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Small Signal Stability Analysis of Power System with AVR & PSS Equipped with Self Tuned Fuzzy PID Controller

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Abstract—*Small signal stability is a very important aspect in power systems as we have to achieve "Maximum power transfer" and "Power system security". Low frequency oscillations (LFOs) are related to small signal stability of a power system. Automatic voltage regulators (AVRs) can improve the steady state stability of a power system, but additional controller in control loop, i.e. power system stabilizer (PSS) with AVR on the generators helps in reducing the harmful effects of LFOs. We know that performance of PSS degrades once conditions change, therefore to overcome the drawback of PSS this paper introduces self tuned fuzzy PID controller. The Fuzzy logic tunes each parameter of PID controller. Thus in this paper the LFOs are analyzed quickly and reduced to zero in minimum possible time. Also, small signal stability of power system is investigated by eigen values analysis.*

Keywords: *LFOs, AVRs, PSS, Fuzzy logic, PID controller.*

1. INTRODUCTION

Small Signal stability (or small disturbance) stability is the ability of the power system to maintain synchronism under small disturbances. Such disturbances occur continually on the system because of small variations in loads and generation [1].

These disturbances give rise to oscillations which must be damped to maintain system stability. Instability can be of two forms: (i) Steady increase in rotor angle due to lack of sufficient synchronizing torque that results in Non-Oscillatory instability. (ii) Rotor oscillations of increasing amplitude due to lack of sufficient damping torque that results in Oscillatory instability [1].

Oscillations can occur in two modes:

(i) Local plant mode Oscillations: These are associated with units at generating station swinging with respect to the rest of the system. The frequencies of these oscillations lie in the range of (0.8- 2) Hz.

(ii) Inter Area Oscillations: These are associated with swinging of many machines in one part of the system against machines in other parts. The frequencies of these oscillations lie in the range of (0.1 – 0.7) Hz [2].

This paper explains that with the incorporation of self tuned fuzzy PID Controller along with Generic PSS and AVR, the appearance of Non-linearities and uncertainties in the system is removed or overcome quickly.

This paper consists of six sections in which section one is Introduction. Section two consists of Generic PSS. Section three consists of designing of Self Tuned Fuzzy logic controller. Section four consists of Circuit Description. Section five consists of necessary Tables and Graphs. Section six consists of Conclusion.

2. GENERIC POWER SYSTEM STABILIZER

The presence of AVR and PSS greatly influence the damping of modes of oscillations to a great extent and can be assessed by means of Eigen values. If Eigen values lie in the left half complex plane, system is stable otherwise if they lie in the right half plane, system is unstable. The AVR normally controls the generator stator terminal voltage. PSS is very useful in damping system oscillations [1].

Advantages of PSS: (a) Improved damping of the system. (b) Dynamic stability of the system is improved. (c) Reduced power loss. When the system becomes complex with respect to dynamic disturbances then PSS cannot work accurately, instead it affects the operation of the generator. Also Tuning of PSS is time consuming.

PSS produces electric torque component which is in phase with the deviations of the generator rotor speed in order to be able to damp the oscillations . Generally the inputs to the PSS are shaft speed, terminal frequency and active power. However power system instabilities can arise in certain circumstances, due to negative damping effects of PSS on the rotor .The reason for this is that PSS's 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 in an attempt to control its excitation field [3].Therefore PSS must be tuned to provide effective damping and ensure stability of the system. In this paper self tuned fuzzy logic controller is applied along with PSS .

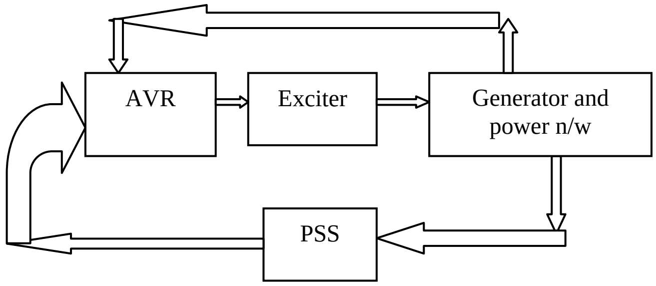

Fig. 1: Block diagram of PSS-Exciter-Generator loop

Necessary State transition Equations are as follows:

$$I = \frac{E\angle\delta - E_o \angle 0^0}{jX} \ldots\ldots \quad (i)$$

$$\Delta\dot{E}'q = -\frac{1}{K_3 T'_{do}}\Delta E'_q - \frac{k_4}{T'_{d0}}\Delta\delta + \frac{1}{T'_{d0}}\Delta E_{fd} \quad (ii)$$

$$\Delta\dot{\delta} = \omega_0 \ \Delta v \ldots\ldots \quad (iii)$$

$$\Delta\dot{v} = -\frac{k_2}{2H}\Delta E'_q - \frac{k_1}{2H}\Delta\delta - \frac{K_d\omega_0}{2H}\Delta v + \frac{1}{2H}\Delta T_m \ldots\ldots (iv)$$

$$\Delta\dot{E}_{fd} = -\frac{K_A K_6}{T_A}\Delta E'_q - \frac{K_A K_5}{T_A}\Delta\delta - \frac{1}{T_A}\Delta E_{fd} + \frac{k_A}{T_A}\Delta V_0 \quad (v)$$

$$\Delta\dot{y} = -\frac{k_2 T_1 k_{pss}}{T_2 2H}\Delta E'_q - \frac{k_1 T_1 k_{pss}}{T_2 2H}\Delta\delta + \frac{k_{pss}}{T_2}\Delta v - \frac{1}{T_2}\Delta y \quad (vi)$$

Important terms used in the equations are as follows:

(a) I= armature current coming out of the generator and flowing through the bus.

(b) $\Delta E'_q$= change in quadrature axes component of stator induced emf in p.u

(c) $\Delta\delta$=change in angle of induced voltage in rad or degree

(d) ω_0=synchronous speed in rad/sec

(e) k_A=exciter gain

(f) k_{pss} =Power system stabilizer gain

(g) T_A=Time constant of the amplifier of an exciter

(h) E_0=infinite bus voltage

3. DESIGNING OF SELF TUNED FUZZY PID CONTROLLER

Fuzzy controllers have got a lot of advantages compared to the classical controllers such as the simplicity of control, the low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic is one of the successful applications of fuzzy set in which the variables are linguistic rather than the numeric variables. Linguistic variables, defined as variables whose values are sentences in a natural language (such as Large or Small), may be represented by fuzzy sets. Fuzzy set is an extension of a "crisp set" where an element can only belong to a set (full membership) or not belong at all (no membership). Fuzzy sets allow partial membership, which means an element may partially belong to more than one set. A fuzzy logic controller is based on a set of control rules called as the fuzzy rules among the linguistic variables [6].

Our basic structure of self tuned fuzzy logic controller consists of 4 parts:

(a) PID Controller: It is a control loop feedback mechanism widely used in industrial control systems. It generally calculates an error value as the difference between a measured process variable and a desired set point. The performance characteristics of the systems such as rise time, overshoot, settling time, steady state error can be improved by tuning value of parameters (K_P, K_i and K_d) of PID Controller. Mathematically PID is represented as:

$$y(t)=K_p\,[e(t)+T_d\frac{d(e)}{d(t)}+\frac{1}{T_i}\int_0^t e(t)d(t)] \ldots. \quad (vii)$$

$$y(t)=[K_p\, e(t)+K_d\frac{d(e)}{d(t)}+K_i\int_0^t e(t)d(t)] \ldots \quad ..(viii)$$

$K_i=\frac{K_p}{T_i}$ and $K_d=K_p.T_d$

(b) Structure of Fuzzy controller:

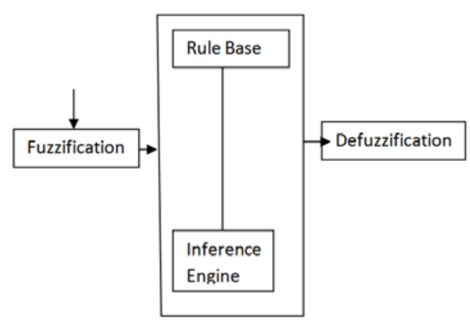

Fig. 2: Structure of Self-tuning fuzzy PID controller:

Here the co-efficients of conventional PID controller are tuned automatically by using fuzzy tuner. [4]

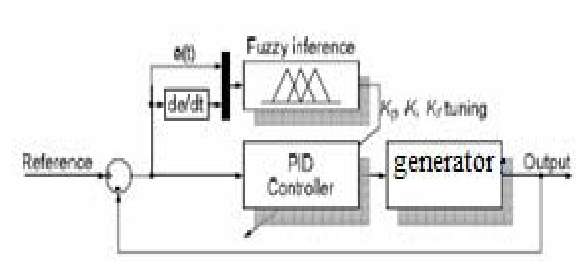

Fig. 3: Structure of fuzzy interface to PID controller.

In the fuzzy logic controller there are four main blocks (i) fuzzification (ii) decision making unit (DMU) (iii) knowledge base (iv) Defuzzification. The necessary inputs to the DMU block are the rule base and data base units. The fuzzification unit converts the crisp data into the linguistic formats. The DMU decides in the linguistic format with the help of logical linguistic rules supplied by the rule base unit and the relevant data supplied by the data base. Error in voltage e(t) and the change of error voltage de(t) is modeled using the equation: e(t) = E_{ref} - E_G and also de(t) = e(t) – e(t-1) where E_{ref} is the reference voltage and $E_G$is the generated emf. The output of the DMU is the input to the defuzzification unit and the linguistic format of the signal is converted back into the numeric format of data in the crisp form. The DMU uses the conditional rules of "IF-THEN-ELSE". In the first stage the crisp variables e(t) and de(t) are converted into fuzzy variables. The fuzzification maps the error and the error changes to linguistic levels of fuzzy sets. The proposed controller uses the following linguistic labels: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero Error (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB). Each fuzzy label has an associated membership function. In this paper the membership function of FIS fuzzy editor incorporated with self tuned PID is as shown:

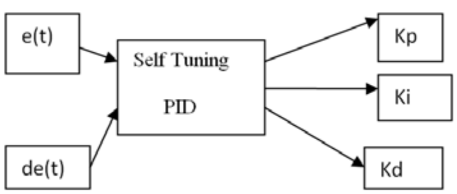

Fig. 4. FIS Fuzzy Inference Block

Rule Base for DMU:

ΔE \ E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

4. CIRCUIT DESCRIPTION

The circuit consists AVR along with Generic PSS along with Fuzzy tuned PID controller (included by subsystem) applied to generator model. The output is derived from the scope.

The output consists of change in rotor angle which is a transient disturbance and if sustained for quite a some time may lead to severe oscillations on the system and hamper its performance. Due to change in load demand dδ is not equal to zero as evident from Fig. 6 but quickly reduced to zero within 4 secs with the help of PSS-FuzzyTuned PID controller with amplifier gain set to 60. But without PSS-PID controller dδ completely sets to zero after 9 secs (Fig. 12) and as said longer oscillation sustained more is the time for the system to become danger prone. Another event that may lead to unstable operation is huge increment in amplifier gain ka that if increased to 300 then oscillation may last even longer, in this case requires 18 secs to completely vanish out as evident from Fig. 13. With the help of PSS-Fuzzy PID controller this error gets reduced to zero in very short time i.e. 8 secs (Fig. 7) as PSS can perform well under steady state conditions but may lose its grip if complexity arrives in the system, that is why Fuzzy tuned PID controller must be incorporated along with PSS to perform under dynamic conditions and eliminate error in time as less as possible. Stability can be observed to be good with ka=60 with PSS-PID (Fig. 8). From Fig. 10 equivalent Bode Response denoting stability can also be observed. Again as ka is increased to 300, two poles can be observed to be lying just on right hand side of real axis (Fig. 9), which could have gone even beyond positive part of real axis that could have affected the other poles but due to the controller the initial instability got stabilized as evident also from the equivalent Bode Response (Fig. 11)..

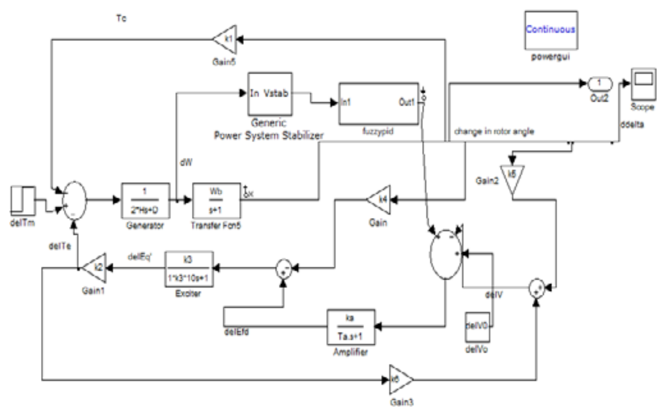

Fig. 5. Simulink block diagram of Heffron-Phillips model with avr & pss equipped with self tuned fuzzy pid controller.

5. TABLES AND GRAPHS

The necessary graphs obtained after simulink the MATLAB Model, are shown in this section .

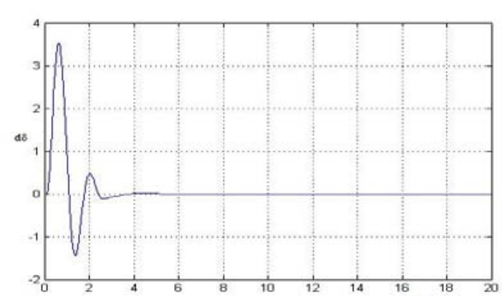

Fig. 6: Rotor angle reduced to zero With PSS-PID (Gain,ka=60)

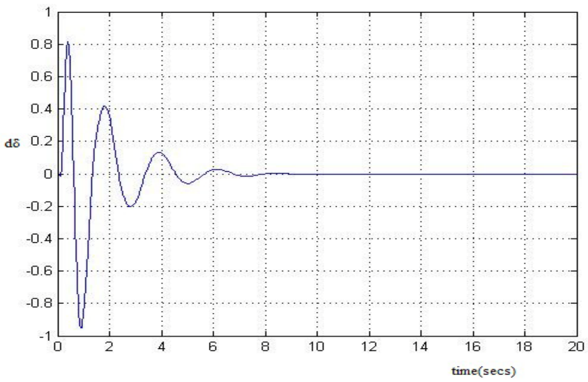

Fig. 7: Rotor angle reduced to zero With PSS-PID (Gain, ka=300)

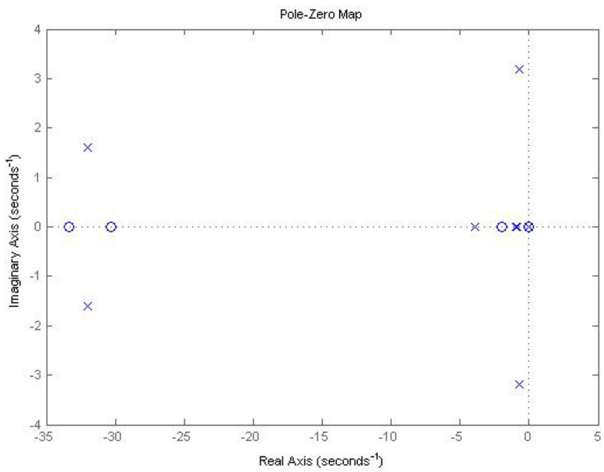

Fig. 8: Poles & Zeroes of the system (Gain, ka=60) with PSS-PID.

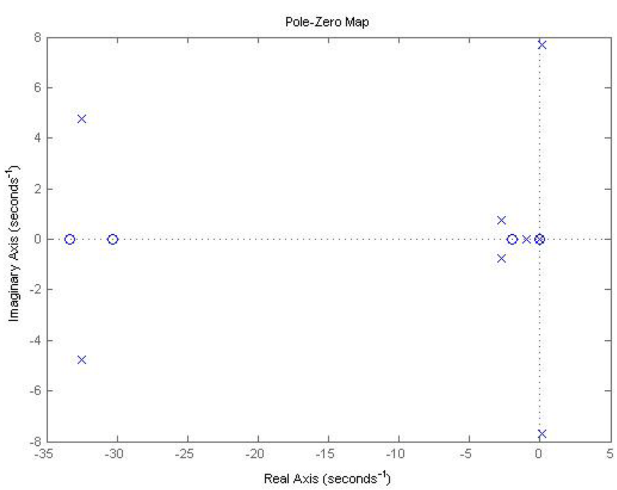

Fig. 9: Poles & Zeroes of the system (Gain,ka=300) with PSS-PID.

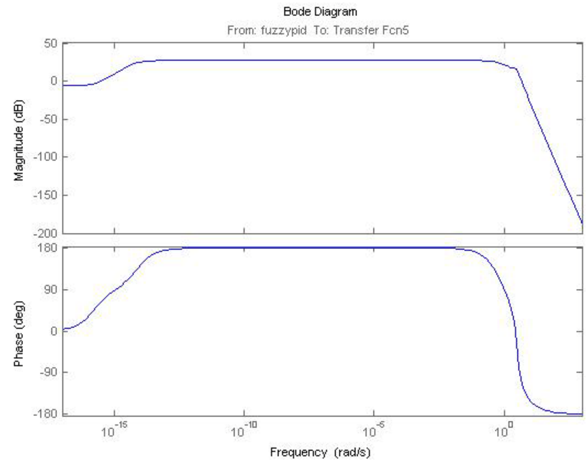

Fig. 10: Bode-Response with PSS-PID (Gain,ka=60)

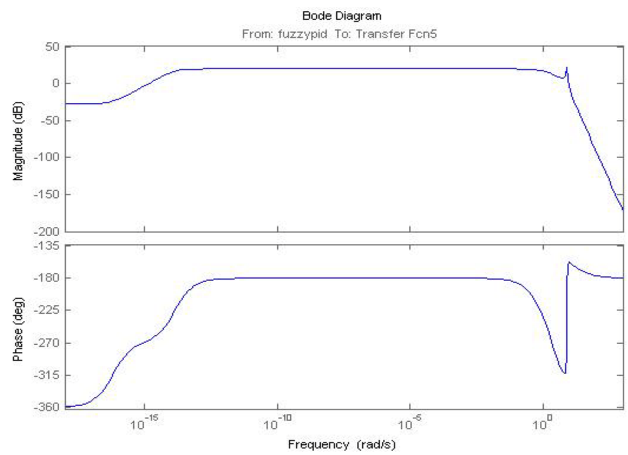

Fig. 11: Bode-Response with PSS-PID (Gain,ka=300)

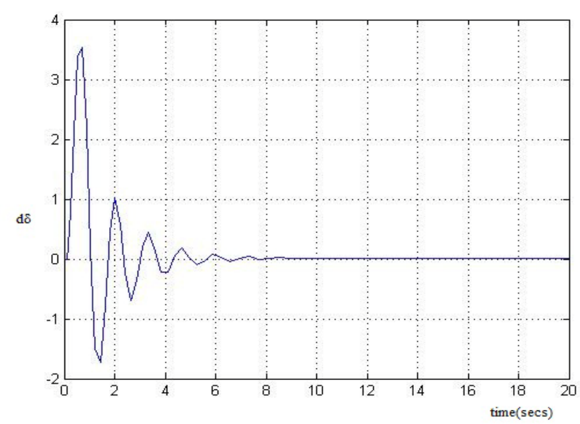

Fig. 12: Rotor angle reduced to zero Without PSS & PID (Gain,ka=60).

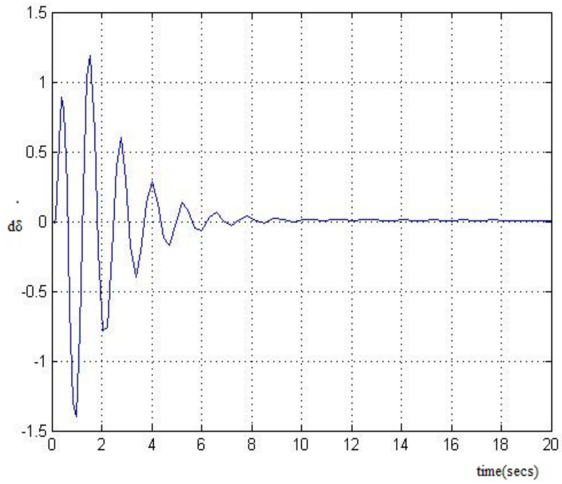

Fig. 13: Rotor angle reduced to zero Without PSS & PID (Gain,ka=300).

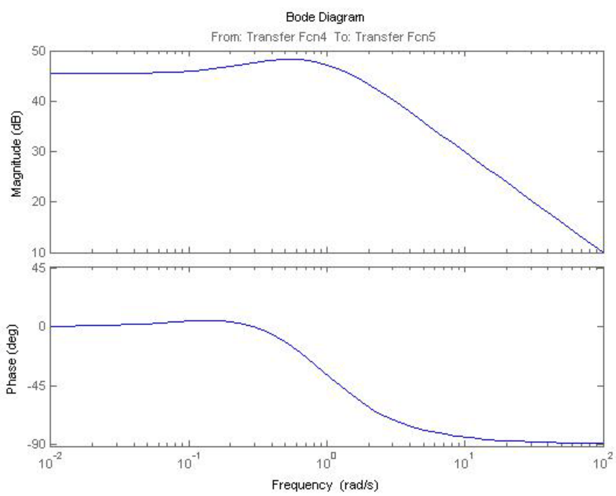

Fig. 14: Bode Response Without PSS-PID (Gain, ka=60)

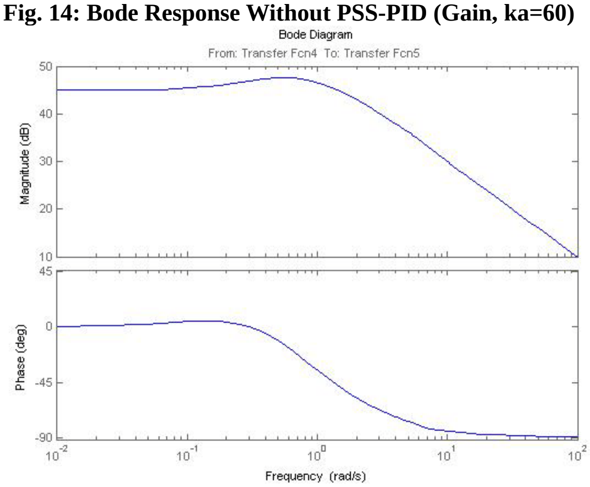

Fig. 15: Bode –Response without PSS &PID (Gain,ka=300)

6. CONCLUSION

This paper shows the effects of changes in load and system parameters can cause steady and transient disturbances that can cause unstable operation but with application of PSS and Fuzzy tuned PID controller these disturbances can be reduced to zero in very short time. For stable operation initially ka was set to 60, we had all negative real parts of Eigen values(E1), but as gain got increased to 300 instability arrived in the system as denoted by the positive real parts of Eigen values (E2,i.e. last 2 rows) but again stability can be observed to have been brought back by the application of generic PSS as we had negative real parts of Eigen values (E3). Futuristic application of this controller can also be made on multi-bus systems as well as in renewable energy systems.

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APPENDIX

SYNCHRONOUS GENERATOR:

d - axis synchronous reactance, X_d = 2.8 p.u, q -axis synchronous reactance, X_q=1.8 p.u, d-axis transient reactance, X_d'= 0.45 p.u, d-axis open circuit transient time constant, $T_{do}^{'}$ =10 secs, Exciter time constant, $T_A = 0.25\ secs$ Generator bus real power, P_{Gi}=1.05 p.u., Generator bus reactive power Q_{Gi}=0.45 p.u Active load demand, P_{Di}=0.55 p.u Reactive load demand, Q_{Di}=0.25p.u, Leakage reactance=0.48 p.u Inertia constant, H=6secs Exciter gain, K_A = 60 Synchronous speed, ω_0 =314 rad/sec

GENERIC POWER SYSTEM STABILIZER:

Sensor time constant = 30e-3, Gain = 0.5 Washout time constant = 25, Lead lag #1 time constants:[T_1 T_2] = [0.154 0.033], Lead lag #2 time constants:[T_3 T_4]= [1 1] ,Output limits [V_{Smax} V_{Smin}]= [-0.045 0.045]

EIGEN VALUES AND CONSTANTS OF THE MODEL:

E1	E2	E3
-2.104+2.667i	-2.262+7.046i	-0.494+9.039i
-2.104-2.667i	-2.262-7.046i	-0.494-9.039i
-0.073+ 4.768i	0.085+ 4.856i	-0.533+ 3.540i
-0.073- 4.768i	0.085-4.856i	-0.533- 3.540i

k1= 0.8901; k2= 0.8043; k3= 0.2835; k4= 1.9156; k5= -0.0171; k6= 0.4406.