Damping of Power System Oscillations by Using Unified Power Flow Controller with POD and PID Controllers

Sudhansu Kumar Samal
Department of Electrical Engineering,
National Institute of Technology,
Rourkela India.
sudhansu.piet@gmail.com

Prof. P.C.Panda
Department of Electrical Engineering,
National Institute of Technology,
Rourkela India.
pcpanda@nitrkl.ac.in

Abstract- **The swift evolution on the area of power electronics has empowered the development of new equipment to be able to benefit more conveniently from the power systems. Power electronic equipment developed under the name of Flexible Alternating Current Transmission Systems (FACTS) is very much popular in last few years. Unified Power Flow Controller (UPFC) is the most popular and widely used FACTS device to control the power flow and to enhance the power system stability in the transmission line. This paper presents the model of a Unified Power Flow Controller which is controlled externally by a newly designed power system controller for the improvements of power system stability and damping effect of an on line power system with occurrence of fault. The proposed controller consist of Power oscillation damping controller and Proportional Integral Differential controller(POD & PID).The PID controller parameter has been optimized by Ziegler-Nichols tuning method. The simulation model is tested for both single-line to ground and three phase faults. A power system network is designed and simulated by using phasor simulated method and the network is examined in three steps; without UPFC, with UPFC but not externally controlled, power system with new proposed controller. The simulation result shows that without UPFC, the system parameters become unstable during faults. When UPFC is connected in the system, then system parameters become stable. Again, when the UPFC is externally controlled by the proposed controller, the power system parameters (P, Q, and V) become stable very rapidly. It has been observed that UPFC rating is only 15 MVA with controller and 100 MVA without controllers. So, UPFC is very effective to enhance the power system stability as well as to damp the power system oscillation.**

Key words*: *FACTs, PID, POD, Power System Controller, UPFC model

I. INTRODUCTION

In recent years, greater demands have been placed on the transmission network, and this demand will continue to increase day by day. While the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. With the boost in electrical power demand, power systems are becoming very much complex to operate and at the same time security problems are also becoming the major issue. This type of Stressed systems is always going through the stability problems due to disturbances [1].Therefore; it is very difficult to build new generation units and transmission system due to environment and energy issues. Hence it is very essential to increase the power transfer capability of the existing transmission lines instead of constructing new facilities. In recent time, the most versatile high power semiconductor devices used in the power system applications for secure loading, power flow control and damping the power system oscillations is Flexible AC Transmission System (FACTs) [2][3]. There are a number of FACTs devices that control power system parameters to utilize the existing power system and also to enhance the dynamic performance and stability of the power system. Out of these, UPFC is the most flexible multi-functional FACTs device. UPFC performs the function of a shunt reactive current injection to control bus voltage and inject series reactive voltage to control power flow in transmission line. For many years power system stabilizer(PSSs) have been one of the most common controls used to damp out power system oscillations and to offset the negative damping of the automatic voltage regulators[4]. The major role of PSS is to introduce modulating signal acting through the excitation system to add rotor oscillation damping Even though power system stabilizer is the main damping control, during some operating conditions, this device may not produce enough damping especially to inter-area mode and therefore, there is an increasing interest in using FACTS devices like STATCOM and UPFC to aid in damping of these Oscillations and it can contribute to improve the voltages profile in the transient state [5]. This paper presents the thyristor based UPFC controllers to improve the performance of multi-machine power system.

II. CONTROL CONCEPT OF UPFC

The Unified Power Controller (UPFC) is the most popular and versatile member of the Flexible AC Transmission System (FACTs) family which is using high Power electronics

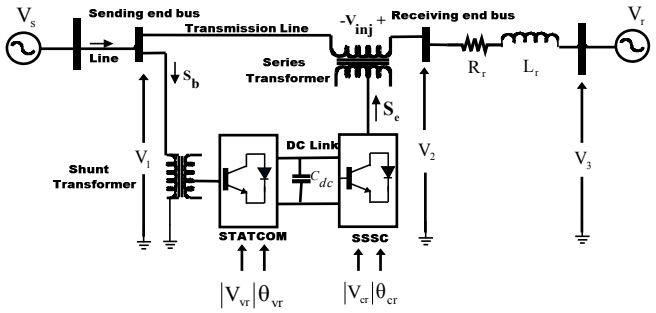


Fig.1. Connection diagram of UPFC with transmission line

components to control power flow on the power grids. The classical connection of UPFC with transmission line shown on the figure.1. The UPFC uses a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are coupled via a common dc link, to allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM and are controlled to provide concurrent real and reactive series line compensation without an external electrical energy source. Both the STATCOM and SSSC are similar solid-state back-to back voltage converters coupled to the ac means through power transformers, and coupled to the DC links through the capacitor. Both the series and shunt converter use a Voltage Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSCs use forced commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage from a DC voltage source. A circuit equivalent of the UPFC within two front end voltage source connected by single transmission line is shown in figure.2.

III. UPFC BASED CONTROL SYSTEM

In UPFC the shunt converter operates as a STATCOM, and it controls the AC voltage at its terminal as well as at the DC bus. It works on a dual voltage regulation loop. A UPFC the two degree of freedom are used to control the active and reactive power. The series converter operates on either Power flow control (automatic control mode) or in manual voltage injection mode [6]. A simplified block diagram of the series converter is shown in fig.3.

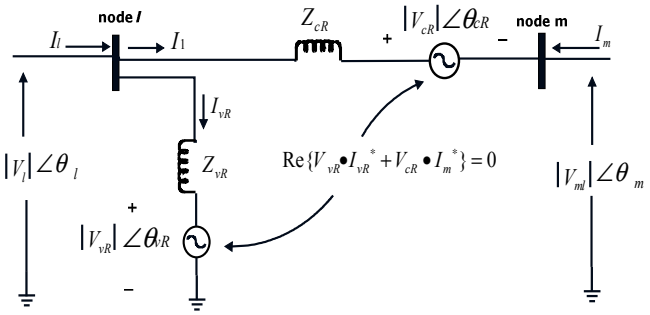


Fig.2. A general circuit equivalent of UPFC

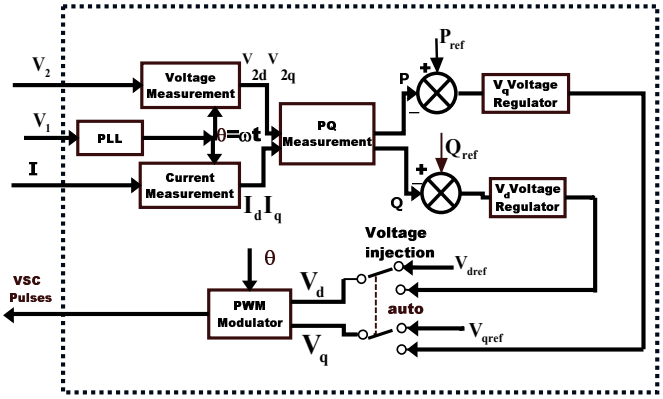


Fig.3. UPFC based control system

In power control mode, the measured active power and reactive power are compared with reference values to produce P and Q errors. The error P and error Q are then given to two voltage regulator to compute the V_d and Vq component of the voltage to be synthesized by the VSC. (Vq in quadrature with V1 control active power and $V_{d\ in}$ phase with V_1 controls reactive power). In manual voltage injection mode the regulators are not used. The reference value of injected voltage V_{dref} and V_{qref} are used to synthesize the converter voltage.

IV.POWER SYSTEM MODEL WITH UPFC

In this study a model of a simple transmission system containing 2-hydrulic power plants connected to a power grid is illustrated [7]. The complete Simulink model is shown in figure.4.A UPFC is used to control the power flow in a 500/230 kV transmission system. The power system is connected in a loop configuration, and it consists of five buses (B1, B2, B3, B4, B5) interconnected with each other via three transmission lines (L1, L2, L3).Two 500/230 KV transformer banks are connected. Two power plants located on the 230 KV systems generate total of 1500 MW which is again transmitted to a 500 KV,1500 MVA and a 200 MW load connected at bus B3. The plant model also included a speed regulator, an excitation system as well as a power system stabilizer (PSS). The complete single line diagram of 2-machine power system with UPFC controller is shown in figure.4.

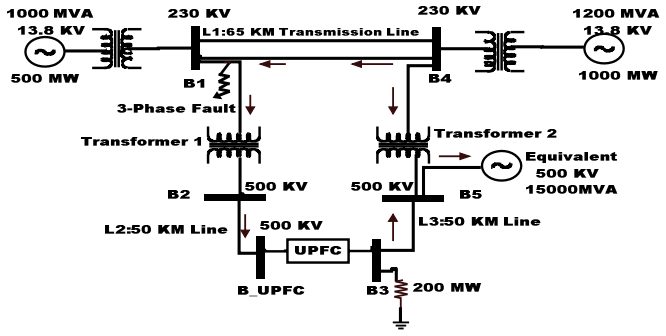


Fig.4. Single line diagram of 2-machine power system with UPFC controller.

The UPFC located at the right end of line L2 is used to control the active and reactive power at the 500 KV bus B3, as well as the voltage at bus B_UPFC. It consists of two VSCs (one connected in shunt and another connected in series and both are interlinked through a DC bus on the DC side of a AC power system, through a coupling reactors and transformers).

V.TEST CASES AND SIMULATION RESULTS

The simulation is carried out for two different types of fault condition.

Case A. Single line to ground fault
Case B. Three phase fault

Case A.1: Single line to ground fault (without UPFC)

When single line to ground fault occurred at 0.1s and the fault breaker opened at 0.2s (3-phase 4-cycle fault), if there is no UPFC used then whole system voltage and power becomes unstable. The simulation results are shown in fig.5andfig.6.

CaseA.2: Single line to ground fault (UPFC without power system controller)

If UPFC is applied then system voltage and power becomes stable with in 1.5s and 1.6s. The simulation results are shown in fig.7 and fig.8.

Case B.1: Three-Phase faults (without UPFC)

During 3-Phase faults, If UPFC is not applied, then again system voltage and power becomes unstable. The simulation results are shown in figure.9 and figure.10.

Case B.2: Three-Phase fault (UPFC without power system controller)

During Three-Phase faults, If UPFC is applied then system voltage becomes stable at 1.5s and power becomes stable at 2.1s.Simulation results are shown in the figure.11 and figure.12**.**

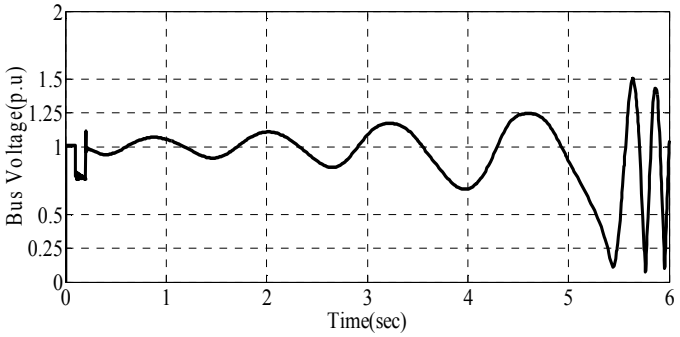


Fig.5. Bus voltage (B1) in p.u. without UPFC

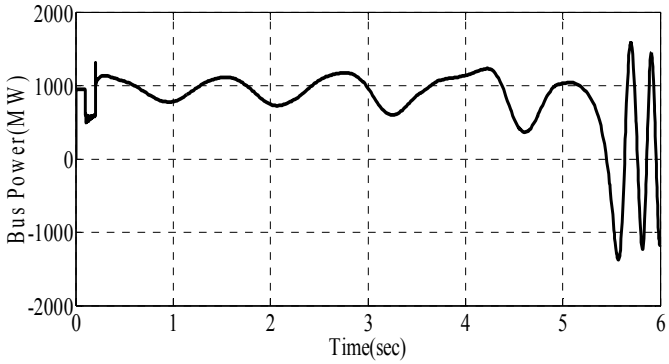


Fig.6. Bus power (B1) in MW without UPFC

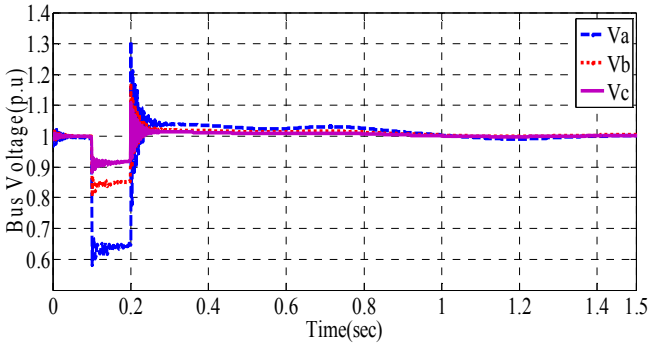


Fig.7. Bus voltage in p.u. (UPFC without power flow controller)

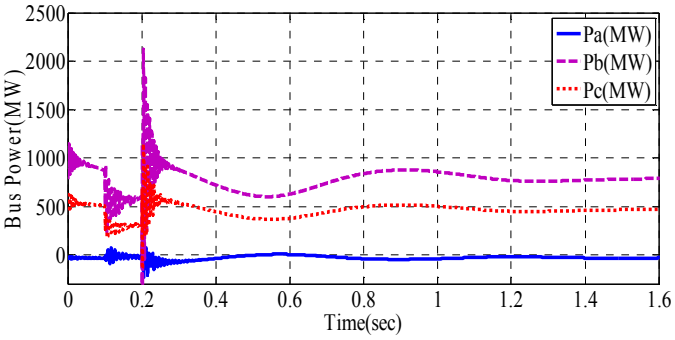


Fig.8. Bus power in MW (UPFC without power flow controller)

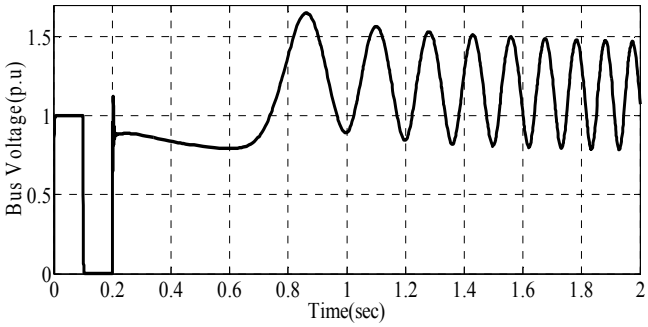


Fig.9. Bus voltage (B1) in p.u. without UPFC

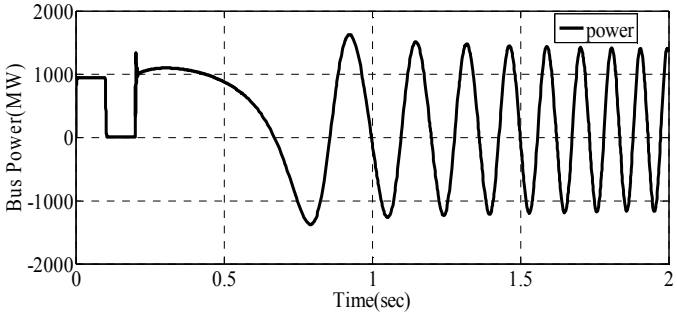


Fig.10. Bus power (B1) in MW without UPFC

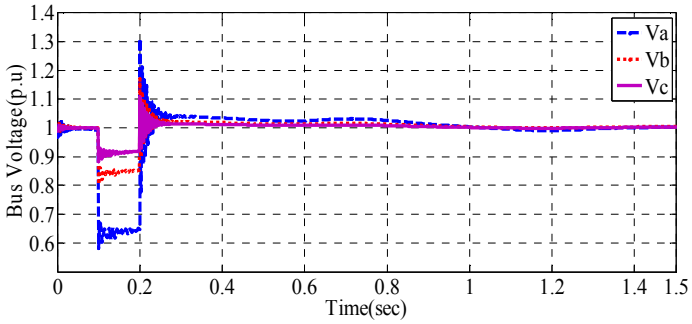


Fig.11. Bus voltage in p.u. (UPFC without power system controller)

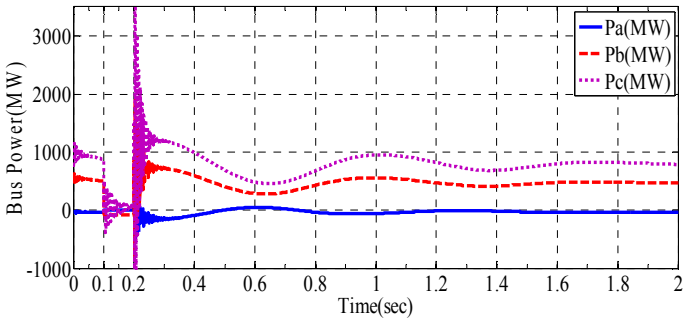


Fig.12. Bus power in MW (UPFC without power system controller)

VI.DESIGN OF POWER SYSTEM CONTROLLER

The proposed power system controller consist of two different controllers, A. Proportional Integral Differential (PID) controller which is tuned by Ziegler-Nichols tuning method, B. Power Oscillation Damping (POD) controller.

A. PID Controller Tuning Process:

PID controller takes the input as machine angular speed deviation and produces an error signal. The process of selecting the controller parameter to meet desire performance is called PID tuning. Most PID controllers are adjusted on-site, many types of tuning rules have been proposed in different literatures [8] [9].The PID controller has three term control signal,

$$u(t) = K_p e(t) + \frac{K_p}{\tau_i}\int e(t)dt + K_p\tau_d\frac{de(t)}{dt} \qquad (1)$$

In Laplace Form,

$$\frac{U(s)}{E(s)} = K_P\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \qquad (2)$$

Block diagram of PID controller Parameters is shown in the figure.13, for selecting the proper controller parameter, Ziegler-Nichols PID tuning method which is being used for the known system dynamics of the given plant is used. In this method, the parameter is selected as $\boldsymbol{\tau_i=\infty}$, $\boldsymbol{\tau_d=0}$.Using the proportional controller action the value of the $\mathbf{K_p}$ is increased from 0 to critical value $\mathbf{K_{cr}}$ which is shown in figure.14., At which the output first exhibits sustained oscillations which is shown in figure.15.

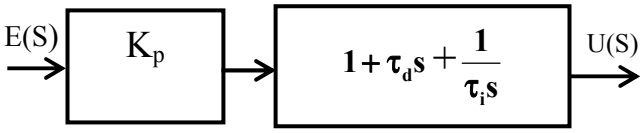


Fig.13.Block diagram of PID controller Parameters

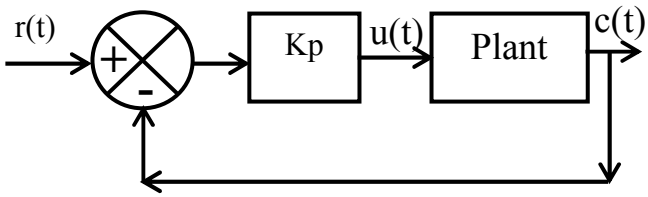


Fig.14. PID controller in proportional action

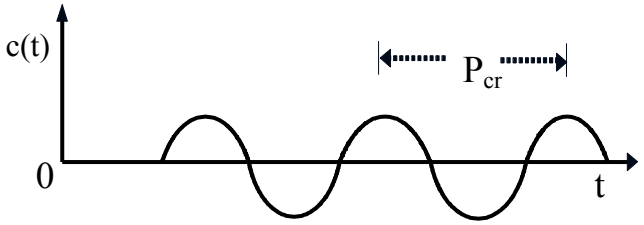


Fig.15. Determination of sustained oscillation (Pcr)

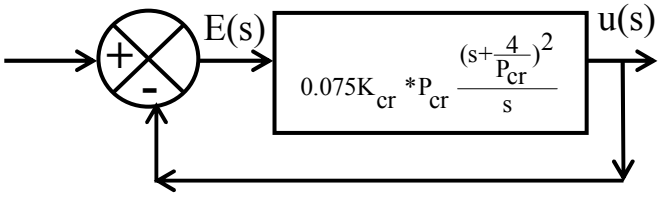


Fig.16. PID controller with tuning parameters

Thus experimentally the critical gain $\mathbf{K_{cr}}$ & its corresponding critical time period $\mathbf{P_{cr}}$ are determined. Then according to Ziegler and Nichols the value of the parameter **Kp, τ_i, τ_d** should set according to the following formula.

$$K_p=0.6K_{cr}\ ,\ \tau_i=0.5P_{cr}\ ,\ \tau_d=0.125P_{cr}$$

Using this tuning method for PID controller, the result which is obtained is given by,

$$G_c(s) = K_p\left(1+\frac{1}{\tau_i s}+\tau_d s\right) \quad (3)$$

$$G_c(s) = 0.6K_p(1+\frac{1}{0.5P_{cr}s}+0.125P_{cr}s \quad (4)$$

$$G_c(s) = 0.075K_{cr}\times P_{cr}\frac{(s+\frac{4}{P_{cr}})^2}{s} \quad (5)$$

Thus the PID controller has a pole at origin and two zeros at S= -4/P_{cr}. It is found that,P_{cr} =0.2s & K_{cr} =200 from figure.5. Block diagram of PID controller with tuning parameter shown in the figure.16. By taking the input as machines angular speed deviation **dω1** and **dω2** it generates an output error signal **dω**, which is shown in the figure.17.

B. Design of POD controller

The power Oscillation Damping Controller takes the inputs as V_{abc} , I_{abc} & convert it as power. At no fault condition the switch remains open but when fault occurred it closed to damp out the oscillation, it also produce an error signal [10] [11]. The internal structure of POD controller is shown in the figure.18.

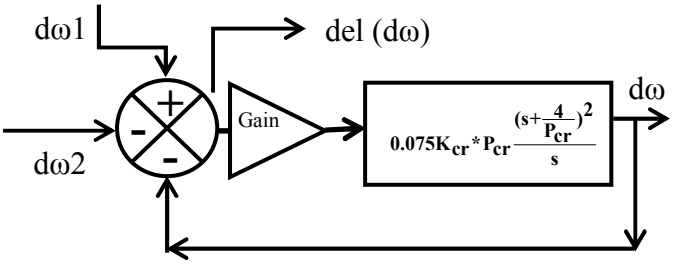


Fig.17. Internal structure of PID controller with dω1& dω2 input

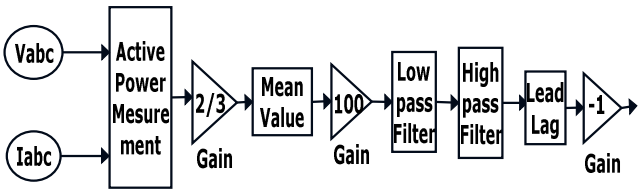


Fig.18. Internal structure of POD controller

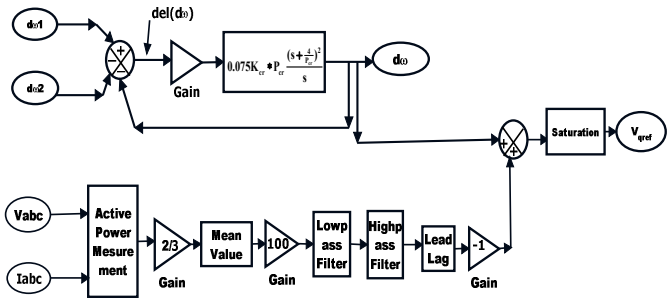


Fig.19. Complete model of Power System Controller

Finally two error signals one from PID and other from POD has been added to form Power System Controller to give the reference voltage signal V_{qref}. This output is used as a reference signal and again given to the UPFC when it operates in manual voltage injection mode for improving the stability and damp out the oscillation. The complete internal structure of power system controller is shown in the figure.19.

Case A.3: Single line to ground fault (UPFC with power flow controller)

If UPFC is applied then system voltage and power becomes stable with in 0.6s and 1.25s. The simulation results are shown in fig.20 and fig.21.

Case B.3: Three-Phase fault (UPFC with power flow controller)

During Three-Phase faults, If UPFC is applied then system voltage becomes stable at 0.3s and power becomes stable at 1.4s.Simulation results are shown in the figure.22 and figure.23.

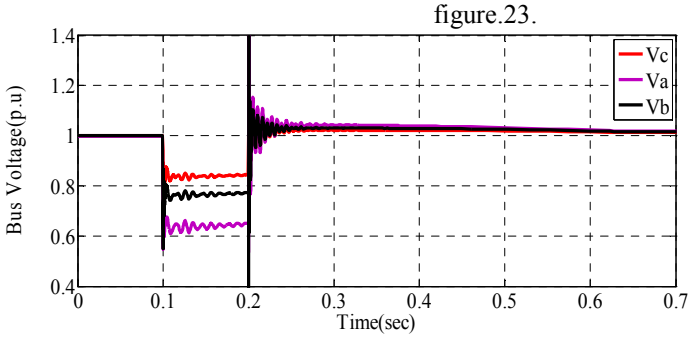


Fig.20. Bus voltage in p.u.(UPFC with power system controller)

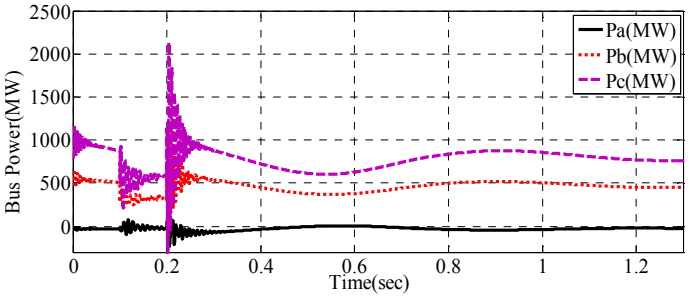


Fig.21. Bus power in MW (UPFC with power system controller)

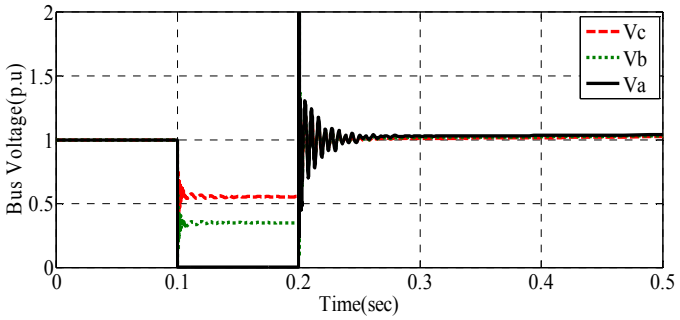


Fig.22. Bus voltage in p.u. (UPFC with power system controller)

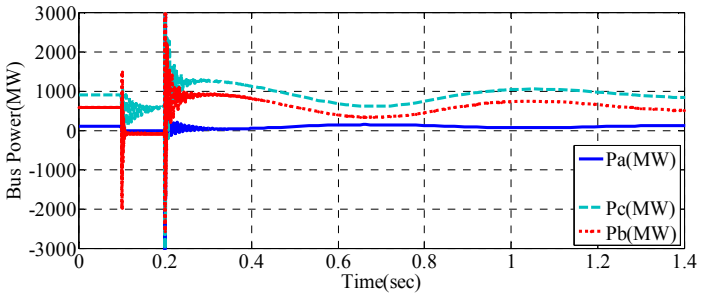


Fig.23. Bus power in MW (UPFC with power system controller)

VII.RESULT & DISCUSSION

The performance of UPFC with Power Flow Controller having same 500KV transmission line is summarized in table below.

		Stability Time			
		1-Phase Fault		3-Phase Fault	
Status	**UPFC**	**Volt**	**P**	**Volt**	**P**
No UPFC	**NO**	**inf**	**inf**	**inf**	**inf**
UPFC	**100MVA**	**1.5s**	**1.6s**	**1.5s**	**2.1s**
UPFC+PFC	**15MVA**	**0.6s**	**1.25s**	**0.3s**	**1.4s**

VIII. CONCLUSIONS

This paper presents the effectiveness of the UPFC without and with power flow controller on power system stability improvement i.e. machine oscillation damping, real & reactive power, voltage level for different type of fault conditions. If PFC is used then small rating of UPFC become enough for stabilization of robust power system within very shortest possible time for both steady state and dynamic conditions. This proposed power system controller can be applied for any interconnected multi-machine power system for stability improvement. These proposed controller can applied to STATCOM and may be tuned by different tuning algorithm i.e. ANN, Fuzzy logic, Genetic algorithm. In future a Fuzzy logic based POD controller will be designed to control the UPFC for power system oscillations.

IX. REFERENCES

[1] S. Tiwari, R. Naresh, R. Jha, "Neur network predictive control Predictive control of UPFC for improving transient stability Performance of power system", Applied Soft Computing, Volume 11, Issue 8, December 2011, Pages 4581-4590, ISSN 1568- 4946.

[2] Y.-H. Song, A.T. Johns (Eds)," Flexible A.C. Transmission Systems (FACTS)" IET, 1999, Chapter 7, Pages 1-72.

[3] Hingorani NG, Gyugyi L (2000). Understanding FACTS, IEEE Press, pp., 323-387.

[4] F. L.Gyugyi, C.D. Schauder. S.L. Torgenon and A. Edris, „The Unified Power Flow Controller: A new approach to Power Transmission Control", IEEE Trans. On Power Delivery, Vol. 10, No. 2, 1995, pp. 1088-1097.

[5] Z. Huaang, Y.X. Ni, C. M. She, F. F. Wu, S. Chen, and B.Zhang, "Application of Unified Power Flaw controller in interconnected Power Systems modeling, interface, control, strategy, and case study", IEEE Trans. On Power Systems. Vol.15, No.2, pp. 817-824, May 2000.

[6] " MATLAB Math Library User's Guide", by the Math Works. Inc.

[7] Gyugyi, L.; "Unified power-flow control concept for Flexible AC Transmission Systems," Generation, Transmission and Distribution, IEEE Proceedings, vol.139, no.4, pp.323-331, Jul 1992.

[8] K. Ogata, Modern Control Engineering, Fourth Edition, Prince Hall, 2002, Chapter, 10.

[9] Meysam Eghtedari, Reza Hemmati, and Sayed Mojtaba Shirvani Boroujeni," Multi objective control of UPFC using PID type Controllers" International Journal of the Physical Sciences Vol. 6(10), pp. 2363-2371, 18 May, 2011.

[10] S.N. Dhurvey and V.K. Chandrakar: "Performance Comparison of UPFC in Coordination with Optimized POD and PSS On Damping of Power System Oscillations", WSEAS Transactions on Power Systems, Issue 5, Vol. 3, pp. 287-299, May 2008.

[11] R.H.Adware, P.P.Jagtap and J.B.Helonde, "Power System Oscillations Damping using UPFC Damping Controller", IEEE conference, Third International Conference on Emerging Trends in Engineering and Technology, 2010.