IEEE conference

Dataset · December 2015

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Design and Analysis of Fuzzy Power System Stabilizer

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***Abstract*-- This paper introduces a fuzzy controller as a power system stabilizer (PSS). The fuzzy controller has been designed to provide a supplementary signal to the excitation system of the synchronous generator. Three proposed types of fuzzy control algorithms are inspected and tested in the case of single machine that connected to the network, for various types of disturbance. To show the effectiveness of the proposed controller in damping oscillations a three-phase short circuit condition under various loading conditions is presented to illustrate the application of the developed methodology. The obtained results show that the proposed controller for stabilizing power system can provide very good damping characteristic, comparison with the conventional PSS, through wide range of operating condition for power system and improves dynamic operating of the system substantially.**

***Index Terms*-- Fuzzy control, operating condition, Power system stabilization**

I. INTRODUCTION

Power generators are conventionally provided with automatic voltage regulators (AVRs) to improve their dynamic responses and control their terminal voltages. But, AVRs introduce negative damping torques, which affect the stability unfavorably. Exposed to disturbances, such as short circuits and operating point variations, power systems may demonstrate unacceptable oscillations or loose synchronism. The conventional Power system stabilizers (CPSS) are normally incorporated to repress and damp these oscillations. Other types of PSS such as proportional integral (PIPSS) and proportional integral derivative (PIDPSS) have also been recommended. The gain settings of these controllers are settled based on the linearized model of the power system around a nominal operating point to provide optimal performance at this point. Ordinarily, the power systems are highly nonlinear and the operating conditions can change over a wide range as a result of load changes, line switching, and unforeseeable major disturbances such as three phase faults. Thus a controller must be working in the nonlinear systems and providing good damping characteristics over a wide range of operation conditions such as fuzzy controller. Fuzzy controller has many advantages. They are simple in structure, and comparatively easy to realize mathematical model of the controlled system. The variations of the parameters and operating conditions of the controlled system do not significantly affect the performance of the controller.

Junya Mtsuki describes the experimental results on an application of fuzzy control design to stabilization of electric power systems [1]. Y.J. Cheng presented an integrated tabu–fuzzy knowledge based controller applied to increase the performance of power system stabilizer [2]. T. Hussein introduces a robust adaptive fuzzy controller as a power system stabilizer (RFPSS) used to damp inter-area modes of oscillation following disturbances in power systems [3]. A.L. Elshafei proposes a new power system stabilizer based on adaptive fuzzy systems, that has the ability to adaptively tune its rule-base online [4]. A.A. Abou El-Ela proposes a msulti-stage procedure to overcome the effects of different emergency conditions using multi-objective fuzzy linear programming (MFLP) technique [5]. T.S. Chung investigate a strange control strategy is developed for High Voltage DC (HVDC) links to enhance oscillatory stability of interconnected power systems [6].

In this paper, we concern about the fuzzy controller abilities in power systems. It will be shown that the proposed controller for stabilizing power system can provide very good damping characteristic, comparison with the conventional PSS.

II. FUZZY CONTROL ALGORITHMS

The linear control theory uses a mathematical model of a plant and some specifications of the anticipated behavior in closed loop to design a controller. These controllers are favorably used and have a good behavior in systems that can be supposed as linear in specific range of their operation and pre-determined conditions. The method of root-locus design was tried in the linear control design, and because of having non-acceptable results, would not be deal with profundity in this paper, due to the difficulty to achieve a mathematical model as in numerous nonlinear or unknown systems. In some cases, system does not have constant parameters or has interdependence with others parameters. In these cases, the linear control strategies could be limit in its design and performance. These reasons cause that the human knowledge adds various types of information and mix different control strategies that cannot be added in an analytical control law and do not need an accurate mathematical model [7]. The Knowledge-based fuzzy control uses the experience and the

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knowledge of a proficient about the system behavior. A kind of Knowledge-based fuzzy control is the rule-based fuzzy control, where the human knowledge is approached by means of linguistic fuzzy rules in the form *if-then,* which describes the control action in a special condition of the system. Due to the nonlinear behavior exhibited by the machine, designing a linear control is not successful [8], [9]. By knowing the advantages of the fuzzy control, described before, a nonlinear fuzzy control might be desirable as a power system stabilizer, instead of PSS, by providing a supplementary signal to the excitation system of the synchronous generator. The control proposed for the controller is a Mamdani controller, since it is usually used as feedback controller because the rule base represents a static mapping between the preceding and the consequent variables. For stabilizing power system in a fuzzy controller, the Fuzzy Inference System (FIS) uses the error and/or error derivative as input, and the supplementary signal that inject to excitation system of the synchronous generator, as output [10], [11].

The fuzzy logic controller unlike conventional controllers does not require a mathematical model of the process. However, a understanding of the system and the control requirements is necessary. The fuzzy controller designer must clarify how the information is processed (control strategy and decision), and information flows out of the system (solution/output variable)[7]. The fuzzy logic controller consists of three basic blocks: A) Fuzzification; B) Inference Mechanism; C) Defuzzification

A. Fuzzification

In designing fuzzy controller each control variables which define the control surface be described in fuzzy set symbols using linguistic rules. To decompose each system variables into fuzzy domain, the membership functions must be defined. The membership functions symbolize the extent that which variable is a member of a particular rule. This procedure of converting input/output variables to linguistic rules is designated as Fuzzification that is performed using the rule bases. The control rules are constructed based on the characteristics of the step response. For example, if the output is falling far away from the set point, a large control signal that pushes the output toward the set point is awaited, since a small control signal is required when the output is near and approaching the set point.

B. Inference Mechanism

The behavior of the control surface which explains the input and output variables of the system, is managed by a set of rules. A characteristic of rules would be: If (*fuzzy suggestion of input*) Then (*fuzzy suggestion of output*) Where the fuzzy suggestion is of the type "*x is y*" or "*x is not y*", *x* being a scalar variable and *y* is a fuzzy set associated with that variable. These rules are used to decide the proper control action. When a set of input variables are read, each of the rules that has any grade of truth (a nonzero value of membership grade) in its premises is fired and cause to creating of the control surface by properly adapting it. When all the rules are fired, the resulting control surface, described as a fuzzy set to represent the controllers output. These rules used to create a fuzzy set that semantically represents the concept associated with the rule. To have a smooth, stable control surface, an overlap between adjoining rules is provided such that the sum of the vertical points of overlap should never be greater than one. In the proposed controller the error and/or error derivative is fuzzified and described as fuzzy sets.

C. Defuzzification

The fuzzy set that depicting the controller output in linguistic rules has to be transformed into a feasible solution variable before it can be used to control the system. This is obtained by using a Defuzzification. Various methods of Defuzzification are available. The most prevalently used methods are **a)** Mean of Maxima (MOM) and **b)** Center of Area (COA). COA method is used in this paper, because this method calculates the center of gravity of the final fuzzy space and products a result which is sensitive to all the rules performed. Hence the results tend to move smoothly across the control surface.

The three types of fuzzy control algorithms presented in this paper: **C(1):** a single input-single output control scheme, **C(2):** another single input-single output control scheme and **C(3):** two input-single output control scheme.

C(1): Single input-single output control scheme (type 1)

In the type (1) controller, the acceleration of generator speed $d\dot{\omega}$ is chosen as input and output of the controller is used as a supplementary stabilizing signal, instead of PSS, to a digital AVR of the tested generator. The accelerating control of the studied system is achieved by applying a positive stabilizing control signal U to the excitation loop, while the decelerating control is achieved by applying a negative stabilizing control signal U to the excitation loop. Regarding these, the control rule may be described as fuzzy conditional statements as follows: "if the speed derivative is negative, then the control applied is negative" and "if the speed derivative is positive, then the control applied is positive". Thus at least two rules are needed. To realize a more efficient control, a set of seven rules are determined in this study as follows where PL (positive large), PM (positive medium), PS(positive small), ZR(zero), NS(negative small) , NM(negative medium) and NL(negative large).

Rule 1: if $d\dot{\omega}$ is NL then U is NL.
Rule 2: if $d\dot{\omega}$ is NM then U is NM.
Rule 3: if $d\dot{\omega}$ is NS then U is NS.
Rule 4: if $d\dot{\omega}$ is ZR then U is ZR.
Rule 5: if $d\dot{\omega}$ is PS then U is PS.
Rule 6: if $d\dot{\omega}$ is PM then U is PM.
Rule 7: if $d\dot{\omega}$ is PL then U is PL.

For each of these fuzzy sets, triangular membership function (MF) has been used. These membership functions are shown in Figs. 1, 2.

C(2): Single input-single output control scheme (type 2)

In the type (2) controller, the time derivative of rotor speed of generator ώ is chosen as input, and signal U is the output of the controller. Seven fuzzy subsets have been used in this scheme similar type (1) controller. A set of seven rules are determined in this study as follows. For each of these fuzzy sets, triangular membership function (MF) has been used. These membership functions are shown in Figs. 3, 4.

Rule 1: if $\dot{\omega}$ is NL then U is NL.
Rule 2: if $\dot{\omega}$ is NM then U is NM.
Rule 3: if $\dot{\omega}$ is NS then U is NS.
Rule 4: if $\dot{\omega}$ is ZR then U is ZR.
Rule 5: if $\dot{\omega}$ is PS then U is PS.
Rule 6: if $\dot{\omega}$ is PM then U is PM.
Rule 7: if $\dot{\omega}$ is PL then U is PL.

C(3): A two input- single output control scheme(type 3)

In the type (3) controller, the acceleration of generator speed ($d\dot{\omega}$) and the Rotor speed deviation ($d\omega$) are selected as inputs and the supplementary stabilizing signal U is the output of the controller. The parameters of the controller should be determined by trial and error, using the simulation of system. Seven fuzzy subsets have been used in this scheme similar type (1). For each of these fuzzy sets, Gaussian membership function (MF) has been used. These membership functions are shown in Figs.5, 6, 7. 49 fuzzy subsets results through these fuzzy sub-sets for computing the output is shown in table 1.

TABLE1
FUZZY CONTROL RULES

$d\omega / d\dot{\omega}$	NL	NM	NS	ZR	PS	PM	PL
NL	**NL**	**NL**	**NL**	**NM**	**NS**	**NS**	**ZR**
NM	**NL**	**NM**	**NM**	**NM**	**NS**	**ZR**	**PS**
NS	**NL**	**NM**	**NS**	**NS**	**ZR**	**PS**	**PM**
ZR	**NL**	**NM**	**NS**	**ZR**	**PS**	**PM**	**PL**
PS	**NM**	**NS**	**ZR**	**PS**	**PS**	**PM**	**PL**
PM	**NS**	**ZR**	**PS**	**PM**	**PM**	**PM**	**PL**
PL	**ZR**	**PS**	**PS**	**PM**	**PL**	**PL**	**PL**

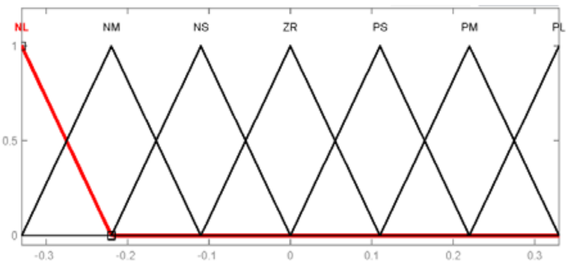

Fig.1. Membership Function of dώ in type (1) fuzzy controller

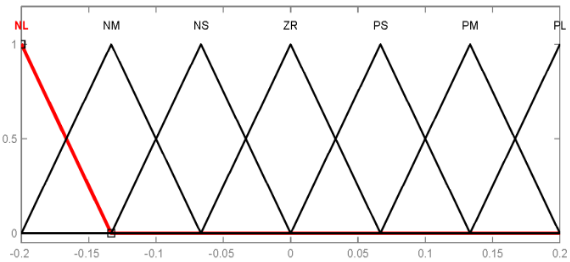

Fig.2. Membership Function of output in type (1) fuzzy controller

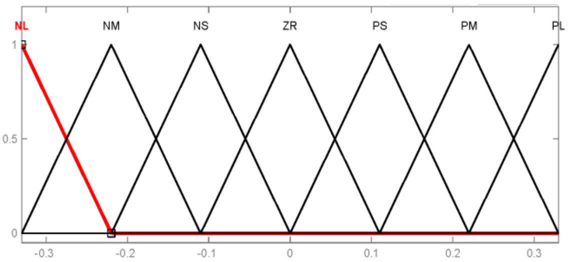

Fig.3. Membership Function of ώ in type (2) fuzzy controller

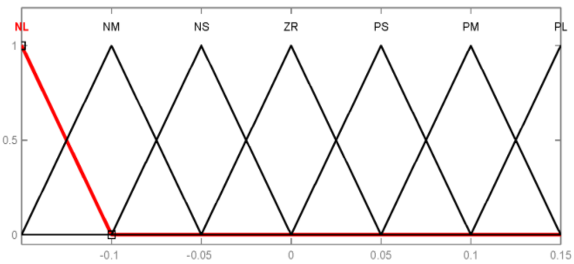

Fig.4. Membership Function of output in type (2) fuzzy controller

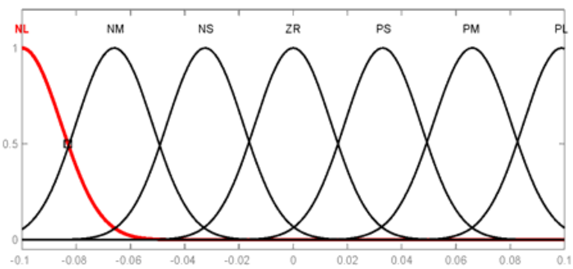

Fig.5. Membership Function of dω in type (3) fuzzy controller

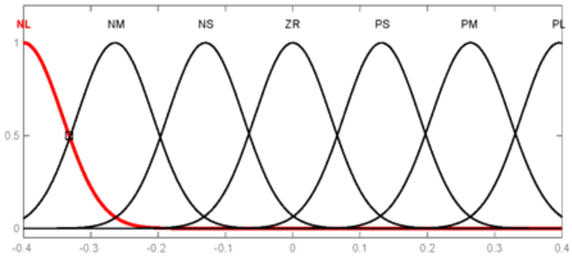

Fig.6. Membership Function of $d\dot{\omega}$ in type (3) fuzzy controller

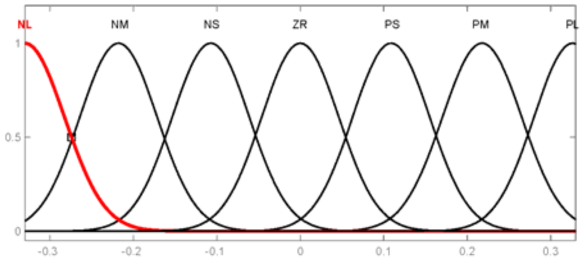

Fig.7. Membership Function of output in type (3) fuzzy controller

III. SYSTEM DESCRIPTION

The model of system, consists of a 200MVA, 13.8KV Three phase, 60Hz**,** 32 pole synchronous generator. The generator is connected to the network (10000MVA, 230KV) through a transmission line, as shown In Fig.8. The basic parameters of the generator as shown in the appendix. The generator is equipped with a digital AVR and a digital PSS.

IV. IMPLEMENTATION OF FUZZY CONTROL

To show the design process as well as to investigate the effectiveness of the fuzzy controllers, We set the three phase short circuit faults during [0.5 0.57] of time for three cases, namely AVR only, AVR with PSS and AVR with Fuzzy Control.

A. System responses under AVR only

Figs.9, 10 illustrates the dynamic behaviors of the generator following a three phase short circuit faults in the case of AVR only in the one-machine connected to the network. The following variables are plotted: electrical output power (Pe) and rotor speed deviation (dω). The oscillations of the variables decay very slowly.

B. System responses under AVR and PSS

The dynamic behaviors of the system under AVR and PSS are shown in Figs11, 12. From these figures it can be seen that the oscillations of the variables are more quickly damped than those under AVR only.

C. System responses under AVR and Fuzzy controller

Figs13, 14 shows the dynamic behaviors of the system under the type (1) fuzzy controller and AVR. From these figures, it can be seen that the oscillations are more quickly damped than those under AVR and PSS. The dynamic behaviors of the system under the type (2) and (3) fuzzy controller and AVR are shown in Figs.15, 16 and Figs17, 18 respectively.

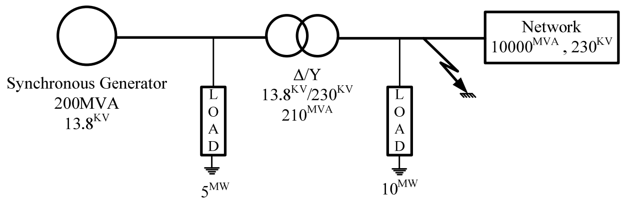

Fig.8. The model of system

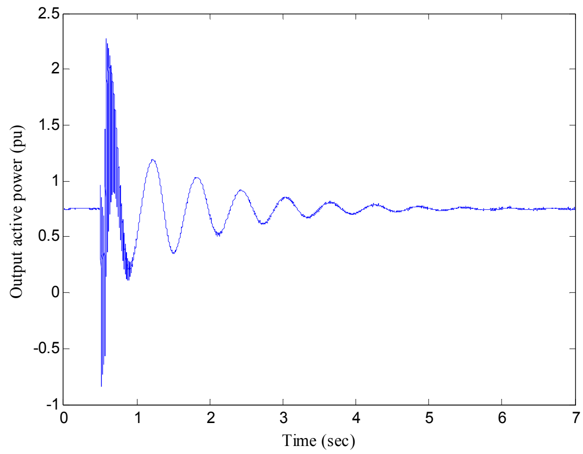

Fig.9.Output active power under AVR only

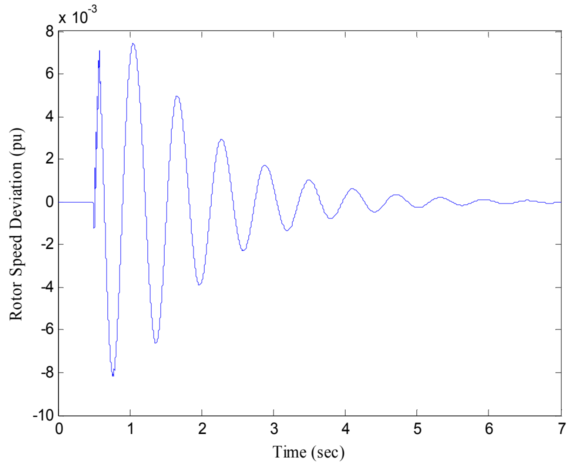

Fig.10.Rotor speed deviation under AVR only

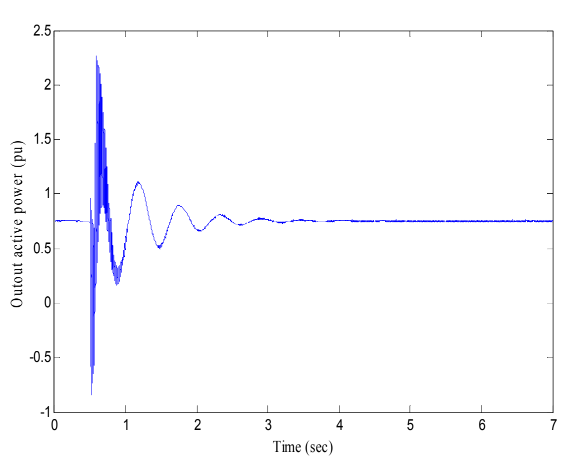

Fig.11.Output active power under AVR and PSS

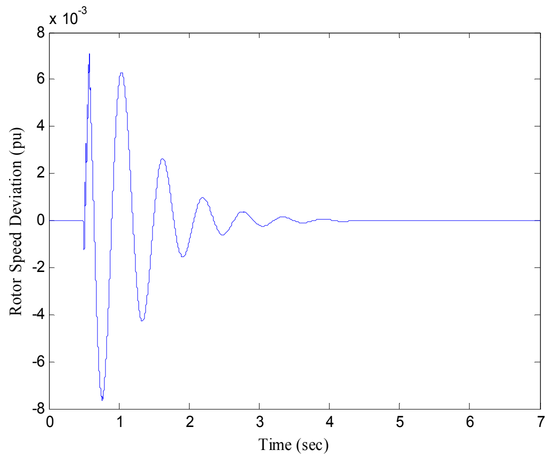

Fig.12.Rotor speed deviation under AVR and PSS

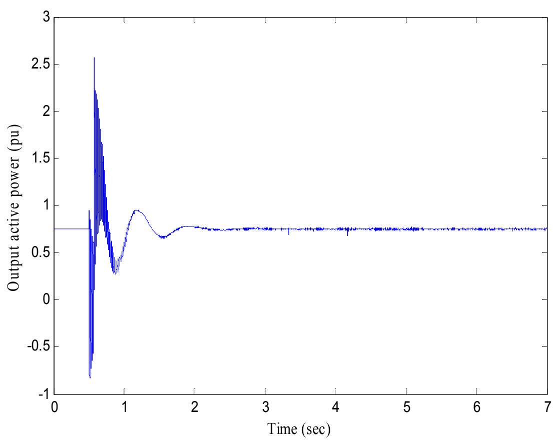

Fig.13.Output active power under AVR and type (1) fuzzy controller

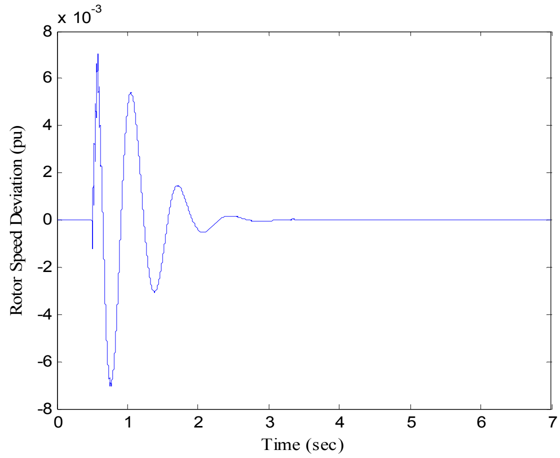

Fig.14.Rotor speed deviation under AVR and type (1) fuzzy controller

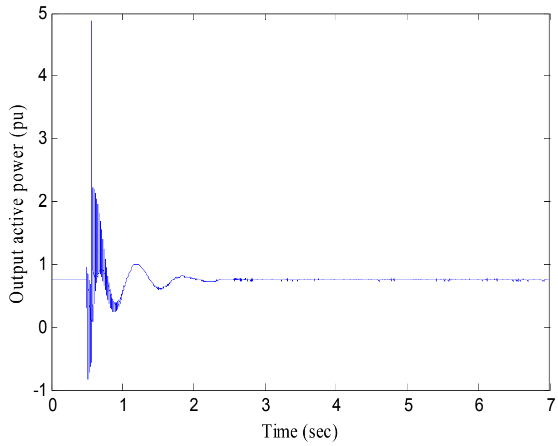

Fig.15.Output active power under AVR and type (2) fuzzy controller

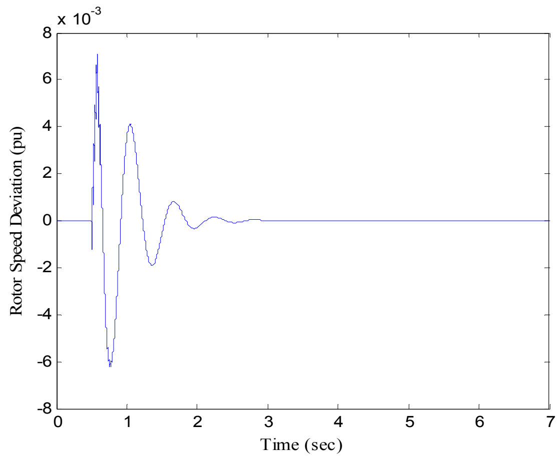

Fig.16.Rotor speed deviation under AVR and type (2) fuzzy controller

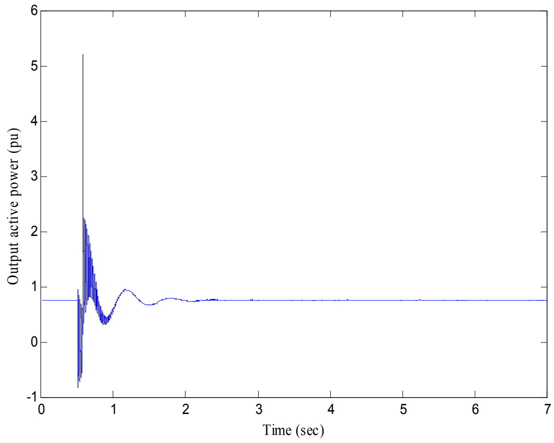

Fig.17.Output active power under AVR and type (3) fuzzy controller

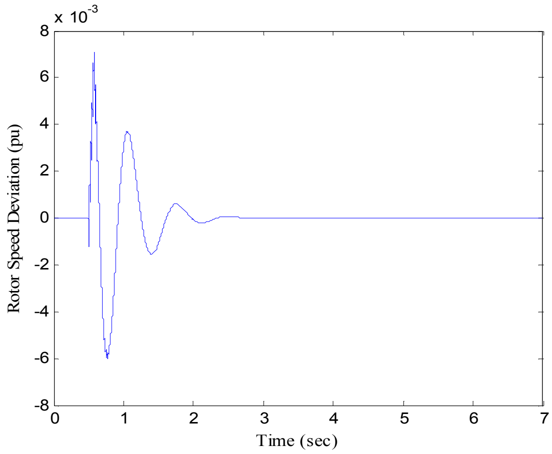

Fig.18.Rotor speed deviation under AVR and type (3) fuzzy controller

V. CONCLUSIONS

The control performances of the proposed fuzzy controllers, insist of PSS, under various operating conditions are investigated. The fuzzy controller has been designed to provide a supplementary signal to the excitation system of the synchronous generator. With reference to figures presented in the previous section, type (1) controller show that even the unaffected control for the disturbances is, unexpectedly, highly rewarded with successful performances mainly due to the fast control action. The results illustrates that a slightly improvement of the system stability was achieved by the type (2) fuzzy controller in comparison with type (1) controller. A considerable improvement of the system stability was obtained by type (3) fuzzy controller, in comparison with that by the conventional power system stabilizer based on the**,** mathematical models. The design of the fuzzy controllers requires no mathematical model of generator and power system as would be needed by the conventional power system stabilizers. Regarding this and its simple control scheme also, the performances of the proposed fuzzy controllers were reasonably pleasant, probably due to their nonlinearity, although determination of optimal fuzzy control parameters by trial and error was required.

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VII. APPENDIX

Machine Parameters:
The parameters of the tested generator are as follows:

$x_d = 1.305$	$x_l = 0.18$	$T'_d = 1.01$
$x'_d = 0.296$	$x''_q = 0.243$	$T''_d = 0.053$
$x''_d = 0.252$	$R_s = 2.85\times 10^{-3}$	$T''_{q0} = 0.1$
$x_q = 0.474$		$H = 3.2$

VIII. BIOGRAPHI

Alireza Roosta was born in Iran. He received his B. S. and M.S degree in control Eng. from Tehran University and PhD degree in Electrical Eng. form INPG (France). Currently, he is an Assistant Professor with the Shiraz University of Technology. His research interests include stability and control and impact of DGs on power system.

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