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The Effect of Power System Stabilizer on Small Signal Stability in Single-Machine Infinite-Bus

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Abstract: Power system oscillations are a characteristic of the system and they are inevitable. Power System Stabilizer (PSS) can help the damping of power system oscillations. This controller has become an accepted solution for oscillatory instability problems and thus improves system stability. Small signal stability is the system ability to maintain synchronism when a small disturbance occurs. This study provides an analysis of the small signal stability of the power system under different system conditions and operating loads. Several simulations have been done to show the effect of the line parameters on the power system oscillations stability.

Key words: Small signal stability, transmission line model, power system stabilizer, dynamic analysis

INTRODUCTION

Power systems are capital intensive big complex systems. In general in a modern interconnected power system, transmission lines are under-utilized and uncontrolled. That are more heavily loaded then ever before to meet the growing demand. The dynamic stability categorized two sub-classes: small signal stability and transient stability. Small signal stability analysis using linear techniques provides valuable information about the inherent dynamic characteristics of the power system and assists in its design. Among the various methods of damping of power system oscillations, excitation control is one of the most common and economical method. PSS is added to excitation systems to enhance the damping of electric power systems during low frequency oscillations (Gupta *et al*., 2003).

The PSS is a control device to improve the stability of the system by introducing a supplementary signal to an Automatic Voltage Regulator (AVR). The AVR is an exciter control device which maintains the terminal voltage of the generator at a constant level. A dynamical model of PSS is included to investigate the effect in providing positive damping to overcome the undamped electromechanical modes. In some cases, PSSs are used as an additional control feature so that excitation system with a high response may be used without compromising the small signal instability of the generators.

Power system stabilizers have been shown to be effective in stabilizing the modes where there are different oscillation frequencies. PSS have been used for many years to add damping to electromechanical oscillations. To design a PSS with better performance, several approaches have been applied to PSS design problem and many useful results have been published. These include pole placement, H_∞ optimal control, adaptive control, variable structure control and different optimization and artificial intelligence techniques (Abdel-Magid *et al*., 1999; Shoulaie *et al*., 2009; Gibbard *et al*., 2004; Hasanovic *et al*., 2004).

According to Lee and Park (1998), to tackle the problem of the unmeasurable state variables in the conventional SMC, three kinds of controllers have been developed and the PSS has been applied for a small-signal stability study. In (Mrad *et al*., 2000) an adaptive fuzzy synchronous machine PSS that behaves like a PID controller for faster stabilization of the frequency error signal and less dependency on expert knowledge is proposed. In (Shamsollahi and Malik, 1999) an indirect adaptive PSS is designed using two input signals, the speed deviation and the power deviation to a neural network controller. In (Nambu and Ohsawa, 1996) a similar linearization method without having to explicitly identify internal rotor angle and resort to a single machine setting is described. In (Jiang, 2009) the dynamic characteristics of the proposed PSS based on synergetic control theory are studied in a typical single-machine infinite-bus power system and compared with the cases with a conventional PSS and without a PSS. Two techniques for the tuning of PSS parameters based on the integral of squared error criterion and the phase compensation criterion are studied by Bhattacharya *et al*. (1997).

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Modern power systems are highly complex and strong non-linearity and their operating conditions can vary over a wide range. Operating conditions of a power system are continually changing due to load patterns, electric generation variations, disturbances, transmission topology and line switching.

For small signal stability, the linearized system model is acceptable. The dynamic equations governing the performance of the single machine infinite-bus are non-linear. They are linearized about an operating point for small signal stability studies.

This study presents a newly developed linearized block diagram of a power system with a PSS which represents the dynamics of power system. The analysis of the performance of PSS under different system conditions and operating loads was described.

The simulation results show the effects of the transmission line parameters and line model on small signal stability.

MATERIALS AND METHODS

Transmission line model: A transmission line is a crucial link between power generation units and distribution units in consumption areas. In this study, it is considered that the transmission line parameters are uniformly distributed and the line can be modeled by a two-port, four-terminal networks as shown in Fig. 1.

Figure 1 shows the actual line model where U_{SE} and I_{SE} are the sending-end voltage and current and U_{RE} and I_{RE} are the receiving-end voltage and current. The relation between the Sending End (SE) and Receiving End (RE) quantities can be written as (Chen *et al*., 2006):

$$\begin{bmatrix} \bar{U}_{SE} \\ \bar{I}_{SE} \end{bmatrix} = \begin{bmatrix} \bar{A} & \bar{B} \\ \bar{C} & \bar{D} \end{bmatrix} \begin{bmatrix} \bar{U}_{RE} \\ \bar{I}_{RE} \end{bmatrix} \quad (1)$$

Where generalized circuit constants (ABCD) of a line of length a are parameters that depend on the transmission line constants and given by:

$$\begin{cases} \bar{A} = \bar{D} = \cosh(\gamma a) \\ \bar{B} = \bar{Z}_C \sinh(\gamma a) \\ \bar{C} = \dfrac{1}{\bar{Z}_C} \sinh(\gamma a) \end{cases} \quad (2)$$

Where:
Z_C = Characteristic impedance of the line
γ = The line propagation constant

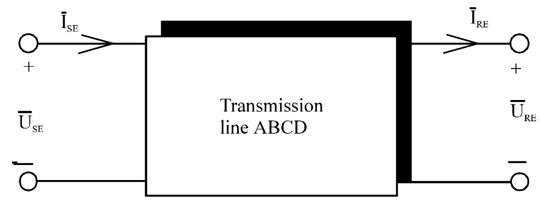

Fig. 1: Representation of two-port network

$$\begin{cases} \bar{Z}_C = \sqrt{\dfrac{\bar{z}}{\bar{y}}} \\ \bar{\gamma} = \sqrt{\bar{z}\,\bar{y}} \end{cases} \quad (3)$$

Where z is series impedance per unit length/phase and y is shunt admittance of per unit length/phase. The maximum power transferred by a line can be increased by decreasing either the characteristic impedance or electrical length or both. If A D - B C = 1 and A = D, the currents at the SE and RE of the line can be written as:

$$\begin{cases} \bar{I}_{SE} = \dfrac{\bar{A}}{\bar{B}} \bar{U}_{SE} - \dfrac{1}{\bar{B}} \bar{U}_{RE} \\ \bar{I}_{SR} = \dfrac{1}{\bar{B}} \bar{U}_{SE} - \dfrac{\bar{A}}{\bar{B}} \bar{U}_{RE} \end{cases} \quad (4)$$

Where, $A = A\angle\alpha$ and $B = B\angle\beta$. The total series inductance determines primarily the maximum transmissible power at a given voltage. The shunt capacitance influences the voltage profile and thereby the power transmission along the line. Reactive power cannot be transmitted over long distance; therefore reactive compensation has to be effected by using various devices. The parameter and variable of the transmission line such as line impedance, terminal voltage and voltage angle can be controlled by FACTS devices in a fast and effective way.

Study system and mathematical model: A simplified dynamic model of power system is considered in this study. As shown in Fig. 2, this model is consisted a single synchronous generator including the voltage regulator and exciter connected through a transmission line to very large network approximated by an infinite bus. Synchronous generators are normally equipped with AVR which continually adjust the excitation so as to control the armature voltage. The excitation voltage E_F is supplied the exciter and is controlled by the AVR. The torque angle δ is defined as the angle between the infinite bus voltage, U_B and the internal voltage of quadrature axis, E'_q. The equal parameters between bus T and bus B are A, B, C and D, so that:

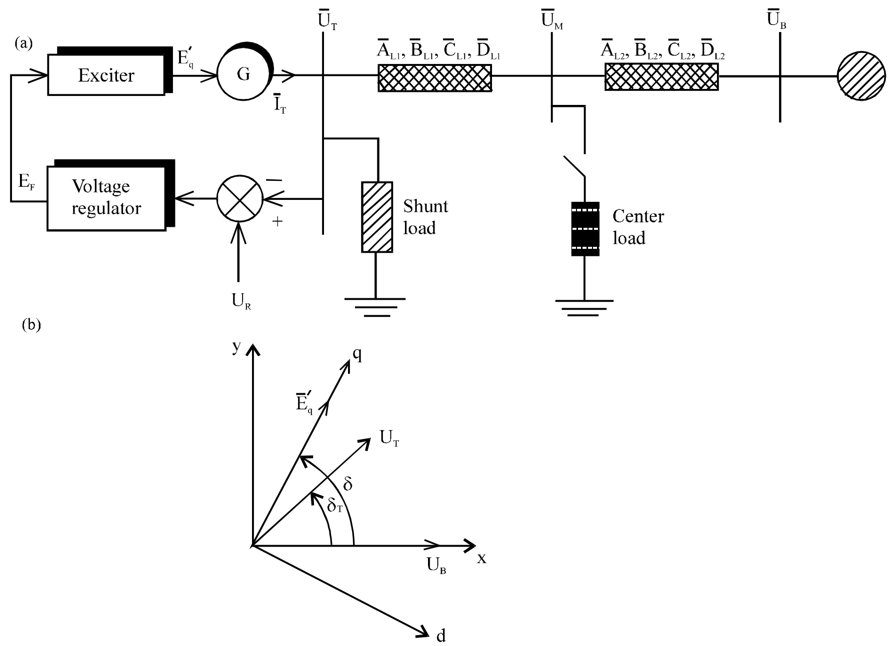

Fig. 2: A single machine infinite bus power system with phasors diagram (a) Power system configuration (b) Voltage phasor diagram

$$\begin{bmatrix} \bar{A} & \bar{B} \\ \bar{C} & \bar{D} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \bar{Y}_L & 1 \end{bmatrix} \begin{bmatrix} \bar{A}_{L1} & \bar{B}_{L1} \\ \bar{C}_{L1} & \bar{D}_{L1} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \bar{Y}_C & 1 \end{bmatrix} \begin{bmatrix} \bar{A}_{L2} & \bar{B}_{L2} \\ \bar{C}_{L2} & \bar{D}_{L2} \end{bmatrix} \quad (5)$$

Where Y_L is admittance of shunt load in generator bus, Y_L is admittance of shunt load in bus M and $A_{L1}B_{L1}C_{L1}D_{L1}$and $A_{L2}B_{L2}C_{L2}D_{L2}$ are line parameters in section 1 and 2. The stator algebraic equations are expressed as:

$$\begin{cases} U_d = U_T \sin\delta_i = X_q i_q - R_A i_d \\ U_q = U_T \cos\delta_i = E'_q - X'_d i_d - R_A i_q \end{cases} \quad (6)$$

Where:

δ_i	=	The angle between the terminal voltage (U_T) and the internal voltage
X_d	=	The direct axis reactance
X'_d	=	The direct axis transient reactance
X_q	=	The quadrature reactance
R_A	=	Armature resistance
i_d and i_q	=	d- and q-axes stator current

The electric power is:

$$P_E = (X_q - X'_d) i_d i_q + E'_q i_q \quad (7)$$

The network constraint equation for the system is:

$$\bar{U}_T = \frac{1}{\bar{A}} \bar{U}_B + \frac{\bar{B}}{\bar{A}} \bar{I}_T \quad (8)$$

Resolving into d and q components gives:

$$u_d = \frac{U_B}{A} \sin(\delta + \alpha) + \frac{B}{A} i_d \cos(\beta - \alpha) - \frac{B}{A} i_q \sin(\beta - \alpha) \quad (9)$$

$$u_q = \frac{U_B}{A} \cos(\delta + \alpha) + \frac{B}{A} i_d \sin(\beta - \alpha) + \frac{B}{A} i_q \cos(\beta - \alpha) \quad (10)$$

The armature current components are:

$$i_d = Y_d E'_q - \frac{1}{Z_E^2} \frac{U_B}{A} \left[\frac{B}{A} \sin(\delta + \beta) + X_q \cos(\delta + \alpha) \right] \quad (11)$$

$$i_q = \frac{1}{Z_E^2} \frac{U_B}{A} \left[X'_d \sin(\delta + \alpha) - \frac{B}{A} \cos(\beta + \delta) \right] + Y_q E'_q \quad (12)$$

Where:

$$Y_d = \frac{X_1 \cos\alpha - R_2 \sin\alpha}{Z_E^2} \quad (13)$$

$$Y_q = \frac{X_2 \sin\alpha + R_1 \cos\alpha}{Z_E^2} \quad (14)$$

$$Z_E^2 = R_{E1} R_{E2} + X_{E1} X_{E2} \quad (15)$$

$$R_{E1} = B\cos\beta - X_d^{'} D\sin\alpha + R_A D\cos\alpha \tag{16}$$

$$R_{E2} = B\cos\beta - X_q D\sin\alpha + R_A D\cos\alpha \tag{17}$$

$$X_{E1} = B\sin\beta + X_q D\cos\alpha + R_A D\sin\alpha \tag{18}$$

$$X_{E2} = \frac{B}{D}\sin\beta + X_d^{'}\cos\alpha + R_A\sin\alpha \tag{19}$$

$$\begin{aligned} Z_E^2 = (\frac{B}{D})^2 + \frac{B}{D}(X_d^{'} + X_q)\sin(\beta - \alpha) \\ + X_d^{'} X_q + 2R_A\frac{B}{D}\cos(\beta - \alpha) + R_A^2 \end{aligned} \tag{20}$$

The initial torque angle, currents and voltages of the system in the steady state are δ_o, I_{To}, I_{do}, I_{qo}, U_{To}, U_{do} and U_{qo}. The variation of the d and q armature windings is:

$$\Delta i_d = Y_d\,\Delta E_q^{'} + F_d\,\Delta\delta \tag{21}$$

$$\Delta i_q = Y_q\,\Delta E_q^{'} + F_q\,\Delta\delta \tag{22}$$

Where:

$$F_d = -\frac{U_B}{Z_E^2}(R_{E2}\cos\delta_o - X_{E1}\sin\delta_o) \tag{23}$$

$$F_q = \frac{U_B}{Z_E^2}(R_{E1}\sin\delta_o + X_{E2}\cos\delta_o) \tag{24}$$

The non-linear differential equations of the single machine infinite bus power system are:

$$\frac{d}{dt}\delta = \omega_o\,\omega \tag{25}$$

$$\frac{d}{dt}\omega = \frac{1}{2H}(P_M - P_E - K_D\,\omega) \tag{26}$$

$$\frac{d}{dt}E_q^{'} = \frac{1}{T_{do}^{'}}[E_F - E_q^{'} + (X_d^{'} - X_d)i_d] \tag{27}$$

$$\frac{d}{dt}E_F = \frac{1}{T_E}[-E_F + K_E(U_R - U_T)] \tag{28}$$

In the design of power system stabilizer for improving the dynamic stability of power system, linearized incremental models are usually employed. Basic linear differential equations describing dynamics of the single machine infinite bus power system are:

$$\frac{d}{dt}\Delta\delta = \omega_o\,\Delta\omega \tag{29}$$

$$\frac{d}{dt}\Delta\omega = -\frac{K_1}{J}\Delta\delta - \frac{K_D}{J}\Delta\omega - \frac{K_2}{J}\Delta E_q^{'} + \frac{1}{J}\Delta P_M \tag{30}$$

$$\frac{d}{dt}\Delta E_q^{'} = \frac{1}{T_{do}^{'}}[\Delta E_F - K_3\Delta E_q^{'} - K_4\Delta\delta] \tag{31}$$

$$\begin{aligned} \frac{d}{dt}\Delta E_F = \frac{1}{T_E}[K_E\Delta U_R - K_E K_5\Delta\delta - \\ K_E K_6\Delta E_q^{'} - \Delta E_F] \end{aligned} \tag{32}$$

The characteristic equation system without PSS is given by:

$$\begin{aligned} \Delta(s) = s^4 + \left(\frac{K_3}{T_{do}^{'}} + \frac{1}{T_E} + \frac{K_D}{J}\right)s^3 + \\ \left(\frac{K_3 + K_E K_6}{T_{do}^{'}T_E} + \frac{K_D(T_{do}^{'} + K_3 T_E)}{J\,T_{do}^{'}T_E} + \frac{\omega_o K_1}{J}\right)s^2 + \\ \left[\frac{\omega_o K_1(T_{do}^{'} + K_3 T_E)}{J\,T_{do}^{'}T_E} - \frac{K_2 K_4\omega_o}{J\,T_{do}^{'}} + \frac{K_D(K_3 + K_E K_6)}{J\,T_{do}^{'}T_E}\right]s + \\ \frac{\omega_o}{J\,T_{do}^{'}T_E}[K_1(K_3 + K_E K_6) - K_2(K_4 + K_E K_5)] \end{aligned} \tag{33}$$

The sensitivity constant of model power system are derived by small perturbation analysis on the synchronous machine equations and hence are functions of machine parameters and operating conditions. Small perturbation transfer function models of the synchronous generator equipped with an exciter and regulator voltage shown in Fig. 3.

The coefficient K_1 is normally positive. The constants K_2, K_3, K_4 and K_6 are usually positive, however K_5 may take either positive or negative values. Constant K_1 and K_2 are derived from the electric torque expression, K_3 and K_4 from the field winding circuit equation, K_5 and K_6 from the generator terminal voltage magnitude. These constants are functions of system parameters and the initial operating condition and given by:

$$K_1 = F_q[E'_{qo} + I_{do}(X_q - X_d^{'})] + F_d I_{qo}(X_q - X_d^{'}) \tag{34}$$

$$\begin{aligned} K_2 = I_{qo} + Y_q[E_{qo}^{'} + I_{do}(X_q - X_d^{'})] + \\ Y_d I_{qo}(X_q - X_d^{'}) \end{aligned} \tag{35}$$

$$K_3 = 1 + (X_d - X_d^{'})Y_d \tag{36}$$

$$K_4 = F_d(X_d - X_d^{'}) \tag{37}$$

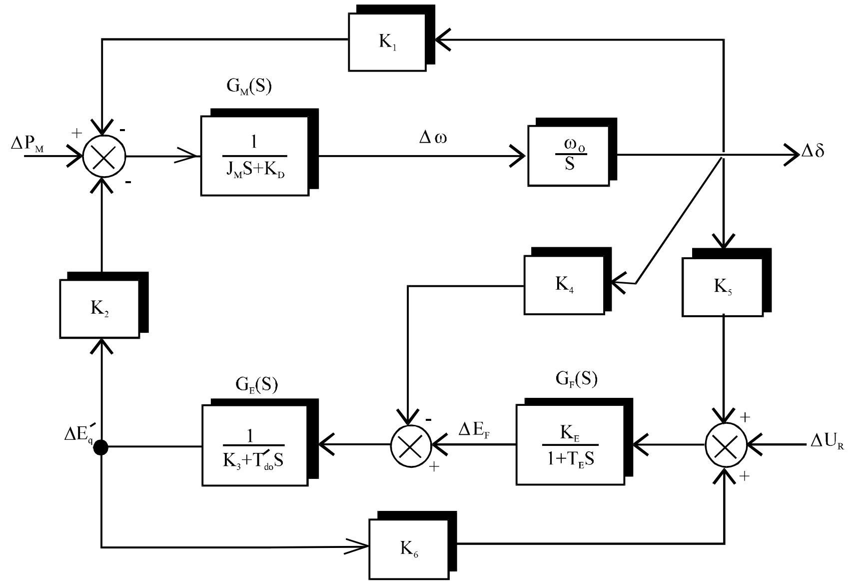

Fig. 3: Small perturbation transfer function model of a SMIB power system

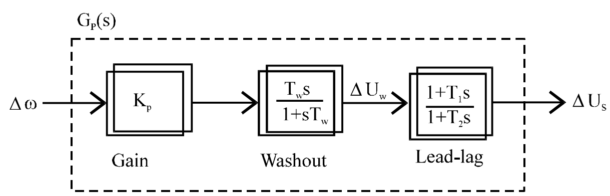

Fig. 4: Block diagram of a supplementary excitation control

$$K_5 = \frac{U_{do}}{U_{To}} X_q F_q - \frac{U_{qo}}{U_{To}} X_d' F_d \tag{38}$$

$$K_6 = \frac{U_{do}}{U_{To}} X_q Y_q + \frac{U_{qo}}{U_{To}} (1 - X_d' Y_d) \tag{39}$$

Power system stabilizer: Power system oscillations are a characteristic of the system and they are inevitable. Power system oscillations are initiated by normal small changes in system loads and they become much worse following a large disturbance. The AVR can inject negative damping into the system at high power loading, leading power factors and large tie-line reactance (Rajkumar and Mohler, 1995). This so-called negative damping may be eliminated by introducing a supplementary control loop known as the power system stabilizer. The basic function of a PSS is to extend the stability limits by modulating the generator excitation to provide damping for the rotor oscillations of synchronous machines. The PSS can enhance the damping of power system, increase the static stability and improve the transmission capability. Two

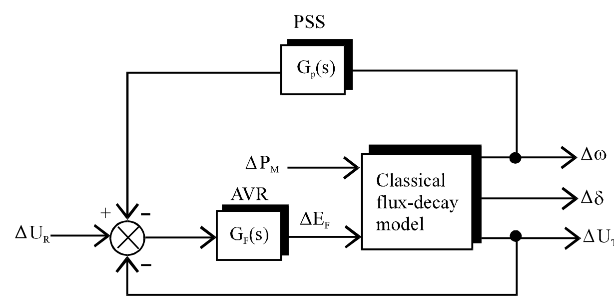

Fig. 5: Block diagram of the SMIB with PSS and AVR

distinct types of oscillations are already identified: local mode oscillation and inter-area mode oscillation (Jiang, 2007). Local mode are largely determined and influenced by local area states. Usually, PSS is designed for damping local electromechanical oscillations. The PSS output is added to the difference between reference and actual value of the terminal voltage.

The design goal of PSS is to improve the damping torque coefficient with the least influence on the synchronizing torque coefficient by adding the PSS signal to AVR. A diagram illustrating the principle mode of operation of a PSS is shown in Fig. 4, where the generator speed deviation ($\Delta\omega$) from that synchronous frequency is input signal. A PSS is directly connected to the AVR of power system synchronous generator. The block diagram of the SMIB system with PSS and voltage control loop shown in Fig. 5.

The task of the PSS is to add an additional signal U_S (output from the PSS) into the control loop which compensates for the voltage oscillations and provides a damping component that is in phase. The washout block is a high-pass filter with a time constant high enough to allow signals associated with the speed oscillations to pass through unchanged (Machowski *et al*., 1998). The signal washout block serves as a high-pass filter. By choosing a large T_W value, the washout block will not have any effect on gain phase shift at the oscillating frequency.

The lead-lag network provides the appropriate phase-lead characteristic to compensation the phase lag between the exciter input and the generator electrical torque (Abdel *et al*., 2000).

The goal is to eliminate phase lag as best as possible throughout a wide rang of frequencies of interest, then adjust gain as outlined below. The stabilizer gain K_P determines the size of that contribution. A gain high as practicable is required for best contribution to system damping.

The gain K_P is adjusted to obtain the desired damping for unstable or poorly damped modes. The time constants T_W, T_2 are usually prespecified. The remaining parameters, namely time constant T_1 and stabilizer gain K_P are assumed to be adjustable parameters. The PSS frequency characteristic is adjusted by varying the time constant of system.

Typical range of the optimized parameters are 0.06-1 for T_1 and 0.001-50 for K_P. The time constants T_W and T_2 are set as 5 and 0.05 sec, respectively (Abido, 2002). For the system with PSS, the new state variable vector becomes (Shahgholian *et al*., 2007):

$$X = [\Delta\delta \quad \Delta\omega \quad \Delta E_q' \quad \Delta E_F \quad \Delta U_W \quad \Delta U_S]^T \tag{40}$$

In this case, the equation describing the AVR can be written as:

$$\frac{d}{dt}\Delta E_F = \frac{1}{T_E}[K_E \Delta U_R - K_E K_5 \Delta\delta - K_E K_6 \Delta E_q' - \Delta E_F + K_E \Delta U_S] \tag{41}$$

The dynamic of the PSS can be expressed by the following differential equations:

$$\frac{d}{dt}\Delta U_W = -\frac{K_P K_1}{J}\Delta\delta - \frac{K_P K_D}{J}\Delta\omega - \frac{K_P K_2}{J}\Delta E_q' - \frac{1}{T_E}\Delta U_W + \frac{K_P}{J}\Delta P_M \tag{42}$$

$$\frac{d}{dt}\Delta U_S = -\frac{K_P K_1 T_1}{J T_2}\Delta\delta - \frac{K_P K_D T_1}{J T_2}\Delta\omega - \frac{T_1 K_P K_2}{J T_2}\Delta E_q' + \left(\frac{1}{T_2} - \frac{T_1}{T_2 T_W}\right)\Delta U_W - \frac{1}{T_2}\Delta U_S + \frac{K_P T_1}{J T_2}\Delta P_M \tag{43}$$

The characteristic equation system without PSS is given by:

$$\Delta(s) = s^6 + a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0 \tag{44}$$

Where:

$$a_5 = \frac{K_3}{T_{do}'} + \frac{1}{T_E} + \frac{1}{T_W} + \frac{1}{T_2} \tag{45}$$

$$a_4 = \frac{K_3}{T_{do}' T_2} + \frac{1}{T_E T_W} + \left(\frac{1}{T_2} + \frac{K_3}{T_{do}'}\right)\left(\frac{1}{T_E} + \frac{1}{T_W}\right) + \frac{K_E K_6}{T_{do}' T_E} + \frac{\omega_o K_1}{J} \tag{46}$$

$$a_3 = \frac{K_3}{T_{do}' T_2}\left(\frac{1}{T_E} + \frac{1}{T_W}\right) + \frac{1}{T_E T_W}\left(\frac{1}{T_2} + \frac{K_3}{T_{do}'}\right) + \frac{K_6 K_E}{T_{do}' T_E}\left(\frac{1}{T_2} + \frac{1}{T_W}\right) + \frac{K_P K_2 T_1 K_E}{J T_{do}' T_2 T_E} - \frac{K_2 K_4 \omega_o}{J T_{do}'} + \frac{K_1 \omega_o}{J}\left(\frac{K_3}{T_{do}'} + \frac{1}{T_E} + \frac{1}{T_W} + \frac{1}{T_2}\right) \tag{47}$$

$$a_2 = \frac{\omega_o K_1}{J}\left[\frac{K_3}{T_{do}' T_2} + \frac{1}{T_E T_W} + \left(\frac{1}{T_2} + \frac{K_3}{T_{do}'}\right)\left(\frac{1}{T_E} + \frac{1}{T_W}\right)\right] - \frac{K_2 \omega_o}{J}\left(\frac{K_4}{T_{do}'}\left(\frac{1}{T_E} + \frac{1}{T_W} + \frac{1}{T_2}\right) + \frac{K_3 K_5}{T_{do}' T_E}\right) + \frac{K_3 + K_E K_6}{T_{do}' T_E T_W T_2} + \frac{K_E K_P K_2}{T_{do}' T_E J T_2} \tag{48}$$

$$a_1 = -\frac{K_2 \omega_o}{J}\left[\begin{array}{l}\frac{K_4}{T_{do}'}\left(\frac{1}{T_E T_W} + \frac{1}{T_E T_2} + \frac{1}{T_W T_2}\right) + \\ \frac{K_5 K_E}{T_{do}' T_E}\left(\frac{1}{T_W} + \frac{1}{T_2}\right)\end{array}\right] + \frac{\omega_o K_1}{J}\left[\begin{array}{l}\frac{K_3}{T_{do}' T_2}\left(\frac{1}{T_E} + \frac{1}{T_W}\right) + \frac{1}{T_E T_W}\left(\frac{1}{T_2} + \frac{K_3}{T_{do}'}\right) + \\ \frac{K_6 K_E}{T_{do}' T_E}\left(\frac{1}{T_2} + \frac{1}{T_W}\right)\end{array}\right] \tag{49}$$

$$a_0 = \frac{\omega_o K_1}{J}\left[\frac{K_3 + K_E K_6}{T'_{do} T_E T_W T_2} + \frac{K_E K_P K_2}{T'_{do} T_E J T_2}\right] - \frac{\omega_o K_2}{J T'_{do} T_2 T_E}\left[\frac{K_4}{T_W} + \frac{K_E K_P K_1}{J} + \frac{K_E K_5}{T_W}\right] \quad (50)$$

A necessary condition for stability of the system is that all the roots in equation characteristic have a negative real part which in turn requires that all coefficients (a_0, …, a_5) are positive.

The natural modes of system response are related to the eigenvalues. The real component of the eigenvalues gives the damping and the imaginary component gives the frequency of oscillation.

RESULTS AND DISCUSSION

Table 1 shows the parameters of the SMIB system used in digital computer simulation to verify the performance of the proposed control scheme. The effects of the line model on sensitivity constant of linear model of power system are shown in Table 2. The steady state operating points of the model power system with normal loading are U_{do} = 0.7234, U_{qo} = 0.6905, I_{do} = 0.5754, I_{qo} = 0.4110, U_{bo} = 0.7088 and δ_o = 64.8799°.

The effect of line model on system damping with and without PSS for normal loading is shown in Table 3 and 4.

Without PSS, the system was slightly damped because its dominant poles were close to the imaginary axis in the complex plane.

The damping ratio determines the rate of decay of the amplitude of the oscillation. The damping ratio of the mechanical mode is improved as it changes from 0.0963-0.5972 with short model to 0.5858 with medium model and to 0.5824 with long model.

The selection of the washout time constant T_W value depends upon the type of modes under study (Awed-Badeeb, 2006), the T_W does not have a significant impact on the complex mode correspond. The effect of PSS gain on system damping for normal loading is shown in Table 5.

The damping ratio of the mechanical mode is changes from 0.6274 at K_P = 10-0.5934 at K_P = 30. Also, the damping ratio of the electrical mode is changes from 0.4418 at K_P = 10- 0.2716 at K_P= 30.

Therefore, an increase in the gain K_P decreases both the natural frequency and the damping ratio of system mechanical mode. Conversely, increasing the gain K_P

Table 1: Data of the SMIB system

Parameters	Values
Generator	
X_q	1.76
X_d	1.81
X'_d	0.30
J	7.00
K_D	4.00
T'_{do}	8.00
f	60.0
Power system stabilizer	
T_1	0.8
T_2	0.1
T_W	10
K_P	20
Automatic voltage regulator	
K_E	50
T_E	0.01
Transmission line	
R	0.113 Ω km^{-1}
L	1.618×10^{-3} H km^{-1}
C	8.488×10^{-9} F km^{-1}
V_{base}	230 KV
S_{base}	200 MVA
Line length	300 km
Shunt load	
G	0.3
B	0.3
Loading normal	
U_{To}	1.0
P_{Eo}	0.9
Q_{Eo}	0.1
Leading power factor	
U_{to}	1.0
P_{eo}	0.7
Q_{eo}	-0.3
Line length (km)	300
Base in line	
V_{base}	230 KV
S_{base}	200 MVA

Table 2: Sensitivity constant of model power system for line different models

Constants	Short line model	Medium line model	Long line model
K_1	0.7094	0.6773	0.6675
K_2	1.2019	1.1965	0.1948
K_3	2.4005	2.3541	2.3402
K_4	1.1071	1.0595	1.0454
K_5	-0.0495	-0.0462	-0.0450
K_6	0.6735	0.6897	0.6944
δ_o	64.8799°	64.9242°	65.2988°
U_{Bo}	0.7088	0.6335	0.6303

Table 3: The effect of line model on system eigenvalues without pss for normal loading

Short line model	Medium line model	Long line model
-95.5844	-95.4733	-95.4406
-4.12630	-4.26080	-4.30250
-0.5804±j5.9996	-0.5658±j5.8563	-0.5604±j5.8127

Table 4: The effect of line model on system eigenvalues with pss for normal loading

Short line model	Medium line model	Long line model
-97.6702	-97.5577	-97.5244
-0.1015	-0.1015	-0.1015
-1.5009±j2.0160	-1.4631±j2.0241	-0.1.4516±j2.0262
-5.0990±j14.2435	-5.1901±j14.1796	-5.2174±j14.1594

Table 5: The effect of PSS gain on system eigenvalues for normal loading

K_P	Without PSS	10	20	30
Mechanical mode	-0.5804±j5.9996	-2.1390±j2.6551	-1.5009±j2.0160	-1.2493±j1.6946
Electrical mode	-4.1263, -95.5844	-4.9709±j10.0950	-5.0990±j14.2435	-4.8619±j17.2304
Control	-	-0.1007, -96.6511	-0.1015, -97.6702	-0.1022, -.98.6468

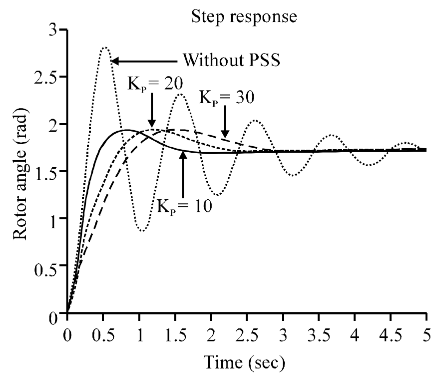

Fig. 6: Effect of gain K_P on load angle

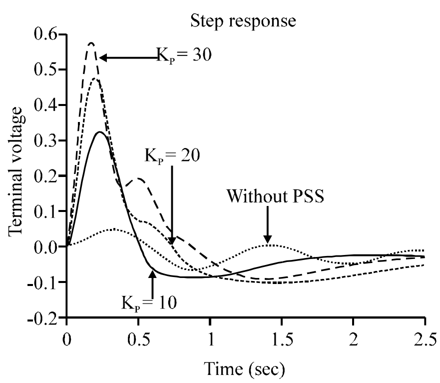

Fig. 7: Effect of gain K_P on generator terminal voltage

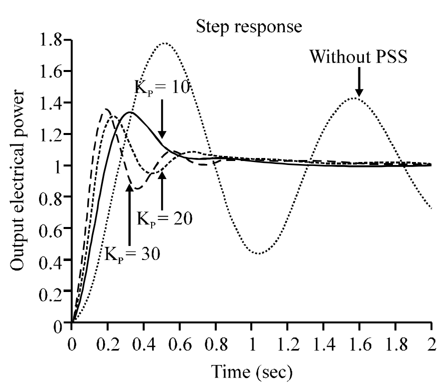

Fig. 8: Effect of gain K_P on output electrical power

increases the natural frequency and decreases the damping ratio of system electrical mode. The step responses with different of gain K_P for normal load are

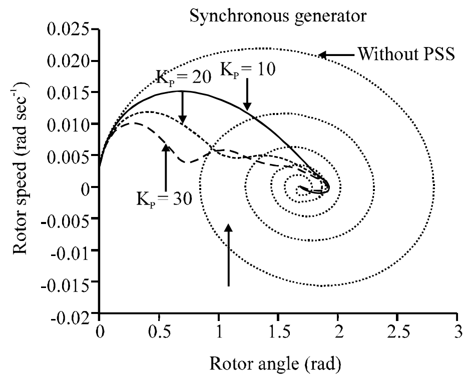

Fig. 9: Effect of gain K_P on rotor speed – load angle

shown in Fig 6-9. From the simulation results of the mathematical model, it is inferred that the damping of the power system is improved with the help of PSS. We can see that with the addition of the PSS, the system has become very stable.

CONCLUSION

Power system stabilizers have been thought to improve power system damping by generator voltage regulation depending on system dynamic response. The PSS is a supplementary control system which is often applied as part of excitation control system. This study proposes a linearized block diagram of a power system with a PSS and the performance of the PSS controller for the damping of oscillations in a SMIB using small signal model.

For power system dynamic researches transmission line is modeled using the parameters of line. The transfer functions are studied using Matlab and the step response verified by time domain simulation.

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