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Fuzzy Logic Based UPFC Controller for Damping Power System Oscillations

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ABSTRACT:-Low frequency electromechanical oscillations are inevitable characteristics of power systems and they greatly affect the transmission line transfer capability and power system stability. In this paper a new control methodology based on Fuzzy Logic technique to control a Unified Power Flow Controller (UPFC) installed in a single-machine infinite-bus power System to damp low frequency power system oscillations is presented. A Linear Phillips-Heffron model of a single-machine infinite bus power system equipped with a UPFC is used to model the system. The Fuzzy Logic based UPFC controller is designed by selecting appropriate controller parameters based on the knowledge of the power system performance. Simple Fuzzy Logic controller having only one input using mamdani-type inference system is used. The effectiveness of the new controller is demonstrated through time-domain simulation studies. The results of these studies show that the designed controller has an excellent capability in damping power system oscillations.

I. INTRODUCTION

The power transfer in an integrated power system is constrained by transient stability, voltage stability and small-signal stability. These constraints limit the full utilisation of the available transmission corridors. The flexible AC transmission system (FACTS) is the technology that provides the corrections to the transmission functionality required in order to fully utilise the existing transmission facilities, hence minimising the gap between the stability and thermal-loading limits. As lines are loaded near their thermal limits the occurrence of the Low Frequency Oscillations has increased in the system. Traditionally, power system stabilizers (PSS) are being used to damp low frequency oscillations. The unified power flow controller (UPFC) is a FACTS device which can control power-system parameters such as terminal voltage, line impedance and phase angle. UPFC can also provide the damping to these low frequency power oscillations.

Fuzzy logic provides a general concept for description and measurement. Most fuzzy logic systems encode human reasoning into a program to make decisions or control a system.Fuzzy controllers are based on fuzzy logic systems. In this paper, for a system of single machine connected to infinite, a fuzzy logic based controller for the UPFC is designed and simulated. In many papers of UPFC controlling LFO, the angular velocity deviation $\Delta\omega$ and load angle deviation $\Delta\delta$ have been used as the controllers input. But as we know both signals can be derived from each other hence in this paper we have taken only one control signal $\Delta\omega$. This paper is organized as follows; in Section II, the model of the power system including UPFC is explained. The proposed fuzzy controller is explained in Section III. The results of the simulation are finally given in Section IV and Section V is conclusion.

II. DYNAMIC MODELING OF POWER SYSTEM WITH UPFC

Fig. 1 shows a single-machine-infinite-bus (SMIB) system with UPFC. In Fig. 1 me, mb and δe, δb are the amplitude modulation ratio and phase angle of the reference voltage of each voltage source converters respectively. These values are the input control signals of the UPFC.

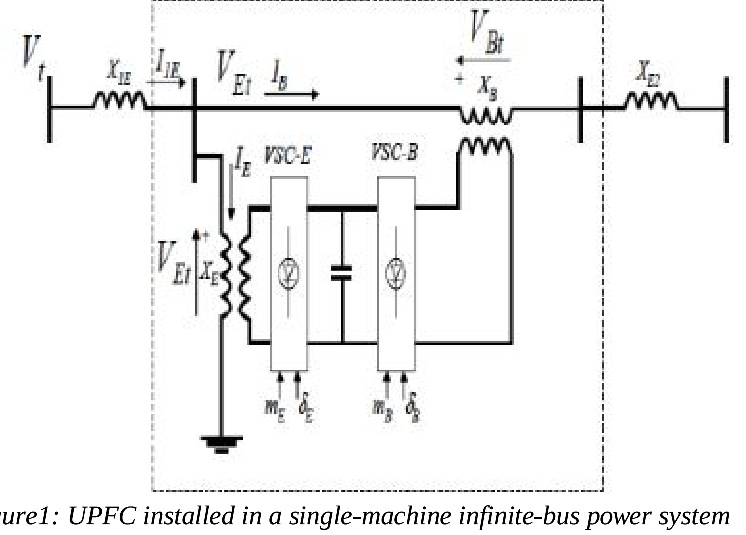

Figure1: UPFC installed in a single-machine infinite-bus power system

Dynamic model of SMIB system with UPFC, in the state space representation obtained is as shown below:

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \\ \Delta\dot{V}_{dc} \end{bmatrix} = \begin{bmatrix} 0 & \omega_o & 0 & 0 & 0 \\ -\frac{K_1}{M} & -\frac{D}{M} & -\frac{K_2}{M} & 0 & -\frac{K_{pd}}{M} \\ -\frac{K_4}{T'_{do}} & 0 & -\frac{K_3}{T'_{do}} & \frac{1}{T'_{do}} & -\frac{K_{qd}}{T'_{do}} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} & -\frac{K_A K_{vd}}{T_A} \\ K_7 & 0 & K_8 & 0 & -K_9 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \\ \Delta V_{dc} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_A}{T_A} \\ 0 \end{bmatrix} \Delta V_{ref}$$

$$+ \begin{bmatrix} 0 & 0 & 0 & 0 \\ -\frac{K_{pe}}{M} & -\frac{K_{p\delta e}}{M} & -\frac{K_{pb}}{M} & -\frac{K_{p\delta b}}{M} \\ -\frac{K_{qe}}{T'_{do}} & -\frac{K_{q\delta e}}{T'_{do}} & -\frac{K_{qb}}{T'_{do}} & -\frac{K_{q\delta b}}{T'_{do}} \\ -\frac{K_A K_{ve}}{T_A} & -\frac{K_A K_{v\delta e}}{T_A} & -\frac{K_A K_{vb}}{T_A} & -\frac{K_A K_{v\delta b}}{T_A} \\ K_{ce} & K_{c\delta e} & K_{cb} & K_{c\delta b} \end{bmatrix} \begin{bmatrix} \Delta m_E \\ \Delta\delta_E \\ \Delta m_B \\ \Delta\delta_B \end{bmatrix}$$

III. DESIGN OF PROPOSED FUZZY LOGIC CONTROLLER

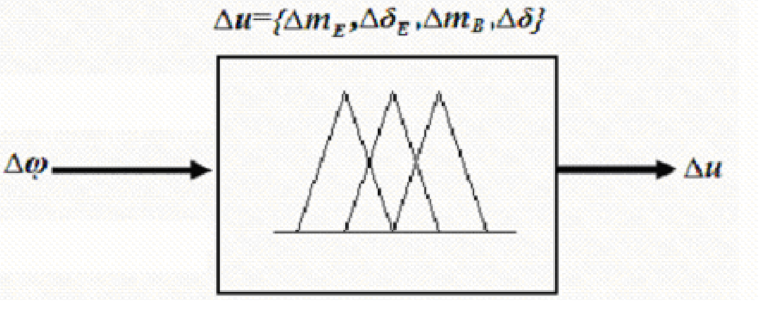

Fig. 2: Single input-single output fuzzy logic Controller

The input to the fuzzy controller is taken as angular velocity deviation (Δω) and the output is damping signal Δu. One of the UPFC inputs (ie. m_e, m_b and δ_e, δ_b) is controlled by this fuzzy controller output Δu. The basic structure of the fuzzy logic controller is as shown in figure2.

The equal spaced triangular shaped membership functions are used in this study. The inputs and outputs are fuzzified using seven fuzzy sets: LN (large negative), MN (medium negative), SN (small negative), Z (zero), SP (small positive), MP (medium positive), and LP (large positive). The membership functions of the input and output signals are as shown in Figure 3 and Figure 4.

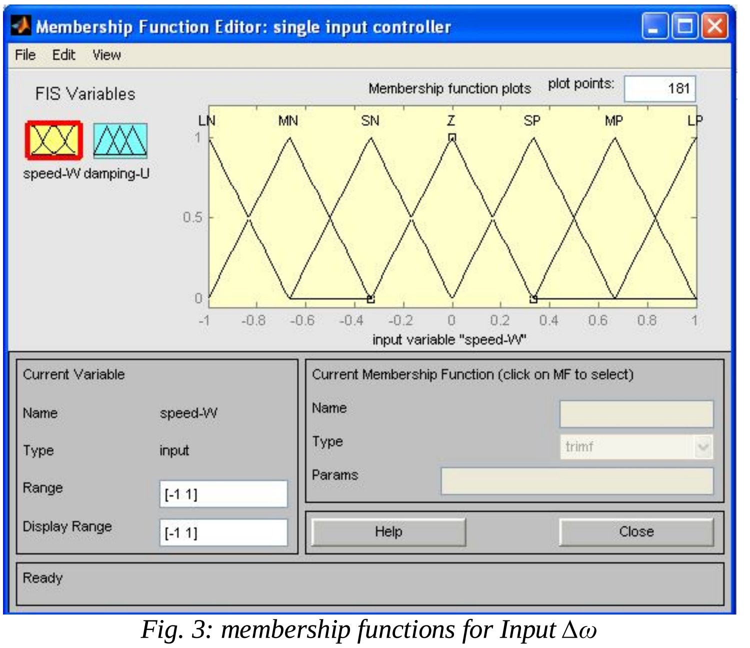

Fig. 3: membership functions for Input Δω

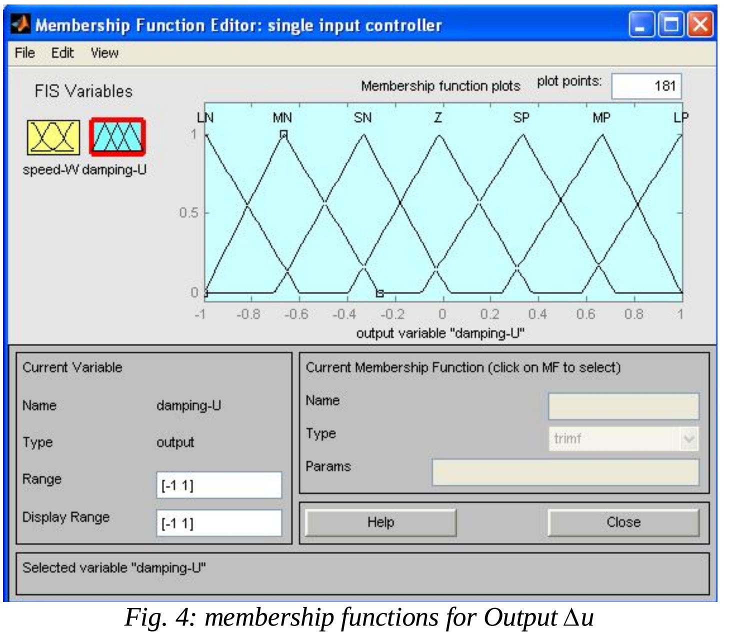

Fig. 4: membership functions for Output Δu

TABLE 1: RULE BASE FOR SINGLE INPUT-SINGLE OUTPUT FUZZY CONTROLLER

Δω	LN	MN	SN	Z	SP	MP	LP
Δu	LN	MN	SN	Z	SP	MP	LP

The rule base used in this controller is chosen as shown in table 1. It can be considered as **If** $\Delta\omega$ is LN then Δu is LN. and similarly for others also. The membership functions of the input, output and rule base for all the controllers can be the same. Based on the output control signal these controllers can be named as m_E controller, m_B controller, δ_E controller and δ_B controller. The only difference among all the controllers design is the range of these values. For this controller method of aggregation used is maximum, implication is minimum and the method of defuzzifcation used is centroid.

IV. SIMULATION RESULTS

For the operating conditions, given in appendix I, the model shown by equation 1 is simulated with the help of Matlab Simulink software without any damping controller i.e. Δu=0 for a step rise of 0.01p.u in the mechanical power input of the machine at the time instant t=0.5 second .The response of the system is shown in figure .From this result it is clear that without any damping controller system is unstable in nature.

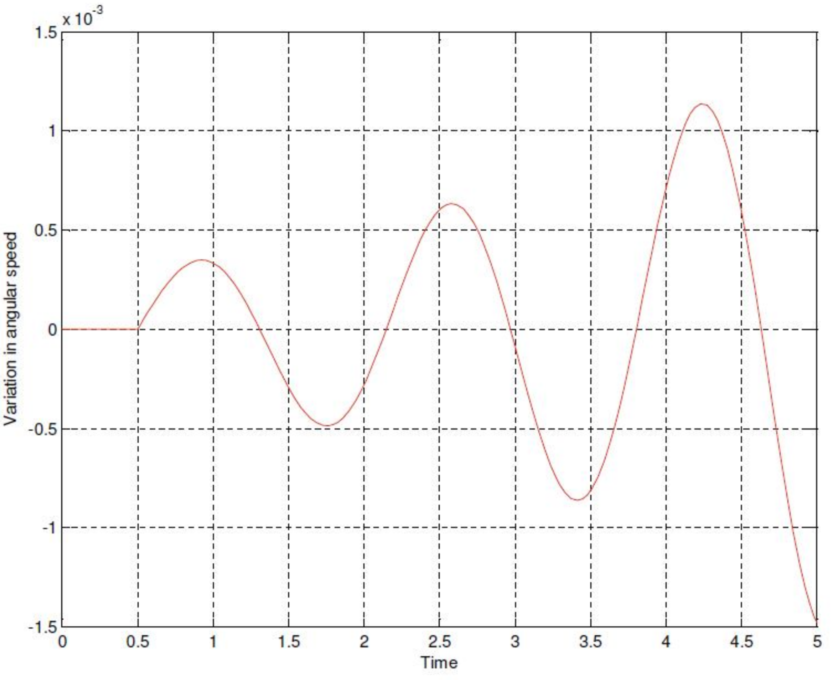

Fig. 5: Response of system without any damping controller

The model shown by equation 1 is again simulated with the fuzzy damping controller with control signal considering m_E , m_B, δ_E and δ_B respectively.

The response of the system is as shown in figure 6. This shows the variation of Δ **ω** of the synchronous machine in the system taken in consideration for a step rise of 0.01 p.u in the mechanical power input of the machine at the time instant t = 0.5 second when the machine is operating in the nominal operating conditions as listed in Appendix-I.

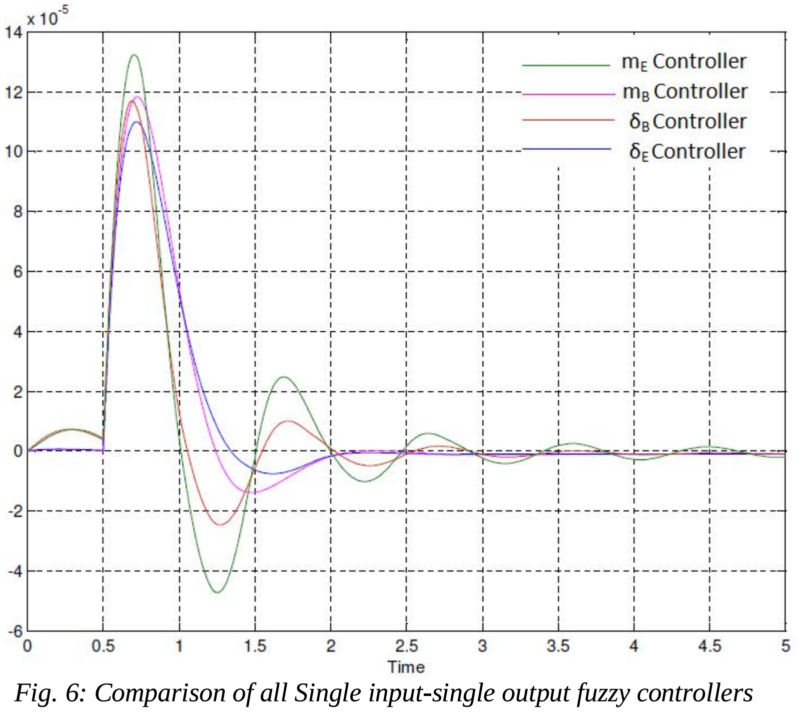

Fig. 6: Comparison of all Single input-single output fuzzy controllers

By observing these results we find that the fuzzy controller for all the control signals is showing better damping capabilities. From figure 6 , it is observed that δ_E and δ_B controllers are more effective in damping low frequency oscillation having settling time about 2.2 to 2.3 sec where as for m_E and m_B controller it is 4.5 & 3.5 sec respectively. Similarly peak overshoot of δ_E and δ_B controllers is 11×10^{-5} and 11.75×10^{-5} respectively. Thus we observed that δ_E controller is more effective having lowest peak overshoot. Hence we can conclude that among all the fuzzy controller (i.e. m_E controller, m_B controller, δ_E controller and δ_B controller) δ_E controller is most suitable and efficient and having greater damping capabilities.

V. CONCLUSION

In this paper a fuzzy controller has been used to damp low frequency oscillations in SMIB system with UPFC. The modified Phillips-Heffron model is used in this study. fuzzy control system having only one input Δ ω is developed in this paper , to study its effectiveness in damping oscillations, four types of UPFC controllers mainly m_E controller, m_B controller, δ_E controller and , δ_B controller have been designed. Investigations done shows that all the controllers as quite robust & performing well .The investigations reveals that the fuzzy control system with damping controller δ_E and damping controller δ_B provides robust performance to decrease low frequency oscillations. Further out of these two δ_E controller is most suitable and efficient controller.

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APPENDIX I

Synchronous Machine :
H = 4 .0 s, D = 0.0 , $T'do$ = 5.044 s, Xd = 1.0 p.u, $X'd$ = 0.3 p.u, Xq = 0.6 p.u
Excitation system:
Ka = 100 , Ta = 0.01 s
Transformer and Transmission line:
X_{tE} = 0.1 p.u , X_E = 0.1 p.u , X_B = 0.1 p.u , X_{Bv} = 0.3 p.u, X_e = 0.5 p.u
Nominal operating condition:
P_e = 0.8 p.u , Q_e = 0.2 p.u , V_t = 1.0 p.u , f = 60Hz
UPFC parameters:
m_E = 0.4, m_B = 0.08, δ_E = -85.3°, δ_B = -78.2°, V_{dc} =2 p.u, C_{dc} = 1 p.u

