Design and Tuning a new Power System Stabilizer PART I

S.M. ABDALLA, T. HUSSEIN ELMENFY*

Department of Electrical and Electronic Engineering, Near East University, Lefkosa, Northen CYPRUS
salih.abbar@yahoo.com
Department of Electrical and Electronics Engineering, University of Benghazi, Benghazi, LIBYA
*Tawfiq.elmenfy@uob.edu.ly (+2180927619035)

Abstract-This paper presents a new power system stabilizer used to damp local and inter-area modes of oscillation following small and large disturbances in power system. The proposed PSS belong to integral of accelerating power family. The bode plots and root locus are used to explore the process of tuning PSS parameters. The work arranged to three parts. The first part describe the proposed (PPSS), the power system model consists of a one-machine with slack bus system and IEEE ST1A static excitation system. The second part demonstrate the comparison between different types of power system stabilizers which used a three machine nine bus system with IEEE ST1A static excitation system, and three types of PSSs (Delta ω PSS, MB-PSS and Kundur Delta Pa PSS) are chosen to compared with the proposed technique.The third part belong to the simulation of the first part with special cases by PPSS controller.The simulation results shows that superiority of the proposed PSS over other conventional stabilizers used in the literature.

Keywords: Automatic Voltage Regulator AVR;Excitation Systems; Power System Stabilizer PSS

1. Introduction

The PSS Controller is a supplementary signal in the automatic voltage regulator (AVR) used to add damping to the rotor oscillations of the synchronous generators. The disturbances occurring in a power system induce electromechanical oscillations of the rotor of electrical generators. The oscillations must be sensitively damped to look after the system stability. The output signal of the PSS is used as an additional input to the auto channel of excitation system. The PSS input signal can be either the machine speed deviation, electrical power or acceleration power. All stabilizing intelligence is thus derived from measurement of machine voltages and currents [1][2].

The commonly used PSS in the power plants referred to conventional PSS (CPSS), is a fixed parameters controller. The CPSS first introduced in 1950's, is based on linear transfer function designed using classical control theory [3].

The power system stabilizer normally consists of a phase lead/lag compensation blocks, a signal washout block, and a gain block. The input signal to the stabilizer is the equivalent rotor speed deviation,electrical power output or acceleration power. But due to constant stabilizer gain and the complexity of system modeling, different operating conditions, unpredictable fault locations, changing the grid structures, calls for new technology to be introduced in damping of small signal oscillation of the system giving origin new type of linguistic based power system stabilizer called Intelligent PSS.

The Fuzzy PSS removes most of the drawbacks of the conventional power system stabilizer. Standared FPSS introduced in [3][4]. FPSS is used for stability enhancement of a single machine infinite bus system, in order to accomplish the stability enhancement, speed deviation and acceleration of the rotor synchronous generator are taken as the inputs to the fuzzy logic controller. Supervisory power system stabilizer (PSS) using an adaptive fuzzy logic controller driven by an adaptive fuzzy set (AFS) introduced in [4][5][6], the adaptive FLC algorithm uses a genetic algorithm to tune the parameters of the fuzzy set of each PSS. The FLC's are simulated and tested when the system is subjected to different disturbances under a wide range of operating points.Enhanced through a novel stabilizer developed around an adaptive fuzzy sliding mode control which applies the Nussbaum gain to a nonlinear system model

of a single-machine infinite-bus (SMIB) and multi-machine power system stabilizer subjected to a large disturbance introduced in [8], the Nussbaum gain is used to avoid the positive sign constraint and the problem of controllability of the system.Type-2 Fuzzy Logic Power System Stabilizer (FLPSS) is presented in [9] to improve the damping of power system oscillations, to accomplish the best damping characteristics three signals are chosen as input to FLPSS, Deviation in speed, deviation of speed derivative and deviation of power angleare taken as input to fuzzy logic controller.
The Conventional Power System Stabilizer (CPSS) parameters are tuned by various methods and algorithms to achieve optimal damping over a wide range of operating conditions. The CPSSs lack of robustness over wide range of operating conditions under nonlinearity.
In this paper two conventional PSSs connected in parallel tuned based local and inter-area oscillations is proposed..

Part 1 - Design and Tuning Methodology

2. Proposed PSS Model

2.1. Fundamental

Many research articles have been written and discussed [10][11][12] to measure accelerating power by deriving mechanical power through measurements of prime mover turbine variables such as hydro-gate positions or steam pressures, and the others researches avoids this method. In this paper, we explore both methods. The proposed model consists of two channels, one for the mechanical power and the second for the electrical power. Both channels consists of a general gain, a washout high-pass filter, two first order phase compensation systems, and an output limiter. The gain is expressed the magnitude of generator damping by the stabilizer. The washout high-pass filter removes low frequences. The phase-compensation system is represented by a set of first order lead lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.Fig. 1. shows the PPSS with double stabilizer input signals. The first one is the electrical power and other is the mechanical power.

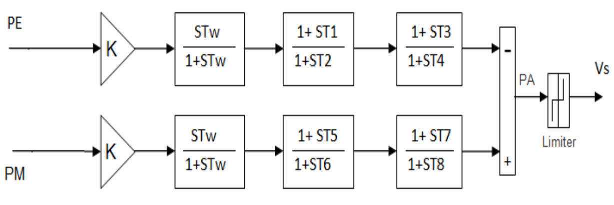


Fig.(1): Type PPSSmodel

2.2 Derivation PPSS Model

According to researches have been written and discussed in the field of derivation the accelration power from electrical power and mechnical power. Fig.2. shows the principle sketch. The target is the difference between the mechanical power and output electrical power as in Eq.(1).

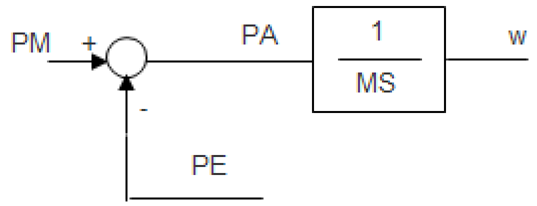


Fig.(2): Derivation the acceleration l power from electrical power and mechanical power

$P_A = P_M - P_E$ ……………………………………….(1)

Where:

P_a = *acceleration power*
P_m = *mechanical power*
P_e = *Electrical power*

Eq.(1) shows that obtaining the accelerating power by measurements of electrical and mechanical powers.
The measurement problem of mechanical power is difficult and need more to periodic calibration and maintenance, and mechanical power effects are only of value in the lower bandwidths.
The aim for use of electrical power rather than speed, because electrical power is proportional to the rate of change of speed in the oscillation frequencies and provides an easier way, less noise problems, of obtaining the required lead than by differentiation of speed measurements [1].The variation in speed can be written as,

$\Delta\omega = \frac{1}{M}\int (P_m - P_e)\ dt$ …………………………….. (2)

The equation in Laplace transform,with the derivation of speed from electrical and mechanical power is,

$\Delta\omega(s) = \frac{\Delta P_m(s) - \Delta P_e(s)}{MS+D}\omega_o$ …………………………(3)

The damping coefficient is small in the frequency range about 0.2 to 3 Hz, Ms>>D and damping coefficient can be neglected[11]. Where $\omega_0$is base frequency = 377 rad/s.
The derivation of speed from electrical and speed is

$\Delta\omega^*(s) = (\Delta\omega(s) + \frac{\Delta P_e(s)}{Ms}\omega o - (\frac{\Delta P_e(s)}{Ms}\omega o)$ ……….. (4)

$Vs = [\left(\Delta\omega(s) + \frac{\Delta P_e(s)\omega o}{Ms}\right) Z_1(s) - (\frac{\Delta P_e(s)\omega o}{Ms}) Z_2(s)]$..(5)

Where Z is phase compensation, washout and gain. If Z1 ≠ Z2, will be discuss in special case part-3.

$$Z = K[\frac{STw}{1+STw}][\frac{1+sT_1}{1+sT_2}][\frac{1+sT_3}{1+sT_4}] \quad \text{……………. (6)}$$

Fig.(3) and Fig.(4)shown each input signal pass through signal conditioning alone, and the stabilizer output is the difference between both channels.

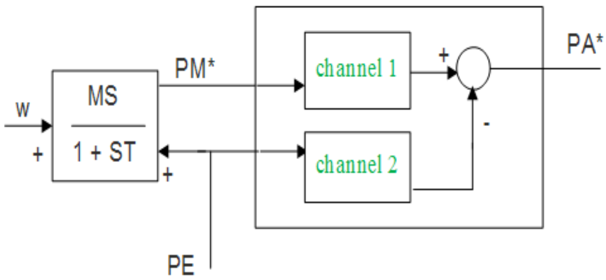


Fig.(3): Principle sketch derivation PPSSmodel

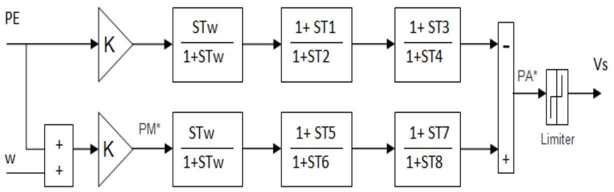


Fig. (4): Type Derivation -PPSSmodel

The advantage of PPSS in Fig. (4) is that, the stabilizer is sourced only from the generator's speed and electrical power output [1]. Rotor speed can be derived from measurement of frequency of a the q-axis voltage (Eq = et + jiXq). For salient pole machines, the synchronous impedance gives the required compensation and in round rotor machines, the chosen of the correct compensating impedance is a little more complex.

2.3. Sytem Tuning Methodology Local Oscillation Mode

When add PSS to the auto channel of excitation system control, the poles and zeros of the PSS affect in the location of the eigenvalues in the S-plane. The aim of the tunning steps are to shift all oscillatory poles to the left of the S-plane. The gains and time constants of lead lag are the main purpose to tuning the PPSS.

The steps are as follows:

1- The parameters of the single machine system, AVR, exciter and operation situation the tuning should be input in orderto calculate the linear transient model. The transfer function of ST1A AVR is

$$\text{AVR}(s) = \frac{\text{Ka}(1+sT_f)}{1+T_b s+T_a T_f s^2} \quad \text{……………………..(7)}$$

2- To improve transient stability and eliminate the steady state error.The first step is to select the suitable phase compensation for the PSS. To illustrate this process to get the maximum damping in the range from 0.2 Hz to 3 Hz, the procedure of compensation should have a phase lag less than 90°, and set PSS parameters according to the lead-lag phases of each frequency.
The lead-lag transfer function in each channel can be set at the same values, and setting is more flexible, and each channel has the same format.The transfer function of a lead-lag controller can be written

$$G_s = k[\frac{1+sT_1}{1+sT_2}][\frac{1+sT_3}{1+sT_4}] \quad \text{……………………..(8)}$$

The PSS in Eq. (8) contain two lead lag compensaters and the purpose is to compensate the phase lag between speed variation and electrical torque [12].Root locus technique based MATLAB are used as tuning tool to get (T_1, T_2, T_3, T_4) [13].

3- The PSS gain could be selected based the plot of the roots of the closed loop system with PSS on the S-plane. For the single machine infinite bus with local mode of oscillations, the gain value should be selected based of many factors [12]

- According to control mode and instability point, the final PSS gain setting with the integral of accelerating power, the designing gain margins are about 20dB.
- The variations in local mode frequency with and without PSS in system should be less than 10%. The PSS gain should be chosen to limit the effect of the stabilizer on the synchronizing torque coefficient.
- The level of torsional signal in the PSS depends on what kind of input signal is used. It is highest in speed transducers, and lowest in electrical power.

4-The range of washout Time constant (T_ω) is between 1 to 20 sec. , and is chosen much largest time constant in signal conditioning [14], and the design of limiter set as a function of generator terminal voltage limit.

3. Simulation Results

We have considered single-machine, slack-bus system. The base MVA is 100, and system frequency is 60 Hz [14] and hydro turbine governor[15]. The system data are given in Appendix A. The system has been simulated with a classical model for the generators in the time domain. The disturbance here is the transient by a 3-phase fault occurring with (t = 11s) and fault is cleared with (t = 11.2s). During simulation time, the system is stable without PSS. The purpose of use excitation system type ST1A is fast response[16]. The parameter of ST1A in Appendix A and was described in [17].

3.1. PSS Gain Test

The aim is to minimize the overshoots and settling time. In Scenario 1, the authors looking for healthy points by test the PSS gain. During the simulation the most influential factor was gains, and Figs (5,6,7). Shows the values of gain set at (3,10,20) respectively, at K=20,we get the maximum damping with the output of stabilizer exceed the limit about (0.38)pu and Fig.(8) shows the V_s was limited. Fig.(5) shows that values of gain with (10) and (20), the oscillations decays faster.

3.2. PSS Phase Compensation Test

In Scenario 2,We chose the weakest point in scenario 1 and try to re-tuning,the gainat $K = 3$, and this value is considered acceptable.Figs (9,10) show the excitation limit ±6.43 is affect in study. And excitation system response in about (3) sec, the output of stabilizer did not exceed to the limit ±0.19.

In Scenario 3,We use $\Delta\omega$ as input signal to channel 2 only, and without electrical power signalby set K=10,and this model was discused in [14].The comparison and discussion will be in the second part.

Scenario 1:

$T_1 = T_3 = T_5 = T_7 = 0.3$

$T_{2,}T_4, T_6, T_8 = 0.03$, T_ω= 10. limiter ±0.19

Transducer time delay TD > 0.03

Scenario 2:

$K_1 = K_2$=3

$T_1 = T_5$=0.4 , $T_3 = T_7$= 0.3

$T_2 = T_6$ = 0.12, T_4=T_8 =0.1 , T_ω=10, limiter ±0.19

Transducer time delay TD > 0.03

Scenario 3:

$K_1 = 0$, K_2=23

$T_5 = T_7 = 0.06$, $T_6 = T_8$ = 0.03, limiter ±0.19

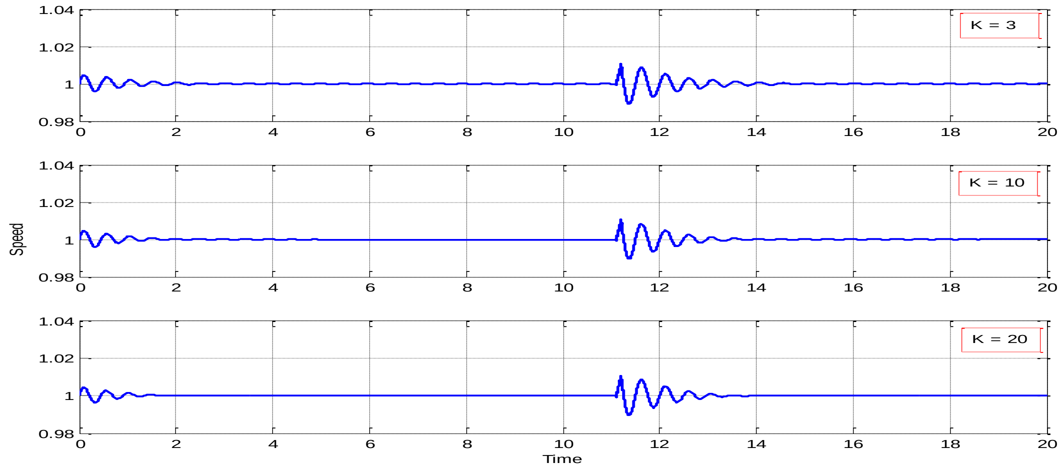


Fig.(5): Scenario 1- Speed in (pu).

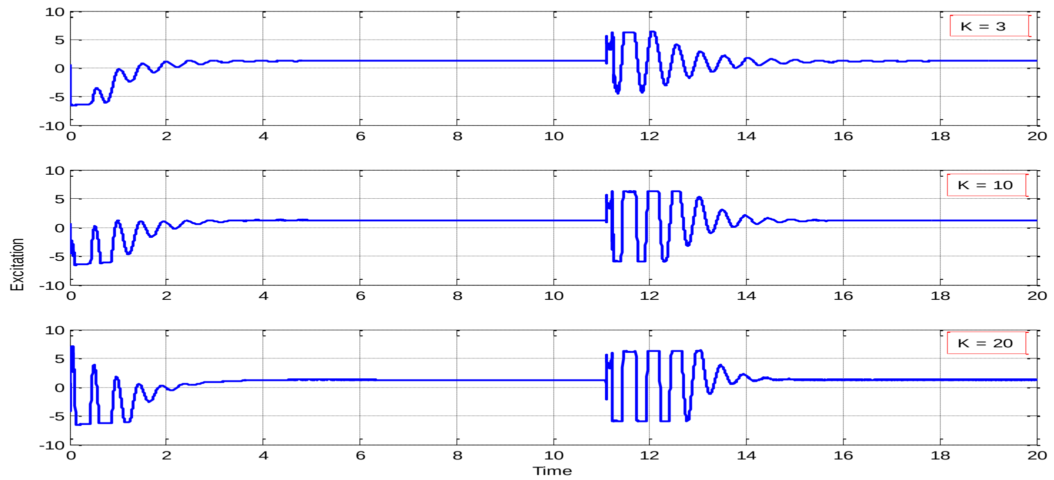


Fig. (6):Scenario 1- Excitation output in (pu).

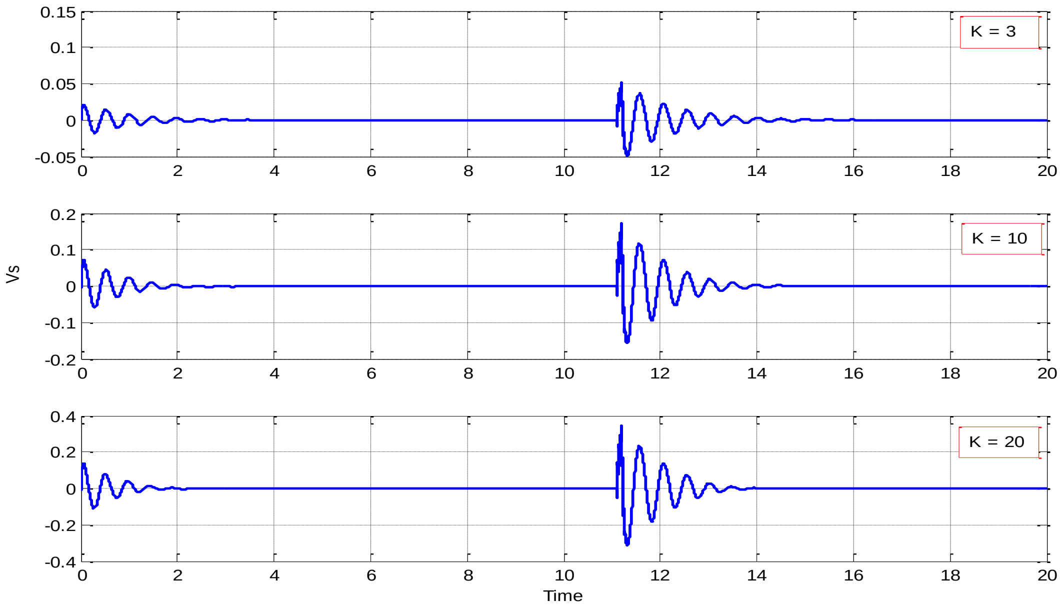


Fig.(7):Scenario 1-Stabilizer output without limiter

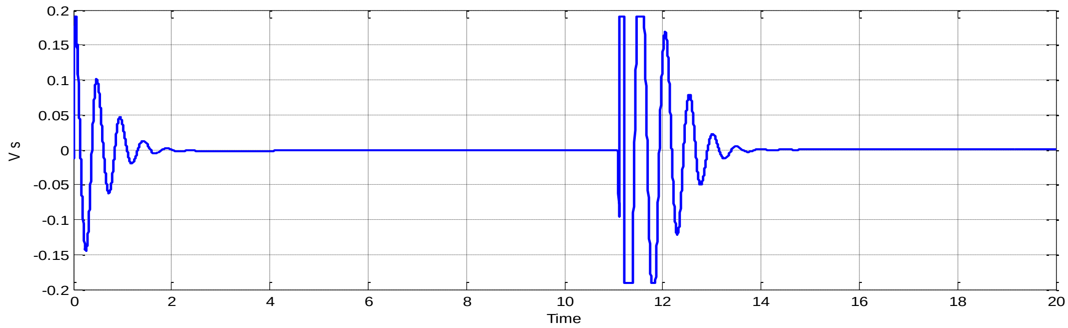


Fig.(8): Scenario 1-Stabilizer output in (pu) with $K = 20$ and limiter ± 0.19

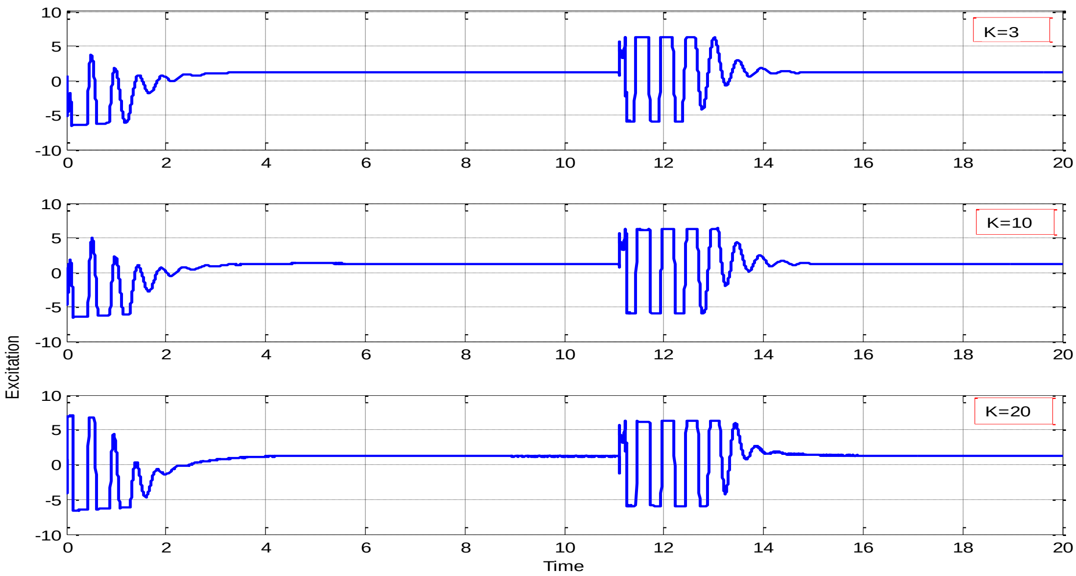


Fig.(9): Scenario 2-Excitation output in(pu)

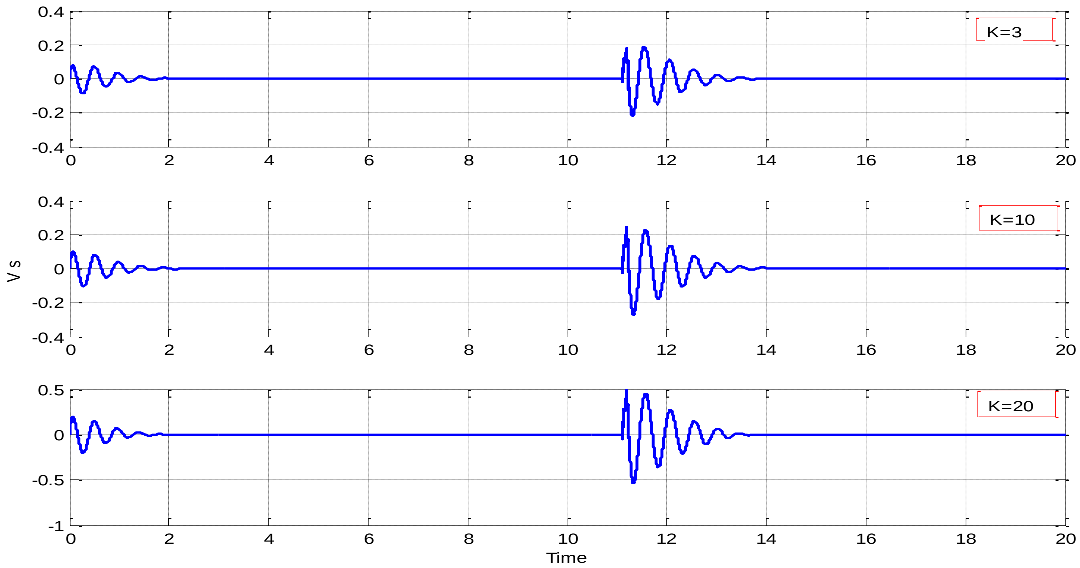


Fig.(10): Scenario 2-Stabilizer output in (pu) without limiter

Part 2 - PPSS vs MB-PSS, PSS4B, Delta w PSS and Delta Pa PSS

4. Multi-Machine System

The main target of this section is to study the effect of the ST1A excitation system. Types of PPSS, MB-PSS PSS4B, Delta w PSS and Delta Pa PSS are chosen. The aim of performing transient stability on the power system is to study the stability of a system under disturbances (3-phase fault).

We have considered multi-machine, nine-bus system shown in Fig. (11). The base MVA is 100, and system frequency is 60 Hz. The system data are given in Appendix B. The system has been simulated with a classical model of the generators. The disturbance here is the transient by a 3-phase fault occurring at approximately in the middle of line 5–7 with (t = 11s), and cleared at (t = 11.3s).The excitation system models, AVR and PSS were compared and these models are shown in Table 1. We looking for the best response situation and optimal points. The fault in the system may be going to instability and the units will losses the synchronism. If the system can keep synchronism until the fault is cleared, then the all system will be in stable condition. Through the instability not only the swing in rotor angle for the final position continue increasing, but also the variation in angular speed. In such a case the system will not come to its final position. The unbalanced status or transient condition may go to instability where the units in the power system fall out of synchronism and may be all the power system going to black-out.

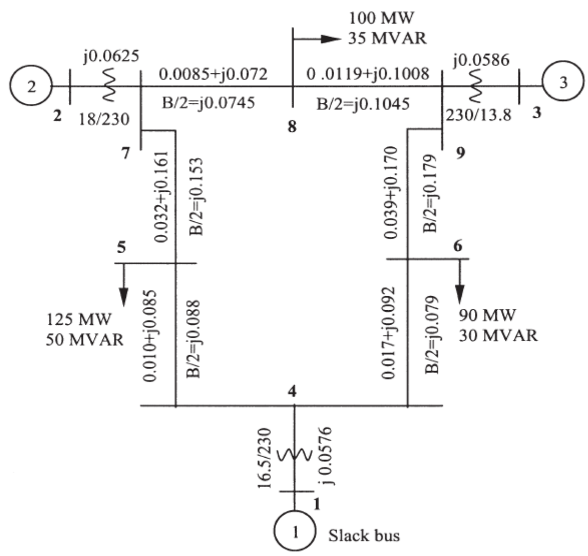


Fig. (11): Multi-machine, nine-bus system

Table 1. Models and Cases

<table>
<tr><td colspan="2">Case 1: Type ST1A Without Stabilizer</td><td>Case 2: Type ST1A model and Type Delta w PSS</td></tr>
<tr><td colspan="2">Case 3: Type ST1A Type MB-PSS</td><td>Case 4: Type ST1A model and Type Kundur Delta Pa PSS</td></tr>
<tr><td colspan="2">Case 5:Type ST1A model and Type PPSS</td><td>Case 6: PPSS Scenario 3</td></tr>
<tr><td>For All Cases</td><td>fault duration time, is 0.3 second. Cycles =660 -678</td><td>fault resistance0.001
Fault Location 40 % between bus 5-7</td></tr>
</table>

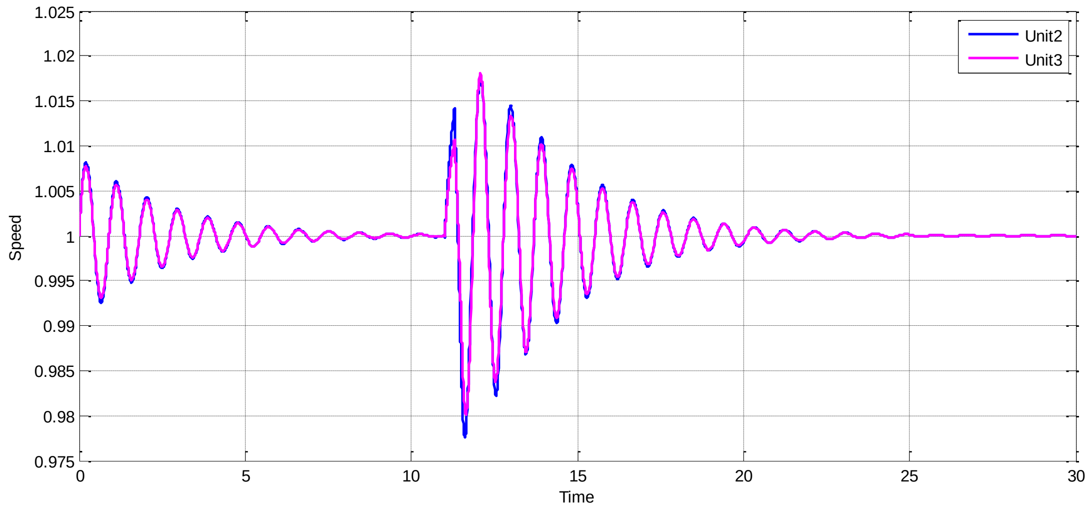
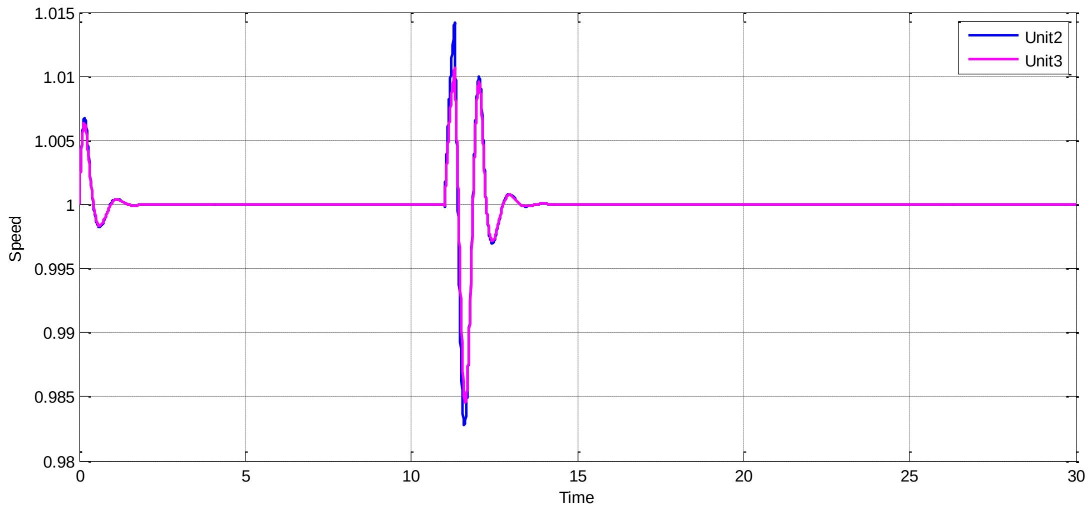


Fig. (12): Case 1-Speed without PSS in (pu)



Fig, (13): Case2-speed in (pu)

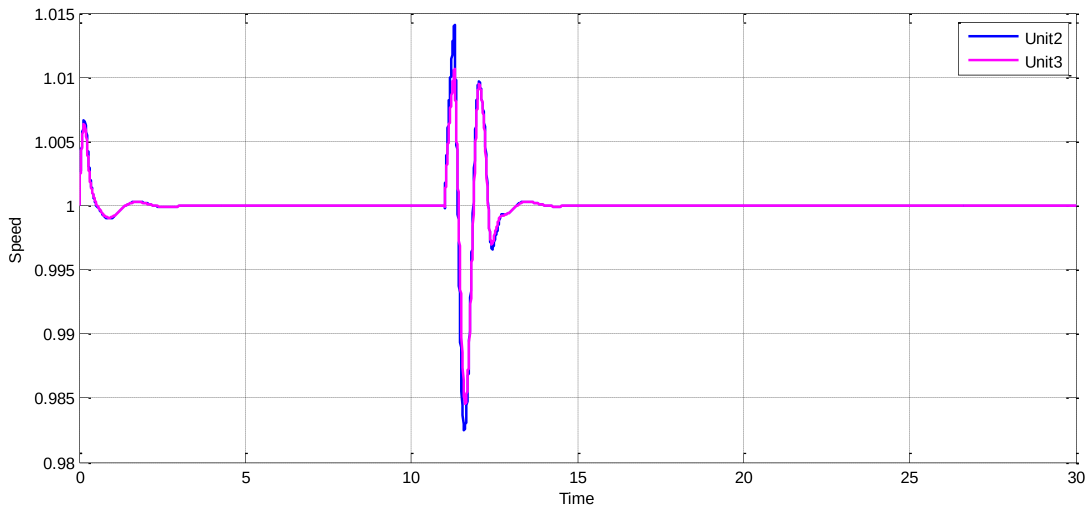


Fig. (14): Case3-speed in (pu)

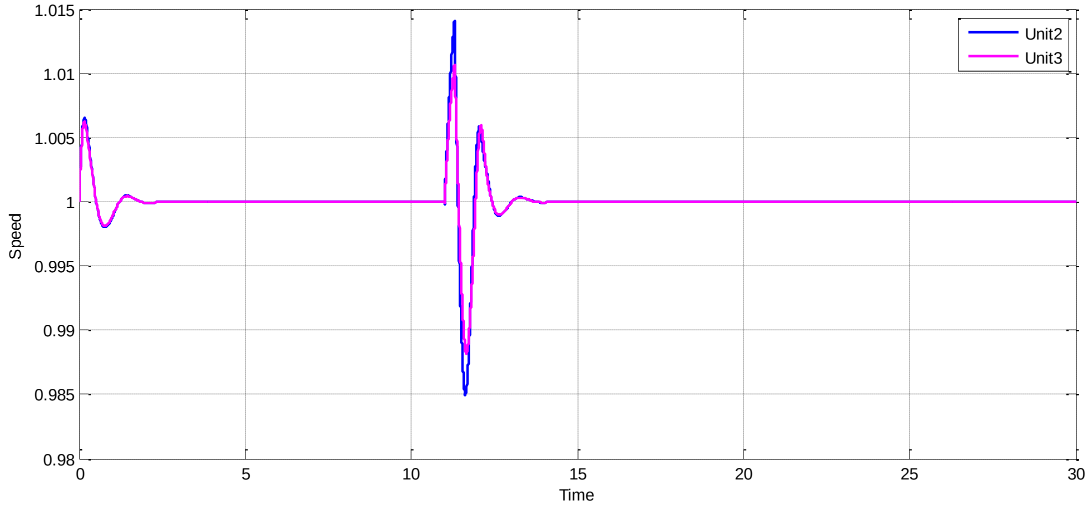


Fig. (15): Case4-Speed in (pu)

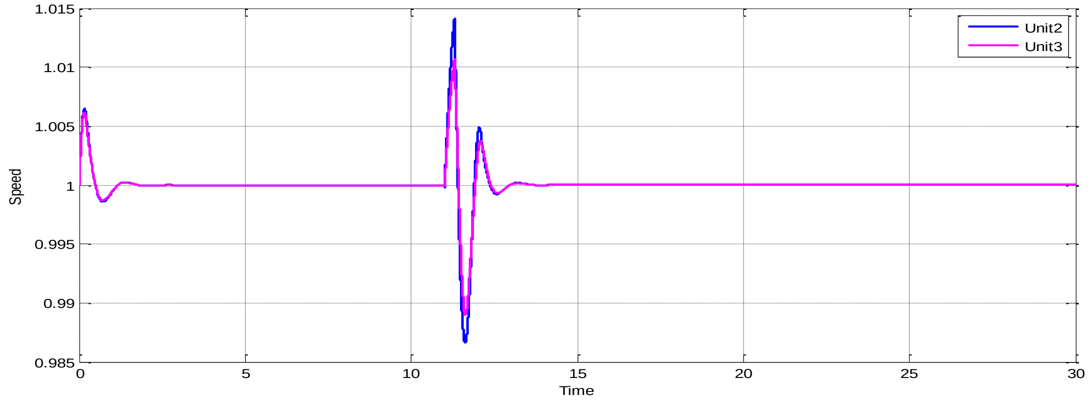


Fig. (16): Case5-Speed in (pu)

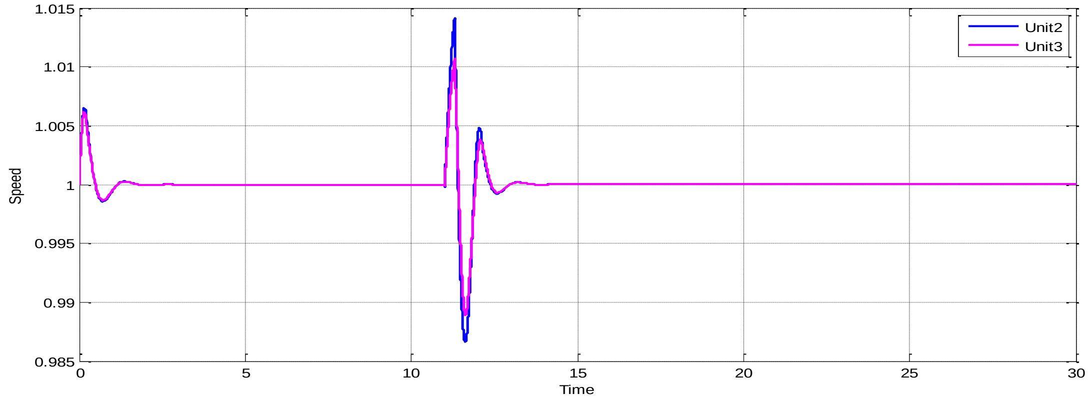


Fig. (17): Case6-Speed in (pu)

5. Simulation Results

Case 1: Form Fig. (12) noted that, the setling time is about (15)sec. and the system can maintain synchrounism.

Case 2: From Fig. (13) noted that, the settling time is about 2 sec. and the overshoot is about 1014 pu.

Case 3: The excitation sytem ST1A with MB-PSS &PSS4B have the settling time is about (2) sec. Fig. (14) shows unit (2) havs higher oscillation than unit (3).

Case 4: The excitation sytem ST1A model with Kundur PSS the settling time about (2) sec. Fig.(15) shows the unit (2) havs higher oscillation than unit (3).The overershoot for unit (2) is (1.014 to 0.987) pu,and for unit (3) is 1.01 to 0.985 (pu) and it is clear that minimization of second oscillations between 1.005 to 1(pu)

Case 5: The excitation system ST1A model with proposed PPSS the settling time is about (2) sec. Fig. (16) shows the unit (2) havs higher oscillation than unit (3).The overshot for unit (2) is (1.014 to 0.987) pu,and for unit 3 is (1.01 to 0.985)pu. It is obvious that minimization of second oscillations between (1.005 to 1) pu for unit 2 and (1.004 to 1) pu for unit (3). The case 5 showsthe proposed PSS has the best output response compared to other cases.

Case 6: Almost the same result in case 5, it is so obvious in fig.(16) and (17).

Part 3 - THE FLEXIBILITY OF PPSS MODELS FOR STABILIZING SYSTEM OSCILLATIONS

The PID-PPSS is Proportional Integral Derivative Power System Stabilizer in form of integral of accelerating power. The aim is to explore the flexibility of PPSS for local oscillations that occur in power system. The study system consists of a one-machine with slack bus system with AVR IEEE ST1A excitation systems.

6. Local Oscillation Mode

6.1. PID-PSS Block

The PID-PSS is shown in Fig.(18). The input of the PID stabilizer is the speed deviation ($\Delta\omega$) of which the integral is the torque angle ($\Delta\partial$).[13] From Fig.(18),$V_S$can be written as:

$$VS = [K_P + \frac{K_I}{s} + sK_D]\Delta\omega(s) \qquad (9)$$

PID controller stabilizes the gain, reduces the steady state error and peak overshoot of the system. Fig. (18) shows the systemwith PSS based PID controller.

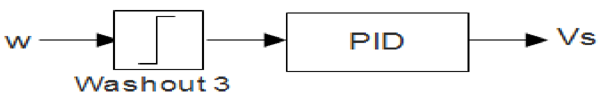


Fig. (18): Type PID-PSSmodel

6.2. PID-PPSS Model

According to the Fig. (4) Type Derivation PPSSmodel, we add PID controller to $\Delta\omega$ input signal channel 2 , as it is shown in the Fig. (19).

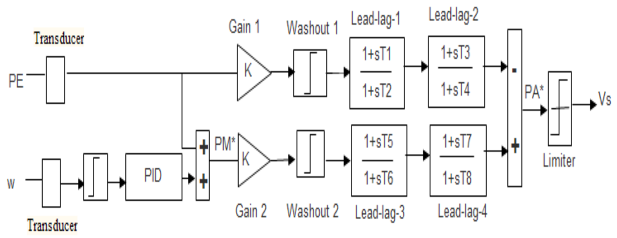


Figure 19.PID-PPSS

we can re-write Equation (5) forrequirements ofpart 3 as

$$Vs = [(F\,\Delta w(s) + \frac{\Delta P_e(s)\omega o}{Ms})Z_1(s) \;-(\frac{\Delta P_e(s)\omega o}{Ms})Z_2(s)]$$

(10)

Where F is The function of a PID controller.

$$F = [K_P + \frac{K_I}{s} + SK_D] \qquad (11)$$

7. Simulation Results

7.1. Scenario 1, Washout Time ConstantTest

We have considered single-machine, slack-bus system in part-1. The aim is to minimize the overshoots and eliminate steady state error. According to the Scenario 1-part-1, we looking for healthy points by test the washout time constant and parameters of PID. During the simulation the most influential factor was washout, and Fig. (20) shows the values of gain set with (3). The value of washout time constant TW3 >TW1=TW2, we get the maximum damping with the output of stabilizer exceed to the limit about 0.49(pu) and Fig. (20) shows the V_S is limited, and the values of gain with (3) lead the oscillations to decays faster. The parameters of PID is P= 9.42358890, I = 24.02577569 and D =0. The system tuning by PI controller and Fig. (21) show the respone time PI-PSS, and Fig. (22) show the Bode PI-OZAB.

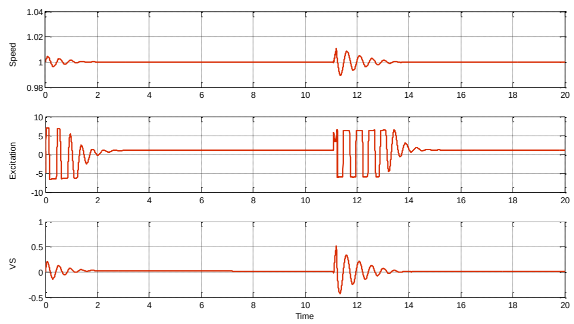


Fig. (20): PI-PPSS Scenario 1 with gain=3

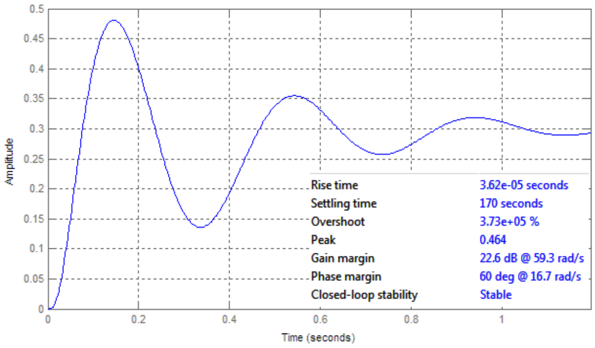


Fig. (21): Respone time PI-PPSS Scenario 1 with gain=3

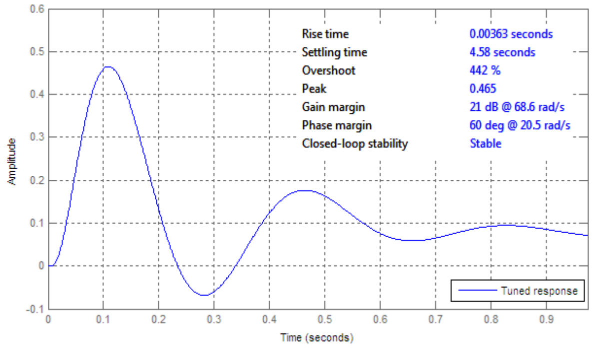


Fig (24): Respone time PID-PPSS special case with gain=3

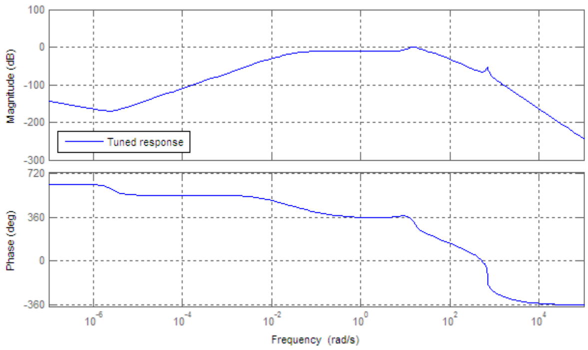


Fig. (22): Bode PI-PPSS Scenario 1 with gain=3

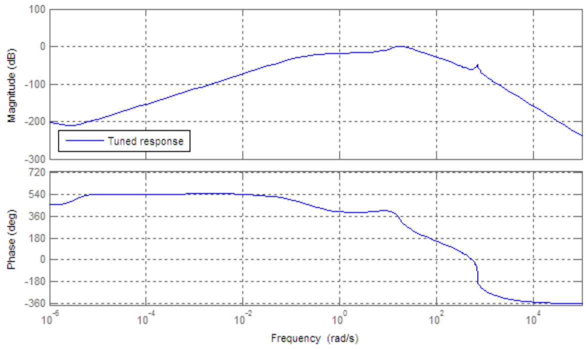


Fig. (25): Bode PID-PPSS special case with gain=3

7.2. Special Case, Z1 ≠Z2

The parameters of PID is P= 6.266191381, I = 6.0227547429 and D = 0.7767887632. One set of thelead-lag phases for eachchannels in Fig. (19), and the parameters are T1=0.04. T2=0.02, T3=0.06, T4=0.03, washout time constant TW3 <TW1=TW2, and TW1=TW2=10 TW3=8, K1=K2=3. The results shown in Fig. (23) and The system tuning by PID controller and Fig. (24) shows the respone time of PID-OZAB, and Fig. (25) shows the Bode plot of PID-OZAB.

We get the maximum damping with the output of stabilizer exceed to the limit about 0.5 p.u and Fig. (23) shows the V_S is limited, and that values of gain with 3, the oscillations is decays faster.

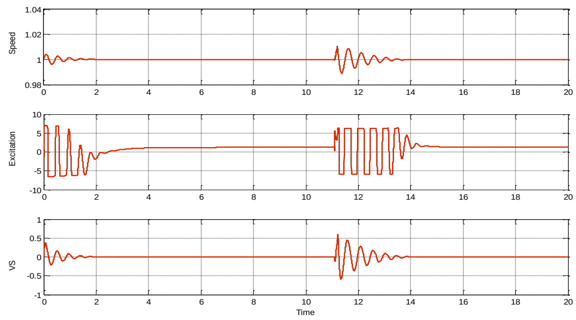


Fig. (23):PID-PPSS special case with gain=3

8. Conclusions

Power systems could loose synchronism and experience system separation if the low-frequency inter-area modes of oscillations are not damped efficiently. A conventional power system stabilizer can provide adequate damping for a limited range around its tuning point. This paper has proposed the design and tuning of a new power system stabilizer (PPSS). In part-1, during the test, the design proved good stabilized. It was found that the PSS output signal was stabilized when T_1, T_3, T_5 and T_7were set at (0.06) sec., and T_2, T_6 and T_8were set at (0.03) sec. with $K = (20)$.The goal is trying to balance between phase compensation and gain and to find out and observe the effect of the system itself. The range of gain from (10 to 20) are acceptable values, and the relationship between the lead and lag time constants during tuning range from (2 to 5) were acceptable.

In the second part the comparison between the proposed technique and various types of PSSs in multi-machine power system shown the robustness of proposed technique to damping the inter-are modes of oscillations.

Also, the flexibility of PPSS models for stabilizing power system oscillations by additional control such as PI and PID.

Scientific field is open for researchers in the sensitivity of PSS and location issue.

APPENDIXES

Appendix A. System Modelsparameter

Table A1. Generator Data

Rated MVA	247.5
kV	16.5
H (s)	3.2
Power factor	1.0
Type	Hydro
Speed	180 r/min
xd	0.8958
x'd	0.1198
Xd''	0.252
xq	0.8645
x'q	0.1969
*x*l (leakage)	0.0625
Tdo	6.00
T 'qo	0.535

Table A2. *Data for a Type ST1A Excitation System*

K_A= 210	T_{B1}= 0	K_F= 0
T_A= 0	V_{RMAX}= 6.43	T_F= 0
T_C= 1.0	V_{RMIN}= -6.0	KLR= 4.54
T_B= 1.0	K_C= 0.038	ILR= 4.4
T_{C1}= 0		

Appendix B. System Modelsparameter

Table B1. Generators Data

Gen no.	1	2	3
Rated MVA	247.5	192.0	128.0
kV	16.5	18.0	13.8
H (s)	23.64	6.4	3.01
Power factor	1.0	0.85	0.85
Type	Hydro	Steam	Steam
Speed	180 r/min	3600 r/min	3600 r/min
xd	0.1460	0.8958	1.3125
x'd	0.0608	0.1198	0.1813
xq	0.0969	0.8645	1.2578
x'q	0.0969	0.1969	0.25
*x*l (leakage)	0.0336	0.0521	0.0742
Tdo	8.96	6.00	5.89
T 'qo	0	0.535	0.600

Table B2. Type Delta w PSS

T_1= 0.05	V_{SMIN} = -0.15
T_2= 0.02	V_{SMAX} =0.15
T_3= 3	K_S=30
T_4=4.5	T_w= *10*

Table B3. Simplified settings MB-PSS PSS4B

K_S= *10*= 1	V_{LMAX}=*.075*
F_L= 0.2	V_{IMAX}=*.15*
K_L= 30	V_{HMAX}=*.15*
T_w= *10*= 1.25	V_{SMAX}=*.15*
F_I= 40	K_H= 160
F_H= 12	

Table B4. Type Delta Pa PSS

T_1= 0.06	V_{SMIN} = -0.15
T_2= 1	V_{SMAX} =0.15
T_3= 0	K_S=3.1
T_4= 0	T_w= *1*

NOMENCLATURES

D : Damping coefficient
Vs : The stabilizer output
Pa : Accelerating power
P_E : Electrical Power
P_M : Mechanical Power
P_M^* : Derivation from PE and w
w : Rotor Speed
H : Inertia constant
M = 2H
s = d/dt
Xd, Xq : The d-,q-axis synchronous reactance
Xd', Xq' : The d-,q-axis transient reactance
Td', Td'' : d-axis transient &subtransient short-circuit time constant
$Tq'', Tq0''$: q-axis subtransient short-circuit time, q-axis subtransient open-loop time constant

References

[1]. F.P. deMello, L.N. Hannett, and J.M. Undrill, Practical Approaches to Supplementary Stabilizing from Accelerating Power," IEEE Trans., Vol. PAS-97, pp. 1515-1522, September/October 1978.

[2]. W. Hu ,J. Liang, Y. Jin and F. Wu "Model of Power System Stabilizer Adapting to Multi-Operating Conditions of Local Power Grid and Parameter Tuning" MPDI, June 2018.

[3]. T Hussein, A Shamekh "Adaptive rule-base fuzzy power system stabilizer for a multi-machine system" 21st Mediterranean Conference on Control and Automation, 1514-1519, Greece June 2013.

[4]. S. Ramamoorthy"Design and Implementation of Fuzzy Logic Based Power System Stabilizers" Middle-East Journal of Scientific Research 20 (11): 1663-1666, 2014.

[5]. Faisal Jamsh and J. Igbal "Design of an Adaptive Power System Stabilizer using Robust System-Response Prediction" IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy, 2020.

[6]. J. N. Rai, Ram Bhagat "Enhancement of power system damping using Fuzzy Power System Stabilizer" IJAPIE,Vol 1(2), 22-27, 2016

[7]. Y. A. Al-Turki, A.-F. Attia, H. F. Soliman" Optimization of Fuzzy Logic Controller for Supervisory Power System Stabilizers" ActaPolytechnica Vol. 52 No. 2/2012.

[8]. E. Nechad M. Naguib N. Essounbouli A. Hamzaoui" Adaptive Fuzzy Sliding Mode Power System Stabilizer Using Nussbaum Gain" International Journal of Automation and Computing, Volume 10, Issue 4, pp 281–287, August 2013.

[9]. K.R.Sudha and I.E.S.Naidu " Stability Enhancement of Power System Using Type-2 Fuzzy Logic Power System Stabilizer "International Journal of Fuzzy Logic Systems (IJFLS) Vol.6, No.1, January 2016

[10]. H. Boules, S. Peres, T. Margotin, M.P. Houry "Analysis And Design of A Robust Coordinated AVR/PSS" IEEE Transactions on Power Systems, Vol. 13, No. 2, pp. 568 -575 ,May 1998

[11]. Watson, W., Manchur, G., "Experience with Supplementary Damping Signals for Generator Static Excitation Systems", IEEE Trans. PAS, pp. 199-203, January/February 1973.

[12]. Bayne, J.P., Lee, D.C., Watson, W., "A Power System Stabilizer Stabilizing Signal for Thermal Units Based on Derivation of Accelerating Power", IEEE Trans. paper F 77-137-3, IEEE Winter Meeting, January 1977.

[13]. J.P. Bayne, D.C. Lee, W. Watson. "A Power System Stabilizer for Thermal Units Based on Derivation of Accelerating Power". IEEE Transaction Vol PAS-96, pp 1777-1783, Dec. 1977.

[14]. D.C. Lee, R.E. Beaulieu. J.R.R. Service, "A Power System Stabilizer Using Speed and Electrical Power Inputs - Design and Field Experience, IEEE .

[15]. A. Murdoch, S. Venkataraman "*Integral of accelerating power type PSS part 1-theory,design, and tuning methodology*" *IEEE Transactionson Energy Conversion*, vol. 14, pp. 1658, 1999.

[16]. R. C. Dorf, S. Jung, J. Dawes, and L. Ng "A S-Plane Analytic Technique for Lead-Lag Controller Design" Proceeding of the American Control Conference Seattle. Washington, pp. 2227-2228, June 1995.

[17]. P. Kundur, "Power System Stability and Control". McGraw-Hill, 1994.

[18]. IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, "Hydraulic Turbine and Turbine Control Models for Dynamic Studies," IEEE® Transactions on Power Systems, Vol.7, No.1, , pp. 167-179, February, 1992.

[19]. F. Zhang, & Z. Xu,, "Effect of exciter and PSS on SSR damping". *In Proceedings ofPower Engineering Society General Meeting*, pp. 1-7. Tampa, FL: IEEE, 2007.

[20]. IEEE Standard 421.5. IEEE Recommended practice for excitation system models for power system stability studies, 2006.

BIOGRAPHIES

SALIH MOHAMED ABDALLA was born in Benghazi Libya, on February 29, 1976. He received the B.Sc from High Institute of Electrical and Electronics Technology in 1998 and MSc. degrees in Electrical Engineering in 2015 from Near East University, Department of Electrical and Electronic Engineering.In 2009 he becamehead ofthe Department of Electrical Engineeringat Sarir gas turbine power plant,general electric company of LibyaGECOLHisresearch interest in the area of power system analysis, electrical machines, network theory and control systems.

Tawfiq Hussein Elmenfy, was born in Tripoli Libya, on 1/1/1969. He received his B.Sc degree in electrical engineering from Bright Star University of technology, Brega, Libya, in 1990 and From 1991 up to 2003, he has been with General Electricity Company of Libya (GECOL).

He received MSc & PhD degrees in electrical engineering from faculty of engineering, Cairo University, Cairo, Egypt, in 2005, 2009 respectively. Currently, he is Dean of Faculty of Engineering, University of Benghazi. Area of interesting, power system stability and control, adaptive control system, Fuzzy logic control system.