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Fuzzy Logic based Power System Stabilizer to improve Small-Signal Stability of Power System

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Abstract: Power System Stabilizers are used to improve small-signal stability of power system. A conventional lead-lag based power system stabilizer does not give satisfactory performance under continuously variable conditions. In this paper Fuzzy Power System Stabilizer is proposed to improve small-signal stability of the Single Machine Infinite Bus system. The effect of excitation system, Automatic Voltage Regulators on small-signal stability is also studied. Fuzzy Power System Stabilizer is tested under various disturbance conditions. Simulation results reveal that Fuzzy Power System Stabilizer give better performance than conventional power system stabilizer.

Keywords: Power System; Single Machine; Excitation System; Voltage Regulators

I. INTRODUCTION

Small signal stability [1] is the ability of a power system to maintain synchronism under small disturbances. The small disturbances are continuous small variation in loads and generation. When there is disturbance in the power system, the rotor of the generator adjusts the slip between rotating stator field and rotor field, it results in electro-mechanical oscillations of rotor which changes the power output, frequency and voltage. The electro-mechanical oscillations when not properly damped may activate protective relays to isolate unstable machine from rest of the system.

A synchronous generator takes mechanical torque as input and gives electrical torque as output. The change in electrical torque (ΔTe) output following small change in mechanical torque input (ΔTm) is resolved into two components:

$$\Delta Te = Ts\ \Delta\delta + TD\ \Delta\omega$$

Where Ts is synchronizing torque coefficient and TD is damping torque coefficient. $\Delta\delta$ is rotor angle deviation and $\Delta\omega$ is rotor speed deviation. System is stable when it has sufficient synchronizing torque and damping torque. Lack of sufficient synchronizing torque results in continuous increase in rotor angle and lack of sufficient damping torque results in continuously increasing oscillations of rotor following a disturbance. These electro-mechanical oscillations are in the range of 0.2Hz to 2Hz.

Power system stabilizers (PSS) [1] are used to damp electro-mechanical oscillations of rotor of synchronous machine. Power system stabilizer takes rotor speed deviation ($\Delta\omega$) as input signal and gives output voltage which is added to excitation system of synchronous generator.

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II. SINGLE MACHINE INFINITE BUS SYSTEM

Fuzzy logic based power system stabilizer (PSS) is designed for Single Machine Infinite Bus (SMIB) [1] system.

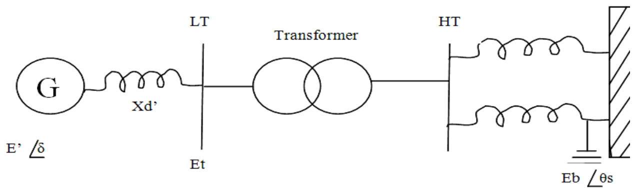

Figure 1: Single Machine Infinite Bus system.

A synchronous machine is connected to infinite bus through step-up transformer and double circuit transmission line. To check the performance of fuzzy PSS the disturbance considered is loss of circuit-2.For analysis purpose, the system is reduced to Thevenin equivalent of transmission network external to the machine. The dynamics of the synchronous machine connected to large system will make no change in voltage, frequency of the Thevenin's voltage Eb. So a voltage source of constant voltage and frequency is known as infinite bus. The effect of constant field excitation system, Automatic Voltage Regulator (AVR) along with PSS on small signal stability is studied in this paper. State-Space model of SMIB system is developed to design fuzzy logic based power system stabilizer.

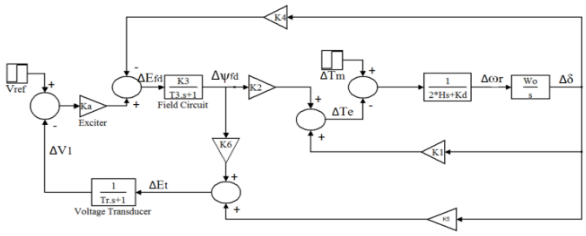

Figure 2: State-Space model of SMIB system.

Power System Stabilizer

Power System Stabilizer (PSS) [2] is used to damp electro-mechanical oscillations of rotor of synchronous generator. These electro-mechanical oscillations are due to insufficient damping torque. Since damping torque is proportional to rotor speed deviation (Δω), power system stabilizer takes rotor speed deviation as input signal and gives output as voltage signal to excitation system, thus producing additional damping torque.

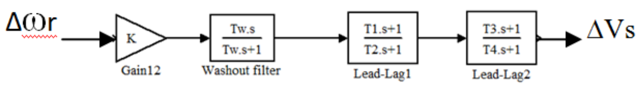

Figure 3: Power System Stabilizer block diagram.

A conventional lead-lag based power system stabilizer consists of gain block, washout filter and two stage lead-lag compensator block. The stabilizer gain (K) determines amount of damping provided by power system stabilizer. Washout filter act as high-pass filter with time constant high enough to pass high frequency signals. Lead-Lag block compensates for the phase lag between input and output.

The implementation of conventional Power System Stabilizer (CPSS) in SMIB system is shown below.

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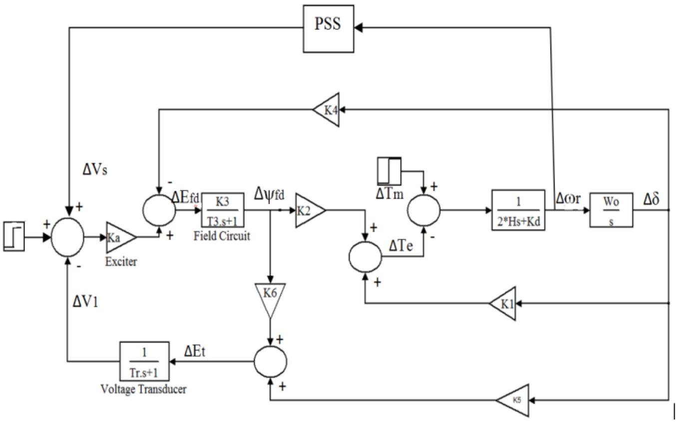

Figure 4: PSS in State-Space model of SMIB system.

III. FUZZY LOGIC BASED POWER SYSTEM STABILIZER

Exemplar based Inpainting technique is used for inpainting of text regions, which takes structure synthesis and texture synthesis together. The inpainting is done in such a manner, that it fills the damaged region or holes in an image, with surrounding colour and texture. The algorithm is based on patch based filling procedure. First find target region using mask image and then find boundary of target region. For all the boundary points it defined patch and find the priority of these patches. It starts filling the target region from the highest priority patch by finding the best match patch. This procedure is repeated until entire target region is inpainted.
The algorithm automatically generates mask image without user interaction that contains only text regions to be inpainted.

IV. EXPERIMENTAL RESULTS

Fuzzy Logic System

Fuzzy logic is a form of Artificial Intelligence (AI) dealing with the development of computer programs based on human intelligence and thinking. Fuzzy Logic Theory [3] was proposed by Dr. Lofti A. Zadeh in 1965. Fuzzy logic has find application in process control, modeling, diagnosis, agriculture, military science, power systems etc. Fuzzy logic is mainly used for making decisions with vague, imprecise information.

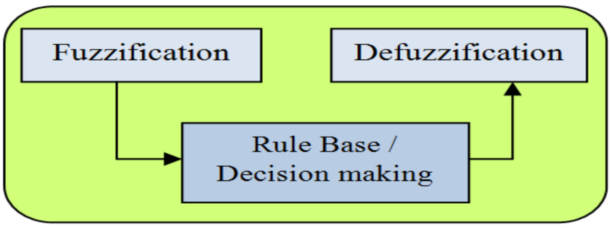

Figure 5: Components of Fuzzy Logic System.

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Fuzzification: The quantities in the real world are crisp. The conversion of crisp (real) number into fuzzy number is called fuzzification. In fuzzy logic, a variable or object has degree of membership in the range of 0 to 1. It is the classification of input data into suitable values of membership functions.

Rule base/ Decision making: Fuzzy logic controller takes decisions according to fuzzy rule base. The rules are formulated by considering the values of membership functions of input variables. If a fuzzy logic controller has 2 input variables and each input variable has 7 membership functions, then total numbers of rules to be formulated are 7x7 = 49.

Implication rule is used to obtain the output of each of each individual rule. The output of each rule is aggregated to obtain the final output. Some of the commonly used implication and aggregation methods are Mamdani type, Surgeno type implication.

Defuzzification: Conversion of fuzzy control action into crisp control action is called defuzzification. Commonly used defuzzification method is Centroid method.

Development of Fuzzy logic based Power System Stabilizer

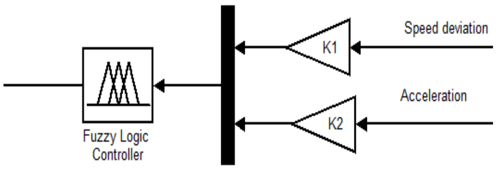

Figure 6: Fuzzy PSS.

Fuzzy logic based Power System Stabilizer has two input variables and one output variable. The input variables are rotor speed deviation and acceleration. The output variable is voltage signal which is fed to excitation system of SMIB system. Each input variable has seven triangular membership functions. These membership functions have values in the range from -1 to 1. Each membership function has a particular name. Fuzzy logic toolbox [5] is used to develop fuzzy PSS.

NB	Negative Big
NM	Negative Medium
NS	Negative Small
ZE	Zero
PS	Positive Small
PM	Positive Medium
PB	Positive Big

Table 1: Fuzzy membership function names.

Fuzzy logic based PSS produces output voltage according to fuzzy rule base [3]. Since each of the two input variables has 7 membership functions, the total number fuzzy rules are 7x7 = 49. These rules are framed on the basis of knowledge of the working of power system stabilizer.

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

Table 2: Fuzzy PSS Rules.

Fuzzy logic based PSS in SMIB is shown in figure. Each input of fuzzy PSS have gain block. These gain blocks normalize the input variables to match with the range of membership functions of each variable.

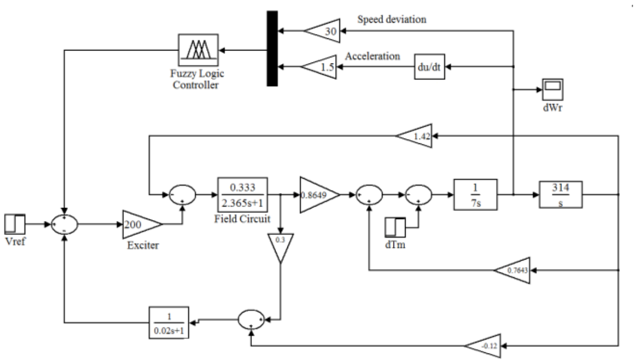

Figure 7: Fuzzy PSS in State Space model of SMIB system.

V. RESULTS AND DISCUSSION

The performance of Fuzzy Power System Stabilizer and conventional lead-lag based Power System Stabilizer is tested in Matlab/Simulink [3] environment. The disturbance considered to test small-signal stability is 5% change in mechanical power input to synchronous machine.

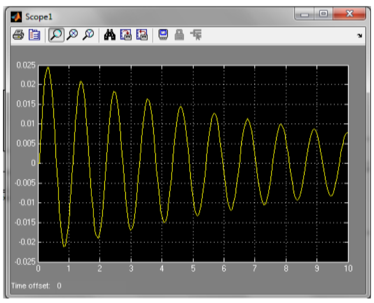

Figure 7: Rotor speed deviation for 5% change in mechanical power input with Constant Field Excitation only.

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Figure 8: Rotor speed deviation for 5% change in mechanical power input with AVR and K5 Positive.

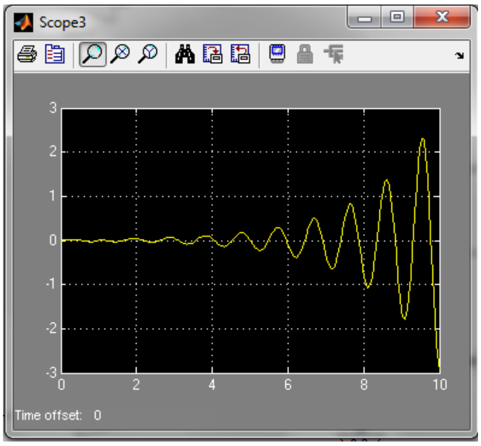

Figure 9: Rotor speed deviation for 5% change in mechanical power input with AVR and K5 Negative.

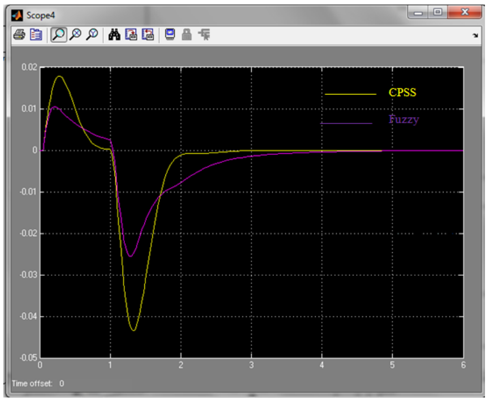

Figure 10: Rotor speed deviation for 5% change in mechanical power input with CPSS and Fuzzy PSS.

State-Space model of synchronous machine has constants K1, K2, K3, K4, K5, and K6. The value of K1, K2, K3, K4 and K6 is positive.K5 can be positive or negative.K5 is negative for high reactance and high power output, K5 is positive for small reactance and small power output. In normal cases K5 is negative.

The effect of value of K5 on electro-mechanical oscillations is studies. It is observed that

- When K5 is positive Automatic Voltage Regulator (AVR) produces negative synchronous torque and positive damping torque.
- When K5 is negative Automatic Voltage Regulator produces positive synchronous torque and negative damping torque.

The robustness of fuzzy power system stabilizer is tested for different cases of change in mechanical power input to synchronous machine.

VI. CONCLUSION

The performance of Fuzzy Power System Stabilizer is compared with conventional lead-lag based power system stabilizer for different disturbance conditions. Simulation results reveal that Fuzzy Power System Stabilizer is more robust and give better performance than lead-lag based power system stabilizer.

APPENDIX

Synchronous machine

P = 0.9, Q = 0.3, E_t = 1, E_b = 0.995, E_{fd} = 2.395, X_d' = 0.3, Ld = 1.81, Lq = 1.76, Ld" =0.23, Lq" = 0.25, Tdo' = 8s, Tqo' = 1s, Tdo" = 0.03s, Tqo" =0.07s, L_l = 0.15, Ra = 0.003 H = 3.5MWs/MVA, f = 50Hz

Automatic Voltage Regulator

K_a = 200, Tr = 0.02s

Power System Stabilizer

K = 20, Tw = 10s, T1 = 0.05s, T2 = 0.02s, T3 = 3s, T4 = 5.4s.

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