Analysis and Simulation of the Single-Machine Infinite-Bus with Power System Stabilizer and Parameters Variation Effects

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***Abstract*- The idea of power system stabilizer (PSS) or supplementary excitation control is to apply a signal through the excitation system to produce additional damping torque of the generator in a power system at all operating and system conditions. In this paper the study of the dynamic behavior and transient stability of the single-machine infinite-bus (SMIB) with used the eigenvalue analysis is presented. Finally, the simulation results of system dynamic performance response for PSS parameters variation is achieved and discussed.**

I. INTRODUCTION

An important application area for the synchronous machine is used almost exclusively in power systems as a source of electrical energy. Keeping voltage within certain limits help to reduce energy losses and improves voltage regulation. Voltage control is a difficult task because voltages are strongly influenced by dynamic load fluctuations. Power system is a complicate nonlinear system which structure, parameter and running mode usually change. The study of the linearized system is necessary for some purposes, such as control loop design. The most common disturbance is load variations, but parameter variations are also common, and the closed loop control system is used to compensate for such variations.

Low or negative damping in a power system can lead to spontaneous appearance of large power oscillations. Several methods for increasing the damping in a power system are available such as static voltage condenser (SVC), high voltage direct current (HVDC) and power system stabilizer (PSS). Operating conditions of a power system are continuall-y changing due to load patterns, electric generation variations, disturbances, transmission topology and line switching [1]. The enhance system damping; the generators are equipped with power system stabilizers that provide supplementary feedback stabilizing signals in the excitation systems [2]. The control strategy should be capable of manipulating the PSS effectively, robustness, valid in a wide range of operating conditions, easy to implement, improvement in transient stability, the developing time and the cost [1]. Various topologies and many control methods have been proposed for PSS design with good performance and used in power system stability control and successfully improve system damping, such as adaptive controller [3], robust controller [4, 5], extended integral controller [6], state feedback controller [7], fuzzy logic controller [8] and variable structure controller [9]. In [10] 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 [11], an indirect adaptive PSS is designed using two input signals, the speed deviation and the power deviation to a neural network controller.

Reactive power increases transmission system losses, reduces power transmission capabilities, and may cause large amplitude variations in the receiving-end voltages. The balance of reactive power in the system implies that constant of the voltage. The AVR maintains the terminal voltage by regulation of the excitation field of the synchronous machines and in turn controls the reactive power output. Maintaining stability during a fault condition is a secondary for the AVR [12]. A number of publications have been reported on AVR modeling and control [13, 14]. A PID controller based on a neural network and adaptive control theory for the synchronous generator system is presented in [15]. In [16] a novel approach to the design of the optimal excitation control strategy for a synchronous generator system is proposed, based on Lyapunov's direct method. In [17] the dynamic behavior and transient stability of AVR system with PID controller and stabilizer with parameters variation is presented. A comparative study of digital AVR for use on engine generator between H_∞ control and direct design PID control proposed in [18].

The small signal analysis is justified for studying the system response for small perturbations. This paper provides an eigenvalue analysis of the dynamic performance of one machine infinite bus system with PSS under different system condition and operating loads. The remainder of this paper can be outlined as follows. In section II the plant model of the system is described. Identification of a state space model of a generator for multi-input multi-output PSS as also different transfer functions is introduced in section III. Finally, various simulation results using Matlab are shown under parameters variation in section IV and discussed in section V.

II. DESCRIPTION OF THE PLANT MODEL

The reaction of the AVR in front of the terminal voltage oscillate is to force field current changes in the generator. 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

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the static stability and improve the transmission capability. The PSS output is added to the difference between reference and actual value of the terminal voltage. Usual input signal for the PSS are the rotor speed deviations, the accelerating power, active power output or the system frequency. A diagram illustrating the principle mode of operation of a PSS is given in Fig.1, where the generator speed deviation ($\Delta\omega_r$) from that synchronous frequency is input signal. The automatic voltage regulator of the generator and the voltage transducer are represented by simple first order function $G_R(s)$ with the time constant T_R and the gain K_R and $G_E(s)$ with the time constant T_E and the gain K_E.

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 [16]. The washout time constant T_W is usually fixed between 5 and 20 seconds [7]. The lead-lag network is a lead compensation to improve the phase lag through the system [19]. The stabilizer gain K_P determines the size of that contribution. That constant should of course not be chosen lager than necessary to obtain the needed damping, since this could lead to undesired side effects [20]. The time constants T_W, τ_2 and τ_4 are usually prespecified. The remaining parameters, namely time constants τ_1 and τ_3 and stabilizer gain K_P are assumed to be adjustable parameters. The PSS frequency characteristic is adjusted by varying the time constant of system.

III. EQUATION SYSTEM

Modern power systems are highly complex and strong nonlinearity and their operating conditions can vary over a wide range. Synchronous generator excitation control is one of the most important measures to enhance power system stability and to guarantee the quality of electrical power it provides [21]. Also, that is one of the important factors in the transient study of power system analysis. The synchronous generator is driven by a turbine with a governor and excited by an external AVR and a PSS. A generator is normally equipped with an exciter for primary control and a governor for frequency control as shown in Fig. 2. The excitation and governing controls of the generator play an important role in improving the dynamic and transient stability of the power system. The load bus is modeled as an infinite bus, which is normally used to replace a stiff large system with constant voltage magnitude and angle.

The first step in the analysis and design of control systems is mathematical modeling of the system. The two most common methods are the transfer function approach and the state equation approach. In order to use the transfer function and linear state equations, the system must first be linearized. In this study, a single machine connected to infinite bus through a transmission line, and operating at different loading conditions, is considered. The model is shown in Fig.3.

The major function of the excitation systems is to control the field winding current of the synchronous machine so as to regulate terminal voltage of the machine. There are many different types of excitation systems available. Power source used, including dc excitation systems, ac excitation systems and static excitation systems [22]. Typically the excitation system is a fast response system where the time constant is small. A simplified schematic picture of a generator with excitation system is depicted in Fig. 4. Two alternate excitation control schemes were considered, one with and the other without transient reduction (TGR) [23]. TGR is used for obtaining the desired transient gain. The cylindrical rotor machine is simulated by seven first order differential equation in the dq frame. The field circuit is represented by simple first order function $G_F(s)$ with the time constant T_3 and the gain K_3.

Power system is a typical dynamic system. By linearizing about an output point, the total linearized system model including AVR and PSS can be represent by the following equation:

$$\frac{d}{dt}\Delta X = A\,\Delta X + B\,\Delta U$$
$$\Delta Y = C\,\Delta X + D\,\Delta U$$

where ΔX is the state vector, ΔY is the output vector, ΔU is the input vector, A is the state matrix, B is the control or input matrix, C is the output matrix and D is the feed forward matrix.

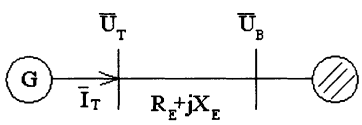

Fig.1: Schematic diagram of single machine infinite bus (SMIB) system

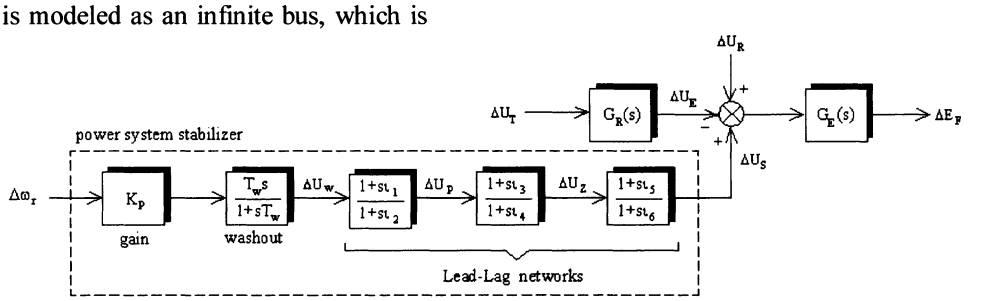

Fig.2: Block diagram of a PSS

The natural modes of system response are related to the eigenvalue. Analysis of the eigenvalue properties of A provides valuable information about the system stability for small perturbations that occur in the system. The complete system to be simulated contains three separate blocks: mechanical loop, electrical loop and PSS. The small perturbation transfer function block diagram of one machine infinite bus system with PSS is shown in Fig.5. By defining the state vector and input vector as follow as:

$$X=[\Delta\omega_r \quad \Delta\delta \quad \Delta\lambda_F \quad \Delta U_E \quad \Delta E_F \quad \Delta U_S \quad \Delta U_W]^T \qquad (1)$$

$$U=[\Delta T_m \quad \Delta U_R]^T \qquad (2)$$

the state equation governing the power system with ignored of the T_3, T_4, T_5 and T_6 of the lead-lag network in the PSS are given by:

$$\frac{d}{dt}\Delta\omega_r=\underbrace{\frac{-K_D}{2H}}_{a_{11}}\Delta\omega_r+\underbrace{\frac{-K_1}{2H}}_{a_{12}}\Delta\delta+\underbrace{\frac{-K_2}{2H}}_{a_{13}}\Delta\lambda_F+\underbrace{\frac{1}{2H}}_{b_{11}}\Delta T_m \qquad (3)$$

$$\frac{d(\Delta\delta)}{dt}=\underbrace{\omega_o}_{a_{21}}\Delta\omega \qquad (4)$$

$$\frac{d}{dt}\Delta\lambda_F=\underbrace{\frac{-K_3K_4}{T_3}}_{a_{32}}\Delta\delta+\underbrace{\frac{-1}{T_3}}_{a_{33}}\Delta\lambda_F+\underbrace{\frac{K_3}{T_3}}_{b_{32}}\Delta E_F \qquad (5)$$

$$\frac{d}{dt}U_E=\underbrace{\frac{K_5K_R}{T_R}}_{a_{42}}\Delta\delta+\underbrace{\frac{K_6K_R}{T_R}}_{a_{43}}\Delta\lambda_F-\underbrace{\frac{1}{T_R}}_{a_{44}}\Delta U_E \qquad (6)$$

$$\frac{d}{dt}\Delta E_F=\underbrace{\frac{-1}{T_E}}_{a_{55}}\Delta E_F+\underbrace{\frac{-K_E}{T_E}}_{a_{54}}\Delta U_E+\underbrace{\frac{K_E}{T_E}}_{a_{59}}\Delta U_S+\underbrace{\frac{K_E}{T_E}}_{b_{52}}\Delta U_R \qquad (7)$$

$$\frac{d}{dt}\Delta U_W=\underbrace{K_Pa_{21}}_{a_{61}}\Delta\omega_r+\underbrace{K_Pa_{21}}_{a_{62}}\Delta\delta+\underbrace{K_Pa_{23}}_{a_{63}}\Delta\lambda_F$$
$$+\underbrace{\frac{-1}{T_W}}_{a_{66}}\Delta U_W+\underbrace{\frac{1}{2H}}_{b_{61}}\Delta T_m \qquad (8)$$

$$\frac{d}{dt}\Delta U_P=\underbrace{\frac{\tau_1}{\tau_2}a_{61}}_{a_{71}}\Delta\omega_r+\underbrace{\frac{\tau_1}{\tau_2}a_{62}}_{a_{72}}\Delta\delta+\underbrace{\frac{\tau_1}{\tau_2}a_{63}}_{a_{73}}\Delta\lambda_F$$
$$+\underbrace{\left(\frac{1}{\tau_2}+\frac{\tau_1}{\tau_2}a_{66}\right)}_{a_{76}}\Delta U_W+\underbrace{\frac{-1}{\tau_2}}_{a_{77}}\Delta U_P+\underbrace{\frac{\tau_1}{\tau_2}b_{61}}_{b_{71}}\Delta T_m \qquad (9)$$

where δ, H, K_D and T_m are rotor angle, inertia constant, damping coefficient and mechanical load torque, respectively. The six parameters K_1, K_2, K_3, K_4, K_5 and K_6 are obtained in terms of the main power system parameters.

IV. EFFECT OF PARAMETER VARIATION ON DYNAMIC RESPONSE

Without computer simulation it would not be easy to examine the effects of system physical parameters on dynamic response in terms of system variation. In this section by using state equations, SMIB system response with PSS and AVR in terms of input variation for the system values is obtained as shown in table I. In each part with variation of parameters, the effects of each one on frequency response and step response is examined.

For the present study, the gain K_P and time constants have been varied and the time response have been computed for SMIB at a normal operating of P=0.9, Q=0.3, R_E=0 and X_E=0.2 with system parameters are given in Table I.

A. washout time constant (T_W)

The T_W should be high enough to pass stabilizing signals at the frequencies of interest relatively unchanged [23].

TABLE I
SYSYTEM PARAMETERS

Parameter	Nominal value	Parameter	Nominal value
K_1	0.7643	T_R	0.02
K_2	0.8649	H	3.5
K_3	0.3230	K_D	0
K_4	1.4187	T_W	1.4 sec
K_5	-0.1463	T_1	0.154 sec
K_6	0.4168	T_2	0.033 sec
T_3	2.365	K_P	9.5
T_E	0	K_R	1
K_E	200		

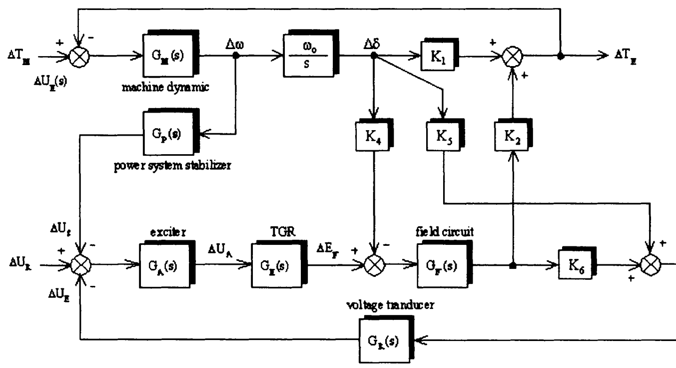

Fig.3: Linearised small perturbation model of synchronous generator

The roots of characteristic equation for three different values of T_W are given in table II. Figure 6 shows the step response for changing of T_W.

B. stabilizer gain (K_P)

The PSS gain should be set a value corresponding to the desired damping. The roots of characteristic equation for three different values of the K_P are given in table III. Figure 7 shows the step response for changing of K_P. From the results, we see that the K_P variation affects the peak of the curve, settling time and overshoot, but has no effect on the final values of motor speed in a stable system.

Table II
CHARACTERISTIC EQUATION ROOTS FOR SMIB SYSTEM IN TERMS OF DIFFERENT VALUES OF T_W

T_W=5	T_W=10	T_W=20
-39.06	-39.06	-39.05
-19.77±j12.67	-19.76±12.64	-19.76±12.63
-1.06±j6.71	-1.07±j6.74	1.08±j6.75
-0.20	-0.10	-0.05

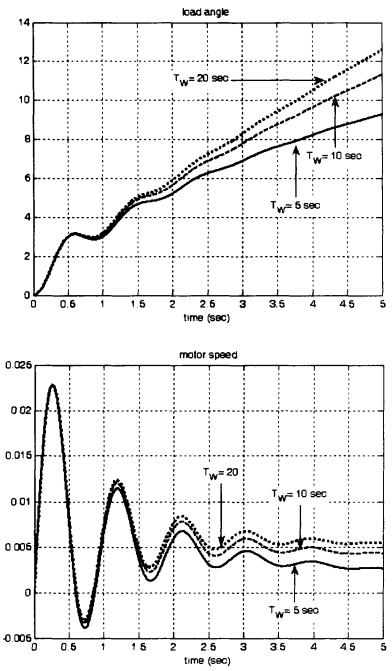

Fig.4: Speed motor and load angle step response for SMIB system in terms of T_W

Table III: Characteristic equation roots for SMIB system in terms of different values of K_P

K_P=10	K_P=30	K_P=50
-39.23	-42.34	-43.82
-19.66±j13.15	-16.70±23.13	-15.67±29.88
-1.07±j6.56	-2.45±j4.46	2.69±j2.95
-0.74	-0.81	-0.90

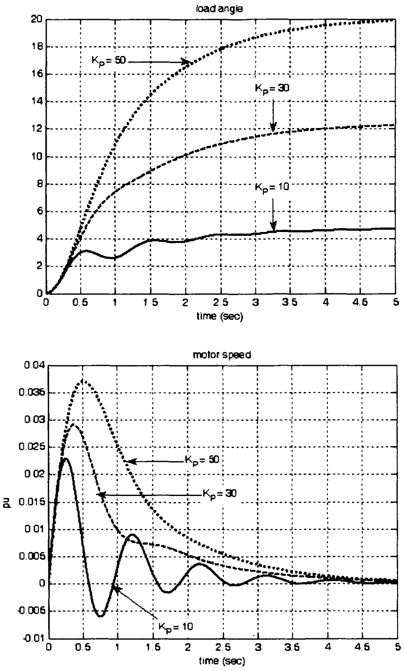

Fig.5: Speed motor and load angle step response for SMIB system in terms of K_P

V. CONCLUSION

Power system stabilizer (PSS) is a supplementary controller to damped low frequency oscillations and to improve dynamic performance of the generating unit. The use of eigenvalue analysis to study of the PSS in exciter control system working at various operating conditions is investigated in this paper. Finally, the SMIB system is simulated and the effects of some parameters are investigated.

REFERENCE

[1] Y.J.Lin, "Systematic approach for the design of a fuzzy power system stabilizer", IEEE/POWERCON, pp.747-752, November 2004.

[2] M.A.Abido, "Optimal design of power system stabilizers using particle swarm optimization", IEEE Trans. On Ene. Con., Vol.17, No.3, pp.406-413, Sep. 2002.

[3] B.Wu, O.Malik, "Multivariable adaptive control of synchronous machine", IEEE, pp., 2006.

[4] Q.Zhao, J.Jian, "Robust controller design for generator excitation systems", IEEE Tran. On Ene. Conv., Vol.10, No.2, pp.201-209, 1995.

[5] A.Hasanovic, A.Feliachi, A.Hasanovic, N.B.Bhatt, A.G.Degroff, "Pratical robust PSS design through identification of low order transfer functions", IEEE Trans. On Pow. Syst., Vol.19, No.3, pp.1492-1581, August 2004.

[6] R.Hoen-Su, M.Kyoung_Il, M.Y.Hyun, "Extended integral based governor for power system stabilizer", IEEE/PESS, Vol.3, pp.1610-1614, 2002.

[7] A.Elices, L.Rpuco, H.Bourles, T.Margotin, "Conversion of state feedback controllers to the standard AVR+PSS form", IEEE/PTC, June 2003.

[8] N.Hossenizadeh, A.Kalam, "A rule based fuzzy power system stabilizer tuned by a neural network", IEEE Trans. On Ene. Conv., Vol.14, No.3, pp.773-776, September 1999.

[9] S.S.Lee, J.K.Park, "Design of reduced order observer based variable structure power system stabilizer for unmeasurable state variables", IEE Proc. Conf. Transm. Distrb., Vol.145, No.5, pp.525-530, September 1998.

[10] F.Mrad, S.Karaki, B.Copti, "An adaptive fuzzy synchronous machine stabilizer", IEEE Trans. Syst. Man. Cybern, Vol.30, No.1, pp.131-137, Jan. 2000.

[11] P.Shamsollahi, O.P.Malik, "Adaptive control applied to synchronous generator", IEEE Trans. On Ene. Conv., Vol.14, No.4, pp.1341-1346, 1999.

[12] L.Ren, G.W.Irwin, D.Flynn, "Nonlinear identification and control of a turbogenerator – An on-line scheduled multiple model/controller approach", IEEE Trans. On Ener. Conv., Vol.20, No.1, pp.237-245, March 2005.

[13] D.Flynn, B.W.Hogg, E.Swidenbank, K.J.Zachariah, "A self tuning automatic voltage regulator designed for an inductrial environment", IEEE Trans. On Ene. Conv., Vol.11, No.2, pp.429-434, June 1996.

[14] M.G.M.Ardle, D.J.Morrow, P.A.Calvert, O.Cadel, "A fuzzy tuning PID automatic voltage regulator for small salient poles alternative", IEEE/ICPST, Vol.1, pp.103-108, December 2000.

[15] W.Jun, G.Zhang, "The adaptive PID controller based on neural network for the synchronous generator excitation system", IEEE/IPEMC, Vol.2, pp.681-683, August 2004.

[16] J.Machowski, J.W.Bialek, S.Robak, J.R.Bumby, "Excitation control system for use with synchronous generators", IEE Proc. Tran. Dist., Vol.145, No.5, pp.537-546, September 1998.

[17] J. Faiz, Gh. Shahgholian, M.Arezoomand, "Analysis and simulation of the AVR system and parameters variation effects", IEEE/POWRENG, 450-453, April 2007.

[18] M.Asama, H.Ukai, M.Sone, K.Nakamura, "Comparative studies of digital AVR for use on engine generator between H∞ control and direct design PID control", IEEE/PCC, Vol.1, pp.211-214, April 2002.

[19] Y.L.Abdel, M.A.Abido, A.H.Mantawy, "Robust tuning of power system stabilizer in multimachine power systems", IEEE Trans. On Pow. Sys., Vol.15, No.2, pp.735-740, May 2000.

[20] P.Kundur, "Power system stability and control", McGraw-Hill, 1994.

[21] J.Wen, S.Cheng, O.P.Malik, "A synchronous generator fuzzy excitation controller optimally desined with a genetic algorithm", IEEE, pp.106-111, 1997.

[22] X.C.Zhang, G.H.Cheng, Z.Xu, "User defined excitation system models for power system stability analysis in PSASP", IEEE/PES, pp.1-5, 2005.

[23] K.Bhattacharya, J.Nanda, M.L.Kothari, "Optimization and performance analysis of conventional power system stabilizers", Elec. Pow. & Ene. Syst., Vol.19, No.7, pp.449-458, 1997.