

# Fuzzy Control Scheme for Damping of Oscillations in Multi Machine Power System with UPFC

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**Abstract** Power stability is an important issue that is becoming increasingly important to power systems at all levels. We are unable to achieve the stability of the system due to some factors. Low frequency oscillation's is one of the major factors that affect the transmission line capacity. Traditionally power system stabilizers (PSS) are being used to damp these inevitable oscillations. In advanced technology FACTS devices such as unified power flow controllers (UPFC) are used to control the power flow in transmission lines. They can also replace the PSS to damp the low frequency oscillations effectively through direct control of voltage and power. In our model, single machine infinite bus power system with UPFC is considered. The designed FUZZY based UPFC controllers adjusts four UPFC inputs by appropriately processing of input error signal and provides an efficient damping. The results of the simulation show that the UPFC with FUZZY LOGIC controller is effectively damping the LOW FREQUENCY OSCILLATIONS.

**Key Words:** FACTS Devices<sup>1</sup>, UPFC<sup>2</sup>, Power Oscillation Damping Controller<sup>3</sup>, Fuzzy Logic Controller<sup>4</sup>, Power System Stability<sup>5</sup>.

## 1.INTRODUCTION

The demand for electric power is increasing day by day. Recent major black-outs across the globe caused by system instability, even in very sophisticated and secure systems, illustrate the problems facing secure operation of power systems. Earlier, stability was defined as the ability of a system to return to normal or stable operation after having been subjected to some form of disturbance. This fundamentally refers to the ability of the system to remain in synchronism [1]. However, modern power systems operate under complex interconnections, controls and extremely stressed conditions. Further, with increased automation and use of electronic equipment, the quality of power has gained utmost importance, shifting focus on to concepts of voltage stability, frequency stability, inter-area oscillations etc. thus increasing the electric power demand. Nowadays FACTS devices can be used to control the power flow and enhance system stability, which provides the needed correction of the transmission system [2] [3].

FACTS (Flexible AC Transmission System) is defined as an alternating current transmission system incorporating semiconductor-based power electronics and other static controllers in order to enhance power transfer capacity and increase controllability of transmission. It increases the ability to accommodate changes in operating conditions simultaneously, maintain steady state and transient stability margins.

FACTS devices have shown very promising results when used to improve the power system steady state performance [2]. In addition, because of the extremely fast control action associated with FACTS-device operations, they have been very promising elements for utilization in power system damping enhancement. Unified Power Flow Controller (UPFC), being one the member of the FACTS device thus emerged as one of the effective controllers for controlling and optimization of the power flow in the electrical power transmission systems [3]. This device was formed due to the combination of the two other FACTS devices, namely Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). These are connected to each other by a common DC link, which is a typical a storage capacitor. The all parameters of the power transmission line (impedance, voltage and phase angle) can be control simultaneously by UPFC [4]. In addition, it can perform the control function of the transmission line real / reactive power flow, UPFC bus voltage and the shunt-reactive- power flow control [5].

The control mechanism and the controller have an important effect on the performance of UPFC. A novel fuzzy inference system described in matrix form was proposed and used to improve the dynamic control of real and reactive power [6]. Two fuzzy logic controllers based on Mamdani type fuzzy logic were used.

The fuzzy logic control technique has been an active research topic in automation and control theory since the work of Mamdani proposed in 1974 based on the fuzzy sets theory of Zadeh proposed in 1965 to deal with the system control

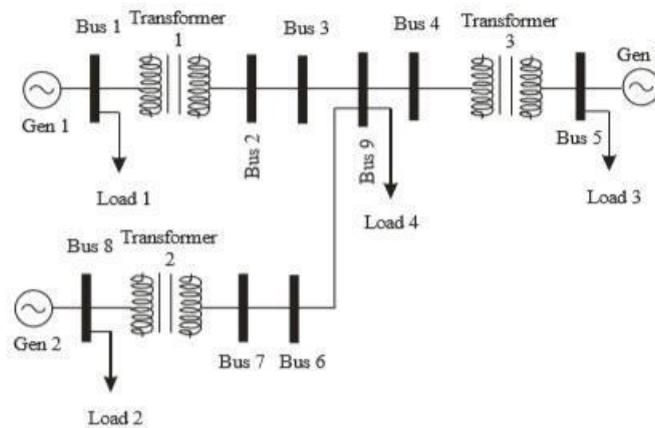
problems which are not easy to be modelled [7]. The concept of FLC is to utilize the qualitative knowledge of a system to design a practical controller. Fuzzy logic controllers are nothing but rule-based controllers in which a set of rules representing a control decision mechanism to adjust the effect of certain cases coming from power system is considered. Further, these FLCs do not require a mathematical model of the system & can cover a wide range of operating conditions with much robustness inherency. FLCs combined with UPFC can definitely reduce the POD in multi-machine systems [8].

**2. SINGLE LINE DIAGRAM OF POWER SYSTEM**

The multi machine power system network consisting of three generators, nine bus and four loads used for the simulation model is shown in the form of a single line diagram without and with controller in Fig. 1 & 2 respectively.

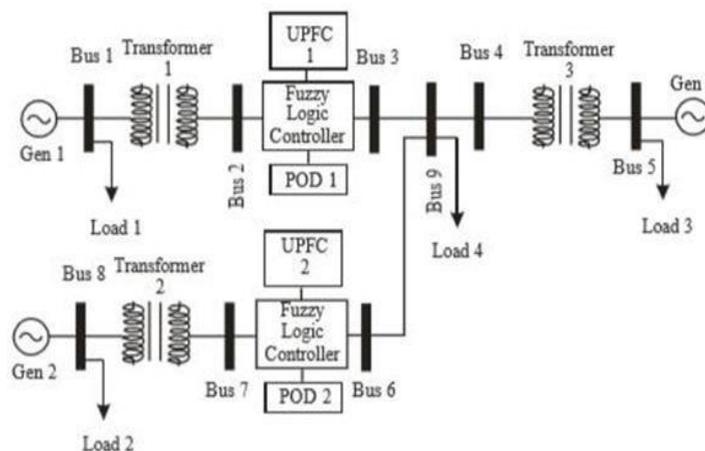
The generators 1, 2 and 3 are connected to buses 1, 5 and 8. Two UPFC's are used for controlling & damping the power system oscillations in the integrated plant [9]. One is connected between bus 2 & 3 and the other is connected between buses 6 and 7.

Three transformers T1, T2 & T3 are used in the system near the generator buses for the stepping up and stepping down purposes. Transmission lines are connected between the buses 3-9-4-6.



**Figure- 1: A 3-machine, 9-bus interconnected power system model with 4-loads without the controller**

Figure 1 and 2 represents the single line diagram of 3- machine system without and with hybrid controller. The generators 1, 2 and 3 are connected to buses 1, 5 and 8. Two UPFC's are used for controlling & damping the power system oscillations in the integrated plant [9]. One is connected between bus 2 & 3 and the other is connected between buses 6 and 7 [12].



**Figure -2: A 3-machine, 9-bus interconnected power system model with 4-loads & 2 POD-UPFC & the fuzzy logic controller**

### 3. CONTROL STRATEGY

The development of the control strategy for damping of oscillations in power system in this work is to develop UPFC-POD Controller coordinated with Fuzzy Logic Controller. A controller is a device which brings stability to the system when there is a disturbance or a noise or a fault, thus safeguarding the equipment from further damages, i.e., which controls each & every operation in the system making decisions.

UPFC consists of two solid state synchronous voltage source converters coupled through a common DC link capacitor as shown in Fig. 3, i.e., 2 voltage source inverters sharing a common DC storage capacitor. Two coupling transformers are used. As shown in Fig. 3, the UPFC consists of a boosting transformer and an excitation transformer linked by back-to-back converters 1 and 2. The first converter 1 is connected in shunt and the second one 2 in series with the line [10] [11]. Converter 1 can also generate or absorb reactive power and thereby provide independent shunt reactive compensation for the line. Converter 2 provides the main function of the UPFC by injecting additional voltage with controllable magnitude and phase angle in series with the transmission line through series transformer. The UPFCs are used at certain locations in an integrated power system in between some buses. Fig. 3 represents the buses in the integrated power system model.

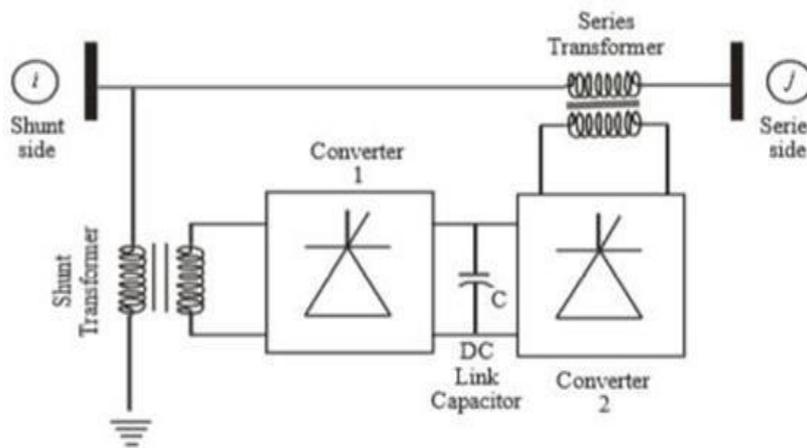


Figure -3: A block diagram of the UPFC scheme used in

#### FACTS (single line diagram)

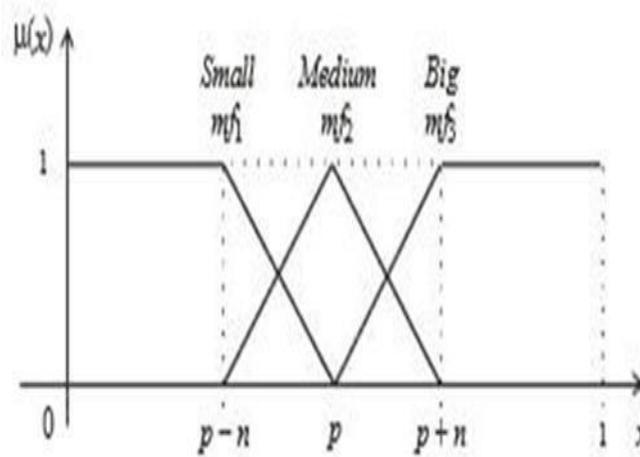
Fuzzy logic is, introduced by Lotfi A. Zadeh, a mathematical tool to dealing with uncertainty. In general, fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. On the contrary, the tradition binary set theory describes crisp events, that is, events that either do or do not occur. It uses probability theory to explain if an event will occur, measuring the chance with which a given event is expected to occur. The theory of fuzzy logic is based upon the notion of relative graded membership and so are the functions of cognitive processes. Our basic structure of the fuzzy logic coordination controller to damp out the oscillations in the power system consists of 3 important parts, viz., fuzzification, knowledge base - decision making logic (inference system) and the defuzzification, which are explained in brief as follows.

The necessary inputs to the decision-making unit blocks are the rule-based units and the data-based block units. The fuzzification unit converts the crisp data into linguistic variables. The decision-making unit decides in the linguistic variables with the help of logical linguistic rules supplied by the rule base unit and the relevant data supplied by the data base. The output of the decision-making unit is given as input to the defuzzification unit and the linguistic variables of the signal are converted back into the numeric form of data in the crisp form. The decision-making unit uses the conditional rules of „IF-THEN-ELSE“.

The inputs Pupfc1 and Pupfc2 are the active power flow through the UPFC1 and UPFC2. The output signals are command signals adjusted to the UPFC controllers 1 and 2. In this way, the conventional POD controllers are tuned by using fuzzy-coordination controllers. Fuzzification is a process whereby the input variables are mapped onto fuzzy variables (linguistic variables). Each fuzzified variable has a certain membership function. The inputs are fuzzified using three fuzzy sets: B (big), M (medium) and S (small).

The developed fuzzy rules included in the fuzzy coordinated controller are given below in the form of an algorithm as follows:

- i. If (input\_1 is mf1) and (input\_2 is mf1) then (output\_1 is mf3)(1)
- ii. If (input\_1 is mf1) and (input\_2 is mf2) then (output\_1 is mf2)(1)
- iii. If (input\_1 is mf1) and (input\_2 is mf3) then (output\_1 is s1)(1)
- iv. If (input\_1 is mf2) and (input\_2 is mf1) then (output\_1 is mf3)(1)
- v. If (input\_1 is mf2) and (input\_2 is mf2) then (output\_1 is mf2)(1)
- vi. If (input\_1 is mf2) and (input\_2 is mf3) then (output\_1 is s1)(1)
- vii. If (input\_1 is mf3) and (input\_2 is mf1) then (output\_1 is mf3)(1)
- viii. If (input\_1 is mf3) and (input\_2 is mf2) then (output\_1 is mf2)(1)
- ix. If (input\_1 is mf3) and (input\_2 is mf3) then (output\_1 is s1)(1)



**Figure -4: Membership function used in the fuzzification process**

Figure 4 represents the membership function used in the fuzzification process. The membership functions are taken as Small (mf1), Medium (mf2) and Big (mf3). The 9 fuzzy rules has already been discussed above.

Table 1 : The 9-fuzzy rules used for determining the output decisions (Inference table) rule base used for the control purposes

PUPFC1	Small set S mf <sub>1</sub>	Medium set M mf <sub>2</sub>	Big Set B mf <sub>3</sub>
PUPFC2			
Small set S mf <sub>1</sub>	B	M	S
Medium set M mf <sub>2</sub>	B	M	S
Big Set B mf <sub>3</sub>	M	S	S

Control decisions are made based on the fuzzified variables. Inference involves rules for determining output decisions. Due to the input variables having three fuzzified variables, the fuzzy-coordination controller has nine rules for each UPFC controller. The rules can be obtained from the system operation and the knowledge of the operator. To improve the damping of oscillations in power systems, supplementary control laws can be applied to existing power system. These supplementary actions are referred to as power oscillation damping (POD) controller. Commonly the POD controllers involve a transfer function consisting of an amplification link, a washout link and two lead-lag links shown in Fig.6. In this paper the active power of the transmission line is used as input signal. For dynamic performance of a multi-machine system, the behavior of the controllers must be coordinated. Otherwise the power system will be deteriorated [14].

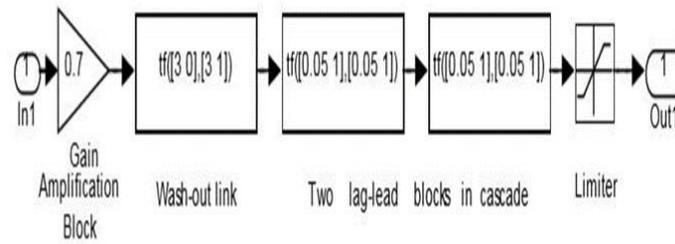


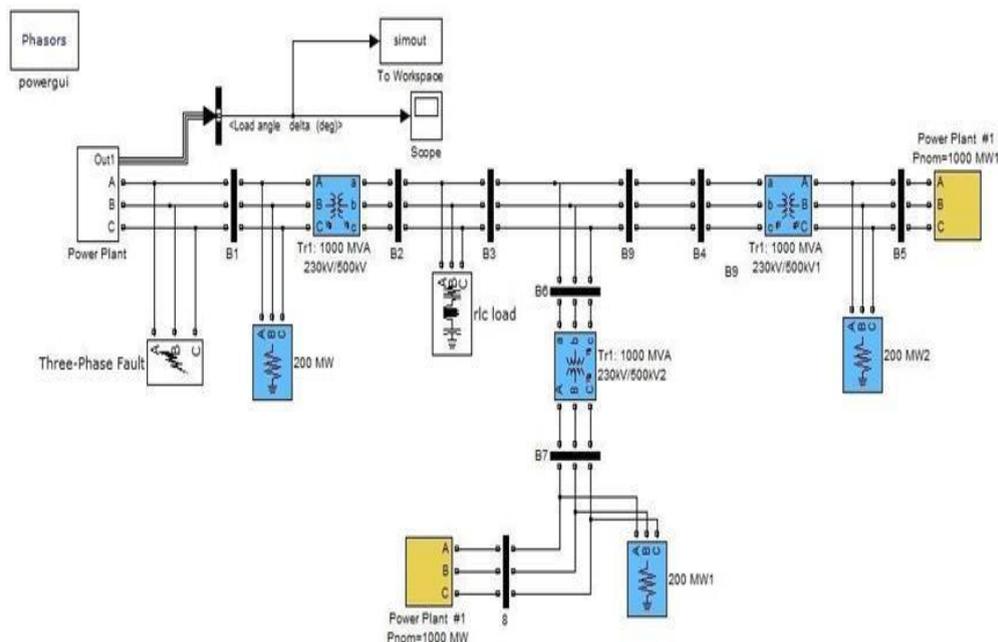
Figure -5: UPFC-POD controllers

#### 4. SIMULATION STUDY

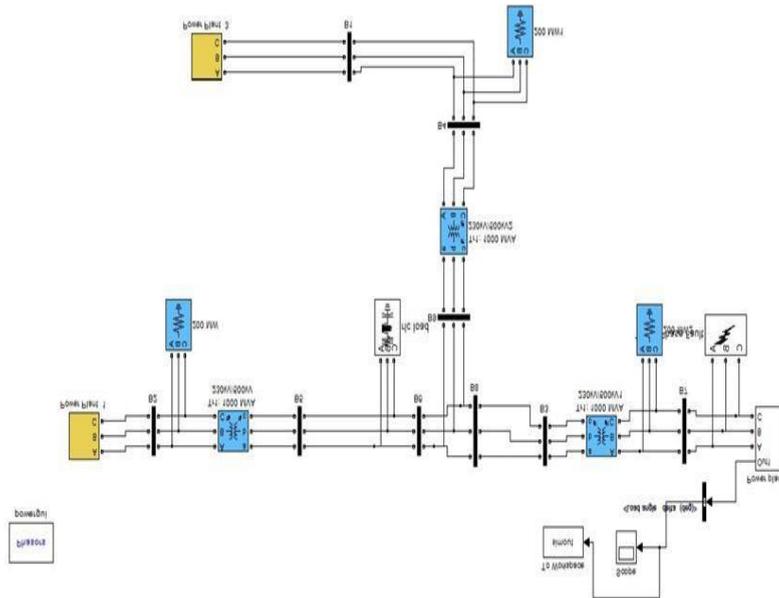
Simulink model for the multi machine power system with and without controller has been developed in MATLAB. Fig.7 and Fig. 8 shows the simulation model of 3-generator, 9- bus system with 3 phase faults in the system at generator sites one and two respectively. Fig.9 shows the simulation model of the power system installed with two Fuzzy-POD- UPFC controllers, i.e., first one between 2<sup>nd</sup> and 3<sup>rd</sup> bus and the second one is at 6<sup>th</sup> and 7<sup>th</sup> bus [12].

The power system can have any fault like 3- phase to ground fault, L-G fault, L-L fault and L-L-G fault. The system is investigated under all types of fault and at all generator sites. The 3 phase to ground symmetrical fault and S-L-G fault has been made to occur near the first generator for duration of 66 ms from the first cycle to the fifth cycle in this paper. Figure 8 represents Simulink model of 3 machine 9-bus system when the fault has been occurred at generator 2. The conventional POD controller coordinated with Fuzzy controller acting as a pre-amplifier for the system, whose output is given as the input signal to the UPFC. This is done in order to compare the effectiveness of the incorporated controller in the model when the fault takes place with the model without the controller when the fault takes place [13].

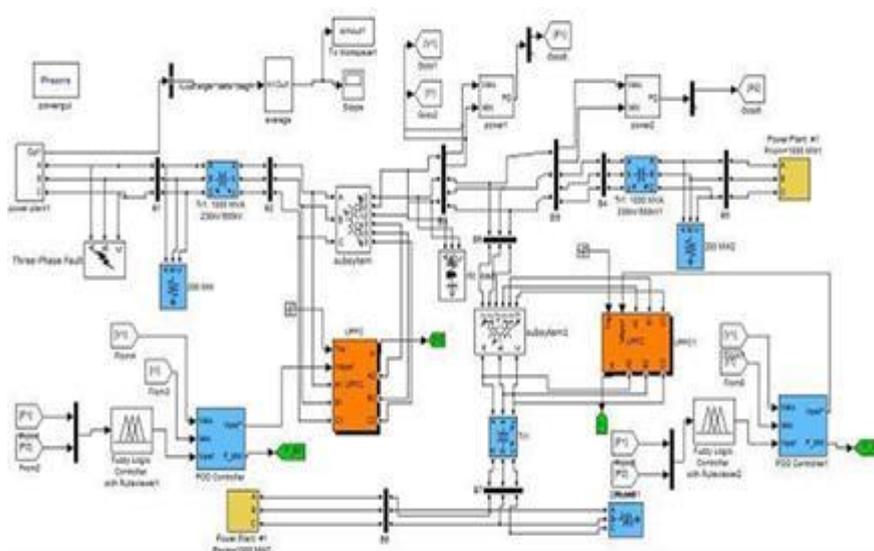
A set of 9 fuzzy rules are written and called in the form of a file in the developed Simulink model with the controller. Figure 9 represents the Simulink model of the power system under study with fuzzy coordinated UPFC-POD controller for damping of low frequency oscillations.



**Figure -6: The developed Simulink model of a 3- machine, 9-bus system under 3-phase fault at generator 1 without Fuzzy based UPFC-POD (without controller)**



**Figure -7: The developed Simulink model of a 3- machine, 9-bus system under 3-phase fault at generator 2 without Fuzzy based UPFC-POD (without controller)**

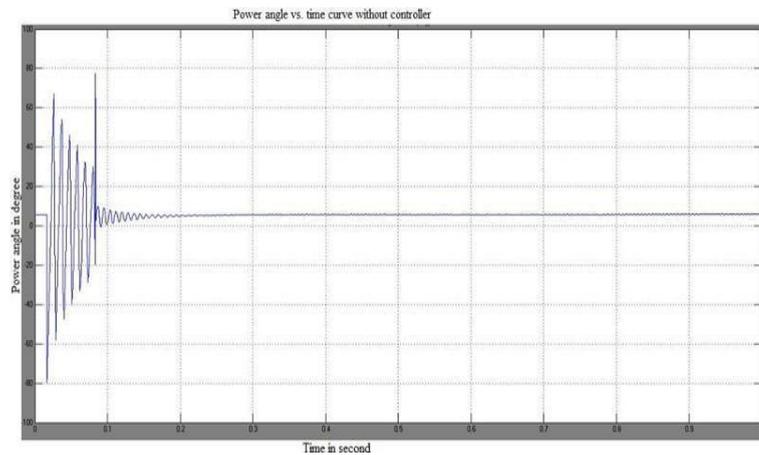


**Figure -8: The developed Simulink model of a 3- machine,9-bus system with Fuzzy-POD-UPFC (with controller)**

### 5. SIMULATION RESULT & DISCUSSION

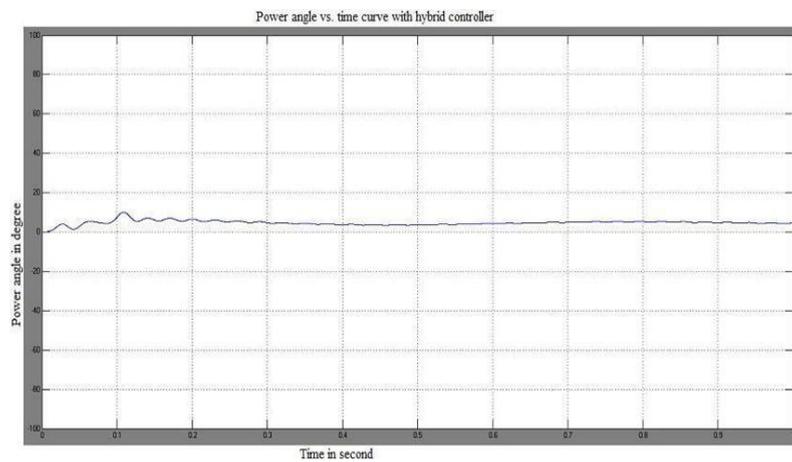
The three phase to ground fault is made to occur near the first generator for duration of 66 ms i.e., from first cycle to fifth cycle. The simulations have been carried out for 1 second with and without controller under fault condition using MATLAB10 software. The effectiveness of the controller can be seen by observing the power angle characteristics which clearly shows that the oscillation due to occurrence of fault has reduced appreciably.

The dynamic performance of the power system has improved with the incorporation of the fuzzy coordination scheme. It has also been observed that with the controller, the power angle characteristics curves exhibit very less overshoots & undershoots, the oscillations are also damped out in a lesser time.



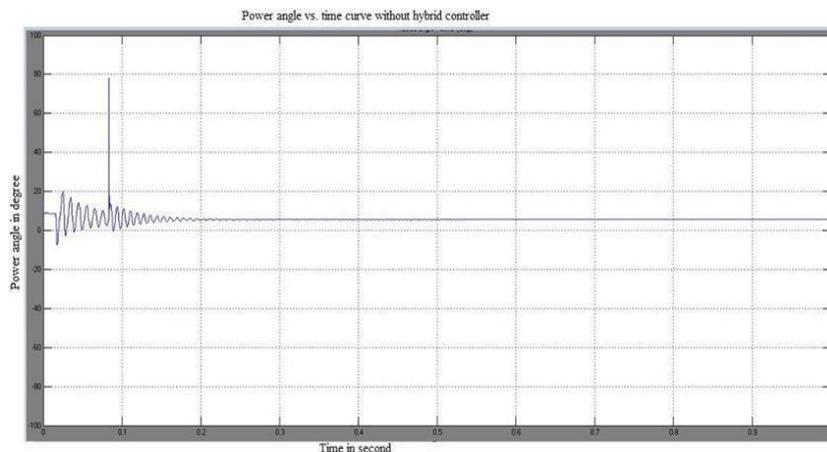
**Figure -9: Simulation result of power angle vs. time curve under 3 phase fault (without Fuzzy-POD-UPFC)**

The maximum deviation of power angle under three phase fault in the system is about 78 degree, which can be seen in figure 9. There is oscillations during the fault condition which has been minimized using controllers.



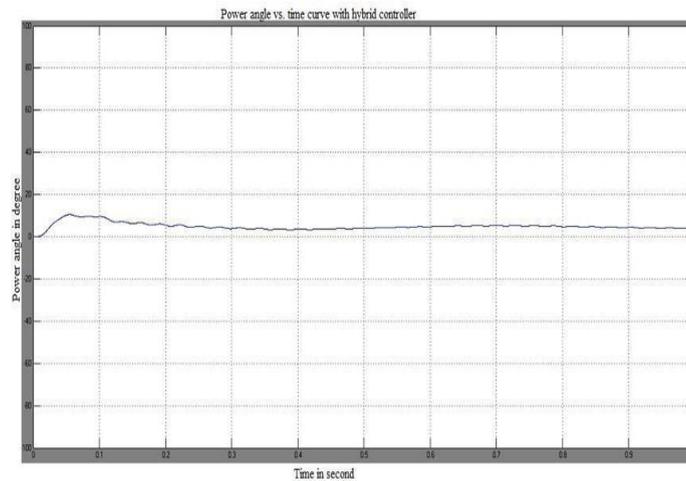
**Figure -10: Simulation result of power angle vs. time curve under 3 phase fault (with UPFC-POD & fuzzy control)**

The hybrid controller consists of Fuzzy-UPFC-POD has been used to damp the oscillations due to fault in the system. Figure 10 shows the power angle curve for the system under 3-phase fault with hybrid controller. The controller greatly reduces the oscillations in the system. The maximum deviation of the power angle with controller under 3 phase fault is 11 degree. In case of L-G fault the maximum power angle deviation is about 76 degree as shown in figure 11.



**Figure -11 Simulation result of power angle vs. time curve under L-G fault (without Fuzzy-POD -UPFC)**

The system under L-G fault with hybrid controller improves the power flow by reducing the oscillations due to fault, shown in figure 13. The maximum power angle curve for this system is observed as 10 degree. So, it improves the performance of the system.



**Figure -12: Simulation result of power angle vs. time curve under L-G fault (with UPFC-POD & fuzzy control)**

## 6. CONCLUSION

The above simulations shows that the system considered when used without any damping controller is underdamped in nature. The fuzzy controller is designed for this UPFC controller. The simulation results shows that when there is a small perturbation in the power system, the proposed UPFC based fuzzy controller is effectively damping the oscillations.

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