International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 4, April 2014

# Performance Evaluation of UPFC in long Transmission Line

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**Abstract:** ***Nowadays the measurement of reliability indices for proper evaluation of reliability in a power system has become a great challenge to power engineers. The HV lines are now installed in different countries as well as in India also. But the amount as well as quality of power transfer is very much responsible towards congestion in power system. FACTS technologies have been introduced to overcome the various operational difficulties during control of power flow as well as power compensation. By properly locating these FACTS devices the phase angle, impedance and voltage profile of the selected bus can be controlled. The UPFC is the most versatile, multifunction controller which uses the complex power electronic devices for the efficient control as well as optimization of power flow in transmission line. In this paper firstly, the basic operating principle of UPFC has been discussed. Additionally the power transmission capacity has also been improved by implementing the UPFC in a modeled power system which has been implemented in MATLAB.***

**Keywords:** FACTS, UPFC, Power flow Control, MATLAB, SIMULINK, VSC

## 1. Introduction

In modern power system to increase operating flexibility, controllability, transmission capacity, enhancing transient stability, enhancement of ATC, mitigation of sub-synchronous resonance and for precise control of power flow, new types of FACTS devices are extensively used especially for transmission systems in newly deregulated electricity markets. The UPFC [1, 3, 5] is a part of a family of power electronic equipment capable of producing a controlled synchronous voltage source (SVS) for use in modern electric power transmission system. It may be either connected in series or in parallel to power transmission lines for the purpose of better utilization of electric power system and optimization of power flow. The development of first commercial UPFC is carried out under the joint sponsorship of the EPRI, AEP and Westing House of USA [2]. In order to realize the mechanism as well as the control strategy of UPFC, Analog and Digital Simulators are normally used. In digital simulation, the electromagnetic transient programs are widely used for UPFC analysis [4]. A power frequency model of UPFC has been developed in MATLAB to interface it into the ac power transmission network for analyzing its various effects on large- scale power systems. Simulation results show that the proposed UPFC control strategy can improve the overall system dynamic performance effectively in addition to independently control the real and reactive power in the transmission line.

## 2. Characteristics and Operating Principle of UPFC

UPFC is the representative of the most versatile and last generation of FACTS devices. This new FACTS device represents both the features of STATCOM and SSSC and thus having the capacity of controlling the all transmission line parameters (voltage, phase angle and line impedance). The UPFC uses one VSI (act as an SVS) connected in series to the transmission line through a series transformer while another VSI is connected in shunt with the local bus through a shunt transformer. These two VSI are connected back to back through a common dc link including a storage capacitor.

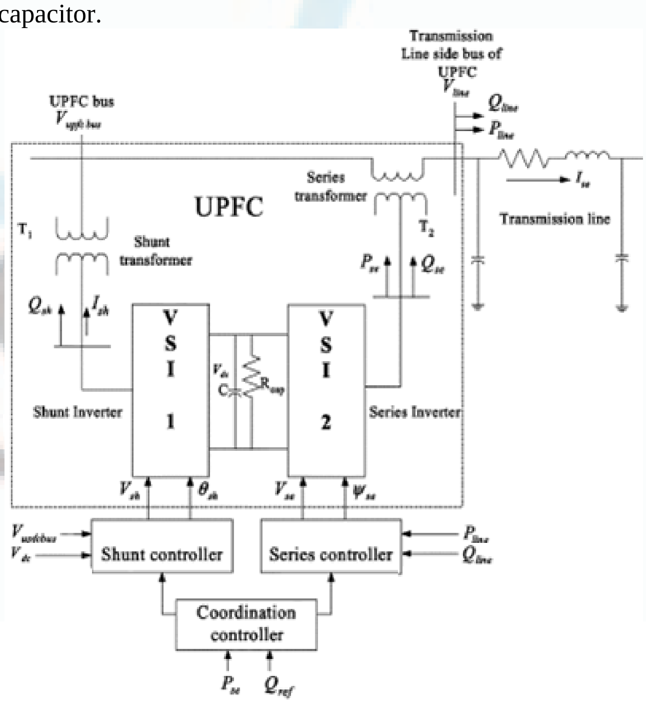


**Figure 1:** Model Block Diagram of an UPFC connected with transmission line

The utility of VSI inside the UPFC is to generate the necessary reactive power by electronic way at its ac terminals and thus better voltage regulation is obtained at the connection point. But the drawback of the VSI is unless there is a suitable power source at its dc side terminals, exchange of real power would be improper. Three phase controllable voltage source is connected in series with the line to control both the active & reactive power flow in the transmission line as well as to the load. Here the net real power absorbed from the line by the UPFC equal to the losses of both the VSI as well as the transformers and the exchange of reactive power with the line is provided by the remaining capacity of the shunt connected VSI. However the two VSI can work independently by separating the dc side.

## 3. Different Control Modes of UPFC:

The central control system of UPFC gives exact real time control algorithms for every equipment configurations. Additionally the control system provides only one of several possible control modes which would be selected for each power circuit configuration. Actually the configuration of UPFC acts as an ideal ac to ac converter where the real power may flow in either direction between the two ac sides of the VSI. As the functions of the two inverters are different shunt inverter is also known as ‘exciter’ and series inverter is also known as ‘booster’. The reactive power flow between the two ac sides of the VSI can be controlled independently. The main control modes of UPFC are described below as:-

### a) Shunt Inverter

The shunt inverter is operating in such a way to inject or draw a controllable current from the ac bus. This controlled current consists of two components with respect to the line voltage: one is red or direct component and one is reactive or quadrature component. The real component is normally determined by the necessity of balancing the real power of series inverter. A little amount of real power is also needed to provide the power losses of inverter as well as magnetics. The reactive component either capacitive or inductive of the current can be set to absorb or generate reactive power from the line. This shunt inverter has two different modes:

I. **VAR Control Mode:**
In this mode of operation the reference input is an inductive or capacitive VAR request which is maintained by controlling signal independent of the bus voltage variation. Here the VAR reference input translates into corresponding required shunt current and adjusts gating signal of the VSI to establish the desired current. In this mode the dc bus voltage $V_{dc}$ acts as feedback signal.

II. **Automatic Voltage Control Mode:**
In Voltage Control Mode the reactive current of shunt connected VSI is regulated efficiently to maintain the required transmission line voltage at the point of connection to the reference value with a predefined slope. Characteristics and this slope factor defines the per unit voltage error of per unit of reactive current of VSI.

### b) Series Inverter

The series inverter controls the amplitude as well as the angle of the voltage injected in series with the line. The injection of the voltage always tries to balance the flow of power between the two VSI to keep the constant voltage across the dc link capacitor. Here three optional modes are there to obtain the actual value of the injected voltage.

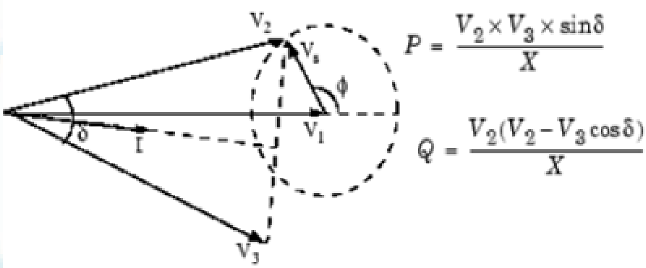


**Figure 2:** Phasor Diagram of Voltage and Currents related with UPFC

I. **Direct Voltage injection mode:**
Here the reference inputs are directly proportional to the amplitude and phase angle of the voltage vector, which is generated by the series inverter.

II. **Automatic Power Flow Control Mode:**
In this mode the series injected voltage is determined continuously by a ‘vector control system’ to maintain the desired values of P & Q despite of any external disturbance or change of system parameters. This is probably the most powerful mode of operation with conventional line compensating devices.

III. **SSSC Mode:**
For enabling this mode of operation the series inverter is disconnected from the dc sides of the shunt inverter. This controller also adjusts the injected ac voltage continuously in quadrature with the transmission line current. Here the injected voltage can be controlled by changing the amplitude of the bus voltage, while maintaining a constant switching pattern on the series inverter. The amplitude of the injected voltage would be determined by the reference input.

IV. **Phase Angle Shifter Emulation Mode:**
In this mode, the phase displacement between the sending and receiving end voltage is the reference input.

V. **Line Impedence Emulation Mode:**
Here, the reference input is an impedance value to insert in series with the line impedance.

### c) UPFC Control Block Diagram

Nowadays the FACTS technology provides greater flexibility than the SSSC for controlling the both active and reactive power of transmission line. Here in UPFC mode, the active power is transferred from the shunt connected VSI to the series converter through the DC bus. Contrary to the SSSC where the injected AC voltage ($V_s$) is constrained to be in quadrature with line current, this injected voltage now may have any angle with respect to line current.

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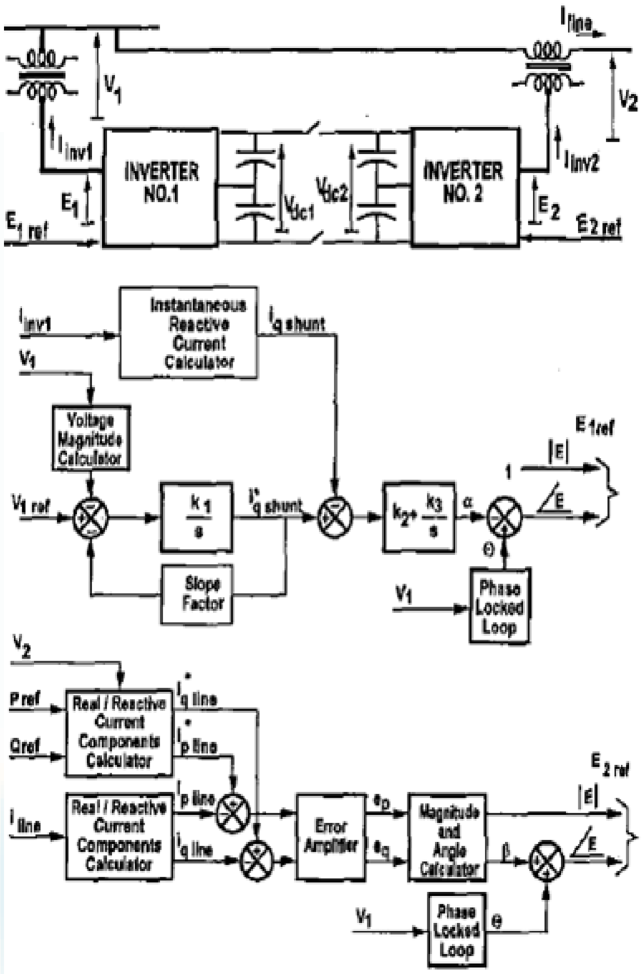


**Figure 3:** Control Block Diagram for shunt inverter in voltage control mode and series inverter in power flow control mode [6]

For example, if the amplitude of the injected AC voltage $V_s$ is maintained constant and if its phase angle with respect to $V_1$ is varied between 0 to 360 degrees, the locus of the voltage vector $V_2$ (= $V_1$ + $V_s$) is a circle as shown on the phasor diagram As the locus is changing, the phase shift δ between voltages $V_2$ and $V_3$ at the two line ends also varies and it is notified that both the active and the reactive power transfer to any one of the line end can be controlled efficiently by using the two degrees of freedom. In UPFC the shunt connected VSI controls the output AC voltage and the voltage of the DC bus. In fact, it uses it uses a dual voltage regulation loop and an outer loop which regulates both AC & DC voltages.

## 4. Description of SIMULINK Model of UPFC

In this model of UPFC we can observe that the system is a 5 bus system comprising of buses B1, B2, B3, B4, B5 interconnected through transmission lines L1, L2, L3. The system is a 230kv system having an equivalent source of 500kv, 15000MVA and a power plant to generate power. The power plant includes a speed regulator and an excitation system as well as a power system stabilizer (PSS).

Three loads are connected to the system out of which two are inductive load and the other one is resistive load. The inductive load is of 200 MW capacity where as the resistive load is of 100 MW capacity. The reason for using the inductive load is that most of the industrial load is inductive in nature. Here three breakers are connected to the load. The simulation time of the system is 0.5 seconds.

Initially the breaker remains closed. Since here the breaker is operated in the internal control mode of operation so the initial status and the transition times of the breaker are considered here. Here the transition times are selected from 0.1008 seconds to 0.3508 seconds. It indicates that the breaker will operate within this time interval. It will open at 0.1008 seconds and close at 0.3508 seconds. A bypass breaker is also used here to connect or disconnect the UPFC block. During normal operation most of the power generated is transferred through the 800MVA transformer bank. As a result the transformer is overloaded. The UPFC can release the power congestion and control the active and reactive power through the bus B3.

## 5. MATLAB SIMULINK Model of a Distribution system having UPFC

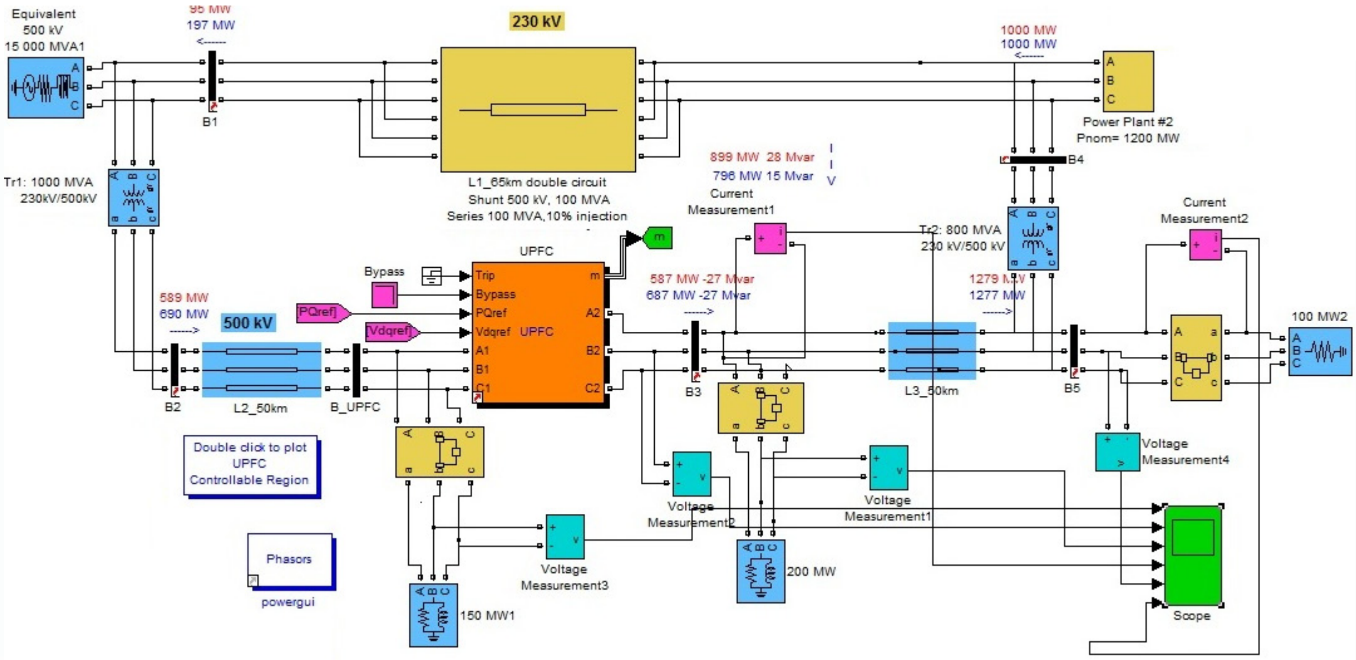

**Figure 4:** SIMULINK Model of UPFC

## 6. Results

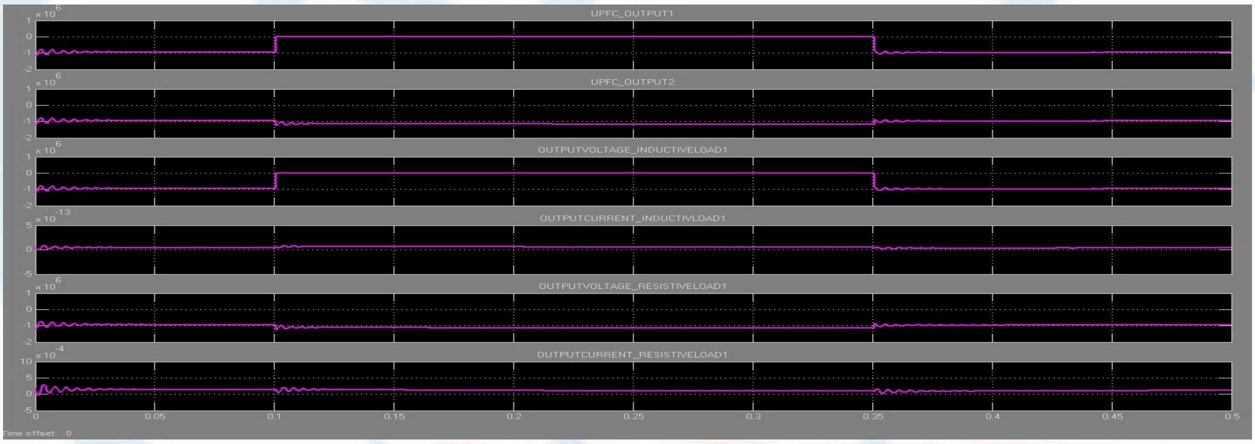


**Figure 5:** Output Waveform1 of SIMULINK Model

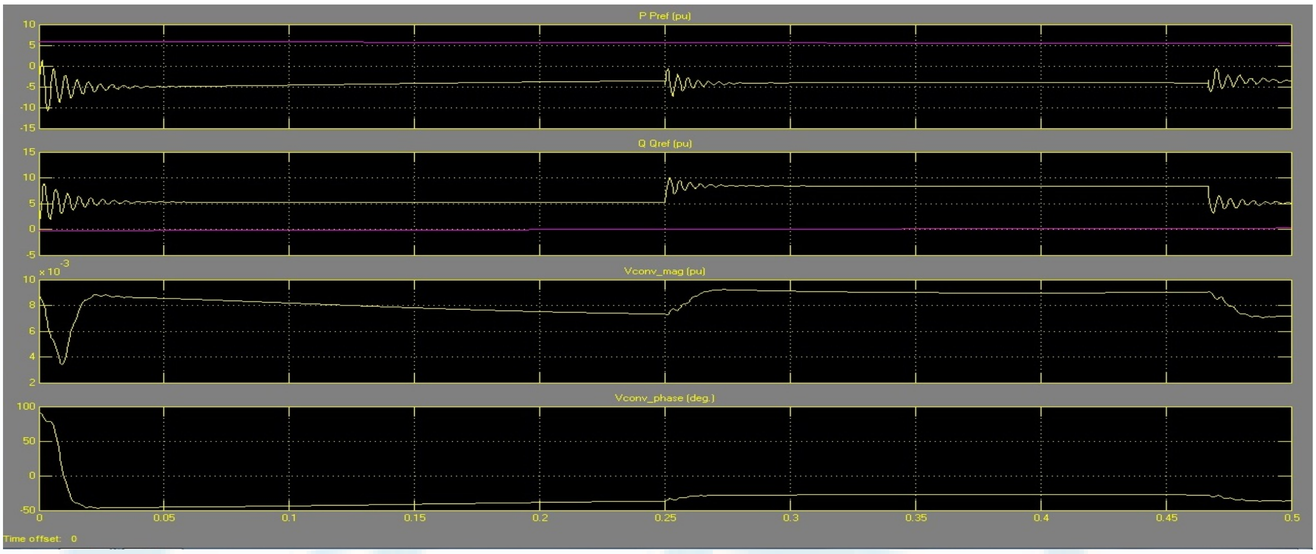


**Figure 6:** Output Waveform2 of SIMULINK Model

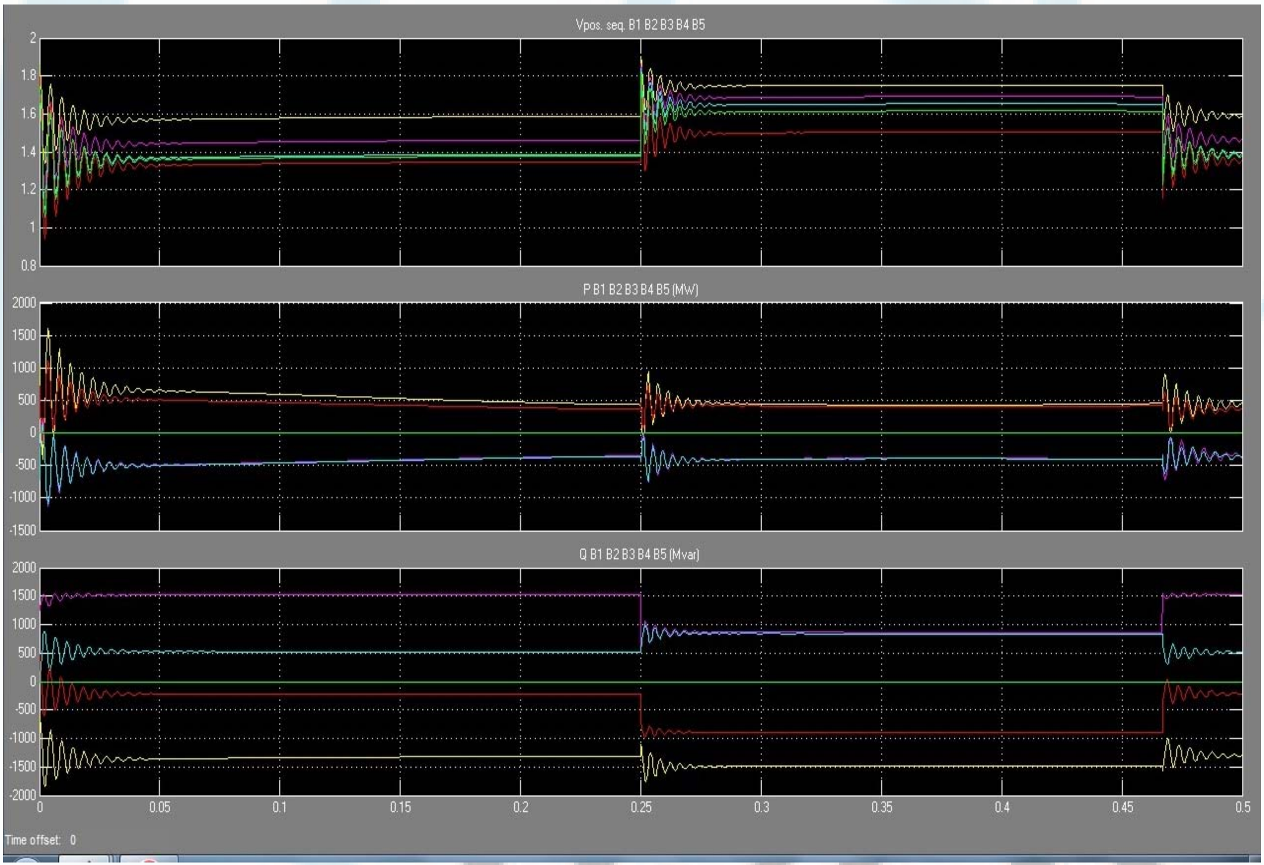


**Figure 7:** Output Waveform3 of SIMULINK Model

## 7. Analysis of the Output Result of the SIMULINK Model:

From the above SIMULINK model we have attained three output waveforms after simulation. Here the 'first waveform (Fig.5)' represents the output voltage curve under the inductive load. The voltage curve is found to increase within the interval of 0.1008 seconds to 0.3508 seconds. The breaker closes at 0.3508 seconds so after that the voltage profile across the load has been improved successfully during UPFC operation. The 'second waveform (Fig6)' describes the reference waveforms of the active and reactive power. It is found that the natures of the curves are damped sinusoidal in certain intervals thereby indicating the stable characteristics of the controller. The 'third waveform (Fig7)' describes the positive sequence voltage and the active and reactive power of the five buses that is B1, B2, B3, B4, B5. The curves are also damped sinusoidal in nature and attains stability in the intervals of 0.05 to 0.25 seconds and from 0.3 to 0.47 seconds.

## 8. Conclusion

The following conclusion is obtained from the above output graphs:

- Congestion is eliminated and better power flow control is obtained
- Transient stability is improved.
- Voltage profile across different types of load is enhanced

## 9. Discussion

The presented UPFC model works satisfactorily in the study of power flow control and power system dynamics with proper accuracy. The constant power flow control is required for steady state control and the constant series compensation control is also required for first swing stability. In the modeling of our test system, the simulation result shows that the voltage profile across the load has been improved significantly and the steady state stability has been achieved faster. Thus both the control modes of UPFC is very much effective in power flow control and improving the dynamic performance of the system.

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## Author Profile

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**Mr. Sudip Das** was graduated in Electrical Engineering from Kalyani University in the year of 2004. After that he joined in MNC as Asst. Engineer. He obtained his M.E (Power Engineering) degree from Jadavpur University in 2008. Now his research topic is Improvement of Power Plant through Modern Automation Technology. He has total six years Industrial experiences & more than three years teaching experiences. Now he is associated with JIS College of Engineering as Asst. Professor. He is also a member of IEEE, Calcutta Section.

**Dr. Sakti Prasad Ray** was graduated in 1973 with first class (Gold Medalist) in Electrical Engineering from North Bengal University, W. B. He was Post-graduated from the Calcutta University in Electrical Engineering in 1980 and obtained his PhD (Engg.) degree from Jadavpur University. His current area of research work is Electromagnetic Field Theory, FACTS, and Power System etc. He joined in the Department of Electrical Engineering, IIEST [Formerly known as B. E. College (D.U)] after passing post graduation and has more than thirty four years teaching and research experience there. He has published many Research Papers in various National/International Reputed Journals as well as Conference.