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Performance Enhancement of Power System using FACTS Controller

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Abstract: Power demand is increasing substantially, due to which transmission networks are heavily loaded, so system stability becomes a problem. Environmental and economic constraints do not allow the increase in the lines. To resolve these issues, a continuous research engineered in designing the circuits to improve transmission line flow on the prevailing lines without losing stability. Flexible AC transmission systems (FACTS), an emergent power electronics-based technology is the outcome of the research and having advantages of improving stability by fast damping of power oscillations apart from improving power quality and increase in power flow. In this paper Unified Power Flow Controller (UPFC) has been selected for improving dynamic stability of SMIB system, and the parameters of UPFC are controlled by Fuzzy control logic for improving the dynamic stability and comparison has been made with conventional Phase compensation control strategy.

Keywords: FACTS Controller, SMIB, UPFC, dynamic stability, Fuzzy Logic and Phase compensation

1. Introduction

In the last few years, more emphasis has been laid on designing of power system to manoeuvre at efficient operating conditions for stability and reliability of the power system. The transmission line capacity has been increased due to increased consumption of power. Therefore, stability and security play a major role in the discussion. Earlier power system stabilizer was used as a common approach for damping oscillation in the system [1-2]. However, PSS also failedto damp power system oscillation, especially at low frequency [3]. To overcome this problem, other alternatives were suggested to make the system accurately stable. It has been observed that FACTS devices were more effective in controlling power flow and also damps the oscillations during fault in system. Recently many control devices were executed under FACTS technology. Implementation of FACTS devices gives flexible voltage stability as well as regulation in addition to the system stability by achieving appropriate control signal [4]. The FACTS devices is a collection of various efficient controllers which work at rated power, voltage, impedance, phase angle frequency and also below rated frequency. UPFC have been proven to be the best among all the FACTS controllers due to its oscillations damping capabilities even at low frequencies and maintaining stability in an interconnected power system [4]. UPFC is capable of power flow control in transmission lines, stability improvement and manage the in-phase voltage, impedance of line and phase angle altogether to provide voltage support [5]. In the proposed work a linearized model of single machine infinite bus (SMIB) system equipped with UPFC has been considered to study the changes in system parameters with a target of boosting the damping performance of the system. The UPFC controller have been considered in the present work in order to amend the exertion needed for tracking the reference and upgrade the small signal stability of the system, under deliberation, by power system oscillation damping.

2. Unified power flow controller (UPFC)

Unified power flow controller (UPFC) is a recent technology FACTS device, for regulating the parameters of power system mainly terminal voltage, impedance of line and phase angle, serving the purpose of controlling power flow and maintaining stability of the power system. Unified power flow controller (UPFC) comprise of a static synchronous series compensator (SSSC) along with static synchronous compensator (STATCOM) coupled through a common DC link to allow real power flow in either directions and are controlled to provide concurrent real and reactive line compensation without an external electric energy source.

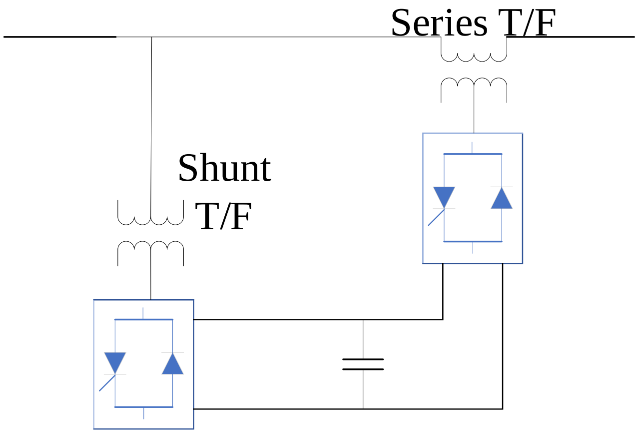

Figure1: UPFC (unified power flow controller)

3. Case Study

The study system comprises of a generating station supplying bulk power to an infinite bus bar over a long-distance transmission line. The generating station is represented by an equivalent synchronous generator and the large power system is represented as an infinite bus. Two control strategies i.e. phase compensation and Fuzzy logic techniques have been proposed for regulating the parameters of UPFC controller ($m_{sh}$and m_{se}) and simulation results are compared for dynamic stability. All system parameters are given in appendix.

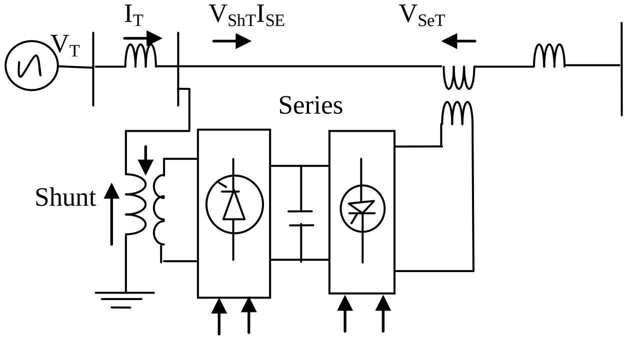

Figure 2: Equivalent circuit of SMIB with UPFC controller

A) Modelling of UPFC controller

UPFC Controller having parameters m_{sh} , m_{se} δ_{sh} and δ_{se} is represented by the following differential equations [1]

$$\frac{di_{shR}}{dt} = -\frac{r_{sh}}{l_{sh}} i_{shR} - \frac{m_{sh} v_{dc}}{2l_{sh}} \cos(wt + \delta_{sh}) + \frac{V_{shR}}{l_{sh}}$$

$$\frac{di_{shY}}{dt} = -\frac{r_{sh}}{l_{sh}} i_{shY} - \frac{m_{sh} v_{dc}}{2l_{sh}} \cos(wt + \delta_{sh} - 120^0) + \frac{V_{shY}}{l_{sh}}$$

$$\frac{di_{shB}}{dt} = -\frac{r_{sh}}{l_{sh}} i_{shB} - \frac{m_{sh} v_{dc}}{2l_{sh}} \cos(wt + \delta_{sh} + 120^0) + \frac{V_{shB}}{l_{sh}}$$

$$\frac{di_{seR}}{dt} = -\frac{r_{se}}{l_{se}} i_{seR} - \frac{m_{se} v_{dc}}{2l_{se}} \cos(wt + \delta_{se}) + \frac{V_{seR}}{l_{se}}$$

$$\frac{di_{seY}}{dt} = -\frac{r_{se}}{l_{se}} i_{seY} - \frac{m_{se} v_{dc}}{2l_{se}} \cos(wt + \delta_{se} - 120^0) + \frac{V_{seY}}{l_{se}}$$

$$\frac{di_{seB}}{dt} = -\frac{r_{se}}{l_{se}} i_{seB} - \frac{m_{se} v_{dc}}{2l_{se}} \cos(wt + \delta_{se} + 120^0) + \frac{V_{seB}}{l_{se}}$$

$$\frac{dv_{dc}}{dt} =$$

$$\frac{m_{sh}}{2c_{dc}} [cos(wt + \delta_{sh}) \ldots\ldots\ldots cos(wt + \delta_{sh} - 120°) \ldots\ldots\ldots cos(wt + \delta_{sh} 120°)] \begin{bmatrix} i_{shR} \\ i_{shY} \\ i_{shB} \end{bmatrix} +$$

$$\frac{m_{se}}{2c_{dc}} [cos(wt + \delta_{se}) \ldots\ldots\ldots cos(wt + \delta_{se} - 120°) \ldots\ldots\ldots\ldots cos(wt + \delta_{se} + 120°)] \begin{bmatrix} i_{seR} \\ i_{seY} \\ i_{seB} \end{bmatrix}$$

By applying Park's transformation and neglecting resistance and transient of the transformer of the UPFC, the above equations have been reduced to:

$$\begin{bmatrix} v_{shtd} \\ v_{shtq} \end{bmatrix} = \begin{bmatrix} 0 \ldots\ldots - x_{sh} \\ x_{sh} \ldots\ldots\ldots 0 \end{bmatrix} \begin{bmatrix} i_{shd} \\ i_{shq} \end{bmatrix} + \begin{bmatrix} \dfrac{m_{sh} \cos \delta_{sh} v_{dc}}{2} \\ \dfrac{m_{\mathrm{sh}} \ \sin \delta_{sh} v_{dc}}{2} \end{bmatrix}$$

$$\begin{bmatrix} v_{setd} \\ v_{setq} \end{bmatrix} = \begin{bmatrix} 0 \ldots\ldots - x_{se} \\ x_{se} \ldots\ldots\ldots 0 \end{bmatrix} \begin{bmatrix} i_{sed} \\ i_{seq} \end{bmatrix} + \begin{bmatrix} \dfrac{m_{se} \cos \delta_{se} v_{dc}}{2} \\ \dfrac{m_{\mathrm{se}} \ \sin \delta_{se} v_{dc}}{2} \end{bmatrix}$$

$$\frac{dv_{dc}}{dt} = \frac{3m_{sh}}{4c_{dc}} [\cos \delta_{sh} \ldots\ldots\ldots\ldots \sin \delta_{sh}] \begin{bmatrix} i_{shd} \\ i_{shq} \end{bmatrix} +$$

$$\frac{3m_{se}}{4c_{dc}} [\cos \delta_{se} \ldots\ldots\ldots\ldots \sin \delta_{se}] \begin{bmatrix} i_{sed} \\ i_{seq} \end{bmatrix}$$

B) Modelling of SMIB system

The non-linear differential equations from which the traditional Phillips-Heffron linear model of a single-machine infinite-bus power systems derived are:

$$\dot{\delta} = w_{\circ} \Delta w$$

$$\dot{\Delta w} = (P_m - P_e - D\Delta w) / 2H$$

$$E_q^{'} = (-E_q + E_{qe}) / T_{do}$$

$$\dot{E}fd = -\frac{1}{T_A} E_{fd} + \frac{K_A}{T_A} (v_{to} - v_t)$$

Where

$$P_e = E_q^{'} V_b \sin \delta / X_{d\Sigma}^{'} - V_b^2 (X_q - X_d^{'}) \sin 2\delta / 2X_{d\Sigma'} X_{q\Sigma}$$

$$E_q = X_{d\Sigma} E_q^{'} / X_d - X_d^{'}) V_b \cos \delta / X_{d\Sigma}^{'}$$

Where

C) Modelling of SMIB system equipped with UPFC controller

$$\overline{V_T} = jX_{tE} \overline{I_t} + \overline{V_{SHT}}$$

$$\overline{V_{SHT}} = \overline{V_{SET}} + jx_{BV} \overline{I_{SE}} + \overline{V_{SE}}$$

In d-q frame of reference, the equations are represented as,

$$v_{dt} + jv_{qt} = x_{tsh}(i_{shd} + i_{shd} + ji_{shq} + ji_{seq}) + v_{shtd} + jv_{shtq}$$

$$= x_q(i_{shq} + i_{seq}) + j[E_q{}' - x_d{}'(i_{shd} + i_{sed})]$$

Hence, transformer currents derived as,

$$\begin{bmatrix} i_{shq} \\ i_{seq} \end{bmatrix} = \begin{bmatrix} x_q + x_{tE} + x_{sh} \ldots\ldots x_q + x_{tE} \\ x_{sh} \ldots\ldots\ldots\ldots\ldots - x_{se} - x_{seV} \end{bmatrix}^{-1} \begin{bmatrix} \dfrac{m_{sh}\cos\delta_{sh}v_{dc}}{2} \\ \dfrac{m_{sh}\cos\delta_{sh}v_{dc}}{2} - \dfrac{m_{se}\cos\delta_{se}v_{dc}}{2} - V_b\sin\delta \end{bmatrix}$$

$$\begin{bmatrix} i_{xhd} \\ i_{sed} \end{bmatrix} = \begin{bmatrix} x_d{}' + x_{tE} + x_{sh} \ldots\ldots x_d{}' + x_{tE} \\ x_{sh} \ldots\ldots\ldots - x_{se} - x_{seV} \end{bmatrix}^{-1} \begin{bmatrix} E_q{}' - \dfrac{m_{sh}\sin\delta_{sh}v_{dc}}{2} \\ \dfrac{m_{se}\sin\delta_{se}v_{dc}}{2} - \dfrac{m_{sh}\sin\delta_{sh}v_{dc}}{2} + V_b\cos\delta \end{bmatrix}$$

$$T_e = P_e = V_q I_q + V_d I_d$$

$$E_q = E_q{}' + (x_d - x_d{}')i_{dt}v$$

$$v_{qt} = E_q{}' - x_d{}' i_{dt}$$

$$v_t = \sqrt{v_{dt}{}^2 + v_{qt}{}^2}$$

$$v_{dt} = x_q i_{qt}$$

$$i_{dt} = i_{shd} + i_{sed}$$

$$i_{qt} = i_{shq} + i_{seq}$$

By linearizing equation (5), (6) and (7), the state variable equation of the power system installed with UPFC are,

$$\begin{bmatrix} \dot{\Delta\delta} \\ \dot{\Delta w} \\ \dot{\Delta E_q{}'} \\ \dot{\Delta E_{fd}} \end{bmatrix} = \begin{bmatrix} 0 \ldots\ldots\ldots\ldots w_0 \ldots\ldots\ldots\ldots 0 \ldots\ldots\ldots\ldots 0 \\ -\dfrac{K_1}{M} \ldots\ldots - \dfrac{D}{M} \ldots\ldots - \dfrac{K_2}{M} \ldots\ldots\ldots\ldots 0 \\ -\dfrac{K_4}{T_{do}{}'} \ldots\ldots 0 \ldots\ldots - \dfrac{K_3}{T_{do}{}'} \ldots\ldots \dfrac{1}{T_{do}{}'} \\ -\dfrac{K_A K_5}{T_A} \ldots\ldots 0 \ldots\ldots - \dfrac{K_A K_6}{T_A} \ldots - \dfrac{1}{T_A} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta w \\ \Delta E_q{}' \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ -\dfrac{K_{pd}}{M} \\ -\dfrac{K_{qd}}{T_{do}{}'} \\ -\dfrac{K_A K_{vd}}{T_A} \end{bmatrix} [\Delta v_{dc}]$$

$$+ \begin{bmatrix} 0 \ldots\ldots\ldots\ldots\ldots\ldots 0 \ldots\ldots\ldots\ldots\ldots\ldots 0 \ldots\ldots\ldots\ldots\ldots\ldots 0 \\ -\dfrac{K_{psh}}{M} \ldots\ldots - \dfrac{K_{p\delta sh}}{M} \ldots\ldots\ldots\ldots - \dfrac{K_{pse}}{M} \ldots\ldots\ldots\ldots - \dfrac{K_{p\delta se}}{M} \\ -\dfrac{K_{qsh}}{T_{do}{}'} \ldots\ldots - \dfrac{K_{q\delta sh}}{T_{do}{}'} \ldots\ldots\ldots\ldots - \dfrac{K_{qse}}{T_{do}{}'} \ldots\ldots\ldots\ldots - \dfrac{K_{q\delta se}}{T_{do}{}'} \\ -\dfrac{K_A K_{vsh}}{T_A} \ldots - \dfrac{K_A K_{v\delta sh}}{T_A} \ldots\ldots - \dfrac{K_A K_{vse}}{T_A} \ldots\ldots - \dfrac{K_A K_{v\delta se}}{T_A} \end{bmatrix} \begin{bmatrix} \Delta m_E \\ \Delta\delta_E \\ \Delta m_B \\ \Delta\delta_B \end{bmatrix}$$

Where Δm_{sh} , Δm_{se} , $\Delta\delta_{sh}$, $\Delta\delta_{se}$ are the deviation of input control signals to the UPFC and Δv_{dc} is change in DC bus voltage between two VSCs and K_1 to $K_6$are linearized constants. By linearizing the equation (),

$$\Delta v_{dc} = \frac{(K_7\Delta\delta + K_8\Delta E_q^{'} + K_{ce}\Delta m_{sh} + K_{c\delta sh}\Delta\delta_{\backslash sh} + K_{cse}\Delta m_{se} + K_{c\delta se}\Delta\delta_{se})}{K_9 + s}$$

$$\Delta f = \left[\Delta v_{dc}......\Delta u_k\right]$$

$$K_s = \begin{bmatrix} -\dfrac{K_{sd}}{M} \\ -\dfrac{K_{suk}}{M} \end{bmatrix}, K_l = \begin{bmatrix} -\dfrac{K_{ld}}{T_{do}^{'}} \\ -\dfrac{K_{luk}}{T_{do}^{'}} \end{bmatrix}, K_u = \begin{bmatrix} -\dfrac{K_A K_{ud}}{T_A T_{do}^{'}} \\ -\dfrac{K_A K_{uuk}}{T_A T_{do}^{'}} \end{bmatrix}$$

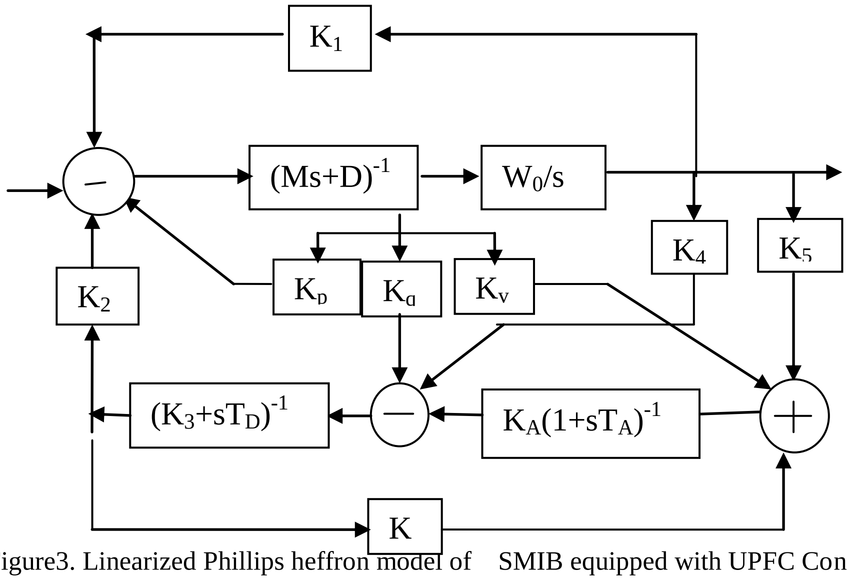

Figure3. Linearized Phillips heffron model of SMIB equipped with UPFC Controller

4. Phase Compensation Technique

Phase compensation technique, an economical and satisfactory solution of controlling the modulating index parameters of UPFC controller for providing additional damping to the generator rotor oscillations. This technique provides additional drivers to the excitation system. The structure comprises of Gain block, wash out circuit and lead lag compensator. The angular velocity of the rotor shaft is taken as the input signal to the lead lag compensator. Two phase compensation technique based damping controllers are implemented to modify the values of modulating index parameters (m_e and m_b) respectively of UPFC controller toproduce the required damping torque. The parameters of damping controller are given in appendix.

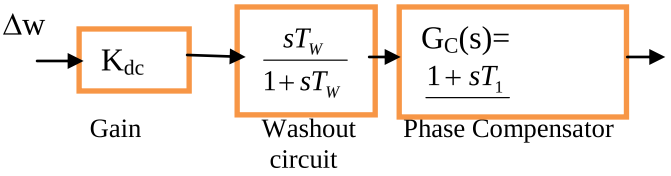

Fig: 6 damping Controller

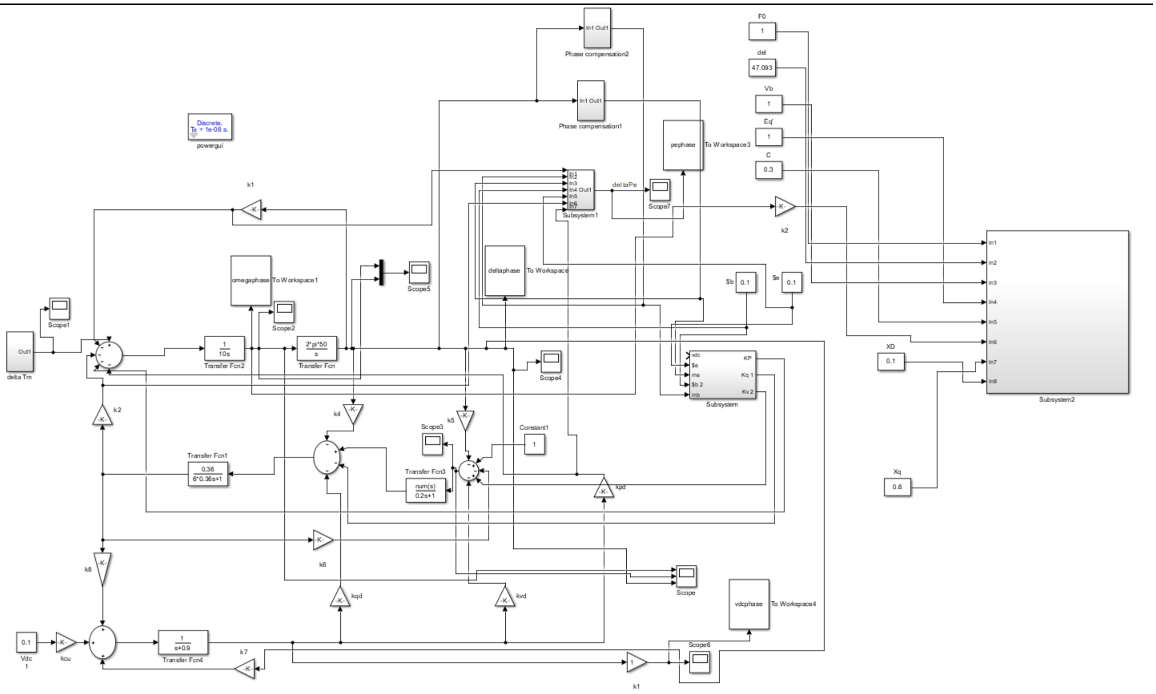

Fig: Simulation Diagram of SMIB system with UPFC damping Controller

5. Fuzzy logic Technique

Δw and Δδ are two inputs which are given to the Fuzzy logic controller to regulate the modulating indicesΔm_e, and Δm_b,

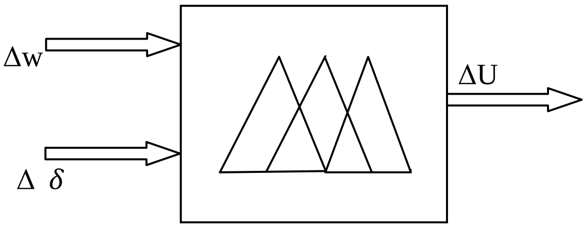

Fig FLC structure

A. Input and output membership function

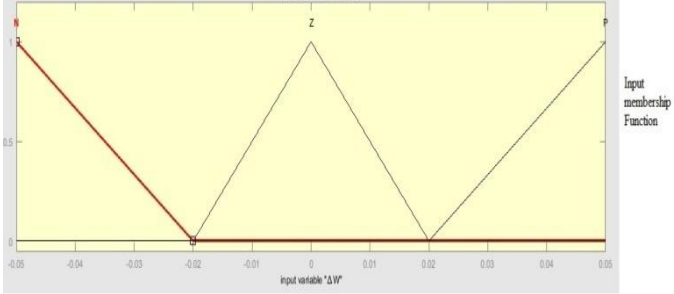

Fig. First input membership function

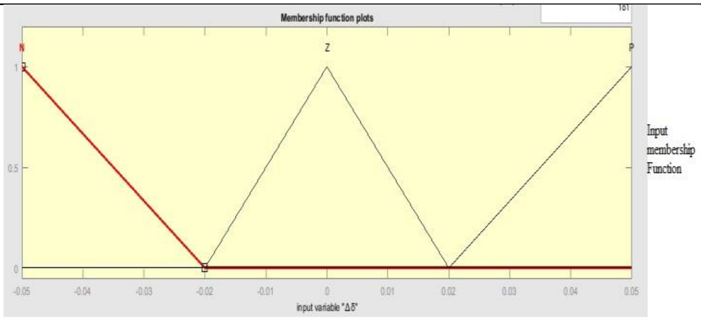

Fig. Second input membership function

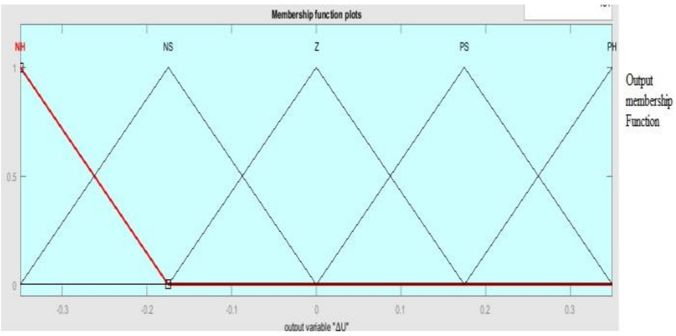

Fig: Output membership function

B. Fuzzy Rules

Rules implemented are,

1. If (ΔW is N) and (Δδ is N) then (ΔU is NH)
2. If (ΔW is N) and (Δδ is Z) then (ΔU is NS)
3. If (ΔW is N) and (Δδ is P) then (ΔU is Z)
4. If (ΔW is Z) and (Δδ is N) then (ΔU is NS)
5. If (ΔW is Z) and (Δδ is Z) then (ΔU is Z)
6. If (ΔW is Z) and (Δδ is P) then (ΔU is PS)
7. If (ΔW is P) and (Δδ is N) then (ΔU is Z)
8. If (ΔW is P) and (Δδ is Z) then (ΔU is PS)
9. If (ΔW is P) and (Δδ is P) then (ΔU is PH)

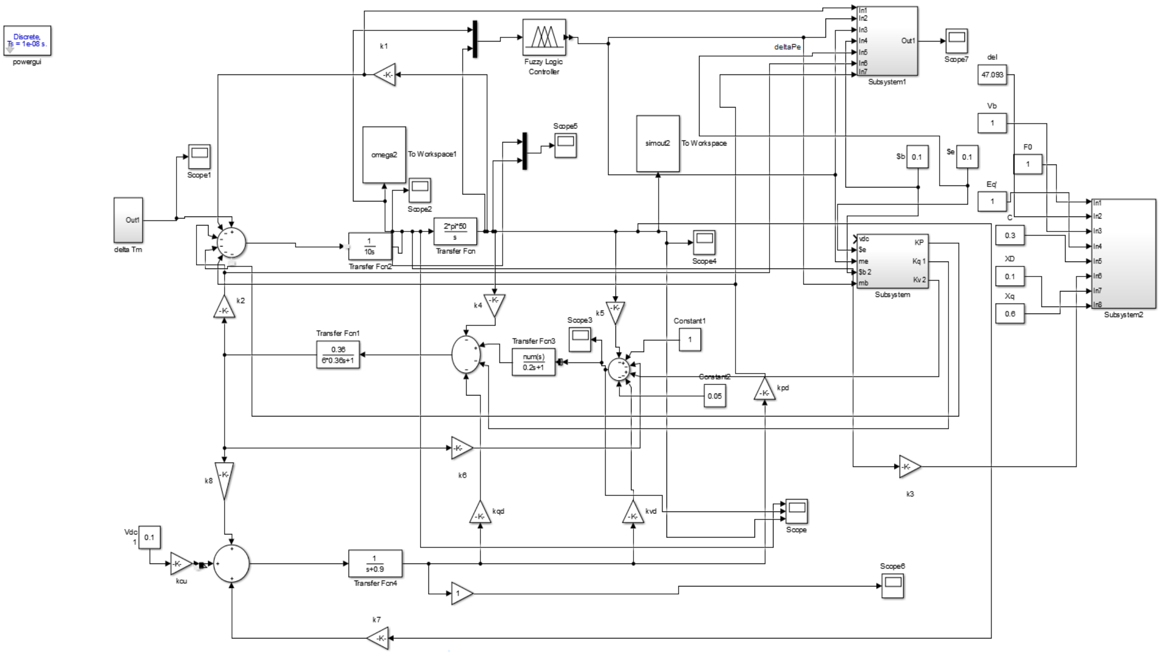

Fig Simulation Diagram of UPFC Controller with Fuzzy based echnique

6. Simulation

Simulation is carried out in MATLAB by varying mechanical torque by 10%. Four cases have been analyzed,

1. Without UPFC controller.
2. With UPFC controller.
3. With phase compensation technique based UPFC damping controller.
4. With Fuzzy logic based UPFC controller.

Results:

For all the above cases, simulation results with respect to variation in rotor speed, rotor angle& terminal voltage are shown in fig. (a) to (e).

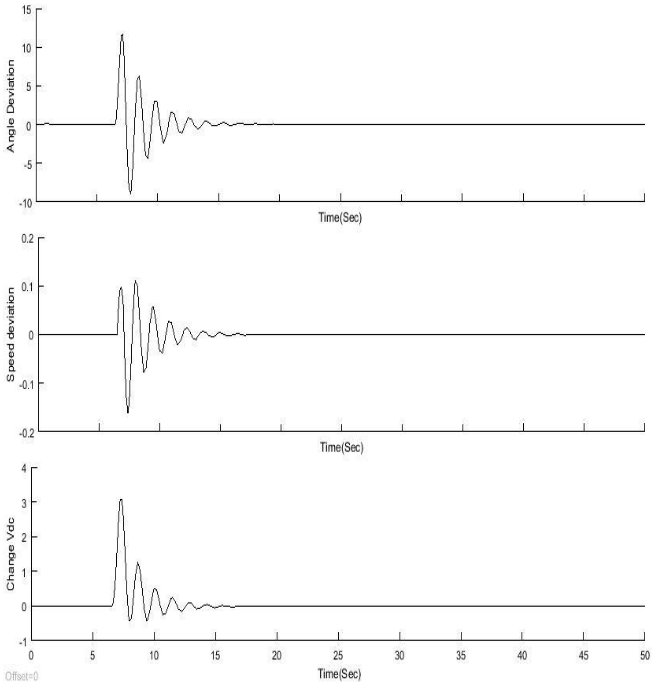

Fig (a): Without UPFC Controller

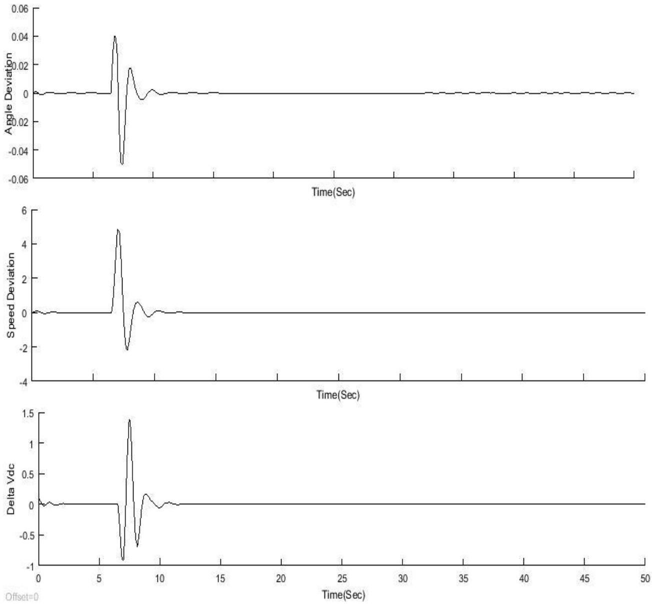

Fig (b): With UPFC Controller

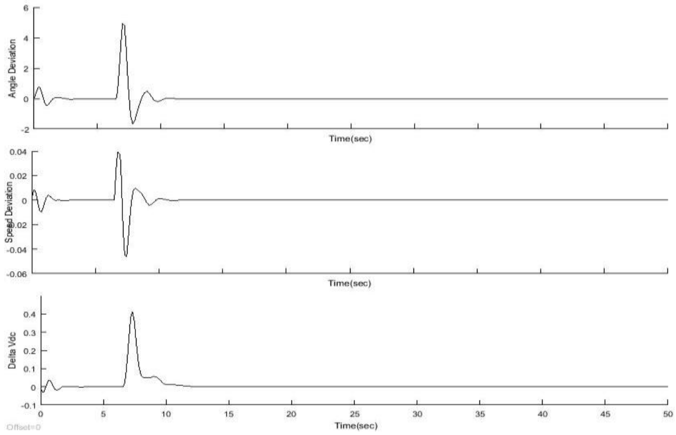

Fig (c): Phase compensation based UPFC based damping controller

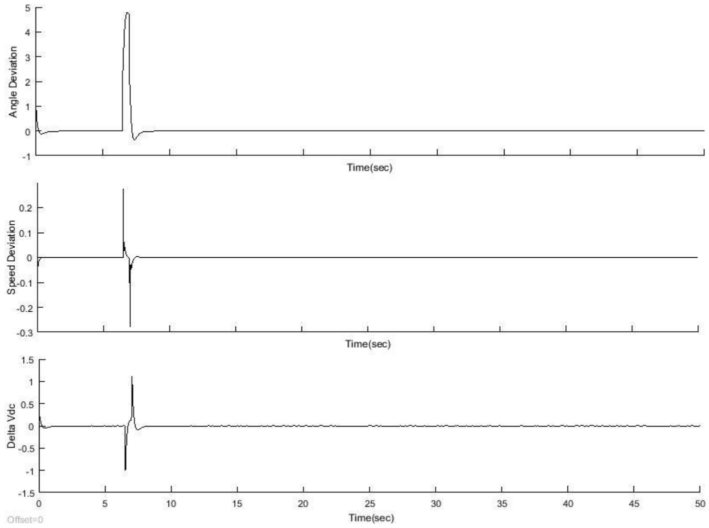

Fig (d): FUZZY Logic based UPFC damping controller

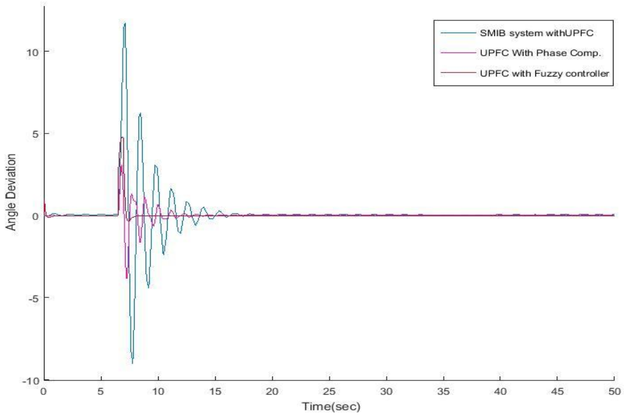

Fig (e): Comparison of all techniques

Settling Time	UPFC without any control technique	UPFC with phase compensation technique	UPFC with Fuzzy based control technique
T_s	13.5 sec	7.5sec	1.5 sec

Table: Comparison of settling time

7. Conclusion

Fuzzy Logic based controller is extremely effective in enhancing the dynamic stability of SMIB system by fast damping out low frequency rotor mechanical oscillations. Henceforth can be employed to provide the substitute for conventional phase compensation based damping controller and can be implemented in controlling the highly complex power system in real-time.

8. Appendix

A. Data:

Generator: M=2H=8.0MJ/MVA D=0.0
Td0= 5.044s
Excitation system: Ka=100 Ta=0.01s
Transformer : Xte= 0.01 pu Xe=Xb=0.1pu
Transmissionline : X_{BV} =0.3pu Xe= $X_{BV}+X_E+X_{TE}$=0.5pu
Operating condition : Pe=0.8pu Vt= 1pu Vb=1pu F=50HZ
UPFC parameter= m_{sh}=0. 4013 m_{se}=0.0789 $\delta_{sh}=85.378^0$
$\delta_{se}=78.2174^0$
Parameter of the DC link: V_{dc}=2 puC_{dc}=1pu
Pe=0.8pu Qe=0.162pu δ_o=47.093
E_{do}=0.73058pu E_{bqo}=0.69704pu e_{do}=0.9710pu
e_{qo}=0.3986pu i_{qo}=0.6669pu i_{do}=0.4719pu

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