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SUPRESSION OF LOW FREQUENCY OSCILLATIONS(LFO) IN THE POWER SYSTEM BY NUERO FUZZY LOGIC CONTROLLER

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ABSTRACT

Low-frequency oscillations (LPF) in electric power systems due to the uncontrollability of the disturbance in the power system. These oscillations need to be controlled to maintain system stability. Several control devices, such as power system stabilizers, lead lag controllers are used to enhance power system stability. The UPFC can be used to effectively control these low-frequency power system oscillations. It is done by designing a supplementary signal based on either the real power flow along the transmission line to the series converter side or to the shunt converter side through the modulation of the voltage magnitude reference signal. In this work the linearized model of synchronous machine connected to infinite bus (Single Machine-Infinite Bus: SMIB) with UPFC, adaptive neuro-fuzzy controller for UPFC is designed and simulated to suppress the low frequency oscillations. Simulation is performed on the characteristics of the fuzzy controlled bus system. It is evident that the fuzzy logic controller has effective operation than the conventional lead-lag controller through the obtained results.

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

INTRODUCTION

There is no single acceptable definition of the term electric power quality. The term generally applies to the goodness of the electric power supply, voltage regulation, frequency, voltage wave shape, current wave shape, level of impulses and noise, and the absence of momentary outages [4]. The regulation of the network frequency constitutes one of the essential elements for the “quality” of operation; excessive frequency variations would not, in fact, be tolerated by many end-users, or by auxiliary equipment of the generating power stations themselves [9].The growth of the demand for electrical energy leads to loading the transmission system near their limits. Thus, the un-controlling of the system is leads to develop the frequency oscillation. The damping torque is used to provide the balancing in the system.

FACTS controllers allow steady-state, quasi-steady-state, dynamic, transient control actions and they provide important equipment and system protection functions. 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. For systems which are without power system stabilizer (PSS), excellent damping can be achieved via proper controller design for UPFC parameters.

It is usual that Heffron-Philips model [13] is used in power system to study small signal stability. This model has been used for many years providing reliable results. 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, Conventional lead-lag control, Genetic algorithm approach, and robust control methods.

In this work, 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. 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.

This paper is organized as follows: in Section II, 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 shown in Section IV. Finally conclusions are presented in section V

POWER SYSTEM MODEL INCLUDING UPFC

UPFC is one of the famous FACTS devices that are 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 me, mb and δe, δb are the amplitude modulation ratio and phase angle of the reference voltage of each voltage source converter respectively [12].

A linearized model of the system is used in dynamic studies of power system [2]. 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 [7]. The representation of the power system equipped with the UPFC can be represented as shown in equation (1) and torque generation of the Heffron Philips model is given by equation (2). The control variables of the system are the speed variation, angle variation in the rotor calculated from the characteristics of the single machine system. These variables are given as the controlling signals to the fuzzy controller [11].

Generally, the study of the synchronous machine is driven from a constant voltage-frequency ratio, the motor develops the same maximum torque at all speeds. For the salient pole rotor this will occurs at the load angle which is influenced by the relative values of L_q and L_d. The steady state representation of the torque developed in the salient pole rotor is given as equation (2) .

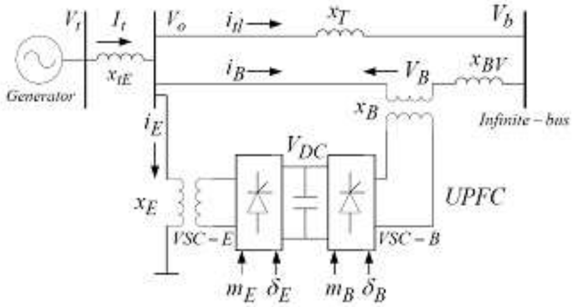

Fig.1 A single machine connected to infinite bus with UPFC

$$\begin{bmatrix}\Delta\delta^I\\ \Delta w^I\\ \Delta E_q^1\\ \Delta E_{fd}^I\\ \Delta V_{dc}^i\end{bmatrix}=\begin{bmatrix}0 & w_0 & 0 & 0 & 0\\ \frac{-k_1}{M} & \frac{-D}{M} & \frac{-k_2}{M} & 0 & \frac{-k_{pd}}{M}\\ \frac{-k_4}{T_{do}^I} & 0 & \frac{-k_3}{T_{do}^I} & \frac{1}{T_{do}^I} & \frac{-k_{qd}}{T_{do}^I}\\ \frac{-k_4k_5}{T_A} & 0 & \frac{-k_Ak_6}{T_A} & \frac{-1}{T_A} & \frac{-k_Ak_{vd}}{T_A}\\ k_7 & 0 & k_8 & 0 & -k_9\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta w\\ \Delta E_q^I\\ \Delta E_{fd}\\ \Delta v_{dc}\end{bmatrix}+$$

$$\begin{bmatrix}\frac{-k_{pe}}{M} & \frac{-k_{pe}\delta_e}{M} & \frac{-k_{pb}}{M} & \frac{-k_p\delta_b}{M} & 0\\ \frac{-k_{qe}}{T_{do}^I} & \frac{-k_{qe}\delta_e}{T_{do}^I} & \frac{-k_{qb}}{T_{do}^I} & \frac{-k_q\delta_b}{T_{do}^I} & 0\\ \frac{-k_Ak_{ve}}{T_A} & \frac{-k_Ak_v\delta_e}{T_A} & \frac{-k_Ak_{vb}}{T_A} & \frac{-k_Ak_v\delta_b}{T_A} & 0\\ k_{ce} & k_c\Delta_e & k_{cb} & k_c\delta_b & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}\Delta mE\\ \Delta\delta E\\ \Delta mb\\ \Delta\delta b\\ v_{dc}\end{bmatrix} \quad (1)$$

Where ΔmE, ΔmB, ΔδE and Δδb are the deviation of input control signals of the UPFC.

$$T = \frac{3P}{w_0}\left|\frac{\frac{V^2}{\lambda}R+VE_{fo}\lambda X_{qo}sin\delta+\frac{V^2}{2}(X_{do}-X_{qo})sin2\delta-VRE_{fo}cos\delta}{R^2+\lambda^2X_dX_q}\right| \quad (2)$$

CONTROLLER DESIGN

The switching of the convertors must be reliable, accurate and effective in the operation in order to control the frequency ranges in the loads, controlling pulses require controlling the variable parameters. Power full control strategies to the convertors required to obtain stable controlled switching with low sensitivity and burden against the controlling parameters.

A) Lead-Lag Controller Design:

Lead lag compensation is used for the good stability margin, having the poor steady state accuracy. The characteristic of lead lag compensator is given by the equation (3).

$$C_{LL}(S) = k_{LL}\frac{1+sT_z}{1+sT_p} \quad (3)$$

The compensator selection and design based upon the parameters as given below:

1. Compensator Selection
2. Unity Gain Frequency
3. Desired Phase Margin
4. Compensator Zero-Pole Placement
5. Compensator Gain Calculation
6. Stability Margin Variation
7. Results.

B). Adaptive Neuro-Fuzzy Controller Design

Fuzzy logic controller is the new hybrid technology totally depends upon the human thinking. The controllers easily designed based on the controlling variable are taken as the inputs by taking the sample values. Generally some samples of the values of the controlling parameter variation as the input to the controller and specific function is taken as the expected function of the controller. The main steps in the implementation of a fuzzy logic controller as follows:

1. *Fuzzification.*

The variation in the speed and angle of the rotor, Δδ and Δw as taken as the inputs to the fuzzy controller. In Figure 2, a Sugeno type of fuzzy system has the rule base with rules such as follows [5]:

1. If Δδ is A1 and Δω is B1 then f1=p1 Δδ+q1 Δω+r1.

2. If Δδ is A2 and Δω is B2 then f2=p2 Δδ+q2 Δω+r2.

2. I*nterference Engine:*

The result of the fuzzy control algorithm can be obtained by using the control rules, membership functions, and an interference engine.

a) Type: 'Sugeno'
b) And Method: 'Prod'
c) Or Method: 'Probor'
d) De-Fuzzification Method: 'Wtaver'
e) Implication Method: 'Prod'
f) Aggregation Method: 'Sum'
g) Input: [1x2 Struct]
h) Output: [1x1 Struct]
i) Rule: [1x20 Struct]

μ_A and μ_B 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

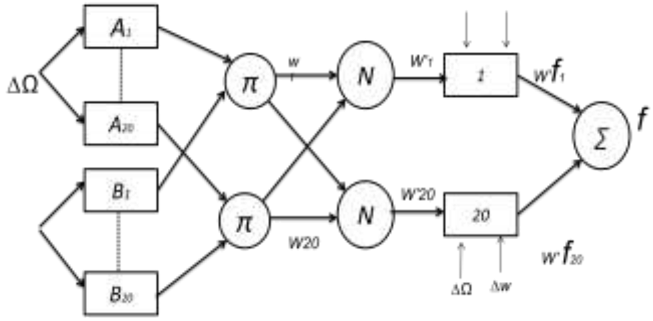

Fig.2 ANFIS architecture for 2 input Sugeno fuzzy model with 20 rules

1) Evaluating the rule premises*:*

$$w_i = \mu_{Ai}(\Delta\delta)\mu_{Bi}(\Delta w), i = 1,2,3, \ldots 20. \quad (3)$$

2) Evaluating the implication and the rule consequences*:*

$$f(\Delta\delta, \Delta w) = \frac{w_1(\Delta\delta,\Delta w)f_1(\Delta\delta,\Delta w)+\cdots\ldots+w_{20}(\Delta\delta,\Delta w)f_{20}(\Delta\delta,\Delta w)}{w_1(\Delta\delta,\Delta w)+\cdots.+w_{20}(\Delta\delta,\Delta w)} \quad (4)$$

Or leaving the arguments out

$$f = \frac{w_1 f_1+w_2 f_2+\cdots.w_{20}f_{20}}{w_1+w_2+\cdots w_{20}} \quad (5)$$

This can be separated to phases by first defining

$$w_i^{-} = \frac{w_1}{w_1+w_2+\cdots w_{20}}, i = 1,2,3, \ldots 20 \quad (6)$$

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

$$f = w_1^{-} f_1 + w_2^{-} f_2 + \cdots . w_{20}^{-} f_{20} \quad (7)$$

The above relation is linear with respect to P_i, Qi r_i and i=1, 20. So parameters can be categorized into 2 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 [20]. This network is called adaptive by Jang and it is functionally equivalent to Sugeno type of a fuzzy system. It is not 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 shown in figure 3. The membership functions for input variable Δω are presented in figure 4and 5.

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 controller, for each controls parameters, a controller must be designed.

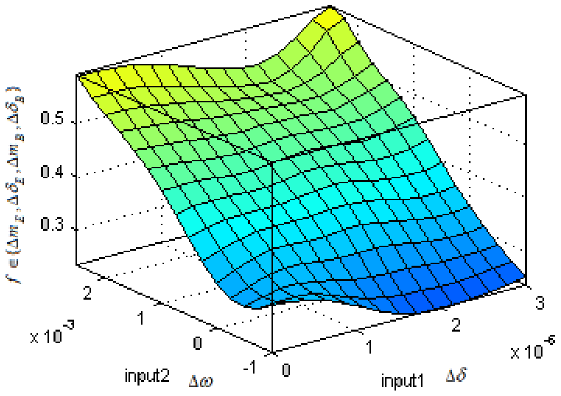

Fig.3 The rules surface

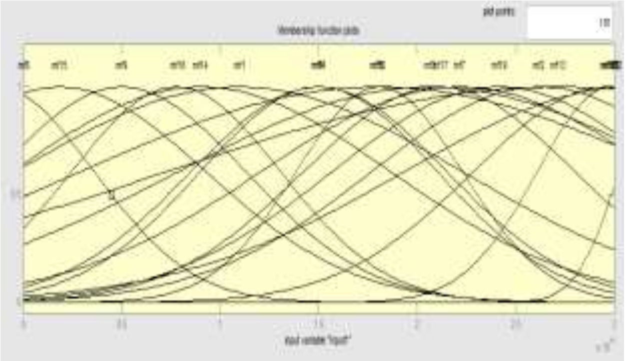

Fig.4 The membership functions for input variable Δω

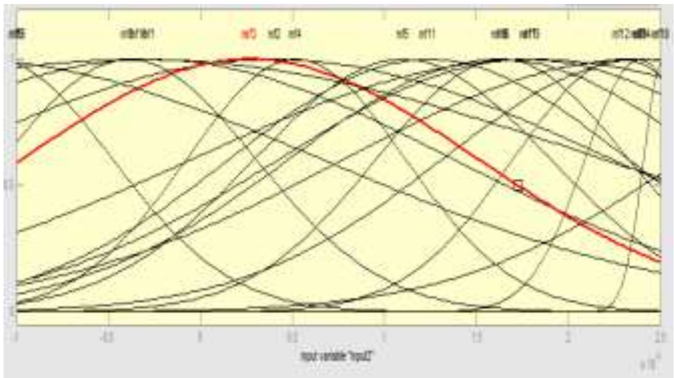

Fig.5 The membership functions for input variable Δδ

SIMULATION & RESULTS

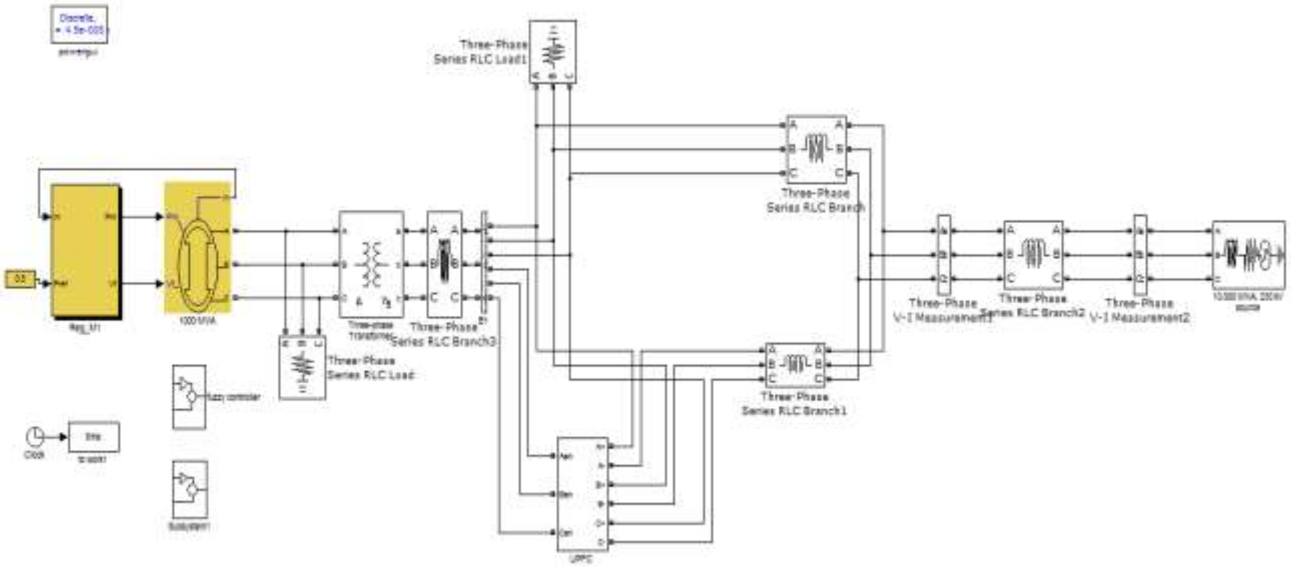

Fig 6: Modeilling and Simulation of the power system including UPFC

In this work, LFO is linearily controlled by controlling the angular velocity (speed) , rotor angle variation . These values are given as a input to the lead-lag and fuzzy controllers. Its clearly shows form the Fig 7 to that the lead-lag controller response is not as good as neuro-fuzzy controller response and also neuro-fuzzy controller decreases settling time. In addition maximum overshoot has decreased in comparison with lead-lag controller response.

A)Wave Form

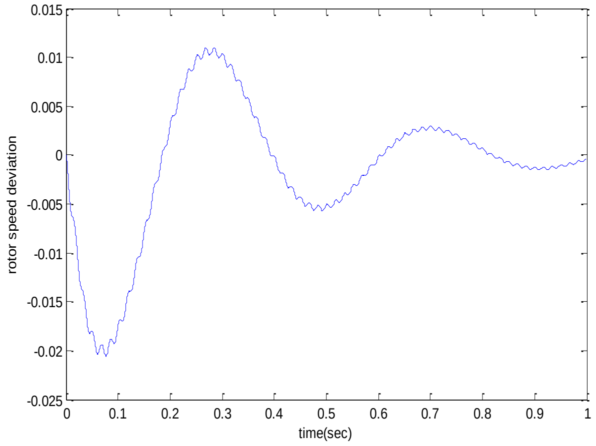

Fig 7. Angular velocity variation in the rotor by lead lag controller

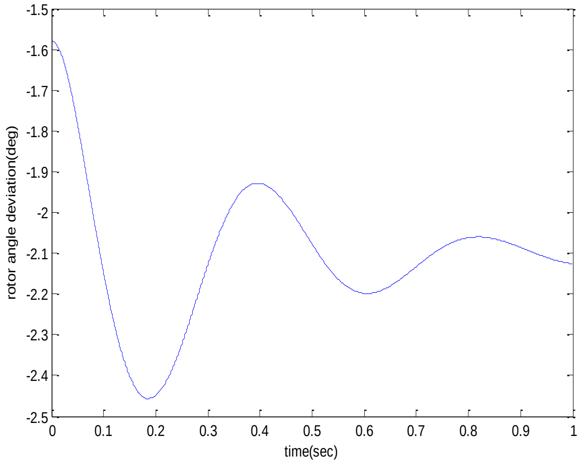

Fig 8. Angle variation in the rotor by lead lag controller

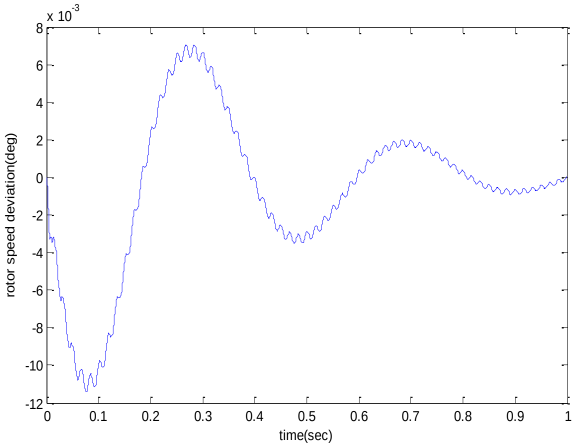

Fig 9. Angular velocity variation in the rotor by fuzzy logic controller

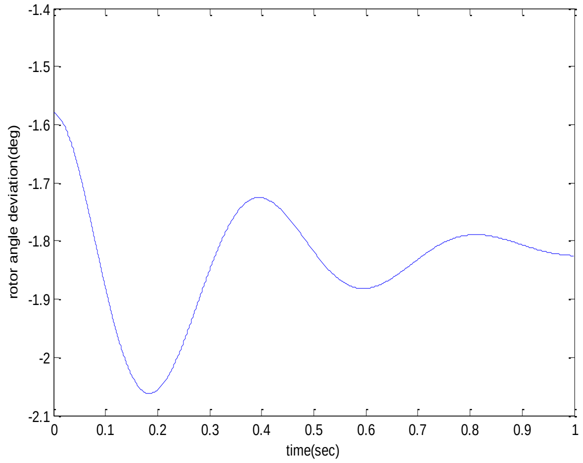

Fig 10. Angle variation in the rotor by fuzzy logic controller

B)Tabular Form[6]

Time(sec)	Lead Lag Controller		Fuzzy Logic Controller	
	Angle Deviation	Speed Deviation	Angle Deviation	Speed Deviation
0	1.52	-0.000141	-1.579	0
0.1	-2.2	-0.01739	-1.887	-0.01025
0.2	-2.44	0.003215	-2.057	0.002138
0.3	-2.135	0.0103	-1.849	0.006653
0.4	-1.931	-0.000740	-1.727	-0.000142
0.5	-2.087	-0.00539	-1.1819	-

				0.003037
0.6	-2.198	4.89e-006	-1.881	0.00033
0.7	-2.137	0.002949	-1.832	0.001921
0.8	-2.061	0.0004826	-1.789	4.8e-005
0.9	-2.086	-0.001322	-1.806	0.0009026
1	-2.125	-0.000111	-1.825	0

CONCLUSION

By the comparison of the results, fuzzy logic controller has the effective operation rather than the convenctional lead-lag controllers. By using the adaptive techniques, by the damping torque, low frequency oscillation are reduced and nullified to the steady state operation of the system. Fuzzy logic controllers are desinged to nearest of the humanity and doesn't require any system paprameters or operating conditions. Fuzzy logic controllers canb be apply to various tpes of convertors and controllers to control the capability, quality of the system. 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

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