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Enhancement of SMIB Performance Using PSS with Advanced Controllers

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Abstract- **Power System under consideration consists of the single machine connected to an infinite bus (SMIB) through a tie-line. In the SMIB representation, the dynamic interaction between the various machines in the power station is not considered, but it is still adequate for many types of studies, especially when the machines are identical and operate at nearly the same load levels. .A PID controller along with PSS is used for the better results than PSS alone. Analysis of a large interconnected power system is time consuming and may even exceed the storage capacity of modern fast computers because high order model is costly. Therefore a low order linear model will be derived for high order system to obtain optimized design of controller. Results for both the controllers are shown separately in this paper.**

Index Terms— **SMIB, PID-PSS, Order Reduction**

I. INTRODUCTION

The stability of power system is the core of power system security protection which is one of the most important problems researched by electrical engineers. As the permanent network extension and ongoing interconnections, the complexity of power system is increasing worldwide. Hence, it becomes more easily to get failures, even the catastrophic failures. For example, in a short span of two months in 2003, there were several blackouts that happened around the world and affected a number of customers; On August 14, 2003, in Northeast United States and Canada, the blackouts affected approximately 50 million people. It took over a day to restore power to New York City and other affected areas. It is considered as one of the worst blackouts in the history of these countries. Hence to make the power system stable ,one method is to update the coordination of protection, another method is to increase the stability margin of each generator. When the latter method is chosen, design of controller using two techniques mentioned above is done.

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II. RESEARCH WORK ON PSS

A) Necessity of a PSS

In power system, PSS is used to add damping to generator's electromechanical oscillations. It is achieved by modulating the generator's excitation so as to produce adequate of electrical torque in phase with rotor speed deviations.

B) History of PSS

The earliest PSS is Speed-Based Stabilizer. It directly derives the input signal by measuring the shaft speed. It is successfully used in hydraulic units since the mid-1960s. The stabilizer's input signal was obtained from a transducer which using a toothed-wheel and magnetic probe to get shaft speed signal in form of frequency and transform the frequency signal into voltage signal by a frequency-to-voltage converter. The big disadvantage of this type of PSS is the noise caused by shaft run-out and other random causes. Conventional filters cannot remove these low frequency noises without affecting the useful signal measured.

C) Conventional PSS

Frequency-based stabilizer is another type of PSS. It directly uses terminal frequency as the input signal for PSS application at many locations in North America. Terminal voltage and current inputs were combined to generate a signal that approximates to the generator's rotor speed. However, the frequency signals measured at thermal units' terminals still contain torsional components. It is still necessary to filter torsional modes when the power system stabilizers are applied in steam turbine units. Hence, in the frequency- based stabilizers have the same limitations as the speed-based stabilizers. Power-based stabilizer uses the electrical power as the input signal. Because of the easily measuring of electrical power and its relationship to generator shaft speed, the electrical power was considered to be a good choice as the input signal to early power system stabilizers.

III. CONTROLLERS

Among the Advanced controllers, mostly used controllers are proportional and integral controller for which the steady state error is almost zero for Type 1 with respect to step input. Under some operating conditions non linearities in the plant or controller can stop an Integral controller from removing the steady state error. If the Integrator output is not limited, then during this time the total of the integrated (summed) error will continue to build. Once the restrictions are finally removed, problems can arise because this built up "energy" must be removed before the integral control can act normally… this can take a long time. To avoid this, anti-windup circuits are added that place ± limits on the integral total. These limits are usually placed on the summed output of the P&I controller as well.

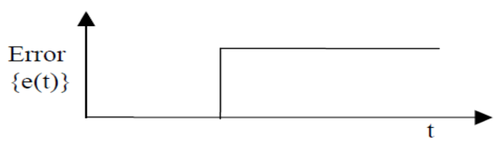
A) PID Controller

In order to overcome this error PID controller is used .

Proportional action: responds quickly to changes in error deviation.

Integral action: is slower but removes offsets between the plant's output and the reference.

Derivative action: Speeds up the system response by adding in control action proportional to the rate of change of the feedback error. Consequently this is susceptible to noise in the error signal, which limits the derivative gain. When present this allows larger values of K_P and K_I smaller TI to be used than possible in pure PI regulators, but large values of derivative gain K_D will cause instability.



Fig(i): PID Regulator error vs time

$$U(t)= K_P\left[e(t)+\frac{1}{T_I}\int e(t)\,dt+T_D\frac{de(t)}{dt}\right] \text{------- (i)}$$

$$K_I = \frac{K_P}{K_I} \text{-- (ii)}$$

$$K_D = K_P T_D \text{---------------------------------- (iii)}$$

B) Tuning of PID Controller

Ziegler Nichols method is used for the tuning of PID controller

$$G_c(S) = K_p \text{---------------------------------- (iv)}$$

$$G_c(S) = K_p\left[1+\frac{1}{ST_1}\right] \text{--------------------------(v)}$$

$$G_c(S) = K_p\left[\frac{1}{ST_1}+\frac{1+ST_D}{1+S0.1T_D}\right] \text{--------------- (vi)}$$

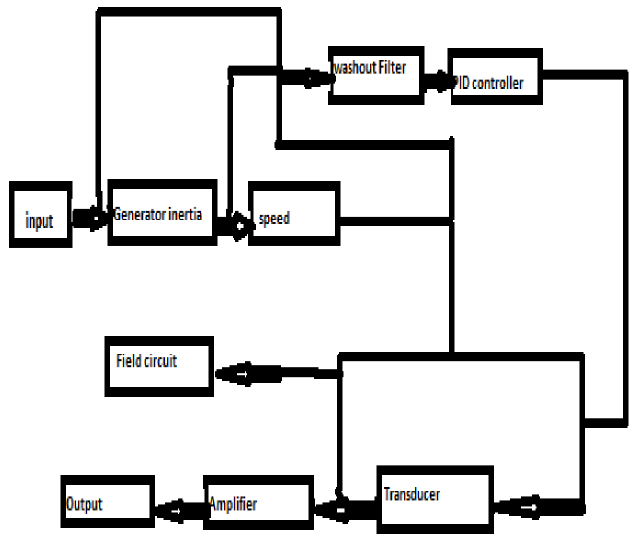
are the equations of controllers for proportional, PI and PID controllers respectively.

1. Set TD = 0
2. Increase KP until the system just starts to oscillate ($K_P = K_{P0}$). The frequency of oscillation here is W_C the period is TO=2p/W_C

Table 1:Ziegler Nichols Tuning Parameters

Type	K_P	K_I	K_D
PI	25.37	17.67	0
PD	25.37	0	3
PID	25.37	17.67	3

The control signal u(t) will be sent to the plant in which is equal to the proportional gain (k_P) times the magnitude of error plus integral gain (k_I)times integral of the error plus derivative gain(k_D) times derivative of the error and the new output is obtained which is fed back and compared to the reference in order to find the new error signal.



Fig(ii): Block diagram model of PSS with PID controller

IV . CONTROLLER DESIGN USING ORDER REDUCTION TECHNIQUE

Controller shown in fig (ii) can be replaced by a compensator which is designed using model reduction technique. Now-a-days large interconnected systems are controlled using computer algorithms and analysing stability margins for high order interconnected systems is complex and thus a low order replica of the system helps to overcome this difficulty as the dimensionality of the algorithm reduces. The lower order model will be analyzed and the results are attributed to the original system. This procedure is known as Large **Scale System Modelling.**

There are many methods available for large scale system reduction techniques out of which dominant pole time moment matching method is used as it always retains stability of original system in it's low order models unlike majority of available order reduction techniques.

A) Obtaining Lower Order Transfer Function

Dynamic stability analysis of large interconnected systems is time consuming and is complex in computation. If a low order linear model is derived for a high order system, then the preliminary design and optimization is achieved with very much ease. Many methods of order reduction have been developed by several authors using time domain as well as frequency domain techniques. In this paper, a new technique of order reduction is introduced, which is known as dominant pole time moment matching method. In this method a denominator polynomial is generated using dominant pole method and numerator polynomial is obtained using time moment matching method. From the obtained lower order transfer function, a compensator is designed in order to improve the stability of system by tracing the stability margins.

B). Controller Design from Reduced Model

From the obtained lower order transfer function ,stability analysis is performed using bode plot analysis and stability margins such as gain and phase margins are obtained along with gain and phase cross over frequencies. In this process, steady state constants can also be indirectly computed. Design techniques in frequency domain are governed by the following facts:

1)steady state errors are improved by increasing bode gain K_B.

2)system stability is improved by increasing gain and phase margins.

3)overshoot is decreased by increasing phase stability margin.

4)Rise time is reduced by increasing system bandwidth.

In this paper, system stability is chose to be improved by increasing gain and phase margins.

The linearized differential equations for a Heffron Phillips model as shown in the block diagram of fig 2 can be given by:

$$\Delta\dot{\omega} = \frac{-K_1}{2H}\Delta\delta - \frac{K_2}{2H}\Delta E'_q \text{ ------------------------------------ (vii)}$$

$$\Delta\dot{\delta} = \omega_0 \Delta\omega \text{ -- (viii)}$$

$$\Delta\dot{E} = \frac{-k_4}{T'_{d0}}\Delta\delta - \frac{1}{T'_{d0}k_3}\Delta E'_q + \frac{1}{T'_{d0}}\Delta E_{fd'} \text{ -------------------(ix)}$$

$$\Delta\dot{E}_{fd} - \frac{K_A K_5}{T_A}\Delta\delta - \frac{K_A K_6}{T_A}\Delta E'_q - \frac{1}{T_A}\Delta E_{fd} - \frac{K_A}{T_A}\Delta V_{pss'} \text{ --------(x)}$$

Where $\Delta\delta$ change in rotor is angle and $\Delta E'_q$ is change in change in d-flux linkages and $\Delta\omega$ is change in speed and $\Delta E_{fd'}$ is change in field circuit.

T'_{do} is field open circuit time constant and T_A is amplifier time constant.

K_1 is the influence of torque angle on electric torque.

K_2 is influence of internal voltage on electric torque.

K_4 is influence of torque angle on internal voltage.

K_5 is influence of torque angle on system voltage.

K_6 is influence of internal voltage on terminal voltage.

The state space form of the system can be arranged as following:

$$A=\begin{bmatrix} 0 & \frac{-K_1}{2H} & \frac{-K_2}{2H} & 0 \\ 2\pi f & 0 & 0 & 0 \\ 0 & \frac{-K_4}{T'_{do}} & \frac{-1}{T'_{do}k_3} & \frac{1}{T_{do}} \\ 0 & \frac{-K_A K_5}{T_A} & \frac{K_A K_6}{T_A} & \frac{-1}{T_A} \end{bmatrix} \text{ ------------------------- (xi)}$$

$$B=\begin{pmatrix} 0 & 0 & 0 & \frac{K_A}{T_A} \end{pmatrix} \text{ ------------------------------------ (xii)}$$

The transfer function obtained using this model is of 4^{th} order which can be reduced to standard second order for bode plot analysis.

C). Choice of Controller

Power systems are highly non linear and exhibit frequency oscillations and so the stability of power systems is one of the most important aspects in electric system operation. In order to overcome these oscillations in the stability aspect, phase lag and phase lead controllers are designed. Phase lag controllers are used to reduce the system bandwidth and the stability margins are improved keeping steady state errors, constant. The phase lead controllers are used to improve the gain and phase margins in order to increase the system bandwidth.

Due to attenuation of phase lag controller at high frequencies, the system bandwidth is reduced and therefore, a phase lead controller is designed and results are obtained by replacing the PID controller shown previously with this designed controller.

D). Design of Controller

1)The value of bode gain K_b is determined from bode diagram by:

$$K_b=\frac{KZ_1Z_2\ldots\ldots}{P_1P_2\ldots\ldots\ldots} \text{ ------------ (xiii)}$$

2)Phase and Gain margins are determined from bode plots. From that, the desired phase and gain margins are to be decided to improve the stability of the system.

3)Phase difference between actual and desired phase margins is taken and $\emptyset_m$ is 5^0-10^0 more than this difference.

4)Parameter ‘a’ is calculated using :

$$a = \frac{1+\sin\emptyset_m}{1-\sin\emptyset_m} \text{ -------- (xiv)}$$

5)A gain of ΔG=20log(a) db is added and a pole is selected as p_c=-0.5ΔG

6)A controller is obtained by the equation:

$$G_C = \frac{as+p_c}{s+p_c} \text{ ------------- (xv)}$$

V) RESULTS

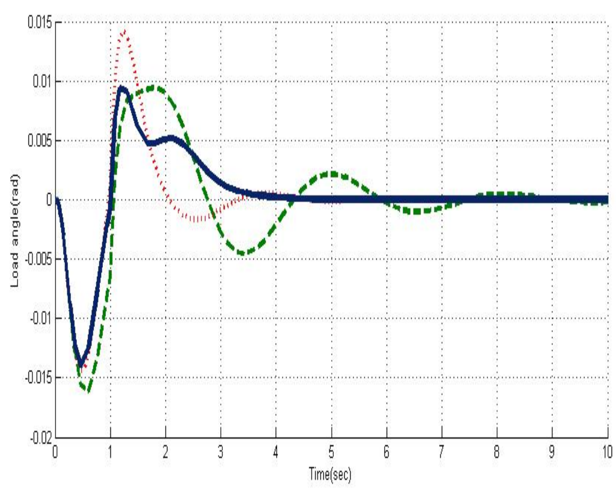


Fig (iii) comparison of waveforms a) without controller b) with PID-PSS c)with controller by order reduction technique.

VI) CONCLUSION

It can be observed that SMIB system performance is enhanced and it is seen that a controller designed using model order reduction technique yielded better result compared with PID-PSS, with less settling time and reduced peak overshoot.

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