Stability Improvement During Damping of Low Frequency Oscillations with Fuzzy Logic Controller

A.V.Sudhakara Reddy[1], M. Ramasekhara Reddy [2], Dr. M. Vijaya Kumar[3]
[1](M. Tech, Department of Electrical & Electronics Engg, JNTUACE, Pulivendula, A.P, India.)
[2](Assistant Professor, Department of Electrical & Electronics Engg, JNTUACE, Pulivendula, A.P, India.)
[3](Professor, Department of Electrical & Electronics Engg, JNTUACE, Anantapur, A.P, India.)

Abstract

Low Frequency Oscillations (LFO) occur in power systems because of lack of the damping torque in order to dominance to power system disturbances as an example of change in mechanical input power. In the recent past Power System Stabilizer (PSS) was used to damp LFO. FACTs devices, such as Unified Power Flow Controller (UPFC), can control power flow, reduce sub-synchronous resonance and increase transient stability. So UPFC may be used to damp LFO instead of PSS. UPFC damps LFO through direct control of voltage and power. A comprehensive and systematic approach for mathematical modelling of UPFC for steady-state and small signal (linearize) dynamic studies has been proposed. The other modified linearize Heffron-Philips model of a power system installed with UPFC is presented. For systems which are without power system stabilizer (PSS), excellent damping can be achieved via proper controller design for UPFC parameters. By designing a suitable UPFC controller, an effective damping can be achieved. In this research the linearize model of synchronous machine (Heffron-Philips) connected to infinite bus (Single Machine-Infinite Bus: SMIB) with UPFC is used and also in order to damp LFO, adaptive neuro-fuzzy controller for UPFC is designed and simulated. Simulation is performed for various types of loads and for different disturbances. Simulation results show good performance of neuro-fuzzy controller in damping LFO.

Keywords – Neuro-Fuzzy Controller, Low Frequency Oscillations (LFO), Unified Power Flow Controller (UPFC), Single Machine-Infinite Bus (SMIB).

I. INTRODUCTION

Flexible AC Transmission Systems, called FACTS, got in the recent years a well known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. The growth of the demand for electrical energy leads to loading the transmission system near their limits. Thus, the occurrence of the LFO has increased. FACTs Controllers has capability to control network conditions quickly and this feature of FACTs can be used to improve power system stability. The UPFC is a FACTS device that can be used to the LFO. The primarily use of UPFC is to control the power flow in power systems. The UPFC consists of two voltage source converters (VSC) each of them has two control parameters namely me, δe ,mb and δb [3]. The UPFC used for power flow control, enhancement of transient stability, mitigation of system oscillations and voltage regulation [3]. A comprehensive and systematic approach for mathematical modelling of UPFC for steady-state and small signal (linearized) dynamic studies has been proposed in [4-7]. The other modified linearized Heffron-Philips model of a power system installed with UPFC is presented in [8] and [9]. For systems which are without power system stabilizer (PSS), excellent damping can be achieved via proper controller design for UPFC parameters. By designing a suitable UPFC controller, an effective damping can be achieved. It is usual that Heffron-Philips model is used in power system to study small signal stability. This model has been used for many years providing reliable results [10]. In recent years, the study of UPFC control methods has attracted attentions so that different control approaches are presented for UPFC control such as Fuzzy control [11-14], conventional lead-lag control, Genetic algorithm approach, and Robust control methods .

In this case study, the class of adaptive networks that of the same as fuzzy inference system in terms of performance is used. The controller utilized with the above structure is called Adaptive Neuro Fuzzy Inference System or briefly ANFIS. Applying neural networks has many advantages such as the ability of adapting to changes, fault tolerance capability, recovery capability, High-speed processing because of parallel processing and ability to build a DSP chip with VLSI Technology. To show performance of the designed adaptive neuro-fuzzy controller, a conventional lead-lag controller that is designed in is used and the simulation results for the power system including these two controllers are compared with each other. The following Section, the model of the power system including UPFC is presented. The proposed Adaptive Neuro-Fuzzy controller and lead-lag compensator are explained in Section III. The results of the simulation are finally given in Section IV. Finally conclusions are presented in section V.

II. MODEL OF THE POWER SYSTEM INCLUDING UPFC

UPFC is one of the famous FACTs devices that is used to improve power system stability. Fig.1 shows a single machine- infinite-bus (SMIB) system with UPFC. It is assumed that the UPFC performance is based on pulse width modulation (PWM) converters. In figure 1 m_e, m_b and δ_e, δ_b are the amplitude modulation ratio and phase angle of the reference voltage of each voltage source converter respectively. These values are the input control signals of the UPFC.

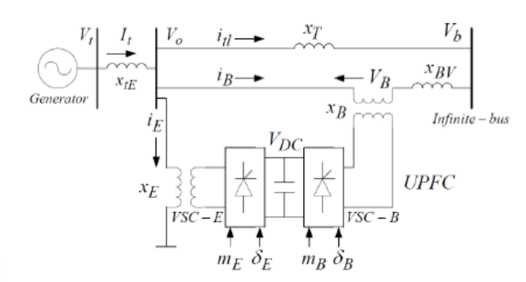

Fig.1 A single machine connected to infinite bus with UPFC

As it mentioned previously, a linearized model of the power system is used in dynamic studies of power system. In order to consider the effect of UPFC in damping of LFO, the dynamic model of the UPFC is employed; In this model the resistance and transient of the transformers of the UPFC can be ignored. The Linearized state variable equations of the power system equipped with the UPFC can be represented as [8].

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \\ \Delta\dot{v}_{dc} \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0 \\ -\frac{k_1}{M} & -\frac{D}{M} & -\frac{k_2}{M} & 0 & -\frac{k_{pd}}{M} \\ -\frac{k_4}{T'_{do}} & 0 & -\frac{k_3}{T'_{do}} & \frac{1}{T'_{do}} & -\frac{k_{qd}}{T'_{do}} \\ -\frac{k_A k_5}{T_A} & 0 & -\frac{k_A k_6}{T_A} & -\frac{1}{T_A} & -\frac{k_A k_{vd}}{T_A} \\ k_7 & 0 & k_8 & 0 & -k_9 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \\ \Delta v_{dc} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ -\frac{k_{pe}}{M} & -\frac{k_{p\delta e}}{M} & -\frac{k_{pb}}{M} & -\frac{k_{p\delta b}}{M} \\ -\frac{k_{qe}}{T'_{do}} & -\frac{k_{q\delta e}}{T'_{do}} & -\frac{k_{qb}}{T'_{do}} & -\frac{k_{q\delta b}}{T'_{do}} \\ -\frac{k_A k_{ve}}{T_A} & -\frac{k_A k_{v\delta e}}{T_A} & -\frac{k_A k_{vb}}{T_A} & -\frac{k_A k_{v\delta b}}{T_A} \\ k_{ce} & k_{c\delta e} & k_{cb} & k_{c\delta b} \end{bmatrix} \begin{bmatrix} \Delta m_E \\ \Delta\delta_E \\ \Delta m_B \\ \Delta\delta_B \end{bmatrix} \qquad (1)$$

Where ΔmE, ΔmB , $\Delta\delta E$ and $\Delta\delta B$ are the deviation of input control signals of the UPFC. Also in this study IEEE Type- ST1A excitation system was used.

III.OPERATING PRINCIPLE OF UPFC

In the presently used practical implementation, The UPFC consists of two switching converters, which in the implementations considered are voltage source inverters using gate turn-off (GTO) thyristor valves, as illustrated in the Fig 2.1. These back to back converters labeled "Inverter 1 and "Inverter 2" in the figure are operated from a common dc link provided by a dc storage capacitor.

This arrangement functions as an ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminal.

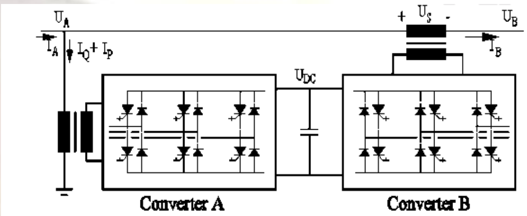

Fig. Basic circuit arrangement of unified power flow controller

The basic function of inverter 1 is to supply or absorb the real power demanded by Inverter 2 at the common dc link. This dc link power is converted back to ac and coupled to the transmission line via a shunt-connected transformer. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and there by it can provide independent shunt reactive compensation for the line.

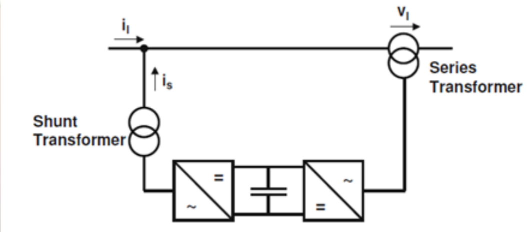

Fig2.Principle configuration of an UPFC

The UPFC consists of a shunt and a series transformer, which are connected via two voltage source converters with a common DC-capacitor. The DC-circuit allows the active power exchange between shunt and series transformer to control the phase shift of the series voltage. This setup, as shown in Figure 1.21, provides the full controllability for voltage and power flow. The series converter needs to be protected with a Thyristor bridge. Due to the high efforts for the Voltage Source Converters and the protection, an UPFC is getting quite expensive, which limits the practical applications where the voltage and power flow control is required simultaneously.

IV. CONTROLLER DESIGN

I. Lead-Lag Controller Design

As mentioned before, in this study two different controllers have been used to damp LFO. The first one is conventional lead-lag controller. It consists of gain block, washout block, lead-lag compensator block. The washout block is considered as a high-pass filter, with the time constant T_W. Without this block steady changes in input would modify the output. The value of TW is not critical and may be in the range of 1 to 20 seconds. In this study, the parameters obtained from lead-lag controller design that is presented in, were used.

II. Adaptive Neuro-Fuzzy Controller Design

Another controller is adaptive neuro-fuzzy controller. In this section, we will present the procedure of designing of the adaptive neuro-fuzzy controller. In this research, the neuro fuzzy controller has 2 inputs that are Δδ and Δω and it has 1 output that is $f \in \{\Delta m_E, \Delta\delta_E, \Delta m_B, \Delta\delta_B\}$□ . For each input 20 membership functions and also 20 rules in the rules base is considered. Figure 5 demonstrates the structure of adaptive neuro-fuzzy controller for a sugeno fuzzy model with 2 inputs and 20 rules.

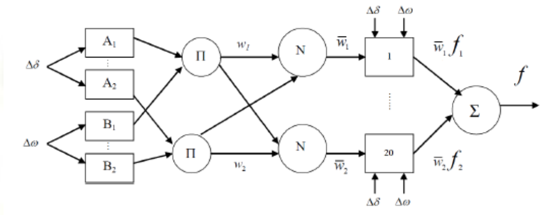

Fig.3 ANFIS architecture for a two-input Sugeno fuzzy model with 20 rules

In Figure 3, a Sugeno type of fuzzy system has the rule base with rules such as follows:

1. If $\Delta\delta$ is A1 and $\Delta\omega$ is B1 then $f1=p1\ \Delta\delta+q1\ \Delta\omega+r1$.
2. If $\Delta\delta$ is A2 and $\Delta\omega$ is B2 then $f2=p2\ \Delta\delta+q2\ \Delta\omega+r2$. μ_{A_i} □and μ_{B_i} are the membership functions of fuzzy sets Ai and Bi for i=1,…,20. In evaluating the rules, we choose product for T-norm (logical *and*). Then controller could be designed in following steps:

1. Evaluating the rule premises:

$$w_i = \mu_{A_i}(\Delta\delta)\ \ \mu_{B_i}(\Delta\omega), \qquad i= 1.....20 \qquad (2)$$

2.Evaluating the implication and the rule consequences:

$$f(\Delta\delta, \Delta\omega) = \frac{w_1(\Delta\delta,\Delta\omega) f_1(\Delta\delta,\Delta\omega)+\cdots+w_{20}(\Delta\delta,\Delta\omega) f_{20\ (\Delta\delta,\Delta\omega)}}{w_{1(\Delta\delta,\Delta\omega)}+\cdots+w_{20(\Delta\delta,\Delta\omega)}}$$

Or leaving the arguments out

$$f = \frac{w_1 f_1+\cdots+w_{20} f_{20}}{w_1+\cdots+w_{20}} \qquad (3)$$

This can be separated to phases by first defining

$$\bar{w}_i = \frac{w_i}{w_1+\cdots+w_{20}} \qquad (4)$$

These are called normalized firing strengths. Then *f* can be written as

$$f = \bar{w}_1 f_1 + ... + w_{20} f_{20} \qquad (5)$$

The above relation is linear with respect to p_i, q_i, r_i and i=1,…,20. So parameters can be categorized into 2 sets: set of linear parameters and set of nonlinear parameters. Now Hybrid learning algorithm can be applied to obtain values of parameters. Hybrid learning algorithm is combination of linear and nonlinear parameters learning algorithm. Description for learning procedure can be found in . This network is called adaptive by Jang and it is functionally equivalent to Sugeno type of a fuzzy system. It is not a unique presentation. With regard to the explanations presented and with the help of MATLAB software, adaptive neuro-fuzzy controller can be designed.

The rules surface for designed controller is shown in figure 3.The membership functions for input variable $\Delta\omega$ □ are presented in figure 4.

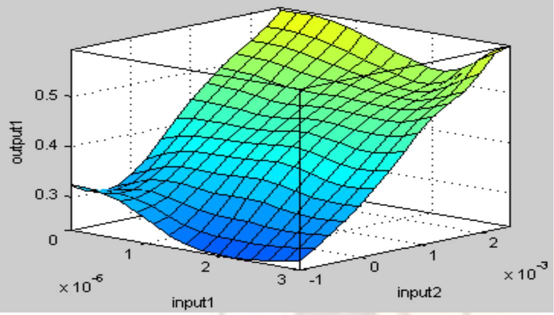

Fig.3 The rules surface

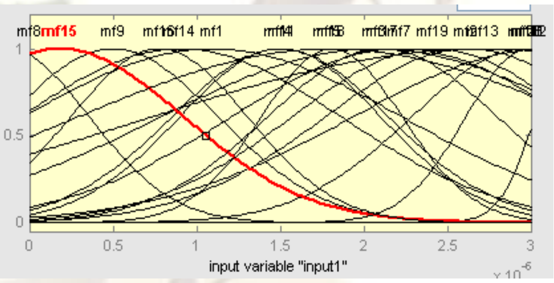

Fig.4 The membership functions for input variable $\Delta\omega$

One of the advantages of using neuro-fuzzy controller is that we can utilize one of the designed controllers for instance Δme controller in place of the other controllers. While if we use conventional lead-lag controllers, for each control parameters, a controller must be designed.

V. SIMULATION RESULTS

In this research, two different cases are studied. In the first case mechanical power and in the second case reference voltage has step change and deviation in ω (Δω) and deviation in rotor angle δ (Δδ) is observed. The parameter values of system are gathered in Appendix. In first case, step change in mechanical input power is studied. Simulations are performed when mechanical input power has 10% increase (ΔP_m=0.1 pu) at t=1 s. Simulation results for different types of loads and controllers (Δm_E, $\Delta\delta_E$, Δm_B, $\Delta\delta_B$) and step change in mechanical input power are shown in figures 5 to 9.

Generator Parameters :

$M = 2H = 8.0 MJ/MVA$, $D = 0.0$, $T_{d0}' = 5.044_S$
$X_d = 1.0 pu$, $X_q = 0.6$, $X_d' = 0.3$
Exciter (IEEE Type ST1): $k_A = 100$, $T_A = 0.01_S$
Reactances: $X_{IE} = 0.1\ pu$, $X_E = X_B = 0.1\ pu$,
$X_{Bv} = 0.3\ pu$, $X_E = 0.5\ pu$
Operation Condition: $P_e = 0.8\ pu$, $V_t = V_b = 1.0\ pu$
UPFC parameters: $m_E = 0.4013$, $m_B = 0.0789$, $\delta_E = -85.3478°$, $\delta_B = -78.2174°$
DC link: $V_{dc} = 2\ pu$, $C_{dc} = 1\ pu$

Results with Lead-Lag controller :

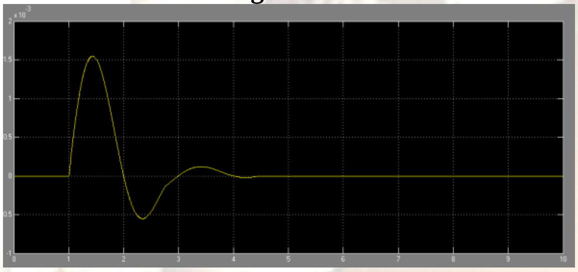
Figure 5.1

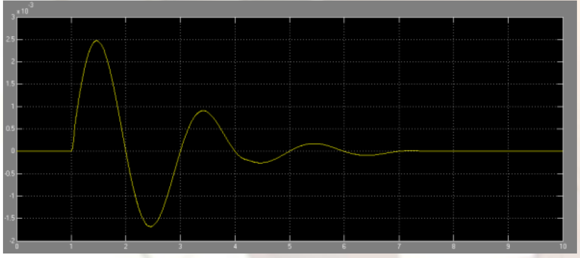
Figure 5.2

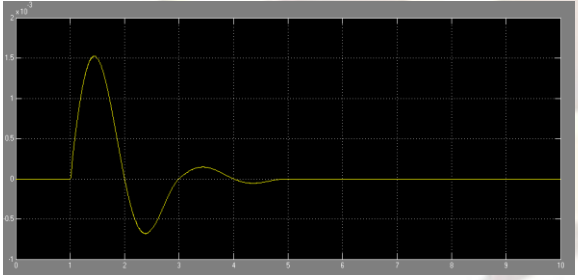
Figure 5.3

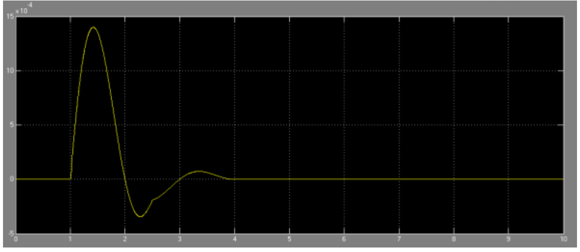
Figure 5.4

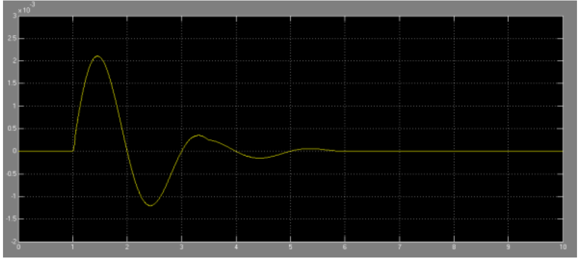
Figure 5.5

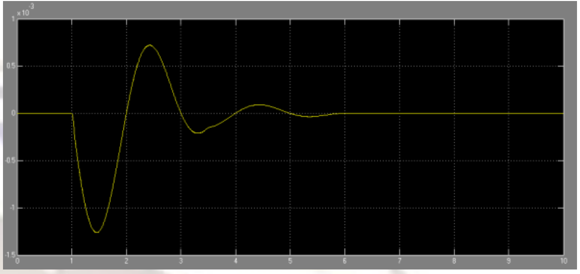
Figure 5.6

Results with Fuzzy controller :

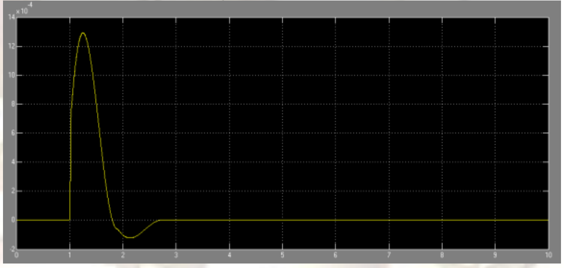
Figure 6.1

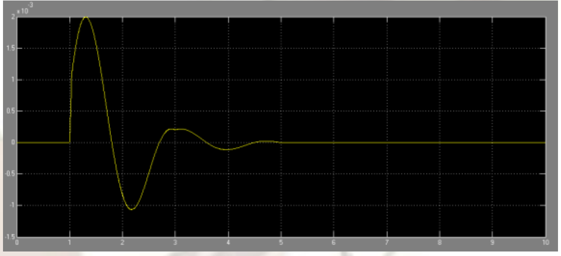
Figure 6.2

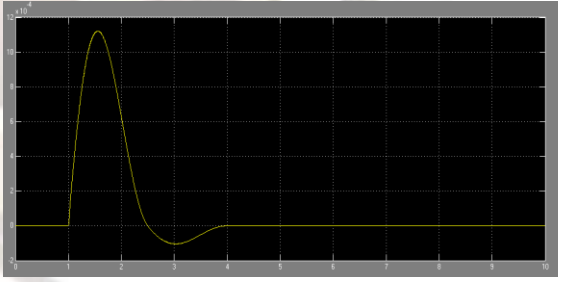
Figure 6.3

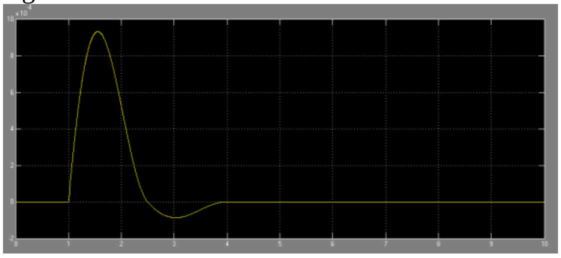
Figure 6.4

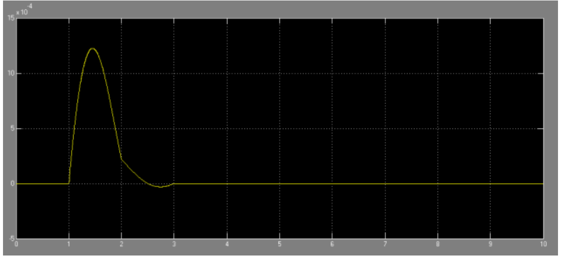

Figure 6.5

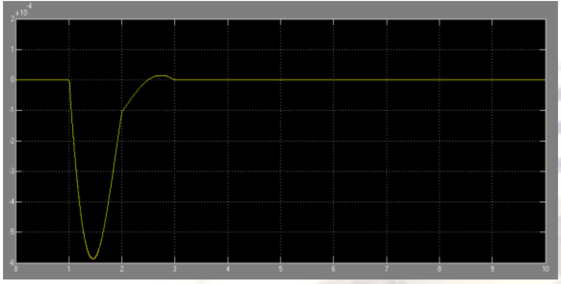

Figure 6.6

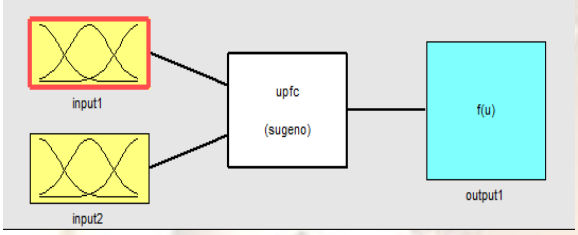

Figure 7. FIS Editor

Fig 5.1 & 6.1 shows angular velocity deviation during step change in mechanical input power for nominal load (me Controller). Fig 5.2 & 6.2 shows angular velocity deviation during step change in mechanical input power for light load (me Controller). Fig 5.3 & 6.3 shows angular velocity deviation during step change in mechanical input power for nominal load (δe Controller). Fig 5.4 & 6.4 shows angular velocity deviation during step change in mechanical input power for nominal load (mb Controller). Fig 5.5 & 6.5 shows angular velocity deviation during step change in mechanical input power for nominal load (δb Controller). Fig 5.6 & 6.6 shows Response of angular velocity for 5% step change in reference voltage in the case of nominal load (δb Controller).

As it can be seen from figures 5.1 to 5.6, lead-lag controller response is not as good as neuro-fuzzy controller response which shown from figures 6.1 to 6.6 and also neuro-fuzzy controller decreases settling time. In addition maximum overshoot has decreased in comparison with lead-lag controller response. In second case, simulations were performed when reference voltage has 5% increase (ΔVref = 0.05 pu) at t=1 s. Figure 10 demonstrates simulation result for step change in reference voltage, under nominal load and for δ_b Controller.

Consequently simulation results show that neuro- fuzzy controller successfully increases damping rate and decreases the amplitude of low frequency oscillations. Results comparison between conventional lead-lag compensator and the proposed neuro-fuzzy controller for the UPFC indicates that the proposed neuro-fuzzy controller has less settling time and less overshoot in comparison with the conventional lead-lag compensator. Hence the performance of system can be improved i.e., another way stability of power system can be improved with fuzzy controller.

V. CONCLUSIONS

With regard to UPFC capability in transient stability improvement and damping LFO of power systems, an adaptive neuro-fuzzy controller for UPFC was presented in this paper. The controller was designed for a single machine infinite bus system. Then simulation results for the system including neuro-fuzzy controller were compared with simulation results for the system including conventional lead-lag controller. Simulations were performed for different kinds of loads. Comparison. showed that the proposed adaptive neuro-fuzzy controller has good ability to reduce settling time and reduce amplitude of LFO. Also we can utilize advantages of neural networks such as the ability of adapting to changes, fault tolerance capability, recovery capability, High-speed processing because of parallel processing and ability to build a DSP chip with VLSI Technology. Fuzzy logic is a convenient way to map an input space to an output space. Mapping input to output is the starting point for everything. Hence stability of the system can be improved.

REFERENCES

[1] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission System, IEEE Press, 2000.

[2] H.F.Wang, F.J.Swift," A Unified Model for the Analysis of FACTS Devices in Damping Power System Oscillations Part I: Single-machine Infinite-bus Power Systems**"**, IEEE Transactions on Power Delivery, Vol. 12, No. 2, April 1997, pp.941-946**.**

[3] L. Gyugyi, C.D. Schauder, S.L. Williams, T.R.Rietman, D.R. Torgerson, A. Edris, "The UnifiedPower Flow Controller: **A** New Approach to PowerTransmission Control", IEEE Trans., 1995, pp. 1085-1097.

[4] Wolanki, F. D. Galiana, D. McGillis and G. Joos, “Mid-Point Sitting of FACTS Devices in Transmission Lines,” IEEE Transactions on Power Delivery, vol. 12, No. 4, 1997, pp. 1717-1722.

[5] M. Noroozian, L. Angquist, M. Ghandari, and G. Anderson, “Use of UPFC for optimal power flow control”, IEEE Trans.

on Power Systems, vol. 12, no. 4, 1997, pp. 1629–1634.

[6] A Nabavi-Niaki and M R Iravani. ‘Steady-state and Dynamic Models of Unified Power Flow Controller (UPFC) for Power System Studies.’ IEEE Transactions on Power Systems, vol 11, 1996, p 1937.

[7] K S Smith, L Ran, J Penman. ‘Dynamic Modelling of a Unified Power Flow Controller.’ IEE Proceedings-C, vol 144, 1997, pp.7.

[8] H F Wang. ‘Damping Function of Unified Power Flow Controller.’ IEE Proceedings-C, vol 146, no 1, January 1999, p 81.

[9] H. F. Wang, F. J. Swift, “A Unified Model for the Analysis of FACTS Devices in Damping Power System Oscillations Part I: Single-machine Infinite-bus Power Systems,” IEEE Transactions on Power Delivery, Vol. 12, No. 2, April, 1997, pp. 941-946.

[10] P. Kundur,"Power System Stability and Control",McGraw-Hill.

[11] M. Banejad, A. M. Dejamkhooy , N. Talebi, " Fuzzy Logic Based UPFC Controller for Damping Low Frequency Oscillations of Power Systems", 2nd IEEE International Conference on Power and Energy, 2008, pp. 85-88.

[12]

P.K., Dash, S. Mishra, G. Panda, , "Damping multimodal power system oscillation using a hybrid fuzzy controller for series connected FACTS devices", IEEE Trans. on Power Systems, Vol. 15, 2000, pp. 1360 -1366.