IMPROVEMENT POWER SYSTEM STABILITY USING OPTIMUM PID CONTROLLER IN NON-LINEAR POWERSYSTEM

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Abstract: The objective of the Power System Stabilizer (PSS) is added to excitation system to improve the damping during low frequency oscillations. The performance of PID-PSS depends upon the generator operating point and the system *parameters*, but a reasonable level of robustness can be achieved depending on the tuning method. In this paper a optimization method based on Grey Wolf Optimizer is used for tuning the PID parameters. In GWO-PID-PSS, the nonlinear model of single-machine infinite bus system is linearized at various operating point and a linear model is obtained. For this model, a common PID parameters are tuned using GWO algorithm. This robust GWO-PID-PSS is applied to non-linear model of a single machine system at various equilibrium points. The simulation results clearly indicate the effectiveness and validity of the fast output sampling technique method.This paper also extended to a comparative analysis of Optimum PID using Grey Wolf Optimizer (GWO) based PSS and fast output sampling based PSS for small signal stability enhancement. The simulation results are analyzed using MATLAB/Simulink tool and shows the effectiveness of proposed controller.

Keywords: Nonlinear model, PID-PSS, GWO-PID-PSS, Power system stabilizer, Fast output sampling feedback, Grey wolf optimizer (GWO).

1. INTRODUCTION

Power system stabilizers were developed to aid in damping these oscillations via modulation of the generator excitation. This development has brought an improvement in the use of various tuning techniques and input signals and in the ability to deal with turbine-generator-shaft torsional modes of vibrations [1]. In the past five decades the PSS have been used to provide the desired system performance under condition that requires stabilization. Stability of synchronous generator depends on a number of factors such as the setting of automatic voltage regulator (AVR). Many generators are designed with high gain, fast acting AVRs to enhance large scale stability to hold the generator in synchronism with the power system during large transient fault conditions. But with the high gain of excitation systems, it can decrease the damping torque of generator. A supplementary excitation controller referred to as PSS have been added to synchronous generators to counteract the effect of high gain AVRs and other sources of negative damping [2].

To provide damping, the stabilizers must produce a component of electrical torque on the rotor which is in phase with speed variations. The application of a PSS is to generate a supplementary stabilizing signal, which is applied to the excitation system or control loop of the generating unit to produce a positive damping. The most widely used conventional PSS is the lead-lag PSS, where the gain settings are fixed at certain value which are determined under particular operating conditions to result in optimal performance for that specific condition. However, they give poor performance under different synchronous generator loading conditions [3].

Conventional PSS (CPSS) is widely used in existing power systems and has made a contribution in enhancing power system dynamic stability. The parameters of CPSS are determined based on a linearised model of the power system around a nominal operating point where they can provide good performance. Since power systems are highly non-linear systems, with configurations and parameters that change with time, the CPSS design based on the linearised model of the power system cannot guarantee its performance in a practical operating environment [4],[5]. To improve the performance of CPSS, numerous techniques have been proposed for their design, such as using intelligence optimization methods (simulated annealing, genetic algorithm, Tabu search, fuzzy, neural networks and many other non linear techniques. The intelligent optimization algorithms are used to determine the optimal parameters for CPSS by optimizing an Eigen value based cost function in an off-line mode. Since the method is based on a linearised model and the parameters are not updated on-line, therefore, they lack satisfactory performance during practical operation. The rule-based fuzzy logic control methods are well known for the difficulty in obtaining and adjusting the parameters of the rules especially on-line. Recent research indicates that more emphasis has been placed on the combined usage of fuzzy logic systems and other technologies such as neural networks to add adaptability to the design [6]-[8].

Recently modern control methods have been used by several researchers to take advantage of optimal control techniques. These methods utilize a multivariable state space representation of multimachine power system model and calculate a gain matrix which when applied as a state feedback control will minimize a prescribed objective function. In practice, not all of the states are available for measurement. In this case, the optimal control law requires designing the state observer. This increases the implementation cost and reduces the reliability of the control system. Another disadvantage of the observer based control system is that even a slight variation of the model parameters from their nominal values may result into significant degradation of the closed loop performance. Hence it is desirable to go for an output feedback design. In recent years there have been several attempts at designing power system stabilizer using H_∞ based robust control techniques. In this approach, the uncertainty in the chosen system is modeled in terms of bounds on frequency response. An H_∞ optimal controller is then synthesized which guarantees robust stability of the closed loop system. But, this will lead to dynamic output feedback, which may be feasible but leads to a higher order feedback system [2].

The static output feedback problem is one of the most investigated problems in control theory. The complete pole assignment and guaranteed closed loop stability is still not obtained by using static output feedback.

Another approach to pole placement problem is to consider the potential of time varying fast output sampling feedback. It was shown by Chammas and Leondes [2] that a controllable and observable plant was discrete time pole assignable by periodically time-varying piecewise constant output feedback. Since the feedback gains are piecewise constant, their method could be easily implemented and indicated a new possibility. Such a control law can stabilize a much larger class of systems than the static output feedback [9]-[12].

Therefore, an adaptive PSS which considers the nonlinear nature of the plant and adapts to the changes in the environment is required for the power system (Liu et al., 2005). In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods (Sumathi et al., 2007; Jiang et al., 2008; Sudha et al., 2009; Linda & Nair, 2010; Yassami et al., 2010) and Fuzzy logic method (Dubey, 2007; Hwanga et al., 2008). Also the application of robust control methods for designing PSS has been presented earlier (Bouhamida et al., 2005; Gupta et al., 2005; Mocwane& Folly, 2007; Sil et al., 2009).

II. POWER SYSTEM STABILIZERS

Implementation of a PSS implies adjustment of its frequency characteristic and gain to produce the desired damping of the system oscillations in the frequency range of 0.2 to 3.0 Hz.

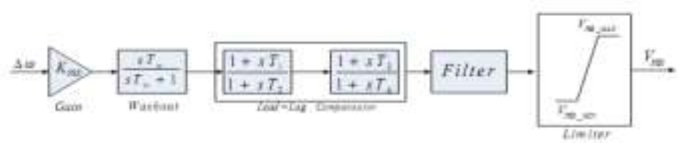


Figure 1: Block-diagram of Conventional Power System Stabilizer

Conventional Power System Stabilizer as shown in fig. 1, where Kpss represents stabilizer gain and the stabilizer frequency characteristic is adjusted by varying the time constant Tw, T1, T2, T3 and T4. A power system stabilizer can be made more effective if it is designed and applied with the knowledge of associated power characteristics. Power system stabilizer must provide adequate damping for the range of frequencies of the power system oscillation modes.

Single Machine Infinite Bus System: this system consist of a synchronous generator which is connected via two transformer to n infinite bus system through a transmission line. It is seen that the SM connected to the infinite bus always concerned with the frequent load change and it may leads to be serious stability problem and should be discussed.

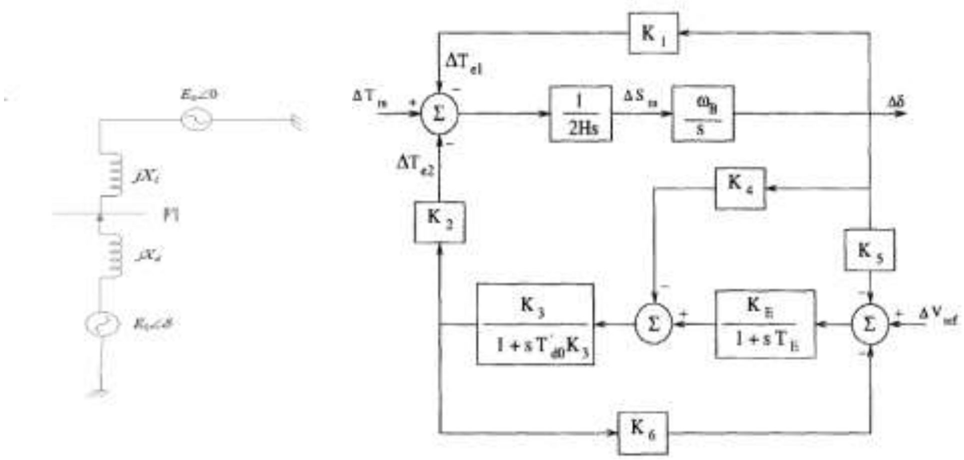


Fig.2: Single Machine Infinite Bus System (a)Block diagram and (b) linearized model.

Grey Wolf Optimizer (GWO)

This section discuss about GWO algorithm fundamentals and mathematical formation [11] with flowchart as shown in fig.3.

A. *About Grey Wolf*:

Grey wolf optimization is a new Meta heuristic algorithm proposed for solving many multi model functions. It's inspired by grey wolves. Four types of grey wolves such as α, β, δ, and ω are employed to derive the leadership of hierarchy of grey wolves. The main steps are hunting, searching for prey, encircling prey and attacking prey.

B. Wolf behavior in nature:

Social behavior:

Hierarchy exits in pack .α is the leader and decision maker. β and δ assist α in decision making. Rest of the wolves(ω) are followers.

Encircling prey:

As mentioned above, grey wolves encircle prey during the hunt. In order to mathematically model encircling behavior the following equations are proposed:

$$\vec{D} = \left|\vec{C} \cdot X_P(t) - \vec{X}(t)\right| \quad \& \quad \vec{X}(t+1) = \vec{X}_P(t) - \vec{A} \cdot \vec{D} \quad (1)$$

Where:

t- Indicates the current iteration,

$\vec{A}$ & $\vec{C}$ - are coefficient vectors,

$\vec{X}_P$ - is the position vector of the prey,

$\vec{X}$ - indicates the position vector of a grey wolf.

The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\vec{A} = 2\vec{a} \cdot r_1 - \vec{a}$$
$$\vec{C} = 2 \cdot \vec{r}_2 \tag{2}$$

where components of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations and r_1, r_2 are random vectors in [0,1]

Hunting behavior:

Group hunting behaviour is of equal interest in studying optimization.

A. Tracking, chasing, and approaching the prey.
B. Pursuing, encircling, and harassing the prey until it stops moving.
C. Attacking the prey.

Grey wolves have the ability to recognize the location of prey and encircle them. The hunt is usually guided by the alpha. The beta and delta might also participate in hunting occasionally. However, in an abstract search space we have no idea about the location of the optimum (prey). In order to mathematically simulate the hunting behavior of grey wolves, we suppose that the alpha (best candidate solution) beta, and delta have better knowledge about the potential location of prey. Therefore, we save the first three best solutions obtained so far and oblige the other search agents (including the omegas) to update their positions according to the position of the best search agent. The following formulas are proposed in this regard.

$$\vec{D}_\alpha = \left|\vec{C}_1 \cdot \vec{X}_\alpha - \vec{X}\right| \; \vec{D}_\beta = \left|\vec{C}_2 \cdot \vec{X}_\beta - \vec{X}\right| \; \vec{D}_\delta = \left|\vec{C}_3 \cdot \vec{X}_\delta - \vec{X}\right| \tag{3}$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1 \cdot (\vec{D}_\alpha) \; \vec{X}_2 = \vec{X}_\beta - \vec{A}_2 \cdot (\vec{D}_\beta) \; \vec{X}_3 = \vec{X}_\delta - \vec{A}_3 \cdot (\vec{D}_\delta) \tag{4}$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \qquad (5)$$

- *Advantages over other techniques:*
- Easy to implement due to simple structure.
- Less storage requirement than the other techniques.
- Convergence is faster due to continuous reduction of search space and Decision variables are very less (α, β and δ).
- It avoids local optima when applied to composite functions also. Only two main parameters to be adjusted (a and C).

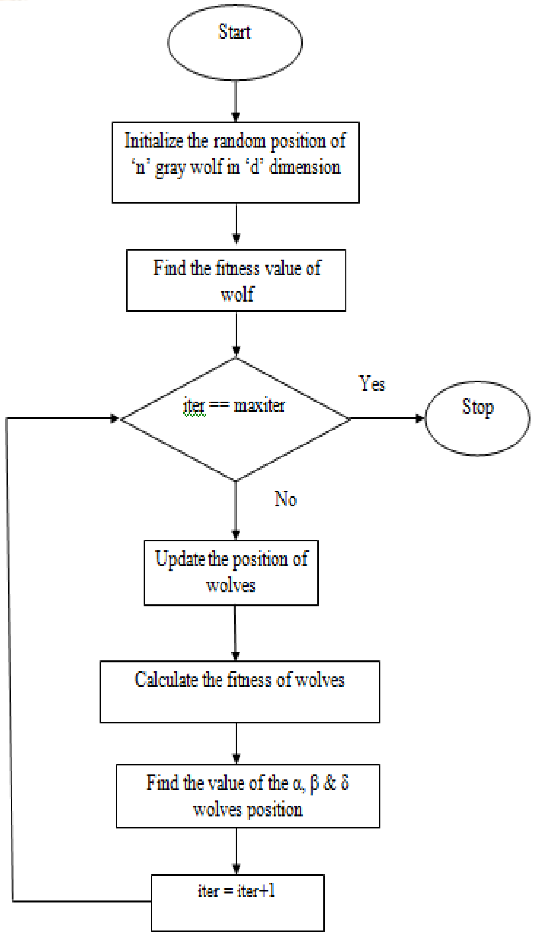


Fig. 3: Flowchart of GWO algorithm

PID-PSS DESIGN USING GWO Algorithm

The PSS parameters are optimized by stimulating a disturbance to the system. Then, PSS parameters with minimum rotor speed deviations are selected via iterative GWO process asshown in Fig. 4. In this paper, J is used as a fitness function in GWO search process[19].

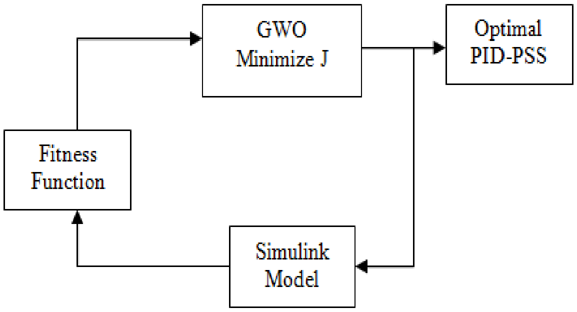


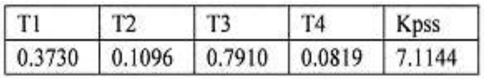
Figure 4: PID-PSS Design with GWO

CASE STUDY

A SIMULINK based block diagram including all the nonlinear blocks is generated with single machine data as given in [13]. GWO is used in this paper to tune PID-PSS parameters as described in the section 5. Table 1 presents the PID-PSS parameters as designed by GWO and Tw=10. The sixteen models of single machine infinite bus with different generating power (P_{go}) from 0.4pu to 2pu and different external impedances $x_e$from 0.2 to 0.8. pu. Response of all sixteen plants has been studied and found that the same GWO and fast output sampling method are working satisfactorily. The figures 1-6 shows comparison of the responses of the plants for GWO-PID-PSS and fast output sampling method based PSS. GWO-PID-PSS gives better results compared to fast output sampling method.

Table1

Optimal PSS parameters as designed by PID-PSS GWO



T1	T2	T3	T4	Kpss
0.3730	0.1096	0.7910	0.0819	7.1144

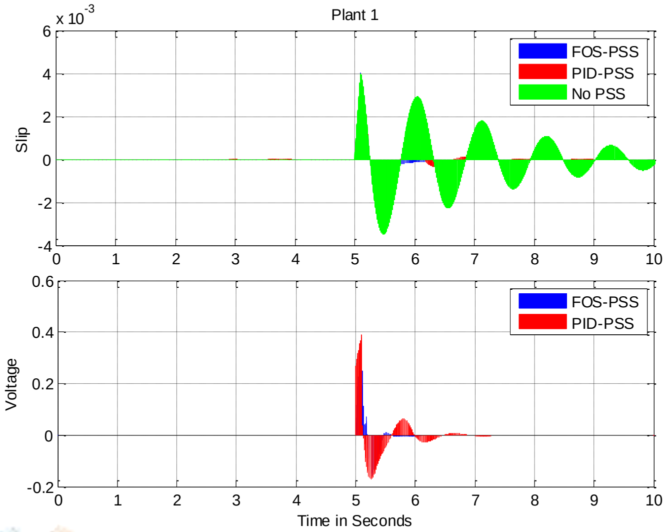


Figure 1: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

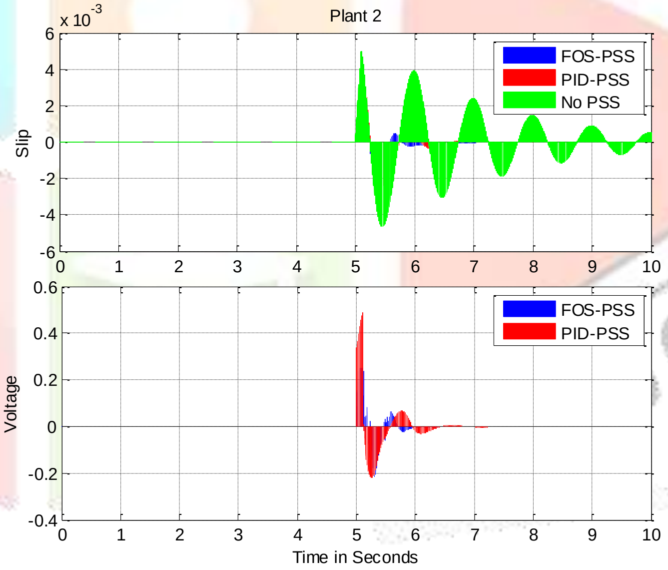


Figure 2: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

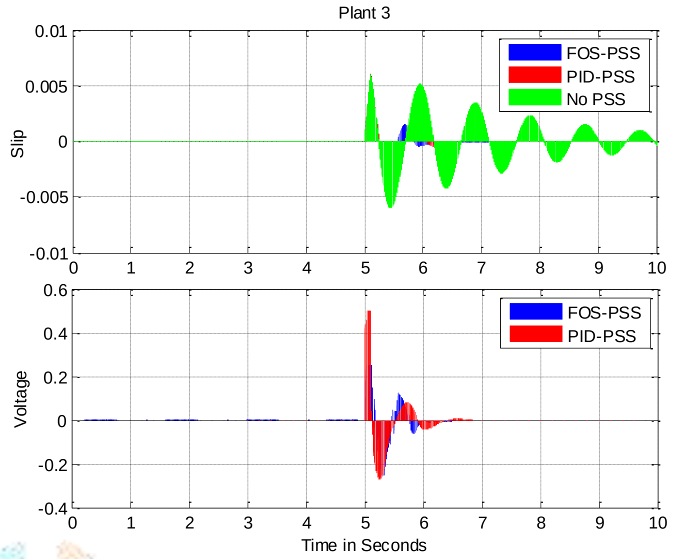


Figure 3: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

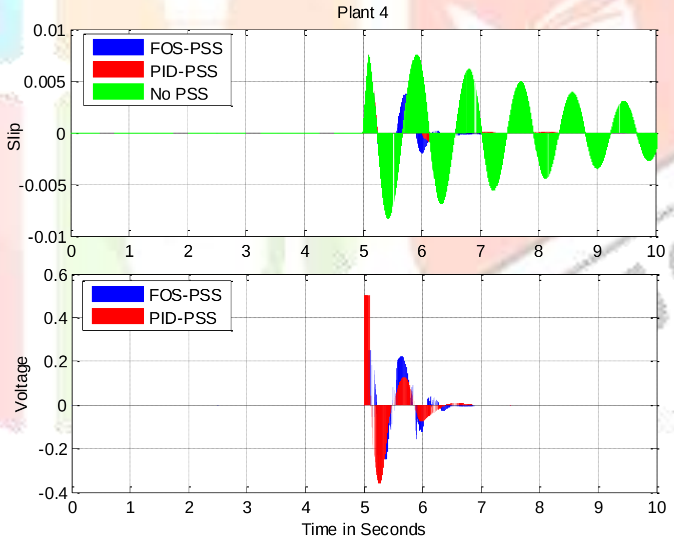


Figure 4: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

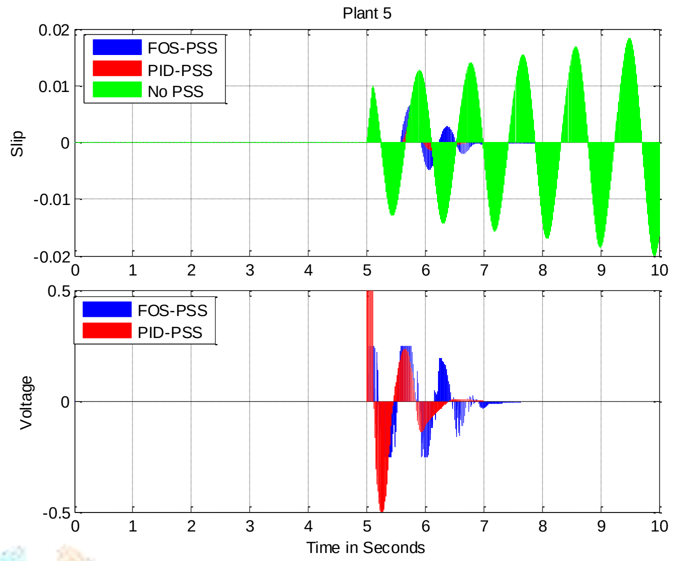


Figure 5: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

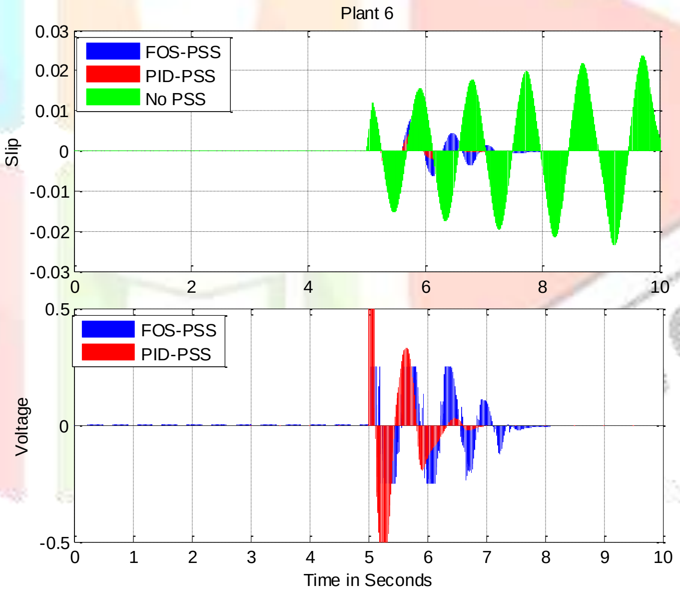


Figure 6: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

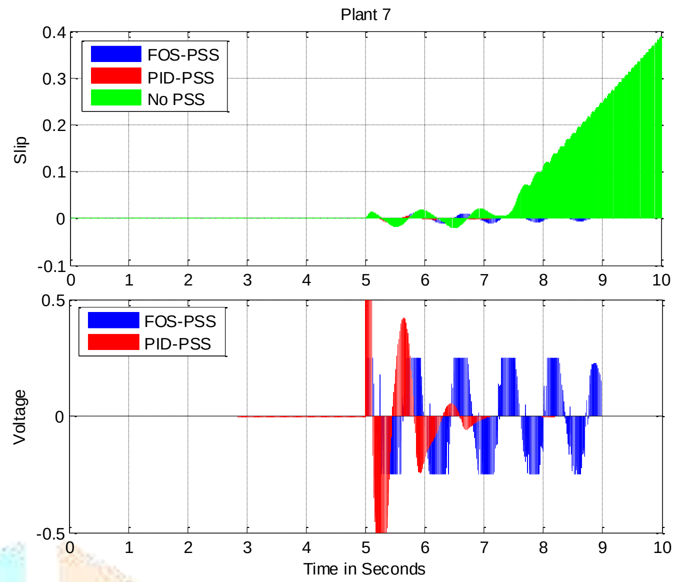


Figure 7: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

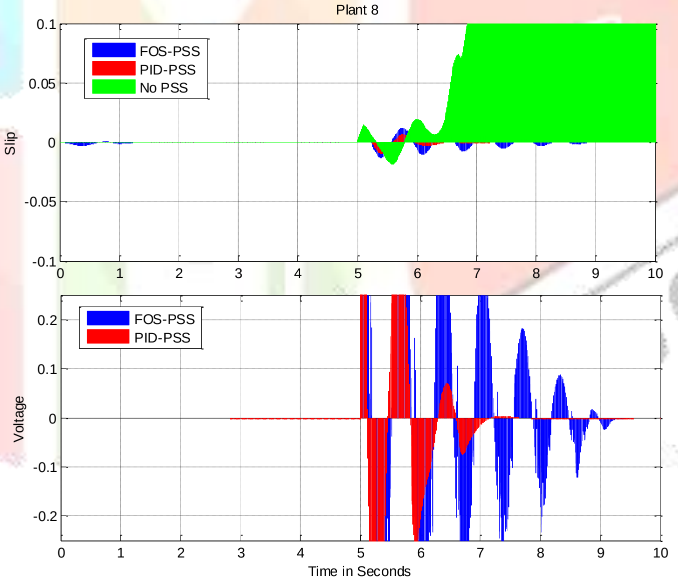


Figure 8: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

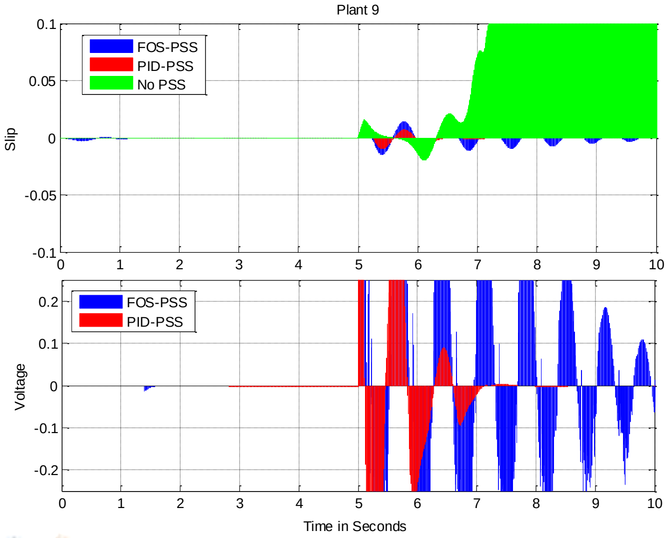


Figure 9: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

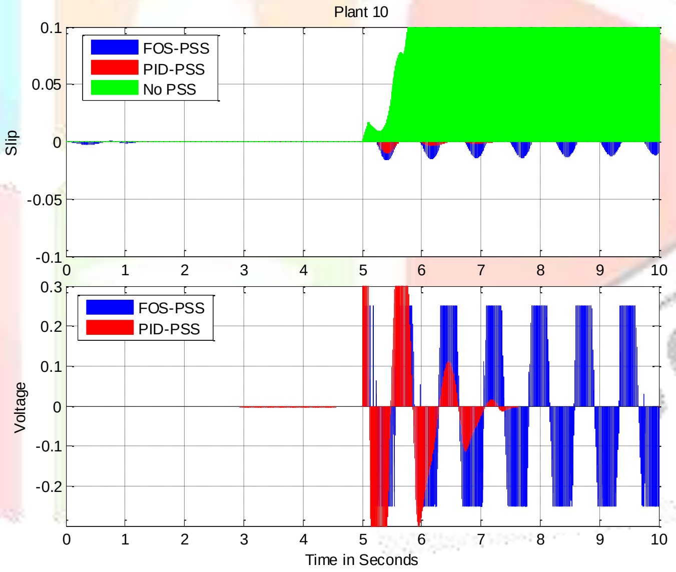


Figure 10: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

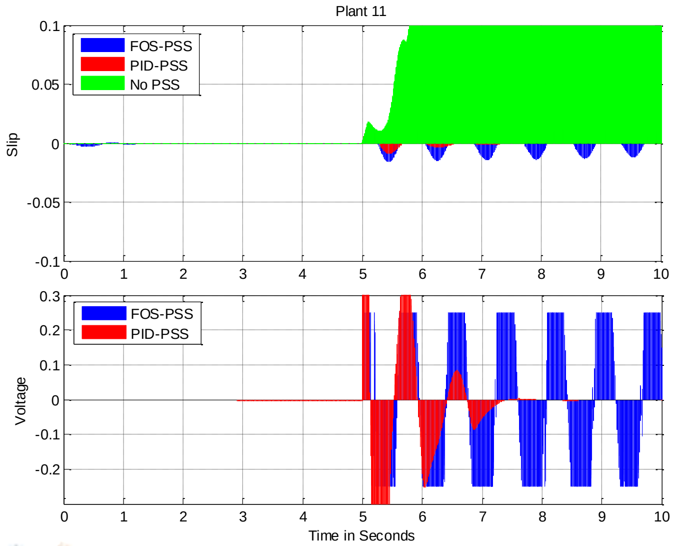


Figure 11: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

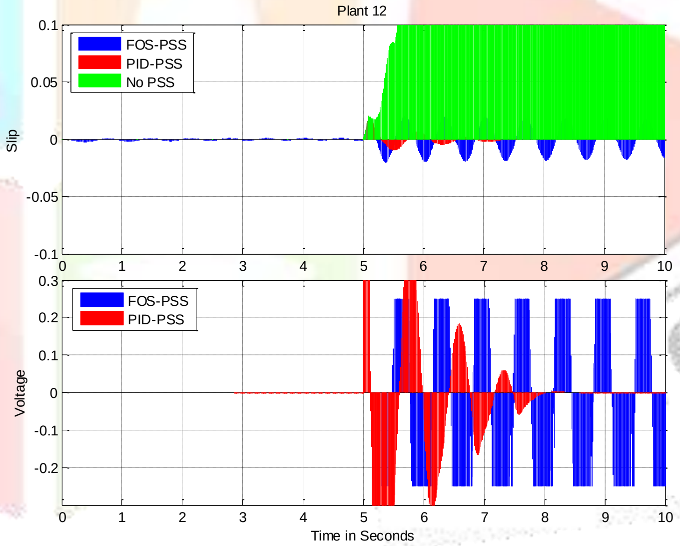


Figure 12: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

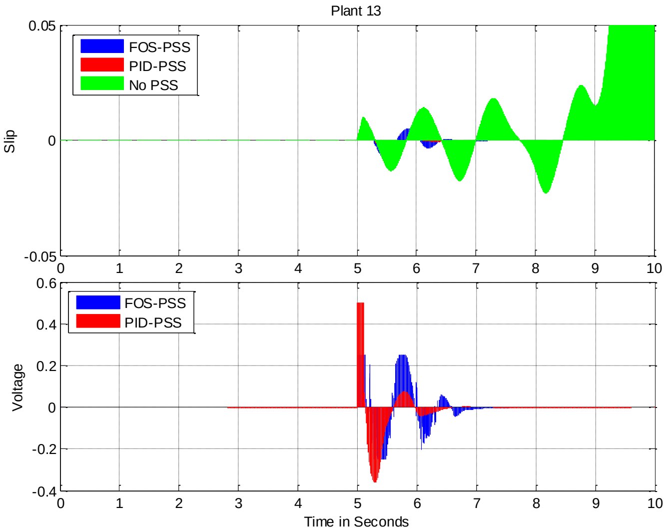


Figure 13: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

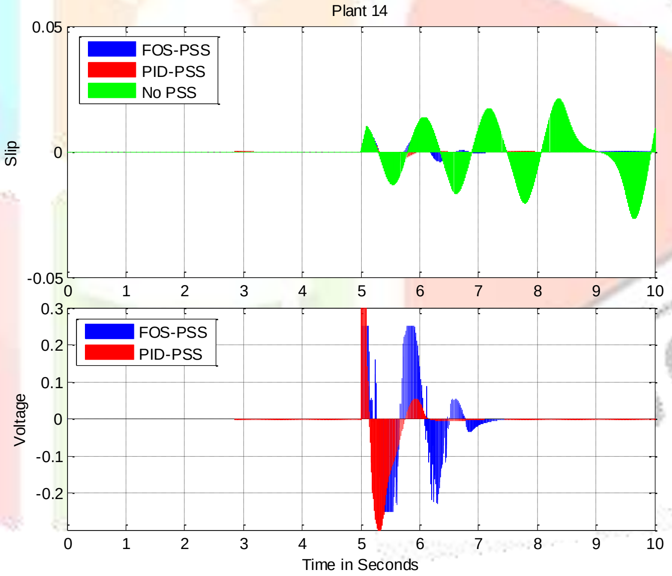


Figure 14: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

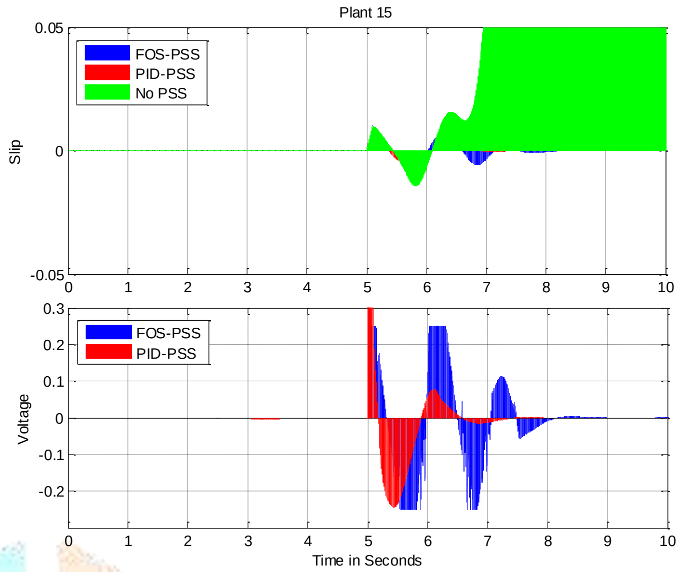


Figure 15: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

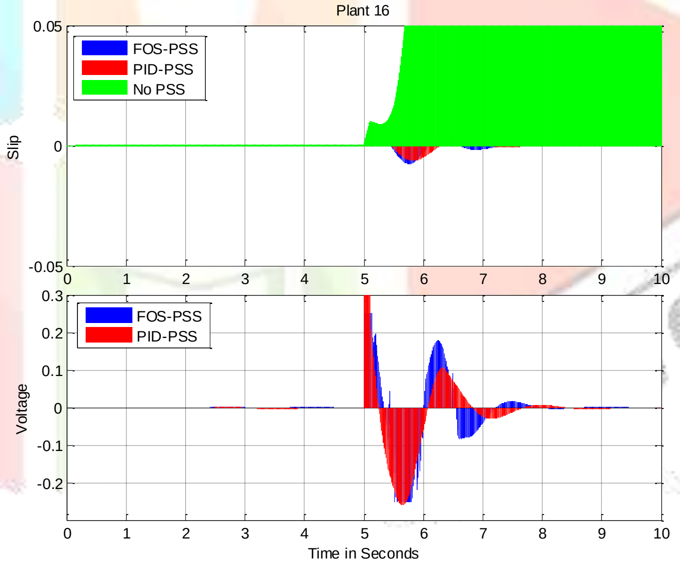


Figure 16: Closed loop Responses of Single Machine Infinite bus with No PSS, Robust Fast Output Sampling and GWO PID

Conclusion

The system considered for simulations, is single machine infinite bus system with 16 various plants. Simulations with GWO-PID and fast output sampling method are carried out with all plants and gives encouraging results. The results show that for various plants, the responses of the GWO-PID-PSS are stable. GWO-PID-PSSgives better results compared toFast output sampling method.

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