International Journal of Engineering Innovation & Research
Volume 4, Issue 2, ISSN: 2277 – 5668

Enhancing Angular Stability in Multi-Machine Power System with using a New Control Method

Mohsen Ghorbani
Department of Electrical Engineering,
Ahar Branch, Islamic Azad University, Ahar, Iran

Davood Azizian
Department of Electrical Engineering,
Abhar Branch, Islamic Azad University, Abhar, Iran

Abstract – **In this paper, application of Posicast control method to generator excitation system and Automatic Voltage Regulator (AVR)are presented. The method is one of the simplest possible control design methods that can be applied to Mitigate the oscillations caused by changing the excitation reference signal and occurrence large or small sudden faults. In other words, Posicast controller both improve and damping tle oscillations caused by changing the excitation reference signal and large or small suddn3-phase faults occurred in the different parts of the transmission lines. In this work, shown that the proposed controller improve angular stability in multi-machine power system. In facts, Posicast controller improve small signal and transient stability in four generators system. Stability of the designed controller is shown using extensive time domain simulations. Performance of Posicast controller in IEEE power system standard is evaluated in MATLAB/Simulink environment.**

Keywords – **Angular Stability, Generator Excitation System, Posicast Controller, Automatic Voltage Regulator (AVR).**

I. Introduction

Changing the reference signal of the excitation and Automatic Voltage Regulator (AVR) systems is one of the excitation control methods in controlling the terminal voltage of the generator and reactive power. The basic function of an excitation system is to provide direct current to the synchronous machine field winding. In addition, the excitation system performs control and protective functions essential to the satisfactory performance of the power system by controlling the field voltage and thereby the field current. The control includes voltage and reactive power control and stability improvement of the system. The protective functions guarantee that the requests will not exceed the capabilities of the generator [1]. Changing the reference signal of the excitation system is one of excitation control methods in controlling terminal voltage of the generator and as a result reactive power absorption in large power plants. On the other hand, this control method causes the oscillations in overall of the system. To have a stable and continuous operation condition, the oscillations damping is main target. Further, the oscillations can create excessive heat in the field windings. Therefore mitigation of the oscillations can extend the life of the field windings [2].As in [3], using AVR to control the terminal voltage of the generator by changing the generator field voltage has been discussed. Design of AVR system for synchronous generators using a thyristor based controller to produce the excitation voltage is discussed in [4], [5].

This Paper is extracted from the Master thesis.

A generator excitation predictive control scheme is introduced in [6], [7]. However, all the previously published papers are categorized as feedback control systems. Complicated controllers are modeled to guarantee stability and high performance of the system against possible disturbances. Implementing such controllers increases the complexity of excitation system and imposes extra costs. In this effort, Posicast control method is applied to improve angular stability in multi machine power system. In facts, controller design to damp oscillations small signal and transient to adding generator excitation system. It is already shown that transient and small signal stability of the system can be improved using this method [8]. In this paper, complete and comprehensive application Posicast controller are presented. A performance index is also used to show the improvements in dampening capability of the designed controller. Therefore, there is no need to be worried about overall system stability.

II. History of Posicast Controller

The invention of Posicast control is due to Prof. Otto J. M. Smith, who described the basic principles in the Sept. 1957 [9]. A decade later, application of half-cycle Posicast to vibrating structures was proposed in [10]. Posicast compensation is applied within a feedback system rather [11], [12]. The first reported applications were for mechanical structures. Recently, Posicast based feedback control is used in the field of power engineering, such as digital control of the boost converters [13], Dynamic Voltage Restorer [14], resonant damping of Z-source current-type inverter [15]. And so on. Posicast is a feed-forward control method that dampens oscillations in systems whose other transient specifications are otherwise acceptable. When properly tuned, the controlled system yields a transient response that has deadbeat. Consider a system having a lightly damped step response as shown in Fig. 1.

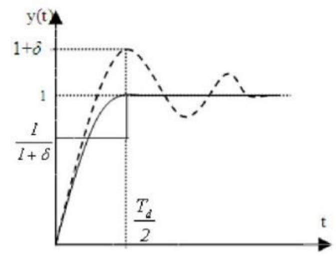

Fig.1. Step Response of the system with (solid line) and without (dashed line) Posicast and the control signal generated by Posicast.

The overshoot in the response can be described by two parameters. First, the time to the first peak is one half the under damped response period T_d. Second, the peak value is described by 1+δ, where δ is the normalized overshoot, which ranges from zero to one [16]. Posicast separates the original step input command into two parts, which are illustrated in Fig. 1. The first part is a certain step which it causes the first and biggest overshoot, the oscillatory response accurately reaches to the desired final value. The second part of the modified input is full scale and time-delayed to absolutely stop the remaining oscillatory response, therefore causing the system output to stay at the desired value. The resulting system output is shown in Fig. 1 (dashed line); the compensated and (solid line) uncompensated output are shown for comparison. The principal of half cycle Posicast control is shown by block diagram in Fig. 2. The designed model has two forward paths. The upper path is the original or uncompensated command input. In the lower path, a section of the original command is initially subtracted, so that the maximum value of the response oscillation will not be overshoot at the desired final value [16].

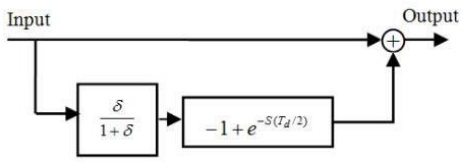

Fig.2. Open-loop half cycle Posicast

The transfer function is given by the function 1+P(s), where P(s) is given by:

$$P(s)=\frac{\delta}{1+\delta}\left[-1+e^{-s\left(\frac{T_d}{2}\right)}\right] \quad (1)$$

The aforementioned method is open-loop compensation therefore it has high sensitivity to the parameter variations and to design mismatch. This issue can be adjustment via applying Posicast within a feedback system instead of using classical feed-forward structure [11], [12]. A block diagram explaining the control method is shown in Fig. 3.

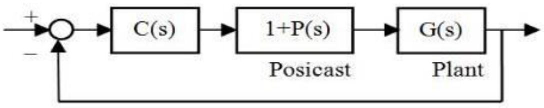

Fig.3. Posicast within a feedback system

However, recent works suggest that Posicast be applied within a feedback system. The proposed control method is a significant departure from classical Posicast [16].

III. Application of Posicast to Control Voltage

In this section, Posicast controller is installed in four generators system. In other words, Posicast controller is installed in one of the excitation generators system in (G1). First, Small signal and after transient analysis done the case study.

IV. Configuration Of Test System

The configuration studied in this work is shown in Fig. 4 [1]. The system studied, have two similar area that connected through a transmission system. It consists of four synchronous generators. Area1 consists of two coupled synchronous generator, Area2 consists of two coupled generator units, rated power of each synchronous generator is 900 MW. The nominal voltage is 230 KV. In this system Line lengths is 440 KM and each generator is described by a 7th order nonlinear mathematical model that describing equations are expressed in [17]. Parameters of the generators are borrowed from [1]. A hydraulic turbine and governor system is also considered in the simulations. The model used for this system is an IEEE standard model expressed in [18]. The parameters of system are mentioned in appendix part.

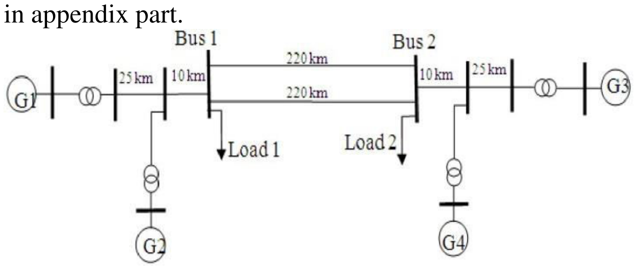

Fig.4. The multi-machine system

But don't forget that, Power System Stabilizer (PSS) applied to enhance of the system oscillations damping in the synchronous generators by controlling its excitation.

V. Angular Stability Analysis Presence of Posicast Controller

A. *Small signal Stability Analysis*

In this section, application Posicast controller for small signal stability analysis in system four generators presented. As mentioned earlier, two parameters are required in the Posicast design process. These parameters have been obtained from the step response of the system and are listed in table.1. The excitation system after adding Posicast is shown in Fig. 5. As shown in the Fig. 5, the half cycle Posicast is used within the feedback loop. In this system the terminal voltage of the generator is feedback to the Posicast controller in order to be compared with the setpoint.

Table.1. Parameters obtained from step response

Parameter	Value	Unit
δ	0.38	*p.u*
$T_d/2$	0.25	*sec*

While comparing Fig. 2 and Fig.3 it is concluded that the C(s) in the Fig. 3 is substituted with an integrator and a constant gain. The integrator increases the robustness of the controller and causes a zero steady-state error. Due to the important and essential that only a Posicast controller

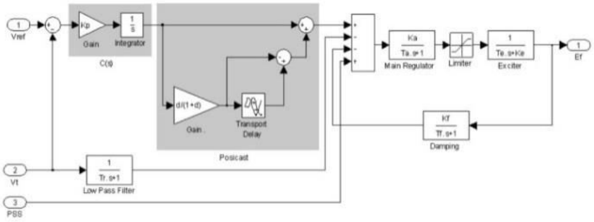

Fig.5. The AVR and excitation system after adding Posicast controller

for damped to mitigation small signal and transient stability installed in a excitation system of the first generator case study and all other generators have the standard ST1A excitation system that introduced in [18]. To evaluate the performance of the modeled Posicast controller, a step change in the reference signal of the excitation is considered. The reference signal of the first generator is increased from 0.99 p.u. to 1.033 p.u. after initial dynamic condition at t=3 sec. After 0.4 sec, the reference signal is decrase to 1.1 p.u. Bus1 voltage. Bus1 voltage, Terminal voltage generator, Rotor speed deviation and the active power transferred from bus1 to bus2, are shown in figures; 6, 7, 8 and9 respectively.

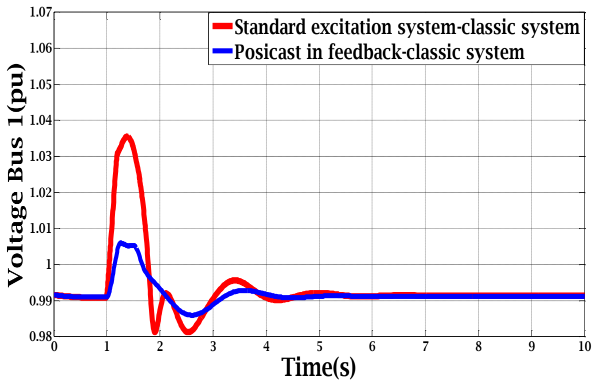

Fig.6. Bus1 voltage(pu)

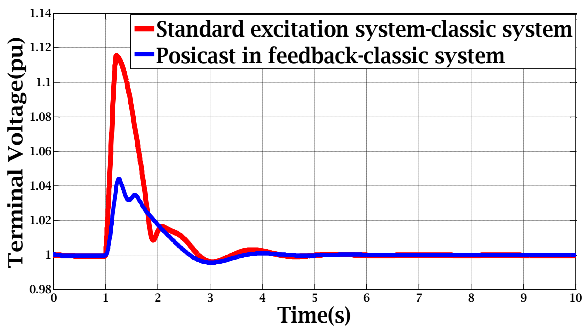

Fig.7. Terminal voltage generator(pu)

As shown in the figures; 6, 7, 8 and 9,Posicast controller improves the small signal dynamics of the case study system. In other words, when the Posicast controller is used in the excitation system, performance of the system in damping the oscillations has increased drastically. In facts, designed controller has decreased the first overshoot for step change in the reference signal. So Posicast controller smooths the step input in order to mitigate the

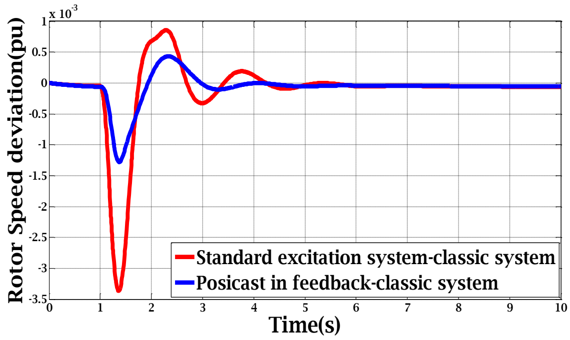

Fig.8. Rotor speed deviation(pu)

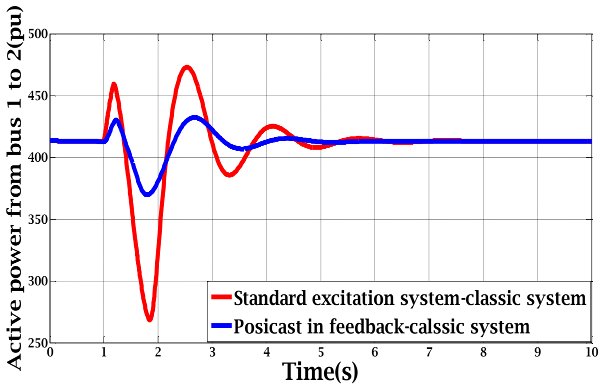

Fig.9. Active power transferred from bus1 to bus2(pu)

overshoot in the output signal and therefore it improves the dampening ability of the system. In order to see how effective the Posicast controller in improving the damping of transient oscillations a performance index is used in this section. In this work, the integral of the absolute value of the time derivative of the total kinetic energy divided by the system base power is selected as the objective function. Therefore, the objective function is expressed simply as [19].

$$W_c(\text{sec}) = \frac{\int_0^T \left|\frac{d}{dt}W\right| dt}{systembasepower} \qquad (2)$$

Where T=*10* sec is the simulation time and *W* is the total kinetic energy J which can be calculated easily by knowing the rotor speed of the generator [19].

$$W(sec) = \frac{1}{2} J \omega_m^2 (J) \qquad (3)$$

Again in (3) *J* denotes the moment of inertia in Kg.m2 and ωm rotor angular velocity in mechanical radians per second. The smaller the value of Wc, the better the system's performance.

With the above definitions, we can table performance index for the system under study to obtain. The Performance index is calculated for the of all four generators with and without Posicast controller and is listed table 2.

Table 2. Performance index values

Generator	Without Posicast	Posicast in feedback
G1	*0.2012*	*0.02414*
G2	*0.16*	*0.01732*
G3	*0.0982*	*0.01557*
G4	*0.09292*	*0.01494*

International Journal of Engineering Innovation & Research
Volume 4, Issue 2, ISSN: 2277 – 5668

It can be observed that the Posicast improves the performance of all four generators; however the improvement is significant for the first generator which is the generator with a Posicast excitation controller. It should be noticed that the Posicast is applied just on excitation system of the first generator (in G1), This characteristic validate adaptive characteristic of the controller.

B. Transient Stabilty Analysis

In this section, application Posicast controller for transient stability analysis in system two area four generators presented. The structure of the excitation system as shown in Fig. 10.Here too, like the previous case (Small signal analysis), Posicast controller is used within feedback system. using Posicast in feedback increases the robustness of the system. But, in thecasebefore, there wasn't any feedback from $P_a = P_m - P_e$(P_m=Mechanical toruqe and P_e=Electrical toruqe). Most of the PSS designs use this signal as an input signal because almost all faults occurred in the network effect this signal [1]. We have used this signal to improve the stability of the system, too. This signal is added to the Posicast input signal. In other words both changing the excitation reference signal and both the faults occurred in the network can be handled with a Posicast controller. This is the most important advantage of the offered controller over the designs that use two different controllers for damping the oscillations caused by changing the excitation reference signal and the ones caused by the sudden line faults.

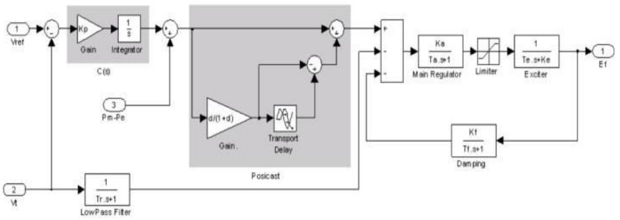

Fig.10. The AVR and excitation system after adding Posicast controller, with feed signal P_m-P_e.

In facts, P_m-P_e signal is used to increase the system transient stability.This signal has very small deviations for changes in VRef. So, this signal is only important for transient stability and has no effect on the voltage control application we are studying.In order to investigate the transient stability of the system, it is assumed that three faults are occurred in the beginning, middle and the end of the transmission line. The configuration test system that three faults are accurred in the transmission line as shown in Fig. 11. For the convenience, we have a Location three faults in transmission line very briefly at table 3.The faults are considered 3-phase short circuit and occur at t=1 sec. After 0.1 sec the line breaker detaches the faulty line from the network. Bus1 voltage, terminal voltage generator and active power transferred from area 1 to area 2 as shown in figures; 12, 13 and14 Respectively.

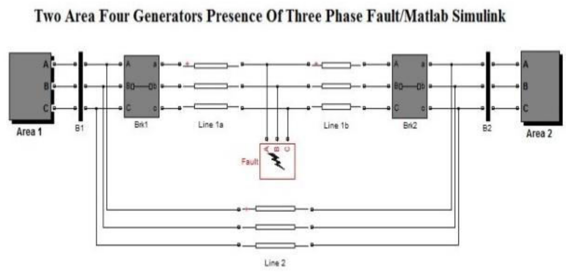

Fig.11. Two area four generators presence of three faults in Matlab/Simulink layout

Table 3. Location three faults in transmission line

Name Three faults	Location three faults
F1	beginning of the Line 1
F2	middle of the Line 1
F3	end of the Line 1

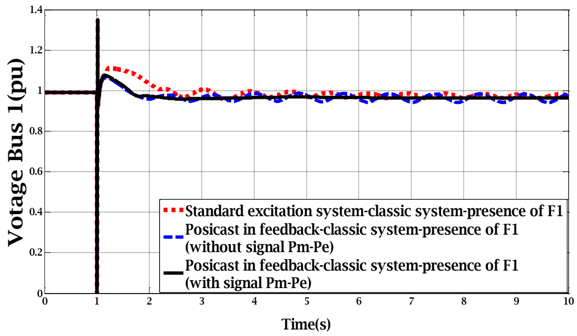

Fig.12. Bus 1 voltage after the F1

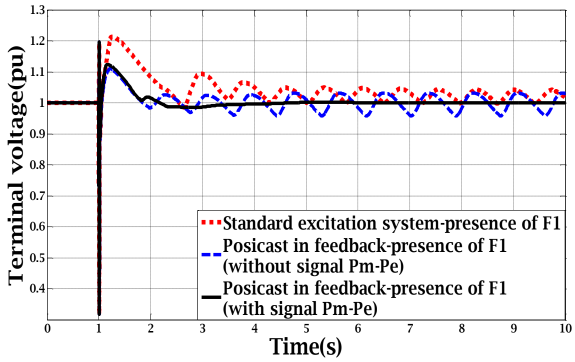

Fig.13. Terminal voltage after the F1

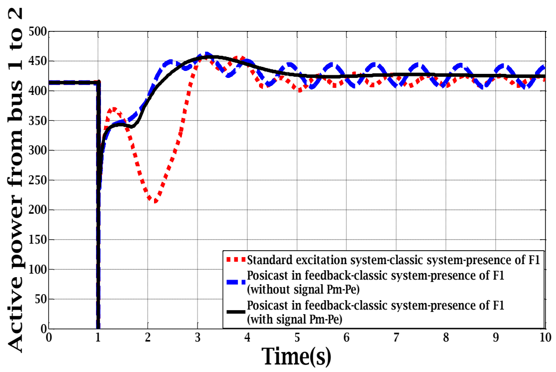

Fig.14. Active power from bus 1 to bus 2 after the F1

As shown in the figures; 12, 13 and 14 the oscillations are damped by using the Posicast controller feeding back from the P_m-P_e signal and the system reaches to a new post fault operating condition in a few seconds after the fault (F1) is cleared, The following simulations, Figures;15 to 20, Application Posicast controller with feeding back from the P_m-P_e signal to three faults(F2 and F3) are showing. Respectively figures the same previous state.

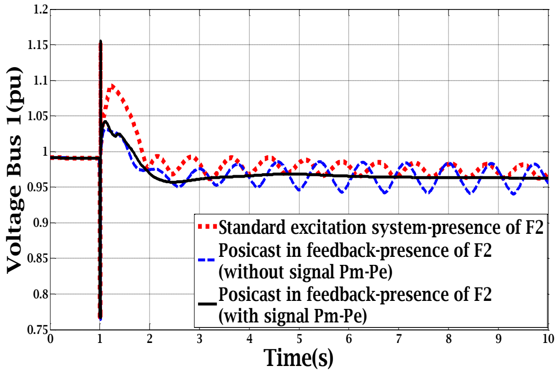

Fig.15. Bus 1 voltage after the F2

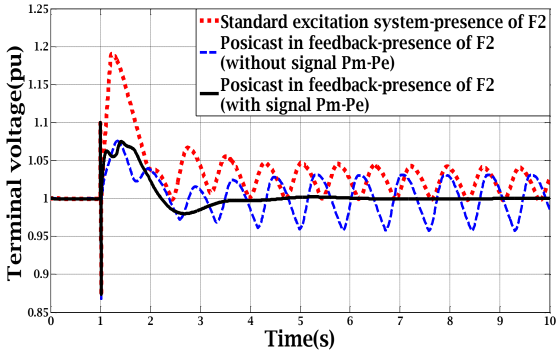

Fig.16. Terminal voltage after the F2

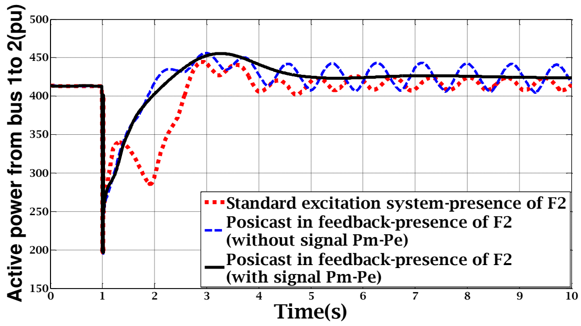

Fig.17. Active power from bus 1 to bus 2 after the F2

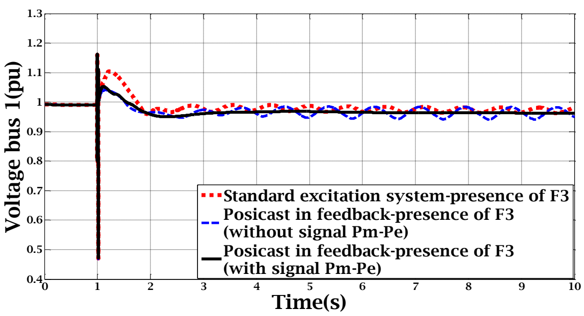

Fig.18. Bus 1 voltage after the F3

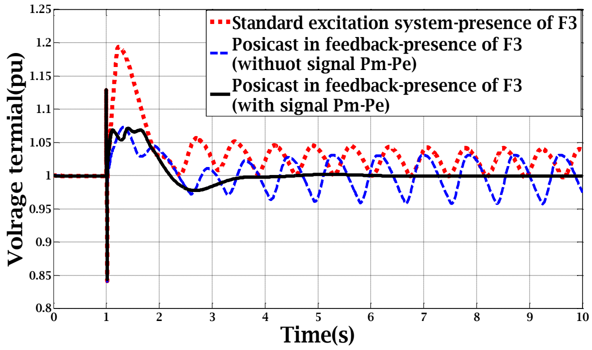

Fig.19. Terminal voltage after the F3

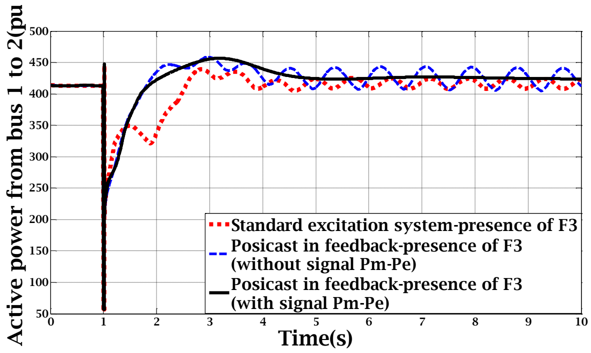

Fig.20. Active power from bus 1 to bus 2 after the F3

With observing figures; 15 until 20, we know that Posicast controller along feeding the P_m-P_e signal is able not only damped to disturbance come from three fault is applied at the beginning of the transmission line, but can is also damped cause swings in the middle and end of line, that the features and capabilities of the recommended controller. Table. 4,performance index Posicast controller at the time of the various modes of transmission line indicates the fault.

Table.4. Index Performance Posicast controller at various modes faults in transmission line

Name three faults	Location three faults	Standard excitation system	Posicast in feedback
F1	beginning of the Line 1	0.911	0.631
F2	middle of the Line 1	0.531	0.397
F3	end of the Line 1	0.321	0.331

The table 4, as showing performance of the proposed controller in damping power system oscillations of three faults in transmission line. In facts, this table is an affirmation of simulations conducted in the transient stability analysis.

VI. Conclusion

In this paper angular stability(small signal and transient stability) of the two area four generators system has been investigated. In other words, oscillations can be improved as well as the transient and small signal stability by using just one Posicast controller. The oscillations can be caused by changing the reference signal of excitation system or by other undesirable events like sudden faults happened in transmission lines. Several considerable remarks obtained from the simulation results:

1-In multi-machine power system has been shown that when a Posicast controller is used in the generator excitation system, the overall performance of the system increases in damping the disturbances effecting the excitation reference signal and the large or small faults occurred in the transmission line.

2-It has been shown that the voltage stability of the generator can be improved using the offered controller.

3-There are considerable improvements both in overshoot and both settling time of the signal applied to the generator field windings. The smaller the voltage variations applied to the field windings the longer the life of the generator therefore we can conclude that using Posicast controller can also extend the life of field windings.

4- The Posicast controller structure is very simple and is easy to implement in the system performance, Thereforepractical application of this controller can be economic, androbustness is other advantage of the designed controller.

ACKNOWLEDGEMENT

This article is extracted from the Master's thesis.

REFERENCES

[1] P. Kundur, Power System Stability and Control, McGraw-Hill, 1994.

[2] Grigsby, L., 2006. PowerSystemStabilityandControl. Second Edition, CRC Press, New York, USA

[3] E. Swidenbank, S. McLoone, D. Flynn, G.W. Irwin, M.D. Brown, B.W. Hogg, "Neural network based control for synchronous generators"IEEE Transactions on Antennas and Propagation, Vol. 55, No. 1, pp. 1673–1678, 2007.

[4] C. S. Hoong, T. Taib, K. S. Rao, I. Daut, "Development of automaticvoltage regulator for synchronous generator" National Power andEnergy Conference, pp. 180 –184, Nov. 2004.

[5] M. S. Ghazizadeh, M. Saidy and F. M. Hughes, " Predictive analoguegenerator excitation controller" IEE Proceeding on Generation, Transmission and Distribution, Vol. 144,pp. 271-278, May 1997.

[6] P. Mitra, S. Chowdhury, S. P. Chowdhury, S. K. Pal, Y. H. Song, G. A. Taylor, "Performance of a Fuzzy Logic Based Automatic VoltageRegulator in Single and Multi-Machine Environment" UniversitiesPower Engineering Conference, Vol. 3, pp. 1082–1086, 2006.

[7] C. H. Cheng, Y. Y. Hsu, "Damping of Generator Oscillation Using an Adaptive Static Var Compensator "IEEE Trans on Power Systems, Vol. 7, No. 2, pp. 718-724, May 1992.

[8] M. R. Aghamohammadi, A. Ghorbani and S. Pourmohammad, "Enhancing Transient and Small Signal Stability in Power SystemsUsing a Posicast Excitation Controller" The 43th InternationalUniversities'Power Engineering Conference UPEC, pp. 57–61, March2008.

[9] O. J. M. Smith, "Posicast control of damped oscillatory systems" 1957.

[10] G. Cook, "An application of half-cycle Posicast," IEEE Transactions onAutomatic Control, Vol. 11, no. 3, pp. 556–559, July 1966.

[11] J. Y. Hung, "Application of Posicast principles in feedback control" IEEE International Symposium on Industrial Electronics, pp. 500–504, July 2002.

[12] John Y. Hung, "Feedback control with Posicast," IEEE Transactions onIndustrial Electronics, vol. 50, no. 1, pp. 94–99, February 2003.

[13] Q. Feng, J. Y. Hung, and R. M. Nelms, "Digital control of a boostconverter using Posicast," in Proceedings of 18th Annual IEEE AppliedPower Electronics Conference and Exposition, pp. 990–995, Miami, FL,February 2003.

[14] P. C. Loh, D. M. Vilathgamuwa, S. K. Tang, and H. L. Long, "Multilevel Dynamic Voltage Restorer," IEEE Power ElectronicsLetters, Vol. 2, No. 4, pp. 125–130, December 2004.

[15] P. C. Loh, C. J. Gajanayake, D. M. Vilathgamuwa, and F. Blaabjerg, "Evaluation of resonant damping techniques for Z-source current-typeinverter," IEEE Applied Power Electronics Conference and Exposition, March 2006.

[16] John Y. Hung ," Posicast Control Past and Present" IEEE MultiDiciplinary Engineering Education Magazine, Vol. 2, No.

[17] Cheng, C.H., Y.Y. Hsu, 1992. "Damping of Generator Oscillation Using an Adaptive Static VarCompensateur "IEEE Trans on Power Systems, 7(2): 718-724.1, March2007.

[18] IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, "Hydraulic Turbine and TurbineControl Models for Dynamic Studies," IEEE Transactions on PowerSystems, Vol. 7, No.1, pp. 167-179, February, 1992.

[19] "Recommended Practice for Excitation System Models for PowerSystem Stability Studies," IEEE Standard 421.5, August 1992.

APPENDIX

The parameters of the generator, transmission line, transformer and the hydrolic turbine, governor system and the excitation system including AVR are presented in tables 5 to 7, respectively. All the values are in p.u.

Table 5: Parameters of generators, transmission line and the transformer

MVA	200	X_l	0.18
f	60	T'_d	1.01
R_s	0.002	T''_d	0.053
X	1.305	T''_q	0.1
X'_d	0.296	H	3.2
X''_d	0.252	X_T	0.08
X'_q	0.474	R_{line}	0.04
X''_q	0.243	X_{line}	0.2

Table 6: Parameters of hydrolicturbin-governor system

K_a	200	R_P	0.18
T_a	60	K_P	1.01
g_{min}	0.002	K_i	0.053
g_{max}	1.305	K_d	0.1
$Vg_{max\,(pu/s)}$	0.296	$T_d\,(sec)$	3.2
$Vg_{min\,(pu/s)}$	0.252	$T_w\,(sec)$	0.08

International Journal of Engineering Innovation & Research
Volume 4, Issue 2, ISSN: 2277 – 5668

Table 7: Parameter of excitation system and AVR

$E_{f\ min}$	$E_{f\ min}$	T_R	K_A	T_A
-11.5	-11.5	0.02	0.001	300

AUTHOR'S PROFILE

Mohsen Ghorbani
was born in Mianeh, Iran, 1989. He received his B.Sc. degree from department of electrical engineering, Abhar Branch, Islamic Azad University, Abhar, Iran, in 2012, He is currently a M.S student in department of electrical engineering, Ahar Branch, Islamic Azad University, Ahar, Iran. His research interests include power system dynamic, power quality and renewable energy.

Davood Azizian
was born in Rasht, Iran, 1981, He both received his B.Sc. and M.Sc. degrees in electrical engineering, from the Zanjan University, Zanjan, Iran, in 2003 and 2005, and the Ph.D. degree from Science & Research Branch, Islamic Azad University, Tehran, Iran, 2010. He is currently an Assistant Professor in department of electrical engineering, Abhar Branch, Islamic Azad University, Abhar, Iran. His research interests include power system dynamic and design transformer.