study is given in Section 3. The optimal PID tuning parameters using PSO for PSS is shown in Section 4. Finally, a conclusion is specified in Section 5.

2 Particle Swarm Optimization

Particle swarm optimization (PSO) is one of the evolutionary computation techniques. PSO was first introduced in year 1995 [14]. It was developed for simulation the behavior of social systems such as fish schooling and birds flocking. The basic assumption behind the PSO algorithm is, birds find food by flocking and not individually. This leads to the assumption that information is owned jointly in flocking. The PSO technique requires less computation time and less memory because of the simplicity inherent in the above systems. The particle swarm optimization (PSO) has been proved to be a powerful competitor in the field of optimization. It has been recently applied to several power system problems and has been shown to perform well [7,15].

PSO algorithm is basically developed for two-dimension solution space. The position of each individual is represented by xy axis position and its velocity is expressed by u_x in x direction and u_y in y direction. Modification of the individual position is realized by the velocity and position information of system. PSO algorithm for N dimensional problem formulation based on the above concept can be described as follows.

For N dimensional space, let p be the particle position and u is the velocity in a search space. Let i be a particle in the total population. Position of the i^{th} particle can be represented as $p_i = (p_{i1}, p_{i2}, \ldots, p_{in})$. The best previous position of the i^{th} particle is stored and represented as $p_{best,i} = (p_{best,i1}, p_{best,i2}, \ldots, p_{best,in})$. The entire p_{best} are evaluated by using a fitness function, which differs for different problems. The best particle among all p_{best} is represented as g_{best} The velocity of the i^{th} particle is represented as $u_i = (u_{i1}, u_{i2}, \ldots, u_{in})$.

The modified velocity of each particle can be calculated using the information, (i) the current velocity (ii) the distance between the current position and p_{best} and (iii) the distance between the current position and g_{best}. This can be formulated as an equation.

$$\mu_{ij}^{(iter+1)} = w * \mu_{ij}^{(iter)} + c_1 * rand_1 * (p_{best},_{ij} - p_{ij}^{(iter)}) + c_2 * rand_2 * (g_{best},_{ij} - p_{ij}^{(iter)}) \quad (1)$$

$$p_{ij}^{(iter+1)} = p_{ij}^{(iter)} + u_{ij}^{(iter+1)} \quad (2)$$

$$i = 1,2,3 \ldots I \text{ and } j = 1,2,3 \ldots N$$

where : $N =$ number of dimensions in a particle
$I =$ number of particles
$w =$ inertia weight factor
$c_1, c_2 =$ acceleration constant
$rand_1, rand_2 =$ uniform random value in the range [0,1]
$u_{ij}^{(iter)} =$ velocity of j^{th} dimension in i^{th} particle,
$u_j^{(\min)} \le u_{ij}^{(iter)} \le u_j^{(\min)}$
$p_{ij}^{(iter)} =$ current position of the j^{th} dimension in i^{th} particle at iteration $iter$.

The use of linearly decreasing inertia weight factor w has provided improved performance in all the applications. Its value is decreased linearly from about 0.9 to 0.4 during a run. Suitable selection of the inertia weight provides a balance between global and local exploration and exploitation, and results in fewer iterations on average to find a sufficiently optimal solution. Its value is set according to the following equation:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \quad (3)$$

where $w_{\max}$ and $w_{\min}$ are both random numbers called initial weight and final weight respectively. $iter_{\max}$ is the maximum iteration number. $iter$ is the current iteration number.

In Equation (1), the first term indicates the current velocity of the particle, second term represents the cognitive part of PSO where the particle changes its velocity based on its own thinking and memory. The third term represents the social part of PSO where the particle changes its velocity based on the social-psychological adaptation of knowledge. More detail of PSO algorithm describe in [7].

3 Power System Consideration Study

The power system considered in this paper is a four machines 10-bus power system as shown in Fig. 1[16]. Machine data and excitation system data are shown in Table 1 and Table 2, respectively. Fully details of this system can be found in [16].

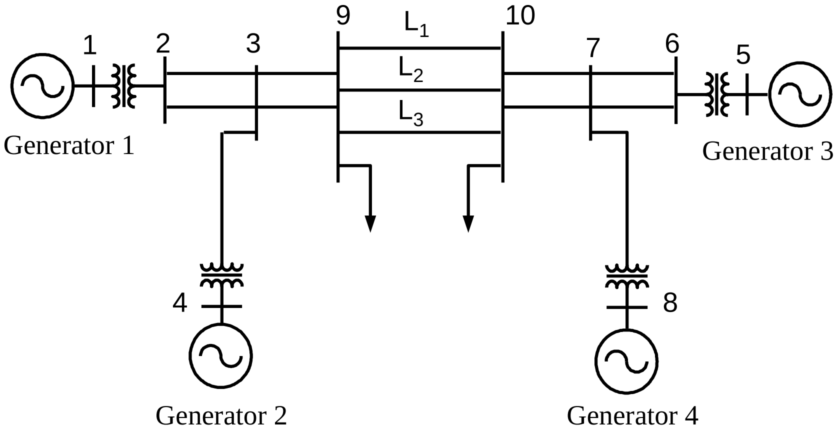


Fig. 1 Four-machine 10-bus power system

Table 1 Machine Data

Variables	Gen. # 1	Gen. # 2	Gen. # 3	Gen. # 4
X_1 (pu)	0.022	0.022	0.022	0.022
R_a (pu)	0.00028	0.00028	0.00028	0.00028
X_d (pu)	0.2	0.2	0.2	0.2
X'_d (pu)	0.033	0.033	0.0033	0.0033
T'_{d0} (sec)	8.0	8.0	8.0	8.0
X_q (pu)	0.19	0.19	0.19	0.19
X'_q (pu)	0.061	0.061	0.061	0.061
T'_{q0} (sec)	0.4	0.4	0.4	0.4
H (sec)	54.0	54.0	63.0	63.0
D (pu)	0	0	0	0

Table 2 Excitation System Data

Variables	Gen. # 1	Gen. # 2	Gen. # 3	Gen. # 4
K_A (pu)	200	200	200	200
T_A (sec)	0.02	0.02	0.02	0.02

All components in excitation systems are static. Static rectifiers supply the excitation current directly to the field of the generator. Due to the very high exciter ceiling voltage of some static excitation systems, additional field current limiter circuits may be employed to protect the generator rotor and exciter. The IEEE type ST1A model is adopted in this paper [17]. List of parameters for ST1A model and PSS with PID compensator, as shown in Fig. 2, are illustrated in Table 3 and Table 4.

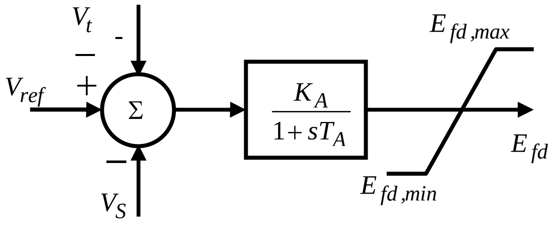
Generally, traditional method of tuning doesn't guarantee optimal parameters and in most cases the tuned parameters needs improvement through trial and error. Although in this paper, the PID controller parameters were obtained using PSO technique. For comparison, however, the PID controller parameters were also obtained using the conventional Ziegler-Nichols tuning technique [18].

Table 3 List of ST1A model parameters

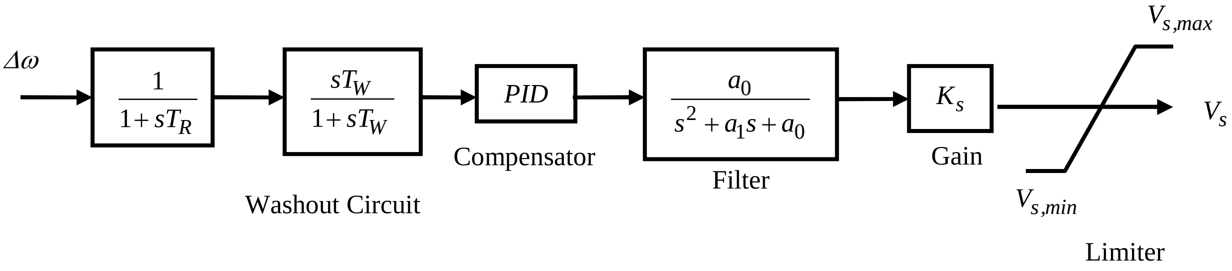
$K_A = 200$	$T_A = 0.02$ s	$T_B = 1.0$ s	$T_C = 1.0$ s
$K_F = 0$	$T_F = 1.0$ s	$K_C = 0.04$	$K_{LR} = 4.54$
$I_{LR} = 5$	$V_{R,Max} = 7.0$		$V_{R,Min} = -6.4$

Table 4 List of PID – PSS model parameters

$K_S = 200$	$T_R = 0.02$ s	$T_W = 1.0$ s	$a_0 = 570$
$a_1 = 35$	$V_{S,Max} = 0.1$		$V_{S,Min} = -0.1$



(a) Voltage Regulator and Exciter Block Diagram



(b) PID – PSS Block Diagram

Fig. 2 Block Diagram of Consideration Power system

4 Simulation Results and Discussions

It is recognized that the highest magnitude of power system disturbance which disturbing power system stability caused by three phase fault.

For the purposed optimization technique, the objective function is investigated for each individual by simulating the example power system, considering a severe disturbance. For objective function calculation, a three phase short-circuit fault in one of the 3 parallel transmission lines is considered. Three phase fault occurred at bus 9. Circuit breaker at bus 9 disconnected L1 for fault clearing time at 0.1 s.

The fitness function came from time-domain simulation of power system. Using each set of controllers' parameters, the time domain simulation is performed and the fitness value is determined. Table 5 shows the specified parameters for the PSO algorithm. Table 6 shows the optimal PID parameters for PSS tuning obtained by using the conventional Ziegler-Nichols tuning technique (ZN – PID). Table 7 shows the optimal PID parameters for PSS tuning obtained by using the PSO algorithm (PSO – PID).

Table 5 Parameters used for PSO algorithm

PSO parameters	Value/Type
Swarm size	: 50
No. of Generations	: 200
c_1, c_2	: 1.7 , 1.7
w_{start}, w_{end}	: 0.9, 0.4

Table 6 Optimal ZN – PID Parameters

Parameters	Gen. #1	Gen. #2	Gen. #3	Gen. #4
T_d	11.2	11.2	11.2	11.2
T_f	2.8	2.8	2.8	2.8
T_i	2.8	2.8	2.8	2.8
K_p	2.975	2.975	2.975	2.975

Table 7 Optimal PSO – PID Parameters

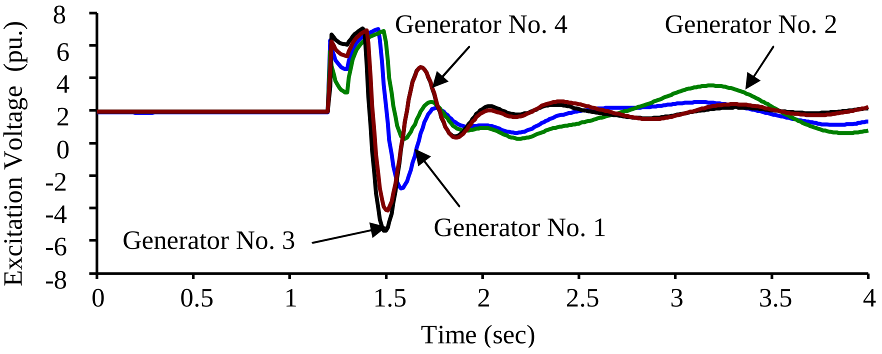
Parameters	Gen. #1	Gen. #2	Gen. #3	Gen. #4
T_d	2.3974	6.1594	9.4851	5.9602
T_f	4.2360	9.9121	6.1551	7.1733
T_i	7.6341	4.8217	0.1254	1.8560
K_p	6.3511	3.6074	9.6508	9.0330

In order to review significance and robustness of proposed technique, simulation studies are carried out for three phases fault disturbances and fault clearing sequence. The performance of proposed controller under transient and dynamic condition is verified using the optimal PID tuning parameters.

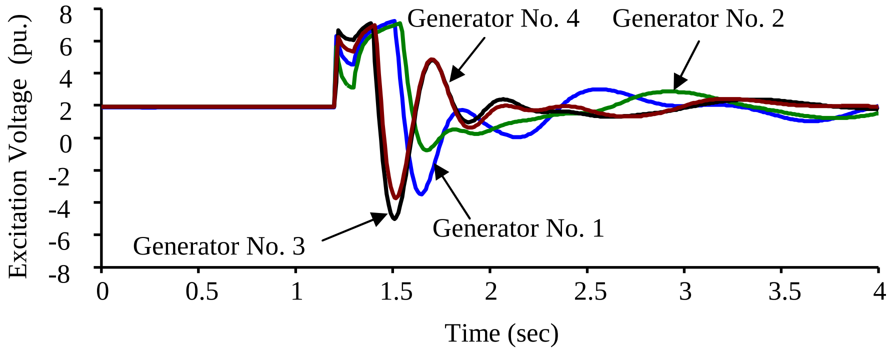
The results shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6, by comparing with and without PSS, obviously unstable of the power system via the excitation voltage, slip speed and rotor angle, could be notified in the both cases. Although with PSS, the power system can not reach the stable point.

In Fig. 7, Fig. 8, Fig. 9 and Fig. 10, obviously the effectiveness of the purpose technique can be seen when comparing with the conventional technique. All generators with PSS having ZN - PID tuning can not reach the steady state condition. Only the two generators close to fault bus reach the steady state while the other generators still have no stable. In case of PSO-PID tuning parameters, all generators of the power system with PSS having PSO-PID tuning reached the steady state condition faster than that in case of ZN – PID tuning.

From four transient responses of the consideration multi-machine power system, the effectiveness of PSS with optimal PID parameter tuning using particle swarm optimization is validate.

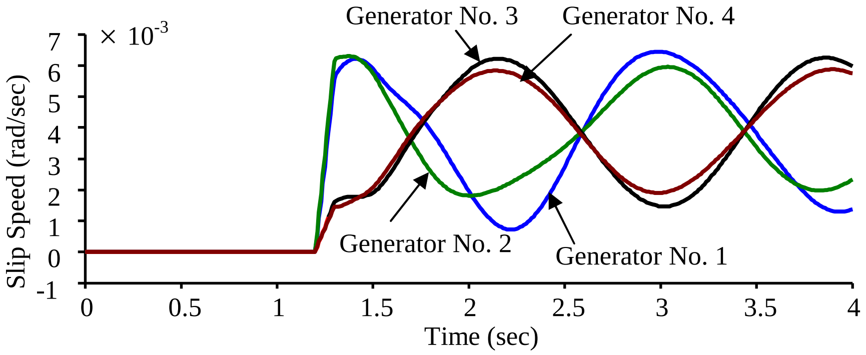


(a) Without PSS

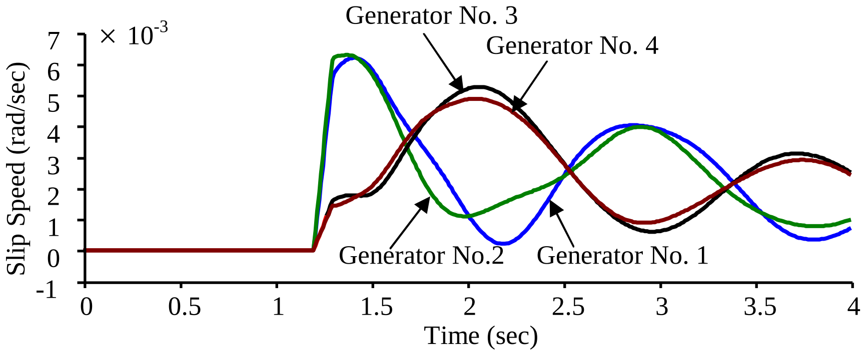


(b) With PSS

Fig. 3 Excitation Voltage Response to a Three Phase Short Circuit Fault at bus 9

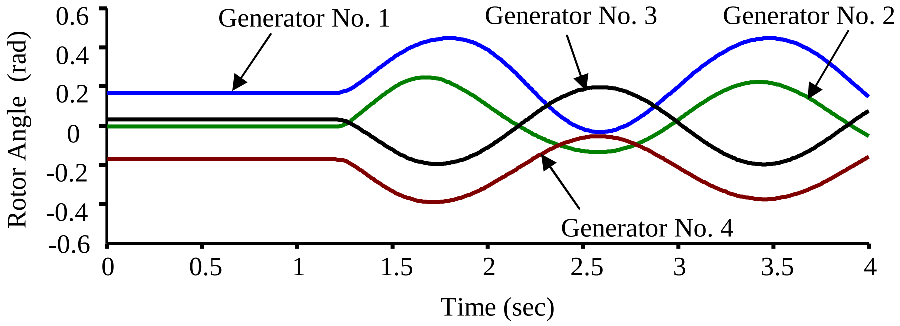


(a) Without PSS

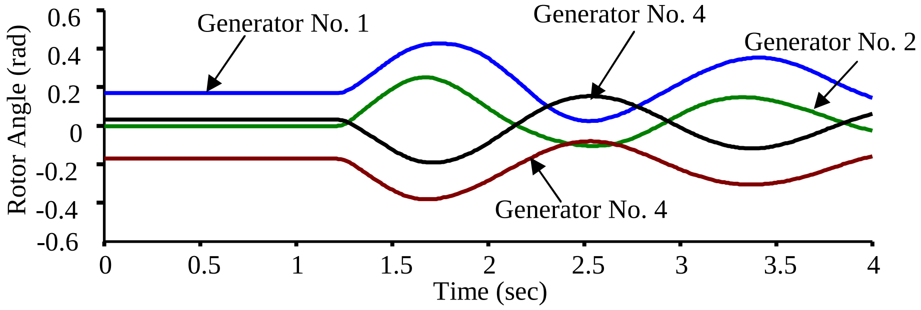


(b) With PSS

Fig. 4 Slip Speed Response to a Three Phase Short Circuit Fault at bus 9

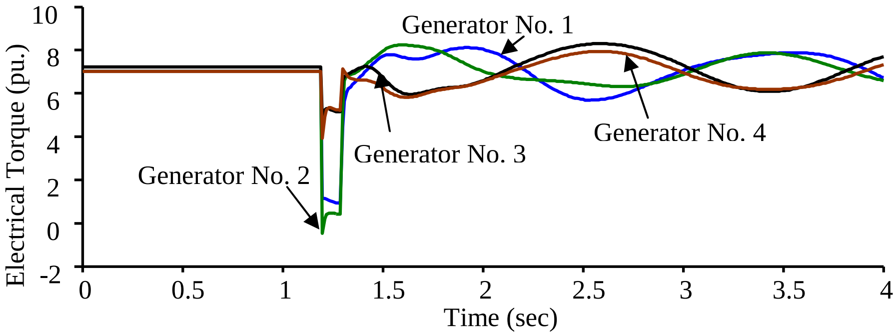


(a) Without PSS

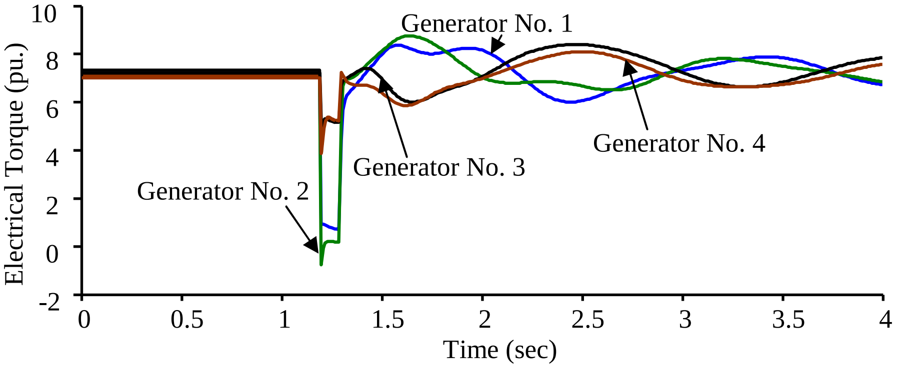


(b) With PSS

Fig. 5 Rotor Angle Response to a Three Phase Short Circuit Fault at bus 9

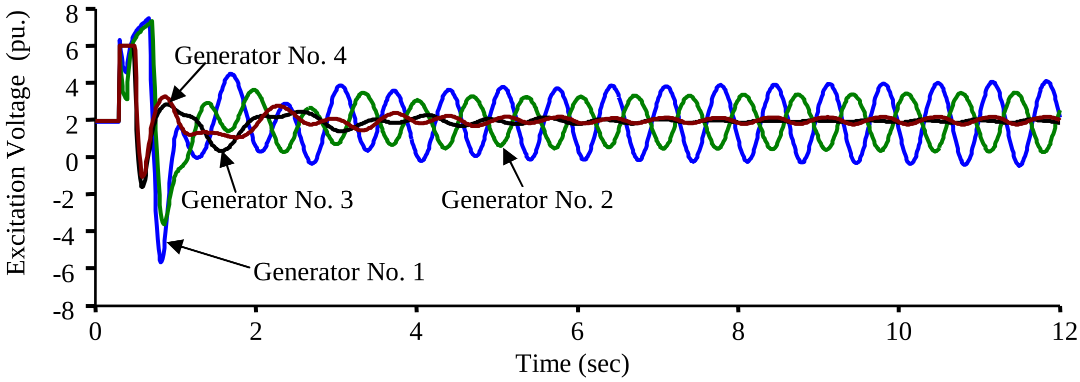


(a) Without PSS

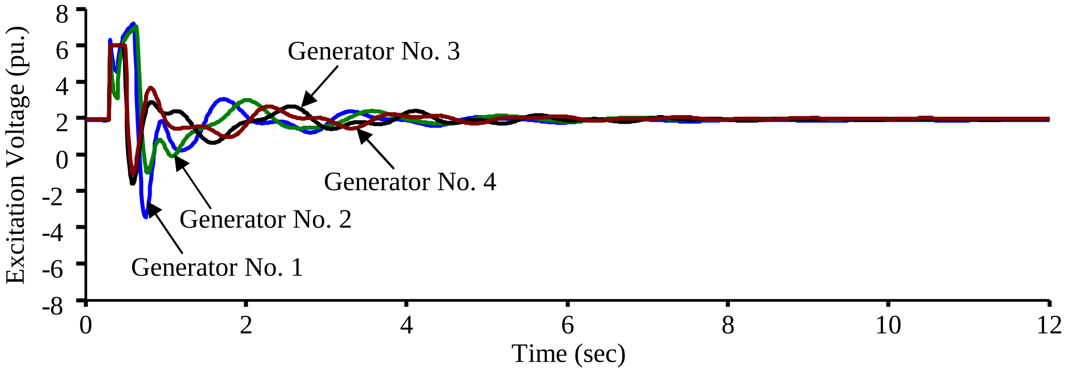


(b) With PSS

Fig. 6 Rotor Angle Response to a Three Phase Short Circuit Fault at bus 9

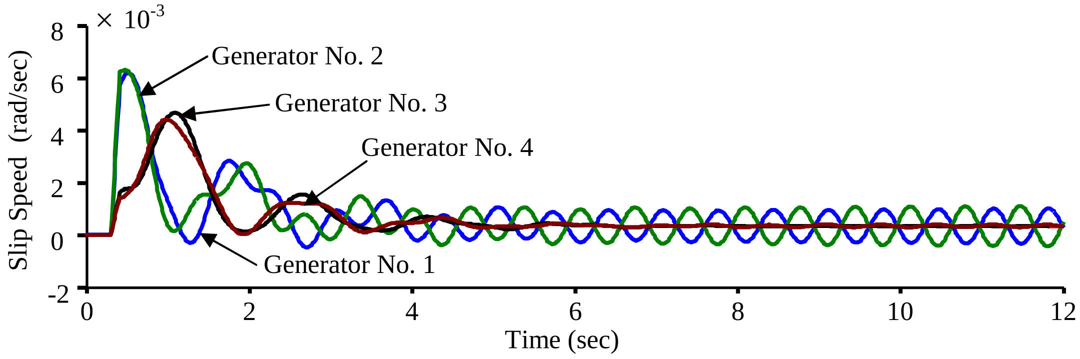


(a) With ZN – PID - PSS

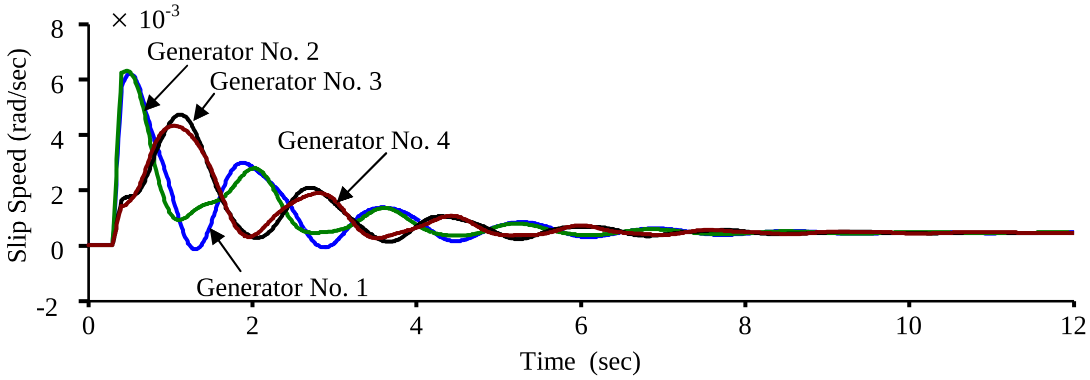


(b) With PSO – PID - PSS

Fig. 7 Excitation Voltage Response to a Three Phase Short Circuit Fault at bus 9 With PID Tuning

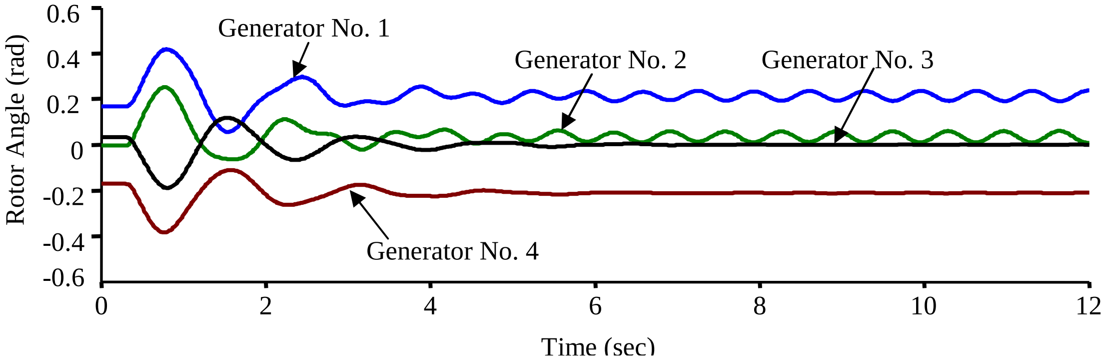


(a) With ZN – PID - PSS

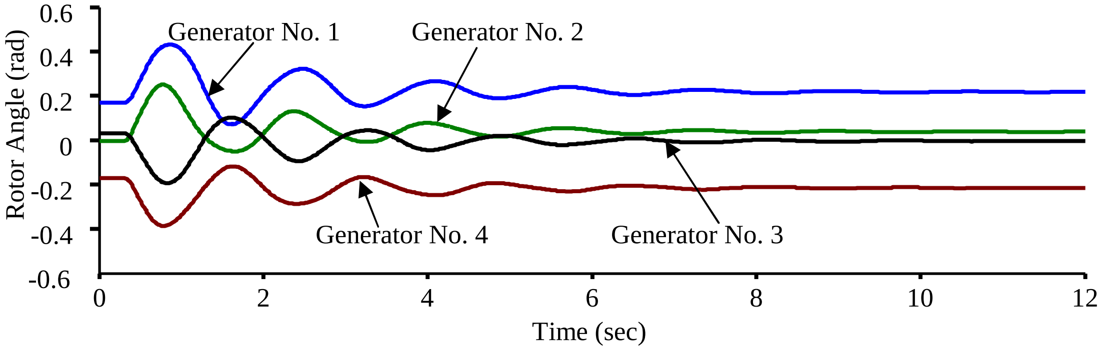


(b) With PSO – PID - PSS

Fig. 8 Slip Speed Response to a Three Phase Short Circuit Fault at bus 9 With PID Tuning

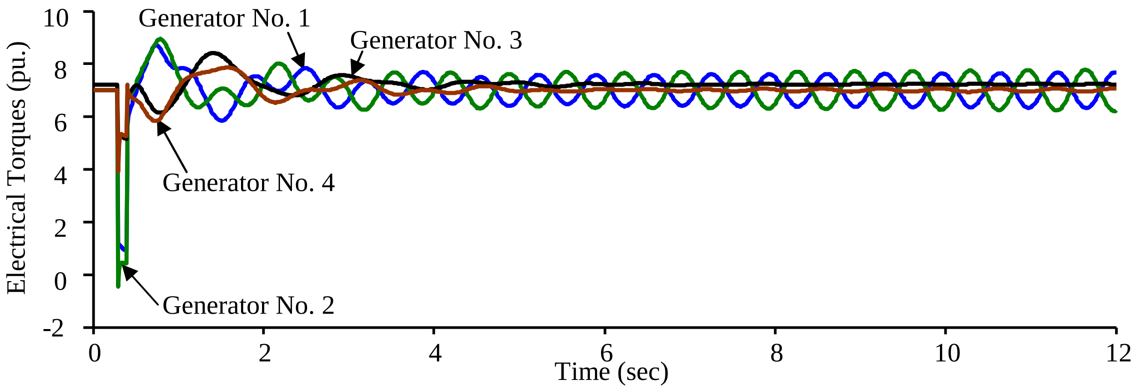


(a) With ZN – PID - PSS

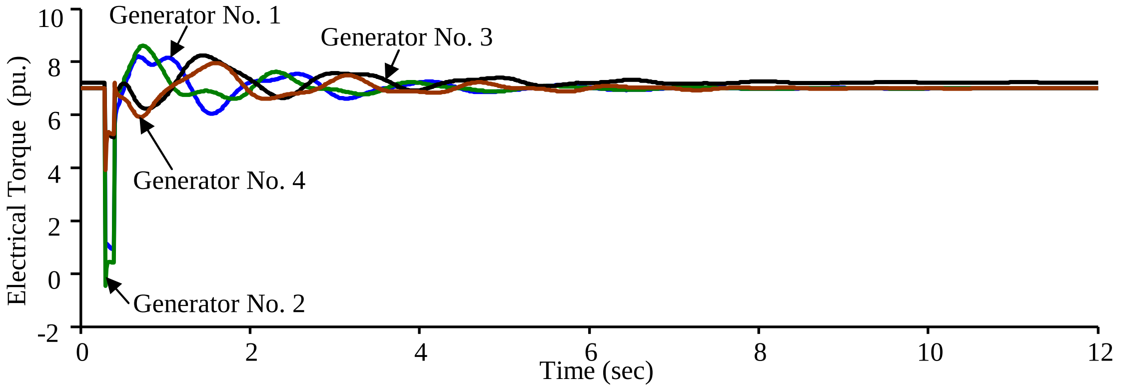


(b) With PSO – PID - PSS

Fig. 9 Rotor Angle Response to a Three Phase Short Circuit Fault at bus 9 With PID Tuning



(a) With ZN – PID - PSS



(b) With PSO – PID - PSS

Fig. 10 Electrical Torque Response to a Three Phase Short Circuit Fault at bus 9 With PID Tuning

5 Conclusion

Stability enhancement of multi-machine power system by power system stabilizer is presented in this paper. Particle swarm optimization technique is implemented to search for optimal PID controller parameters. The success of proposed optimal PID tuning technique, multi–machine power system stability improvement, is established by a weakly connected example power system subjected to three phases fault disturbances. The dynamic performance of proposed optimal PID tuning technique for PSS was compared with a conventionally designed optimal PID tuning for PSS to demonstrate its advantage as well. In conclusion, the effectiveness of proposed optimal PSO – PID tuning for PSS and its ability to afford proficient damping of multi-machine power system transient and dynamic disturbance is definite.

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