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Damping of Power System Oscillations by UPFC Equipped with Fuzzy Logic Controller

Jayendra Parjapati*, Navita and Sreekanth K. Reddy*****

ABSTRACT

The power system becomes much larger and complex, so there is more chance of occurrence of fault and contingency. Due to fault into the system, power oscillations occurred. The power oscillations are the major issue in the power system operation. Due to power oscillations, losses are increases and power transfer capability is reduce. In the recent years, PSS is used for damping of power oscillation. But now days, FACTS devices are used. In this paper, single machine infinite bus (SMIB) model is used for analysis. UPFC is installed for damping of power oscillation. For the improvement of the results, fuzzy logic controller (FLC) is used. The complete model is performed in MATLAB/Simulink environment. Simulink results demonstrate that fuzzy logic controller is more effectively damp the power oscillations.

Keywords: FACTS, UPFC, fuzzy logic controller, MATLAB/simulation, single machine infinite bus (SMIB), power system oscillation, power system stabilizers (PSS)

1. INTRODUCTION

Due to increase in complexity in the power system, it becomes less stable against disturbance. Due to fault into the system, power oscillations occurred [3]. Due to any fault and disturbance into the system, rotor angle oscillates near the steady state value at the natural frequency. If the system is under damped and fault is occur into the system, due to oscillations in rotor angle, power is also oscillate near the normal operating condition and steady state value. The range of power oscillations are between 0.1 to 2 Hz. This range depends upon the number of generators into the system [5].

In the past, power system stabilizers (PSS) are used for damping of power oscillations. But there are many problems in the PSS. It is used for local mode of oscillations and it produces large variation in the voltage profile [2]. To control the power system, mechanical controllers are used. But there are many problems of using mechanical controllers. The first major disadvantage is that it provides the control action at slow rate. And second disadvantage is that we cannot use it in frequent manner. To overcome these problems, we use FACTS devices. The recent development in power electronics, power electronic based devices are used for damping of oscillations. Alternating current transmission systems are combined with power electronic based devices and other static devices to increases the stability of power system and increase the power transfer capabilities of the system. FACTS devices are capable to increase the power transfer into the transmission line. In this paper, UPFC is used damping of oscillation. UPFC is the most versatile device which controls all the three parameters (angle, impedance and voltage) effectively. The

* M.Tech. Scholar, Lovely Professional University, *Email: jayendraparjapati@gmail.com*

** Assistant Professor, School of Electronics and Electrical Engineering, *Email: navita.17119@lpu.co.in*

*** Assistant Professor, School of Electronics and Electrical Engineering, Lovely Professional University, Punjab, India, *Email: sreekanth.14898@lpu.co.in*

control of real and reactive power flow is independently and simultaneously done by UPFC [6]. Fuzzy logic controller is designed with UPFC for enhancement of stability of the system. Fuzzy sets defined the uncertainty in human language and very effective manner. It defined the uncertainty in very simple manner so that every person should understand. All the logical operations like union, intersection, product and equality are also defined in this theory [9]. This paper investigates the damping of power oscillations in single machine infinite bus model (SMIB). SMIB model is designed in MATLAB/Simulink environment with UPFC. This paper is structured as follow: section II presents about power system oscillation; section III presents UPFC principal operation; section IV presents fuzzy logic controller; section V presents simulations and results and section VI concludes the paper.

2. POWER SYSTEM OSCILLATION

Due to any fault and disturbance into the system, rotor angle oscillates near the steady state value at the natural frequency. If the system is under damped and fault is occur into the system, due to oscillations in rotor angle, power is also oscillate near the normal operating condition and steady state value. The range of power oscillations are between 0.1 to 2 Hz. This range depends upon the number of generators into the system [4].

Reasons of Power System Oscillations

1. Dynamic loading in system.
2. Sub Synchronous Resonance in the system.
3. Occurrence of fault.
4. Due to insufficient damping torque [8].

Affects of Power System Oscillations

1. Power transfer capability is reduce.
2. It affects the loads and equipments.
3. Reduction of thermal capacity of line.
4. Low frequency power swing increase [4].

Benefits of Power Oscillation Damping

1. Enhancement of thermal capacity of line.
2. Less affect on loads and equipments.
3. Increase power transfer capacity.
4. Losses are reduced [4].

3. UPFC PRINCIPLE OPERATION

The UPFC is a versatile device which is used for compensation of reactive power and controls all the parameter that affects the power flow into the line. UPFC is a multifunction device that solves the problem of power delivery industry [6].

The power transfer from the line is given by equation:

$$P = \frac{E_S E_R}{X} \sin \delta \tag{1}$$

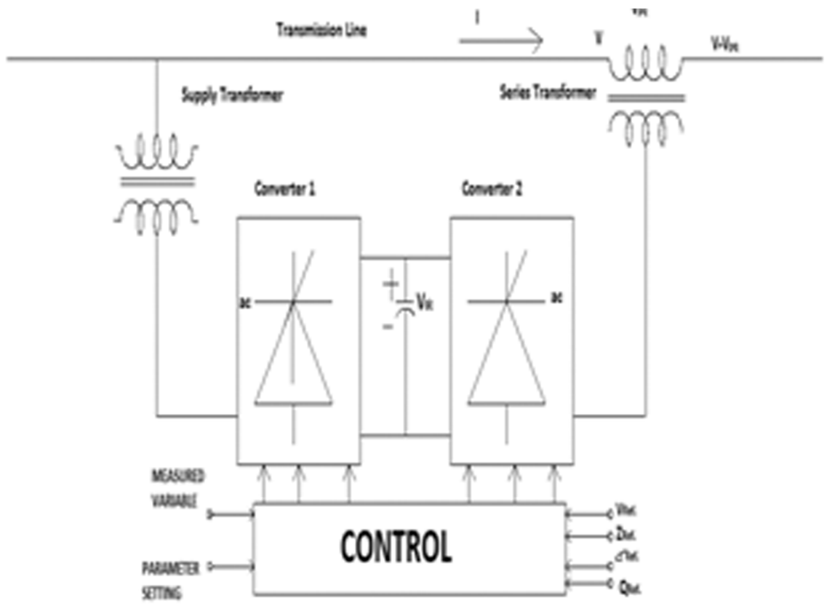

Figure 1: Implementation of the UPFC by two back-to-back voltage-sourced converters.

So the power is dependent on three parameters (voltage, impendence, and angle). UPFC control all the three parameters which affect the power flow through the line and for this ability of UPFC, it is defined as "unified".

UPFC consist of two voltage source converters which are connected by a common dc link, as shown in figure 1. There is back-to back connection between converters, in which one converter is labeled as converter 1 and another is converter 2. A capacitor is used as dc link. The real power exchange between the converters is done by dc link and real power can flow in either direction by dc link. Both the converters can independently absorb and supply the reactive power [6].

3.1. Mathematical Modeling of UPFC

Generally, UPFC is represented by voltage phasor V_{pq} at the fundamental frequency. UPFC is injected voltage phasor in series with transmission line whose magnitude is V_{pq} ($0 \le V_{pq} \le V_{pqmax}$) and phase angle ρ ($0 \le \rho \le 2$) [6].

The transmitted real power and supplied reactive power at the receiving end is given by equation 2.

$$P - jQr = Vr\frac{(Vs + Vpq - Vr)^*}{jX} \tag{2}$$

Where symbol * means the conjugate of a complex number and $j = e^{j\frac{\pi}{2}}\sqrt{-1}$. For uncompensated line $V_{pq} = 0$, then (2), the total real and power can be written in the form

$$P - jQr = Vr\frac{(V_s - V_r)^*}{jX} \tag{3}$$

For compensated line $V_{pq} \neq 0$, equation (2.1) can be written in the form

$$P - jQr = Vr\frac{(V_s - V_r)^*}{jX} + \frac{VV_{pq}^*}{-jX} \tag{4}$$

Substituting

$$V_S = V_e^{j\frac{\delta}{2}}\left(\sin\frac{\delta}{2} + j\cos\frac{\delta}{2}\right) \tag{5}$$

$$V_r = V_e^{-j\frac{\delta}{2}}\left(\sin\frac{\delta}{2} + j\cos\frac{\delta}{2}\right) \tag{6}$$

And

$$V_{pq} = V_{pqe}^{\;j\left(\frac{\delta}{2}+\rho\right)}\left\{\sin\left(\frac{\delta}{2}+\rho\right) + j\cos\left(\frac{\delta}{2}+\rho\right)\right\} \tag{7}$$

The following expressions are obtained for P and Q_r:

$$P(\delta,\rho) = P0(\delta) + P_{pq}(\rho) + \frac{V^2}{X}\sin\delta - \frac{VV_{pq}}{X}\cos\left(\frac{\delta}{2}+\rho\right) \tag{8}$$

And

$$Qr(\delta,\rho) = Q0r(\delta) + Q_{pq}(\rho) + \frac{V^2}{X}(1-\cos\delta) - \sin\left(\frac{\delta}{2}+\rho\right) \tag{9}$$

Where

$$P_0(\delta) = \frac{V^2}{X}\sin\delta \tag{10}$$

And

$$Q_{0r}(\delta) = -\frac{V^2}{X}(1-\cos\delta) \tag{11}$$

Equation (9) and (10) showed the real and reactive power at angle δ for uncompensated line. The angle ρ vary from 0 to 2π and transmission angle vary from o to π. The real power and reactive power independent from δ and controllable between $-VV_{pq}/X$ and $+VV_{pq}/X$ [6].

The range of transmitted real power is

$$P_0(\delta) - \frac{VV_{pq\max}}{X} \le P_0(\delta) \le P_0(\delta) + \frac{VV_{pq\max}}{X} \tag{12}$$

And the reactive power is controllable between

$$Q_{0r}(\delta) - \frac{VV_{pq\max}}{X} \le Q_{0r}(\delta) \le Q_{0r}(\delta) + \frac{VV_{pq\max}}{X}$$

4. FUZZY LOGIC CONTROLLER

Fuzzy sets defined the uncertainty in human language and very effective manner. It defined the uncertainty in very simple manner so that every person should understand. All the logical operations like union, intersection, product and equality are also defined in this theory. Fuzzy logic is used linguistic variable and the linguistic variables are those variables whose variables are word not number [9].

The FLC consists of four process, Fuzzification, rule base, fuzzy interface engine and defuzzification. Mamdani type FLC with double input single output has been used. Output active power and rotor speed

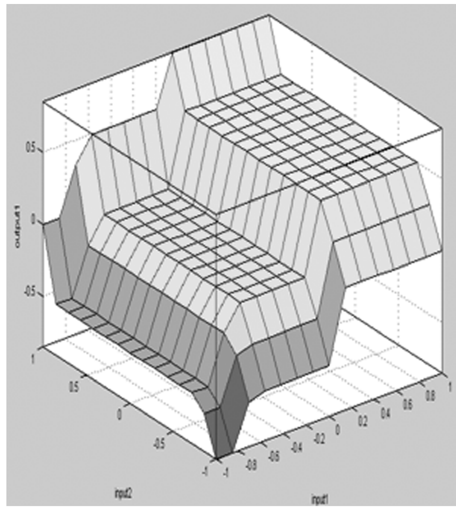

Figure 2: Surface plot of FLC

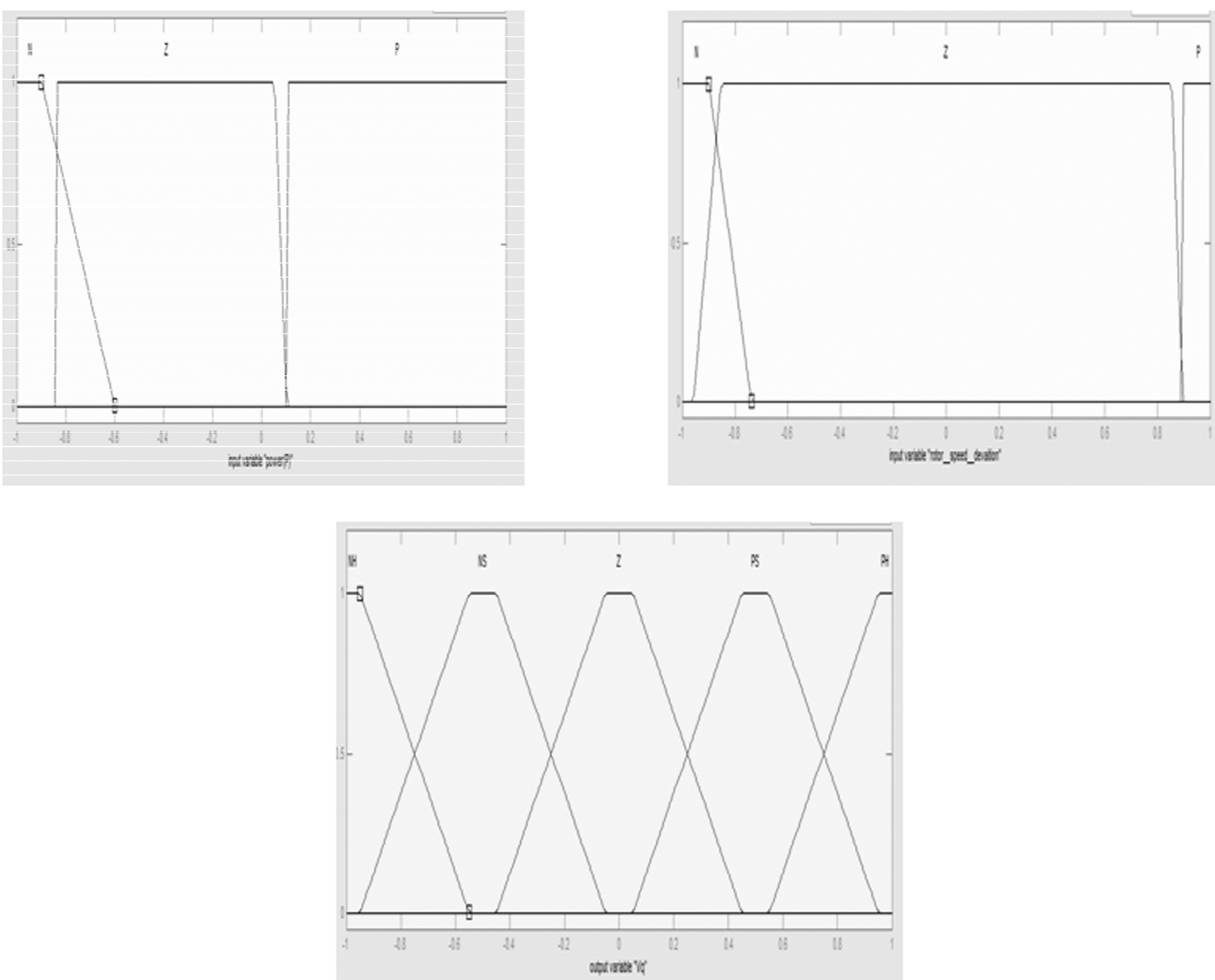

Figure 3: Membership functions for inputs and output of FLC

deviation is given as input to the fuzzy controller [10]. In this study, the membership functions that are used are trapezoidal (trap.) membership function. The output membership functions that are used are also trapezoidal membership function. Linguistic variables chosen as negative (N), zero (Z), positive (P) are used for both the inputs. For the output, linguistic variables chosen as negative small (NS), negative high (NH), zero (Z), positive small (PS) and positive high (NH). The fuzzy set implementation is given in table 1. The membership functions are shown in figure 3. The surface plot is given in figure in 2.

Table 1, given below gives the basic concept how the fuzzy rule base has been designed.

Table 1
Fuzzy set

Power	*Rotor angle deviation*		
	N	Z	P
N	NH	NS	Z
Z	NS	Z	PS
P	Z	PS	PH

5. SIMULATIONS AND RESULTS

In this single machine infinite bus (SMIB) system, the initial mechanical power is taken Pm = 0.701218 and voltage reference V_f = 1.54063. The rating of first transformer is equal to 1000 MVA. The rating of step up transformer is 1000 MVA, 15.7/400 kV. The length of the transmission line is equal to 500 km which is divided into 200 km and 300 km length. For analysis of power oscillation damping, a three phase fault is created in the system. After occurrence of fault, we analysis the variation in the rotor angle and active power. We created the fault in the system during 0.2 to 0.4 seconds. There is large variation in the rotor angle and output active power between this time duration. These oscillations are damped out using different FACTS devices. In this, we use UPFC to damp out the power oscillations from the system.

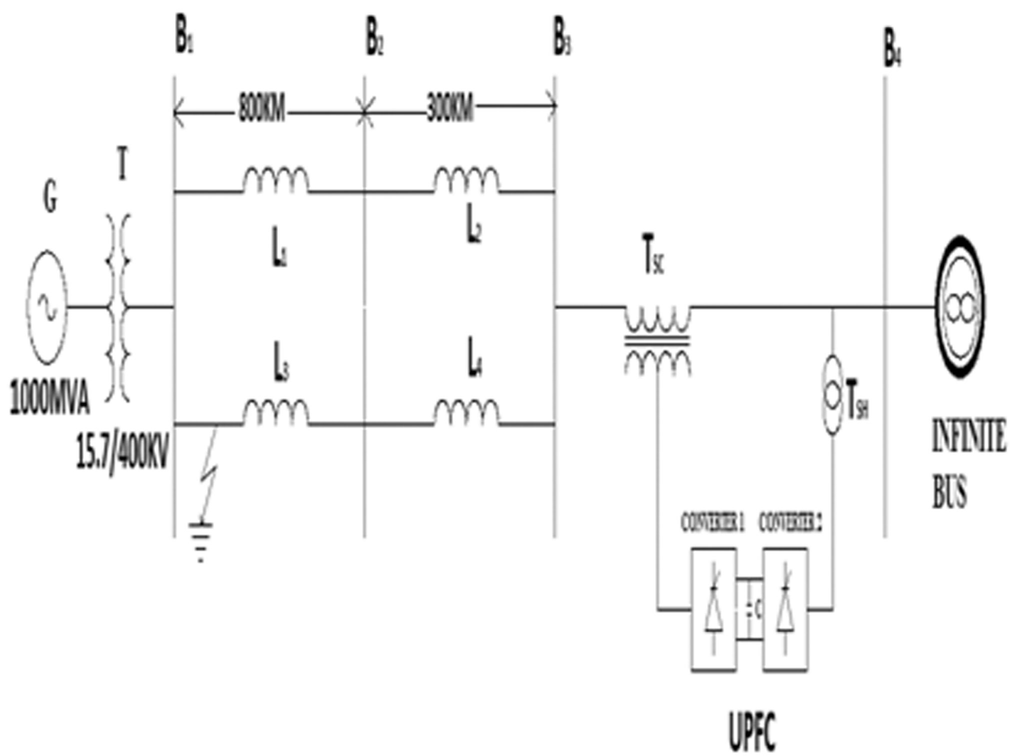

Figure 4: Single line diagram of SIMB system with FACTS device

5.1. Results

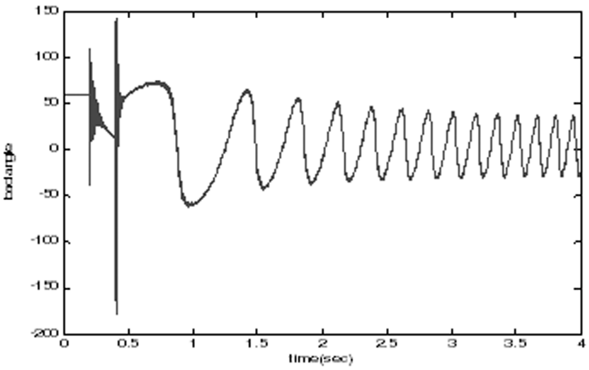

Figure 5: Variation of rotor angle with three phase fault

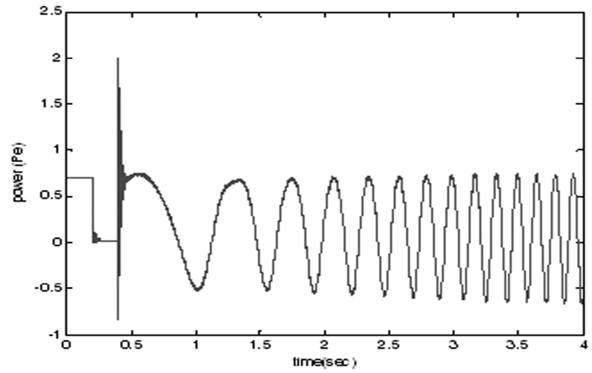

Figure 6: Variation of power with three phase fault

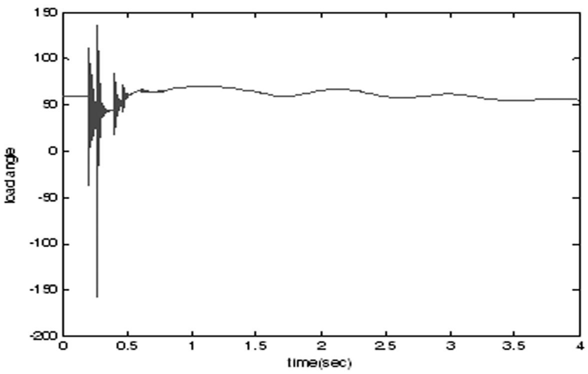

Figure 7: Variation of rotor angle with UPFC

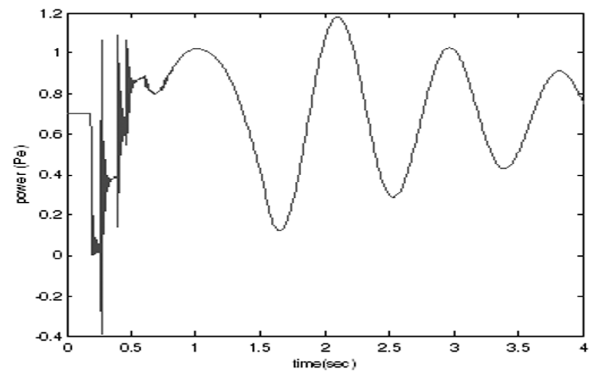

Figure 8: Variation of power with UPFC

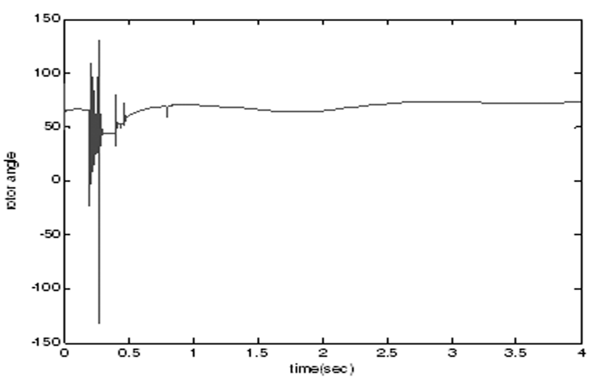

Figure 9: Variation of rotor angle with UPFC+FLC

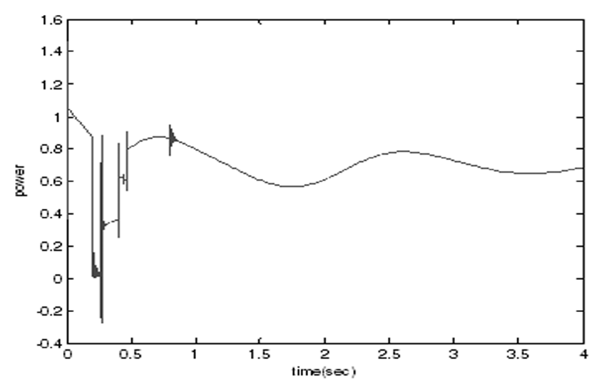

Figure 10: Variation of power with UPFC+FLC

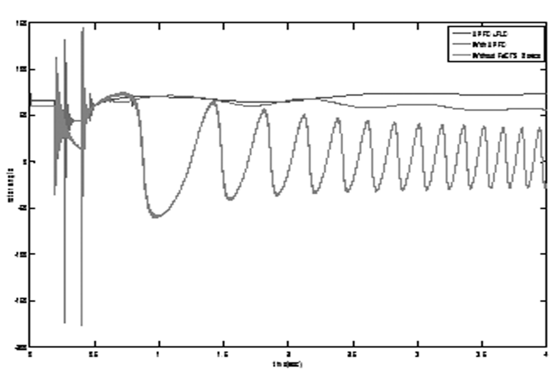

Figure 11: Output comparisons in load angle

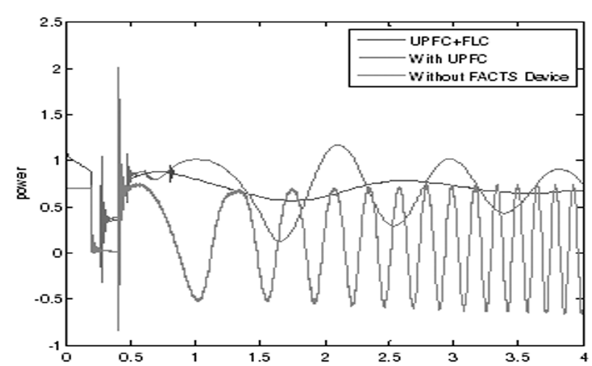

Figure 12: Output comparisons in power

Table 2
Output comparison

S. No.	*System Parameter*	*Without Any Facts Device*	*UPFC*	*UPFC+FLC*
1.	LoadAngle	Maximum Peak Overshoot = 144	Maximum Peak Overshoot = 140	Maximum Peak Overshoot = 128
		Settling Time = Very Large	Settling Time = Small	Settling Time = Very Small
2.	Power	Maximum Peak Overshoot = 2 p.u.	Maximum Peak Overshoot = 1.2 p.u.	Maximum Peak Overshoot = 0.96 p.u.
		Settling Time = Very Large	Settling Time = Small	Settling Time = Very Small

6. CONCLUSIONS

In this study, single machine infinite bus (SIMB) is used for analysis of power oscillations. A MATLAB simulation of the system is used for study the effect of oscillations on the power system and methods for damping these oscillations. It has been observed that oscillations are damp out by use of FACTS devices. Power oscillation are damp out from the system, power quality is improved.

The work done so far can be summarized in the following points:

a) Oscillations are occurs in the system due to faults in the system.

b) Due to these oscillations, power quality is decreases and life of the equipments is reduced.

c) Due to oscillations in power and load angle, equipments are damaged.

d) Power oscillations are damped by using UPFC.

e) Better results are achieved by using fuzzy logic controller.

f) Better results can be achieved in future by using different optimization techniques.

7. APPENDIX

The data which is used in MATLAB model is given as

I. Transformer parameters:

a. T = 1000MVA, 15.7/400 kV

b. R_2 = 0.0059 p.u.

c. L_2 = 0.127 p.u.

d. R_m = 500Ω

II. Generator parameters:

Table 3
Generator parameters

S_o	MVA	1000	X_d’	p.u.	0.32
V_n	kV	15.7	X_q”	p.u.	0.213
X_d	p.u.	1.896	X_d”	p.u.	0.213
X_q	p.u.	1.896	X_d’	p.u.	0.32

(*contd...*)

(*Table 3 contd...*)

X_2	p.u.	0.26	t_d’	p.u.	1.083
X_0	p.u.	0.0914	t_q’	p.u.	1.1
R_a	p.u.	0.00242	t_d’’	p.u.	0.135
J	kg-m^2	10^5	t_q’’	p.u.	0.135

III. Transmission Line parameters:

a. Number of phases = 3

b. F = 60Hz

c. Line 1 = 200 km

d. Line 2 = 300km

e. $R_1 = 0.007\Omega$/km

f. $R_0 = 0.032\Omega$/km

g. $L_0 = 0.9337*10^{-3}$H/km

h. $L_1 = 0.103*10^{-2}$ H/km

i. $C_1 = 12.74*10^{-9}$ F/km

j. $C_0 = 1.1*10^{-8}$ F/km

IV. UPFC parameters:

a. System nominal voltage = 400kV

b. F = 60Hz

c. Shunt converter rating = 160MVA

d. R_1 = 0.004 p.u.

e. L_1 = 0.1 p.u.

f. C = 483.75μF

g. Series converter rating = 160MVA

h. R_2 = 0.005 p.u.

i. L_2 = 0.06 p.u.

V. For per unit calculation

a. V_{base} = 15.7 kV

b. S_{base} = 1000MV

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