

UPFC in order to Enhance the Power System Reliability

Vikash Anand¹, Dr. M. M. Chaudhary²

¹ Research Scholar, Electrical Engineering, N.I.T (Patna), India

² Professor, Electrical Engineering, N.I.T (Patna), India

Abstract: The maintenance and reliability of the power system has become a major aspect of study. The solution is the use of FACTS devices especially the use of UPFC. Unified Power Flow Controller (UPFC) is the most widely used FACTS device to control the power flow and to optimize the system stability in the transmission line. It is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. This controller offers advantages in terms of static and dynamic operation of the power system. The UPFC with its various modes of operation is understood. Second, the operation of control system used in its converters is also studied. Finally by help of modeling of a power system in SIMULINK / MATLAB SIMPOWERSYSTEM and by installing single phase UPFC in transmission link, its use as power flow controller and voltage injection and constructing a lab scale model of UPFC is discussed also.

Keywords: MATLAB, Measuring Devices, Single Phase Supply, Series Converter, STATCOM

I. INTRODUCTION

Power system is the interconnection of generating unit, substation, and distributing unit. Generation part is the main source that supply to the load. In this area the value of voltage is about 132 kV and above. While the substation make a function like medium channel. It is use in transmitting the power from the generating station to the load. In this area the value of voltage that is used about 11kV and 66 kV. The distribution part of the power system is the load. The voltage flow at the distribution unit is 240V for single phase and 415V for three phases. In the recent year the power demand by consumer is greater than the power flow through the transmission line system. In order to provide the power demanded by the consumer, the new generation technology must be build. Because of economic and environmental reason rebuild the new generation and transmission system become more difficult.

To overcome these problem new technologies were developing to replace the mechanical control. Flexible AC Transmission System (FACTS) which was introduced by Hingorani is applying to the transmission system to increase the controllability. It optimizes the utilization for existing power system capability by replacing mechanical controller with the reliable and high speed power electronic devices.

The latest generation of FACTS controllers is based on the concept of the solid state synchronous voltages source (SVS) introduced by L.Gyugyi in the late 1980. The SVS behave as an ideal synchronous machine because it can generate fundamental three phase balanced sinusoidal voltage of controllable amplitude and phase angle. It can generate the reactive power and with the approximate storage device, it can also exchange the real power with the AC system. The SVS can be implemented by the use of voltage sourced converter (SVC). The SVS can be used as a shunt or series compensator. If it is operated as shunt compensator, it is called as static condenser (STATCOM) and if as series compensator, it is called static synchronous series compensator (SSSC). But the most versatile controller in the FACTS family is unified power flow controller (UPFC) because it can operate as a shunt and series compensator.

II. FACTS DEVICES

In the power system FACT controllers are used for the control of voltage, impedance and phase angle. In the past, traditional controllers are employed whereas nowadays these traditional controllers are replaced by thyristor valves. FACTS controllers are basically categories in two types such as-Thyristor based FACT controllers and Voltage source converter based controllers. The power transfer ability of transmission system depends on many factors such as steady state stability limit, transient stability limit and thermal limit. Due to the fault in the system, there is increase in the system loss and decrease in the system reliability. Therefore with increase in the demand and supply, it becomes necessary to installed FACTS controllers in the power system. By utilizing FACTS controllers we can improve system stability, voltage and security. In any substation, there is a number of transmission lines hence it is difficult to compensate all the transmission lines

together. To solve this problem Inter Line Power Flow Controller is developed. This is the second generation of FACTS controller. It provides the capability of direct transfer of real power between the compensated lines. By this there is balance of real and reactive power flow between the lines. If there is not proper coordination between various FACTS controllers or they are not installed in proper location then there is a cause of voltage instability. Hence it becomes necessary that FACTS controllers are installed at proper location and there is proper coordination between them. Unified Power Flow Controller is the most versatile power flow controller among all the facts controllers. A lot of researches have been done to improve the performance of UPFC controller. The recently proposed Hoo learning method is used for updating the parameter radial basic function neural network controllers as the UPFC Controller.

FACTS controllers may be based on thyristor devices with no gate turn-off, or with power devices with gate turn-off capability. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines.

FACTS controllers can be divided into four categories:

- i. Series controllers
- ii. Shunt controllers
- iii. Combined series-series controllers
- iv. Combined series-shunt controllers

1. Series Controllers

The series controller could be variable impedance, such as capacitor, reactor, etc., or a power electronic based variable source of main frequency, sub synchronous and harmonic frequencies to serve the desired need. They inject voltage in series with the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. Static Synchronous Series Compensator (SSSC) is one such series controller.

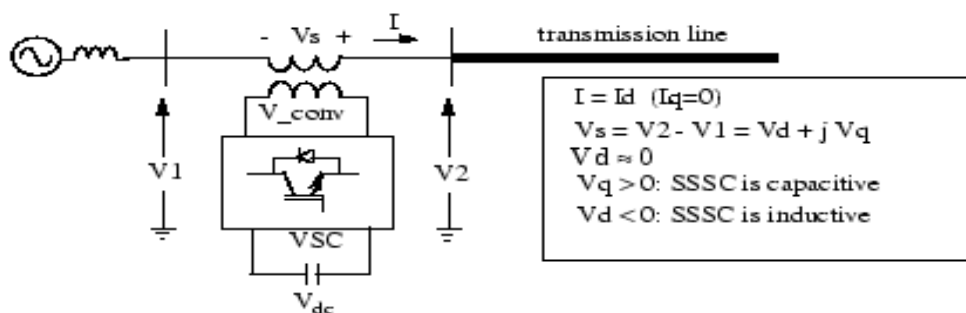


Fig.1 Series Controller

2. Shunt Controllers

Shunt controllers is also variable impedance, variable source, or a combination of these. All shunt controllers inject current into the system at the point of connection. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. Static Synchronous Compensator (STATCOM) is one such controller.

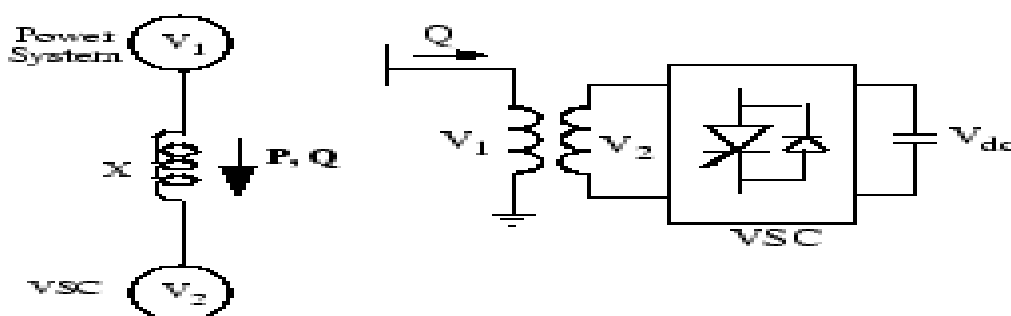


Fig.2 Shunt Controller

3. Combined Series-Series Controllers

This could be a series combination of separate series controllers, which are controlled in a coordinated manner, in a multilane transmission system. Interline Power Flow Controller comes in this category.

4. Combined Series-Shunt Controllers

This could be a combination of separate shunt and series controllers, which are controlled in a coordinated manner, or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with shunt part of the controller, voltage in series in the line with the series part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link.

III. UNIFIED POWER FLOW CONTROLLER (UPFC)

1. Static Representation of UPFC

The Unified Power Flow Controller (UPFC) consists of a combination of Static Synchronous Compensator (STATCOM) and a Static Synchronous Series Compensator (SSSC). Both the compensators are coupled via a DC link, which allows bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminal of the STATCOM.

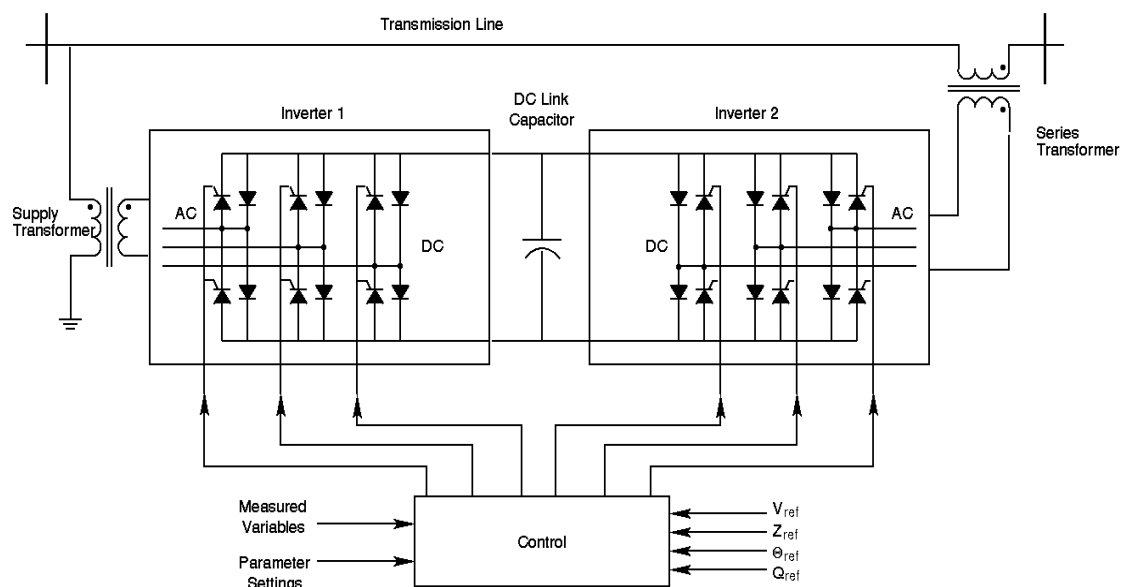


Fig.3 A Simple Model of UPFC

In the circuit we can see that there are two transformers that is shunt & series transformer & both the transformers are connected by two Gate-Turn-Off (GTO) converters and a DC circuit having a capacitor. Common DC link between both the converter works as a channel for the flow of power. The shunt converter is primarily used to provide the real power demand of the series converter via a common DC link terminal from the AC power system. Shunt converter can also generate and absorb reactive power at its AC terminal. Therefore with proper control it can also act as an independent advanced static VAR compensator providing reactive power compensation for the line and thus executing indirect voltage regulation at the input terminal of the UPFC. A series converter is used to generate voltage source at fundamental frequency with variable amplitude and phase angle, which are added to the AC transmission line by series connected boosting transformer. The converter output voltage, injected in series with the line, can be used for direct voltage control, series compensation, phase shifter and their combinations. This voltage source can internally generate or absorb all the reactive power required by different type of controls applied and transfers active power at its DC terminal.

2. Characteristics and Operation Modes of UPFC

In the power system there are many major issues where the capability & utilization of FACTS are noticed. These issues are power system stability loss, Line outage, cascading, line tripping, and congestion.

Representative of the last generation of FACTS devices is the Unified Power Flow Controller (UPFC). The UPFC can control simultaneously all three parameters of line power flow -line impedance, voltage and phase angle. Such "new" FACTS device combines the features of two "old" FACTS devices: the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). These two devices are two Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through a series transformer. Both the converters are connected to each other by a common dc link including a storage capacitor. Shunt inverter is used to balance the real power flow exchanged between the series inverter and the transmission line and for voltage regulation at the point of connection injecting an appropriate reactive power flow into the line. Series inverter is used to control the real and reactive line power flow inserting an appropriate voltage with controllable magnitude and phase in series with the transmission line. Thus, UPFC accomplishes the functions of active and reactive series compensation, reactive shunt compensation, and phase shifting. Instead of these functions, UPFC allows a secondary but important function such as stability control to suppress power system oscillations for improving the transient stability of power system. Because of changes in the future electricity market scenario, there is a need for flexible and fast power flow controllers, such as the UPFC. To investigate the impact of UPFC on the performance of the power system, there is a corresponding need for reliable and realistic models of these controllers.

Control of power flow is achieved by adding the series voltage, V_s with certain amplitude, $\angle V_s$ and phase shift, ϕ to V_1 . This will give a new line voltage V_2 with different magnitude and phase shift. As the angle ϕ varies, the phase shift δ between V_2 and V_3 also varies.

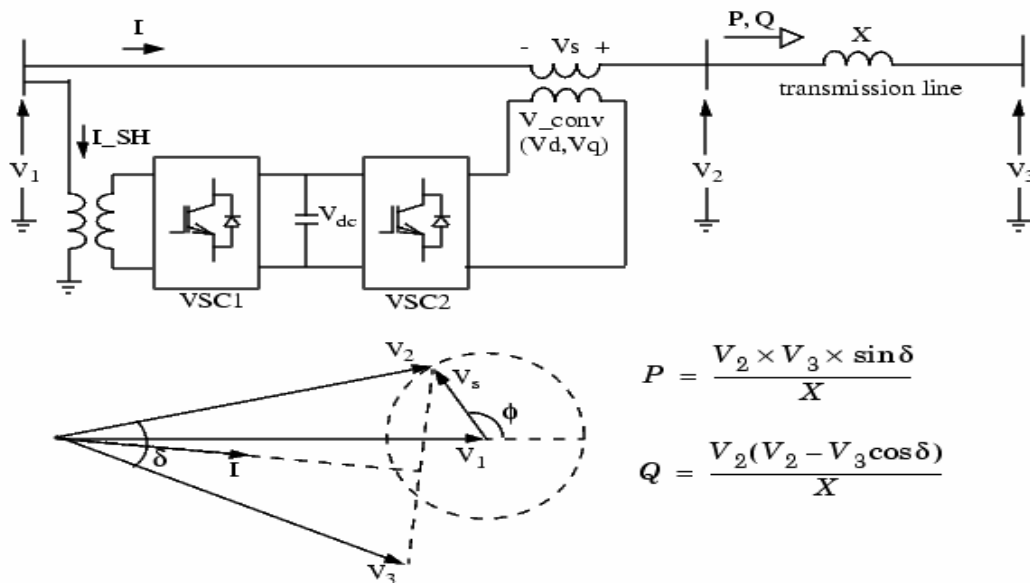


Fig.4 Single line diagram of UPFC and Phasor diagram voltage and current

With the presence of the two converters, UPFC not only can supply reactive power but also active power. The equation for the Active and Reactive power is given as follows.

$$P_{12} = \frac{V_1 V_2}{X_{12}} \sin \delta$$

$$Q_{12} = \frac{V_1 V_2}{X_{12}} (1 + \cos \delta)$$

3. Functional Control of Shunt Inverter

The shunt inverter is used to inject a controllable current I_c into the transmission line. This current consists of two components with respect to the line voltage.

1. The real or direct component i_d
2. Reactive or quadrature component i_q

The direct component is automatically determined by the requirement to balance the real power of the series inverter where as quadrature component can be independently set to any desired reference level (inductive or capacitive) within the capability of the inverter, to absorb or generate respectively reactive power from the line.

So, two control modes are possible:

1. VAR control mode: The reference input is an inductive or capacitive VAR request.
2. Automatic Voltage Control mode: The goal is to maintain the transmission line voltage at the connection point to a reference value.

4. Functional Control of Series Inverter

The series inverter injects a voltage, V_{se} which is controllable in amplitude and phase angle in series with the transmission line. This series voltage can be determined in different ways:

i) Direct Voltage Injection mode

The reference inputs are directly the magnitude and phase angle of the series voltage.

ii) Phase Angle Shifter Emulation mode

The reference input is phase displacement between the sending end voltage and the receiving end voltage.

iii) Line Impedance Emulation mode

The reference input is an impedance value to insert in series with the line impedance.

iv) Automatic Power flow Control mode

The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

5. Benefits of UPFC in the Power System

UPFC is a versatile and multifunction power flow controller. It has the capabilities of terminal voltage regulation, series line compensation and phase angle regulation. It has also some additional features such as optimal power flow, reliability etc. If we perform the steady state analysis with UPFC, it gives the basic criteria for conducting dynamic stability studies with UPFC. Dynamic stability studies include frequency domain and time domain analysis that include the study of transient stability. Because of unwanted disturbances among the synchronous generator, there is a loss of synchronism. Therefore it is necessary to use a suitable control strategy. The transient stability of power system can be improved with the help of most flexible FACTS devices that is UPFC. By utilizing UPFC in the transmission line, the maximum loading point in the line is increased a compare to other FACTS devices. In order to find such advantages, it is important to locate the UPFC in the appropriate location. Various factors are considered for the optimal location of UPFC such as active power loss, transmission capacity, stability, blackout prevention. Thyristor Controlled Series Capacitor (TCSC) & Static Synchronous Series Compensator (SSSC) is also important FACT device. Series compensator in transmission line decreases unsymmetrical components, reducing net power loss, providing voltage support, limiting short-circuit currents. But the TCSC can work only in inductive and capacitive zone.

6. Location of UPFC Controller

Most of the FACTS devices are generally installed in substations for convenient operation and maintenance. UPFC must be located at or within the middle of the transmission line.

- The branches having transformers have not been considered for the UPFC placement.
- The branches having generators at both the end buses have not been considered for the UPFC placement.
- The line having the highest absolute load curtailment sensitivity factor with respect to UPFC angle is considered the best location for UPFC, followed by other lines having less values of sensitivity factor

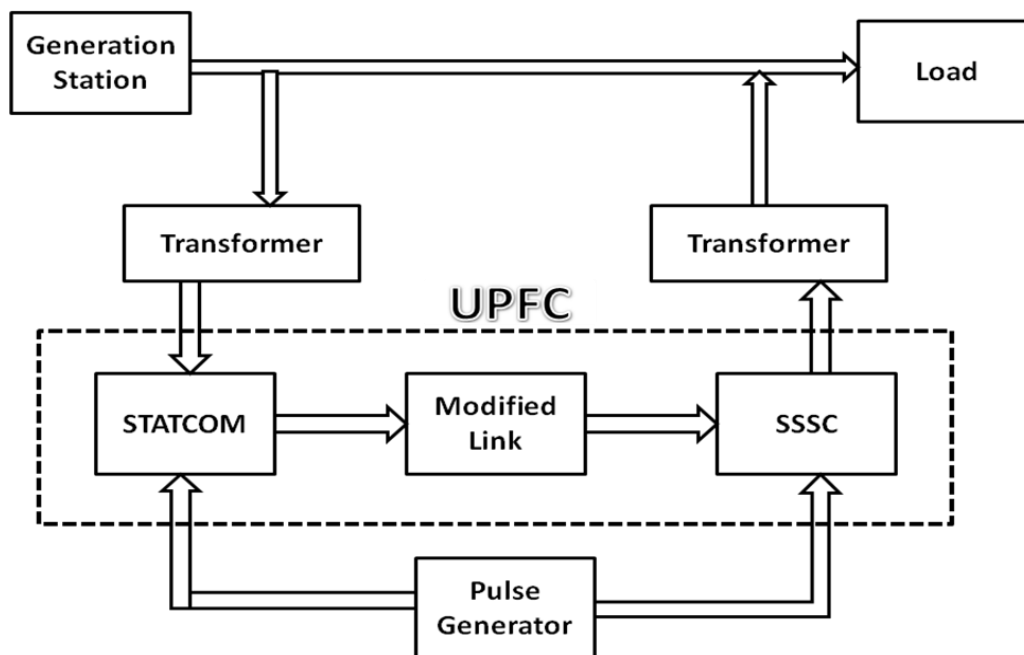


Fig.5 Block Diagram of Modified Location of UPFC

7. Lab Scale Model of UPFC

Programmable Interface Controller (PIC) is being programmed to generate PWM signals to the gate drive that will send the signals to trigger the IGBTs. The comparator provides a reference signal to the PIC controller board to generate triggering signals in synchronization with the supply voltage. A lab scale model is constructed using H- bridge voltage source inverter to act as SSSC.

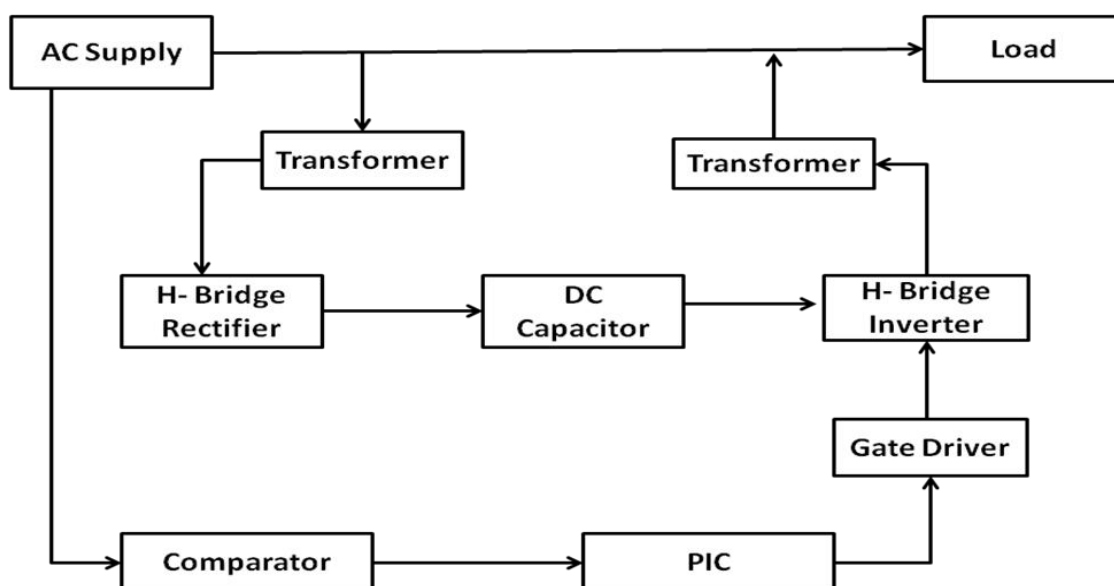


Fig.6 Block Diagram of Lab Scale of UPFC

IV. MODELING AND ANALYSIS OF UPFC

1. SIMULINK Model of Single Phase UPFC

Using the concept of control system, a power system is taken to implement the use of UPFC. The two modes i.e the power flow control and the voltage injection mode are simulated in MATLAB / SIMPOWERSYSTEM to see the effect of UPFC on a power system. Study is carried out to verify the utility of FACTS devices.

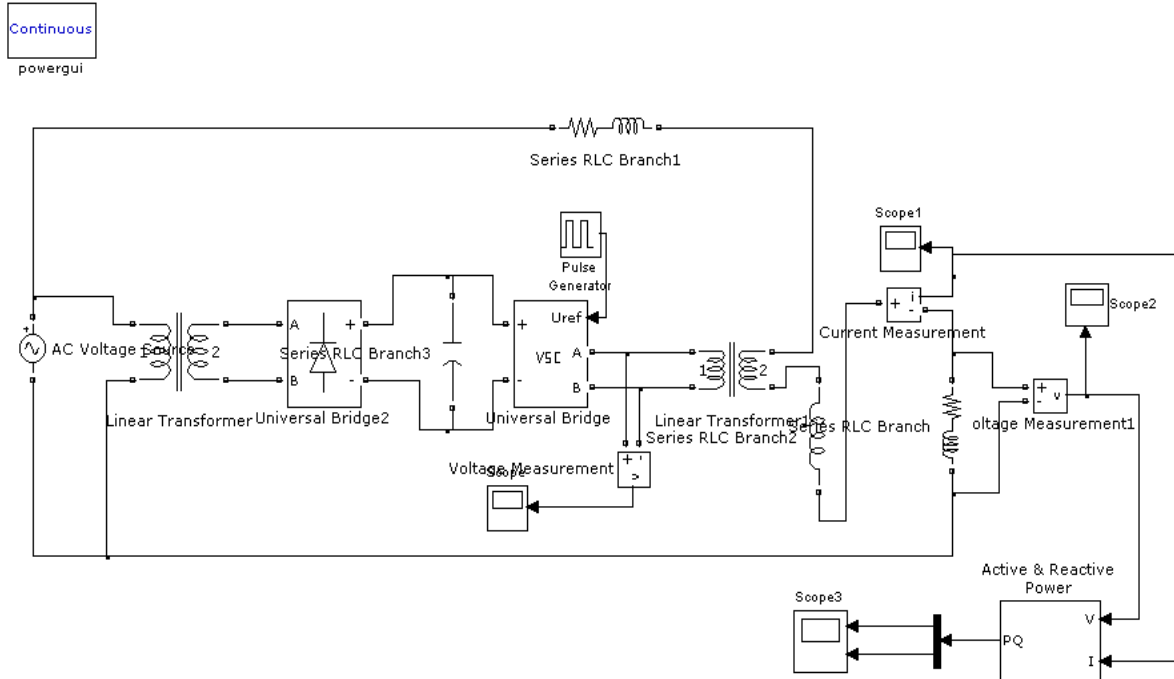


Fig.7 SIMULINK model of Single line UPFC

The capacitor connected in the model is used to balance instantaneous difference in fundamental power ($V_1 I_1 \cos \phi_1$) and power at different frequency ($V_n I_n \cos \phi_n$). The UPFC is assumed to be installed in the single phase power system with voltage source at sending end and single phase load at receiving end.

The single phase model is shown in fig.7, the value of capacitance is taken as infinity for simplicity in the single phase model. The transmission line parameters will be same, only have to do is to add another transmission line running parallel to existing line. The basic idea of this project is to attempt to transmit power or exchange power between the series and parallel part of UPFC.

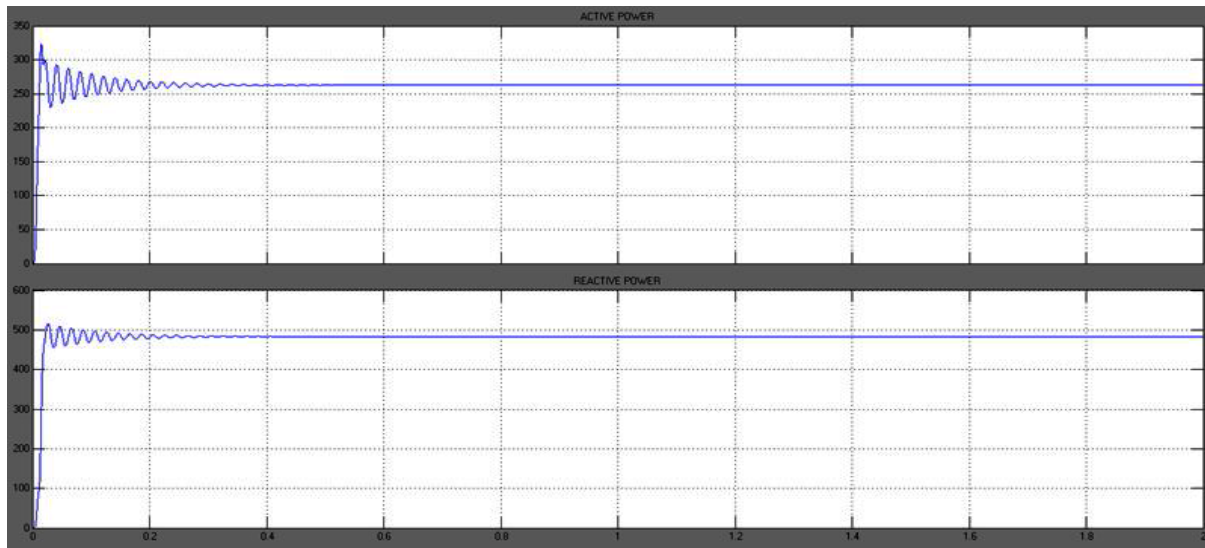


Fig.8 Output Waveform for Active and Reactive Power

V. CONCLUSION

It represents a single phase UPFC concept of transmitting power with DC link capacitor. This gives more flexibility of UPFC installation. The active power exchange between shunt and series is transmitted through a single DC link transmission line. Therefore, to control the power from one end to another end, this concept of power flow control and voltage injection is highly acceptable.

- Power flow control is achieved and congestion is less
- Transient stability is improved
- Faster steady state achievement
- Improved voltage profile

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