Power System Stability Optimization Using Proportional-Integral-Derivative (PID) Controller

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Abstract*—Instability has become an issue of concern in the operation of power system due to the increasing stress on power system networks. The system suffering from incessant power failure as a result of fault on either the generating plants or on the transmission lines is adversely affecting the economic growth of the country. Most stability improvement techniques carried out in Nigeria were based only on the load flow, transformer tap changer, reactors and power loss reduction which have not been effective. In order to solve these problem of instability caused by low frequency oscillation in power system, Proportional Integral Derivative (PID) controller with Power System Stabilizer (PSS) was proposed in this work for the stability optimization of the power system. The analysis of the PSS in this work was based on the parameters of the PSS tuned using the four methods: CPSS, PSO, ICA and Generic. The performance improvement was carried out through simulation in MATLAB. The first stage of simulation was to examine the damping capability of the PSS without any external technique such that the system will be stable. Secondly, with external technique. From available results, all the PID controlled plants recorded improved performance and stability characteristics except the Generic-PID which recorded very high settling time of 1.03e+4 seconds and overshoot of 74%. However, all the PID controlled plant were stable. The ICA-PID achieved best performance and stability improvement characteristics with settling time of 0.0478seconds, overshoot of 4.4%, and phase margin of 67.6 degrees. So, ICA-PID controller is recommended for power system stability robustness.

***Index Terms*— Power System Stability, Optimization, Power System Stabilizer (PSS), Proportional Integral Derivative Controller (PID), Low Frequency Oscillation, Damping**

I. INTRODUCTION

The electric power system is characterized by power imbalance which is caused by overloading, power loss, line faults etc. This power imbalance in most cases causes low frequency oscillations which results to power instability. The oscillations may be small but often remain or persist for a long period of time. In some cases, the oscillations will continue to rise with adverse effect and limitations on the power system transfer capabilities which may eventually cause the generating plant to trip off or separate from the supply grid if adequate damping device is not provided (Shayeghi et al, 2010).

In most cases, the stability improvement is carried out at the generating plant based on the controller application in which the governor is included, or at the transmission substations based on power loss reduction techniques such as the transmission of more of 330KV as planned to be implemented in Nigeria, load flow analysis and load shading, transformer tap-changer and reactor devices. The technology behind the controllers and their applications for the power system stability optimization is more difficult and requires more design capabilities due to the involvement of the generating plant parameters into the design process. However, the PID controller technology is proposed in this work because is highly effective in ensuring optimum operation of the power system and also it is cheaper.

II. DYNAMIC MODEL OF PSS

The analysis of the PSS in this work was based on the parameters of the PSS tuned using the four methods as shown in Tables 1 and 2. Step function method in frequency domain and time domain were considered in order to examine the stability and the peak gain of the PSS for each of the four set of parameters.

The PSS performance improvement was carried out through simulations in MATLAB. The first stage of the simulation examined the damping capabilities of the various PSS without any external technique such that the system will be stable while the second stage of the simulation examined the damping capabilities of the designed PID with various PSS and thereafter, results obtained from the analysis were compared and conclusion made.

The PSS, its basic function is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stability signals. With electric power systems, the change in electrical torque of a synchronous machine following a perturbation can be resolved into two components as follows (Kundur, 1994):

$$\Delta T_e = T_s \Delta\delta + T_D \Delta\omega_r \qquad (1)$$

where $T_s\Delta\delta$ is the component of torque change in phase with the rotor angle perturbation $\Delta\delta$ and is referred to as the synchronizing torque component, T_s is the synchronizing torque coefficient. $T_D\Delta\omega_r$ is the component of the torque in phase with the speed deviation, $\Delta\omega_r$ and is called the damping torque coefficient and T_D is the damping torque coefficient.

Figure 1 shows a block diagram of transfer functions describing the different subsystems of the one machine infinite bus power system and Fig. 2 shows the block diagram of the PSS.

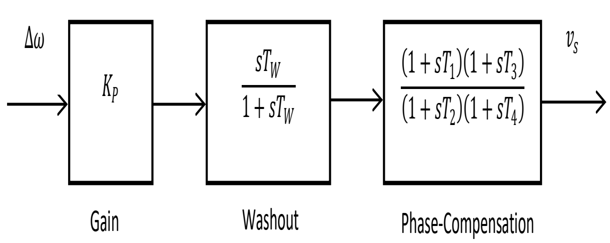

Fig. 1: Block diagram of PSS controlled plant

The transfer function of the PSS is needed for the design of a controller that can help to improve its damping. The PSS output equation and transfer function of the PSS becomes:

$$v_s = k_P \left(\frac{sT_W}{1+sT_W}\right)\left(\frac{(1+sT_1)(1+sT_3)}{(1+sT_2)(1+sT_4)}\right)\Delta\omega \qquad (2)$$

$$G_P = \frac{v_s}{\Delta\omega} = k_P \left(\frac{sT_W}{1+sT_W}\right)\left(\frac{(1+sT_1)(1+sT_3)}{(1+sT_2)(1+sT_4)}\right) \qquad (3)$$

$$G_p = K_P \left(\frac{sT_w}{1+sT_w}\right)\left(\frac{1+sT_3+sT_1+s^2T_1T_3}{1+sT_4+sT_2+s^2T_2T_4}\right) \qquad (4)$$

$$G_p = K_P \left(\frac{sT_W+s^2T_WT_3+s^2T_WT_1+s^3T_WT_1T_3}{1+sT_4+sT_2+s^2T_2T_4+sT_W+s^2T_WT_4+s^2T_WT_2+s^3T_WT_2T_4}\right) \qquad (5)$$

$$G_p = \frac{sK_PT_W+s^2K_PT_WT_3+s^2K_PT_WT_1+s^3K_PT_WT_1T_3}{1+sT_4+sT_2+s^2T_2T_4+sT_W+s^2T_WT_4+s^2T_WT_2+s^3T_WT_2T_4} \qquad (6)$$

$$G_p = \frac{sK_PT_W+s^2K_PT_WT_3+s^2K_PT_WT_1+s^3K_PT_WT_1T_3}{1+sT_4+sT_2+sT_W+s^2T_2T_4+s^2T_WT_4+s^2T_WT_2+s^3T_WT_2T_4} \qquad (7)$$

This analysis examined the control behaviour of the PSS without an additional controller. The analysis requires the PSS transfer function and the parameters of the system.

Table 1 PSS Parameters calculated with various methods (Rafiee et al, 2011)

Method	PSS Parameter
CPSS	K_{PSS}=120, T_W=1.0, T_1=0.024, T_2=0.002, T_3=0.024, T_4=0.0.24
PSO	K_{PSS}=194.8243, T_W=1, T_1=0.0008, T_2=0.0008, T_3=0.0008, T_4=0.0611
ICA	K_{PSS}=195.6586, T_W=1.0, T_1=0.0008, T_2=0.0750, T_3=1.00, T_4=1.00

Table 2 Generic PSS Parameters proposed by (Kasilingam and Pasupuleti, 2014)

Generic	K_{PSS}=125, T_W=2, T_1=5000, T_2=2000, T_3=3, T_4=5.4

A. PSS-PID Controlled Plant

Primarily, the PSS provides the needed damping to nullify the low frequency oscillation which affects the stability of the generating plants if not addressed. However, the PSS alone cannot provide the adequate damping required to maintain stability of the plant even in the presence of disturbance. This is because of the increased complexity of the power system and also the increased level of disturbances. In order to improve the performance of the PSS, a feedback control method must be applied, which can optimize the damping characteristics of the PSS.

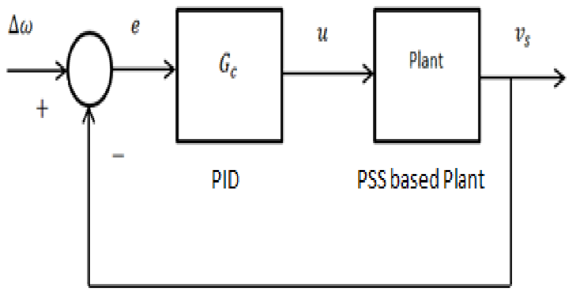

Fig.2. Feedback control system

The feedback control system as shown in Fig. 2 consists of the plant, the controller which was designed using Proportion Integral Derivative (PID) method and the feedback loop. The closed loop control model can be expressed as follows:

$$e(t) = \Delta\omega - v_s \quad (8)$$

$$\frac{v_s}{\Delta\omega} = \frac{G_c G_p}{1+G_c G_p} \quad (9)$$

$$v_s = \frac{G_c G_p}{1+G_c G_p}\Delta\omega \quad (10)$$

where the $e(t)$ is the error which is produced from the difference between the plant actual output v_s and the reference input$\Delta\omega$. G_c is the controller transfer function and G_p is the plant transfer function.

Hence,

$$\frac{v_s}{\Delta\omega} = \frac{G_c\left(\frac{sK_PT_w+s^2K_PT_wT_3+s^2K_PT_wT_1+s^3K_PT_wT_1T_3}{1+sT_4+sT_2+sT_w+s^2T_2T_4+s^2T_wT_4+s^2T_wT_2+s^3T_wT_2T_4}\right)}{1+G_c\left(\frac{sK_PT_w+s^2K_PT_wT_3+s^2K_PT_wT_1+s^3K_PT_wT_1T_3}{1+sT_4+sT_2+sT_w+s^2T_2T_4+s^2T_wT_4+s^2T_wT_2+s^3T_wT_2T_4}\right)} \quad (11)$$

Let,

$$G1 = sK_PT_w + s^2K_PT_wT_3 + s^2K_PT_wT_1 + s^3K_PT_wT_1T_3 \quad (12)$$

$$G2 = 1 + sT_4 + sT_2 + sT_w + s^2T_2T_4 + s^2T_wT_4 + s^2T_wT_2 + s^3T_wT_2T_4 \quad (13)$$

$$\frac{v_s}{\Delta\omega} = \frac{G_c\left(\frac{G1}{G2}\right)}{1+G_c\left(\frac{G1}{G2}\right)} \quad (14)$$

$$\frac{v_s}{\Delta\omega} = \frac{\frac{G_cG1}{G2}}{1+\frac{G_cG1}{G2}} \quad (15)$$

$$\frac{v_s}{\Delta\omega} = \frac{\frac{G2.G_cG1}{G2}}{\frac{G2+G_cG1}{G2}} \quad (16)$$

$$\frac{v_s}{\Delta\omega} = \frac{G2.G_cG1}{G2} \div \frac{G2+G_cG1}{G2} \quad (17)$$

$$\frac{v_s}{\Delta\omega} = \frac{G2.G_cG1}{G2} \times \frac{G2}{G2+G_cG1} \quad (18)$$

Canceling the like terms, gives:

$$\frac{v_s}{\Delta\omega} = \frac{G2.G_cG1}{G2+G_cG1} \quad (19)$$

The objective of the control system is to develop Gc that can improve the damping performance of the PSS using PID control technique. The second objective of the closed loop control design is to achieve a controller that can guarantee stability of the plant.

The proportional-integral-derivative control model is derived as follows:

$$u(t) = K_Pe(t) + K_I\int e(t)dt + K_D\frac{d}{dt}e(t) \quad (20)$$

Applying Laplace transformation

$$U(s) = K_Pe(s) + K_I\frac{1}{s}e(s) + K_Ds\,e(s) \quad (21)$$

$$U(s) = e(s)(K_P + K_I\frac{1}{s} + K_Ds) \quad (22)$$

The transfer function of the PID controller becomes:

$$G_c(s) = K_P + K_I\frac{1}{s} + K_Ds \quad (23)$$

Therefore,

$$U(s) = e(s)\,G_c(s) \quad (24)$$

From equation 2.24, cancellation of the error signal depends on the capability of the controller. Since the error is not specific, rather it changes consistently with time; the controller must be designed to address such an unsteady behavior of the error signal. Therefore, the controller must be designed to work with the past changes or behaviours of the error, its current state and the forecasted future behaviours.

III. PSS ANALYSIS RESULT

The PSS analysis was carried out in four set of experiments using the four set of parameter values of CPSS, PSO, ICA and Generic as shown in Tables 1 and 2.

A. Analysis of Results without PID Controller

In this subsection, the simulation results for the four PSS parameter sets namely, CPSS, PSO, ICA and Generic techniques without PID controller are presented in Fig. 3 to

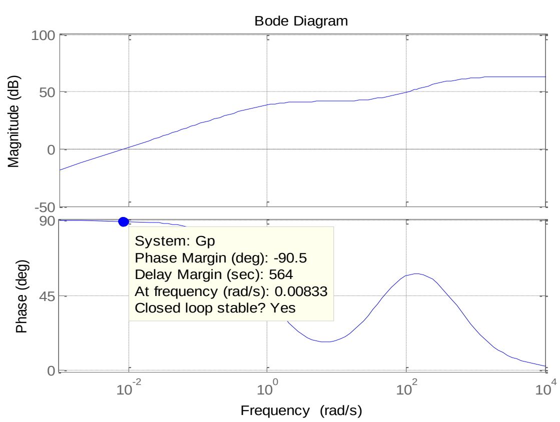

Fig. 3 Step response of the CPSS

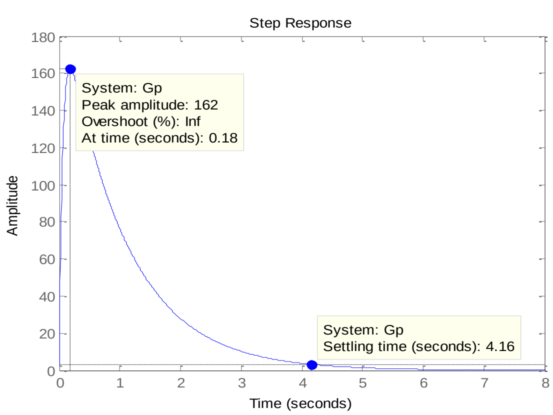

Fig. 4 Bode plot response of CPSS

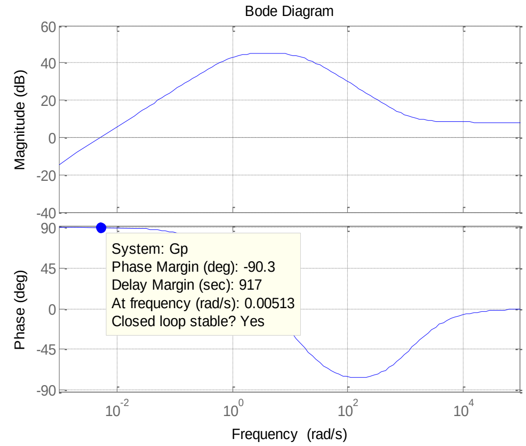

Fig. 5 Bode plot response of the PSO

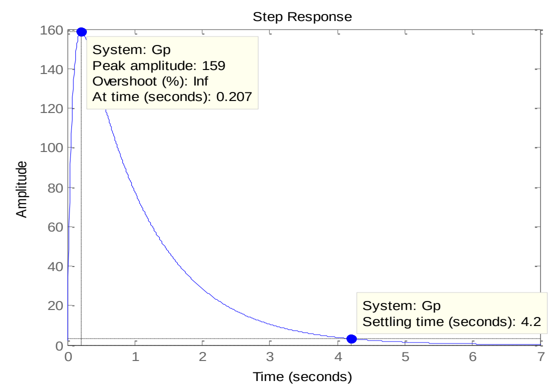

Fig. 6 Step response of the PSO

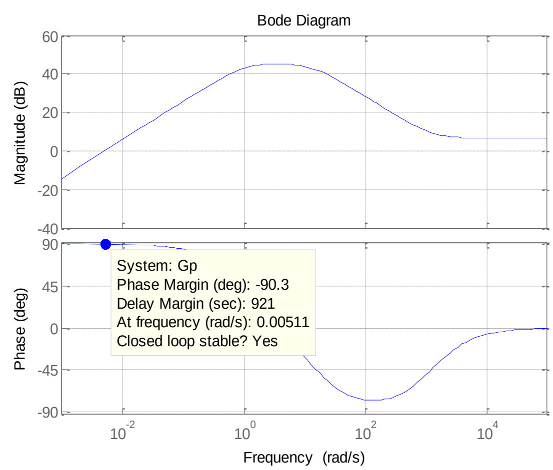

Fig. 7 Bode plot response of the ICA

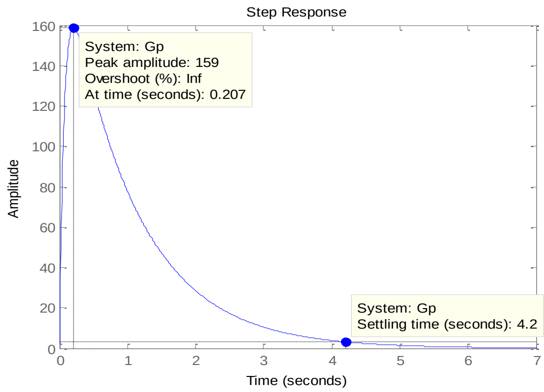

Fig. 8 Step response of the ICA

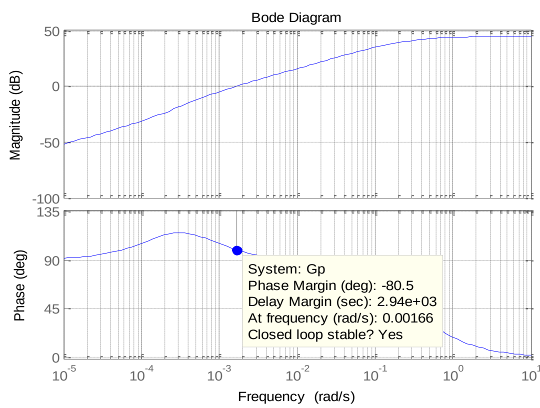

Fig. 9 Bode plot response of the GENERIC

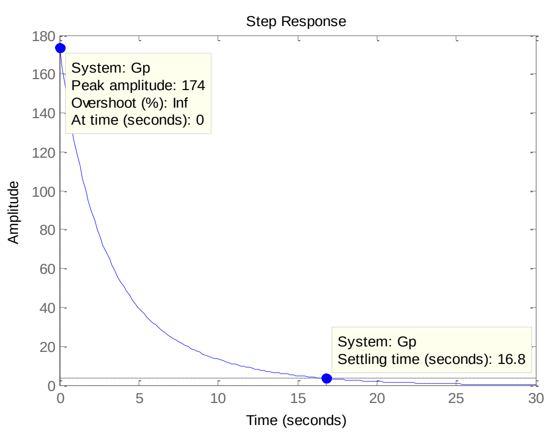

Fig. 10 Step response of the GENERIC

B. Analysis of Results with Designed PID Controller

The controller design was carried out using PID method on the four PSS parameter sets and the following graphs were obtained:

- CPSS-PID Controller:

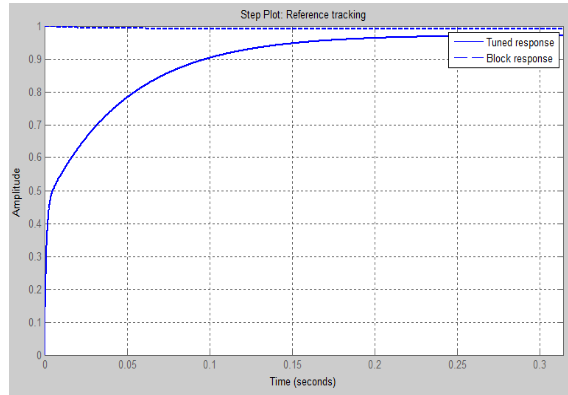

Fig. 11: CPSS-PID reference tracking on time graph

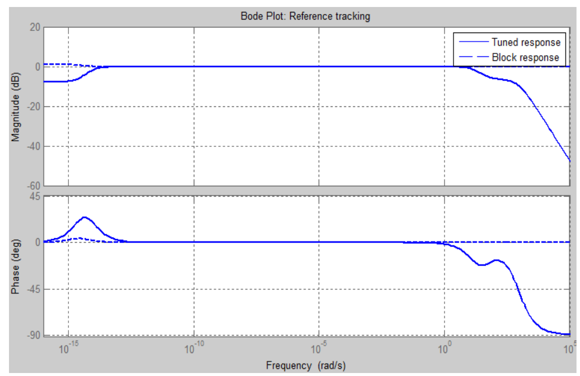

Fig. 12 CPSS-PID reference tracking on frequency graph for the CPSS

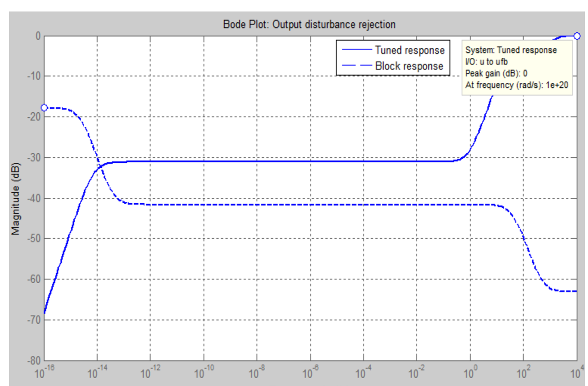

Fig. 13 Output disturbance rejection graph for the CPSS-PID

- PSO-PID Controller:

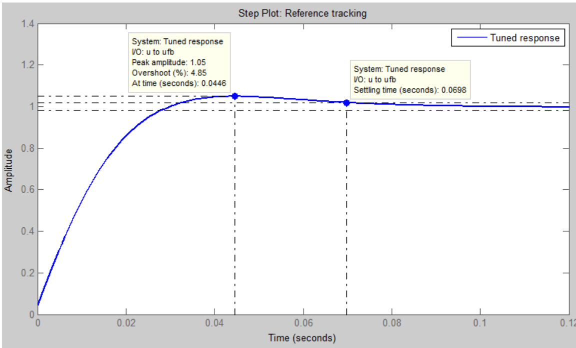

Fig. 14 PSO-PID reference tracking on time graph

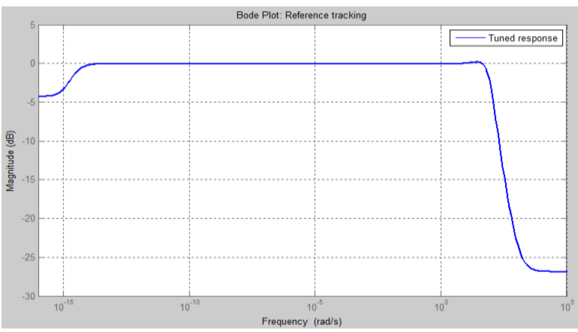

Fig. 15 PSO-PID reference tracking on frequency graph

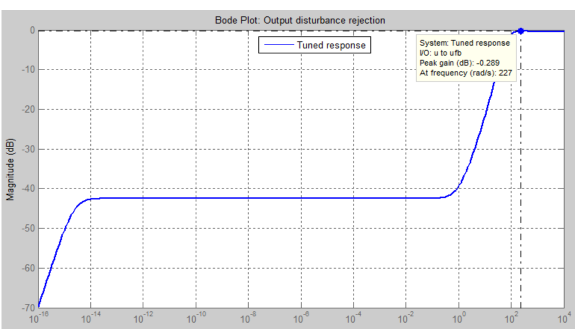

Fig. 16 PSO-PID output disturbance rejection

- ICA-PID Controller

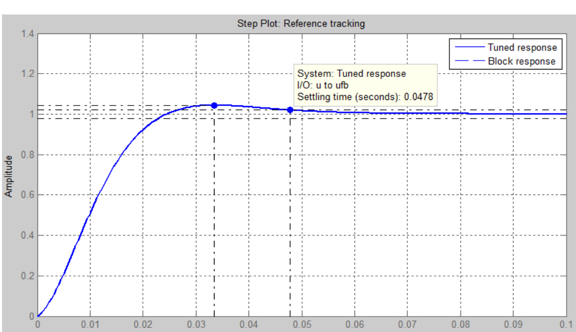

Fig. 17 ICA-PID reference tracking on time graph

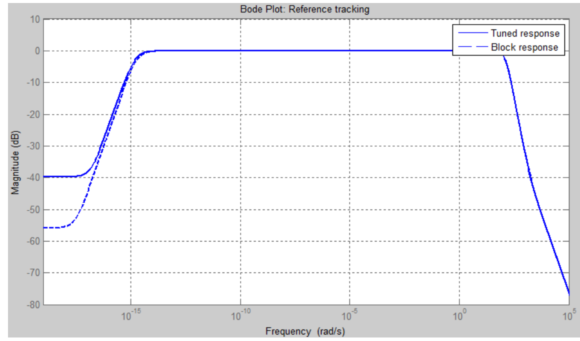

Fig. 18 ICA-PID reference tracking on frequency graph

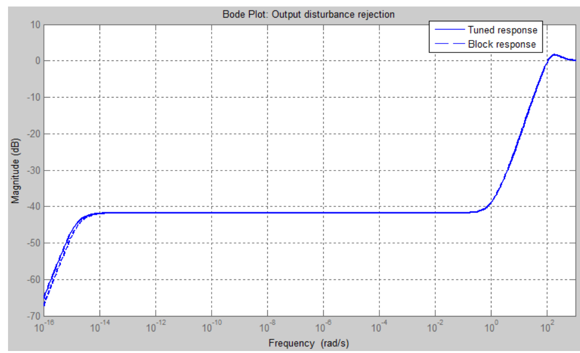

Figure 19 ICA-PID output disturbance rejection

- Generic-PID Controller:

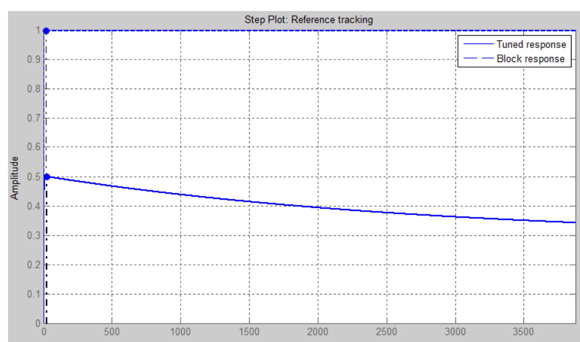

Fig. 20 Generic-PID reference tracking on time graph

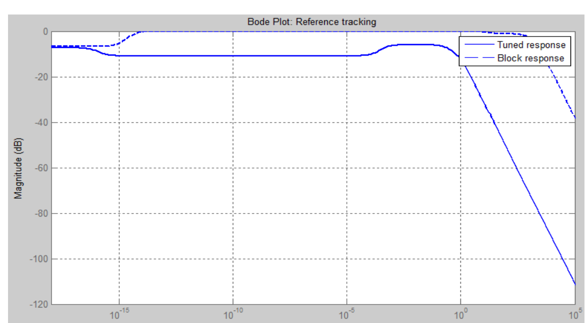

Fig. 21 Generic-PID reference tracking on frequency graph

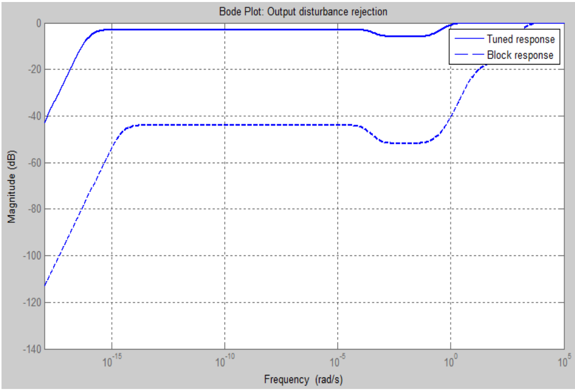

Fig. 22 Generic-PID output disturbance rejection

IV. DISCUSSION OF RESULT

Table 3 shows the comparative analysis of the PSS controlled plant and the PSS-PID controlled plant output characteristics.

Table 3 Comparison of PSS controlled plant and the PSS-PID controlled plant

Performance/stability	PSS Controlled Plant	PSS-PID Controlled Plant
Settling time	16.8sec	0.0478 seconds
Overshoot	Infinity	4.4%
Gain margin	Infinity	Infinity
Phase margin	-80.5	67.6 degrees
System Stability	Unstable	Stable

Table 4 Summary of the Improved Performance and Stability of the PID controlled Plant

Performance/stability	Tuned plant CPSS-PID	Tuned plant PSO-PID	Tuned plant ICA-PID	Tuned plant Generic-PID
Settling time	0.164 seconds	0.069 seconds	0.0478 seconds	1.03e+4 seconds
Overshoot	0%	4.85%	4.4%	74%
Peak	0.972	1.05	1.04	0.499
Gain margin	Infinity	Infinity	Infinity	Infinity
Phase margin	140 degree	77 degree	67.6 degree	176 degree
Closed loop stability	Stable	Stable	Stable	Stable

Deducing from Table 3, it is evident that with PSS controlled plant, the system remains unstable with settling time of 16.8seconds, overshoot and gain margin both at infinity and phase margin at -80.5degrees. In table 4.2 where comparative analysis was conducted for the PSS-PID controlled plant, it is observed that all the PSS-PID controlled plants recorded improved performance and stability characteristics except the Generic-PID which recorded very high settling time of 1.03e+4 seconds and overshoot of 74%. However, all the PID controlled plant was stable. The ICA-PID achieved best performance and stability improvement characteristics with settling time of 0.0478seconds, overshoot of 4.4%, and phase margin of 67.6 degrees.

With the result so far, one could say that stability performance is best achieved with PSS-PID controlled plant(s) than PSS controlled plant(s).

CONCLUSION

The goal of this research work was successfully realized by achieving the objectives of the work. The power system stabilizer was analyzed in order to study its stability and performance characteristics which determine its damping ability. From the review, four tuning methods were used to achieve four sets of PSS parameters and the analyses were based on the four different sets of PSS parameters. The results show that the four sets of the PSS parameters achieved slight stability and very poor performance.

In order to improve the stability and performance characteristics of the PSS to increase its damping ability, the PID controller was applied and stability performance characteristics were achieved.

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