International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

Intelligent Power System Stabilizers using Fuzzy Logic Technique and Sliding Mode Control Strategy

Ngoc-Khoat Nguyen

Abstract: ***Each electric power grid should be equipped with a power system stabilizer (PSS) to ensure the network stability during operation and distribution. The major function of a PSS is to provide an appropriate control signal to the synchronous generator system, making its rotational speed stabilization against disturbances. This paper investigates three control strategies to design such an efficient PSS for the power network, including a PID-based PSS, a fuzzy logic – based PSS (FLC), a fuzzy logic-integrated sliding mode control – based PSS (SMC). With the rapid development of fuzzy logic technique considered to be an intelligent and successful control tool, the PSS controllers applying this control strategy are able to obtain good control performances, satisfying high requirements of the smart grids. Through a number of numerical simulations implemented in MATLAB/Simulink package for a single synchronous generator connected to an infinite bus, this work verifies the feasibility and success of the studied control strategies in designing an efficient PSS controller. Two case studies with load change and without load change will also be carried out in this paper to demonstrate the broad stability range of the proposed PSS controllers. Simulation results reveal that the FLC and the SMC are much better than the conventional PID-based PSS controllers and these two intelligent regulators can be selected for successfully solving the stabilization problem of an electric power grid in practice.***

Index Terms: ***FLC, PID, PSS, SMC.***

I. INTRODUCTION

It should be clear the network stabilization is a major control problem for an electric power grid. The stability of an electric power network should be dependent on the synchronous maintenance. It means that loss of synchronism is able to cause an instability of the network. Furthermore, in practical operation of an electric power grid, it is clear the voltage stability also affects the stability of the network. An effective solution to this problem is to design a power system stabilizer (PSS). Such a device is mainly used in an electric power grid to efficiently extinguish oscillations in low frequencies, bringing the network back to the stable operation mode. Such a PSS is worked depending on auxiliary control principle in which the PSS controller generates supplementary signal for a control loop of the synchronous generator. Traditionally, it acts relying upon the excitation or governor system of the control configuration for a synchronous generator [1-4].

Manuscript published on 30 August 2019.
*Correspondence Author(s)
Dr. Ngoc-Khoat Nguyen, Faculty of Control and Automation, Electric Power University, Hanoi, Vietnam.

The conventional PSS controllers have been working well on specifically electric power grids with particular configurations as well as nominal steady-state points as designed [5]. However, a practical power system, usually characterized by nonlinearities in practice, may not be suitable for applying a conventional PSS controller. It means that once parameters of the network change, the conventional regulator cannot be updated and the stability may not be guaranteed. As a result, it is necessary to replace the conventional PSS regulator with an advanced PSS controller. The PSS controllers based on artificial intelligence, such as fuzzy logic technique-based PSS, should be effective control approaches. It can be said that fuzzy logic control (FLC) has recently become one of the most efficacious control schemes in dealing with nonlinear and complex control problems. It is evident to affirm that the FLC acts relying only on the experiences of experts. This means that an FLC may not need to know exactly parameters of a control system. In contrast, if the experiences of experts are good enough, the FLC is still able to obtain good control performances. Technically, the FLC-based controller is a successful control solution specially for designing the PSS regulators [6-8]. This paper presents the design of the PSS applying three types of controllers including: a conventional PID regulator, a PD-type FLC regulator together with an FL- based sliding mode controller (SMC) for different operating circumstances of the electric power grid. They are studied and compared in terms of their effectiveness and feasibility in dealing with the stabilization problem for a synchronous generator system which is assumed to connect with an infinite bus. The rest of this paper includes four sections. In Section II, the modeling of a typical power system is presented. This is an isolated power system consisting of a synchronous generator together with its excitation system, a transmission line and an infinite bus. Then the design of different controllers in dealing with the network stabilization is described in Section III. As mentioned earlier, three types of PSS regulators will be presented in this section. They are two intelligent FLCs, namely typical PD-type FLC and a FL-based sliding mode controller, and a conventional PID regulator. To testify the feasibility of the method proposed in this study, Section IV presents a number of numerical simulations implemented in MATLAB/Simulink environment for two simulation cases of load change embedded to the power system model mentioned in Section II. Finally, conclusions, discussions and future work derived from this study will be provided in Section V.

II. MATHEMATICAL MODELS FOR THE DESIGN OF PSS CONTROLLERS

An isolated electric power system consisting of a synchronous generator is selected for this study. The system comprises a synchronous generator with a corresponding excitation system and a conventional PSS controller.

A. *A Synchronous Generator Model*

Consider an equivalent model of a typical one-generator power system. As shown in Fig. 1, the system is assumed to generate electric power to an infinite bus.

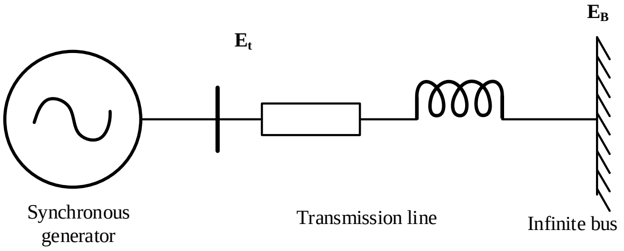

Fig.1: A typical single generator model

According to [4], for the model presented in Fig. 1 and Fig. 2, it is evident to use the following equations:

$$p(\omega_r-\omega_0)=\frac{(T_m-T_{m0})-(T_e-T_{e0})-K_D(\omega_r-\omega_0)}{2H} \quad (1)$$

$$\Delta\psi_{fd}=\frac{K_3}{1+pT_3}(\Delta E_{fd}-K_4\Delta\delta) \quad (2)$$

In (1), ΔT_m denotes the input deviation regarding mechanical torque, meanwhile ΔT_e is the output change concerning electrical torque and p is the differential operator d/dt with time t in seconds. The other symbols can be found in [1].
Here, K_3 and K_4 are two gains as shown in Fig. 2. These two factors are computed when the network is given with enough defined parameters. Section IV executing numerical simulations to testify the feasibility of the proposed PSS regulators will employ these defined parameters.

B. *Mathematical Model of an Excitation System*

A mathematical model describing an excitation system for a generator is presented below: [5]

$$p.\Delta v_1=\frac{1}{T_R}(\Delta E_t-\Delta v_1) \quad (3)$$

$$E_{fd}=K_A(\Delta E_t-\Delta v_1) \quad (4)$$

$$\Delta E_t=K_5\Delta\delta+K_6\Delta\psi_{fd} \quad (5)$$

A mathematical model to design the PSS strategy corresponding to the above equations (1)-(5) is presented in Fig. 2.

C. *Model of a Typical PSS*

A PSS aims to extinguish dynamic oscillations resulting from low frequencies in an electric power grid. The overview of such a PSS can be found in [3-4]. In this study, the main objective is to design an efficient PSS control strategy, thus it is necessary to consider a typical model of a whole system applying the conventional PSS regulator. As shown in Fig. 2, such a PSS uses the deviation of rotational speed as its input. The output derived from the PSS is to fed to the excitation system following auxiliary control strategy. Traditionally, the output signal of such a conventional PSS controller is given below:

$$\Delta v_2=\frac{sT_\omega}{1+sT_\omega}K_{STAB}(\omega_r-\omega_{r0}) = \frac{s.T_w^{'}}{1+sT_\omega} \quad (6)$$

Where $T_w^{'}=T_\omega K_{STAB}\Delta\omega_r$, K_{STAB} and T_ω denote a stabilizing gain and the time constant of the washout filter.

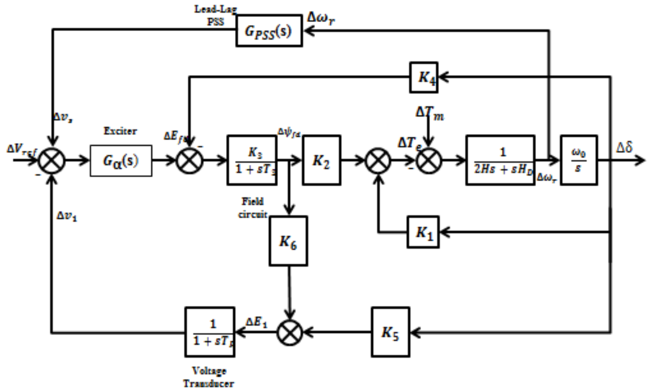

Fig. 2: Linear model of a synchronous generator drawn from grid connected system perturbation [4]

III. DESIGN OF DIFFERENT PSS CONTROLLERS

A. *PID-based PSS Controller*

A typical PID regulator is formed by three elements: P (proportional), I (integral) and D (derivative). These elements normally are connected in parallel. Such a PID controller is used to minimize the error $e(t)$, which is considered to be the input of the controller. This minimization is executed by updating a control signal $u(t)$ which is the output of the PID regulator. In principle, this output signal of such a PID regulator can be calculated as follows:

$$u(t)=K_pe(t)+K_I\int e(t)dt+K_D\frac{de(t)}{dt} \quad (7)$$

Where K_P, K_I and K_D denote the proportional, integral, and derivative gains, respectively. With the parallel configuration, a PID regulator has the following characteristics:

- Kp defines a factor which directly affects the current value of the input signal.
- K_I is defined as a factor affecting the past value of the input signal.
- K_D denotes a coefficient which can compute the possible future value.

The PID controller is suitable for control systems which are applying the tracking control theory. According to this control theory, the error signal between the set-point value and the measured output signal should be damped with good control performances.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

The most difficult problem when using a PID controller is the tuning of three factors Kp, K_I and K_D. In addition, the control quality obtained by using such a PID controller may not meet the requirements of a high quality control system.

B. *Fuzzy Logic – Based PSS*

Fuzzy logic (FL) is considered to be an intelligent technique which can be applied in numerous control problems. Since the working principle of the FL controller is based on the experiences of experts, this type of intelligent controller is highly suitable for nonlinear and uncertain control systems. The fundamental components of a typical FL architecture are shown in Fig. 3. It should be clear there are three processes need to be determined when designing an FLC. They are membership functions (MFs), a rule base and composition of fuzzy sets [5-6]. The FLC used in this study depending on the typical PD-type FLC. Each PD-type FLC has two input variables which are the difference between the set-point value and real value of the system (E) and the error derivative (DE); and the output variable is stabilizing voltage (U). In this paper, seven membership functions (MFs) denoted by NL, NM, NS, ZE, PS, PM and PL are used for both the input E and the output U. Furthermore, the input DE employs three MFs denoted by NS, ZE and PS.

They all are plotted in Figs. 4-6. Besides, Table 1 expresses the rule base for the FLC proposed in this work, corresponding to the 3-D surface describing input/output relationship of the FLC which is depicted in Fig. 7.

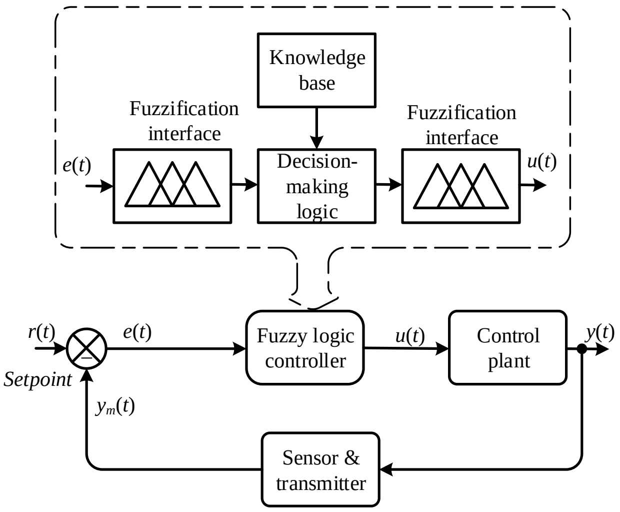

Fig. 3: A typical control system applying the FLC

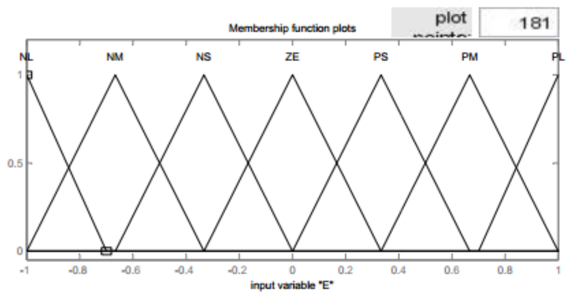

Fig. 4: Plotting seven MFs for the first input (E)

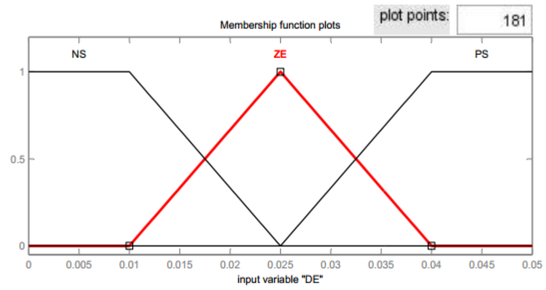

Fig. 5: Membership functions of error derivative (DE)

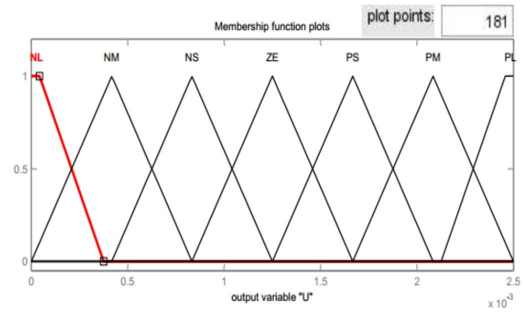

Fig. 6: Illustration of seven MFs for the output (U)

Table 1: Fuzzy rule base for the proposed FLC

Speed deviation	Active power deviation		
	NS	**ZE**	**PS**
NL	NL	NM	NM
NM	NL	NM	NS
NS	NM	NS	PS
ZE	NS	ZE	PS
PS	NS	PS	PM
PM	PS	PS	PM
PL	PM	PM	PL

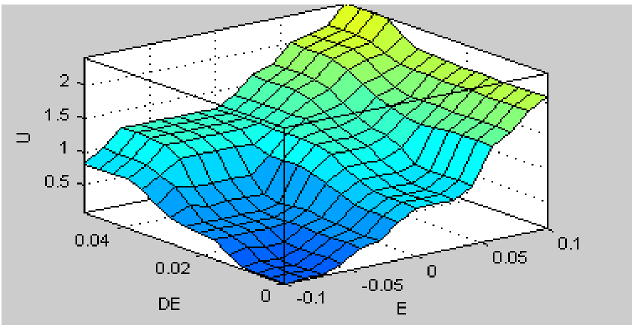

Fig. 7: A 3-D surface describing a relationship between two inputs and the output of the proposed FLC

C. *FL – Integrated Sliding Mode Control-Based PSS*

A classical sliding mode – based controller is typically used when a control system requires a rapid response. A typical configuration presenting the working principle for a sliding mode controller can be depicted in Fig. 8.

Retrieval Number: I8733078919/19©BEIESP
DOI: 10.35940/ijitee.I8733.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

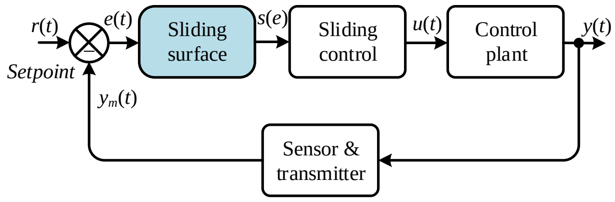

Fig. 8: Typical configuration of sliding mode control

In principle, the sliding surface is mathematically established as follows: [7-8]

$$s(e) = a_0 e(t) + a_1 \frac{de(t)}{dt} + ... + \frac{d^{n-1}e(t)}{dt^{n-1}} \quad (8)$$

A sliding condition is given below:

$$\frac{ds(e)}{dt}\mathrm{sgn}(s(e)) < 0 \quad (9)$$

In a special case study, the sliding surface corresponding to a second-order control plant is as follows:

$$s(e) = a_0 e(t) + \frac{de(t)}{dt} = a_0 e(t) + \dot{e}(t) \quad (10)$$

Finally, the signal considered to be the output of such an SMC can be computed below:

$$u = 2\,\mathrm{sgn}(s(e)) = 2\,\mathrm{sgn}\left(a_0 e + \frac{de}{dt}\right) \quad (11)$$

In order to obtain better control performances, the traditional sliding mode control strategy mentioned above should be integrated with a fuzzy logic inference. The FL – based sliding mode controller proposed in this study consists of two inputs and a single-output component. The inputs are error (E) and error derivative (*DE*). The output variable is stabilizing voltage (U). The two inputs and the output U have four MFs, namely NB, NS, PS and PB. They are shown in Figs. 9-11. In addition to these figures, Table 2 presents the rule base for this FL - based sliding mode controller. The effectiveness of this control methodology will be verified in the following section.

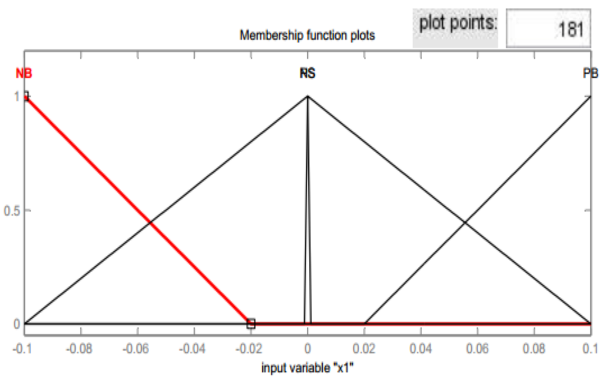

Fig. 9: MFs for the input *E*

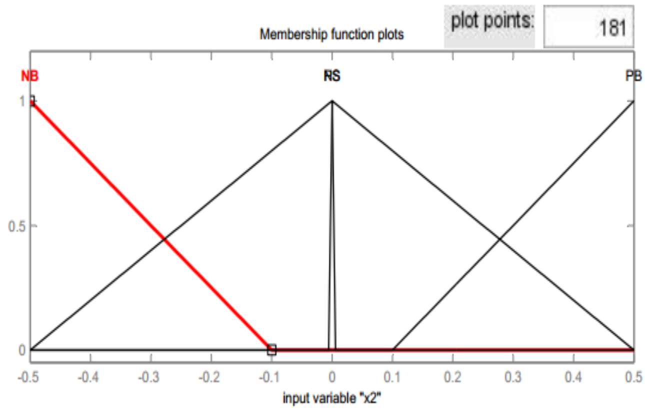

Fig. 10: MFs for the input *DE*

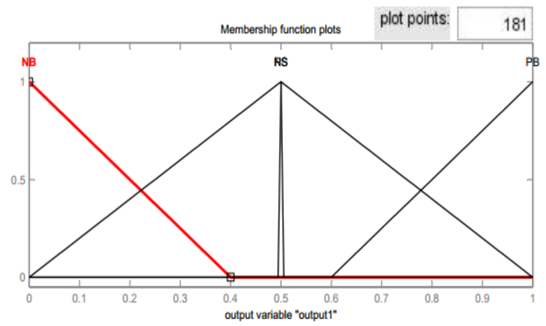

Fig. 11: MFs for the output *U*

Table 2: Rule base for the FL-integrated SMC

Speed deviation		E							
		$e + a_0\dot{e} \geq 0$				$e + a_0\dot{e} \leq 0$			
		NB	**NS**	**PS**	**PB**	**NB**	**NS**	**PS**	**PB**
	PB	PS	PS	PB	PB	n/a	n/a	NS	NS
DE	**PS**	PS	PS	PS	PB	n/a	NS	NS	NS
	NS	PS	PS	PS	n/a	NB	NS	NS	NS
	NB	PS	PS	n/a	n/a	NB	NB	NS	NS

IV. NUMERICAL SIMULATION RESULTS

In this section, to evaluate the feasibility of the three PSS controllers presented in the current study, numerical simulation processes will be implemented using MATLAB/Simulink package. Here, a model of a single synchronous generator together with an excitation system in connection with an infinite bus using parameters provided in [8] is applied to testify the control execution of the PSS controllers. To demonstrate the effectiveness of the two proposed intelligent PSS controllers i.e. FLC and SMC-based PSS over the conventional PID-based PSS, two simulation cases are studied:

(i) The synchronous generator system without load change;

(ii) The synchronous generator system with load change as disturbance.

Retrieval Number: I8733078919/19©BEIESP
DOI: 10.35940/ijitee.I8733.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

As shown in Fig. 12 for the first simulation case, with the PID-based PSS, the dynamic response of the rotational speed of the synchronous generator is much worse than those of the other two intelligent PSS controllers. It is clear that major control performances such as overshoot, settling time and rising time resulting from the PID-based PSS are not good enough to ensure the stability of the whole system (see Fig. 12). The overshoot (maximum peak) obtained from this type of PSS is specially too bad (more than 150%), creating the instability of the network. In addition to Fig. 12, the SMC-based PSS is the best in case of considering major control performances as mentioned earlier. It is evident the SMC – based PSS obtaining highly good control quality, and it is able to efficiently recover the stability of the system. The FLC – based PSS is also able to bring the network back to the stable state, however, the control quality is somewhat worse than the SMC-based counterpart.

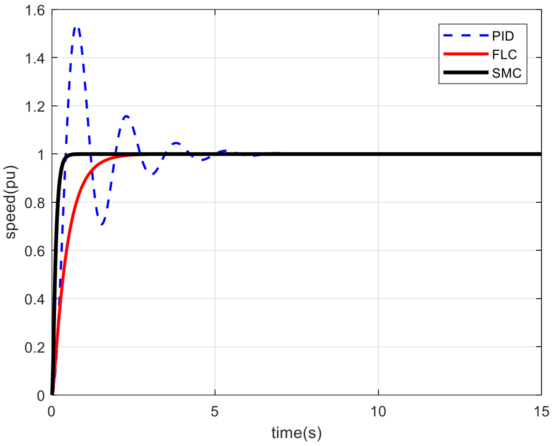

Fig.12: Dynamic responses of the rotational speed of the synchronous machine corresponding to three PSS controllers for the first simulation case

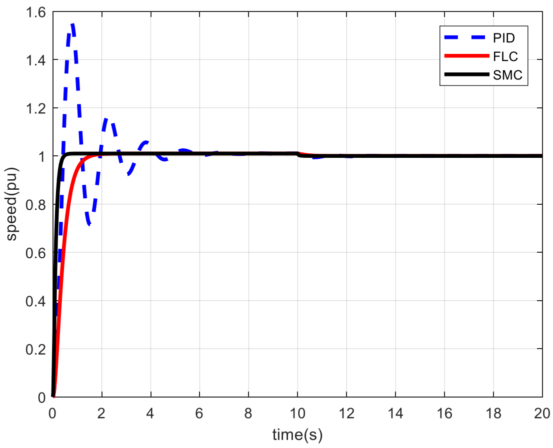

Fig. 13: Dynamic responses of the rotational speed of the synchronous machine corresponding to three PSS controllers for the second simulation case

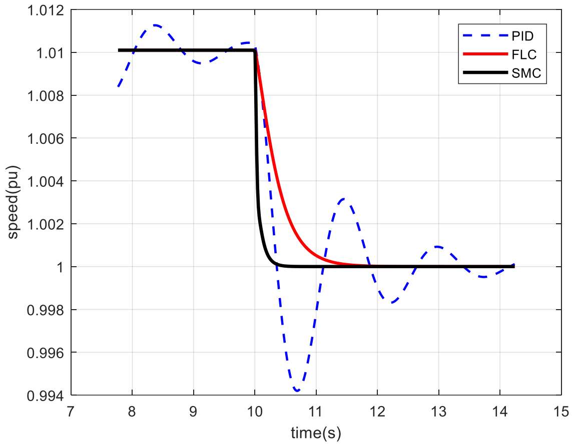

Fig.14: An enlarged part from Fig. 13

To get more evident in confirmation of the outperformance for the proposed intelligent PSS controllers, the second simulation case with load change occurrence will be taken into account. Fig. 13 and Fig. 14 show the dynamic responses of the rotational speeds in the second simulation case when a 2%-load change is embedded to the network at an instant of the 10th second. Similar to the first simulation case, it is found obviously from these figures that the two intelligent PSS controllers with better control performances are able to bring the network back to the stability condition in a highly short time. It verifies clearly the feasibility of the two intelligent PSS controllers proposed in this study.

V. CONCLUSIONS AND DISCUSSIONS

It should be clearly observed in both case studies from the Matlab/Simulink simulation processes that the two intelligent PSS controllers, i.e. FLC and SMC-based PSS regulators, have excellent responses with small oscillations and short response time, while the PID controller obtains large deviations and greater response time. Thus, it is evident to affirm the effectiveness and feasibility of the two intelligent PSS controllers proposed in this study. They are highly suitable for solving the stabilization problem of an electric power system. With high requirements in designing the PSS controllers for a modern electric power grid, it is highly necessary to replace conventional PSS regulators with intelligent PSS controllers. In a case of power systems with high nonlinearities and uncertainties, the FL-based PSS controllers are more appropriate. It can be said that practical power systems must be integrated with multiple control strategies such as frequency and voltage control. As a result, the intelligent PSS controllers need to incorporate these control schemes to successfully build an effectively smart grid. That is exactly the future work arising from this study.

ACKNOWLEDGMENT

The author wishes to thank Dr. Dao Thi Mai Phuong from Hanoi University of Industry for her useful discussions and suggestions concerning numerical simulations implemented in this study.

REFERENCES

1. A. J. Wood, B. F. Wollenberg, G. B. Sheble. Power Generation, Operation, and Control. Willey-Interscience, New York, 2013.
2. J. D. Glover, T. J. Overbye, M. S. Sarma. Power System Analysis & Design. 6^{th} edition, CENGAGE Learning, 2017.
3. Y. N. Yu and Q H Li, "Pole Placement Power System Stabilizers Design of an Unstable Nine Machine System", IEEE Transactions on Power Systems, vol. 5, pp. 353-358, May, 1990.
4. C. J. Wu and Y Y Hsu, "Design of Self - tuning PID Power System Stabilizer for Multimachine Power System", IEEE Transactions on Power Systems, vol. 3, pp. 1059-1064, Aug. 1998.
5. K. A. El-Metwally and O. P. Malik, "Fuzzy Logic Based Power System Stabilizer", IEEE Proc. Gener. Transm. Distri., vol. 142, pp. 277-281, May 1995.
6. H. Taliyat, J Sadeh and R. Ghazi "Design of Augmented Fuzzy Logic Power System Stabilizer to Enhance Power System Stability" IEEE Transactions on Energy Conversion, vol. 11, pp, 97-103, March 1996.
7. T. Hiyama, "Development of Fuzzy Logic Power System Stabilizer and Further Studies", IEEE International Conference on Systems, Man and Cybernetics 1999, vol. 6, pp. 545-550.
8. B. Shah, P. Chaudhari, "Fuzzy and SVM based Power System Stabilizer Single Machine Infinite Bus System", International Journal of Computer Applications, vol. 131, no. 13, pp. 18-21, Dec. 2015.

AUTHORS PROFILE

Dr. Ngoc-Khoat Nguyen received the MSc degree in Automation and Control field at Hanoi University of Science and Technology, in 2009. He received the PhD degree in Electronic Science and Technology at University of Electronic Science and Technology of China, in 2015. He is currently working as an instructor and researcher at Faculty of Control and Automation, Electric Power University in Hanoi, Vietnam. His research interests include renewable energy, evolutionary computing, intelligent control strategies, power electronics and smart electric drives systems. He has published nearly thirty academic papers including ten SCIE, ISI and Scopus – indexed papers following his research fields.

Retrieval Number: I8733078919/19©BEIESP
DOI: 10.35940/ijitee.I8733.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)