IJAPIE-2016-04-204,Vol 1(2), 22-27

INTERNATIONAL JOURNAL OF ADVANCED PRODUCTION AND INDUSTRIAL ENGINEERING

(A Blind Peer Reviewed Journal)

Enhancement of power system damping using Fuzzy Power System Stabilizer

J. N. Rai[1], Ram Bhagat[2]

[1, 2](Electrical Engineering, Delhi Technological University, Delhi, India)

Email: jnrai.phd@gmail.com

Abstarct : *The use of Power System Stabilizers (PSS) has become very common in operation of large electric power systems. However, it is very difficult to design a stabilizer that could present better performance in all operating points of power systems. In an attempt to cover a wide range of operating conditions, FLC has been suggested as a possible solution to overcome this problem.*

This paper presents a study of Fuzzy Power System Stabilizer (FPSS) for stability enhancement of a single machine infinite bus system. In order to accomplish the stability enhancement, speed deviation and acceleration of the rotor synchronous generator are taken as the inputs 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. Simulink Block Design and Matlab-8.1 is utilized in implementing the study. The performance of FPSS is compared with the conventional power system stabilizer and without power system stabilizer.

Keywords: *FLC Fuzzy Logic Control, FPSS: Fuzzy Power System Stabilizer, AVR: Automatic Voltage Regulator*

I. INTRODUCTION

In early days, many power generating plants were equipped with continuously acting automatic voltage regulators. As the power generated increase and high response exciters come into picture with the use automatic voltage regulators grew it became apparent that the high performance of these voltage regulators had a destabilizing effect on the power system. Power oscillations of small magnitude and low frequency often persisted for long periods of time[1]. In some cases, this presented a limitation on the amount of power able to be transmitted within the system. Power system stabilizers were developed to aid in damping of these power oscillations by modulating the excitation supplied to the synchronous machine.

The power system stabilizer normally consists of a phase-lead compensation blocks, a signal washout block, and a gain block. The input signal to the stabilizer is the equivalent rotor speed deviation. But due to constant stabilizer gain and the complexity of system modeling under different operating conditions calls for new technology to be introduced in damping of small signal oscillation of the system giving origin new type of linguistic based power system stabilizer called FPSS. The FPSS removes most of the shortcomings of the conventional power system stabilizer before this fuzzy logic stabilizer auto tuned power system stabilizer is also consider under this thesis to explain some of the generalized aspects of power system stabilizer[2].

II. SYSTEM MODELING

Thevenin's equivalent circuit of a general system configuration for the synchronous machine connected to the large system is shown in figure 1. This general system is used for the study of small signal stability study.

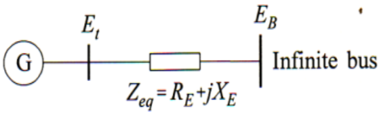


Figure 1: Equivalent circuit General configuration of single machine connected to alarge system through transmission line

The Block diagram representation shown in figure 2 can be used to describe the small-signal performance.

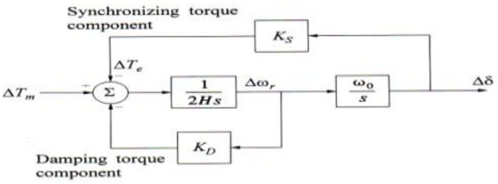


Figure 2: Block diagram of a single-machine infinite bus system with classical generator model

Solving the block diagram we get the characteristic equation:

$$s^2+\frac{K_D}{2H}s+\frac{K_s\omega_o}{2H}=0$$

III EFFECT OF EXCITATION

Under the effect of excitation system dynamics, the block diagram developed is extended to include the excitation system[4]. The terminal voltage error signal, which forms the input to the voltage transducer block, is given by

$$\Delta E_t=K_5\Delta\delta+K_6\Delta\psi_{fd}$$

Where

$$K_5=\frac{e_{d0}}{E_{to}}[-R_a m_1+L_l n_1+L_{aqs}n_1]+\frac{e_{q0}}{E_{to}}[-R_a n_1+L_l m_1+L'_{ads}m_1]$$

$$K_6=\frac{e_{d0}}{E_{to}}[-R_a m_2+L_l n_2+L_{aqs}n_2]+\frac{e_{q0}}{E_{to}}\left[-R_a n_2+L_l m_2+L'_{ads}\left(\frac{1}{L_{fd}}-m_2\right)\right]$$

The influence on small-signal stability is examined by considering the excitation system model shown in Figure 3

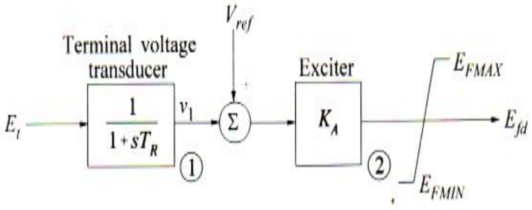


Figure 3 Thyristor excitation system with AVR

The only nonlinearity associated with the model is that due to the ceiling on the exciter output voltage represented by E_{FMAX} and E_{FMIN}. For small-disturbance studies, these limits are ignored as we are interested in a linearized model about an operating point such that E_{fd} is within the limits. Limiters and protective circuits are not modeled as they do not affect small-signal stability.The block diagram representation with exciter and AVR is shown in fig4

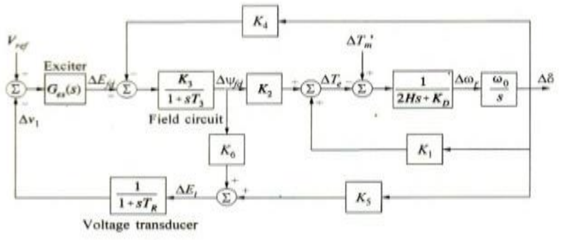


Figure 4:Block diagram representation with exciter & AVR

Change in the time response of the system for the 5% change in mechanical input depicts that the system is unstable.

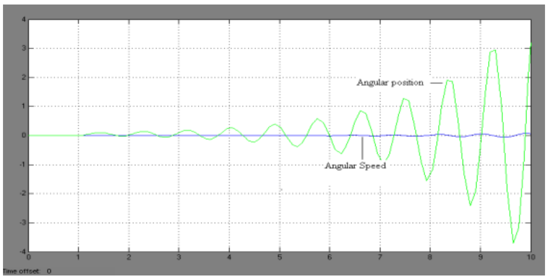


Figure 5: System Response for 5% change in input torque

With AVR, constant K_5 may have either negative of positive values as shown in figure 6, which influences the damping and synchronizing torque coefficient shown in Fig7(a) & 7(b).

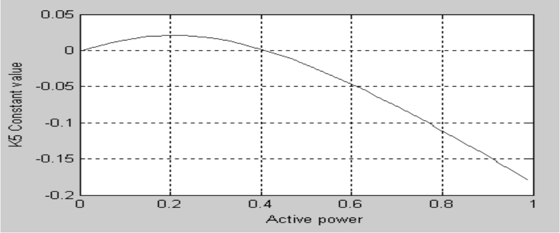


Figure 6 Variation of K_5 with per unit active power

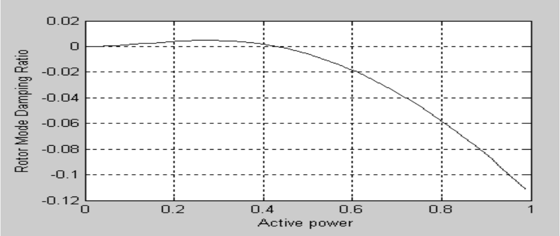


Figure 7(a)Variation of Damping Torque Coefficient with per unit power

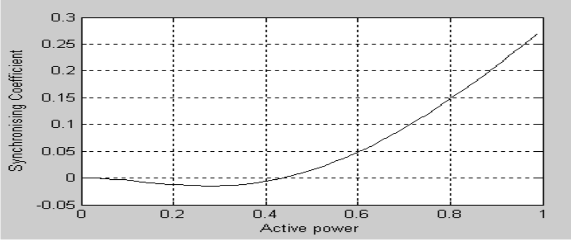


Figure 7(b) Variation of Synchronizing Coefficient with per unit power

Now the effect of variation in excitation on synchronization coefficient and damping torque coefficient is shown in fig 8(a) & 8(b).

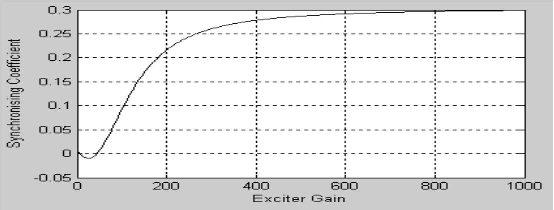


Figure 8(a) Variation of Synchronizing coefficient K_5With K_A

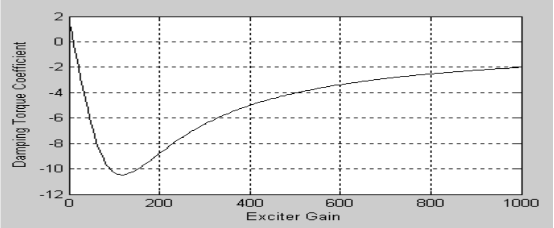


Figure 8(b)Variation of damping torque coefficient with K_A

From the above analysis, we concluded that the effect of AVR on damping and synchronizing torque component is thus primarily influence by constant K_5 and exciter gain K_A. With K_5 negative, the AVR action introduces a positive synchronizing torque component and negative damping torque component. This effect is more pronounced as exciter response increases. The main cause of instability of the system is negative damping coefficient; this adverse affect of low damping should be removed by adding damping to the system.

IV POWER SYSTEM STABILIZER

The basic function of a power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s). To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations.

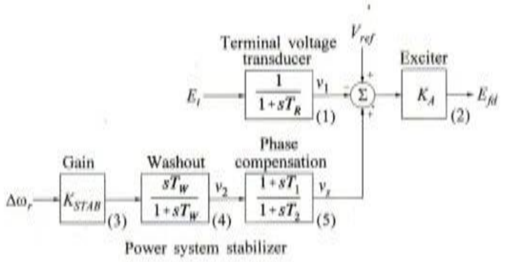


Figure 9 Thyristor excitation system with AVR and PSS

Model used in Simulink/ Matlab to examine the effect of power system stabilizer with automatic voltage regulator on single machine infinite bus system is shown below in figure 10

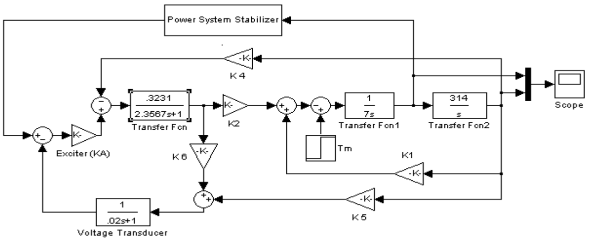


Figure 10 Simulink Model with AVR and PSS

With above constants we will analyze the variation of angular speed and angular position with time this is shown in figure 11(a) and 11(b).

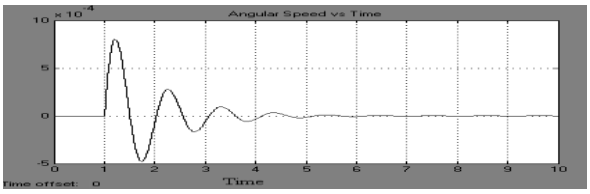


Figure11(a) Variation of Angular Speed with Time

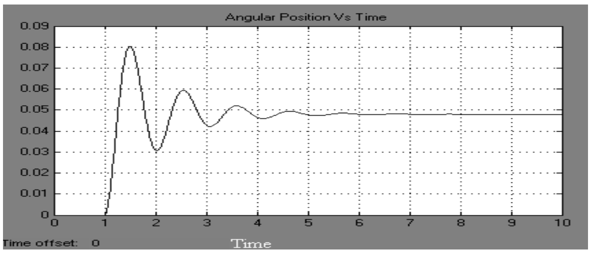


Figure 11(b) Variation of Angular position with Time

With Power system stabilizer the rotor mode damping ratio and damping coefficient increases with increase in exciter gain, This is as evident from the figure 12(a) & 12(b)

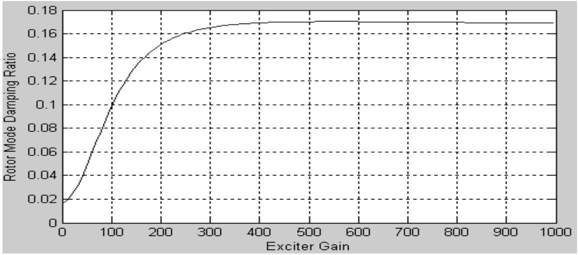


Figure 12(a)Rotor Mode Damping Ratio with Exciter Gain

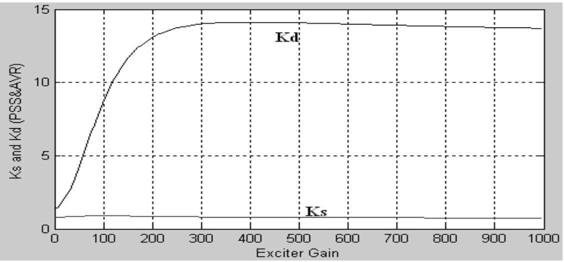


Figure 12(b) Damping and Synchronizing Torque coefficient Vs Exciter Gain for PSS

These power system stabilizers suffer from a limitation that these are not much efficient for damping small signal oscillations over wide range for operating conditions. Also it requires a deep understanding of a system, exact equations and precise numeric values.

To overcome this problem, a FPSS was developed without real-time model identification.

V. FUZZY LOGIC POWER SYSTEM STABILIZER

A fuzzy power system stabilizer (FPSS) is developed using the concept of fuzzy basis functions. The linguistic rules, regarding the dependence of the plant output on the controlling signal, are used to build the FPSS. The FPSS is designed for cogeneration, but simulation studies are based on a one machine-infinite bus model[3,6].

Selection of input and out put variables

Define input and control variables, that is, determine which states of the process should be observed and which control actions arc to be considered. For FPSS design, generator speed deviation $(\Delta\omega)$ and acceleration $(\Delta\dot{\omega})$ can be observed and have been chosen as the input signal of the FPSS. The dynamic performance of the system could be evaluated by examining the response curve of these two variables.

In practice, only shaft speed $(\Delta\omega)$ is readily available. The acceleration signal $(\Delta\dot{\omega})$ can be derived from the speed signals measured at two successive sampling instants using the following equation:

$$\Delta\dot{\omega}(k) = \frac{((\Delta\omega(k) - \Delta\omega(k-1))}{\Delta T}$$

The control variable is the output from the fuzzy logic controller[4].

Membership function

First input to the fuzzy controller is acceleration i.e. $(\Delta\dot{\omega})$ it is normalized by multiplying with some factor X_1 so that its value lies between -1 and 1. The membership function for acceleration is shown in figure 13(a).

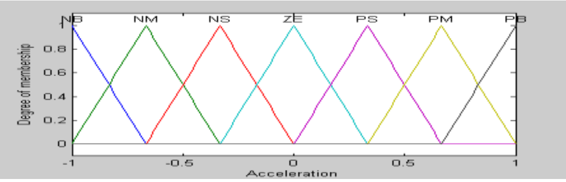


Figure 13(a) Membership Function of Acceleration

Membership function of second input i.e. Speed deviation $(\Delta\omega)$ also has same membership function that of acceleration and with 50% overlap between adjacent fuzzy subsets, the function is shown in figure 13(b).

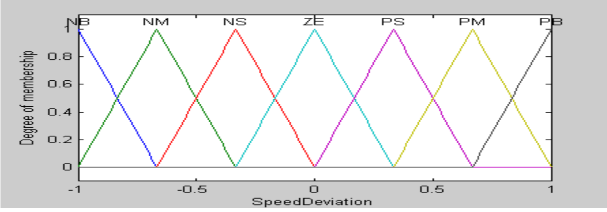
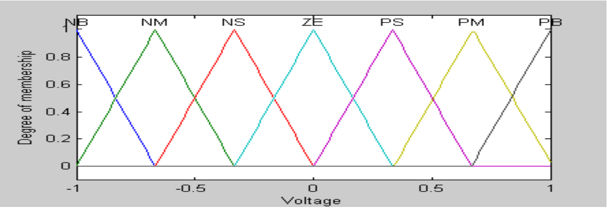


Figure 13(b) Membership Function of Speed Deviation

There is only one output from the fuzzy logic controller i.e. voltage signal, its membership function also contains seven subsets with 50% overlap the only difference is that we have to renormalized the output by multiplying the output from fuzzy controller with a constant gain



.

Figure 13(c) Membership function of output Voltage signal.

Defuzzification

There are five methods of defuzzification namely centroid method, bisector method, middle of maximum method, largest of maximum method and smallest of maximum method. Here in fuzzy logic controller centriod method of defuzzification was opted.The output of the controller is given by following expression:

$$u_k = \frac{\sum_{i=1}^{p} y_i w_i}{\sum_{i=1}^{p} w_i}$$

Fuzzy rule base

A set of rules which define the relation between the input and output of fuzzy controller can be found using the available knowledge in the area of designing FPSS is shown in table 1[5].

VI SIMULATION RESULTS

Model used in Simulink / MATlAB to analyze the effect of fuzzy logic controller in damping small signal oscillations when implemented on single machine infinite bus system is shown below in figure 14(a)

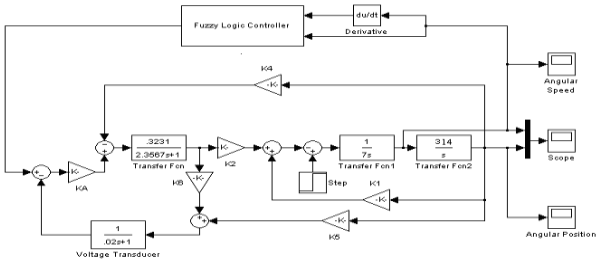


Figure 14(a) Simulink Model with Fuzzy Logic Controller

Table1: Decision Table for fuzzy logic controller

$\Delta\dot{\omega}$ $\Delta\omega$	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	**NB**	**NB**	**NB**	**NB**	**NB**	**NB**	**NB**
NM	**NB**	**NM**	**NM**	**NM**	**NM**	**NS**	**ZE**
NS	**NM**	**NM**	**NS**	**NS**	**NS**	**ZE**	**PS**
ZE	**NM**	**NS**	**NS**	**ZE**	**ZE**	**PS**	**PM**
PS	**NS**	**ZE**	**ZE**	**PS**	**PS**	**PM**	**PM**
PM	**PS**	**PS**	**PS**	**PM**	**PM**	**PM**	**PB**
PB	**PM**	**PM**	**PM**	**PB**	**PB**	**PB**	**PB**

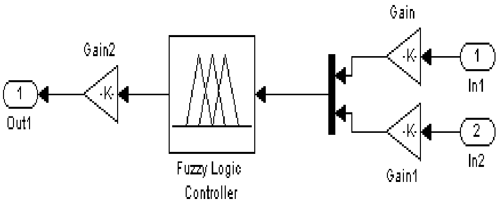


Figure14(b) Expanded form of Fuzzy logic controller block

The fuzzy logic controller block consists of fuzzy logic block and two type of scaling factors. One is input scaling factors, these are two in number one for each input as the other is output scaling factor which determine the extent to which controlling effect is produced by the controller

Using fuzzy logic power system stabilizer it can inferred that it does not require any complex mathematical calculations and the response with fuzzy logic is much improved than with conventional power system stabilizer. It is illustrated using the plots of angular speed and angular acceleration shown in figure 15(a) and 15(b).

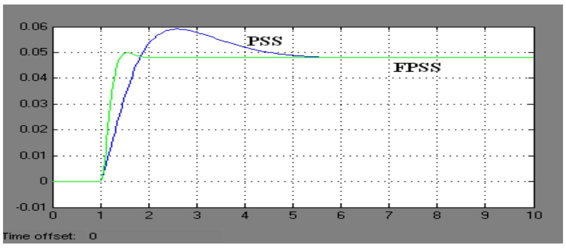


Figure 15(a) Variation of Angular position with time for PSS and FPSS

Figure15(a) shows the relative plots for variation of angular position with time for PSS and FPSS. These results are for 5% change in mechanical torque. From figure it can be perceived that with the application of fuzzy logic the rise time and the settling time of the system decreases also there is significant decrease in the peak overshoot of the system. The system reaches its steady state value much earlier with fuzzy logic power system stabilizer compared to conventional power sytem stabilizer.

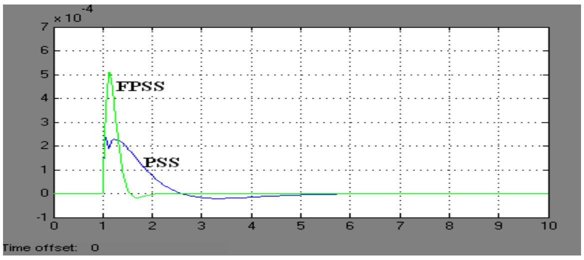


Figure 15(b) Variation of Angular speed with time for PSS and FPSS

From relative plot in fig 15(b) it can be retrieved that oscillations in angular speed reduces much faster with fuzzy logic power system stabilizer than with conventional power system stabilizer. As shown in figure with fuzzy logic the variation in angular speed reduces to zero in about 2 seconds, but with conventional power system stabilizer it takes about 6 seconds to reach to final steady state value.

VI CONCLUSIONS

In this paper FPSS shows the better control performance than power system stabilizer in terms of settling time and damping effect. The proposed FPSS produces better damping effect than PSS. To further increase the stability of the power system a technique was introduced to tune parameters of fuzzy logic controller.

System considered

System operating condition in per unit for 4×555 MVA, 24 KV, 50 Hz generating unit on a common 2220MVA, 24 KV base are: P=0.9; Q=P/3; E_t=1.0

Thyristor exciter gain:

K_A=200; T_R=0.02;

Frequency of oscillation is taken as 10 rad/sec.

REFERENCES

[1] Michael J. Basler and Richard C. Schaefer "Understanding Power System Stabilizer," Basler Electric Company IEEE Trans., pp. 46-67, August 2005.

[2] K.Tomsovic, "Fuzzy systems applications to power systems", IEEE PES Tutorial, july2000.

[3] John Yen and Reza Langari "Fuzzy Logic Intelligent Control and Information" Pearson Education Publishing Company.

[4] Recommended Practice for Excitation System Models for Power System Stability Studies," IEEE Standard 421.5-1992, August 1992.

[5] Timothy J.Rose, "fuzzy logic with engineering applications", Mc – Graw Hill.Inc, Newyork, 1997 [6] J N Rai ,Vijay Priyadarshi ' Dynamic Stability Enhancement of Power System Using Fuzzy Logic based Power System Stabilizer" Proceeding of emerging trends in Electrical and Electronics Engineering, ISBN: 978-93-84869-25-0,vol I,PP 137-144,Feb. 2015.