Power System Stability Enhancement Using Fuzzy Based Power System Stabilizer

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***Abstract*— In this paper, simulation results using MATLAB / SIMULINK of conventional and fuzzy type both power system stabilizers are shown. The performance of the proposed model is tested and performed on Single Machine Infinite Bus System (SMIB). By using different K constant, the performance of SMIB system with proposed model has been analyzed under different system condition i.e. SMIB with excitation system, without excitation system , with excitation system along with conventional PSS (lead-lag) and finally a combination of excitation system and fuzzy logic based PSS. The dynamic models for synchronous machine, excitation system, prime mover, governing system and conventional PSS are detailed in this paper.**

***Keywords*— MATLAB®/SIMULINK, modelling and simulation, power system stability, single machine infinitebus power system, Power System Stabilizer, Fuzzy Logic Power System Stabilizer.**

I. INTRODUCTION

Power system stability is the ability of the system to remain in operating equilibrium condition and it is shown equilibrium between opposite forces.

Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. So, for the improvement of power transfer capability with in the safe stability limit it is necessary to enhancing the transient stability of the power system[1].

The objective of this paper is to investigate the enhancement of transient stability on power system via, Power System Stabilizer (**PSS**). For achieving these objectives, two types of power system stabilizers are used. We check the response of different types of power system stabilizers at event of transient condition. Above mention coordination maintained the rotor angle and speed in synchronism.

To accomplish the above necessity with the use of SIMULINK®/MATLAB software. The implementation and simulation carried out on the Single Machine Infinite Bus system.

Transient stability is the ability of power system to maintain synchronism when subjected to sever transient disturbances such as a fault on transmission facilities, loss of generation, or loss of large load. The resulting system involves large excursions of generators rotor angles and is influenced by the nonlinear power angle relationship. Stability depends on both the initial operating state of the system and the severity of disturbance. Fast acting exciters are used for the improvement of transient stability, and this is achieved by modulating the exciter using power system stabilizers. The basic function of a power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using stabilizing signal(s). To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations[5].

In this paper, the Single Machine Infinite Bus System (SMIB) is used for analysis. This SMIB system analysis gives the simple configurations to extremely useful in understanding basic effects and concepts. After that we can able to develop an appreciation for the physical aspects of the phenomena and gain experience with the analytical techniques, using simple low-order systems, we will be in a better position to deal with large complex system For the transient stability analysis we used the single machine connected to a large system through a transmission line.

II. PROBLEM FORMULATION

For performing stability assessment of power system, numbers of suitable mathematical models describing the system are required. The models must be computationally applicable and should be able to represent the essential dynamics of the power system. For this, a brief idea of mathematical model for synchronous machine, excitation system and the lead-lag power system stabilizer is examined (for small signal analysis).

Assume that all the resistances in the system are neglected ,the classical model representation of the generator will change and convert the system representation into figure 1.

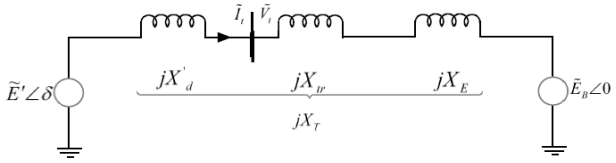

Figure 1: Thevenin's Equivalent Of The Synchronous Generator

In Figure 1, here the infinite bus voltage is shown by $E_{B,}$ X_t is the transfer reactance which combination of direct axis reactance(may be transient) of generator ,transmission line reactance and external circuit reactance.

The pre-disturbance value E` remains constant it is a assumption. Here, E` always lead to infinite bus voltage δ is a factor by which it leads.

A. Equations

The total power of circuit is given by following equation which is complex in nature

$$S = P + jQ' = EI^{*}_{t} = \frac{E'E_B \sin\delta}{X_T} + j\frac{E'(E' - E_B\cos\delta)}{X_T} \quad (1)$$

Here we can take equations of motion (all parameters are in per unit) that is:-

$$P\Delta\omega_r = \frac{1}{2H}[\Delta T_m - K_S\,\Delta\delta - K_D\,\Delta\omega_r] \quad (2)$$

$$P\Delta\delta = \omega_{0\Delta}\omega_r$$

In the vector-matrix form, we obtain

$$\frac{d}{dt}\begin{bmatrix}\Delta\omega_r \\ \Delta\delta\end{bmatrix} = \begin{bmatrix}-\frac{K_D}{2H} & \frac{K_D}{2H} \\ \omega_0 & 0\end{bmatrix}\begin{bmatrix}\omega_r \\ \Delta\delta\end{bmatrix} + \begin{bmatrix}\frac{1}{2H} \\ 0\end{bmatrix}\Delta T_m \quad (3)$$

Where, the speed deviation of generator rotor (in per unit) is denoted by $\Delta\omega_r$ and the inertia constant is H .

Also,

T_m is applied mechanical torque

K_D is the damping torque coefficient

The angle by which rotor falls is known as δ and the unit is in electrical radians the angular speed of rotor is denoted byω_0 (radians/sec).K_s is the synchronizing torque coefficient.

The simplified model of a Static (thyristor) Excitation System is shown in figure 2[2].

A high exciter gain, without transient gain reduction or derivative feedback is used. Parameter T_R represents the time constant of terminal voltage transducer

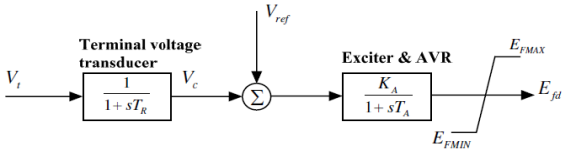

Figure 2: Block Diagram Of Thyristor Excitation System With AVR

The only nonlinearity involved with this model is that due to the ceiling on the exciter output voltage is represented by the terms E_{FMAX} and E_{FMIN} Due to small disturbances these limits are ignored so, here we can assume E_{fd} is always within the limits and in Laplace domain can be given as

$$E_{fd} = \frac{K_A}{1+sT_A}(V_{ref} - V_C) \quad (4)$$

Assuming that V_{ref} is constant during a short period after application of disturbance and by making the equation (2.5) linear, deviation of E_{fdi} with respect to the steady state value is obtained as follows:-

$$\Delta V_t = K_5\Delta\delta + K_6\,\Delta\psi_{fd} \quad (5)$$

$$\Delta E_{fd} = \frac{K_A}{1+sT_A}(-\Delta V_C) \quad (6)$$

In the time domain the equation (6) can be written as

$$\frac{d}{dt}\Delta E_{fd} = -\frac{K_A}{T_A}\Delta V_C - \frac{1}{T_A}\Delta E_{fd} \quad (7)$$

In the time domain equation (5) can be written as

$$\Delta V_C = \frac{K_A}{1+sT_A}\Delta V_t \quad (8)$$

In the time domain equation (8) can be written as

$$\frac{d}{dt}\Delta V_C = \frac{1}{T_R}(\Delta V_t - \Delta V_C) \quad (9)$$

In order to obtain the state-space representation of the system ,the state vector should be defined again equation introduce two new state variables that is ΔV_C and ΔE_{fd} .Although, ΔV_t is not a state variable and should be expressed in terms of other state variables. So we can write that

$$\Delta\omega_r = \frac{K_A}{2H_S + K_D}(\Delta T_m - \Delta T_e) \quad (10)$$

$$\Delta\psi_{fd} = \frac{K_3}{1+sT_3}[\Delta E_{fd} - K_S\,\Delta\delta] \quad (11)$$

The positive values are assigned to the constants K_2, $K_3$and K_4 which is shown in above equations .The positive value of damping torque is introduced in system when positive values assigned to K_4 by varying the field flux (due to armature reaction) in such that manner. There is so many possibilities where K_4 to be negative. For example when light load is connected to a hydraulic generator having no damper windings and connection is made through a line of relatively low reactance to resistance or high R/X ratio to a large system.

III. METHODOLOGY

In this paper, a SMIB is implemented with conventional \PSS and fuzzy based PSS to check enhanced stability of Power System. The main function of a PSS is to provide damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. To enable damping, the stabilizer must give rise to a component of electrical torque in phase with the rotor speed deviation[7].

A. CPSS(Conventional power system stabilizer)

For convenience a conventional PSS is designed by two stage (identical), lead/ lag network which is shown by a gain K_{STAB} and two time constants T_1 and T_2 . This network is connected with a washout circuit of a time constant T_w as shown in Figure 3.

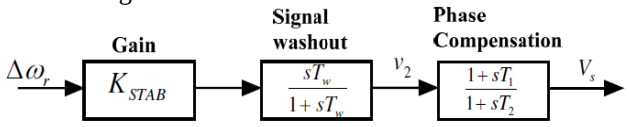

Figure 3.Block Diagram Of PSS

In Figure 3, to compensate the phase lag between output i.e. electric torque of generator and input of exciter, a suitable phase lead characteristics is required. This need is fulfilled by a block named as phase compensation block. The phase compensation unit may consists of a single first order block or two or more first order blocks or second order blocks with complex roots.

The signal washout unit acts as high pass filter, having the time constant T_W high enough to allow signals associated with oscillations in ω_r to pass invariably, which removes D.C. signals. Without this unit steady changes in speed would modify the terminal voltage. So this unit allows PSS to respond only to changes in speed.

The value of the Stabilizer gain K_{STAB} determines the amount of damping required by PSS. Ideally, the maximum damping is achieved from the particular value of the gain but some other consideration restricts the choice of gain value.

B. FPSS(Fuzzy based power system stabilizer)

When a logical mathematical model of the plant is unavailable then FLCs can be used; however system can be controlled by few quality modes which can be done by some learned persons. Fuzzy logic is a method which is a basis of fuzzy logic control, and which is almost similar to human intelligence. The uncertain nature of one knowledge about the actual world can be captured by using this mode. With respect to this, the main part of a fuzzy logic controller (FLC) is dual concept of inference rules and fuzzy logic applications.

An automatic control strategy can be attained by converting a control strategy using an intelligent computer program which is provided by the FLC. When the analysis is done by using some quantity techniques the FLC turns out to be of great use, whereas the process is actually very difficult[9].

The importance of fuzzy logic is useful from the actuality that mostly of human intelligence and especially reasoning is normally an approximation in universe. While carrying out so, the fuzzy logic method allows the designer to handle efficiently very complex closed--loop control problems. There are numerous artificial intelligence techniques available which can be used in modern power systems, but fuzzy logic has become a strong means for finding a solution for this kind of various difficult problems.

In comparison to the traditional PSS, the Fuzzy Logic Controller (FLC) has few edges such as:

1. A simple and quick methodology.
2. It doesn't require any exact systematic mathematical model.
3. It can also take care of nonlinear arbitrary complexity.
4. It uses language based rules with an IF-THEN general structure, which uses underlying principle of human logic.
5. It is more exact and appropriate than that of traditional nonlinear controllers.

The different fuzzy inference systems are common computer algorithms based on the fundamentals of fuzzy set theory, and fuzzy logics.

The fuzzy inference system normally contains inference of the mapping from a particular input set to a given output set using FL as shown. The ultimate base from which the result or conclusion are made are being provided by mapping process. The three logical elements gives the overall basic structure: a rule base, which provides selection of the fuzzy rules; a data base, which defines the membership functions used in the fuzzy rules; and a reasoning mechanism which drives the entire inference procedure without any external driving factor on the rules and given logics to formulate a logical output or desired results.

The fuzzy logic controller is comprised of 4 most important factors: fuzzification interface, knowledge base, decision making logic, and defuzzification interface.

- *Fuzzification:* In this process, the values of input elements are determined i.e. the process transforms the input data into appropriate language based values.
- *Knowledge base:* The knowledge base contains a database which is language based. The database of the program in itself provides the necessary information, which are then helpful to define the language based control rules and fuzzy data manipulation in an FLC. The rule base segregates the control policy of domain experts by using various set of language based control rules[3].
- *Decision making logic:* The decision making logic can be defined as the ability of reasonable human intelligence based on fuzzy concepts.
- *Defuzzification:* The basic modus operandi of defuzzification is scale mapping, in which the range of values of output variables is converted into corresponding universe of discourse. The system is called as non-fuzzy logic decision system if the output is a control action for a given process. There are various known methods for defuzzification like as centroid, height and maximum method,

The common inference process comprises of the following five steps:

Step 1: Input variables are fuzzyfied.

Step 2: Fuzzy operator (AND, OR, NOT) is applied in the IF (antecedent) part of the rule

Step 3:Applying the antecedent to the consequent THEN part

of the rule

Step 4:The consequents across the rules are aggregated

Step 5:Defuzzification

The design starts with imparting the mapped variables inputs output of the fuzzy logic controller (FLC). Generator speed deviation is the first input variable and the second is acceleration. Voltage is the output variable to the FLC.

Centroid Method

Centroid Method is also commonly called as centre of gravity method, it finds out the centre of area Z* which is occupied by the fuzzy set A of universe of discourse Z. It can be represented by the equation for a continuous membership function and for a discrete membership function.

After the selection of applicable variables as input and output of fuzzy controller, it is imperative to decide on the language based variables. These variables are used to convert the numerical values of the input of the fuzzy controller to fuzzy quantities. The quantity of language based variables describing the fuzzy subsets of a variable keeps on changing in accordance to the application. We are using seven language based variables for every input and output variables. The below table shows the Membership functions for fuzzy variables. The crisp values are converted fuzzy variables using membership function. Triangular membership functions are used to define the degree of membership. All input variable are represented using, seven labels and are defined namely, NB, NM, NS, ZE, PS, PM and PB. To form a set of seven membership functions for each fuzzy variable subset is associated with a triangular membership function. The variables are normalized by multiplying with respective gains K_e,$K_{,,}$,$K0$ in order to keep their values between -1 and +1.

Table1.A Set Of Seven Membership Functions For Each Fuzzy Variable

Acceleration Speed Deviation	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NS	ZE	ZE	PS
NM	NB	NB	NM	NS	ZE	PS	PM
NS	NB	NB	NM	ZE	PS	PM	PB
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NB	NM	NS	ZE	PM	PB	PB
PM	NM	NS	ZE	PS	PM	PB	PB
PB	NS	ZE	ZE	PS	PB	PB	PB

IV.IMPLEMENTATION

The system contains a generating unit which is connected to an infinite bus using a transformer and a pair of transmission lines. The terminal voltage of the generator is controlled by the use of an excitation system and automatic voltage regulator. And the governor unit regulates the shaft frequency and controls mechanical power[4].

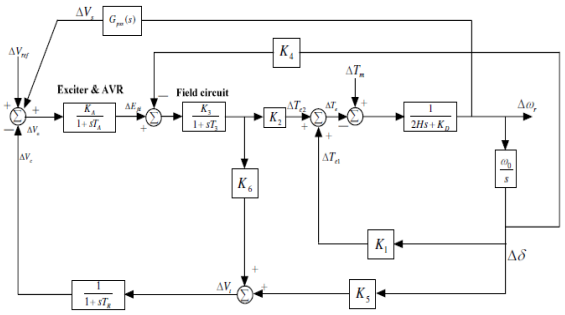

Figure 4. Block Diagram Of A Linear Model Of A Synchronous Machine With A PSS

An introduction of additional damping torque is provided by power system stabilizer to solve its basic purpose. ω_r is a signal which is uses as a input of PSS . If the transfer function of generator and the transfer function of exciter are constant gains terms, a component of damping torque is used as direct feedback of change in angulr speed. Although, both transfer functions (exciter and generator) having phase and gain characteristics are depend upon frequency[10].Therefore, to compensate the lagging of phase between the output of generator (electrical torque) and the input of exciter a suitable phase compensation network is required. So the transfer function of conventional PSS solves the above problem. At all oscillating frequencies the conventional PSS offers a component having pure damping torque only when the phase characteristics of transfer function of PSS exhibits an inverse of the phase characteristics of generator and the exciter.

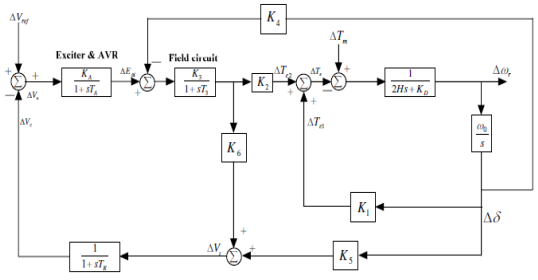

Figure 5.Block Diagram representation of system with AVR and excitation

When a large local load is connected to a machine, contributed partially by the remote large system and partially by the generator is another possibility of K_4 to be negative. The negative damping torque is produced when a torque is generated which has component out of the phase with synchronizing torque and this type of component is generated by induced currents in the field of machine(caused by armature reaction) only with the negative values of K_4.

The value is always positive for coefficient K_6. The parameters(impedences) of external network and the operating conditions of system will decide the sign of constant K_5(either positive or negative) . The Automatic voltage regulator and damping of the system Oscillations is highly effected by the value of K_5[6]. When K_5 is positive, the effect of the AVR is to introduce a negative synchronizing torque and a positive damping torque component. For the low value of generator output and the low value of reactance of externally connected system, the value is positive for constant parameter K_5.

V. RESULTS AND CONCLUSIONS

A .Results

1. *Performance with Conventional PSS*

Figure 6 shows the variation of angular speed and angular position with respect to time when the conventional PSS (lead-lag) is applied for positive value of K5.

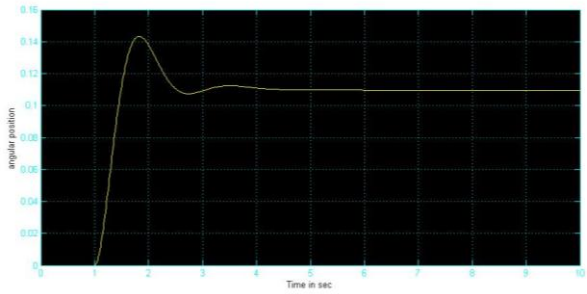

Figure 6 .Response Of System With Excitation And CPSS

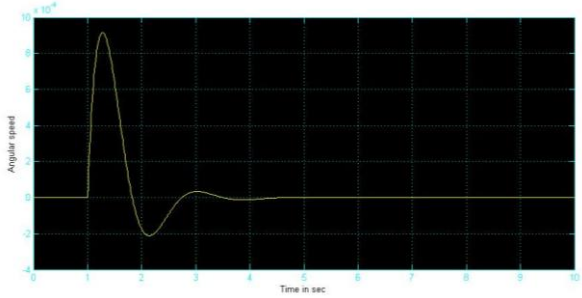

Figure 7.Response Of System With Excitation And CPSS

From the Figure 6 it shows that the system is stable for positive value of K5. The system will also stable for negative value of *K5* constant. But the major difference transients are more for negative constant K5 whereas by the positive value of K5 higher angular position is achieved.

2. *Performance of SMIB using FL Based PSS*

To see the effect on damping of low frequency oscillations, fuzzy logic controller model is implemented in Simulink of MATLAB when fuzzy based PSS is implemented on single machine infinite bus system.

The variation in angular speed of rotor with respect to time and angular position of rotor with respect to time is shown in figure 8 and 9 when the positive value of K_5 is selected in fuzzy logic based PSS model.

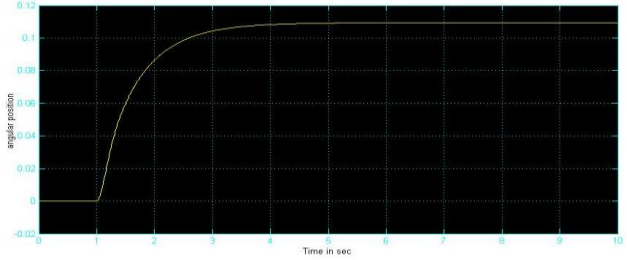

Figure 8 .Response Of System With Fuzzy Based PSS

With using a fuzzy based power system stabilizer how the angular speed varies with respect to time. Here a positive value is assigned to K_5 constant is shown in figure 8.

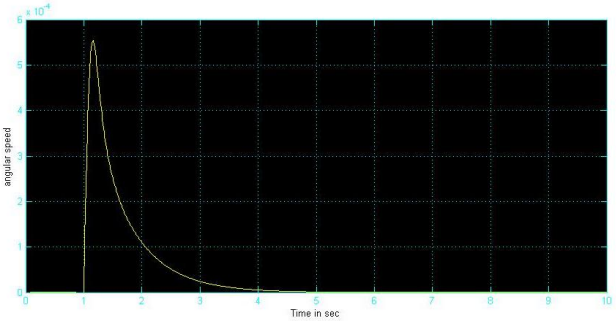

Figure 9.Response Of System With Fuzzy Based PSS

For negative value of K_5constant, the angular position and angular speed settles down to a steady state value with small number of oscillations for negative value of K_5constant. For positive value of constant K_5 angular position attains higher value(with fuzzy logic PSS) than conventional PSS.

B .Conclusion

If a comparisons made between fuzzy logic based and conventional PSS. the response is better in the case of fuzzy based PSS. Also there is no need of complex mathematics in the fuzzy logic controller.

The Conventional power system stabilizer (CPSS) damps the low frequency oscillations at the shaft speed of a synchronous machine connected to infinite bus. Since it is designed on the basis of a block diagram of the system derived for a specific operating point, the CPSS has the good response for this particular operating point. If the operating point of the system changes, the performance of the CPSS will degrade and we have to choose other option.

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