BASIC CONCEPT OF POWER SYSTEM STABILIZER FOR POWER SYSTEM STABILITY AND COMPARISON OF DIFFERENT DESIGN METHODS

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Abstract: A power system stabilizer (PSS) installed in the excitation system of the synchronous generator improves the small-signal power system stability by damping out low frequency oscillations in the power system. It does that by providing supplementary perturbation signals in a feedback path to the alternator excitation system. In our project we review different conventional PSS design (CPSS) techniques along with modern adaptive neuro-fuzzy design techniques. We adapt a linearized single-machine infinite bus model for design and simulation of the CPSS and the voltage regulator (AVR). We use 3 different input signals in the feedback (PSS) path namely, speed variation(w), Electrical Power (Pe), and integral of accelerating power (Pe*w), and review the results in each case. For simulations, we use three different linear design techniques, namely, root-locus design, frequency-response design, and pole placement design; and the preferred non-linear design technique is the adaptive neuro-fuzzy based controller design. The MATLAB package with Control System Toolbox and SIMULINK is used for the design and simulations.

I. INTRODUCTION

Power System Stability, its classification, and problems associated with it have been addressed by many CIGRE and IEEE publications. The CIGRE study committee and IEEE power systems dynamic performance committee defines power system stability as: "Power system stability is the ability of an electrical power system, for given operating conditions, to regain its state of operating equilibrium after being subjected to a physical disturbance, with the system variables bounded, so that the entire system remains intact and the service remains uninterrupted" [3].
The figure below gives the overall picture of the stability problem:

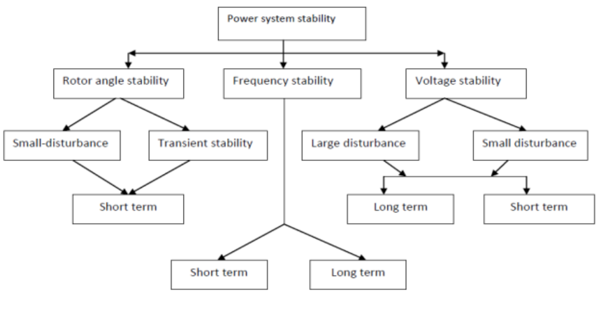

Fig.1. Power-system stability classification [24]

Out of all the stability problems mentioned above, our specific focus in this project is of small disturbance stability which is a part of the rotor angle stability. Also, the voltage stability due to small disturbances is covered.

A. STABILITY ISSUES AND THE PSS:

Traditionally the excitation system regulates the generated voltage and there by helps control the system voltage. The automatic voltage regulators (AVR) are found extremely suitable (in comparison to "ammortisseur winding" and „governor controls") for the regulation of generated voltage through excitation control. But extensive use of AVR has detrimental effect on the dynamic stability or steady state stability of the power system as oscillations of low frequencies (typically in the range of 0.2 to 3 Hz) persist in the power system for a long period and sometimes affect the power transfer capabilities of the system [4]. The **power system stabilizers** (PSS) were developed to aid in damping these oscillations by modulation of excitation system and by this supplement stability to the system [5]. The basic operation of PSS is to apply a signal to the excitation system that creates damping torque which is in phase with the rotor oscillations.

B. DESIGN CONSIDERATIONS:

Although the main objective of PSS is to damp out oscillations it can have strong effect on power system transient stability. As PSS damps oscillations by regulating generator field voltage it results in swing of VAR output [1]. So the PSS gain is chosen carefully so that the resultant gain margin of Volt/VAR swing should be acceptable. To reduce this swing the time constant of the „Wash-Out Filter "can be adjusted to allow the frequency shaping of the input signal [5]. Again a control enhancement may be needed during the loading/un-loading or loss of generation when large fluctuations in the frequency and speed may act through the PSS and drive the system towards instability. Modified limit logic will allow these limits to be minimized while ensuring the damping action of PSS for all other system events. Another aspect of PSS which needs attention is possible interaction with other controls which may be part of the excitation system or external system such as HVDC, SVC, TCSC, FACTS. Apart from the low frequency oscillations the input to PSS also contains high frequency turbine generator oscillations which should be taken into account for the PSS design. So emphasis should be on the study of potential of PSS-torsional interaction and verify the conclusion before commission of PSS [5].

C. PSS INPUT SIGNALS:
Till date numerous PSS designs have been suggested. Using various input parameters such as speed, electrical power, rotor frequency several PSS models have been designed. Among those some are depicted below.

D. SPEED AS INPUT:
A power system stabilizer utilizing shaft speed as an input must compensate for the lags in the transfer function to produce a component of torque in phase with speed changes so as to increase damping of the rotor oscillations.

E. POWER AS INPUT:
The use of accelerating power as an input signal to the power system stabilizer has received considerable attention due to its low level torsional interaction. By utilising heavily filtered speed signal the effects of mechanical power changes can be minimized. The power as input is mostly suitable for closed loop characteristic of electrical power feedback.

F. FREQUENCY AS INPUT:
The sensitivity of the frequency signal to the rotor input increases in comparison to speed as input as the external transmission system becomes weaker which tend to offset the reduction in gain from stabilizer output to electrical torque, that is apparent from the input signal sensitivity factor concept.

II. POWER SYSTEM STABILITY: A PROBLEM

Power system stability is best defined as the ability of an electric power system to regain a state of operating equilibrium after being subjected to a physical disturbance, when variables are bounded so that practically the entire system remains intact [15]. Stability of power system is related to stability of synchronous generator. The mechanical angle between rotor magnetic field and armature magnetic flux of a generator is known as the load angle or power angle. Basically power system stability is a synchronism between rotating field flux and circulating armature flux. Power system stability is classified into different classes based on the variables involved, magnitude of disturbance and time duration of disturbance, as illustrated in Figure 2.

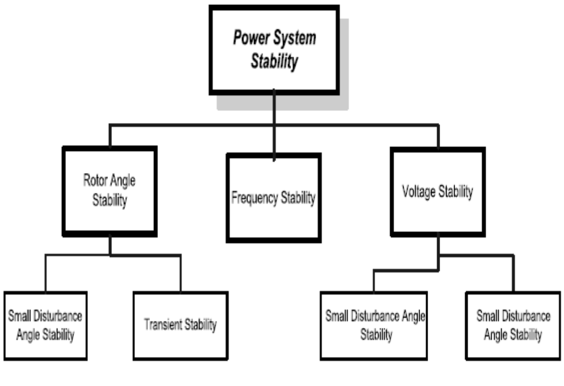

Fig.2- Classification of power system stability

Angle stability is the balance between electromagnetic torque and mechanical torque, whereas voltage stability is akin to match between reactive power generation and consumption. It is hard to draw a clear line of demarcation between these two types of instabilities, since one leads to another. However, it is well-established that voltage instability is caused by load characteristics, whereas angular instability is generator-rotor-dynamics phenomenon. Alternatively, for voltage stability, the vulnerable points of the power systems are generally among load buses, also referred as P-Q bus. Whereas, for angle stability vulnerable points of a system lie within generator buses, also known as P-V bus [16]. Ability of power system to maintain steady state frequency following a severe upset is known as frequency stability. The focus of this paper is transient stability, which is an important subset of angle stability of power system. Transient stability is the ability of a system to remain intact following major disturbances. The time period of interest in transient stability studies generally varies within 3 to 5 seconds and may extend to 10-20 seconds for very large systems, following any disturbance [15]. In addition, transient stability behaviour of power system is best characterized by generator angle and velocity. The problem of transient stability is divided into two main categories; evaluation and prediction [16]. Transient stability evaluation focuses on the time required to isolate faulty section before system becomes instable and it is called critical clearing time. On the contrary, in transient stability prediction the focus shifts to whether transient swings will _nally converge or otherwise.
Power system transient stability can best be explained by equal area criterion [17], illustrated in Figure-3.

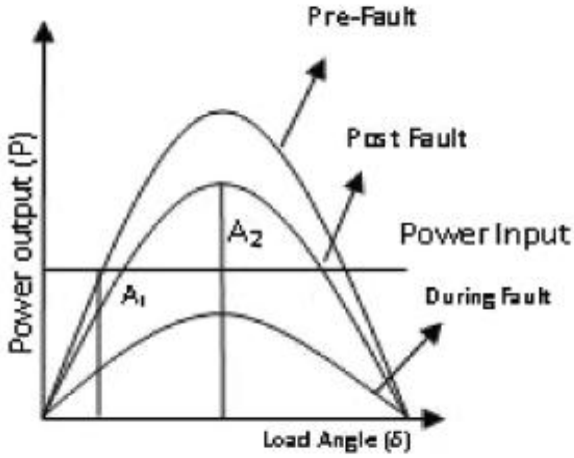

Fig.3- Variation of active power relative to load angle

The difference of input mechanical torque and electrical torque output acting on the rotor of synchronous generator is given by,

$$TA = TM - TEM \quad \ldots\ldots\ldots\ldots(1)$$

Where *TA* is the accelerating torque, *TM* is the mechanical input torque, *TEM* is the induced electromagnetic torque. Area *A*1 in Figure 2 is the accelerating area because resultant of Equation (1) is positive in this case. Whereas *A*2 is called the decelerating area as accelerating torque is negative in this case. As stated by the definition of stability, rotor must remain in a state of dynamic equilibrium for a stable operation. To meet the condition, the magnitude of $A1$ must be either equal to or lesser than $A2$ during any contingency. This can be ensured by either increasing during-fault-curve or post-fault-curve or isolating faulty section in a very short time. Isolation of fault comes under the category of power engineering branch known as power system protection. The former is associated with effective controlling of generators and/or power flow controllers installed at transmission end. The primary control of a power system is carried out at generator end, whereas secondary control is through power flow control at transmission end [18]. Power system stability can be improved by using dynamic controllers as excitation systems, power system stabilizers and FACTS devices [19], controlled islanding [20] and HVDC.

III. POWER SYSTEM STABILITY ENHANCEMENT

Flexible AC Transmission System (FACTS) devices are example of enhancing power systems stability by controlling power flow at transmission end. They are divided into series, shunt and series-shunt categories according to the manner of device connection with the system. The concept behind enhancing power system stability by series FACTS devices such as Static Series Synchronous Compensator (SSSC) is to increase active power flow during faulty condition consequently decreasing area A1 and increasing area A2 [21]. On the other hand, shunt devices as Static Synchronous Compensator (STATCOM) boost power system transient stability by injecting reactive power into system to support the system voltage during disturbance and ultimately leading to decrease of area A1 and increasing area A2 [22]. The most commonly used FACTS controller is Unified Power Flow Controller (UPFC). It consists of two branches; one is connected in series and the other is in shunt with the system. UPFC controller uses notion of both series and shunt FACTS controllers for increasing power system stability effectively than any other FACTS controllers [19,23].Controlled Islanding is a technique in which whole power system is divided into sections, without having any interconnection, to avert major blackouts [15]. Controlled islanding is the last line of defence in strategy to keep power system stable. Additionally, it is not proposed as the answer to all instability problems in the system [20]. High Voltage DC (HVDC) transmission system is potentially a shield against synchronism loss. Nonetheless, it poses problem of voltage instability following disturbance, if the system depletes reactive power reserves [24].The control actions at generator end to thwart the system instability are either in terms of excitation system or power system stabilizers or at mechanical end of power plants. The main cause of transient instability of generator is inability of mechanical torque to quickly balance out changes in electrical torque [15] and also generator rotor inertia plays major role. After disturbance the electrical torque can be resolved into two components, one is synchronizing torque and other is called damping torque given by,

$$\Delta T_E = K_S \Delta\delta + K_D \Delta\omega \quad \text{…….. (2)}$$

Where ΔT_E is load angle also known as torque angle, ω is angular speed and K is constant. The first term of Equation (2) is synchronizing torque. This torque is dependent on air gap magnetic flux and magnetic coupling between rotor and armature of synchronous generator. This component of torque can be enhanced by high initial response Automatic Voltage Regulator (AVR) and negative field forcing capability of Exciter as well [3,24].Excitation system comprises of AVR and Exciter. The second component of Equation (2) is damping torque. It has very profound impact on small signal stability and generator dynamics during transient state following short circuit fault. Damping torque results from the phase lag or lead of excitation current [20,22]. The first swing transient instability is due to lack of sufficient synchronizing torque. Power system can diverge after convergence of first swing mainly because of insufficient damping torque [16].Currently, installed excitation systems are very fast responding systems and can immediately take corrective measures following very small oscillations. Nevertheless, from the time of recognition of desired excitation action to its real fulfilment, there is inevitable time delay owing to high time constant of field and armature windings. During this time period, position of oscillating system is bound to change and thus resulting in need of new excitation adjustment. The overall outcome of this time lag is induction of oscillations at the generator end. Power System Stabilizers (PSS) can effectively be used to damp out generator electromechanical oscillations by minimizing the phase lead and lag between synchronously rotating armature ux and rotor. AVR along with PSS are used to enhance power system stability [15,21].The focus of this research is transient stability enhancement by using efficient controlling at generator end, as it is a primary control.

IV. REVIEW OF DIFFERENT PSS TECHNIQUES

A. PID Control Approach

PID is used for stabilization in the system. The input is the change in speed from the generator. The aim is to control the angle between load and speed of generator. The PSS parameters are tuned from Open loop transfer function to close loop based on Fuzzy logic. Therefore, the open loop transfer function and maximum peak response parameter make the objective function which is used to adjust PID parameters.

B. LAG-LEAD Design

The washout block is used to reduce the over response of the damping during extreme events. Since the PSS produces a component of electrical torque in phase with speed deviation, phase lead blocks circuits can be used to compensate for the lag between the PSS output and the control action(hence lead-lag). It proves its value when the disturbance is multi natured.

C. Pole Placement Method
The pole placement method is applied to tune the decentralized output feedback of the PSS. The objective function is selected to ensure the location of real parts and damping ratios of all electro mechanical modes. At the end of the iterative process, all the electromechanical modes will be moved to the region if the objective function converges to zero [7][8].

D. Model predictive Control
It can handle non linarites and constraints in saturated way for any process model. In these techniques an explicit dynamic model of a plant is used to predict the effect of future actions of manipulated variables on the output.

E. Linear Matrix Inequalities:
The important feature is the possibility of combining design constraints into a single convex optimization problem.it is used in many engineering related problems. The condition that the pole of a system should lay within this region in the complex plane can be formulated as an LMI constraint.

F. Linear Quadratic Regulator
These are well known as compared to lag-lead stabilizers. This is used as a state feedback controller. A co-ordinated LQR design can be obtained with Heffron- Phillips Model and it can be implemented by using the information available within the power system. During the presence of faults even these methods prove to be stable [8].

G. Genetic Algorithm
Genetic algorithm is independent of complexity of performance parameters and to place the finite bounds on the optimized parameters [8]. As a result it is used to tune multiple controllers in different operating conditions or to enhance the power system stability via PSS and SVC based stabilizer when used independently and through different applications.

H. Fuzzy Logic Control
These are rule based controllers. The structure of this logic resembles that of a knowledge based controller; it uses principle of fuzzy set theory in its data interpretation and data logic. It has excellent response with small oscillations. The controller is robust and works effectively under all types of disturbance. It has very short computation time [9] [10].

I. Neural Network
Neural Network is used to approximate the complex non-linear dynamics of power system. Magnitude constraint of the activators is modelled as saturated non-linearity and is used in Lyapnov's stability analysis [9] [10]. The overshoot is nearly same as conventional PSS but settling time is drastically reduced.

J. Anfis PSS
The actual design method may be chosen based on real time application and dynamic performance characteristics. If the training data and algorithm are selected properly then good performance can be observed.

V. PSS: THE EXCITATION SYSTEM MODEL

SIMULINK™ model of the single machine excitation system [5] is given below:-

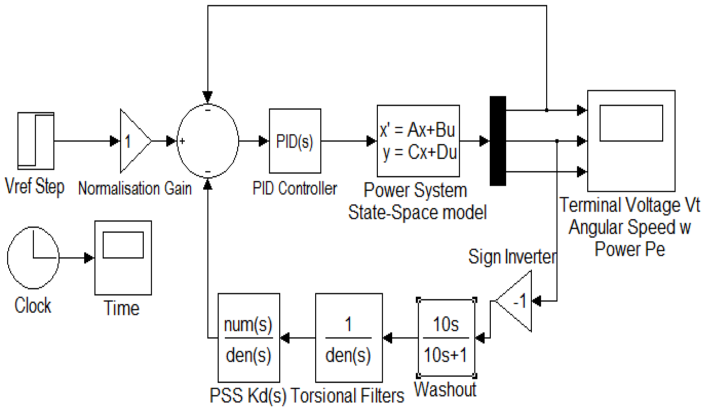

Fig. -4 SIMULINK model of the Single-machine infinite bus [SMIB].

VI. CONCLUSION

From this paper we can study different types of design method of power system stabilizers and also study the concept of power system stability importance. This stabilizer is synthesized using information available at the local buses and makes no assumptions about the rest of the system connected beyond the secondary bus of the step up transformer. As system information is generally not accurately known or measurable in practice, the proposed method of PSS design is well suited for designing effective stabilizers at different system operating conditions. The performance of the proposed stabilizer is comparable to that of a linear quadratic stabilizer and genetic algorithm stabilizer which has been Designed assuming that all system parameters are known accurately.

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