Design of genetic fuzzy logic power system stabilizer for power systems

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In this paper genetic fuzzy logic Power System Stabilizer (PSS) is designed. The proposed PSS design is based on fuzzy logic controller and genetic algorithm. The proposed power system stabilizer is investigated on a single-machine connected to infinite bus power system. The proposed stabilizer showed better performance than other conventional power system stabilizers. The proposed genetic fuzzy logic power system stabilizer can be applied to multimachine power systems.

هذه الورقة العلمية تقترح تصميم مثبت جينى منطقى غائم لنظم القوى الكهربائية. المثبت المقترح صمم باستخدم التحكم الغائم مدمجا مع الخوريزم الجينى. المثبت المقترح اثبت فاعليته وحسن ادائه في خفض التدبدب مقارنة بالمثبت التقليدى .يستفاد من هذه التجربة امكانية تطبيق المثبت على نظم القوى الكهربائية المتصلة ذوات المولدات المتعددة.

Keywords: Power system stabilizer, Fuzzy logic PSS, Genetic fuzzy PSS, Power system control, Power system stabilizer design

1. Introduction

Since the development of large electric power systems, it is still noticed that there are system oscillations at very low frequency in order of several cycles. Once they started they would continue for a while, they might continue to grow and cause system separation. With experience accumulated from interconnected electric power system operations, power system engineers were convinced that the low frequency oscillations are due to the lack of damping of the mechanical mode of the interconnected system. Desired additional damping signal can be provided by supplementary excitation control. The supplementary excitation can be generated by designing a Power System Stabilizer (PSS). Therefore the PSS will contribute to the power system stability limit and extend power transfer capability by enhancing system damping [1-3].

A Conventional Power System Stabilizer (CPSS) was developed by Demello and Concordia [2]. The CPSS has, for a long time, gained some acceptance among power system stabilizer designers. The CPSS uses the generator speed signal to drive the stabilizing signal through a simple compensator with double lead lag transfer function. For implementation by digital hardware, a digital stabilizer has been reported with reasonable damping. Several approaches have been used to design other forms of fixed parameter PSS including pole placement and optimal stabilizer [4].

Fixed parameters PSS has been designed and tuned in order to perform well within a certain range of operating conditions. But when the operating conditions departed from limited range, the fixed parameters stabilizer may deteriorate. Therefore intelligent and adaptive controllers have been proposed in order to improve stability over a wider range of operating points. In recent years, new artificial intelligence-based approaches have been proposed to design adaptive PSS [5].

Fuzzy logic controllers have many advantages, as: Being simple in structure, they are relatively easy to be realized, mathematical models of the controlled system are not required, and variations of parameters and operating conditions do not affect the performance of the fuzzy logic controller. All these advantages have enabled fuzzy logic controllers to attract more and more attentions in recent years [5-7].

However, the following disadvantages limit its application. First, the knowledge used to design a fuzzy logic controller mainly comes from the human experts. This sort of knowledge is sometimes difficult to represent in the required form. Second, the parameters of fuzzy logic controller are usually determined by trial and error. This method is sometimes time-consuming and does not guarantee optimal controller.

In this paper a genetic fuzzy logic power system stabilizer is designed. The proposed PSS design is based on fuzzy logic controller and then use of Genetic algorithm to optimize the parameters of the fuzzy logic PSS. The proposed PSS will be applied to a single machine connected to an infinite bus. The performance of the proposed power system stabilizer will be investigated and compared to the well known conventional PSS.

2. Fuzzy logic controller

L.A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language has been developed to describe the fuzzy properties of reality, which are difficult and sometime even impossible to be described using traditional methods. Fuzzy set theory has been widely used in the control area with reasonable application to power systems [8].

Fuzzy set theory can be considered as a classical set theory. In classical set theory an element of the universe either belongs to or does not belong to that set. The degree of association of an element is continuously varying mathematically, a fuzzy set is mapping from the universe of discourse to the closed interval (0, 1). The membership function is usually designed by taking into consideration the requirement and constraints of the problem. Fuzzy logic implements human experience through membership function and fuzzy rules. Due to the use of fuzzy variables the system can be understandable to an expert operator [8-9]. Simple fuzzy logic control structure is shown in fig. 1.

3. Genetic algorithm

Genetic Algorithms are global search techniques providing a powerful tool for optimization problems by miming the mechanisms of natural selection and genetics. These operation on a population of potential solutions were to produce better and better approximations to a solution. Thus, genetic algorithms are used to solve general optimization problems for which the solution space is not well understood.

In each generation, a new set of approximations is created by selecting the individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. Thus, the population of solutions is successively improved with respect to the search objective by replacing least fit individuals with new ones (offspring of individuals from the previous generation), which are better suited to the environment, just as in natural evolution [10].

Fig. 2 shows a schematic diagram of a genetic algorithm. The process commences with random generation of possible solutions, i.e. the population and the individuals that form it. Each variable is coded in a suitable coding system (binary, integer, real-valued, etc). The population size and the chromosome size are kept constant during the whole search process.

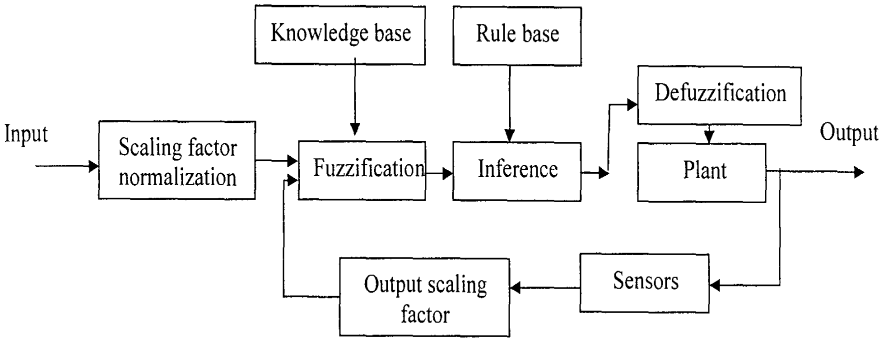

Fig. 1. Simple fuzzy logic control block diagram.

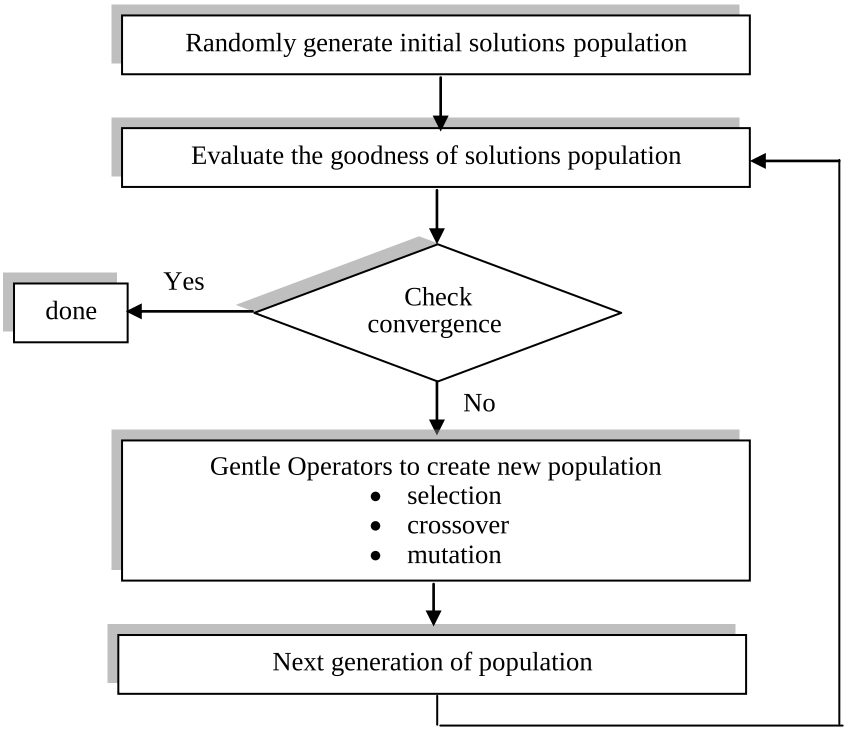

Fig. 2. Genetic algorithm logic.

4. Power system model

Fig. 3 shows the single -machine infinite bus model of power system with an armature current, I, terminal voltage, V_t, an infinite bus voltage V_o, a series transmission impedance, Z, and a shunt admittance, Y. The components detailed description for the model is described in ref. [11].

In order to find the eigenvalue for a system, the system of equations must be written in linear form:

$$x^{\cdot} = Ax + Bu$$

Where

$$x = [\Delta\omega, \Delta\delta, \Delta_{eq}^{'}, \Delta E_{Fd}]$$

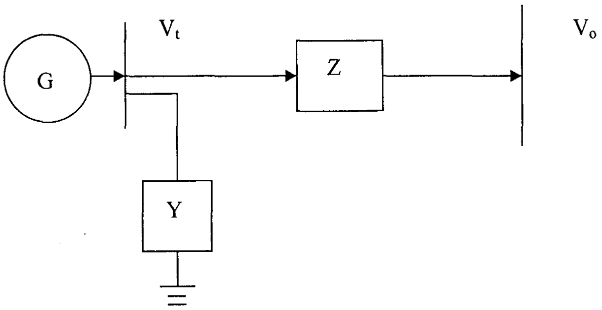

Fig. 3. Single machine connected to infinite bus.

Where $\Delta\omega$ is the rotor speed variation, $\Delta\delta$ is the rotor angle variation, $\Delta_{eq}^{'}$ is the internal voltage variation.

$$\begin{bmatrix} \Delta\dot{\omega} \\ \Delta\dot{\delta} \\ \Delta e_e^{\cdot} \\ \Delta E_{FD}^{'} \end{bmatrix} = \begin{bmatrix} 0 & -K_1/M & -K_2/M & 0 \\ w_b & 0 & 0 & 0 \\ 0 & -K_4/T_{do}^{'} & 1/\left(T_{do}^{'}\right) & 1/T_{do}^{'} \\ 0 & -K_A K_5/T_A & -K_A K_6/T_A & -1/T_A \end{bmatrix} \begin{bmatrix} \Delta\omega \\ \Delta\delta \\ \Delta e_q^{\cdot} \\ \Delta E_{FD}^{\cdot} \end{bmatrix}.$$

From eigenvalue analysis, the eigenvalues for the system above is:
0.295 ± j4.96 and -10.393 ± j3.284

5. Fuzzy logic power system stabilizer design

The design of genetic fuzzy logic power system stabilizers is shown in fig. 4. The two input membership functions are show in fig. 5a and 5b representing P_e and $\Delta\omega$ respectively. The output membership function is shown in fig. 6. These functions range the maximum and minimum variations.

Each function has been divided into seven regions, these regions are: Large Positive variation (LP), Medium Positive variation (MP), Small Positive variation (SP), Zero variation, Medium Negative (MN), and Large Negative variation (LN).

Based on the system performance studied, the fuzzy logic rules have been obtained. These rules represent the actual operating conditions obtained from the numerical solution of the system modeling calculations. Table 1 explains the rule base for the fuzzy logic stabilizer.

Table 1
Rule base for power system stabilizer

$\Delta\omega$ / Pe	PL	PM	PS	ZERO	NS	NM	NL
PL	PL	PL	PM	PM	PS	PS	ZERO
PM	PM	PM	PS	PS	PS	ZERO	NS
PS	PM	PM	PS	ZERO	ZERO	NS	NM
ZERO	PS	PS	ZERO	ZERO	ZERO	NS	NS
NS	PM	PS	ZERO	ZERO	NS	NM	NM
NM	PS	ZERO	NS	NS	NS	NM	NM
NL	ZERO	NS	NS	NM	NM	NL	NL

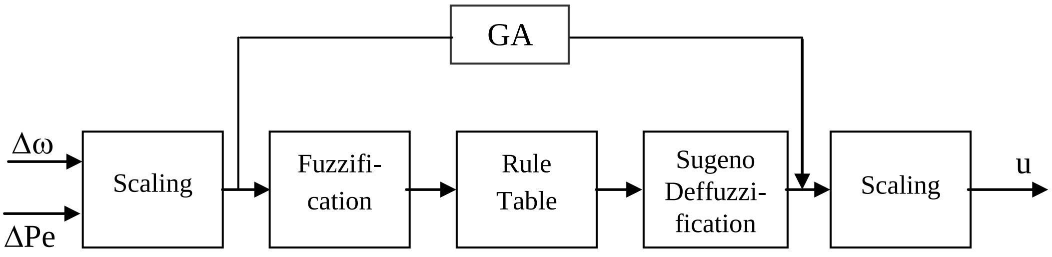

Fig. 4. Genetic fuzzy logic power system stabilizer.

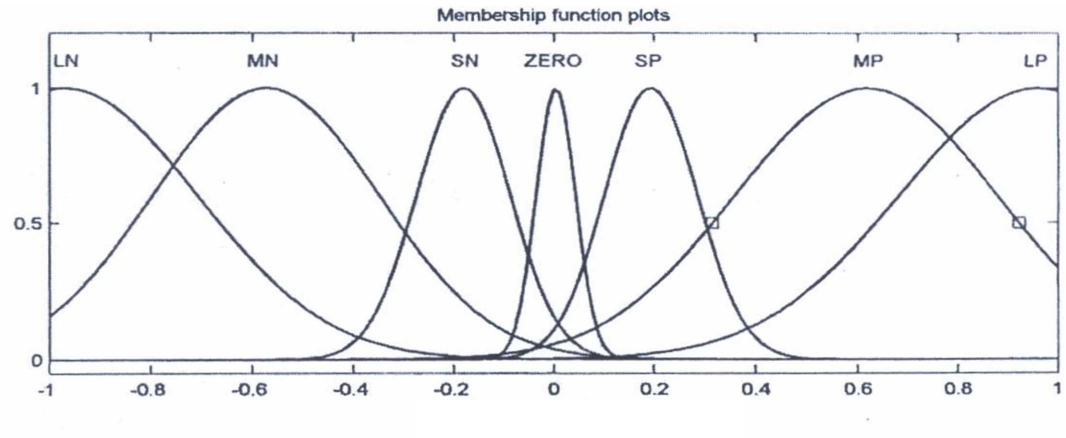

Fig. 5-a. Δω membership functions.

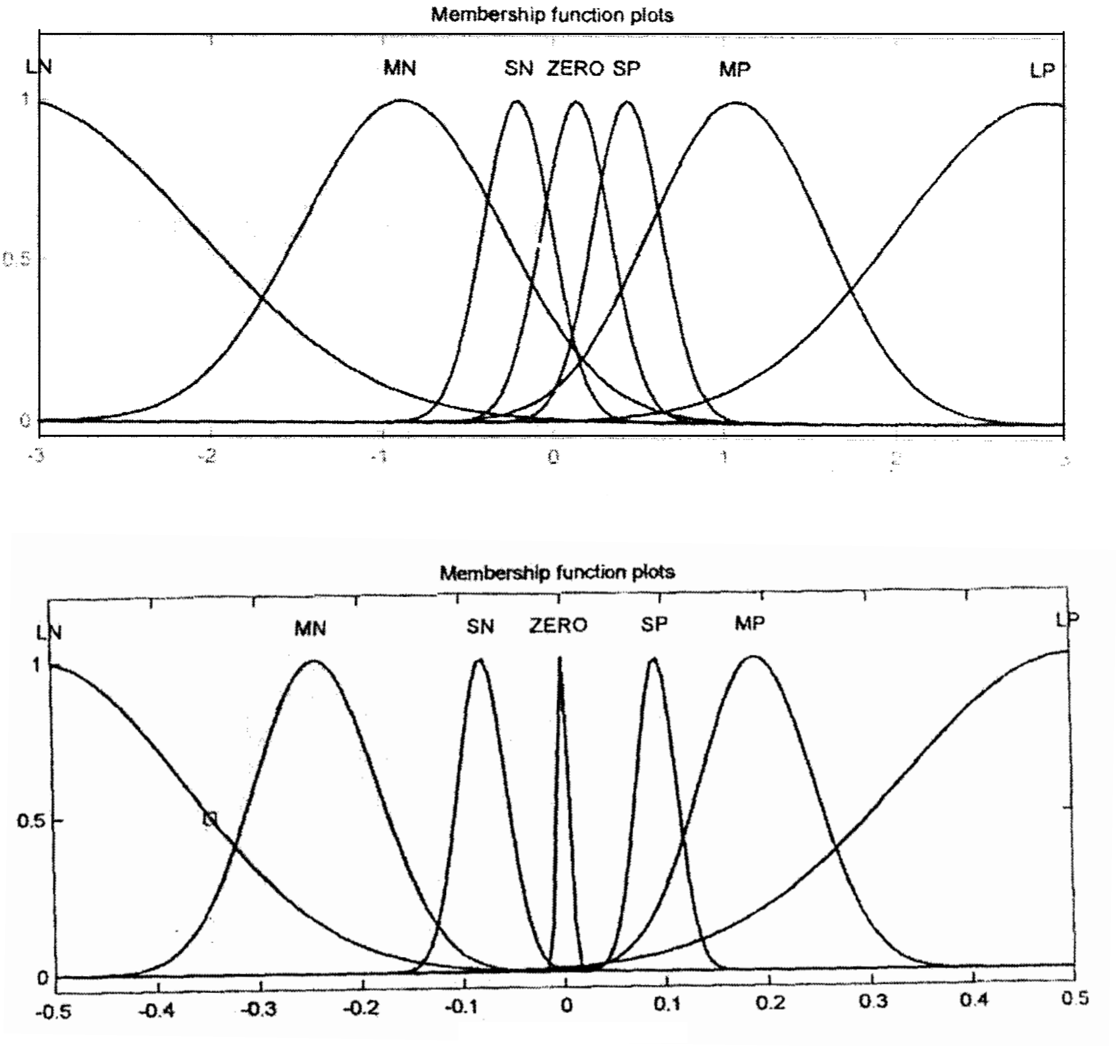

Fig. 6. Output membership functions.

6. Simulation results

The tested system has been implemented by using digital time simulation and coded by using MATLAB version 7.0. The simulation lasts 10 secs. The PSS designed by the aid of MATLAB Tool Box utilizing both fuzzy logic as well as genetic algorithm Tool box.

The designed PSS is tested on single Machine connected to an infinite bus. Figs. 7 and 8 show the speed and electrical power responses without stabilizer respectively. In this case the system continue to oscillate. Figs. 9 and 10 show speed response and electrical power response when the conventional PSS is attached to the power system model. It shows reasonable damping but it takes longer time to settle. Figs. 11, and 12 show rotor angle, and speed responses respectively when fuzzy PSS is attached to the system. With Fuzzy PSS the system starts to perform well and settled after 4 sec. Figs. 13-14 show rotor angle and rotor speed responses. The performance of the proposed Genetic fuzzy power system stabilizer is better than conventional PSS as well as fuzzy logic PSS. However there is no significant difference between the fuzzy logic PSS and genetic fuzzy PSS since the parameters of the fuzzy PSS has been chosen by trial and error to give good response. Table 2 shows the root mean square error for different stabilizers performance.

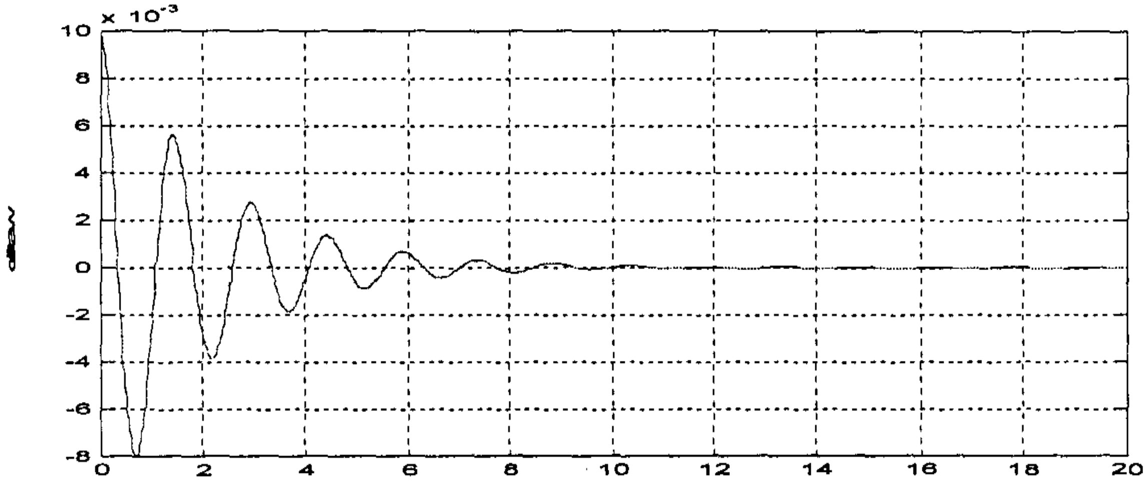

Fig. 7. Variation of $\Delta\omega$ without controller.

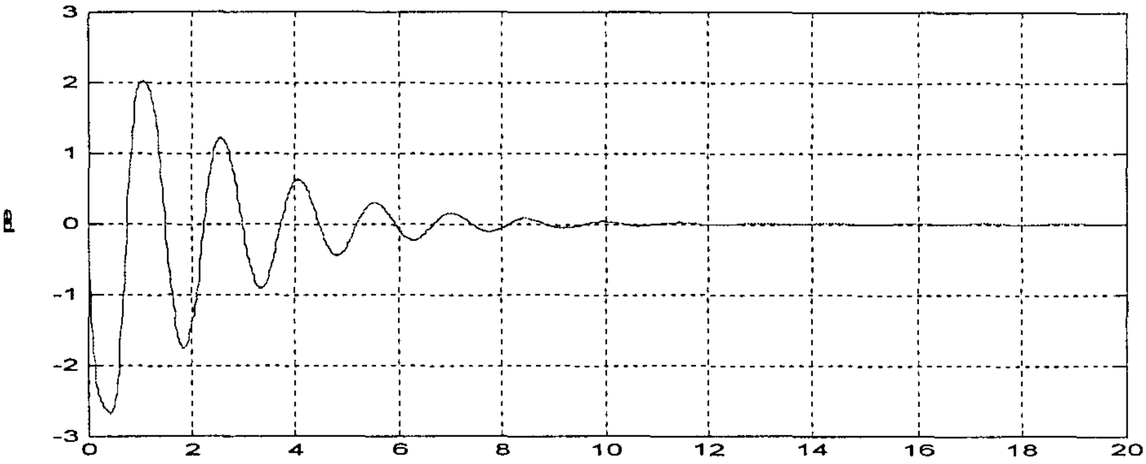

Fig. 8. Electric power response without controller.

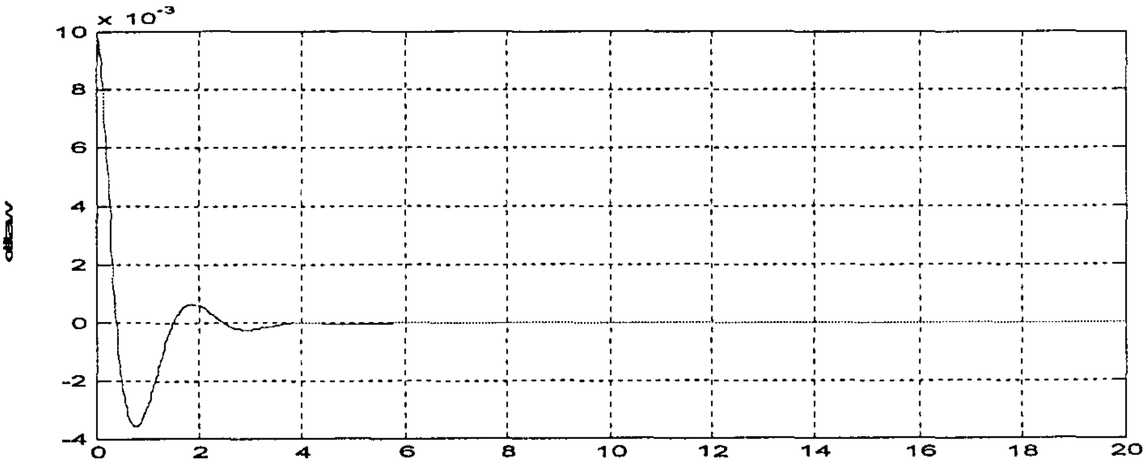

Fig. 9. Rotor speed variation with conventional PSS.

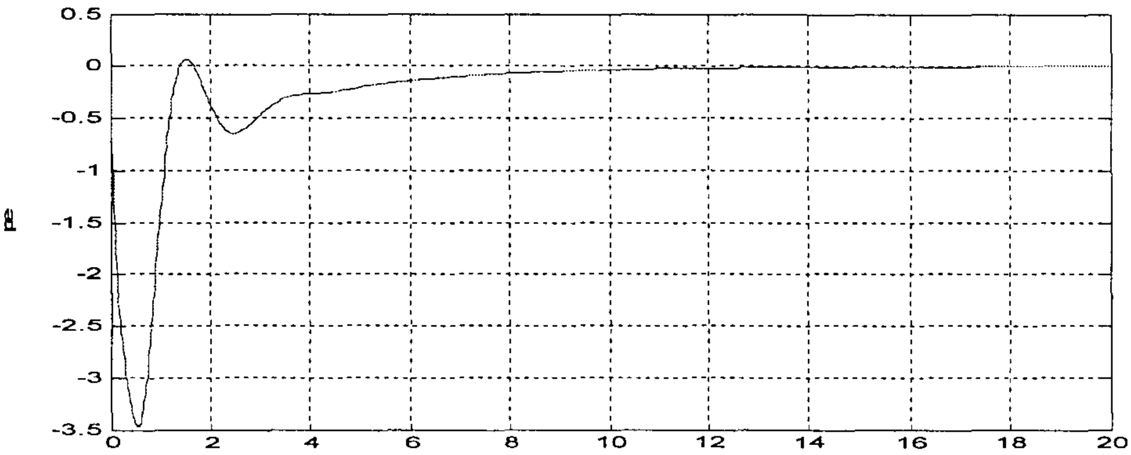

Fig.10. Electric power response with conventional PSS.

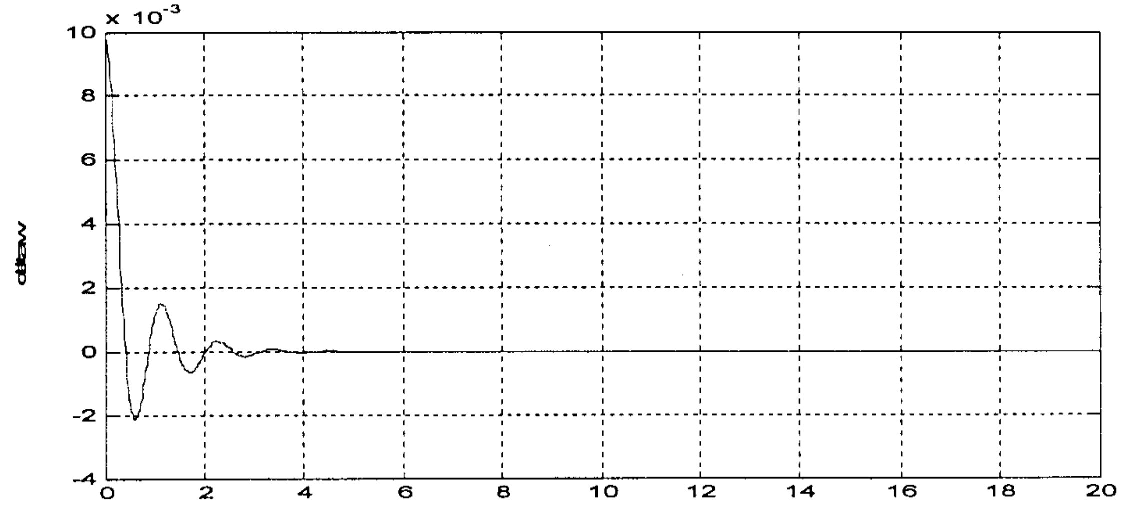

Fig. 11. Rotor speed response with fuzzy PSS.

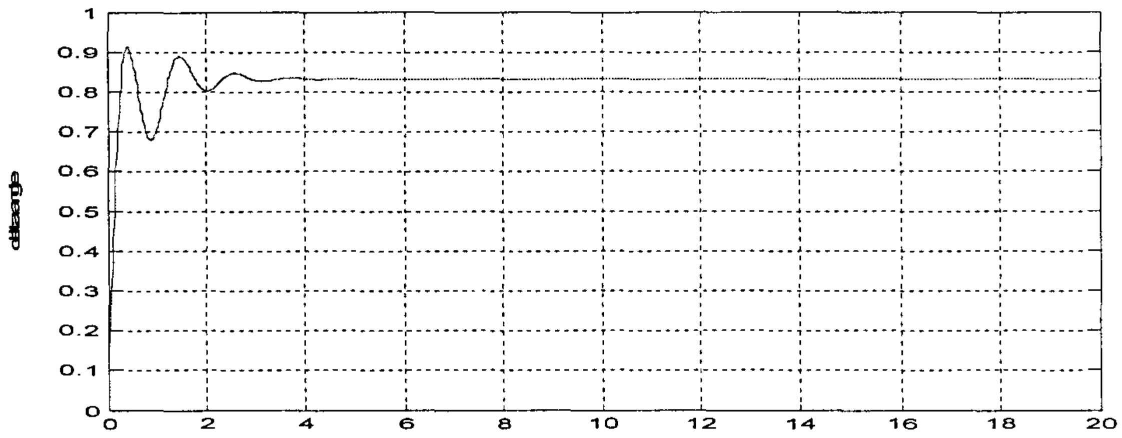

Fig. 12. Rotor angle response with fuzzy PSS.

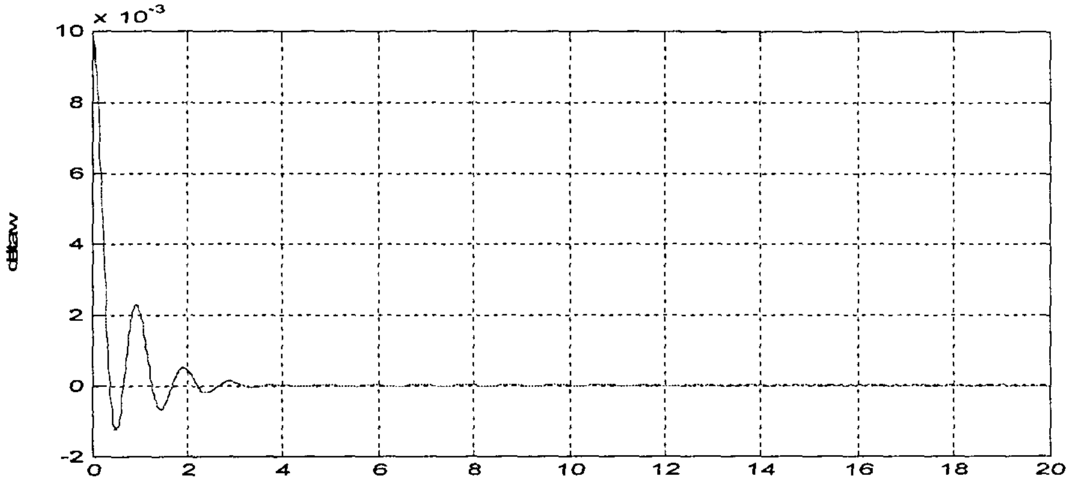

Fig. 13. Rotor speed variation response with genetic fuzzy PSS.

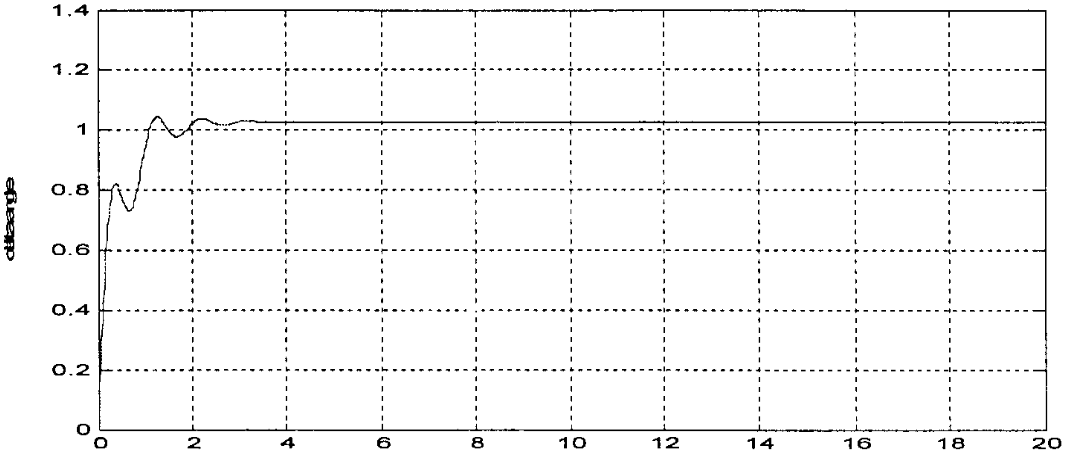

Fig. 14. Rotor angle response with genetic fuzzy PSS.

7. Conclusions

A Genetic fuzzy logic power system stabilizer is designed and proposed in this paper. Genetic algorithm is used to optimize the parameters of fuzzy logic controller. Therefore the designed PSS is an optimal controller. This controller is Multi Inputs Single Output (MISO). The objective of designing PSS is to reduce power system oscillations and enhance damping. Several digital simulations were done to investigate the effectiveness of the proposed PSS. The proposed stabilizer showedbetter performance than other well known PSSs. The proposed genetic fuzzy logic PSS can be applied to multi machine power systems as well.

Table 2
Root mean square error for speed deviation

Case	RMS
Without controller	$3.2069\text{x}10^{-6}$
Conventional PSS	$1.2930\ \text{x}10^{-6}$
Fuzzy PSS	$1.0633\ \text{x}10^{-6}$
Genetic fuzzy PSS	$9.7080\ \text{x}10^{-7}$

References

[1] M.A. Abu-Ela, A.A. Salam, J.D. Mccally and A.A Faud, "Damping Controller Design for Power System Oscillations". IEEE Trans. on Power System, Vol. 11 (02), pp. 767-773 (1996).

[2] F.P. Demello and C. Concordia, "Concepts of Synchronous Machine

Stability as Effected by Excitation Control", IEEE. Trans PAS - / 88 4 (1969).

[3] M. Klein, G.J. Roser, S. Moorty and P. Kunder, "Analytical Investigation of Factors Influencing Power System Stabilizers Performance", IEEE Trans. PWRS, C-7, Sep. 1, pp. 382-388 (1992).

[4] J. Lameres and M. Hash Nehrir, "Fuzzy Logic Based Voltage Controller for a Synchronous Generator", IEEE Computer Application Power, Vol. 12 (2), pp. 46–49 (1999).

[5] M.A. Hassan and O.P. Malik, "Implementation and Laboratory Test Results for Fuzzy Logic Self, Tuned Power System Stabilizer" IEEE OPES Summer Meeting 92. SM 747–9 EC, Seattle (1992).

[6] J. Liu, M. Nehrir and D.A. Pierre, "A Fuzzy Logic-Based Adaptive Power System Stabilizer for Multimachine Systems". IEEE Power Eng. Soc. Summer Meeting, Seattle, WA, July, pp. 15-19 (2000).

[7] Hossinzadeh and Kalam, “A Rules Based Fuzzy Power System Stabilizer Tuned by Neural Network", IEEE Trans. Energy Conversion, 14, pp. 773-779 (1999).

[8] R. Bansel, "Bibliography on the Fuzzy Set Theory and Its Application in Power System", (1994 – 2001). IEEE trans. on Power Systems. 10, pp. 88–97 (1995).

[9] T. Takagi and M. Sugeno "Fuzzy Identification of System and Its Application to Modeling and Control", IEEE Trans. SMC, 15 (1985).

[10] D.E. Gold Berry, "Genetic Algorithm in Search Machine Learning". Addison Wesley (1989).

[11] Yao – Han YU, "Electric Power System Dynamics" (1983).

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