Journal of Theoretical and Applied Information Technology
20th August 2013. Vol. 54 No.2

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

FUZZY SLIDING MODE CONTROLLER FOR POWER SYSTEM SMIB

[1]KHADDOUJ BEN MEZIANE, [1]FAIZA DIB, [2]ISMAIL BOUMHIDI

[1]PhD Student, LESSI Laboratory, Department of Physics, Faculty of Sciences
Dhar El Mahraz,Sidi Mohamed Ben Abdellah University, Fez Morocco
[2] Prof., Department of Physics, Faculty of Sciences Dhar El Mahraz,
Sidi Mohamed Ben Abdellah University, Fez Morocco
E-mail: [1]khaddouj.benmeziane@yahoo.com , [1]dib.fayza@yahoo.fr , [2]iboumhidi@hotmail.com

ABSTRACT

In this paper, a method combining fuzzy logic and sliding mode controller is proposed for the robust control of power system Single-Machine Infinite-Bus (SMIB). The aim of this study is to overcome some shortcoming of conventional power system stabilizer (CPSS), fuzzy logic power system stabilizer (FPSS) and sliding mode controllers (SMC). When conventional PSS is employed, it will result a poor performance. SMC can be used to achieve robust stability in power system. However, in the presence of large uncertainty, a higher switching gain is required, which produce higher amplitude of chattering. In this study, a direct fuzzy logic controller is designed and the sliding mode controller is added to compensate the fuzzy approximation errors. The simulation results clearly indicate the effectiveness and validity of the proposed method, in terms of convergence, time and precision.

Keywords: *Power system Stabilizer, Fuzzy Logic Controller, Sliding Mode Control, Synchronous Machine*

1. INTRODUCTION

Design and application of power system stabilizers has been the subject of continuing development for many years [1]. Most PSS used in electric power systems employ the linear control theory approach based on a linear model of a fixed configuration of the power system and thus tuned at a certain operating condition. Such fixed parameter PSS, called conventional PSS (CPSS), is widely used in power systems, it often does not provide satisfactory results over a wide range of operating conditions [2].

The Sliding Mode Controller (SMC) is a particular type of variable structure control systems that is designed as a robust control to drive and then constrain the system to lie within of the switching function. However in the presence of large uncertainties or higher switching gain is required which produce higher amplitude of chattering.

Fuzzy logic has emerged as a powerful in control applications. It allows one to design a controller using linguistic rules without knowing the mathematical model of the plant.

In this paper our objective is to apply a fuzzy controller combined with sliding mode to overcome shattering of both sliding mode and fuzzy logic controllers and then to obtain a control system for a high performance for power system.

This paper will be divided into five sections. First section presents the modeling of a system of nonlinear electrical power system SMIB in matlab / simulink. The second section deals with the use of a power stabilizer. A brief review of the design method used CPSS will be exposed. The third section concerns the use of fuzzy control for the design of a power stabilizer FPSS, in the fourth section we used a sliding mode control combined with fuzzy controller. The simulation results are presented in fifth section.

2. MODELING OF NONLINEAR POWER SYSTEM

The single machine infinite bus power system model SMIB consists of a synchronous generator, a turbine, a governor, an excitation system and a transmission line connected to an infinite bus. A power stabilizer CPSS, FPSS and FSMC are applied in the excitation of the machine. The model is built in MATLAB/SIMULINK environment [3, 4]. Figure 1 shows the model of the various components of the controlled system.

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

$$\frac{d\omega}{dt}=\frac{1}{M}\left((P_m-P_e)-D.(\omega-\omega_r)\right) \quad (7)$$

$$\frac{d\delta}{dt}=\omega_0.(\omega-\omega_r) \quad (8)$$

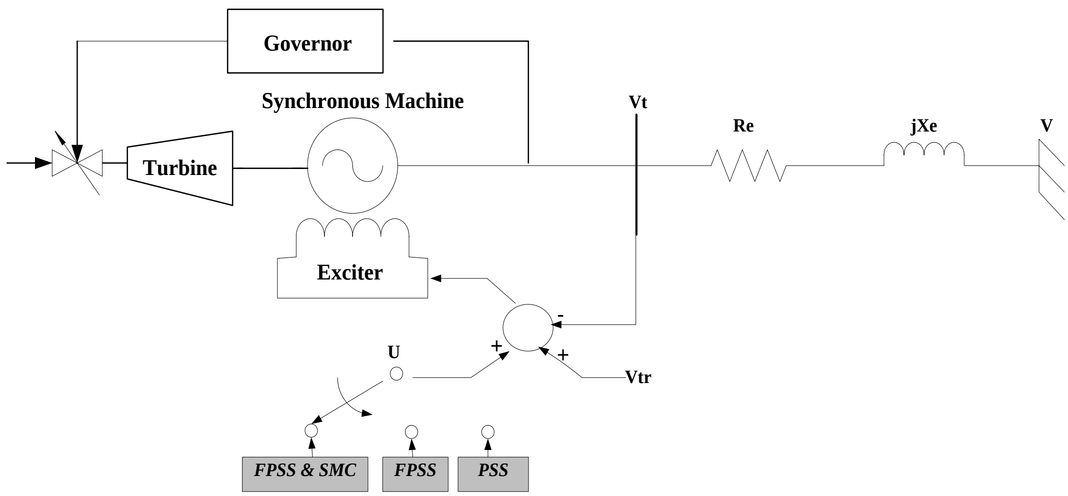

Figure 1. The Single Machine-Infinitive Bus System With Controllers.

A non-linear dynamic model of the system is derived by disregarding the resistances and the transients of generator, transformers and transmission lines [5].
The system equations of the SMIB based power system are as shown below [6].

- Electrical part:

$$\frac{dE_d^{'}}{dt}=\frac{1}{T_{q_0}^{'}}\left((x_d^{'}-x_q).I_q-E_d^{'}\right) \quad (1)$$

$$\frac{dE_q^{'}}{dt}=\frac{1}{T_{d_0}^{'}}\left((x_d^{'}-x_d).I_d+E_{fd}-E_q^{'}\right) \quad (2)$$

$$V_{td}=-V\sin\delta+R_eI_d+x_eI_q \quad (3)$$

$$V_{tq}=V\cos\delta+R_eI_q-x_eI_d \quad (4)$$

$$P_e=E_d^{\prime}I_d+E_q^{\prime}I_q \quad (5)$$

$$V_t=\sqrt{V_{td}^{\,2}+V_{tq}^{\,2}} \quad (6)$$

- Mechanical part:

Equation describing mechanical dynamics of the generator:

- Turbine and governor system:

$$\frac{d\Delta P_m}{dt}=\frac{1}{T_{RH}}.\left(K_{RH}T_{RH}.\frac{d\Delta P_c}{dt}-\Delta P_m\right) \quad (9)$$

$$\frac{d\Delta P_c}{dt}=\frac{1}{T_{CH}}.(\Delta P_h-\Delta P_m) \quad (10)$$

$$\frac{d\Delta P_h}{dt}=\frac{1}{T_{SM}}.(\Delta P_r-\Delta P_h) \quad (11)$$

$$\frac{d\Delta P_r}{dt}=\frac{1}{T_{SR}}.(K_G.\Delta\omega-\Delta P_r) \quad (12)$$

- The excitation model:

$$\frac{dE_{fd}}{dt}=\frac{1}{T_E}\left(K_E.(V_{tr}-V_t-V_s)-E_{fd}\right) \quad (13)$$

$$\frac{dV_s}{dt}=\frac{1}{T_{FE}}\left(K_F.\frac{dE_{fd}}{dt}-V_s\right) \quad (14)$$

- Model of the nonlinear power system SMIB using simulink:

The complete model of the nonlinear Power system SMIB used in the simulation is given in figure 2 [4].

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

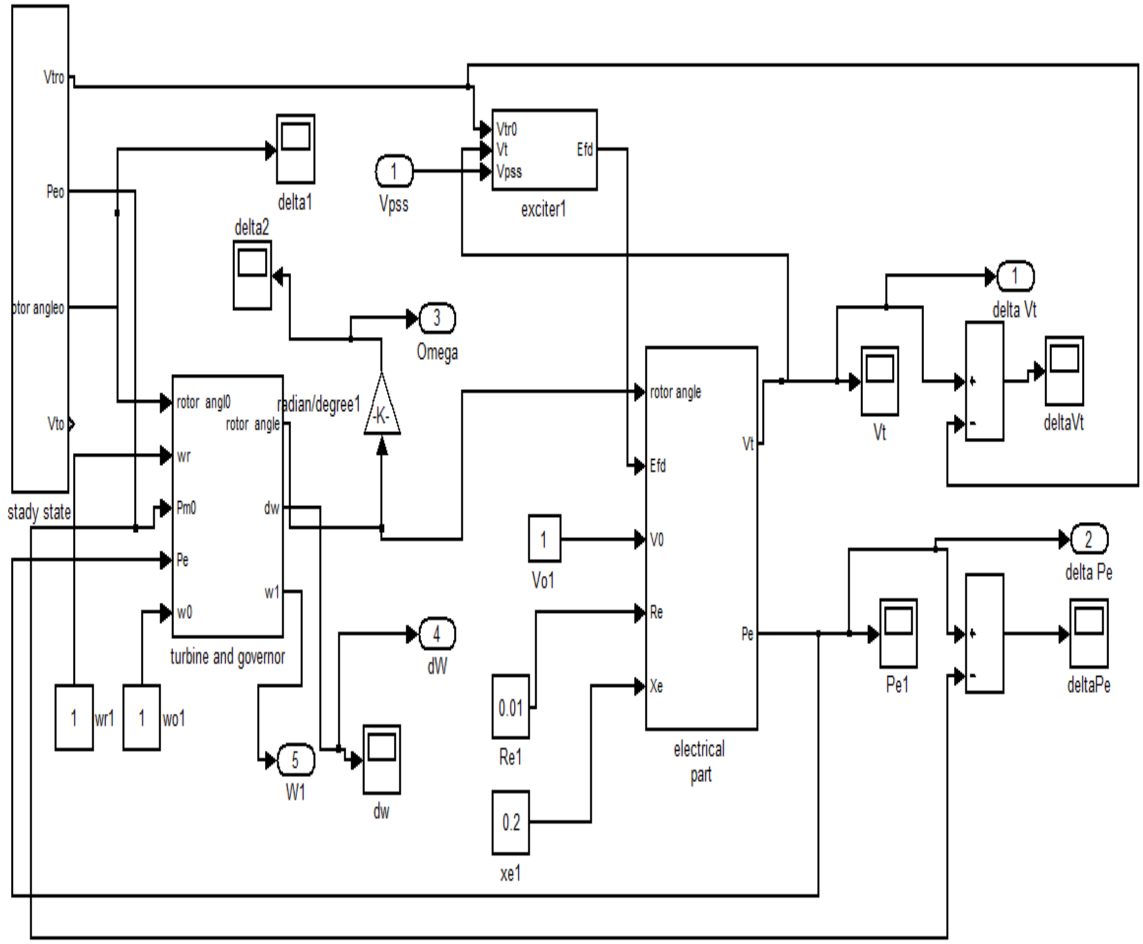

Figure 2. The Complete Model Of The Nonlinear Power System SMIB.

3. CONVENTIONAL POWER SYSTEM STABILIZER

The capacity of a power system to maintain stability depends largely on the power stabilizers or Power System Stabilizer (PSS). The function of the PSS is to damp the oscillations of the generator. It acts on the excitation of the machine [5].

The conventional controller PSS acts on the excitation system of the synchronous machine, this controller has an input (the speed variation Δω) and an output Vpss, which constitutes the input to the excitation system as shown in Figure 1. The performance of a conventional controller is limited. The instrument is sensitive to changes in power system parameters [7].

The transfer functions of the conventional Power System Stabilizer (CPSS):

$$V_{PSS}(s) = K_{PSS}\frac{sT_W}{1+sT_W}\left(\frac{1+sT_1}{1+sT_2}\right)^2 .\Delta\omega$$

The block diagram of the conventional PSS is shown in Fig.3, in which case the generator rotor speed deviation is used as the only stabilizing signal. The CPSS consists of an amplifier, a washout filter and two lead-lag compensators [7].

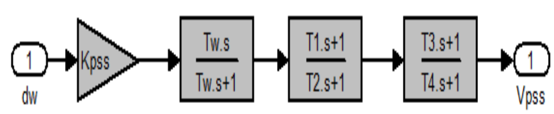

Figure 3. *Block diagram of the Conventional Power System Stabilizer (CPSS).*

Journal of Theoretical and Applied Information Technology
20th August 2013. Vol. 54 No.2

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

4. COMBINED FUZZY POWER SYSTEM STABILIZER AND SLIDING MODE CONTROL

4.1. Fuzzy power system stabilizer: FPSS

A fuzzy logic based PSS gives a consistently better performance than the CPSS [8]. Fuzzy controller design includes the definition the following parameters: Number of partitions of input space and output membership functions, rule base, inference method, fuzzification and defuzzification.

- Fuzzification: transform the measured numerical values to the corresponding linguistic (fuzzy variables with appropriate membership values) [9].

- Knowledge base: include the definitions of the fuzzy membership functions defined for each control variables and the necessary rules to indicate control objectives using linguistic variables.

- Inference mechanism: it should be capable of simulating human decision making and influencing the control actions based on fuzzy logic.

- Defuzzification: Transformation after inference, a fuzzy set of a linguistic variable to numeric values [10].

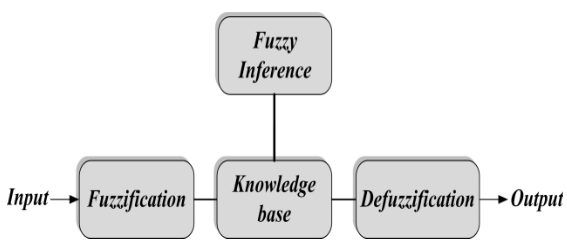

Figure 4. *The concept of a fuzzy logic controller.*

The designs of Fuzzy Logic Controller Two inputs are Considered, changes in speed deviation (Δω) and derivation of change in speed deviation (Δω’). Five membership functions are considered for each input signal which leads to create 25 rules.

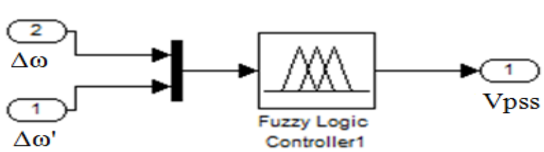

Figure 5. *Fuzzy Logic Controller In Simulink.*

✓ Inputs

• Δω: Signal of the speed error.

• Δω ': signal the acceleration of the machine.

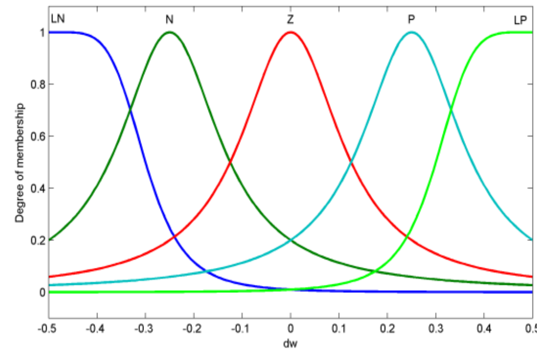

Figure 6. *Membership Function Of Input 1 (Δω).*

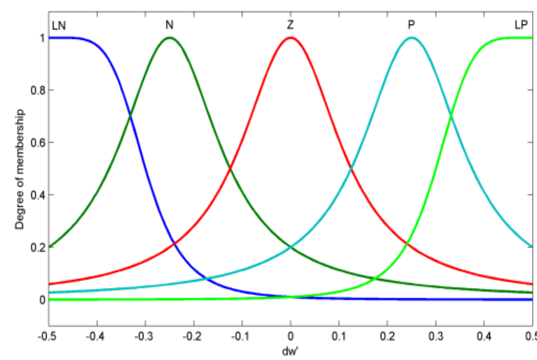

Figure 7. *Membership Function Of Input 2 (Δω').*

✓ Output

• VFPSS: voltage stabilization.

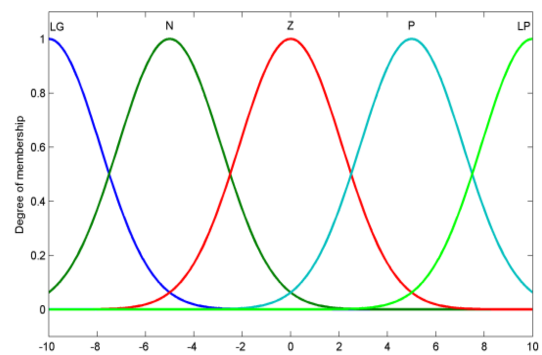

Figure 8. *Membership Functions Of Output (V_{FPSS}).*

✓ bases rules

Fuzzy sets are defined for each input and output variable. There are five fuzzy levels (LN - large negative, N - negative, Z - zero, P - positive, LP -

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

large positive) [11]. The membership functions for input and output variable are gaussian. The 25 rules described presented in a matrix called matrix inference given in the following table:

Table1. *Inference Matrix*

Δω' \ Δω	LN	N	Z	P	LP
LN	LN	LN	LN	N	Z
N	LN	LN	N	Z	P
Z	NG	N	Z	P	LP
P	N	Z	P	LP	LP
LP	Z	P	LP	LP	LP

✓ Control output of Fuzzy PSS

The min - max method inference is used; the defuzzify method used in this FLC is center of area.

$$U_{fpss} = \frac{\sum_{i=1}^{M} w_j . \theta_j}{\sum_{i=1}^{M} w_j}$$

Let θ1, θ 2, …, θ n represent the centroids of M membership functions that are assigned to Ufpss and wi represents the firing strength of the ith rule[12].

4.1.Fuzzy sliding mode control (FSMC)

Sliding Mode Controller (SMC) is a particular type of variable structure control systems that is designed to drive and then constrain the system to lie within of the switching function. There are two main advantages of this approach. Firstly, the dynamic behavior of the system may be adapted by the particular choice of switching functions. Secondly, the closed-loop response becomes insensitive to a particular class of uncertainty and external disturbances.

In this paper, we proposed the combination of fuzzy controller with sliding mode controller. The main objective can be presented in two points:

The first is that the fuzzy controller is obtained without using the nominal model of the system which avoids the limitation of the nominal model required by the sliding mode technique.

The second point is the use of added sliding mode control term to compensate the fuzzy approximation errors and improves the convergence time.

The tracking error vector can be defined as:

$$e = \omega - \omega_r$$

The relative degree is r=2 then, the switching function can be written as:

$$S(e) = ke + \dot{e}$$

The sliding mode control term is [9]:

$$U_{smc} = k_1 sat(S(e))$$

k1 is a positive constant chosen to compensate the fuzzy approximation errors.

Where $$sat(S) = \begin{cases} \frac{S}{\varepsilon} & if\ |S| < \varepsilon \\ sign(\frac{S}{\varepsilon}) & \text{otherwise} \end{cases}$$

The combined sliding mode control and fuzzy logic controller:

$$U = U_{fpss} + U_{smc}$$

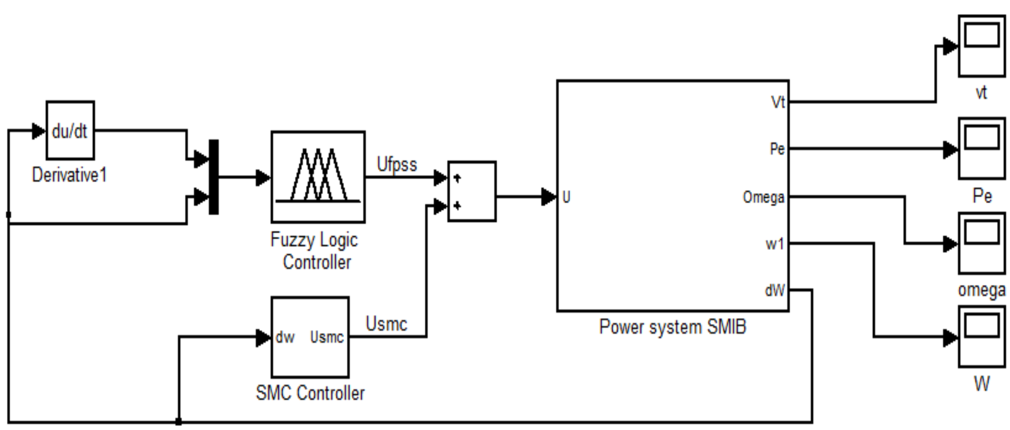

Figure 9. The Complete Model Of Power System Controlled With FPSS & SMC

Journal of Theoretical and Applied Information Technology
20th August 2013. Vol. 54 No.2

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

5. SIMULATION RESULTS

The initial operating conditions are as follows:

$$V_t = 1.11; \quad \omega = 1; \quad \delta = 37.26; \quad P = 0.8;$$

The parameters of the system are given in Appendix B, and the adjusted controller gains are presented in Appendix A.

The purpose of the simulation is to validate the controller FPSS and FSMC. It is used to ensure the dynamic stability of the power system, with the oscillation damping.

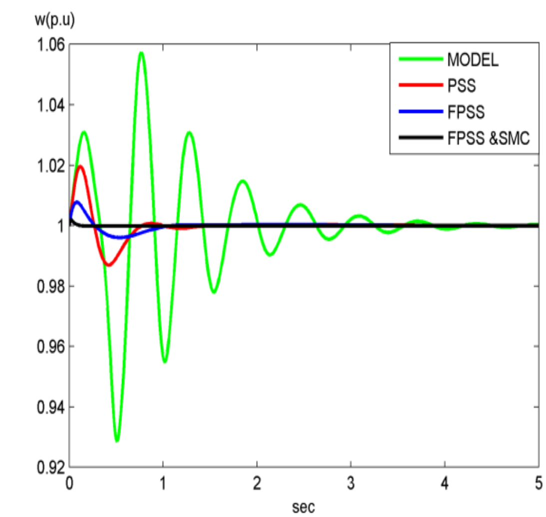

Figure 10. *Rotation speed ω*

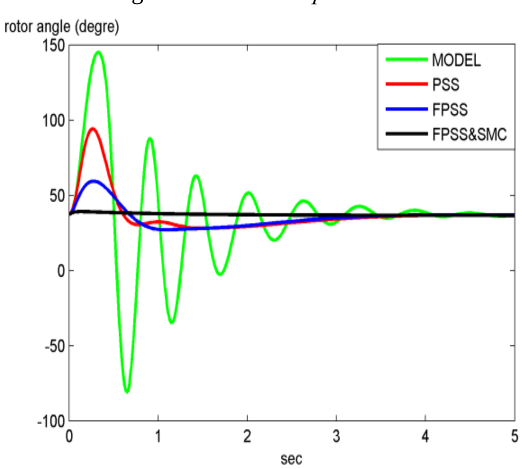

Figure 11. Rotor Angle Δ

In this study the proposed fuzzy PSS and fuzzy PSS combined with sliding mode controller are applied to a power system. The simulation results of power system SMIB are shown in figure 10 to figure 13. This controllers was implemented using Matlab/Simulink, as shown in plots, the proposed controller is able to damp out the oscillations in 0.1 to 0.3 sec. The objective of this proposed method is to stabilize the power system performance and minimize the deviation between the actual and reference field.

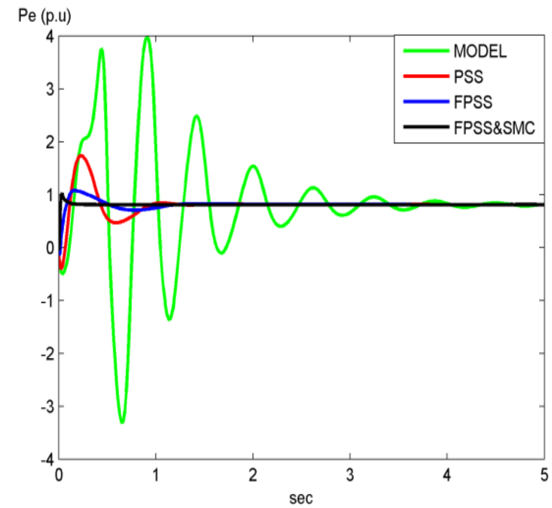

Figure 12. Electric Power Pe

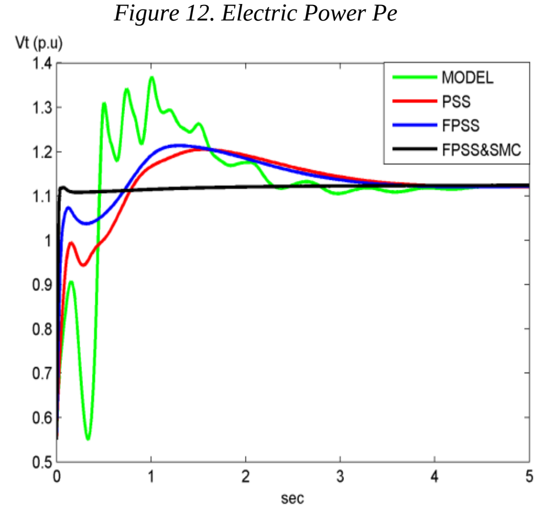

Figure 13. Terminal Voltage Vt

6. CONCLUSION

This study proposes the control method for power system contains a governor and a turbine Related to a synchronous machine connected to an infinite bus by a transmission line. The sliding mode control combined with fuzzy controller has demonstrated the robustness of the nonlinear controller by simulation. The simulation studies assure that the fuzzy power system stabilizer combined with sliding mode controller provides the better damping of oscillations as compared to conventional PSS.

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

7. NOMENCLATURE

V_{PSS} : Output of power system stabilizer
V_{FPSS} : Output of fuzzy power system stabilizer
P_e : Electrical output power
P_m : Generator input power voltage
P_r : Speed relay output power
P_c : Steam chest output power voltage
P_h : Servomotor output power
V_t : Generator terminal voltage
V : Infinitive bus voltage
V_{td} : d axis component of terminal
V_{tq} : q axis component of terminal
V_{tr} : Reference value of the terminal voltage
I_d : d axis armature current
I_q : q axis armature current
δ : Rotor angular position
E'_d : d axis transient voltage
E'_q : q axis transient voltage
E_{fd} : d axis field voltage
V_s : Stabilizing transformer
ω : Angular speed
ω_0 : Base angular speed
ω_r : Governor reference angular speed
T'_{d0} : d axis open circuit time constant
T'_{q0} : q axis open circuit time constant
D : Damping coefficient
M : Inertia constant of generator
K_E : Exciter gain
T_E : Exciter time constant
K_G : Speed relay gain
K_F : Stabilizer circuit gain
T_{FE} : Stabilizer circuit time constant
T_{SR} : Speed relay time constant
T_{SM} : Servomotor time constant
T_{RH} : Reheater time constant
K_{RH} : Reheater gain
T_{CH} : Steam chest time constant
R_e : Equivalent resistance of transmission lines
x_e : Equivalent reactance of voltage transmission lines
x_d : Synchronous reactance
x'_d : Transient reactance
x_q : q axis reactance of generator
P : Real power
Q : Reactive power

8. APPENDIX

A: The parameter values of the power system stabilizer:

Kpss = 9.5	T1 = T3 = 0.145
Tw = 1.4	T2 = T4 = 0.033

B: The parameter values of the synchronous machine:

$P_0 = 0.8$	$K_E = 400$
$Q_0 = 0.496$	$T_E = 0.05s$
$V = 1$	$K_F = 0.025$
$R_e = 0.01$	$T_{FE} = 1s$
$x_d = 1.7$	$K_{RH} = 0.3$
$\omega_0 = 1$	$T'_{d_0} = 5.9s$
$T_{RH} = 8s$	$T'_{q_0} = 0.075s$
$T_{CH} = 0.05s$	$D = 0$
$T_{SR} = 0.1s$	$M = 4.74$
$K_G = 3.5$	$x_q = 1.64$
$T_{SM} = 0.2s$	$x'_d = 0.245$
$\omega_r = 1$	$x_e = 0.2$

REFRENCES:

[1] D.K. Chaturvedi , MSSI, MIEEE, "Adaptive polar fuzzy power system stabilizer", *XXXII National systems conference, NSC 2008*, December 17-19, 2008.

[2] T. Hussein , A. L. Elshafei , A. Bahgat, Design of hierarchical fuzzy logic PSS for a multimachine power system, *Proceedings of the 15th Mediterranean conference on control & automation, july 27-29, 2007*, Athens – Greece.

[3] Wenxin Liu, Ganesh K. Venayagamoorthy, Donald C. Wunsch II, Design of an adaptive neural network based power system stabilizer, *Elsevier Science Neural Networks 16 (2003) pp 891–898.*

[4] A. Demiroren and H. L. Zeynelgil, "Modelling and simulation of synchronous machine transient analysis using SIMULINK", *International Journal of Electrical Engineering Education*, 2002, 39/4 pp 337-346.

[5] P. Kundur, Power System Stability and Control, MacGraw-Hill, 1994

[6] A. Demiroren, H. L. Zeynelgil and S. N. Sengor, "The application of neural network controller to power system with SMES for transient stability enhancement", *John Wiley & Sons, Ltd; European transactions on electrical power*, 2006, pp 629–646.

[7] M. Bounou. "Contribution a l'exploitation robuste des reseaux electriques par la methode de taguchi". *Thesis, Polytechnique, Montréal. 1997*.

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

[8] Hassan M. A. M., Malik O.P. and Hope G. S ., "A Fuzzy Logic Based Stabilizer for a Synchronous Machine", *IEEE Trans. on Energy Conversion*, vol. 6, Iss .3, 1991 pp.407-413.

[9] Vitthal Bandal, B. Bandyopadhyay, and A. M. Kulkarni, "Output Feedback Fuzzy Sliding Mode Control Technique Based Power System Stabilizer (PSS) For Single Machine Infinite Bus (SMIB) System", *IEEE conference publication* 2005,pp 341–346.

[10] M.Hilal, Y. Errami, M.Benchagra and M. Maaroufi,"Fuzzy Power control for doubly fed induction generator based wind farm", *Journal of Theoretical and Applied Information Technology* Vol. 43 No.2, 2012, pp 321-330.

[11] M. R. Yazdchi and S. M. S. Boroujeni ," Power System Stabilizer Design Based on Model
Reference Robust Fuzzy Control", *Research Journal of Applied Sciences, Engineering and Technology* vol. 4, Iss. 8, 2012 pp 852-858.

[12] A. Kolabi, S. Sofalgar, T. Lotfi and M. Yousefi, "Comparing the Power System Stabilizer Based on Sliding Mode Control with the Fuzzy Power System Stabilizer for Single Machine Infinite Bus System (SMIB)", *Research Journal of Applied Sciences, Engineering and Technology* vol. 5 Iss. 1, 2012 pp 16-22.

[13]Alemayehu G/E Abera and B. Bandyopadhyay, "Digital Redesign of Sliding Mode Control with Application to Power System Stabilizer", *34th Annual Conference of IEEE Industrial Electronics, IECON*, 2008, pp 164 - 169.

[14] N. Yadaiah, G. Tulasi Ram Das and A. G.D. Kumar," Design of Robust Intelligent Coordinated Controller for Power Systems Problems", *11th International IEEE Conference on Hybrid Intelligent Systems (HIS)* 2011, pp 686-691.

[15] V.S. Vakula and K.R. Sudha, "Design of differential evolution algorithm-based robust fuzzy logic power system stabiliser using minimum rule base", *Generation, Transmission & Distribution IET*, Vol. 6, Iss. 2, 2012, pp. 121–132.