Journal of Theoretical and Applied Information Technology
30th November 2013. Vol. 57 No.3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

OPTIMAL DESIGN OF POWER SYSTEM STABILIZERS CONTROL FOR MONOMACHINE AND MULTIMACHINE USING INTELLIGENT CONTROL TECHNIQUES -FUZZY LOGIC-

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ABSTRACT

The stability of power electrical networks is a key factor for the delivery of high quality energy. A power system stabilizer (PSS) is designed to deliver a supplement excitation signal to a synchronous machine, to limit frequency oscillations. Frequency oscillations are consequences of either modifying the functioning point, or short circuits. Since power systems are highly non-linear systems, with configurations and parameters that change with time, the Conventional power system stabilizers (CPSS) are designed for a single functioning point. Their performances decrease when the functioning point is modified.
In this paper, a fuzzy expert system (fuzzy power system stabilizer: FPSS) is designed to limit frequency oscillations of a power electrical network. Only 25 rules (comparatively to 49 rules of other works) were used to assure better performances than CPSS. Simulation tests include varying functioning points and short circuits.
Keywords: *Fuzzy expert system, Synchronous machine, Electrical power network, Power system stabilizer*

1. INTRODUCTION

Today, PSSs are widely used on synchronous generators. The most commonly used PSS, referred to as the Conventional PSS (CPSS), is a fixed parameter analog –type device. The CPSS, first proposed in 1950's, is based on the use of a trader function designed using the classical control theory [1]. It contains a phase compensation network for the phase difference from the excitation controller input to the damping torque output. By appropriately tuning the phase and gain characteristics of the compensation network, it is possible to set the desired damping ratio. CPSSs are widely used in the power systems these days and have improved power system dynamic stability.

The CPSS, however, has its inherent drawbacks. It is designed for a particular operating condition around which a linearized trader function model is obtained. The high non-linearity, very wide operating conditions and unpredictability of perturbations of the power system exhibit the following problems to the CPSS:

- The accuracy of linear model for the power system;
- The accuracy of the parameters for that model;
- The effective tuning of the CPSS parameters;
- The interaction between the various machines;
- The tracking of the system non-linearity;

Extensive research has been carried out to solve these problems [2]. Numerous tuning techniques have been introduced to effectively tune the CPSS parameters [3-4-5-6-7]. Mutual interaction between CPSSs in multi-machine systems has also been studied [8-9].To solve the parameter tracking problem, variable structure control theory was introduced to design the CPSS [10-11-12]. However, the CPSS is a linear controller which generally cannot maintain the same quality of performance at other operating conditions.

The adaptive control theory provides a possible way to solve the above mentioned problems relating to the CPSS [13]. At each sampling instance, input and output of the

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generating unit are sampled, and a mathematical model is obtained by some on-line identification method to represent the dynamic behavior of the generating unit at that instant of time. It is expected that the mathematical model obtained at each sampling period can track changes in the system.

Following the identification of the model, the required control signal for the generating unit is produced based on the identified model. There are various control strategies, among them are Pole Assignment (PA) and Pole Shifting (PS) techniques [14-15]. These control strategies are generally developed by assuming that the identified model is the true mathematical description of the generating unit [16-17-18-19].

However, since the power system is a high order nonlinear continuous system, it is hard for the low order discrete identified model to precisely describe the dynamic behavior of the power system. Consequently, a high order discrete model is used to represent the power system, which consumes a significant amount of computing time. The computing time for an adaptive PSS is roughly proportional to the square of the order of the discrete model used in the identification. The longer computing time limits the control effect. This is more significant if the oscillation frequency is relatively high. There must be a compromise between the order of the discrete model and the computing time for parameter identification and optimization.

Designing stabilizers based on FLC is a very active area and satisfactory results have been obtained [20-21-22-23]. Although FLC introduces a good tool to deal with complicated, nonlinear and ill-defined systems, it suffers from a drawback - the "parameter tuning" for the controller. At present, there is no systematic procedure for the design of the FLC. The most straight forward approach is to define Membership Functions (MFs) and decision rules subjectively by studying an operating system or an existing controller. Therefore, there is a need for an effective method for tuning the MFs and decision rules so as to minimum the output error or maximizes the performance index.

2. CONVENTIONAL POWER SYSTEM STABILIZER

The electric power system is a complex system with highly non-linear dynamics. Its stability depends on the operating conditions of the power system and its configuration. Low frequency oscillations are a common problem in large power systems [24].

Excitation control or AVR is well known as an effective means to improve the overall stability of the power system. Power System Stabilizers (PSS) are added to excitation systems to enhance the damping during low frequency oscillations.

The variations of angular velocity of the generators are generally used as input signal of this device, with the installation of PSS near the generator, this signal is locally obtained, and the output of the PSS is applied as a supplementary control signal to the machine voltage regulator terminal [25]. Oscillations of small magnitude and low frequency often persist for long periods of time and in some cases can cause limitations on the power transfer capability [26]. The basic structure of the CPSS is as follows Fig. 1, the input to the conventional PSS is speed deviation.

The PSS gain Ks is an important factor as the damping provided by the PSS increase in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. The basic structure of the CPSS is as follows [25].

1. A gain block
2. A phase compensation block
3. A signal washout block

K_{pss}: PSS gain compensator.

τw, $\tau 1$, $\tau 2$, $\tau 3$, $\tau 4$: PSS phase compensator parameters.

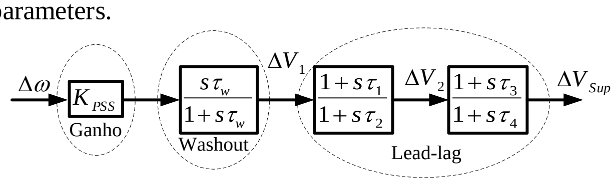

Figure. 1. Basic structure of a typical PSS based on phase compensation.

The operating condition does change as a result of load variation and major disturbances, making the dynamic behavior of the power system to become different, at different operating points. Thus, if the parameters of the stabilizer are kept fixed, PSS performance is degraded whenever the operating point changes.

The design problem of such a controller is to calculate the parameters of the blocks of advance and phase delay, of washout block and gain feedback so that the controller can provide an appropriate phase compensation for a frequency range of interest. These controllers have been used several decades effectively, economically and

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securely in power system to damp oscillations. However, the performance in the oscillations inter-area mode, which typically occur in lines of interconnection of large power systems and so, far the parks generators, may not be effective [27].

However, because of its inherent linear characteristic, it faces many serious problems. The stabilizer should be able to catch the non-linearity of the system and produce the same performance for different operating conditions and different types of disturbances.

3. FUZZY POWER SYSTEM STABILIZER

3.1 Fuzzy Controller Structure

The Fuzzy Logic controller (FLC) can be used in a wide range of control system applications. Compared to classical control, the FL advantage is the possibility of its application in absence of the mathematical model. Whether a physical system, logic or conceptual, the truth is that the classical theory of control requires a thorough knowledge of the process to be controlled and the system's response to several stimuli [28]. This is not always possible and, at best, sometimes it is complicated. Fuzzy Logic plays an essential role, by using uncertain information to describe the performance of the plant and to develop the control.

3.2 Basic Architecture of FLC Systems

The basic idea behind FLC is to incorporate the expert experience of human operator in the design of a controller in controlling a process whose input-Output relationship is described by a collection of FLC rules involving linguistic variables. This utilization of linguistic variables, FLC rules, and approximate reasoning provides a means to incorporate human expert experience in designing the controller.

A FLC consists of several IF-THEN rules, which describes adequate control strategy for the given problem in linguistic terms. The basic configuration of FLC comprises four principle components: a fuzzification interface, a fuzzy rule base, an inference engine, and a defuzzification interface.

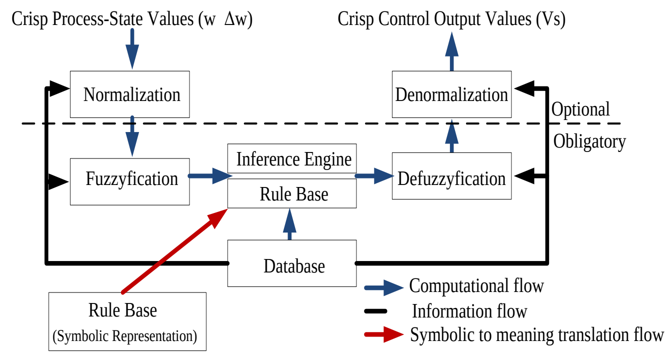


Figure. 2. Block Diagram Of The Fuzzy Controller Structure.

- The fuzzification interface converts the input values of both the error and error change into suitable linguistic values that may be viewed as terms of fuzzy sets.
- The fuzzy-rule base comprises knowledge of the application domain and the attendant control goals. It consists of a fuzzy data base and a linguistic (fuzzy) control-rule base.
- The fuzzy data base is used to define linguistic control rules and fuzzy data manipulation in FLC.
- The control-rule base characterizes the control goals and control policy by means of a set of linguistic control rules.
- The inference engine is a decision-making logic mechanism of FLC.
- The defuzzification interface converts fuzzy control decisions into crisp, non-fuzzy (i.e., physical) control signals.

A block diagram of the fuzzy controller structure is shown in Fig. 2.

3.3 Membership functions

Fuzzy sets must be defined for each input and output variable. Figs. 3 and 4 shows the input and output memberships, respectively of the fuzzy controller. Five fuzzy subsets ***PB*** (Positive Big), ***PS*** (Positive Small), ***ZE*** (Zero), ***NS*** (Negative Small) and ***NB*** (Negative Big) have been chosen for input variables e_O and Δe_O, For the output variables five fuzzy subsets have been used (***PB***, ***PS***, ***ZE***, ***NS***, and ***NB***), in order to smooth the control action.

As shown in Figs. 3 and 4 shapes have been adopted for the membership functions; the value of each input and output variable is normalized in [-1, 1] by using suitable scale factors.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

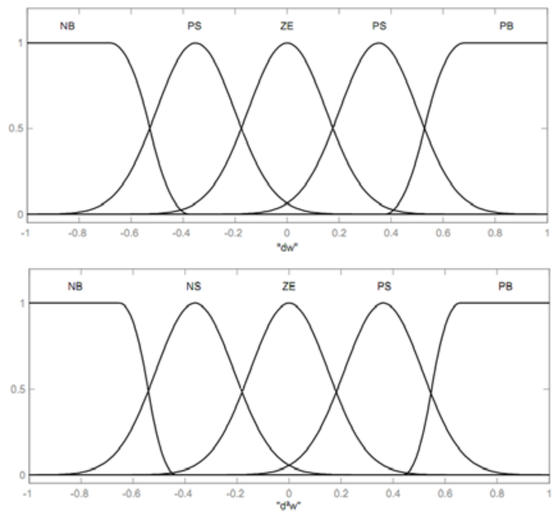
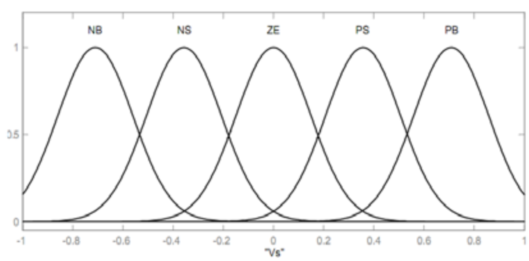


Figure. 3. Membership Normalized Input Functions ($E_o n$,



$\Delta e_o N$)

Figure. 4. Membership Normalized Output Function.

When the controller is select to work as a constant current mode charger, the input variables are the generator speed deviation (Δw), generator acceleration deviation (Δ^2w) and power system stabilizer output (Vs). But the memberships input and output functions are the same.

As a fuzzy inference method, Mamdani´s method is used with max-min operation fuzzy combination law.

TABLE I. Fuzzy Control Rules Table the Rules of FPSS.

Δ²ω Δω	NB	PS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
PS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

Note the stabilizer output is obtained by applying a particular rule expressed in the form of membership function.

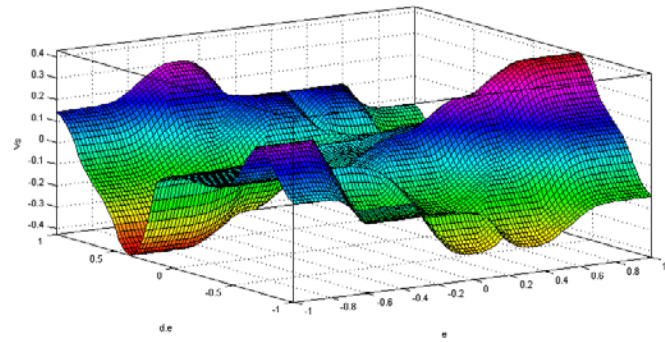


Figure. 5. Control Action Surface The Fpss.

4. SIMULATION RESULTS

The system comprises of synchronous machines, excitation system and power system stabilizer model. The system model is developed as following toolbar.

4.1 Synchronous Machine Model

The configuration of synchronous machine connected to infinite bus through transmission network is represented as the Thevenin's equivalent shown in Fig. 6.

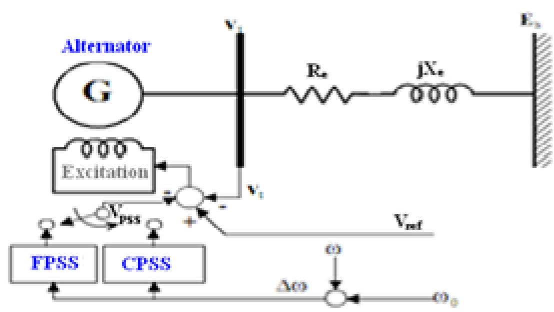


Figure. 6. Single Machine Connected To An Infinite Bus.

42.1.1 Test: changes of the generator operating point

The effect on the generator speed deviation due to 20% variations of active power P_o the nominal point is shown in Fig. 7.

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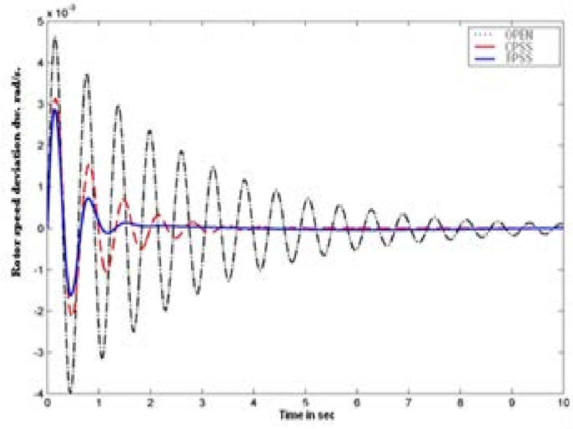

Figure. 7. The Effect On The Generator Speed Deviation Due To 20% Variations Of Active Power Po.

4.1.2 Fault Test

Short circuit of less than few ms as shown in Fig. 8 could easily destroy or disturb the performance of the generator. Moreover, an enhanced correction of the rotor speed deviation signal was achieved by using new developed (FPSS) as shown in Fig. 9.

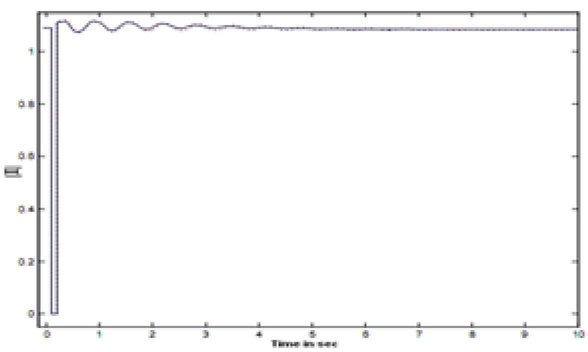

Figure. 8. Response To A Three Phase To Ground Fault At The Middle Of One Transmission Line.

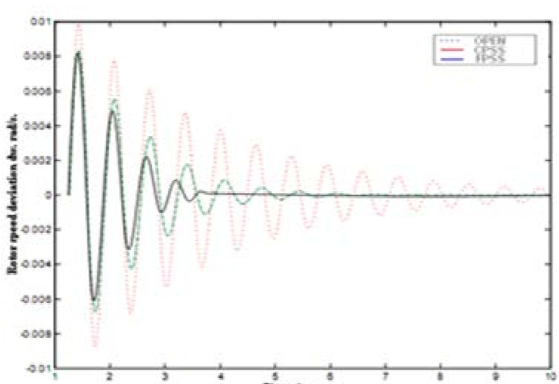

Figure. 9. Response Rotor Angle To A Three Phase Short Circuit

Furthermore, Compared old systems as CPSS, without CPSS and the new developed FPSS in Fig. 9 confirmed a better performance over a wide range of operating conditions.

4.2 Multi-machines System

The objectives of this part are to implement the SIMULINK simulation, of the simple multi-machines System in Fig. 10 using the transient model for the generators, and to use the simulation to examine the interactions between generators. The power system considered in this paper is a two machines 3-bus power system as shown in Fig. 10.

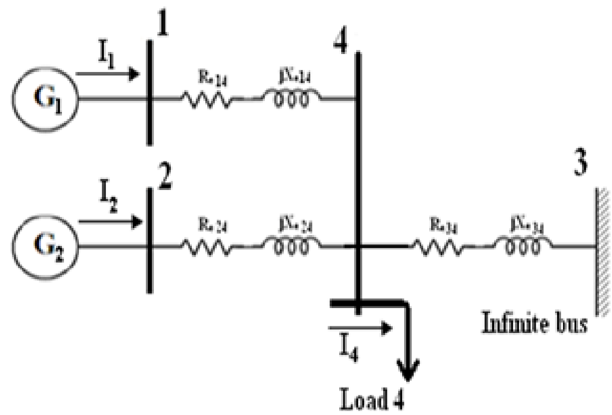

Figure. 10. Multi-Machines Connected To An Infinite Bus Network.

- **Test: changes of the generator operating point**

To demonstrate the capability of the proposed FPSS to enhance system damping over a wide range of operating conditions, four different loading conditions were considered as given in Table II.

TABLE II The Following Table Shows Changes In Operating Points.

Time (s)	0	7,5	15	22,5
Variations operating points (active power P_o)	80%	90%	70%	80%

At the same time, ail the simulation cases are also studied based on a conventional PSS. The simulation results are shown as follows in Figs. 11 and 12

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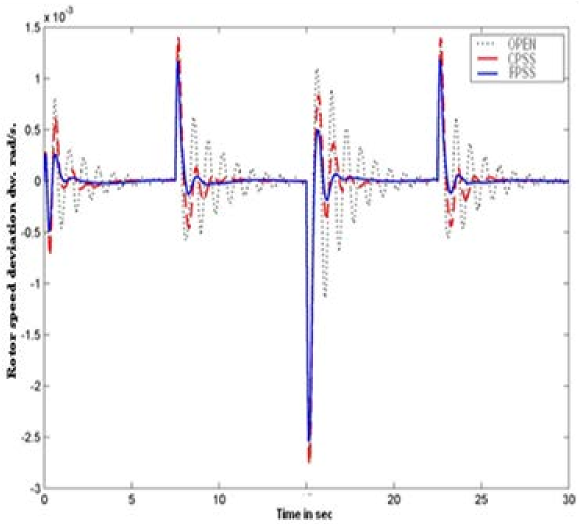

Figure. 11. System Response With FPSS And CPSS Installed On G1.

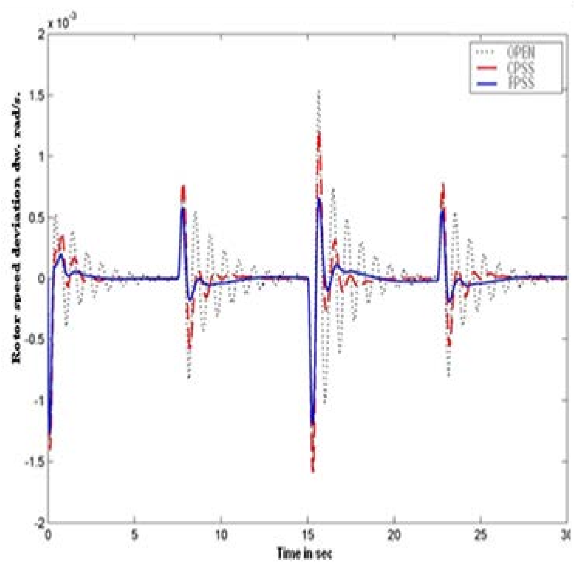

Figure. 12. Response System With FPSS And CPSS Installed On G2

Good results were obtained by using one FPSS automated device in multi-generators systems see (Figs. 11 and 12) the signal $\Delta\omega$ coming from FPSS show clearly that the response of $\Delta\omega$ was enhanced by decreasing the amplitude and the number of oscillations after each change in the operating point.

5. CONCLUSIONS

The behavior of the proposed FPSS is investigated in the single-machine infinite bus system through computer simulation. Various operating conditions such as changes in the operating points and short-circuit fault are also tested. Simulation results show that the proposed FPSS can provide satisfactory damping effect to the power system oscillations over a wide operating range, and significantly improve the system stability.

In a multi-machine power system. There are multi-mode oscillations due to the different inertia of interconnected generator units and weak connection between them. The performance of the proposed FPSS in a 2 machine power system is also investigated in this paper. The simulation results show that the FPSS can not only damp the specified mode of oscillation mainly related to the generating unit on which the RNN PSS is applied, but also cooperate with other FPSSs or CPSSs to damp the local and inter-area oscillations.

Figures should be labeled with "Figure" and tables with "Table" and should be numbered sequentially, for example, Figure 1, Figure 2 and so on (refer to table 1 and figure 1). The figure numbers and titles should be placed below the figures, and the table numbers and titles should be placed on top of the tables. The title should be placed in the middle of the page between the left and right margins. Tables, illustrations and the corresponding text should be placed on the same page as far as possible if too large they can be placed in singly column format after text. Otherwise they may be placed on the immediate following page. If its size should be smaller than the type area they can be placed after references in singly column format and referenced in text

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