Probabilistic Feedforward Neural Network Based Power System Stabilizer for Excitation Control System of Synchronous Generator

Jamshed.A.Ansari, Aslam. P. Memon, Madad Ali Shah

Abstract - An economical and reliable power system is responsible to generate and deliver electric power in an efficient way by controlling terminal voltage and load frequency within permissible limits. An excitation system plays major role in the stability of power system. The high gain and fast action of an Automatic Voltage Regulator (AVR) produces negative damping oscillation in the power system. To reduce these oscillations, Power System Stabilizer (PSS) is connected in conjunction with excitation system. The PSS has been tuned to cope with the changing load conditions. For this purpose, Probabilistic Feedforward Neural Network (PFNN) based power system stabilizer is proposed. The conventional PSS is designed and simulated in Matlab and the frequency deviation and terminal voltage are stored in order to train the Pobabilistic Neural Network (PNN). The simulation results for terminal voltage and load frequency with conventional PSS and PNN based PSS have been compared. The simulation results of PNN based PSS shows that this type of PSS has great control on the oscillations that are produced by AVR. It has also been observed that this type of PSS can enhance dynamic and transient stability of power system with wide range of operating conditions.

Index Terms – Power System Stability, Artificial Neural network, Synchronous generator, Power system stabilizer, Probabilistic neural network

I. INTRODUCTION

The responsibility of a reliable and economic power system is to deliver electric power in a reliable and cost effective style, that needs to maintain the terminal voltage (Vt) and load frequency (f) in their limits. The function of load frequency controller (LFC) and automatic voltage regulator (AVR) is to maintain and control the active and reactive power [2].

In an interconnected power system, the automatic voltage regulator and load frequency controller (LFC) are connected with each generator separately. These controllers have their own set limits for particular operating conditions, they are supposed to maintain any deviation in terminal voltage and load frequency. [12].

The power system network is very complex, non-linear and is subjected to small perturbations due to changing load conditions. The modern AVR is fast acting and has high gain so they can cause negative damping on the rotor of synchronous generator. This behaviour of AVR can be compensated by producing extra stabilizing signals in the control loop. The stabilizing signals are always inserted at the summing system stabilizer (PSS) networks [1]. The PSS is responsible to detect any deviation and then generate a supplementary signal to provide positive damping to the generating unit. The input signals to PSS may be speed, frequency or electrical power [12].

II. LITERATURE REVIEW

In literature, a survey has been taken for power system stabilizer to improve the dynamic as well as transient stability of power system.

A. Conventional PSS

The stability of power system can be defined completely using its mathematical model [3]. The supervisory level power system stabilizer is capable of compensating the nonlinear dynamic operation of power system [4]. The Proportional Integral Derivative (PID) based PSS has minimum overshoot with a small settling time [5].

B. Artificial Neural Network Based PSS

The neural network based PSS is more suitable to tune the various parameters of power system such as terminal voltage and load frequency [6]. There exists a strong correlation between input and output space that enhances the learning capability of Artificial Neural Network (ANN) [5].The Multi-layer Perceptron Feedforward Neural Network (MLPFFNN) is a better controller to tune the various parameters of synchronous generator [11]. The overshoot value and settling time of a Radial Basis Function (RBF) based PSS is very small as compared to other conventional controllers [14].

C. Fuzzy Logic Based PSS

A PSS based on fuzzy controller contains the advantages of both ANN and fuzzy controller, such type of controller improves the stability of power system [12]. The fuzzy logic controllers produce positive damping during the transient behaviour of synchronous generator when it is connected with non-linear loads [10].

D. Optimization Based Power System Stabilizers

Various researchers have worked out to improve the stability of power system by designing optimization based power system stabilizers [14, 16].

The parameters of a Synchronous machine connected with infinite bus (SMIB) can also be tuned using genetic algorithm [14]. The particle swarm optimization (PSO)

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method can be used efficiently to calculate the optimal parameters of PID controller for an AVR system [16].

E. Hybrid Artificial Intelligent Techniques

The series on integration of two or more artificial intelligence techniques is called hybrid artificial intelligent technique.

The optimal parameters of a neuro-fuzzy based PSS can be tuned using genetic algorithm [8]. The neural controller has a robust response with very small oscillations in contrast to fuzzy based PSS and conventional PSS [5].

The power system stabilizers (PSS) which are discussed in literature review have fixed gain. Due to their fixed gain, these can give efficient results on required operating conditions. If their operating conditions are changed, their performance will not satisfactory. Hence their online tuning of parameters is very difficult so they are not suitable for the varying load on power system [9].

Above all, these devices were mostly used in excitation and speed governing systems. The problems encountered with these devices are tuning setting, on-line calibration, adjustments, control parameter drifts, lack of flexibility & adaptability and on-line modifications to cope with network topology variations. The sudden load changes require fast gain and time constant adaptation like in thermal power generation stations.

Due to increase in electrical products, the demand of power system stability is increasing. The synchronous generators have high gain and fast voltage regulators to maintain the synchronism of interconnected power system. In case of sudden disturbances, the stability of power system is increased. A power system stabilizer is connected with the synchronous generator to improve the negative damping torque produced by automatic voltage regulator loop and other sources [6].

III. RESEARCH MODEL & METHODOLOGY

The research is focused on simulation based design of power system stabilizer to control the terminal voltage (Vt) and load frequency (f) of synchronous generator .The research model has been developed in Matlab/Simulink with different controllers. The various models have been proposed in the literature but in this research PNN based controller is designed for excitation control of synchronous generator.

A. Linearized Mathematical Model

A simple linearized model has been developed for describing synchronous generator and excitation system. The linearized equations for the model are given as under [1]:

$$E'_{q\Delta} = \frac{K_{3}E_{FD\Delta}}{1 + K_{3}\tau'_{do}s} - \frac{K_{3}K_{4}\delta_{\Delta}}{1 + K_{3}\tau'_{d0}s}$$
(1)

$$\mathbf{T}_{\mathrm{e}\Delta} = \mathbf{K}_1 \boldsymbol{\delta}_{\Delta} + \mathbf{K}_2 \mathbf{E'}_{\mathrm{q}\Delta} \tag{2}$$

$$V_{t\Delta} = K_5 \delta_{\Delta} + K_6 E'_{q\Delta}$$
(3)
And

 $\dot{E}'_{q} = -\left(\frac{1}{K_{3}\tau'_{d0}}\right)E'_{q} - \left(\frac{K_{4}}{\tau'_{d0}}\right)\delta + \left(\frac{1}{\tau'_{d0}}\right)E_{FD}$ (4)

The equations (1), (2) & (3) represent a simple linearized model of synchronous generator and its excitation system. Here K_1 to K_6 are known as synchronous generator gains of the linearized model and E_{FD} is known as stator electromotive force (EMF).

Using torque equations [1]

$$\dot{\omega} = \frac{T_{m}}{\tau_{j}} - \left(\frac{K_{1}}{\tau_{j}}\right)\delta - \left(\frac{K_{2}}{\tau_{j}}\right)E'_{q} - \left(\frac{D}{\tau_{j}}\right)\omega$$
(5)

The complete model of synchronous generator and its excitation system complete model is shown as under [1].

$$\begin{split} & \overset{\dot{\mathbf{E}}'_{\mathbf{q}}}{\dot{\mathbf{b}}} \\ & \overset{\dot{\mathbf{b}}}{\dot{\mathbf{b}}} \\ & \overset{\dot{\mathbf{b}}}{\mathbf{b}}_{\mathbf{t}} \\ \\ & \overset{\dot{\mathbf{b}}}{\mathbf{b}}_{\mathbf{t}} \\ & \overset{\dot{\mathbf{b}}}{\mathbf{b}}_{\mathbf{t}} \\ \\ & \overset{\dot{\mathbf{b}}}{\mathbf{b}}_{\mathbf{t}} \\ & \overset{\dot{\mathbf{b}}}{\mathbf{b}}_{\mathbf{t}} \\ \\ & \overset$$

This model is called state space model for excitation system, having state variables as under [1].

$$\mathbf{x}^{t} = \begin{bmatrix} \mathbf{E}'_{q} & \boldsymbol{\omega} & \boldsymbol{\delta} & \mathbf{V}_{1} & \mathbf{V}_{3} & \mathbf{V}_{R} & \mathbf{E}_{FD} \end{bmatrix}$$
(6)

The above given expressions represent the complete mathematical model of synchronous generator with its excitation system.

B. Simulation Model

The synchronous generator & its excitation system play a vital role in a power system. An automatic voltage regulator and power system stabilizer are responsible for the stability factor [1]. The proposed simulation model with automatic voltage regulator and PNN based power system stabilizer is shown in Figure.1



Fig. 1: Proposed simulation model [1]

C. Operating Conditions

For the synchronous machine connected to an infinite bus (SMIB) with an external resistance of 0.02 per unit (p.u) and inductance of 0.4 p.u, the following operating conditions are used as depicted in Table.1 [2].

TABLE.1: OPERATING CONDITIONS OF SIMULATION MODEL

Quantity	Value			
Active power (P)	1.0 p.u			
Reactive power (Q)	0.62 p.u			
Load power factor (p.f)	0.85 p.u			
Terminal voltage (V _t)	1.0 p.u			
Bus voltage (V _b)	0.828 p.u			
Angular frequency (ω_R)	377 Rad/sec			
Damping constant (D)	0.8			
Inertia constant (H)	10			
Reference voltage(VRef)	1 p.u			
Change in load voltage (ΔV_L)	0.05			
Amplifier gain (K _A)	400			
Exciter gain (K _E)	200			
Sensor gain (K _R)	1			
Exciter time constant (τ_E)	0.05			
Sensor time constant (τ_R)	0.05			
Amplifier time constant (τ_A)	0.5			
Synchronous generator linear	· parameters			
K ₁	1.0755			
K_2	1.2578			
K ₃	0.3072			
K_4	1.7124			
K ₅	-0.0409			
K ₆	0.4971			
Power system stabilizer pa	rameters			
Washout network Ks	120			
Washout network τ_0	1			
Lead-lag network τ_1	0.024			
Lead-lag network τ_2	0.002			
Lag-lead network τ_3	0.024			
ag-lead network τ_4 0.24				
PID parameters				
Proportional gain (Kp)	1			
Integral gain (Ki)	2			
Derivative gain (Kd)	0.5			

In this research, the performance of SMIB has been thoroughly analyzed using probabilistic feedforward neural network, which is then applied to a conventional PSS.

D. Design of PNN for PSS

A probabilistic neural network has been trained with supervised training process of artificial neural networks. In this research PNN has been made as a special type of conventional controller through the training process. The input and target data to train the PNN are obtained from the input and output of conventional controller. The PNN model is simulated in Matlab in parallel with PID for simulation training. The trained PNN will work in same style as its trainer; it is expected to perform robustly in the most of working conditions. The arrangement of trained PNN will be constant after the training process. The PNN based controller will have better characteristics than other types of controllers. In this research the PNN gives reasonable results at various loading conditions. Since the PNN is based on supervised training so the data of trained network will be available. To achieve this three input signals are recorded at the input of PID and one output signal at the output of PID. The terminal voltage (Vt) and frequency deviation (f) are taken as two required outputs of the proposed system.

IV. RESULTS & DISCUSSIONS

The performance results for terminal voltage and frequency deviation of PNN based power system stabilizer with conventional PSS and PID based PSS are discussed in this section.

A. At Normal Operating Conditions

Responses of speed / frequency deviation. The responses for the frequency deviation with active power P = 1.0 per unit (p.u) and reactive power Q = 0.62 p.u are shown in Fig.2



Fig.2: Combined response of frequency deviation of CPSS, PID based PSS & PNN based PSS

At normal loading conditions, the simulation results for frequency deviation show that PNN based PSS is more suitable and applicable than PID-PSS and CPSS as it improves the efficiency of power system. A PNN based power system stabilizer has significant effect on the frequency deviation.

Responses of terminal voltage (V_t)

The simulation results of terminal voltage have been taken at an active power P = 1.0 p.u and reactive power Q = 0.62 p.u as shown in Fig.3



Fig.3: Combined response of terminal voltage of CPSS, PID based PSS & PNN based PSS

The response of terminal voltage for different power system stabilizers shows that a PNN based PSS is more simple, applicable and efficient than other power system stabilizers. Under normal loading conditions, the response of PNN is robust in settling and rise time characteristics.

B. Responses At 10% Increase In Load

Now the performance of PNN based PSS is evaluated at a 10% increased load on synchronous generator as shown in Fig.4 *Frequency deviation response at 10% increase in load*



Fig.4: Combined frequency deviation response of CPSS, PID based PSS & PNN based PSS at 10% increase in load

Terminal voltage response at 10% increase in load

The responses for terminal voltage are checked at 10% increase in load on synchronous generator as shown in Fig. 5. The simulation results show that the response of PNN based PSS is much better than other power system stabilizers.



Fig.5: Combined terminal voltage response of CPSS, PID based PSS & PNN based PSS at 10% increase in load

From the above detailed discussion, it is evident that PNN based power system stabilizer is more favourable than other types. A PNN based PSS is a suitable approximator. It has a compact network structure and its response is very fast. The comparison of results is shown in Table.2 and Table.3.

TABLE.2: COMPARISON OF FREQUENCY DEVIATION

PSS	Rise	Settling	Overshoot			
	Time	Time	(per unit)			
	(Sec)	(Sec)				
CPSS	2.1	15	0.03			
PID PSS	2.4	11	0.03			
PNN PSS	2.6	07	0.012			

TABLE.3:	COMPA	RISON (OF TERN	MINAL	VOLTAGE

PSS	Rise	Settling	Overshoot
	Time	Time	(per unit)
	(Sec)	(Sec)	
CPSS	0.001	0.4	4
PID PSS	0.001	0.2	3.25
PNN PSS	0.007	0.1	2.7

It is obvious from the results mentioned in Table.2 and Table.3 that settling time and over shoot per unit of PNN based PSS for frequency deviation and terminal voltage is less than CPSS and PID-PSS. These results confirm the applicability and suitability of PNN based power system stabilizer for excitation control system of synchronous generator.

V. CONCLUSIONS

A reliable and economic power system plays a major role in the economy of a country. To achieve the reliable performance of power system various research experiments have been carried out. This research is focused on the probabilistic neural network based power system stabilizer for excitation control of synchronous generator. The inputs to the power system stabilizer are terminal voltage and frequency deviation. A complete model of synchronous generator and its excitation system has been developed to determine the terminal voltage and frequency responses.

The work is focused on the PID based PSS in order to replace it with PNN based PSS. For this purpose, a PID based PSS is developed and is trained in parallel with PNN based PSS. The PNN based PSS results ensured that this type of PSS has superior response at normal load conditions as well as at different load conditions than other PSSs. A PNN- based PSS improves the dynamic as well as transient stability of power system. The comparison of results proves its applicability and suitability. Therefore it is concluded that a PNN based PSS is a robust controller than other types of controllers due to its vigorous performance in dynamic as well as transient stability of power system.

VI. FUTURE RECOMMENDATIONS

The simulation results of the research show the successful applicability and suitability of this type of

controller for excitation system of synchronous generators. Consequently there are many other areas in which research may be performed which are discussed as below:

- The PNN based PSS may be connected in a multi machine system which is connected to industries having non-linear loads.
- A non-linear modeling can be performed due to nonlinear behaviour of input and output signals of excitation control system.
- The output terminal of synchronous generator may directly be connected to load (such as end users, transmission lines, transformer etc), instead of connecting it to an SMIB.
- A higher order model may be required to achieve the better performance for the transient studies in milliseconds and micro seconds.

REFERENCES

- Anderson, P.M.; and Fouad, A. A., "Power System Control and Stability", 2nd Edition, Published by IEEE Press, 2003, pages 658, ISBN 0471238627, 9780471238621, 2007.
- [2] Saddat, H., "Power System Analysis", 3rd edition, McGraw-Hill Inc, 2007.
- [3] Memon Aslam. P., A.R. Shaikh and M. A. Unar, "A Simple Technique of PID Excitation Control of Synchronous Generator", Mehran University Research Journal of Engineering and Technology Vol. 21, No. 01,2002.
- [4] Jesus Fraile Ardanvy, P.J. Zufiria, "Design and Comparison of Adaptive Power System Stabilizers Based on Neural Fuzzy Networks and Genetic Algorithms." Neurocomputing, Vol.70, pp. 2902- 2912, 2007.
- [5] Lachman T. S., Aslam. P. Memon, Zubair A. Memon, "Neural Network Excitation Control System for Transient Stability Analysis of Power System" published in TENCON 2009 -2009 IEEE Region 10 Conference, 23-26 Jan. 2009.
- [6] Malik O.P., M.M.Salem, A.M. Zaki, O.A. Mahgoub and E. Abu El-Zahab, "Experimental Studies with Simple Neurocontroller Based Excitation Controller", IEEE Proc.-Gener. Transm. Distrib. Vol. 149.No I. 2002.
- [7] Yao-nan Yu, "Electric Power System Dynamics", 1st edition, published by Academic Press, 1983, original from the University of Michigan, ISBN 0127748202, 9780127748207, 255 pages, 2006.
- [8] Jesus Fraile Ardanvy, P.J. Zufiria, "Design and Comparison of Adaptive Power System Stabilizers Based on Neural Fuzzy Networks and Genetic Algorithms." Neurocomputing, Vol.70, pp. 2902- 2912, 2007
- [9] Singh Bhim and Gaurav Kumar Kasal, "Neural Network-based Voltage Regulator for an Isolated Asynchronous Generator Supplying Three-phase Four-wire Loads" Science direct Elsevier, Electric Power Systems Research, Volume 78, Issue 6, pp. 985-994, 2008
- [10] Dubey. M, "Design Of Genetic Algorithm Based Fuzzy Logic Power System Stabilizer In Multi Machine Power System " Power System Technology And IEEE Power India Conference, 2008.
- [11] Memon Aslam P, M. Aslam Uqaili, and Zubair Memon, "Design of FFNN AVR for Enhancement of Power System Stability Using Matlab/Simulink", Mehran University Research Journal of Engineering and Technology, ISSN 0254-7821, Vol. 31, No. 03, pp. 529-536, 2012.

- [12] Linda M.M, Nair N.K, "Dynamic Stability Enhancement With Fuzzy Based Power System Stabilizer Tuned By Hottest Nontraditional Optimization Technique "Computing Communication And Networking Technologies (ICCCNT) 2010.
- [13] Wenxin Liu, Venayagamoorthy G.K, Wunsh D.C, "Adaptive Neural Network Based Power System Stabilizer Desin" Neural Networks, 2003 Proceedings Of The International Joint Conference On Volume :4 2003
- [14] Memon Aslam P., M. Aslam Uqaili, and Zubair Memon, "Suitable Feed forward Neural Network Automatic Voltage Regulator for Excitation Control System", Universal Journal Electrical Electronic Engineering (UJEEE), Horizon Research Publications, U.S.A, (ISSN: 2332-3280 Print, ISSN: 2332-3299 Online), Vol. 2. No. 2, pp. 45-51, (2014).
- [15] Chaturvedi D.K., O.P.Malik, "Experimental Studies With a Generalized Neuron-Based Power System Stabilizer", IEEE Trans. On Power Systems. Vol.19, N0.3, 2004.
- [16] Wenxin Liu, Vengamoorthy, G.K Sarangapani, wunsch D.C, Crow M.L, Li Liu, Cartes D.A, "Comparisons Of An Daptive Neural Network Based Controller And An Optimized Conventional Power System Stabilizer" Control Applications,2007 CCA 2007 IEEE International Conference.
- [17] Kumar J, Kumar PP, Mahesh A, Shrivastava A, (2011) "Power System Stabilizer Based On Artificial Neural Network" Power And Energy Systems (ICPS), 2011 International Conference.