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SISO FUZZY TUNED POWER OSCILLATION CONTROLLER FOR UPFC CONNECTED NETWORK

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ABSTRACT

This paper focuses on the design of single input single output fuzzy controller for a Power oscillation controller based UPFC for damping rotor oscillation in power system network. The oscillation due to disturbance cannot damp out only by UPFC, but with single input Fuzzy tuned Damping controller based UPFC can easily damp out the oscillation. Here the proposed system has been implemented in the standard nine-bus system and simulation results are taken by deriving the transient stability algorithm using C compiler software. After the analysis it is found that the Fuzzy based POD controller is very much required for UPFC controller to damp out the power oscillations.

Keywords: single input single output (SISO), fuzzy logic controller, rotor oscillation, static synchronous serious compensator (SSSC), rotor angle stability,power oscillation damping (POD).

1. INTRODUCTION

With the increasing electric power demand, power systems will move to stressed conditions, resulting in detrimental voltage and frequency deviations. Flexible AC Transmission System (FACTS) devices are one of the recent schemes to alleviate such situations is by controlling the power flow along transmission lines and damping out the oscillations.

Damping is provided by the Power System Stabilizer (PSS) which was the commonly used control and often to offset the negative damping of the Automatic voltage regulator. During specific operating conditions, particularly in inter - area modes the PSS fails to produce enough damping by introducing modulating signal acting through the excitation system [1] and hence, other effective alternatives are needed in addition to PSS. Recently, FACTS technology is emerging as an interesting approach to help in alleviating several power system-operating difficulties, such as inter-area oscillations and controlling voltages at critical buses. Amongst the available FACTS devices the SSSC is a series connected reactive power compensation devices that is capable of generating or absorbing reactive power. The output of SSSC can regulate the specific parameters in the system. But independently it is less effective to damped power oscillation [2] - [5].

The FACTS controllers utilize the PI controller which fails to solve inadequacies in the system to provide proper control and the angle stability enhancement.

But this inadequacy can be rectified by POD the suitable controller [4]. Also with fuzzy-logic based POD approach, which is used in the design of a facts controller, uses linguistic rules for both antecedent and consequent parts. This controller provides an extended range for gain control and could choose a linear or nonlinear control schemes.

a) Classical machine model

The synchronous generators are modelled as classical machines with δ and ω as state variables. The generator is represented by the Norton equivalent for network solution. The admittance of the generator is included in the main diagonals of Y matrix.

$$J\frac{d\omega}{dt} = T_m - T_e \qquad (1)$$

$$\frac{d\delta}{dt} = \omega - \omega_0 \qquad (2)$$

b) Transmission line model (short line)

A transmission line is modeled as a short line. It consists of a series impedance comprised of a resistance R and reactance X. between the terminal nodes.

c) Load model

The constant admittance model for load is utilized in transient stability studies.

2. MODELLING OF UPFC

a)Transient stability model

Assuming balanced, fundamental frequency voltages, UPFC with PWM voltage control can be accurately represented in transient stability studies using the basic model. The Model developed with respect to shunt and series controller. Each Controller are provided with voltage magnitude control and DC voltage Control

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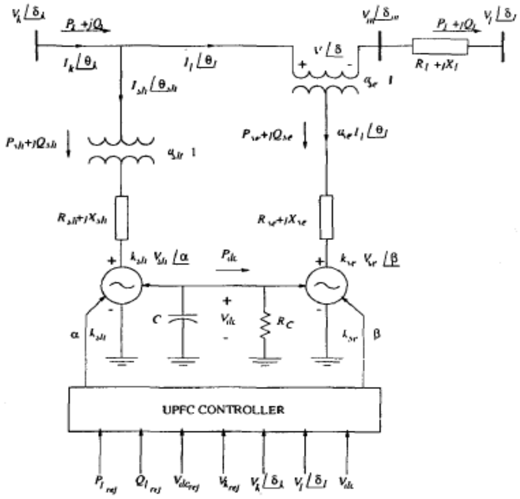

Figure-1. Transient stability model of UPFC.

b) Voltage magnitude controller

This controller controls the AC output voltage magnitude of the voltage source inverter by controlling the modulation index, m of the PWM controller. The controller has a bias corresponding to the steady state value of the modulation index, m_0.

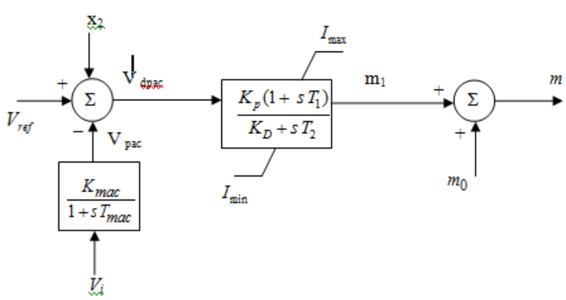

Figure-2. Voltage magnitude controller.

The differential equations are derived from the controller block shown inFigure-2.

$$\dot{V}_{pac} = \frac{1}{T_{mac}}\left[V_i K_{mac} - V_{pac}\right] \tag{3}$$

$$\dot{m}_1 = \frac{1}{T_2}\left[V_{dpac}K_p + K_p T_1 \dot{V}_{dpac} - K_D m_1\right] \tag{4}$$

c) DC voltage controller

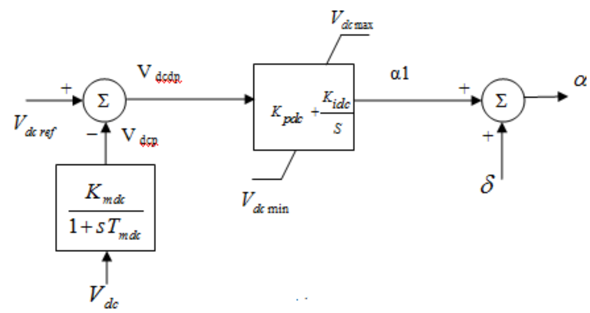

Figure-3.DC voltage controller.

The DC voltage controller controls the phase angle of the output voltage of the voltage source inverter. The phase angle determines the exchange of active power between the controllers with the ac system and is used to directly control the DC voltage magnitude. The controller has a bias corresponding to the phase angle, δ .

The differential equations are derived from the controller blocks given in Figure-3 as,

$$\dot{V}_{dcp} = \frac{1}{T_{mdc}}\left[V_{dc}K_{mdc} - V_{dcp}\right] \tag{5}$$

$$\dot{\alpha}_1 = V_{dcdp}K_{idc} + \dot{V}_{dcdp}K_{pdc} \tag{6}$$

$$P_{ac} = V_i I_s \cos(\delta_i - \theta_s) \tag{7}$$

$$P_{dc} = V_{dc} I_{dc} \tag{8}$$

d) Voltage magnitude controller

This controls the magnitude of series injected voltage of SSSC by controlling the modulation index $m_{se}$of the PWM controller. The controller has a bias corresponding to the steady state value of the modulation index. m_{se0}

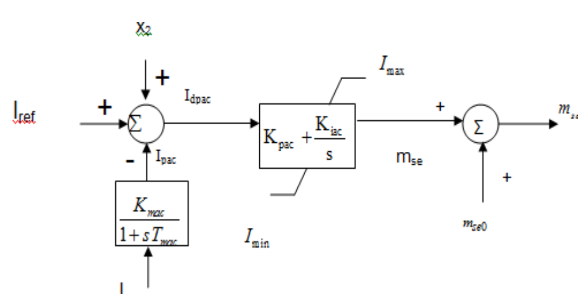

Figure-4. Voltage magnitude controller.

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The differential equations can be derived from the above blocks

$$\dot{I}_{pac} = \frac{1}{T_{mac}}\left[I * K_{mac} - I_{pac}\right] \qquad (9)$$

$$\dot{m}_{se1} = I_{dpac} * K_{iac} + \dot{I}_{dpac} K_{pac} \qquad (10)$$

e) DC voltage controller

This controls the phase angle of series injected voltage by varying. It is used to directly control the DC voltage magnitude. The controller has a bias corresponding to the phase angle β_0.

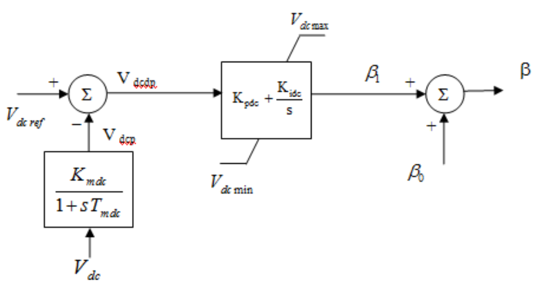

Figure-5.DC voltage controller.

$$\dot{V}_{dcp} = \frac{1}{T_{mdc}}\left[V_{dc} K_{mdc} - V_{dcp}\right] \qquad (11)$$

$$\dot{\beta}_1 = V_{dcdp} * K_{idc} + \dot{V}_{dcdp} K_{pdc} \qquad (12)$$

From Figure-1

$$P_{ac} = \frac{V_k I_{sh} \cos(\delta_k - \theta_{sh})}{CV_{dc}} - \frac{V\, I_1 \cos(\delta - \theta_1)}{CV_{dc}} \qquad (13)$$

$$P_{dc} = V_{dc}\, I_{dc} \qquad (14)$$

The capacitor dynamic equation is

$$\dot{V}_{dc} = \frac{V_k I_{sh} \cos(\delta_k - \theta_{sh})}{CV_{dc}} - \frac{V\, I_1 \cos(\delta - \theta_1)}{CV_{dc}} - \frac{G_c V_{dc}}{C} - \frac{a_{sh}^2 I_{sh}^2 R_{sh}}{CV_{dc}} - \frac{a_{se}^2 I_1^2 R_{se}}{CV_{dc}} \qquad (15)$$

f) UPFC current injection model

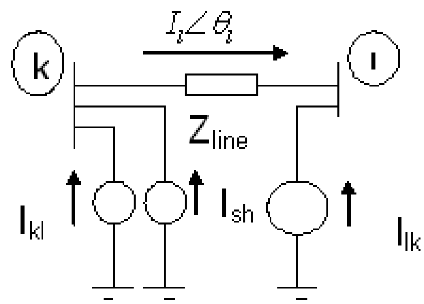

Figure-6.UPFC current injection model.

From the Figure-6, the current injected by UPFC to the HVAC bus is

$$I_{kl} = -\frac{V\angle\delta}{R_l + jX_l} \quad \text{(SSSC)} \qquad (16)$$

$$I_{kl} = \frac{V\angle\delta}{R_l + jX_l} \quad \text{(SSSC)} \qquad (17)$$

$$I_{sh} = \frac{K\, V_{dc}\angle\alpha}{R_t + jX_t} \quad \text{(STATCOM)} \qquad (18)$$

3. MODELLING OF POWER OSCILLATION DAMPING CONTROLLER

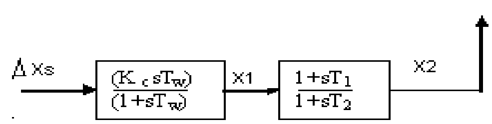

Figure-7.POD model.

The Power Oscillation Damping Circuit is used to damp out power oscillations. The main objective of this circuit is to filter out undesirable signals and provide a phase lead to the signal to compensate for phase lag. Before the phase lead, the stabilizing signal has to pass through a washout circuit to eliminate steady state bias in the output of the ac system, which will modify the power flow. The washout circuit is essentially a high-pass filter. The input signal may be a current, speed or, power.

$$\dot{x}_1 = \frac{1}{T_w}\left[(K_c * T_w * \Delta\dot{x}_s) - x_1\right] \qquad (19)$$

$$\dot{x}_2 = \frac{1}{T_2}\left[(T_{1*}\dot{x}_1) + x_1 - x_2\right] \qquad (20)$$

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4. ITERATIONS USING TRIANGULARISED ADMITTANCE MATRIX ALGORITHM FOR INTERFACING UPFC

The stepwise computations to be performed to advance the simulation by one step from t- Δt to t are as follows. The time step width (Δt) used in the algorithm is 0.01 sec.

Assumptions

i) The machines are considered to be classical (no controllers)

ii) Damping ignored

iii) Loads are assumed as constant admittances

Preparation

i) The initial conditions for δ , ω and voltages are obtained from load flow and the past history terms for δ and ω are obtained from the initial conditions.

ii) The initial condition and past history terms for FACTS controllers and PODC are calculated assuming the system in steady state initially.

Note

i) The loads are converted into the constant admittances and these are pushed in to diagonal elements of the corresponding load buses.

$Y_{TRANBUSii} = Y_{ii} + Y_{Li}$ Here i is for all load buses

ii) The diagonal elements of Y_{bus} corresponding to all synchronous generators are modified as:

$Y_{TRANBUSii} = Y_{ii} + 1/(R_{1i} + j X_{d'})$

iii) The diagonal elements of Y_{bus} corresponding to STATCOM are modified as:

$Y_{TRANBUSii} = Y_{ii} + 1/(R_t + j X_t)$

iv) The diagonal elements of Y_{bus} corresponding to UPFC are modified as: $Y_{TRANBUSii} = Y_{ii} + 1/(R_t + j X_t)$

a) Predict δ using Dahl's formula

$$\delta_{pred}(t) = 2\delta(t-\Delta t) - \delta(t-2\Delta t) + \frac{\Delta t^2}{2H}\left[P_m - P(t)\right]$$

b) Forming RHS of algebraic equations

i) Rotate Norton sources by change in δ (initially $\delta_{pred}(t) - \delta(t-\Delta t)$; later $\delta^{corr} - \delta$ (previous iteration)

ii) Find the Norton current injections at all the generator buses and FACTS controllers connected bus.

For synchronous machine : $I_{NOR} = \dfrac{E_q \angle \delta}{R_1 + jX_{d'}}$

For STATCOM connected bus : $I_{sh}\angle\theta_{sh} = \dfrac{KV_{dc}\angle\alpha}{R_t + jX_t}$

For SSSC connected line : $I_{km} = \dfrac{V\angle\delta}{R_l + jX_l}$

$I_{mk} = -\dfrac{V\angle\delta}{R_l + jX_l}$

For UPFC connected line

$I_{km} = \dfrac{V\angle\delta}{R_t + jX_t}$

$I_{mk} = -\dfrac{V\angle\delta}{R_t + jX_t}$

$I_{sh} = \dfrac{K\ V_{dc}\angle\alpha}{R_t + jX_t}$

c) Solve the network equations $[Y]_{TRANBUS}[V] = [I]_{NOR}$ to get the approximate value of synchronous machine terminal voltage V^{approx}.

d) Compute stator currents $I_i = I_{NORi} - Y_{NORi} * V_i$ and also real power outputs of all generators. $P_{geni} = \mathrm{Re}\{V_i I_i^*\}$.

e) Correct δ using trapezoidal discretized mechanical system equation.

$$\delta^{corr}(t) = -\frac{\Delta t^2}{8H}\omega_0 T_e(t) + \alpha_H(t-\Delta t)$$

Where

$$\alpha_H(t-\Delta t) = \delta(t-\Delta t) + \Delta t\omega_0\left[\omega(t-\Delta t) - 1\right] + \frac{\Delta t^2}{8H}\omega_0\left[2T_m - T_e(t-\Delta t)\right]$$

f) Check for δ convergence. If yes move to next step; else $\delta^{corr} = \delta_{pred}$ and go to step 2.i.

g) Check for ac and dc voltage convergence. If yes move to next step; else go to step-2.ii.

h) Compute generator internal variables and update past history terms.

i) Advance time and go to step-1

Handling network discontinuities

Consider at t=td network discontinuity occurs; this causes jump in voltage, current and power.

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a) After convergence at t=td- we obtain a network solution which is a normal time advance solution. This is referred to as the first solution at the discontinuity.
b) Change Y to reflect the effect of network switching and refactorize.
c) Perform another network solution with the refactorized Y. This is referred to as the second solution.

5. MODEL OF FUZZY BASED POD CONTROLLER

y using sliding mode fuzzy controller with boundary layer control concept, these two linguistic variables can be mixed together and a new single input single output fuzzy controller appears..

The magnitude of the control parameters depends upon on the distance of the state vector from the switching line.

For a second order system with a state vector is

$$x = (e, \dot{e}) \qquad (21)$$

The switching line is defined as:

$$s(x,t) = \dot{e} + \lambda e = 0$$

By the normalization of the state vector a new normalized state plane generates and in the normalized plane we obtain

$$\dot{e}_N + \lambda_N e_N = 0 \qquad (22)$$

By means of relationships

$$e_N = e/\alpha$$

$$\dot{e}_N = \dot{e}/\beta \qquad \lambda_N = \frac{\alpha}{\beta}$$

Where α, β -normalization factor

The Control input can be defined as

$$S_P = \frac{e_N + \dot{e}_N}{\sqrt{2}} \qquad (23)$$

With this approach S_P are the unique input of the fuzzy controller and the change of control voltage

A) Single input fuzzy logic controller

Single input FUZZY POD controller having three inputs

a) Speed
b) Current
c) Power

The block diagram shown in Figure-8 represents the single input fuzzy logic controller scheme for the conventional power oscillation-damping controller. The fuzzy POD controller is tested with three inputs such as Speed, Current, Power. This is sensed from the network. This is supplementary control signal to main PI controller.

Here α, β are the normalization factors, η is the gain factor .Two linguistics functions are available which are "positive" and "Negative". And its Corresponding outputs are $\delta\omega$, δp , δi . Unique input and only two-rule base membership are limited for controlled outputs

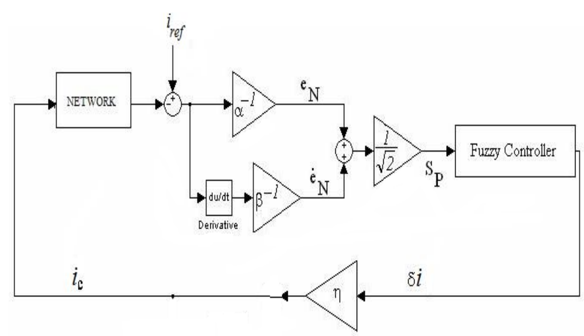

Figure-8.single input and single output controller scheme (current input).

Two possible control rules are as follows:

if S_P is positive $\delta\omega$ is positive

S_P is negative $\delta\omega$ is negative

Similarly the corresponding rule bases are available for remaining inputs. For the defuzzification method mamdani's min implication and center of gravity method is selected for the controller.

6. SIMULATION RESULTS

A standard 9-bus system (Foud and Anderson, 1977) is considered for the investigation as shown in Figure-9. The initial relative rotor angle obtained from the load flow solution is δ_{21} =17.5373

A three phase self-clearing fault is considered for analysis. Three phase fault is applied near to bus 7 at time t=1.01s.and it is cleared at 1.09s. The fault is cleared at 1.09 sec.

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9 bus system

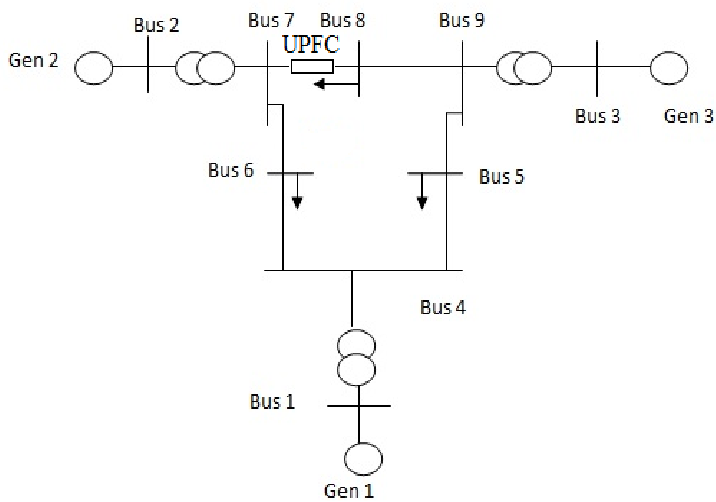

Figure-9. The 9 bus systems.

Line data

Table-1. Line data.

S. No.	From	To	Resistance (R) (P.U.)	Reactance (X) (P.U.)	Susceptance(B/2)(P.U.)
1	1	4	0.0	0.0576	0.0
2	2	7	0.0	0.0625	0.0
3	3	9	0.0	0.0586	0.0
4	4	5	0.01	0.085	0.088
5	4	6	0.017	0.092	0.079
6	5	7	0.032	0.161	0.153
7	6	9	0.039	0.17	0.179
8	7	8	0.085	0.0720	0.0745
9	8	9	0.0119	0.1008	0.1045

Machine data

Table-2. Machine data.

Machine. No.	$X_{d'}$	H
1	0.0608	23.64
2	0.1198	6.4
3	0.1813	3.01

Results

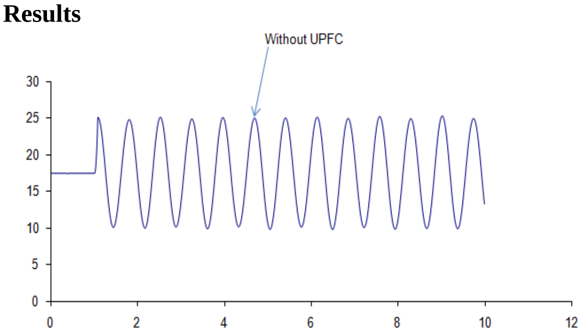

Figure-10. Variation of relative rotor angle deviation of machine 2 with respect to time.

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From the Figure-10 it can be observe that there is an oscillation on rotor angle.

The single line diagram of the standard 9 bus system with UPFC connected between bus 8 and bus 7 is shown in Figure-9. The swing curve obtained without UPFC for machine 2 (relative rotor angle) is shown in Figure-10. The swing curve obtained with UPFC without POD is shown in Figure-10. The swing curves obtained with UPFC with POD with current, eed and power as input are shown in Figures 11, 12, 13 respectively.

With UPFC POD

Input: Current

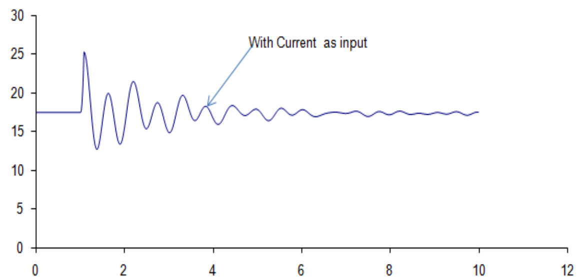

Figure-11. Variation of relative rotor angle deviation of machine 2 with respect to time with UPFC POD when current is given as input.

From the above Figure-11 it can be observed that the power oscillation Damping Controller operating with UPFC to Damp out the oscillation when controller input is current.

POD Input: Omega

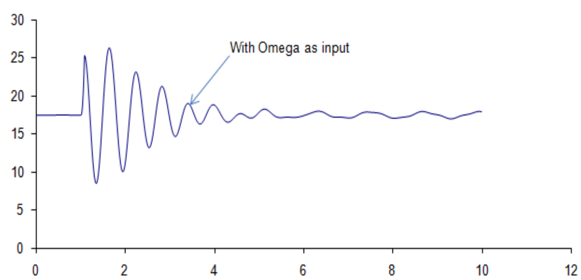

Figure-12. Variation of relative rotor angle deviation of machine 2 withrespect to time UPFC POD when speed is given as input.

From the above Figure-12 it can be observed that the power oscillation Damping Controller operating with UPFC to Damp out the oscillation when controller input is speed

POD Input: Power

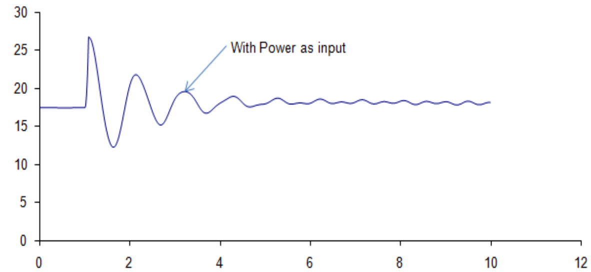

Figure-13. Variation of relative rotor angle deviation of machine 2 with respect to time UPFC PODC when power is given as input.

From the above Figure-13 it can be observed that the power oscillation Damping Controller operating with UPFC to Damp out the oscillation when controller input is Power.

Comparison of all the POD Input

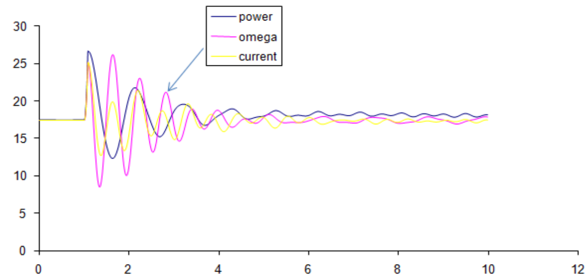

Figure-14. Variation of relative rotor angle deviation of machine 2 with respect to time.

From Figure 11,12,13,14, it can be observed that the performance is better of POD when speed (ω) is used as the input signal. Still there is a need to improve the effectiveness of controllers to damp out the oscillations quickly; hence an attempt is made to use fuzzy controller instead of PI controller, which is robust in nature. In this work a single input and single output fuzzy controller is investigated.

SISO fuzzy based POD Input-Current

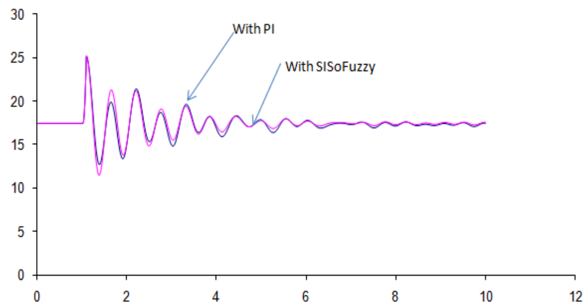

Figure-15. Variation of relative rotor angle deviation of machine 2 withrespect to time Fuzzy UPFC POD when current is given as input.

From the above Figure-15, it can be observed that the fuzzy controller damp out the oscillation quickly, the input given to the fuzzy controller is current

SISO fuzzy based POD Input-Power

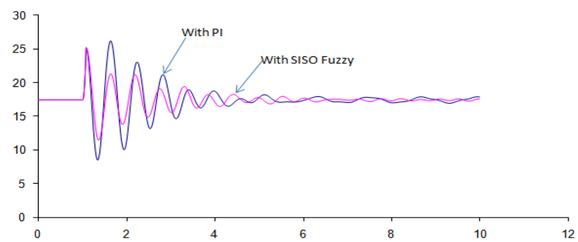

Figure-16. Variation of relative rotor angle deviation of machine 2 withrespect to time Fuzzy UPFC POD when power is given as input.

From the above Figure-15, It can be observed that the fuzzy controller damp out the oscillation quickly.

SISO fuzzy based POD Input-Speed

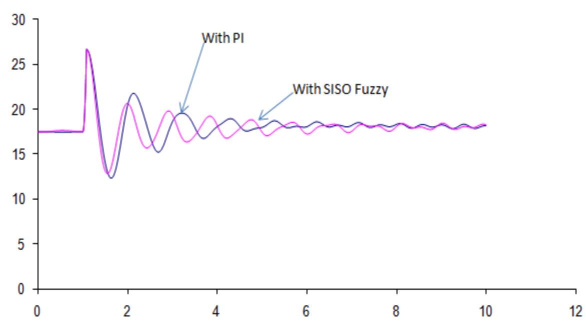

Figure-17. Variation of relative rotor angle deviation of machine 2 withrespect to time Fuzzy UPFC POD when speed is given as input.

From Figure-15, Figure-16 and Figure-17, it can be observed that the performance is better when current is used as the input signal.

7. CONCLUSIONS

In this paper, a standard three-machine nine bus system with UPFC has been established. From the results , it is seen that the damping of the system is improved by UPFC POD and It is also revealed from the analysis the proposed fuzzy Based UPFC POD is more effective in improving transient stability over the conventional PI controller.

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