Journal of Engineering and Technology Management 73 (2024)

Coordinated Automatic generation control with Fuzzy Logic Controller based Power System Stabilizer for Multi-Machine System

Rabindra Behera, Anindita Mohanty
Department of Electrical Engg.
I.G.I.T. Sarang, Dhenkanal
Odisha, India

Abstract

The implementation of green energy also needs a safe and adequate operational facility to enhance the reliability and continuity of Electrical Power supply. Here, the presented work is an effort in this direction. The focus is to maintain voltage stability in case of change in demand. The major challenge in the power system is to take up the assignment of change in power demand and supply management without violation of power quality. The operation and stability of modern power systems involving the synchronous operation of a large number of generators is often threatened by electromechanical oscillations called power swings. High performance excitation systems (AVR) with damper are well suited to combat the loss of synchronism and maintain the steady state and transient stability of the generators in power system. Here, Effort has been given to develop a robust co-ordinate AVR-PSS using a fuzzy logic controller for an effective improvement in the power system stability of a two area system. This study can also be extended for larger power systems.

Keywords: Power system stabilizer; Fuzzy controller; Voltage stability

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1. INTRODUCTION:

The operation and stability of modern power systems have been threatened by the tremendous increase in the electrical energy usage. To meet the rising power demand, a large number of generators operate synchronously. A suitable damping device is needed to combat the loss of synchronism and other stability problems caused by the power swings that are induced by faults occurring within the system. High performance excitation systems (AVR) with damper are well suited to maintain the steady state and transient stability of the generators in power system. In case of relatively weaker tie line interconnections between the power systems, low frequency oscillations ranging from 0.5 – 3 Hz are quite common in the system. An effective means of improving the system damping of the electric power system is by using power system stabilizers . Effort has been given to develop a robust co-ordinate AVR-PSS using a fuzzy logic controller for an effective improvement in power system stability of a multi machine system. In this work, a fuzzy logic based power system stabilizer has been designed for a multi machine infinite bus power system. Simulation results indicate that the proposed fuzzy logic based coordinate AVR-PSS achieves a robust performance for a wide range of system operation conditions and offers superior performance over AVR-PSS without fuzzy logic controller. In this paper, the variousexisting models of the automatic voltage regulator (AVR) and power system stabilizer (PSS), after fuzzification, for multi-machine systems have been proposed. The basic function of an AVR is to achieve required voltage regulation. Then the damping is controlled by the PSS. The various time domain parameter values are further enhanced by fuzzifying the existing models. The AVR loop which is used to regulate the voltage performance of the power system was first used by Heffron-Phillips [1] and later by F. P. DeMello and C. Concordia [2]. The analysis of the design of AVR-PSS for a single machine infinite bus model has been carried out by K. T. Law,
D. J. Hill and N. R. Godfrey [3] who claim that this analysis can help in designing AVR-PSS for multimachine power systems.

2. CONVENTIONAL POWER SYSTEM STABILIZER DESIGN:

The basic function of a PSS is to damp the power swings in the rotor of the generator by controlling its excitation using an auxiliary stabilizing signal. The stabilizer must produce a constituent of electrical torque in phase with the rotor speed deviation for damping effect. For simplicity, a conventional PSS is modeled into two stages (identical) lead/lag network which is represented by a stabilizer gain K_{STAB} and two time constants T_1 and T_2. This network is connected to a washout circuit of time constant T_W.

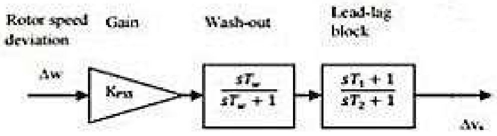

Fig 1. Block Diagram of PSS[9]

In Fig.1 the phase compensation block provides the pertinent phase lead characteristics to compensate for the phase lag that exists between the exciter input and generator electrical torque. K_{PSS}: effect on damping of rotor oscillations. With increase in stabilizer gain, damping increases to a certain point and then decreases. Ideally gain should be set at a value corresponding to max damping. Usually it is set at such a value that results in a high damping of the critical system modes without compromising the stability of other system modes or causing excessive amplification of signal noise. WASHOUT FILTER: It's a high pass filter whose main function is prevention in modification of the field voltage resulting from steady changes in speed. T_W, washout time constant should allow signals associated with oscillations in rotor speed to pass unchanged with a range of 1-20 seconds. PHASE-LEAD COMPENSATION: This compensates the lag between the exciter input (i.e. PSS output) & the resulting electrical torque used to damp the rotor oscillations. The PSS is often required to enhance the damping of local plant modes or inter area mode of oscillation. Speed deviation Δw is a logical signal to introduce a damping torque component.

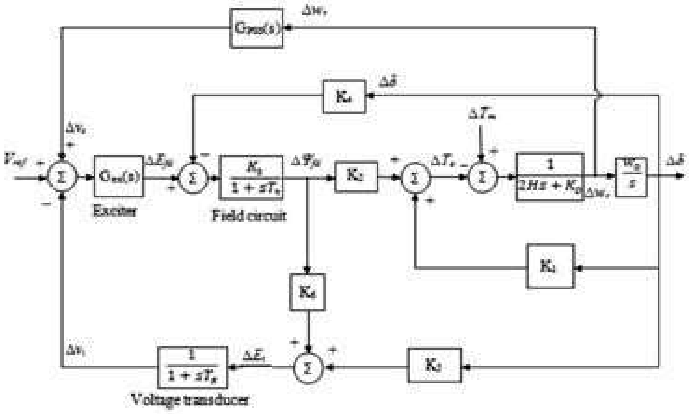

FIGURE 2. Block Diagram representation with AVR and PSS[6]

The theoretical basis of a PSS may be illustrated with the above block diagram in Fig. 2. The system contains a generating unit connected to an infinite bus through a transformer and a pair of transmission lines. The terminal voltage of the generator is connected with the help of an excitation system and AVR. An associated governor monitors the shaft frequency and thus controls the mechanical power. The dynamic characteristics of the system are expressed in terms of the Heffron - Phillips constants or the K constants. There are six constants that describe the relation between the speed of the generator rotor and its voltage control. The machine parameters and the operating conditions determine the Heffron -Phillips constants.

The change in air-gap torque as a function of Δδ and $\Delta\Psi_{fd}$ as follows:

$$\Delta T_e = K_1\Delta\delta + K_2\Delta\Psi_{fd} \quad (1)$$

Where $K_1 = \Delta T_e / \Delta\delta$ with constant Ψ_{fd}.

$K2 = \Delta T_e / \Psi_{fd}$ with constant rotor angle δ.

From the diagram,

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

As long as K_4 is positive, the field fluxes variation caused due to the armature reaction introduce a positive damping torque component.

$G_{ex}(s)$ is the transfer function representing the AVR. The terminal voltage error signal that forms the input to the voltage transducer block is

$$\Delta E_t = K_5 \Delta\delta + K_6 \Delta\Psi_{fd} \quad (3)$$

K_6 is always positive, while K_5 can attain a positive or negative value depending on the operating conditions and the external network impedance $R_E + jX_E$. With $K_A = 0$, $\Delta\Psi_{fd}$ depends on the armature reaction. The effect of AVR is to decrease K_D for all positive K_A.

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3. PROPOSED MULTIMACHINE SYSTEMS :

3.1 Case-A:

In this case a very conventional Heffron-Phillips Models considered for study and analysis. Two such models are selected with different specifications. The following block diagram represents the model of a multi machine connected to an infinite bus system. The model is derived based on the excitation system configuration of the machine. This model helps in determining the small signal and large signal voltage stability study for an external disturbance in a system. Here, attempt has been made to coordinate the Automatic load frequency control lool with the PSS loop. The validity of such a system is ideal, limited and far from the requirement of a real system which consists of a large number of such systems. In order to study and develop a multi-machine block diagram model, the automatic load frequency control (ALFC) loop and the block diagram model has been considered. The ALFC loop is mainly associated with the mechanical input and the system frequency. In case of a multi-area system, the ALFC loop of individual area is connected through a tie line. Here, effort has been made to prepare a MATLAB Simulink model of a multi-machine system considering the ALFC loops and separate AVR-PSS loops as shown in Fig. 3. The PID control of the systems has been coordinated to tabilize the system at its optimum level. The tuning of the Controller has been made using Nichols Zegler method.

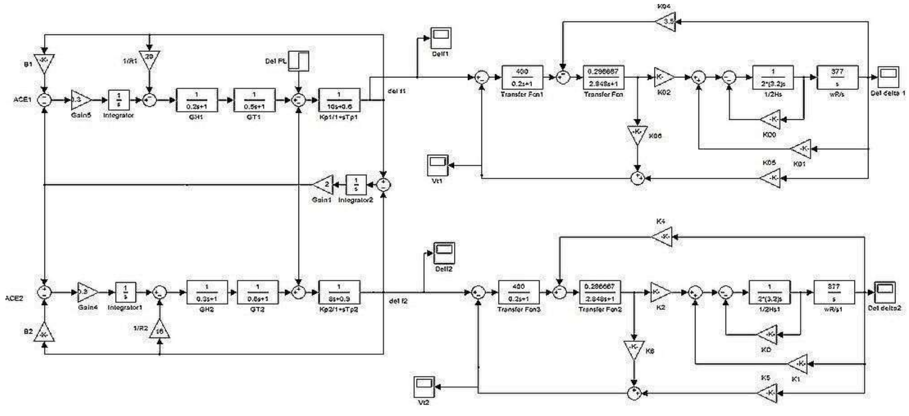

FIGURE 3. Simulink Block Diagram of Multi-machine System of Heffron-Philips Model [4]

3.2 Case-B:

In this case the same machines are considered as that of Case A. However, effort has been made to incorporate a fuzzy logic controller in plase of PID controller that has been used in the conventional model. The detail MATLAB simulink model is given in Fig. 4. The outputs of the two area ALFC serve as input to the exciters of the two identical AVR-PSS model multi-machine systems. The method of tuning has been simplified and set according to the specification of the machine considered herewith. The process of operation is much more simpler than that of the conventional methods.

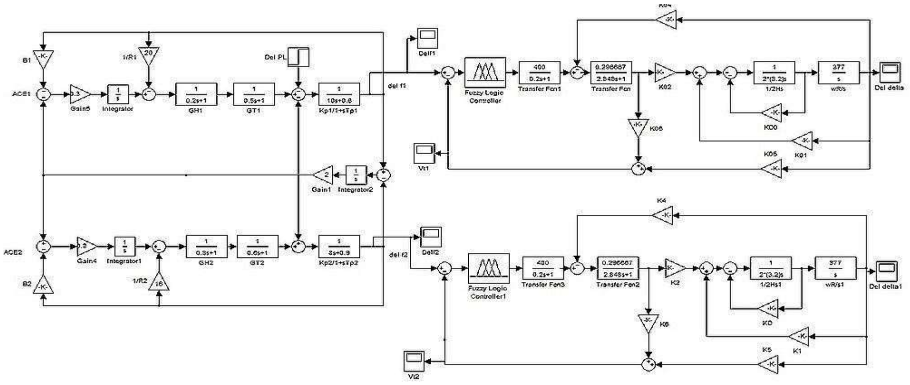

FIGURE 4. Simulink Block Diagram of Fuzzified Multimachine System of Heffron-Philips Model[4]

3.3 **Case C:** THE IDEAL AVR MODEL:

The ideal AVR model has been proposed by K. T. Law, D. J. Hill and N. R. Godfrey [3] in their paper. For the multimachine case, again the two identical models of the ideal AVR model have been considered in collaboration with the two area ALFC.

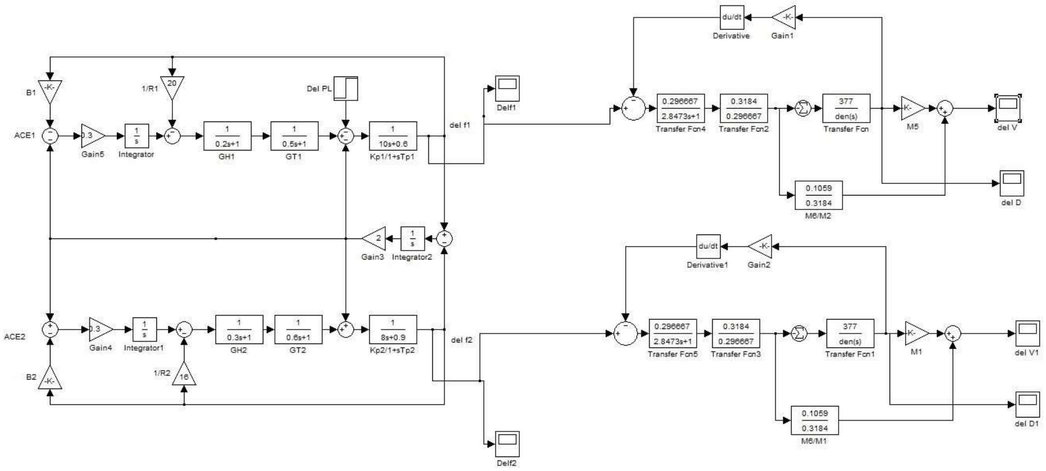

FIGURE 5: Simulink block diagram of multimachine ideal AVR model

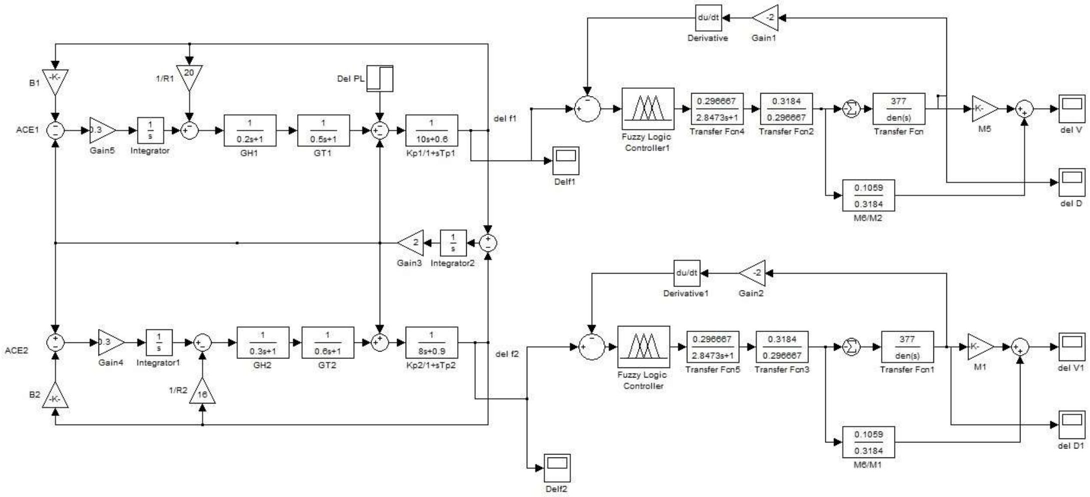

FIGURE 6: Simulink block diagram of fuzzified ideal AVR model

Case D: AVR-PSS MODEL:

This model represents the coordinated AVR-PSS model in the single machine system. The outputs of the two area ALFC serve as input to the exciters of the two identical AVR-PSS model multimachine systems.

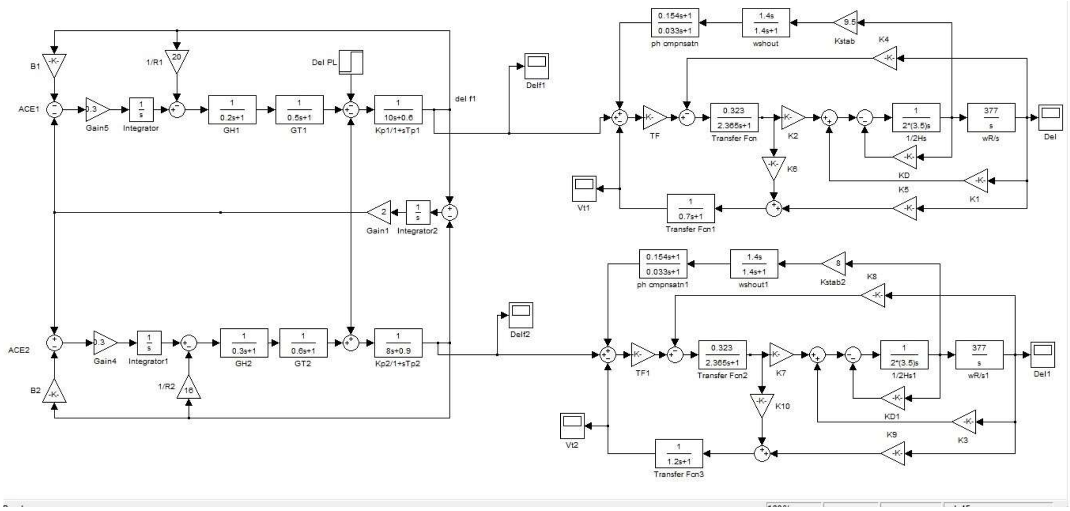

FIGURE 7: Simulink block diagram of multimachine AVR-PSS model

Case E:

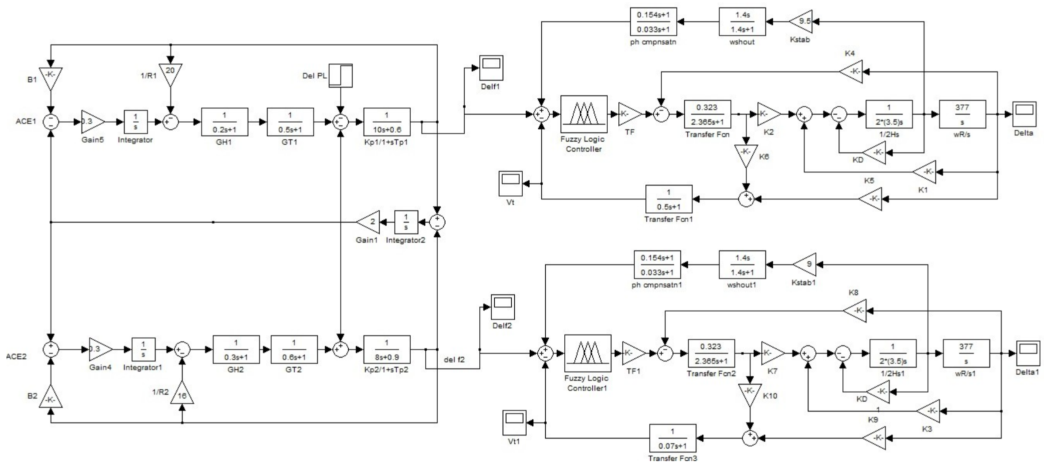

FIGURE 9: Simulink block diagram of fuzzified multimachine AVR-PSS model

4. Results and Discussion:

IEEE data on machine parameters[7]:

R_e= 0, X_e=0.5, V_t= 1, V_∞= 1.05, H = 3.2, T_{d0}= 9.6, K_A= 400, T_A= 0.2, X_q= 2.1, X_d= 2.5, X_d'= 0.39, D = 0.05, Ω = 377, Δ = 65.52, I_d= 0.4014, I_q= 0.3675, V_d= 0.7718, V_q= 0.6358

Simulations and Results:

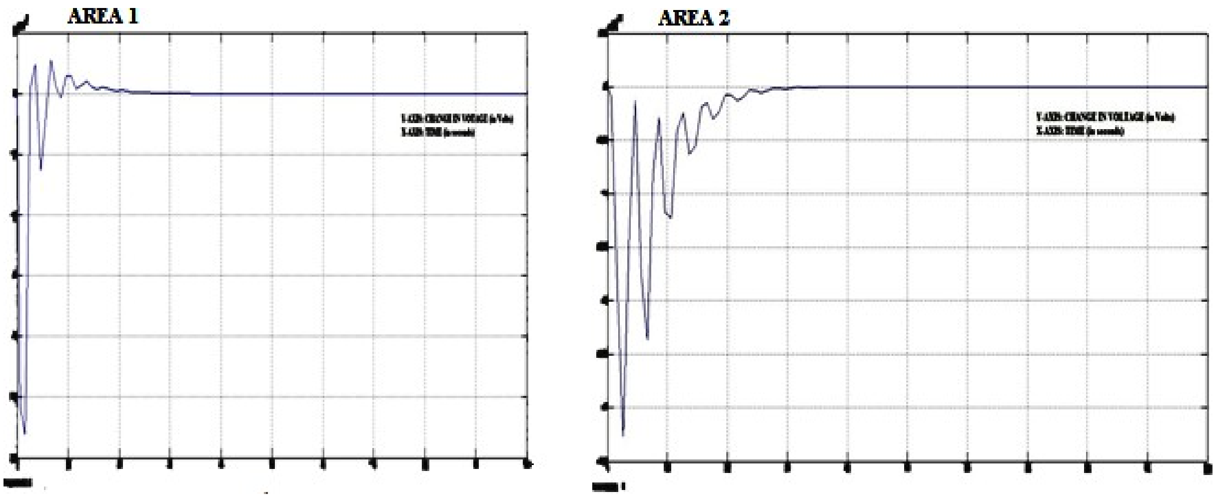

FIGURE 9.Change in Voltages (Volts) in area 1 & area 2 of Multimachine H-P Model

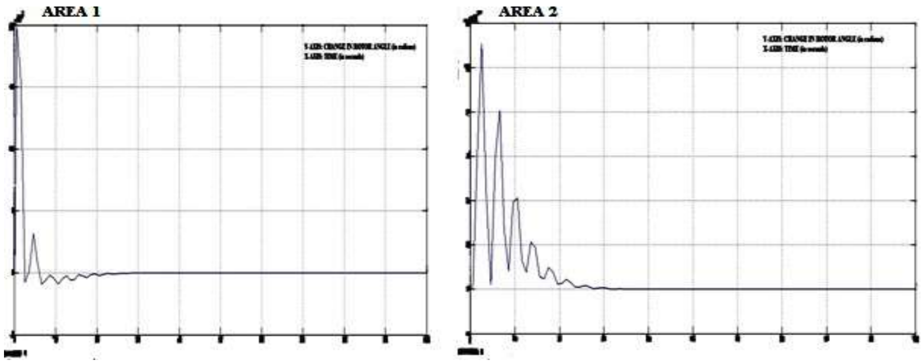

FIGURE 10. Change in Rotor Angles (Radians) in area 1 & area 2 of Multimachine H-P Model

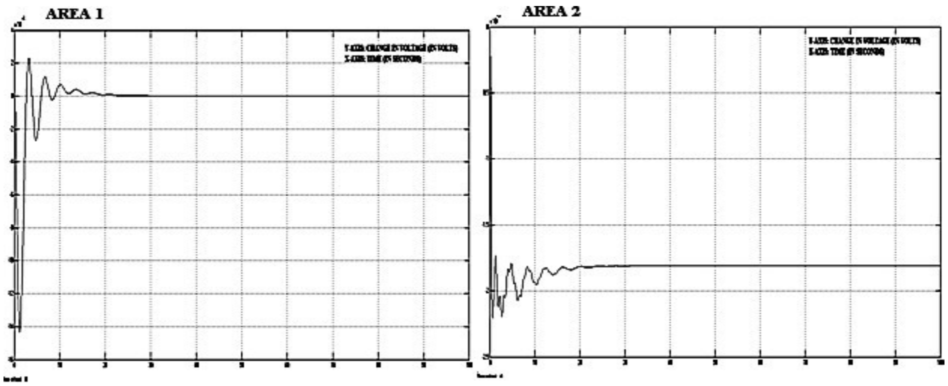

FIGURE 11.Change in Voltages (Volts) in area 1 & area 2 of Fuzzified Multimachine H-P Model

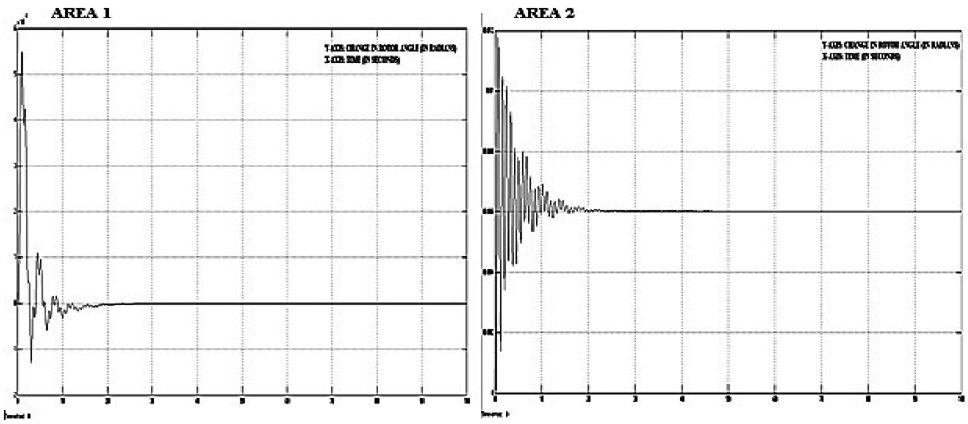

FIGURE 12. Change in Rotor Angles (Radians) in area 1 & area 2 of Fuzzified Multimachine H-P Model

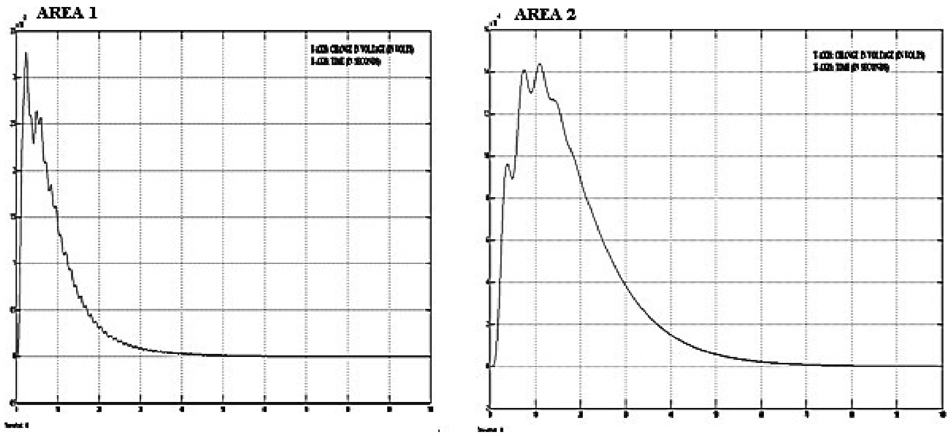

FIGURE 13. Change in Voltages (Volts) in area 1 & area 2 of Multimachine Ideal AVR Model

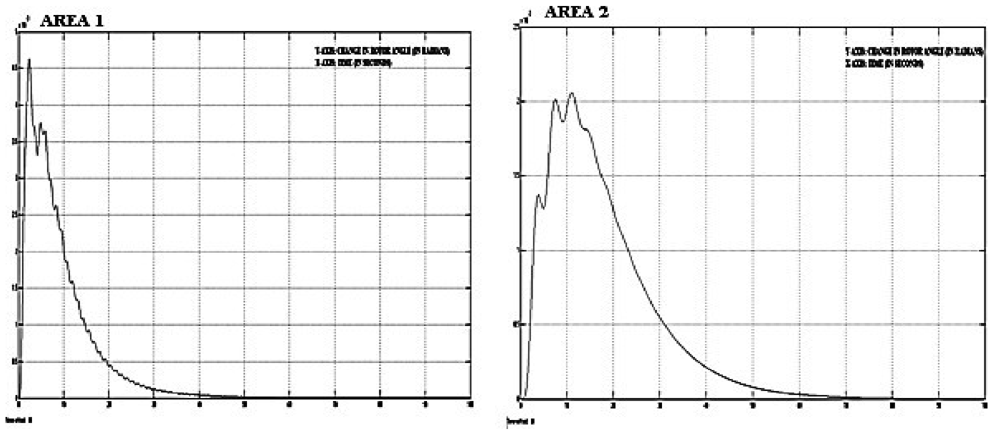

FIGURE 14. Change in Rotor Angles (Radians) in area 1 & area 2 of Multimachine Ideal AVR Model

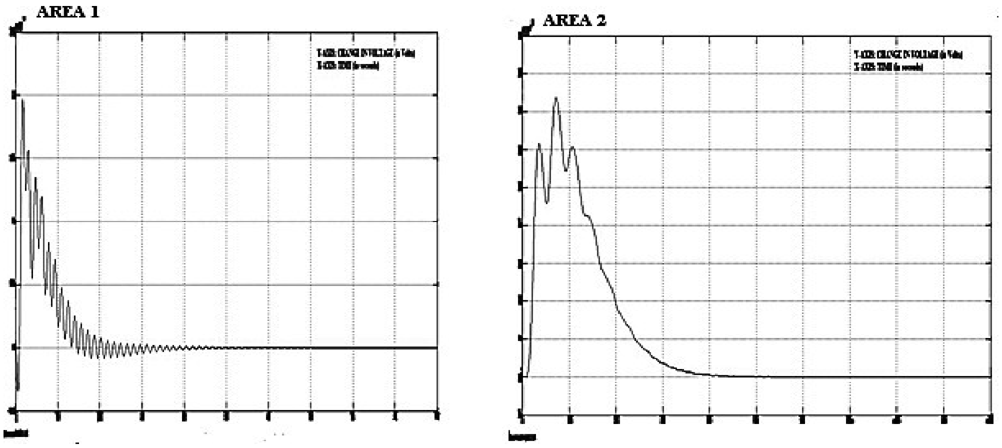

FIGURE 15. Change in Voltages (Volts) in area 1 & area 2 of Fuzzified Multimachine Ideal AVR Model

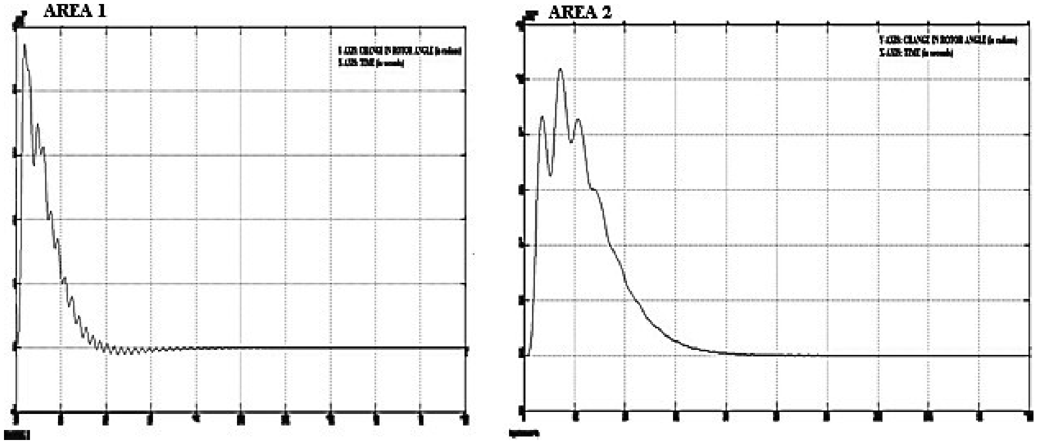

FIGURE 16. Change in Rotor Angles (Radians) in area 1 & area 2 of Fuzzified Multimachine Ideal AVR Model

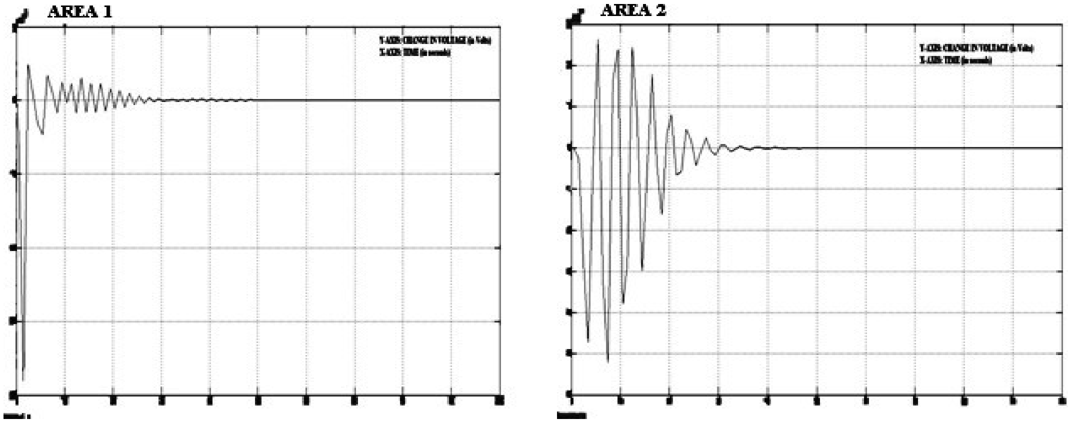

FIGURE 17. Change in Voltages (Volts) in area 1 & area 2 of Multimachine AVR-PSS Model

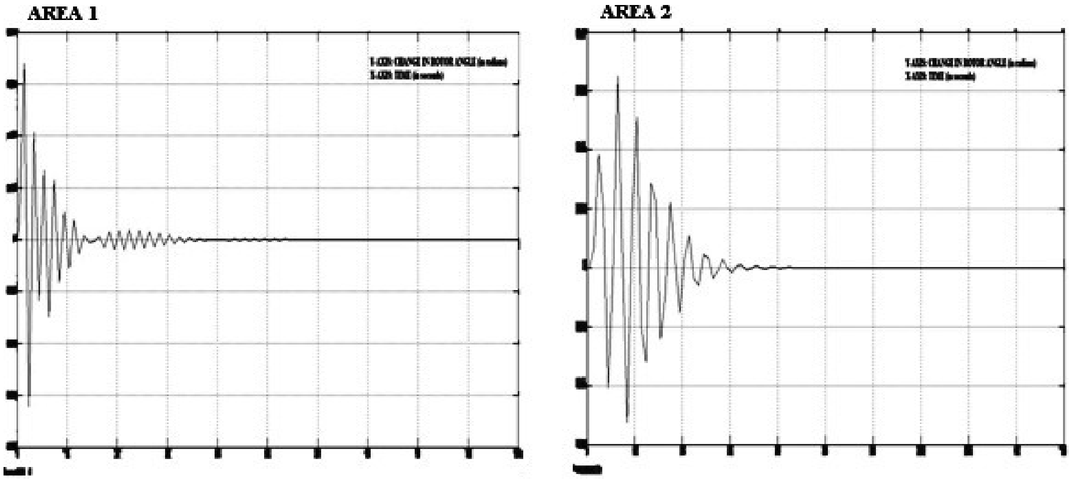

FIGURE 18. Change in Rotor Angles (Radians) in area 1 & area 2 of Multimachine AVR-PSS Model

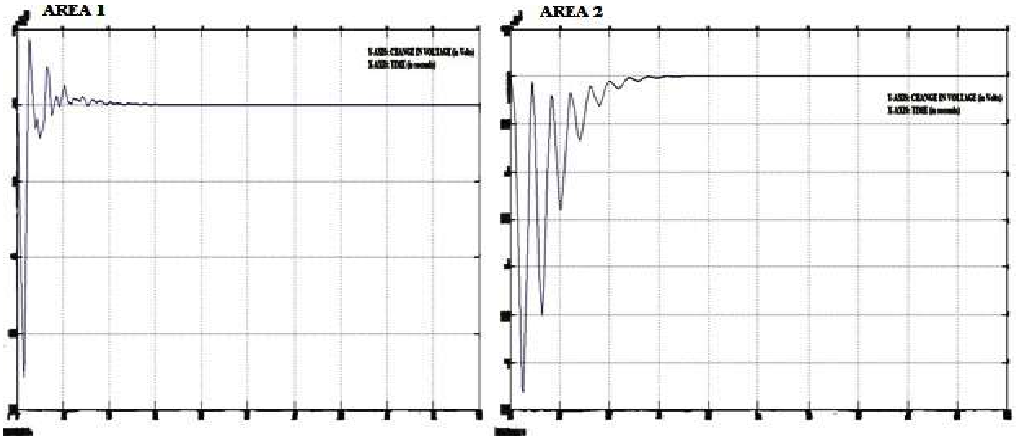

FIGURE 19. Change in Voltages (Volts) in area 1 & area 2 of Fuzzified Multimachine AVR-PSS Model

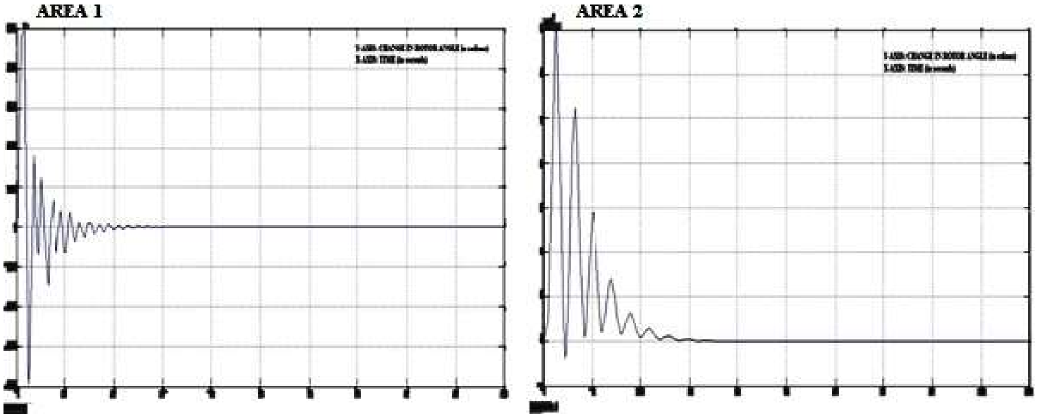

FIGURE 20. Change in Rotor Angles (Radians) in area 1 & area 2 of Fuzzified Multimachine AVR-PSS Model

TABLE 1: MULTIMACHINE SYSTEM: CHANGE IN VOLTAGE (ΔV_T)

SL. NO	TIME DOMAIN PARAMETERS	CHANGE IN VOLTAGE (ΔV_{T1})				CHANGE IN VOLTAGE (ΔV_{T2})			
		H-P	FUZZIFIED H-P	AVR -PSS	FUZZIFIED AVR-PSS	H-P	FUZZIFIED H-P	AVR -PSS	FUZZIFIED AVR-PSS
1.	MAXIMUM PEAK OVERSHOOT, M_p	-0.0115 V	-0.00143 V	-0.019 V	-0.0178 V	0.0032 V	-0.0021 V	-0.004719 V	-0.003173 V
2.	PEAK TIME, t_p	1.6 s	1.12 s	1.4 s	1.5 s	2.6 s	0.66 s	3.4 s	2.5793s
3.	SETTLING TIME (5% criterion), t_s	23.13 s	10.71 s	42.47 s	24.505 s	25.862 s	1.322 s	34.455 s	26.08 s
4.	SETTLING TIME (2% criterion), t_s	30.22 s	26.3 s	48.51 s	28.274 s	29.85 s	1.366 s	34.96 s	30.04 s
5.	STEADY STATE ERROR, e_{ss}	0.0000001	0.00000001	0.0001	0.00000001	0.0000001	0.000000001	0.00001	0.00000001

TABLE 2: MULTIMACHINE SYSTEM: CHANGE IN ROTOR ANGLE ($\Delta\delta_T$)

SL. NO	TIME DOMAIN PARAMETERS	CHANGE IN ROTOR ANGLE ($\Delta\ \delta_{T1}$)				CHANGE IN ROTOR ANGLE ($\Delta\ \delta_{T2}$)			
		H-P	FUZZIFIED H-P	AVR-PSS	FUZZIFIED AVR-PSS	H-P	FUZZIFIED H-P	AVR-PSS	FUZZIFIED AVR-PSS
1.	MAXIMUM PEAK OVERSHOOT, M_p	0.0506 rad	0.0055 rad	0.0678 rad	0.0496 rad	0.011 rad	0.0118 rad	0.0384 rad	0.00698 rad
2.	PEAK TIME, t_p	1.6 s	0.93 s	1.4 s	1.5 s	2.6 s	0.66 s	2.4 s	2.579 s
3.	SETTLING TIME (5% criterion), t_s	25.15 s	8.811 s	34.5935 s	25.824 s	34.25 s	8.98 s	35.595 s	26.92 s
4.	SETTLING TIME (2% criterion), t_s	28.485 s	8.8812 s	49.45 s	18.923 s	30.467 s	1.2418 s	39.48 s	30.84 s
5.	STEADY STATE ERROR, e_{ss}	0.000001	0.000000001	0.0001	0.0000001	0.00001	0.00001	0.00001	0.0000001

Observations:

A block diagram model is considered here for the stability analysis of rotor angle and voltage. The IEEE data for the same has been provided above under the case studies section. The study of the voltage and rotor angle response of the multimachine systems has been undertaken by simulating the Heffron-Phillips model and the AVR-PSS model and their respective fuzzified models. Fuzzified H-P model as shown in Fig. 5 and Fig. 6 exhibit the optimum results in case of multimachine systems considering all the time domain parameters like peak time, settling times (5% and 2% criteria) and steady state error in both the voltage and rotor angle response. Thus it can be proved that fuzzification of the existing models certainly improves machine parameters and hence their performance.

Conclusion:

From the above results, as shown in the tables 1 and 2, it can be observed that there is a considerable improvement in the values of the time domain parameters. Thus, it can been concluded that in multimachine systems, the proposed fuzzified models like Heffron-Philips, Ideal AVR and AVR-PSS have been successful in achieving commensurate and even better values of time domain parameters than the existing non fuzzified models, respectively.

Acknowledgement:

This work has been entirely possible by the help extended by I.G.I.T. Sarang for which we are extremely thankful.

References:

[1] W. G Heffron, R. A. Philips, AlEE Transactions, volume 71, 1952, pages 692-697.

[2] F. P. DeMello, C. Concordia IEEE Transactions on PAS, volume 88, 1969, pages 316-329.

[3] K.T. Law, N.R. Godfrey, D.J. Hill, IEEE Transactions on Power Systems, volume 9, 1994, pages 1218-1225.

[4] Anindita Mohanty, R. Behera, B. P. Panigrahi, IEEE Conference, 2016, pages 1932-1935.

[5] R. Behera, B. P. Panigrahi and B. B. Pati, IEEE Conference, 2010, pages 264-266.

[6] P. Kundur, Mc-Graw Hill-1994.

[7] Peter W. Sauer, M. A. Pai, Prentice Hall Publication, 1998.

[8] Anderson, P. M., Fouad, A. A., Iowa State University Press, Iowa, 1977.

[9] Olle I. Elgerd, Tata Mc-Graw Hill Publication, New-Delhi, 1983.