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Research Paper

FUZZY BASED POWER SYSTEM STABILIZER FOR MULTI MACHINE

ASHOK L. VAGHAMSHI
Asst. Prof.Electrical Engineering Department,
Gujarat Technological University,
Bhuj-370001, India.

DARSHIT T. BRAHMBHATT, HETUL P. VYAS AND VIBHA N. PARMAR
Electrical Engineering Department,
Gujarat Technological University,
Bhuj-370001 India.

ABSTRACT

Power System Stabilizers (PSS) work well at theparticular network configuration and steady state conditions for which they were designed. Once conditions change the performance degrades. This can be overcome by an intelligent nonlinear PSS based on fuzzy logic. Such a fuzzy logic power system stabilizer (FLPSS) is developed, using speed and power deviation, as inputs and provides an auxiliary signal for the excitation system of a synchronous motor, in a multimachine power system environment. The FLPSS's effect on the system damping is then compared with a conventional power system stabilizer's (CPSS) effect on the system. The results demonstrate an improved system performance with the FLPSS and also that the FLPSS is robust.

INTRODUCTION

Poorly damped oscillations occur between remote generating pools or power stations due to different types and settings of the automatic voltage regulators (AVRs) at different power stations. Some research has been conducted into the use of fuzzy logic stabilizers[1-4] to damp oscillations in power systems, though mainly on single machine systems. Power systems are, in reality, multimachine systems. This paper investigates the effects of a FLPSS in a multimachine environment. Conventional power system stabilizers (CPSS) are designed using classical control theory and a linearized model of the system giving optimalbehaviour at only one condition. The

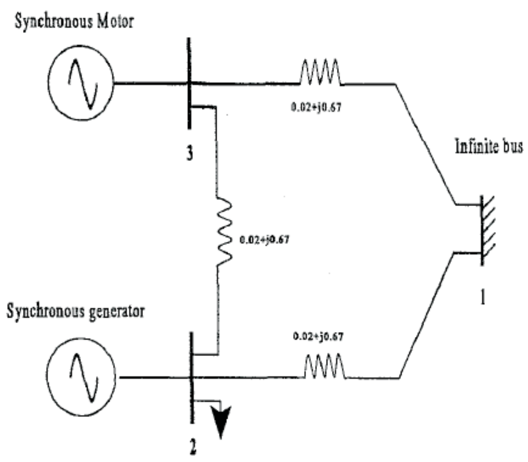

Fig 1- Multi machine system model

system stabilizers (CPSS) are designed using classical control theory and a linearized model of the system giving optimalbehaviour at only one condition. The fuzzy logic approach is much more subjective and allows knowledge and experienced gained of the system, to be utilised in such a manner so as to provide adequate control for the system, even when the system configuration and conditions change.

SYSTEM MODELLING

The multimachine system model is shown in Fig 1 The system consists of a synchronous motor and a synchronous generator, connected through a balanced transmission network to an infinite bus. The generator also supplies a local load. The system is a reduced model of an actual system where the motor represents a pump storage in motoring mode.

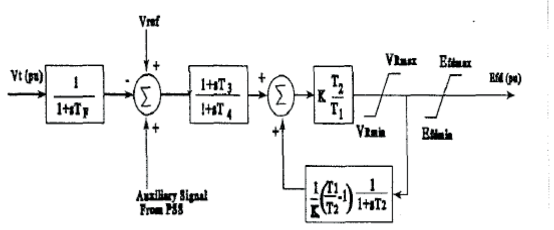

Fig 2-A schematic diagram of Brown Boveri Static exciter.

The prime mover governing systems of both machines are not modelled and the mechanical input power to the generator is assumed constant. Both machines are fitted with Brown Boveri Static Exciters (BBSEX) with a schematic representation shown in Figure 2. The PSS is fitted to the motor and feeds an auxiliary signal into the BBSEXs as shown in Figure 2. Table 1 in Appendix A contains the parameters and time constants for both BBSEXs.Electrically the machines are modeled as a voltage behind a sub transient reactance. These machines have conventionally wound rotors and are represented with two damper windings on the q- axis and one on the d- axis.The d- and q- axes are attached to the major and minor reluctance axes of the rotor respectively. Figure 3 is a schematic diagram of the machine modelling.

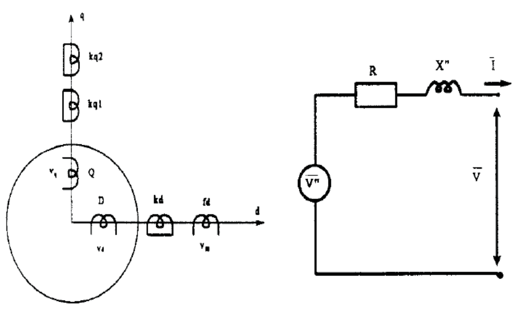

Fig 3-Scematic diagram of machine modeling

The model assumes that:
a) the synchronous machines have sinusoidal air-gap mmfs and linear magnetic circuits.
b) the system is balanced.
c) zero sub-transient saliency i.e. Xd" = Xq" = X".
The machine parameters and constants can be found in Table 2 in Appendix A.

DESIGN AND OPERATION OF THE FUZZY LOGIC STABILIZER

The theory of fuzzy sets [6,7] has been around since 1965 when first proposed by Lotfi A Zadeh. Due to its simplicity and its excellent control of linear and nonlinear devices, fuzzy logic has found widespread use as a tool for engineers in many facets of everyday life.
The FLPSS, like most traditional PSSs, feeds an auxiliary signal into the AVR/excitation system. There are basically three procedures which the FLPSS follows to arrive at the auxiliary signal, namely fuzzification, inference and defuzzification.

FUZZIFICATION

The FLPSS uses speed and electrical power deviation as its input signals. Fuzzification is a process whereby these discrete input variables are mapped onto fuzzy variables, known as linguistic variables. These linguistic variables are what the FLPSS uses to make decisions. Each linguistic variable has a certain membership function, which maps/associates each discrete input variable to linguistic variables. The membership function also assigns a certain degree of membership orweight to each linguistic variable. The degree of membership can be thought of as, how true to a certain linguistic variable is that particular input. The membership functions, for both discrete input variables and the output auxiliary signal, are chosen as triangular. There are seven linguistic variables for each discrete input variable and the output variable, namely, negative big (NB) , negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium(PB) and positive big (PB). There is a 50% overlap of the membership functions.

INFERENCE

Once the discrete input has been fuzzified, i.e. mapped onto linguistic variables, control decisions can now be made based on these linguistic variables. Inference involves two functions, firstly determining output decisions or output linguistic variables based on the input linguistic variables, and secondly, assigning degrees of membership or weights to the output linguistic variables. The FLPSS uses a rule-based system, which places the output decision in a look up table, whereby the input linguistic variables are mapped onto these decisions or output linguistic variables. Due to the input variables having 7 linguistic variables each, the resulting inference table (7x7) has 49 rules. The two discrete input linguistic variables are placed on the borders. The associated output linguistic variable for the combination of these input linguistic variables is placed in appropriate cell.

The rules on which the inference table is based, depend on the 'operator's' knowledge of the system being controlled. The greater the knowledge of the system, the more efficient a decision making table can be set up. For the example in Figure 3, the speed has input linguistic variables PS and PM has input linguistic variables of NS and Z, this maps to output linguistic variables of Z, NS, NS, NM.

To determine the degree of memberships for output linguistic variables, the FLPSS uses what is known as MIN-MAX inference. The degree of membership for each output linguistic variable is given by the minimum of the degree of memberships of the two input linguistic variables determining that output linguistic variable.

As an example, for the combination of power deviation being NS and speed beingPM , the output linguistic variable is NS.

DEFUZZIFICATION

Once the output linguistic variables have been defined, a crisp, discrete output must be derived. Defuzzification is the process whereby crisp numerical output is achieved from a fuzzy set of linguistic variables [6]. If two or more degree of memberships are assigned to the same linguistic variable ,then the maximum of the weights is associated with that linguistic variable.

The centroid method is used for defuzzification.

TUNING OF THE STABILIZER

The optimum ranges for the input and output linguistic variables are obtained from one's knowledge of the system's dynamic behaviour. In the present investigation, the practical system was studied with no stabilizers present and the response for certain types of faults was noted. Thereafter the input and output linguistic variable ranges where tuned so as to counteract the worst case of response achieved. Final fine tuning of the stabilizer was achieved by trial and error.

SIMULATION RESULTS

The simulations were performed in Matlab using the Power System Toolbox (PST) [5] and the Fuzzy Logic Toolbox (FLT) [8]. The PST has built in machine models as well as a loadflow for solving the initial conditions of the system. The FLT allows the user to setup the fuzzy controller and this controller can then be included into the system using Simulink functions.

The system was subjected to one fault but for three different initial conditions. The fault implemented was the permanent removal of the line between the motor and the infinite bus. Results are presented to compare the responses of the machines with no stabilizer present and with the FLPSS in operation. In addition, the response of the system witha CPSS in operation on the motor is shown. The CPSS was tuned for the operating conditions given in Table 3using eigenvalue method.

Case 1 :

The first case uses the initial conditions given in Table 3. The machines' load angles following the permanent removal of the line between bus 3 and the infinite bus are shown in Figure 6 and the electrical power at the terminals of each machine appear in Figure 7.

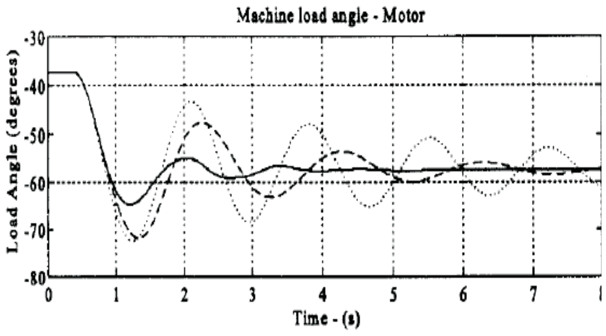

Fig 4(a)

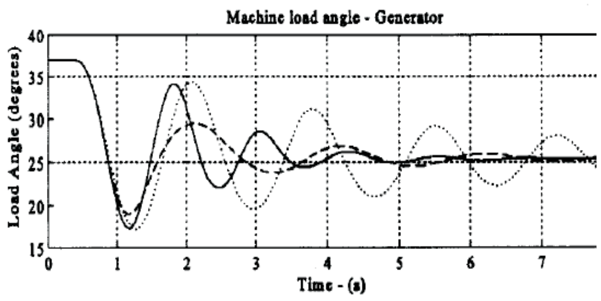

Fig 4(b)

Fig 4-The machine load angles for initial conditions given in Table 4 in Appendix A. The fault implemented is the removal of the line between the motor and the infinite bus.

The fuzzy stabilizer has a profound effect on the dampingof the motor, as seen in Figure 4(a), reducing the magnitude of the first swing and demonstrating a quick settling time. This improvement in damping has come at the initial cost of the generator, which shows a larger first swing, as seen in Figure 4(b). However this is soon damped towithin the response of the CPSS. The electrical power oscillations for case 1 are shown inFigure 5. The action of the FLPSS and CPSS can be seen in damping out power flow oscillations. With the PSS applied at the motor, its negative effect on the initial period of electrical power swing of the generator can be clearly seen (Figure 5b) particularly for the FLPSS. In spite of this poorer response in the initial period, both stabilizers adequately clamp the power oscillations of the generator.

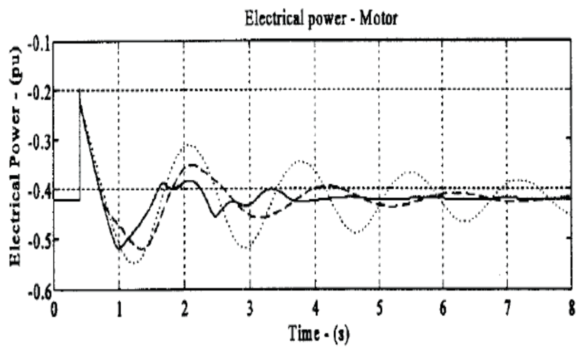

Fig 5(a)

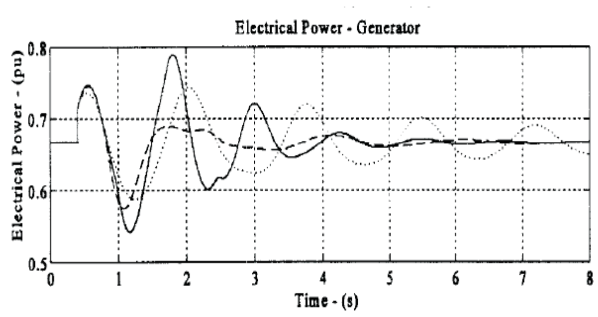

Fig 5(b)

Fig 5-Electrical power responses for the initial conditions given in Table 4 in Appendix A.

Case 2 :

For case 2 the motor's initial operating point is changed so that the motor's reactive power increases from 0.12 lagging (case 1) to 0.56 pu lagging. Figure 6 illustrates the power oscillations for this initial condition when the bus 3/infinite bus line is removed. The power oscillations of the motor with the FLPSS have been almost completely damped out after just 4 seconds and in this respect the performance of the stabilizer is similar to that in Figure 6(a) for case 1.

For the CPSS a comparison of the motor power oscillations in Figure 7(a) with those in Figure 6(a) show a slight degradation of the stabilizer performance at the new operating point of case 2. This is understandable since the CPSS was tuned at the operating point for case 1. For both stabilizers though, the performance in damping power oscillations is satisfactory.

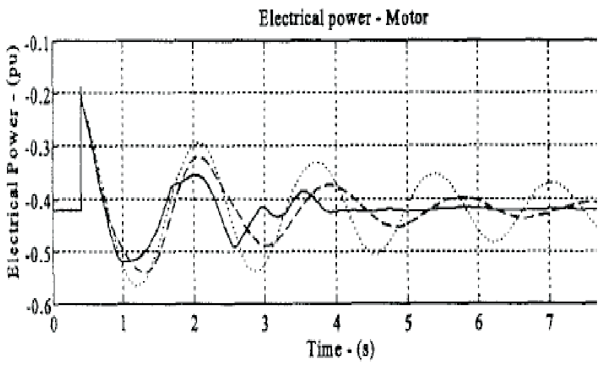

Fig 6(a)

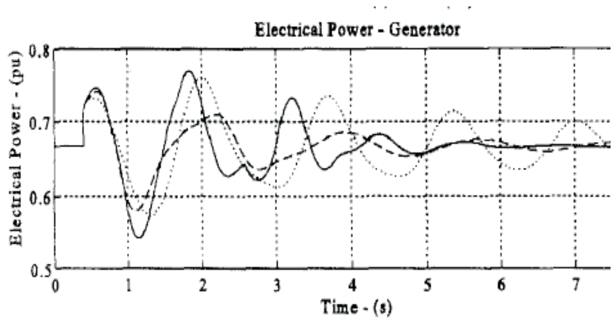

Fig 6(b)

Figure 6 - Electrical power responses for case 2; reactive power of the motor increased to 0.56 lagging.

Case 3 :

For case 3 the motor was returned to the initial condition of Table 3 but the motor's input electrical power was increased from - 0.42 to -0.82 Figure 7 shows the electrical power of the machines for this initial condition when the bus 3/ infinite bus line is removed. It can be clearly seen that for the system with no stabilizer present, the power oscillations are increasing with time and the system may have already gone unstable after 8 seconds.

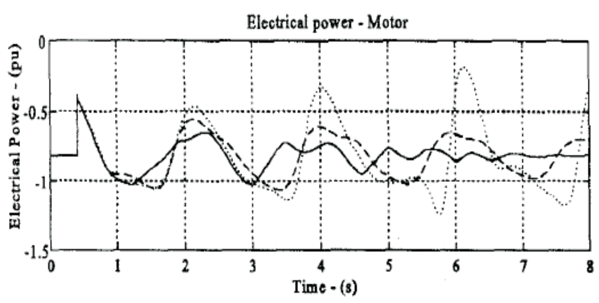

Fig 7(a)

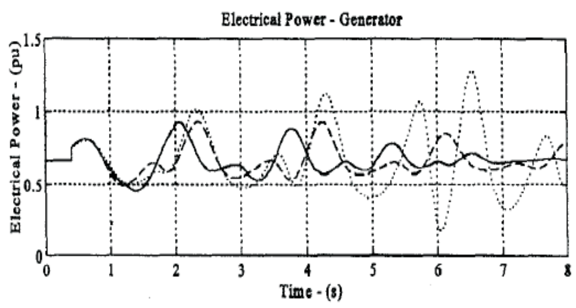

Fig 7(b)

Figure 7 - Electrical power response for case 3; load at bus 3 increased to 0 .82

The CPSS manages to contain the increasing oscillations, but takes a long time to dampen out the power oscillations.

The FLPSS on the other hand manages to successfullydamp out the power oscillations and after 7 seconds the electrical power of both generator and motor have practically returned to steady state. The results at this operating point demonstrate the robustness of the FLPSS

CONCLUSIONS

For the disturbances investigated, the FLPSS has increased the damping of the system causing it to settle back to steady state in much less time than the CPSS. The FLPSS has also proven to be robust and independent of operating point of the machine it is attached to, hence having a greater effect on the multimachine system. The FLPSS, though rather basic in its control proves that it is indeed a good controller due to its simplicity. With careful tuning a much better response can be achieved from the FLPSS. Although the tuning method employed in this investigation was rather crude, fuzzy logic selftuning stabilizers have been developed [4] hence the cumbersome task of trial and error tuning can be overcome.

The theory of fuzzy logic provides many alternatives for setting up a better FLPSS. The membership function shapes can be changed to suite a particular need. Also the number of linguistic variables can be changed to resultingfewer rules to give the same response as a well tuned CPSS.

APPENDIX A

Table 1-*Brown Boveri Static Exciter parameters used for both machines*

	Motor	Generator
Tf(s)	*0.0235*	*0.0235*
K	*321*	*9.48*
T1(s)	*5.46*	*2.18*
T2(s)	*2.52*	*0.616*
T3(s)	*0.0594*	*0.189*
T4(s)	*0.18*	*0.039*
Vrmax	*6.0*	*11.4*
Vrmin	*-6.0*	*-11.4*
Efdmx	*6.0*	*11.4*
Efdmin	*-6.0*	*-11.4*

Table 2-*Machines parameters and time constants. All parameters are Per-unit unless stated otherwise.*

	Motor	Generator
X_d	*1.96*	*1.96*
X_q	*1.75*	*1.75*
X'_d	*0.228*	*0.228*
X'_q	*0.413*	*0.413*
$X''_d = X''_q = X''$	*0.144*	*0.144*
X	*0.11*	*0.11*
$T'_{do(S)}$	*16.8*	*5.3*
$T''_{do(S)}$	*0.0115*	*0.0115*
$T'_{qo(S)}$	*0.155*	*0.155*
$T''_{qo(s)}$	*0.115*	*0.115*
H	*5.5*	*5.5*

Table 3- *Initial system conditions specified to theloadflow. All parameters are per unit*

	Motor	Generator	Infinite bus
V	*1.08*	*1.08*	*1.03*
$P_{generated}$	*-0.42*	*0.67*	*0*
P_{load}	*0*	*0.64*	*0*

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