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Stability Enhancement of Power System using Fuzzy Logic Based Power System Stabilizer

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Abstract

This Paper includes work on the development of a fuzzy logic power system stabilizer to enhance the damping of generator oscillations In order to accomplish a stability enhancement. Speed deviation (Am) and output power (Pm) of the rotor synchronous generator were taken as the input to the fuzzy logic controller. These variables take significant effects on damping the generator shaft mechanical oscillations. The stabilizing signals were computed using the fuzzy membership function depending on these variables. The performance of the fuzzy logic power system stabilizer was compared with the conventional power system stabilizer and without power system stabilizer [2]. To achieve good damping characteristics over a wide range of operating conditions, speed deviation and acceleration of a synchronous machine are chosen as the input. Signal to the stabilizers. The stabilizing signal is determined from certain rules for rule-based power system stabilizer. For fuzzy logic based power system stabilizer, the supplementary stabilizing signal is determined according to the fuzzy membership function depending on the speed and acceleration states of the generator [6]. The simulation result shows that the proposed fuzzy logic based power system stabilizer is superior to rule-based stabilizer due to its lower computation burden and robust performance.

Keywords: Power System Stabilizer, Fuzzy logic Controller, Automatic Voltage Regulator, Multi machine infinite bus, Excitation System.

Introduction

The power system is a dynamic system. It is constantly being subjected to disturbances, according to which generator voltage angle changes. When these disturbances removed, a new corrective steady state operating condition is reached. It is important that these disturbances do not drive the system to unstable condition [1]. The disturbances may be of local mode having frequency range of 0.7 to 2 Hz or of inter area modes having frequency range in 0.1 to 0.8 Hz, these swings are due to the poor damping characteristics caused by modern voltage regulators with high gain. A high gain regulator through excitation control has an important effect of eliminating synchronizing torque but it affects the damping torque negatively. To compensate the redundant effect of the voltage regulators in the excitation system, additional signals are proposed as a input signal in the feedback for the voltage regulators. The additional signals are mostly derived from excitation system deviation, speed deviation or accelerating power. This is accomplished by inserting a stabilizing signal into the excitation system voltage reference summing point junction. The device arrangement is to provide the signal is called “power system stabilizer”.

Excitation control is well known as one of the effective means to enhance the overall stability of electrical power systems. Present day excitation systems predominantly constitute the fast acting AVRs. A highly response excitation system is useful in increasing the synchronizing torque, thus improving the transient stability of the system i.e. to hold the generator in synchronism with power system during large transient fault condition. However, it produces a negative damping especially at high values of external system reactance and high generator outputs. Generator excitation controls have been installed and made faster to improve stability. PSS have been added to the excitation systems to improve the oscillatory instability it is used to provide a supplementary signal to excitation system. The basic function of PSS is to extend the stability limit by modulating generator excitation to provide the positive damping torque to power swing modes [2].

System Modeling

The Mathematical Models needed for small signal analysis of Synchronous Machines, Excitation System and lead-lag power system stabilizer are briefly reviewed. The Guidelines for the selection of Power System Stabilizer parameters are also presented.

Modeling Process of System

The single machine infinite bus power system (SMIB) model used to evaluate the fuzzy logic controller is presented in figure 1. The SMIB consists of a synchronous generator, a turbine, a governor, an excitation system and a transmission line connected to an infinite bus. The model of the SMIB is built in the Matlab/Simulink software suite.

When a power system under normal load condition suffers a perturbance there is synchronous machine voltage angles rearrangement. If for each perturbance that occurs, an unbalance is created between the system generation and the load, a new operation point will be established and consequently there will be voltage angle adjustments. The system adjustment to its new operation condition is called "transient period" and the system behavior during this period is called "dynamic performance". As a primitive definition, it can be said that the system oscillatory response during the transient period, shortly after the perturbance, is damped and the system goes in a definite time to a new operating condition, so the system is stable [11]. This means that the oscillations are damped, that the system has inherent forces which tend to reduce the oscillations.

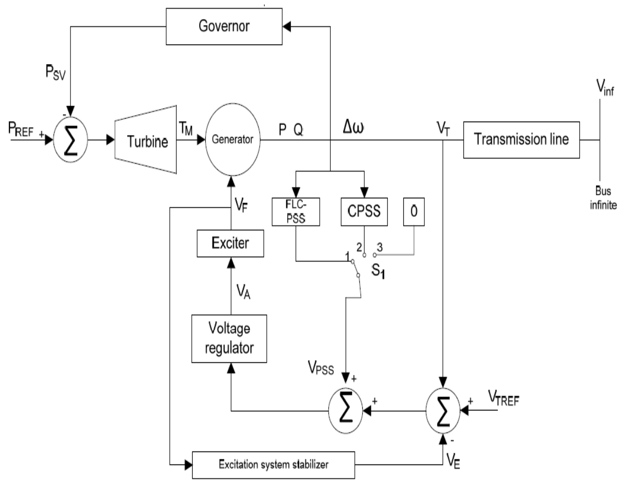


Fig. 1 System model configuration

The instability in a power system can be shown in different ways, according to its configuration and its mode of operation, but it can be observed without synchronism loss.

In figure 1 P_{ref}, is the mechanical power reference, , P_{SV} is the feedback through the governor, , T_M is the turbine output torque, V_{inf} is the infinite bus voltage, , V_{TREF} is the terminal voltage reference, , V_T is the terminal voltage, , V_A is the voltage regulator output, $\Delta\Omega$ is the speed deviation, , V_{PSS} is the PSS output, V_F is field voltage, , V_E is the excitation system stabilizing signal, P, is the power active and Q, is the reactive power at the generator terminal.

The turbine is used to drive the generator and the governor is used to control the speed and the real power. The block diagram of a separately excited turbine and a conventional governor is shown in figure 2.

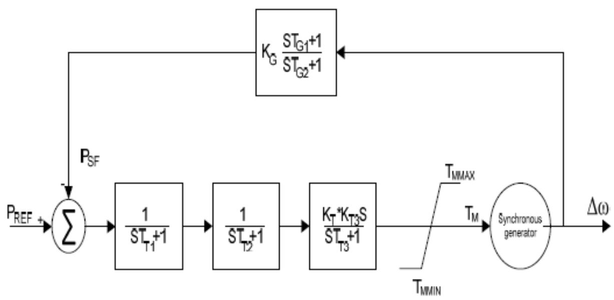


Fig. 2 Block diagram of the turbine and the governor

The block diagram of the excitation system for the generator is presented in figure 3.

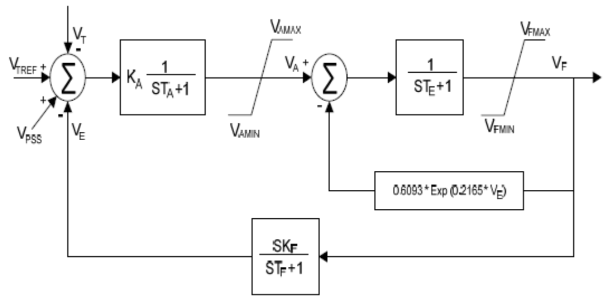


Fig. 3 Block diagram of the excitation system

According to the well-known design method which uses CPSS, the electromechanical oscillations are damped by implementing the PSS as shown in figure 4.

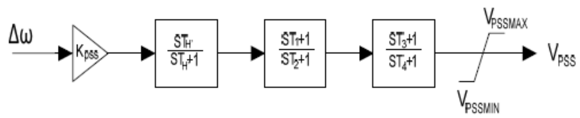


Fig. 4 Block diagram of the conventional power system stabilizer

Automatic devices control the generator's output in voltage and frequency, in order to keep them constant according to pre-established values.

These automatic devices are:

- Automatic voltage;
- Regulator;
- Governor.

The main objective of the automatic voltage regulator AVR is to control the terminal voltage by adjusting the generators exciter voltage. The AVR must keep track of the generator terminal voltage all the time and under any load condition, working in order to keep the voltage within pre-established limits. Based on this, it can be said that the AVR also controls the reactive power generated and the power factor of the machine once these variables are related to the generator excitation level [7].

The AVR quality influences the voltage level during steady state operation, and also reduces the voltage oscillations during transient periods, affecting the overall system stability. The parameters for the generator, AVR, excitation system, turbine and governor are given in reference 2. An indirect adaptive fuzzy logic based power system stabilizer design is proposed in reference 1.

Fuzzy Logic Controller

A. Fuzzy logic Theory

Fuzzy logic is a kind of logic is using graded and quantified statement rather than once that are strictly true or false. The results of fuzzy reasoning are not definite as those derived by strict logic. The fuzzy sets allow objects to have grades of membership from 0 to 1. These sets are represented by linguistic variables, which are ordinary language terms. They are used to represent a particular fuzzy set in a given problem, such as "large", "medium" and "small".

B. Fuzzy Set Definition

Let U be a collection of objects denoted generically by{u}, which could be discrete or continuous. U is called the universe of discourse and u represents the generic elements of U.

A fuzzy set F in a universe of discourse U is characterized by a membership function μ_r which takes values in the interval [0,1]. A fuzzy set may be viewed as a generalization of the concept of an ordinary set that its membership function only takes two values {0,1}. Thus, a fuzzy set F is U may be represent as a set of ordered pairs of a generic elements u and its grade of membership function:

$F = \Sigma^n{}_{i=1} \mu_F (u_i) / u_i$

C. Fuzzification Operator

A Fuzzification Operator has the effect of transforming crisp data into fuzzy sets.

Symbolically,

$x = \text{fuzzifier} (x_o)$

Where xo is a crisp input value from a process, x is a fuzzy set, and fuzzifier represents a Fuzzification operator.

D. Compositional Operator

To infer the output z from the given process states x, y and the fuzzy relation R. The sup-star compositional rule of inference is applied

$z = y_o (x_o R)$

Where o is the sup-star composition

E. Defuzzification Operator

The output of the inference process so far is a fuzzy set, specifying a possibility distribution of control action. In the in-line control, a non-fuzzy (crisp) control action is usually required. Consequently, one most defuzzify the fuzzy control action (output) inferred from the

z_o = defuzzifier (z)

Where z_o is the non-fuzzy control output and defuzzifier is the defuzzification operator.

Proposed Controller

A simple fuzzy controller based on the experience can damp only local modes. To damp both local and inter-area modes of oscillation, the experience is difficult to be obtained. So, the design process needs a systematic method for obtaining the rule base and the domain ranges. The proposed solution of this problem is that is a fuzzy controller is to be developed based on the optimal control theory [4]. This is capable to obtain a near optimal fuzzy controller that is characterized by its systematic nature in design.

• Fuzzification module – the functions of which are first, to read, measure, and scale the control variable (speed, acceleration) and, second, to transform the measured numerical values to the corresponding linguistic (fuzzy variables with appropriate membership values);

• Knowledge base - this includes the definitions of the fuzzy membership functions defined for each control variables and the necessary rules that specify the control goals using linguistic variables;

• Inference mechanism – it should be capable of simulating human decision making and influencing the control actions based on fuzzy logic;

• Defuzzification module – which converts the inferred decision from the linguistic variables back the numerical values.

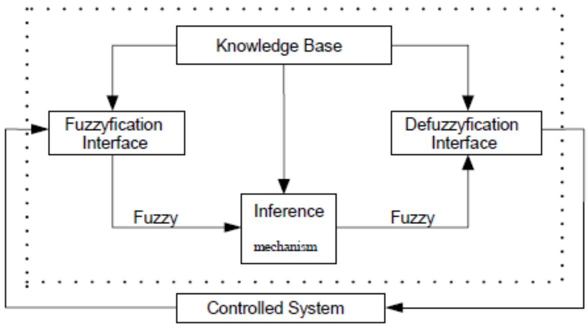


Fig. 5 Schematic diagram of the FLC building blocks

The generator speed deviation is classified into;

{Negative big (NB); negative medium (NM); negative small (NS); zero (ZE); Positive small (PS); positive medium (PM); positive big (PB)}. The generator speed deviation change is classified into: {negative big (dw_NB); negative medium (dw_NM); negative small (dw_NS); zero (dw_ZE); Positive small (dw_PS); positive medium (dw_PM); positive big (dw_PB)}.

C. The output of fuzzy controller is classified into:

{negative big (u_NB); negative medium (u_NM); negative small (u_NS); zero (u_ZE); Positive small (u_PS); positive medium (u_PM); positive big (u_PB)}.

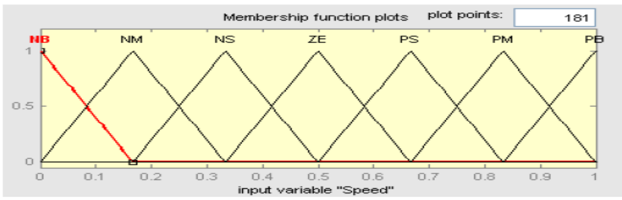


Fig.6. Blocker shows the exciter and the proposed FLC

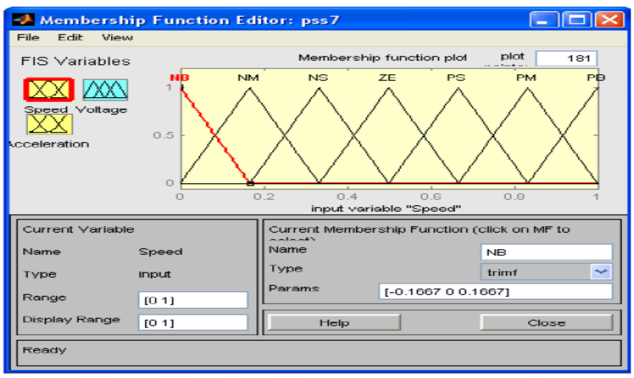


Fig.7. Membership functions normalized in one common universe (NB: negative big, NM: negative medium, NS: negative small, ZE: zero, PS: positive small, PM: positive medium, PB: positive big)

After this classification, the Fuzzification module can be applied. By conversion of a point-wise (crisp) and current value of a process state variable (generator speed deviation signal and generator speed deviation change signal) into their associated fuzzy sets, this will make it compatible with the fuzzy set representation of the process state variable in the rule-antecedents. Each crisp input (either generator speed deviation signal or generator or speed deviation change signal) has seven tuples denoted by: {classed fuzzy set and its membership function value.}

For example if normalized generator speed deviation = -0.2 then it has seven tuples as follows:

Δq / Δp	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

Then each crisp input can be fuzzified to obtain its membership values through the associated seven classes in the normalized universe of discourse.

D. Fuzzy Controller Simulation

In this section the simulation algorithm of the proposed fuzzy controller is discussed. For each time step in the system main simulation, a calculation of the generator speed deviation signal and generator speed deviation change in signal is made. This is achieved by getting the value of the state variable in the state matrix "A" which equal to the generator speed deviation. The value of generator speed deviation signal from the previous generator speed deviation signal. The associated membership values for each normalization input are calculated. Then applying the max-min method inference method to get the control output in fuzzy values. These fuzzy values can be converted to a crisp value by COG method. The signal of the controller is the damping signal that is fed into the reference voltage summing point to get the next state values.

Base Study

For the integrated system both local modes and inter-area modes appear. Then, a simple fuzzy controller based on the experience can only damp local modes. Therefore, the solution of this problem is that a fuzzy controller is to be developed based on the optimal control theory. The optimal controller depends on feeding back signals from all states of the system, to damp both local and inter-area modes [9]. The resultant fuzzy controller should approach the optimal as compared with the optimal controller results for damping small disturbance through many operating conditions. So a near-optimal fuzzy stabilizer for damping both local modes and inter-area modes is developed.

Fuzzy Logic Controller for Damping Oscillation in a Simple Power System;

In this section, it is decided to apply a fuzzy logic controller for a synchronous machine to an infinite bus system. The synchronous machine as represented in is assumed to have a thyristor-type excitation system and connected through a transformer and a transmission line to an infinite bus. To discuss the small signal stability problem, the nonlinear equations representing the system must be linearized.

Result and Discussion

The performance of single machine infinite bus system with lead-lag PSS and fuzzy PSS has been studied in SIMULINK environment. The fuzzy stabilizer has been modeled in fis editor of Matlab. The SIMULINK model of the system with fuzzy PSS.

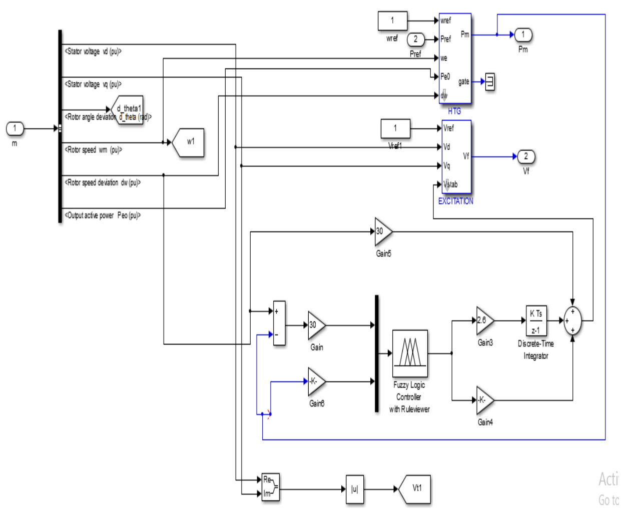


Fig.8 SIMULINK model with fuzzy logic based PSS

Simulation Results and Discussions;

The performances of conventional PSS for single machine infinite bus and PSS with Fuzzy Logic controller based for multi machine infinite bus are studied in the Simulink environment for different operating conditions and the following test cases was considered for simulations.

Case i: For normal load without fault and heavy load condition, the variation of speed deviation, field voltage, rotor angle and load angle were analyzed for Fuzzy Logic Controller based PSS.

Case ii: System was subjected to vulnerable (fault) condition, the variation of above mentioned cases were analyzed.

The above cases are illustrated clearly, how the controller reduces the overshoot and settling time to the nominal level when subjected to Fuzzy Logic Controller based PSS and the inference of the simulation results are as follows.

Case I: Normal load without fault and heavy load.

Here, the synchronous machine subjected to normal load of 1000MW without fault condition in the transmission line and the following observations from the dynamic responses are made in Fig.9 (a-b-c) to Fig. 10 (a-b) with respect to the stability of the system. From the Fig.9 (a) rotor angle deviation, it is observed that the Fuzzy Logic Controller based PSS can provide the better damping characteristic than the other cases. The Fuzzy Logic Controller based PSS reduced the overshoot to 7-10 degree and the system reaches the steady state quickly compared to PSS. By this effect, the field voltage will be stable and in turn it ensures the system stability.

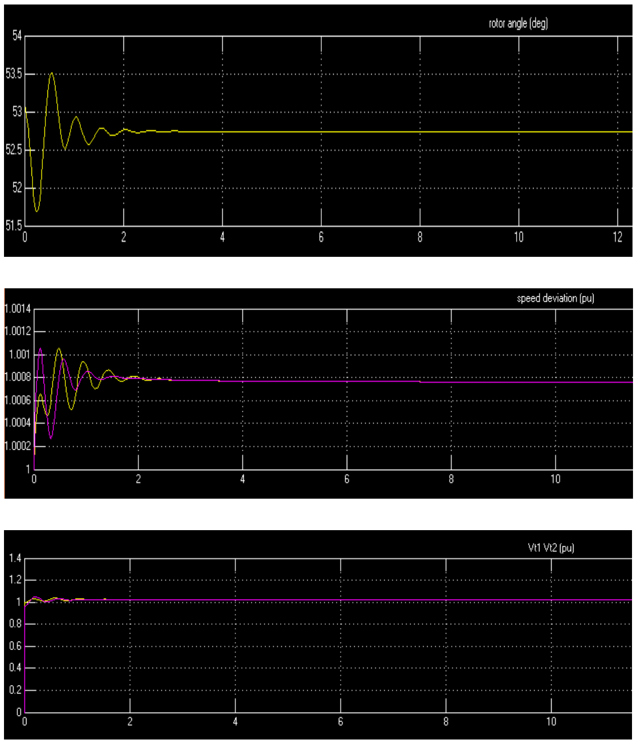


Fig. 9 (a) Rotor angle deviation in degree under normal load

(b) Rotor speed deviation p.u. under normal load

(c) Terminal Voltage in p.u. under load

In the response of Speed deviation Fig.9 (b), the overshoot reduced to 0.6 from 0.8 p.u. using Fuzzy Logic Controller based PSS therefore the system reaches the stable state quickly. It is necessary to maintain the speed in the synchronous generator; care should be taken to make the system to reach steady state as early as possible for that Fuzzy Logic Controller based PSS give better optimal solution compared to others. Fig. 9 (c). the terminal voltage reaches the stable state at 0.8 to 1 p.u. Here also inferred that after the inclusion Fuzzy Logic Controller based PSS the damping oscillation was reduced and also it boosts up to 2 p.u. to 1.2 p.u. According to Fig. 10 (a-b),

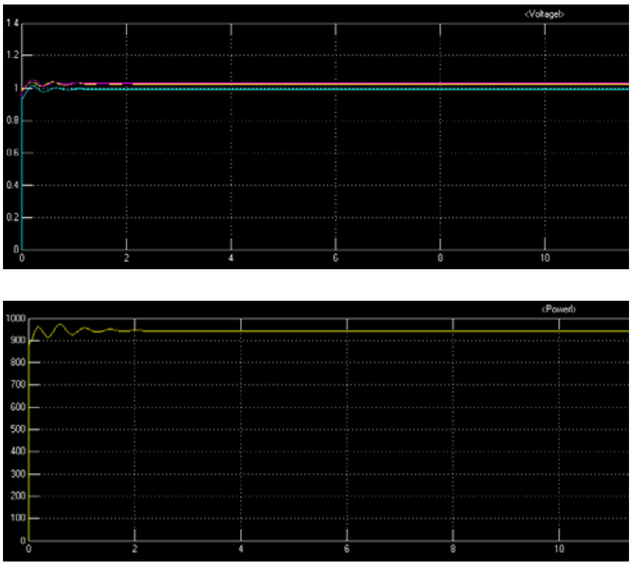


Fig. 10: (a) Field Voltage in p.u. under normal condition

(b) Line Power in MW under normal condition

Fuzzy Logic Controller based PSS improves the field voltage and line power to the maximum extent by reaching the settling time before 1.5 secs. However the field voltage and line power are optimized, the Fuzzy Logic Controller based PSS improves the performance compared to other PSS technology.

Case II: Fault Condition:

This illustrates the stability of the system during vulnerable condition, a three phase fault is assumed to happen at the transmission line. The fault persists in the system after 12 sec and it is cleared after 0.1 sec i.e. 12.1 sec. The parameters of the system during fault condition are illustrated in Fig. 11 (a-b-c) to Fig. 12 (a-b).

From the Fig. 11 (a), the overshoot was high for PSS; therefore the stability of the system was affected. The Fuzzy Logic Controller based PSS reduces the overshoot to 50% and makes the system to reach steady state before 2 secs. From this case, it is inferred that Fuzzy Logic Controller based PSS supports the synchronous generator to maintain synchronous speed even at severe fault conditions. During the fault condition, PSSs maintains the load angle around zero degree.

Normally for the smart system the load angle should be maintained around 30 to 52 degree. The Fuzzy Logic Controller based PSS provides better solution by maintaining the load angle around 20-25 degree.

From the Fig. 11 (b), it is observed that the PSS produced more overshoot and settles at 5 secs about speed deviation of system under fault condition. The Fuzzy Logic Controller based PSS controller gives better solution compared to normal PSS. The combination of Fuzzy Logic Controller based PSS further reduces the settling time to 0.2 secs and also the overshoot.

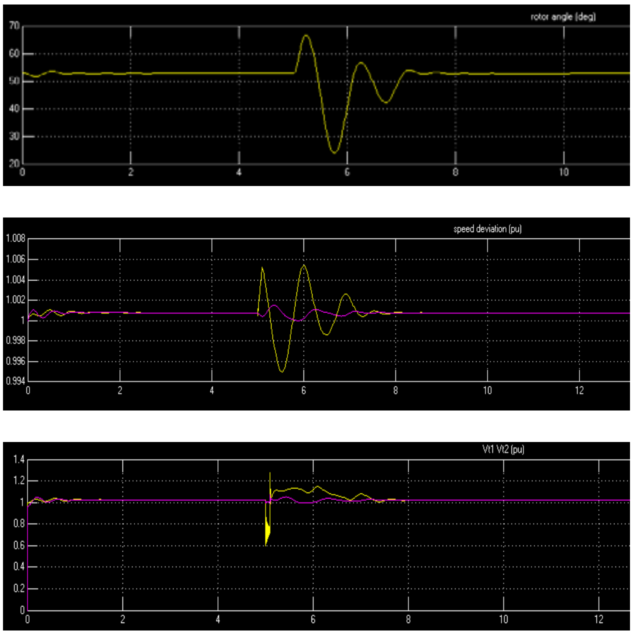
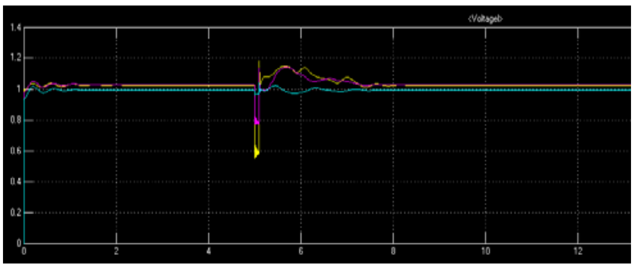


Fig. 11: (a) Rotor angle deviation in degree under fault condition

(b) Rotor speed deviation p.u. under fault condition

(c) Terminal Voltage in p.u. under fault condition

Last one the Fig. 11 (c), it is inferred that the accelerate stabilization of terminal voltage in p.u. with respect to Fault condition. However with the help of Fuzzy Logic Controller based PSS, the rotor angle maintained at normal level compared to PSS.



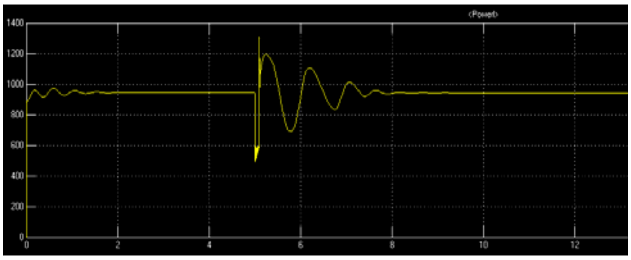


Fig. 12: (a) Field Voltage in p.u. under fault condition

(b) Line Power in MW under fault condition

According to Fig.12 (a-b), Fuzzy Logic Controller based PSS improves the field voltage and line power to the maximum extent by reaching the settling time before 0.1-0.2 secs. However the field voltage and line power are optimized, the Fuzzy Logic Controller based PSS improves the performance compared to other PSS techniques.

Conclusion

Results from this study indicate that under large disturbance conditions, better dynamic responses can be achieved by using the proposed Fuzzy Logic Controller based PSS controller than the other stabilizers. We could also observe in all case studies, from the MATLAB/ Simulink simulation, that the Fuzzy Logic Controller based PSS controller has an excellent response with small oscillations, while the other controller response shows a ripple in all case studies and some oscillations before reaching the steady state operating point. It was shown that an excellent performance of the Fuzzy Logic Controller based PSS control in contrast to the other controllers for the excitation control of synchronous machines could be achieved. Modeling of proposed controller in Simulink environment shown the accurate result when compared to mathematical design approach. A simple structure of a Fuzzy Logic controller based PSS and its wide spread use in the industry make the proposed stabilizer very attractive in stability enhancements.

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