Enhancement Of Power System Stability Using Fuzzy Logic Based Power System Stabilizer

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Abstract

Electromechanical oscillations in a power system often exhibit poor damping when the power transfer over a corridor is high relative to the transmission strength. Traditional approaches to aid the damping of power system oscillations include the use of Power System Stabilizers (PSS). Power system stabilizers are used to generate supplementary control signals for the excitation system in order to damp out the low frequency power system oscillations. This paper describes the design procedure for a fuzzy logic based PSS (FLPSS). Speed Deviation of a synchronous machine and its derivative are chosen as the input signals to the FLPSS. The inference mechanism of the fuzzy logic controller is represented by 49 if-then rules. The proposed technique has the features of a simple structure, adaptivity and fast response and is evaluated on a Single machine and Multi machine Power system under different operating conditions to demonstrate its effectiveness and robustness.

Keywords— Power system oscillations, Power system stabilizer(PSS), Fuzzy logic based PSS (FLPSS), Conventional PSS (CPSS).

I. INTRODUCTION

The occurrence of low frequency electromechanical oscillations as synchronizing power flow oscillations on transmission lines, is a direct consequence of dynamical interactions between synchronous generators when the system is subjected to perturbations [1]-[4]. This phenomenon occurs due to dynamical interactions between groups of generators (a group oscillates against another group), or between one generator (or group of generators) and the rest of the system. The first case characterizes the inter-area modes and the second one the local modes of oscillations and they normally have frequencies in the range of 0.1 to 0.7 Hz and 0.7 to 2.0 Hz, respectively [5]. These modes are worth paying attention because they have low natural damping, which can be either very reduced or negative, mainly due to the voltage regulator action and high loading of the power system. This may have Disastrous consequences to the interconnected Systems stability, leading to partial or total collapses (blackouts) [6].

The most common control action to enhance damping of the power system oscillations is the use of Power System Stabilizers (PSSs). The function of this device is to extend stability limits by modulating generator excitation to provide damping to the electromechanical oscillations [7]-[9]. They provide good damping; thereby contribute in stability enhancement of the power systems.

Designing PSS is an important issue from the view point of power system stability. Conventional PSSs (referred to as CPSSs) use transfer functions designed for linear models representing the generators at a certain operating point [10, 11]. However, as they work around a particular operating point of the system for which these transfer functions are obtained, they are not able to provide satisfactory results over wider ranges of operating conditions. In other words, according to the fact that the gains of the mentioned controller are determined only for a particular operating condition, they may not yet be valid for a wider range around or for other new conditions [12].

This problem is overcome by using Fuzzy logic based technique for designing of PSSs. Fuzzy logic systems allow us to design a controller using linguistic rules without knowing the exact mathematical model of the plant [13, 14]. The application of fuzzy logic based PSSs (FLPSSs) has been motivated because of some reasons such as improved robustness over that obtained using conventional linear control algorithm, simplified control design for difficult-to-be modeled systems and simplified implementation [9, 15]. Fuzzy logic controllers (FLCs) are very useful in the case where a good mathematical model for the plant is not available; however, experienced human operators are available for providing qualitative rules to control the system. In some papers to improve the performance of FLPSSs, a hybrid FLPSS is presented. In [16], a FLC is used with two CPSSs, also Hybrid PSSs using fuzzy logic and/or neural networks or Genetic Algorithms have been reported in some literature [17, 18].

However, there is no systematic procedure for designing FLCs. The most common approach is to define Membership Functions (MFs) and IF-THEN rules subjectively by studying an operating system or an existing controller. So, an adaptive network based approach was presented in [19] to choose the parameters of fuzzy system using a training process. In this technique, an adaptive network was used to find the best parameter of fuzzy system.

The proposed method is illustrated on a Single machine and 3-machine 9-bus power system. MATLAB/SIMULINK and fuzzy logic toolbox have been used for system simulation. The results demonstrate that the proposed FLPSS provides a good damping over a wide range of operating conditions and improves the stability margin of the system as well.

II. EXCITATION SYSTEM MODEL

Excitation system is one of prime importance for the proper operation of synchronous generators. The excitation system can be as simple as a fixed dc power supply connected to the rotor's winding of the synchronous generators. The primary function of a synchronous generator excitation system is to regulate the voltage at the generator output. On other words, using the excitation system in any synchronous machine is to control the field current injected to the rotor. The point of controlling the field current is to regulate the terminal voltage of the machine and maintaining the terminal voltage constant and hence keeping the synchronization of the generator.

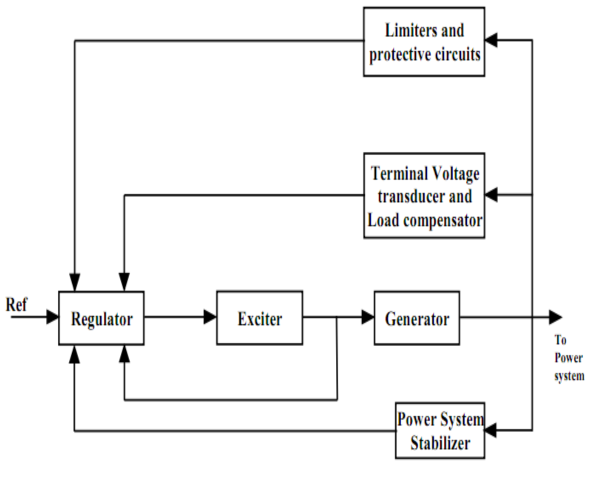

Fig. 2.1 Block Diagram of Excitation system

III. SYSTEM MODELLING

Modeling of the system is an important part of the design. This chapter presents the modeling of the system parts which are; Synchronous machine, Automatic Voltage Regulator and the Power system stabilizer.

3.1 Full order model

The state space form of the synchronous generator model has two main sets of variables which are flux linkages and currents. But these two sets are mutually dependent so, one of them can be eliminated and express in terms of the other.

3.2 Single machine connected to infinite bus linear model

The synchronous generator experience an oscillatory period which can be classified into a transient period and a steady state or dynamic period .The transient period is the first cycles after the disturbance. The consideration on dynamic area reduces the system model to the third order model. Since the interest of this paper is to look after small change in the system, the linearized third order model is sufficient for the analysis. The simplified third order model of synchronous generator connected to infinite bus through a transmission line having resistance Re and reactance Xe has the following assumption over the full order model:

1. Stator winding resistance is neglected.
2. Balancing conditions are assumed and saturation effects are neglected.
3. Damper winding effect is neglected.

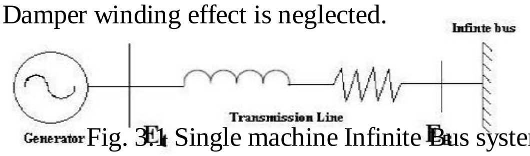

Fig. 3.1 Single machine Infinite Bus system

3.3 Multi machine power system model

The single line diagram of a 3-machine 9-bus power system model shown in Fig.3.2 is used to examine inter-area oscillation control problem. In Fig. 3.2, the generator G1 is considered as reference bus. This system is created especially for the analysis and study of the inter-area oscillation problem [5]. The base MVA is 100 and the system frequency is 50 Hz.

This system exhibits inter-area mode of electromechanical oscillations whose frequency varies from 0.35 to 0.75 Hz depending on the operating conditions. Two sets of Conventional PSSs are used; one for the generator (G2) and another one for the generator (G3).

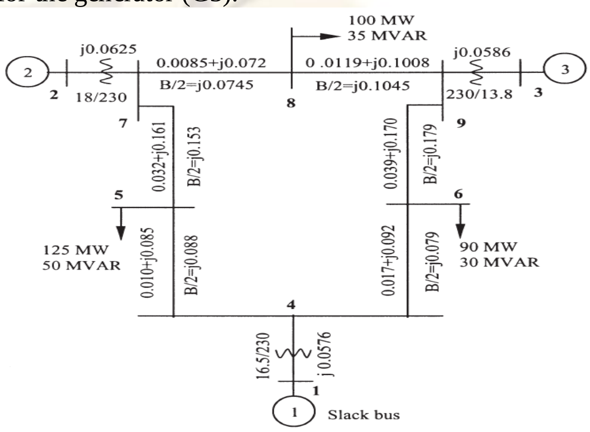

Fig. 3.2 Single Line diagram of 3-machine 9-bus system

4 FUZZY LOGIC POWER SYSTEM STABILIZER

The fuzzy logic control algorithm reflects the mechanism of control implemented by people, without using any formalized knowledge about the controlled object in the form of mathematical models, and without an analytical description of the control algorithm. Here control strategy depends upon a set of rules, which describes the behavior of the controller[8]. It generally comprises four principle components: fuzzification interface, knowledge base, decision making logic and defuzzification interface. In fuzzification, the value of input variables are measured i.e. it converts the input data into suitable linguistic values.

The knowledge base consists of a database and linguistic control rule base. The database provides the necessary definitions, which are used to define the linguistic control rules and fuzzy data manipulation in a fuzzy logic controller[13].The rule base characterizes the control policy of domain experts by means of a set of linguistic control rules. The decision making logic has the capability of stimulating human decision making based on fuzzy concepts.

The defuzzification performs scale mapping, which converts the range of values of output variables into corresponding universe of discourse. If the output from the defuzzifier is a control action for a process, then the system is a non-fuzzy logic decision system.

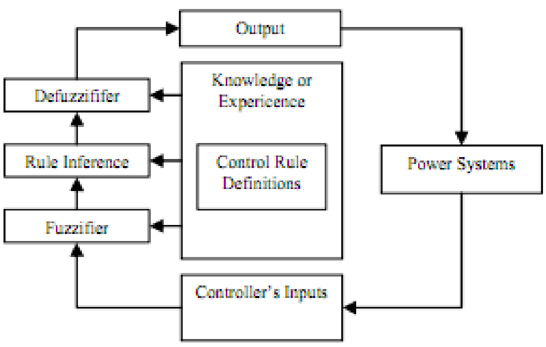

Fig. 4.1 Design Procedure of FLC

The initial step in designing the FLPSS is the determination of the state variables which represent the performance of the system. The input signals to the FLPSS are to be chosen from these variables. The input values are normalized and converted into fuzzy variables. Rules are executed to produce a consequent fuzzy region for each variable. The expected value for each variable is found by defuzzifying the fuzzy regions. The speed deviation ($\Delta\omega$) of the synchronous machine and its derivative ($\Delta\dot{\omega}$) are chosen as inputs to the FLPSS and the output is the stabilizing signal U_{PSS} .

The proposed controller also uses 7 linguistic variables such as: Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Medium (NM) and Negative Big (NB). The membership functions are chosen to be Triangular. The defuzzification of the variables into crisp outputs is tested by using the center of gravity (COG) method.

The two inputs: speed deviation and acceleration, result in 49 rules for each machine. Decision table in 2 shows the result of 49 rules, where a positive control signal is for the deceleration control and a negative signal is for acceleration control.

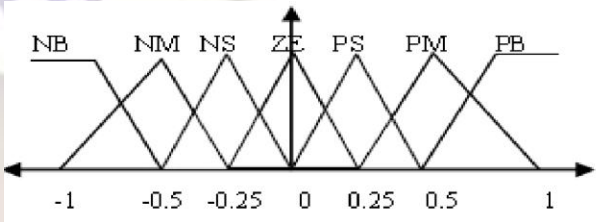

Fig. 4.2 Membership functions of Input/ Output

Speed deviation	**Acceleration**						
	NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	ZE
NS	NM	NM	NS	NS	ZE	ZE	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	ZE	ZE	PS	PS	PM	PM
PM	ZE	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

Table 4.1 Decision Table of 49-rules

SIMULATION RESULTS

5.1 Performance Analysis of Proposed Fuzzy based PSS:

The system is simulated using MATLAB/Simulink toolbox. The models of the synchronous machine, PSS and the excitation system are linked together to form the overall system representation. A number of studies involving variety of tests at different system and operating conditions have been conducted to evaluate the efficacy of the proposed stabilizer.

All results are compared with the performance of a conventional PSS. An illustrative set of results are presented in the following section. For now onwards, the conventional PSS has been referred to as CPSS and proposed Fuzzy based PSS as FLPSS.

5.2 Results

The following set of results are designed for different operating conditions using Fuzzy Logic Based Procedure and are compared with the conventional PSS and without PSS.

(i) **Single machine connected to infinite bus**:-

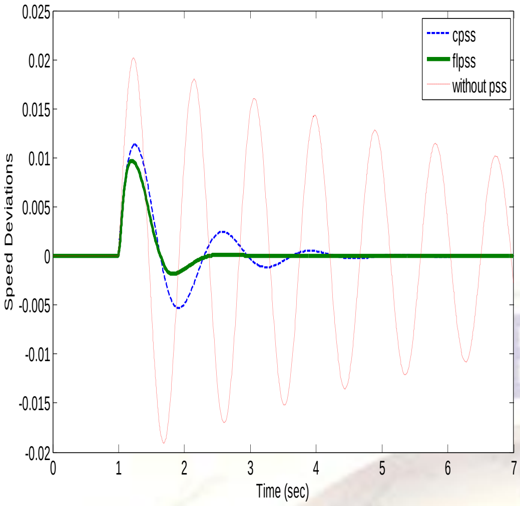

Fig 5.1 Speed changes for S_T=0.9+j0.3, X_E=0.65

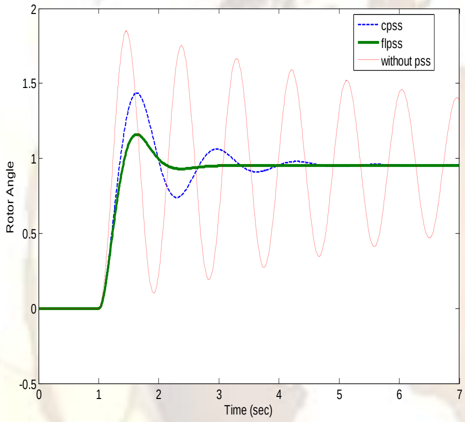

Fig 5.2 Rotor Angle Deviations for S_T=0.9+j0.3, X_E=0.65

(ii) **Multi Machine System:-**

The following set of results is carried out for 3-machine and 9-bus system at a particular fault clearing time of 0.5 sec

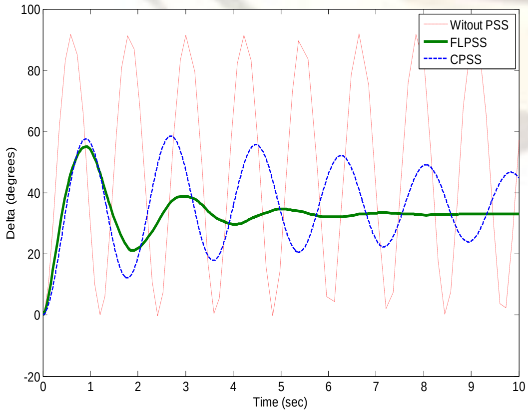

Fig 5.3 Rotor Angular Position of Generator-2

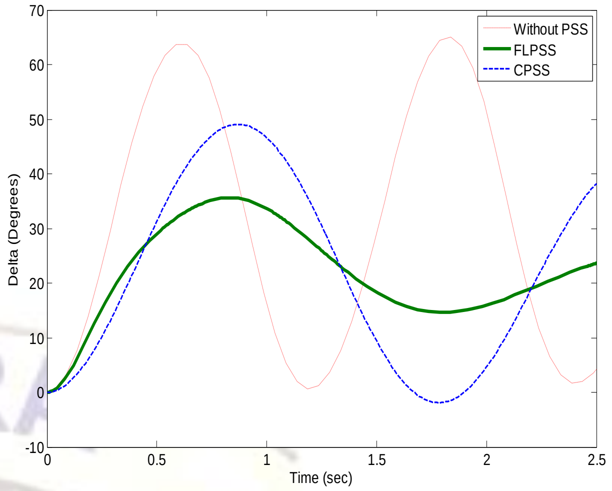

Fig 5.4 Rotor Angular Positions of Generator -3

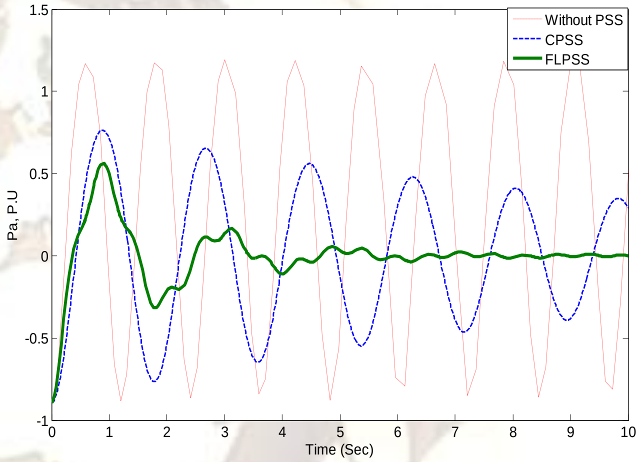

Fig 5.5 Generator-1 Accelerating Power

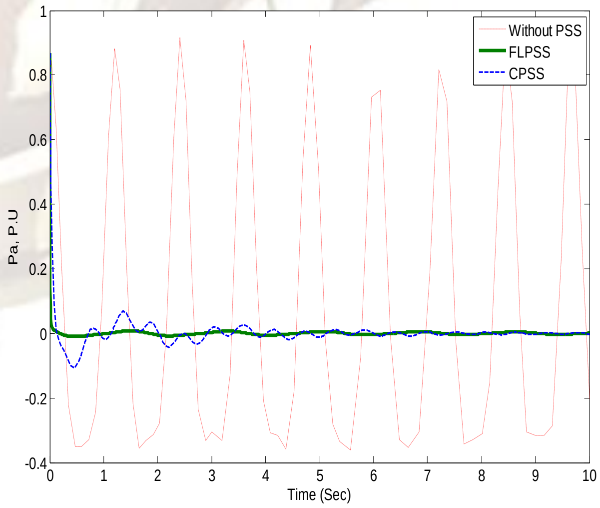

Fig 5.6 Generator -2 Accelerating Power

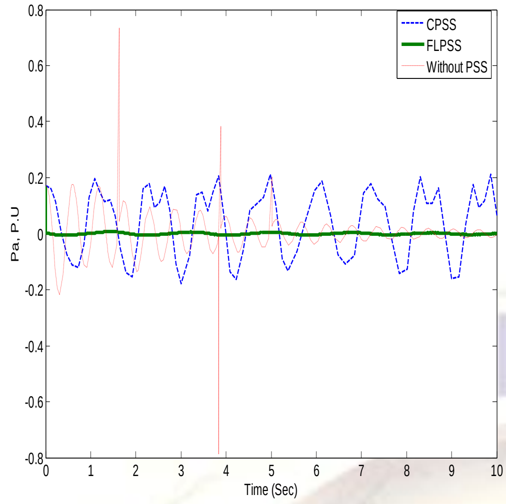

Fig 5.7 Generator-3 Accelerating Power

5.3 Discussions:

- The Comaprisions from the figures 5.1 to 6.0 the "Settling time" is more improved for the Fuzzy based method when compared with Conventional based technique for all operating conditions both in case of Single Machine and Multi Machine Power systems.
- The Overshoot ranges are also improved for the Fuzzy based techniques compared to Conventional technique in all operating conditions.
- The FLPSS, though rather basic in its control proves that it is indeed a good controller due to its simplicity.
- Simulation result shows that for different operating conditions, the fuzzy logic power system stabilizer (FLPSS) has increased the damping of the system causing back to it steady state in much less time than the conventional power system stabilizer (CPSS).

5 CONCLUSIONS

- The main Contribution of this paper is to design and implement an optimal PSS based on two different and advanced Fuzzy logic based techniques and to compare the obtained final response.
- The Dynamic behavior and stability enhancement aspects are also studied in this paper.
- The proposed PSS design using Fuzzy Logic method enhances system response and provides good damping to the system Oscillations compared to Conventional technique.
- Such a nonlinear fuzzy based PSS will yield better and fast damping under small and large disturbances even with changes in system operating conditions.
- Better and fast damping means that generators can operate more close to their maximum generation capacity. This ensures that generators remain stable under severe faults such as three phase short circuits.

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Appendix:-

(i) Single machine system:

Synchronous Machine constants:-

X_d=1.81 p.u, X_d^1=0.3 p.u, X_q=1.76 p.u, R_E=0.003 p.u

T_{do}^1=8.0 sec, H=3.5 sec, K_D=0, f=50Hz

Excitation system constants:-

K_A=200 T_A=0.05 T_R=0.02

Conventional PSS data:-

K_{stab}=17.5, T_w=5sec, T_1=0.154sec, T_2=0.033sec

(ii) Multi machine system:

Generators Data:-

Generator G2:--

X_d=0.8958 p.u, X_d^1=0.1198 p.u, X_q=0.8645 p.u,
T_{do}^1=6sec, H=6.4 sec, K_D=0, f=50Hz, X_E=0.4
R_E=0.003p.u K_A=50 T_A=0.05 T_R=0.02

Generator G3:--

X_d=1.3125 p.u, X_d^1=0.1813 p.u, X_q=1.2578 p.u,
T_{do}^1=5.89sec, H=3.01 sec, K_D=0, f=50Hz, X_E=0.4
R_E=0.003p.u K_A=50 T_A=0.05 T_R=0.02

Conventional PSS data:-

K_{stab}=4, T_w=3sec, T_1=0.1537sec, T_2=0.1sec