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Design of Fuzzy Based Power System Stabilizer for a Multimachine System

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Abstract: Power System Stabilizer (PSS) is installed in the Automatic Voltage Regulator (AVR) of the generator; it must be capable of providing appropriate stabilization signals over a broad range of operating conditions and disturbances. Traditional PSS rely on robust linear design methods. In an attempt to cover a wide range of operating conditions, expert or rule based controllers have also been proposed. Fuzzy logic as a robust control design method has shown promising results. In this study, a systematic approach to fuzzy logic control design is proposed In order to accomplish the stability enhancement speed deviation ($\Delta\omega$) and acceleration power deviation (Δp) of the rotor synchronous generator have been taken as the inputs to the fuzzy logic controller. These variables take significant effects on damping the generator shaft mechanical oscillations. The stabilizing signals have been computed using fuzzy membership function depending on these variables. This thesis presents a study of fuzzy logic power system stabilizer for stability enhancement of multi-machine system, represents a real time system which is executed by one of the thermal power station of TNEB. The performance of the system with fuzzy logic PSS is compared with the system having conventional PSS and the system without PSS.

Key words: AVR, FLPSS, CPSS, PSS, FLC, TNEB

INTRODUCTION

Power system stability may be broadly defined as 'a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance'. Instability in a power system may be manifested in many different ways depending on the system configuration and operating mode. Traditionally, the stability problem has been one of the maintaining synchronous operations. Since, power systems rely on synchronous machines for generation of electrical power, a necessary condition for satisfactory system operation is that all synchronous machines remain in synchronous or, colloquially, "in step". This aspect of stability is influenced by the dynamics of generator rotor angle and power- angle relationships.

The understanding of stability problem is greatly facilitated by the classification of stability into various categories (Singh and Sen, 2003; Majid *et al*., 2002; Kundur, 1994). An effective way to meet the conflicting exciter performance requirements with regard to system stability is to provide a power system stabilizer, but the corresponding fuzzy stabilizer's design (traditional PSS, stabilizers based on nonlinear control theory, robust control theory) depends on detailed mathematical models. Because of the increasingly large scale and emerging uncertain factors and much more complicated mathematical models, the analysis and control of Low-Frequency Oscillations (LFO) become more difficult (Esfahani *et al*., 2000). The conventional power system stabilizers work at the particular network configuration and steady state conditions for which they have been designed. Once the conditions change, the performance degrades (Hiyama, 1989). This can be overcome by an intelligent non- liner PSS based on fuzzy logic. The fuzzy logic based controllers are model-free controllers, i.e., the exact mathematical model of the controlled system is not required. The control strategy depends upon the set of rules which describes the behavior of the controller (Hiyama, 1990). The ability to handle changes in plant parameters due to the changes in operating

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conditions, system conditions and the ability of self tuning of parameters to a certain extent is in-built in such design process (Klein *et al*., 1992; Rajasekaran and Vijayalakshmipai, 2001). Such a Fuzzy Logic based Power System Stabilizer (FLPSS) is developed, using speed deviation and accelerating power deviation, as inputs and provide an auxiliary signal for the excitation system of synchronous machines. In this project, the FLPSS's effect on the system damping is then compared with a conventional PSS and without PSS.

POWER SYSTEM STABILIZER

In power system network, when there is a mismatch between generation and the demand or the sudden change of load causes an oscillations in generator rotor. The basic function of a PSS is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals. To provide damping the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations.

The theoretical basis for a PSS may be illustrated with the aid of the block diagram shown in Fig. 1. Since the purpose of a PSS is to introduce a damping torque component, a logical signal to use for controlling generator excitations is the speed deviation $\Delta\omega$.

If the exciters transfer function $G_{ex}(s)$ and the generator transfer function between ΔE_{fd} and ΔT_e were pure gains, a direct feed back of $\Delta\omega_r$ would result in a damping torque component. However, in practice both the generator and the exciter (depending on its type) exhibit frequency dependent gain and phase characteristics. Therefore, the PSS transfer function, $G_{PSS}(s)$, should have appropriate phase compensation circuits to compensate for the phase lag between the exciter input and the electrical torque. In the ideal case, with the phase characteristics of $G_{PSS}(s)$ being an exact inverse of the exciter and generator phase characteristics to be compensated, the PSS would result in a pure damping torque at all oscillating frequencies.

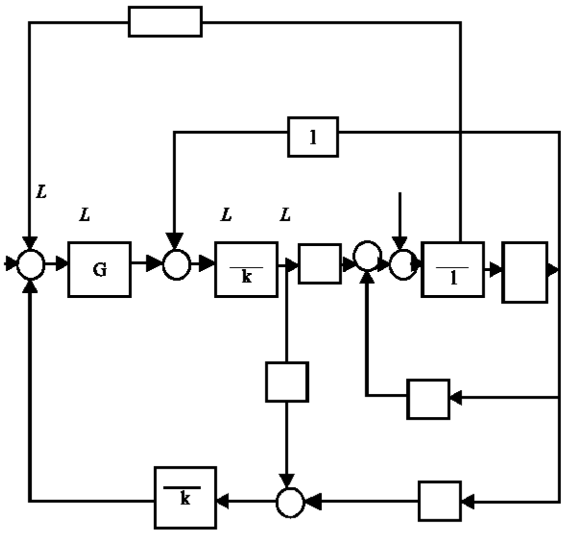

Fig. 1: Block diagram representation with AVR and PSS

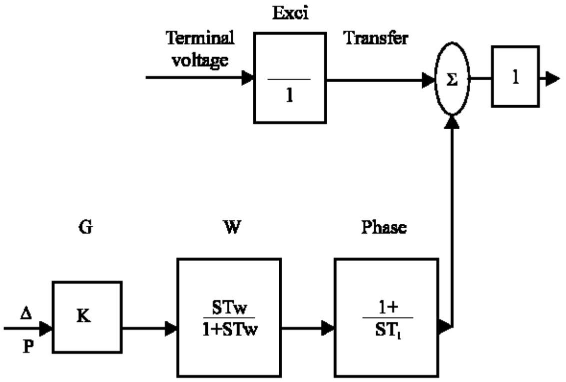

Fig. 2: Block diagram of conventional PSS

It should be recognized that the generator model assumed in the representation shown in Fig. 2 neglects amortisseurs to simplify the system model and allow its representation in the form of a block diagram. However amortisseurs could have a significant effect on the generator phase characteristics and should be considered in establishing the parameters of the PSS.

FUZZY LOGIC

Fuzzy logic emerged into the mainstream of information technology in the late 1980s and early 1990s. Fuzzy logic is a derivative from classical Boolean logic and implements soft linguistic on a continuous range of truth values to be defined between conventional binary. It can often be considered a suspect of conventional set theory. Since, fuzzy logic handles approximate information in a systematic way, it is ideal for controlling non-liner systems and fro modeling complex systems where an inexact model exists or systems where ambiguity or vagueness is common. A typical fuzzy system consists of a rule base, membership functions and an inference procedure (Timothy, 1997). Today, fuzzy logic is found in a variety of control applications including chemical process control, manufacturing and in such consumer products as washing machines, video cameras and automobiles.

Fuzzy logic is a suspect of conventional Boolean logic that has been extended to handle the concept of partial truth- truth-values between "completely true" and "completely false".

Zadeh says that rather than regarding fuzzy theory as a single theory, we should regard the process of fuzzification as a methodology to generalize ANY specific theory from a crisp (discrete) to a fuzzy (continuous) from. Thus recently researchers have also introduced "fuzzy calculus" and "fuzzy differential equations".

Fuzzy rule base: Fuzzy logic has been centered on the point that it makes use of linguistic variables as its rule base. Li-Xin Wang said that "if a variable can take words in natural language as its values, it is called linguistic variable, where the words are characterized by fuzzy sets defined in the universe of discourse in which the variable is defined." Examples of these linguistic variables are slow, medium, high, young and thin. There could be a combinations of this variable too, i.e. "slow-young horse", "a thin young female." These characteristics are termed atomic terms while their combinations are called compounded terms. In real world, words are often used to describe characteristics rather than numerical values. For example, one would say "the car was going at 100 miles per hour." Terms such as slightly, very, more or less, etc. are called linguistic hedges since they add extra description to the variables, i.e. very-slow, more or less red, slightly high, etc. At the heart of the fuzzy rule base are the IF-THEN rules.

A fuzzy IF-THEN rule is expressed as,

IF<fuzzy proposition>, THEN <fuzzy proposition>

Propositions are linguistic variables or atomic terms as described previously. This type of rile-based system is different from the classical expert systems, In that, rules may not necessarily be derived from human expertise; they may also be derived from other sources. Three types of linguistic variable forms exist:

- Assignment statements
- Conditional statements
- Unconditional statements

Fuzzy logic controller design: The traditional control design paradigm is to form a system model and develop control laws from analysis of this model. The controller may be modified based on results of testing and experience. Due to difficulties of analysis, many such controllers are liner. The fuzzy controller approach should be reversed to some extent. General control rules relevant to a particular system based on experience are introduced and analysis or modeling considerations come later. For example, consider the following general control law for a positioning system.

This rule implements a control concept for anticipating the desired position and reducing the control level before the set point is reached in order to avoid overshoot. The quantities "small" and "large" are fuzzy quantities. A full control design requires developing a set of control rules based on available inputs and designing a method of combining all rule conclusions. The precise fuzzy membership functions depend on the valid range of inputs and the general response chrematistics of the system. Within power systems, fuzzy logic controllers have been proposed primarily MATLAB-FIS Editor.

The structure of the Fuzzy Logic Controller (FLC) and its design consist of the following steps:

1 Identification of input and output variables.
2 Construction of control rules.
3 Establishing the approach for describing system state in terms of fuzzy sets, i.e., establishing fuzzification method and fuzzy membership functions.
4 Selection of the compositional rule of the inference.
5 Defuzzification method, i.e., transformation of the fuzzy control statement into specific control actions.

Steps 1 and 2 are application specific and typically straight forward. There are several approaches to Steps 4 and 5 but most of the literature reports using minimum implication and center-of-gravity defuzzification. The design methodology in this tutorial centers on forming general rule membership functions and then determining parameters based on observed response to a disturbance.

Membership function: Each of the input and output fuzzy variables is assigned seven linguistic fuzzy subsets varying from Negative Big (NB) to Positive Big (PB). Each subset is associated with a triangular membership function to form a set of seven membership functions for each fuzzy variable. The membership function for each linguistic variable is as follows.

From this rules the Fuzzy Associate Memory (FAM) Table 1 is developed as shown.

Table 1: FAM table

Speed Deviation	Accelearation power deviation						
	BP	MP	LP	Z	LN	MN	BN
BN	BZ	LN	MN	MN	BN	BN	BN
MN	LP	BZ	LN	MN	MN	BN	BN
LN	MP	LP	BZ	LN	LN	MN	BN
Z	BP	MP	LP	LZ	LN	MN	BN
LP	BP	MP	LP	LP	BZ	LN	MN
MP	BP	BP	MP	MP	LP	BZ	LN
BP	BP	BP	BP	MP	MP	LP	BZ

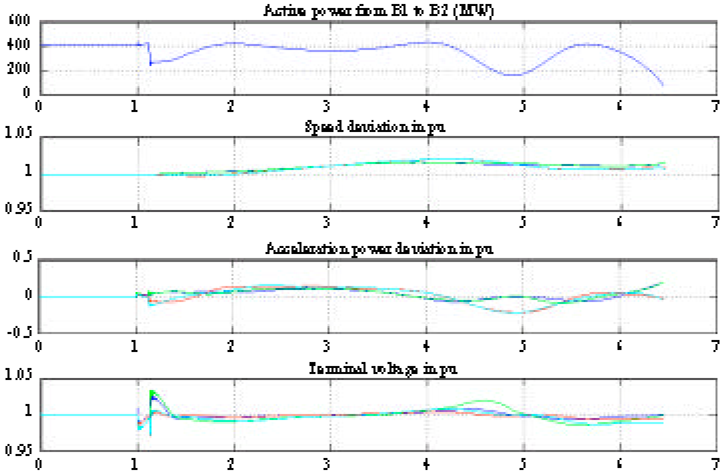

Fig. 3: System performances without PSS

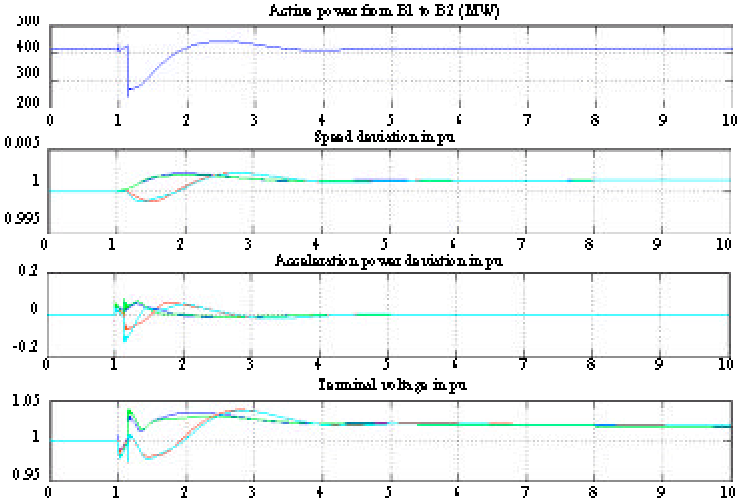

Fig. 4: System performances with CPSS

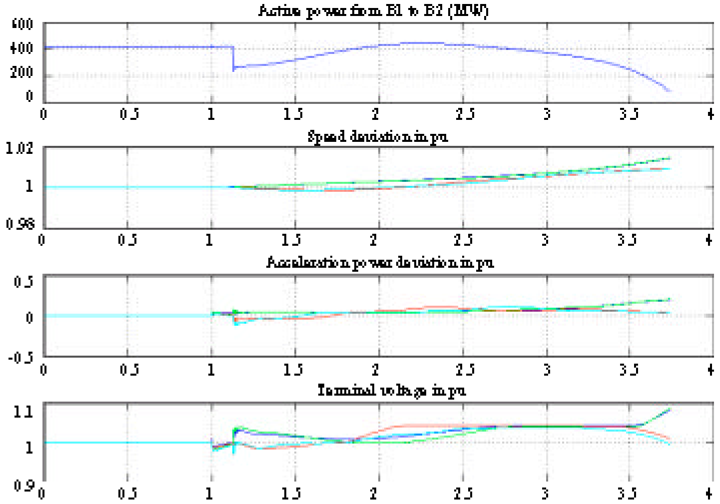

Fig. 5: System performances with FLPSS

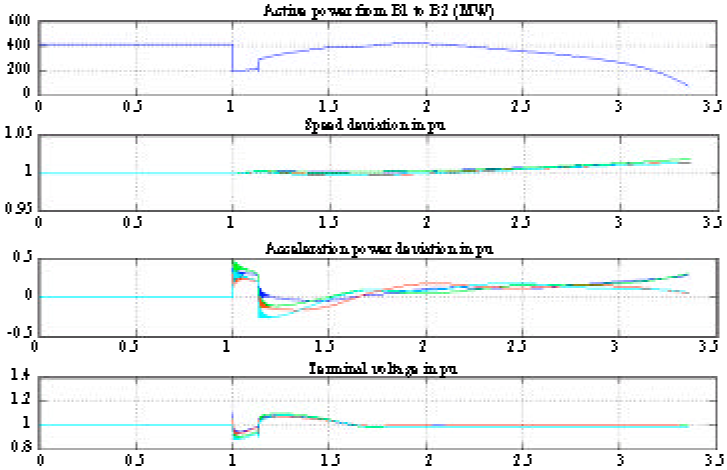

Fig. 6: System performances without PSS

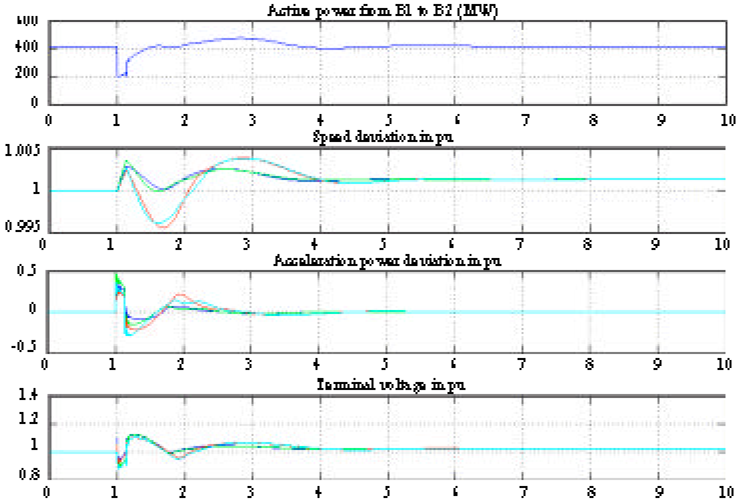

Fig. 7: System performances with CPSS

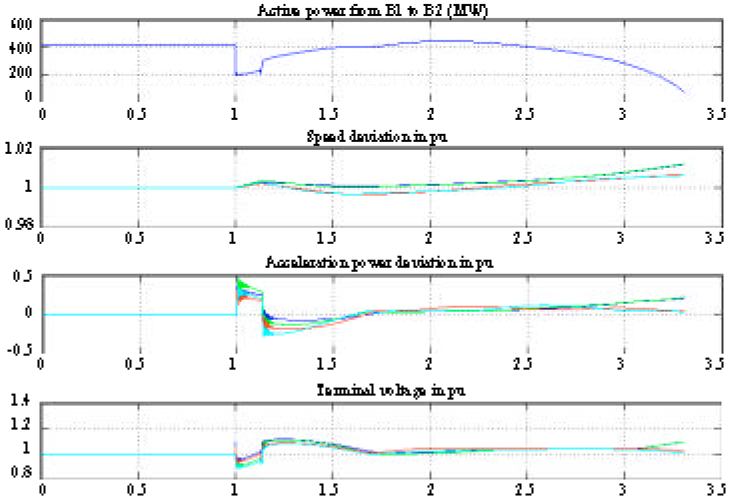

Fig. 8: System performances with FLPSS

SIMULATION STUDY

To investigate the two-area four-machine system performance the following disturbances have been considered in the simulation studies:

- L-G fault at any one of the phase.
- L-L-L-G(Three phase to ground fault).

Single phase fault: Figure 3 shows the system performances without PSS for single phase to ground fault occurs on the line 1 at 110 km. A single-phase fault have been applied at 1.10 sec and cleared at 1.30 sec. Figure 4 Shows the various system responses under delta-omega ($\Delta\omega$) PSS. Figure 5, shows the various system responses of the fuzzy logic power system stabilizer. It should be noted that the oscillation under system with fuzzy logic PSS decays faster than under system with delta ω PSS and also fuzzy logic power system stabilizer achieves a significantly fast damping for power flow from bus 1 to bus 2. A three-phase fault of 0.20 sec duration is simulated at line 1. Figure 6 shows the response of system under without PSS. Figure 7 presents the result of the examined power system under delta-ω PSS. Figure 8 shows the response of system with fuzzy logic power system stabilizer.

From these results, it should be noted that the oscillation under system with fuzzy logic PSS decays faster than under system with delta-ω PSS. The system with delta-ω PSS without PSS takes long time to stabilize the power flow from bus 1 to bus 2 and active power deviation. The simulation results show, the fuzzy logic controller, applied to a power system stabilizer provided better dynamic response than the conventional power system stabilizer. The system with fuzzy logic power system stabilizer is the best since it is effective for all test conditions.

CONCLUSION

This study has been proposed a fuzzy logic power system stabilizer for stability enhancement of a multi-machine system. In order to accomplish the stability enhancement, speed deviation ($\Delta\omega$) and acceleration power deviation (Δp) of the rotor synchronous generator have been taken as the inputs which are derived from a real time thermal power system of TNEB to the fuzzy logic controller. These variables take significant effects on damping the generator shaft mechanical oscillations. The performances of the system during single phase and three phase fault conditions are performed; the resultant characteristics of speed deviation, active power deviation, terminal voltage and active power transfer from bus 1 to bus 2 are observed. The proposed stabilizer is easier to implement in the multi-machine systems and is shown to be quite effective in damping out both local and multimodal oscillations.

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