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POWER SYSTEM PROTECTION USING UPFC

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INTRODUCTION:

Today's power systems are highly complex and require careful design of new devices taking into consideration the already existing equipment, especially for transmission systems in new deregulated electricity markets. This is not an easy task considering that power engineers are severely limited by economic and environmental issues. Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security. In the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS) [1]. The two main objectives of FACTS are to increase the transmission capacity and control power flow over designated transmission routes.

The improvements in the field of power electronics have had major impact on the development of the concept itself. A new generation of FACTS controllers has emerged with the improvement of Gate Turn-Off (GTO) thyristor ratings (4500V to 6000V, 1000A to 6000A). These controllers are based on voltage source converters and include devices such as Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), the Static Synchronous Series Compensators (SSSCs), and the Unified Power Flow Controllers (UPFCs).

The UPFC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC. The UPFC can provide simultaneous control of all basic power system parameters, viz., transmission voltage, impedance and phase angle. It is recognized as the most sophisticated power flow controller currently, and probably the most expensive one.

In this paper, a UPFC control system that includes both the shunt converter and the series converter has been simulated. The performance of the UPFC in real and reactive power flow through the transmission line has been evaluated.

OPERATING PRINCIPLE OF UPFC:

The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer. A basic UPFC functional scheme is shown in fig.1.

The series inverter is controlled to inject a symmetrical three phase voltage system (Vse), of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line.

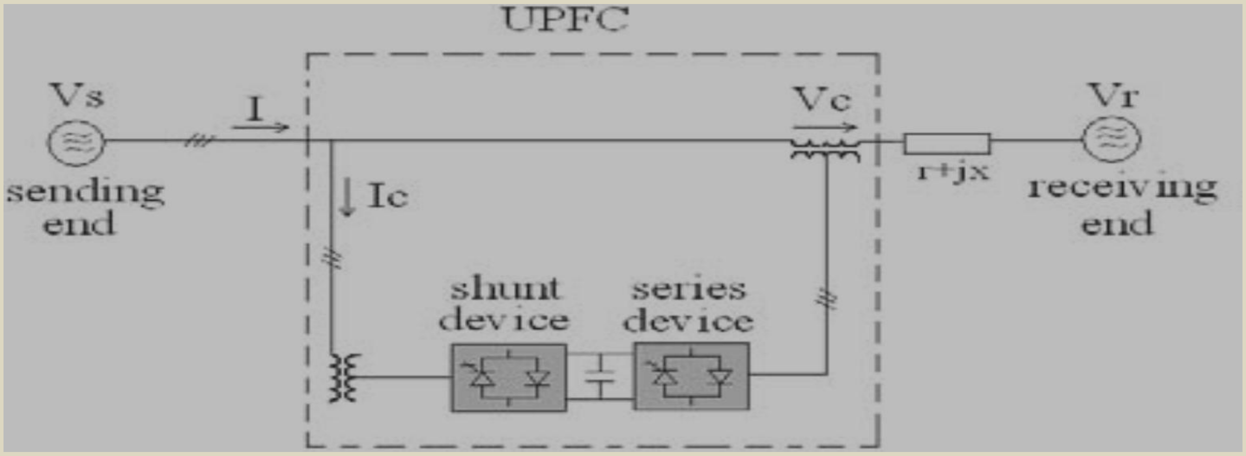


Fig.1 Basic functional scheme of UPFC

The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor Vdc constant. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point.

The two VSI's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power flow on the transmission line. The UPFC has many possible operating modes. In particular, the shunt inverter is operating in such a way to inject a controllable current, ish into the transmission line. The shunt inverter can be controlled in two different modes:

VAR Control Mode:

The reference input is an inductive or capacitive VAR request. The shunt inverter control translates the var reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage, Vdc, is also required.

***Automatic Voltage Control Mode*:**

The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer. The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways.

Direct Voltage Injection Mode:

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

Phase Angle Shifter Emulation mode:

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

Line Impedance Emulation mode:

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

Automatic Power Flow Control Mode**:**

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

MATHEMATICAL MODEL OF UPFC:

The basic structure and operation of the UPFC can be represented through the model shown in fig.2. The transmission line parameters are as shown in Table I.

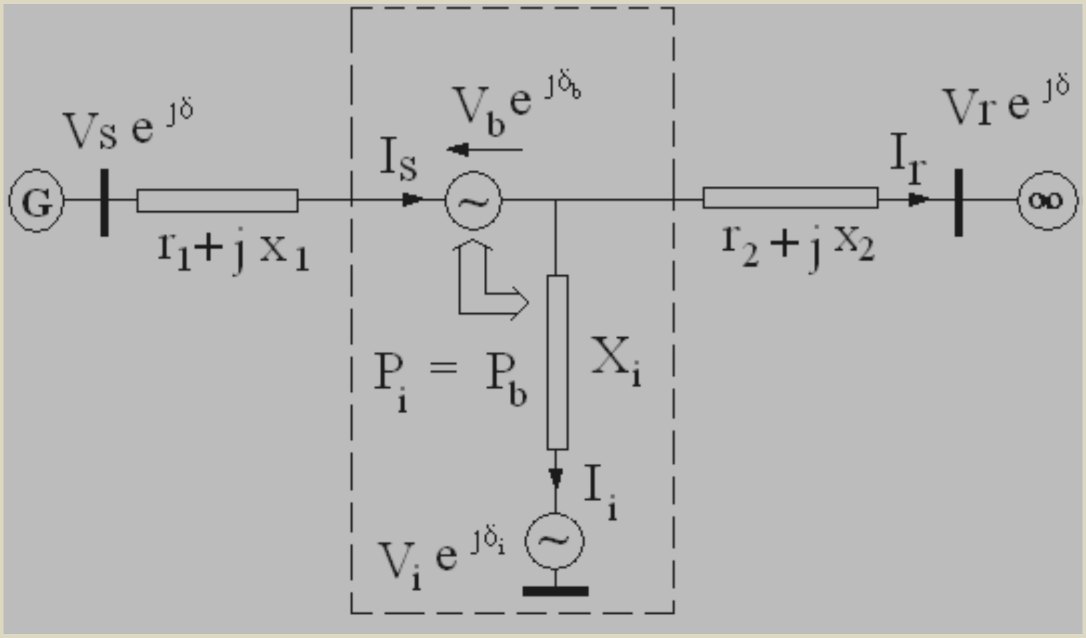
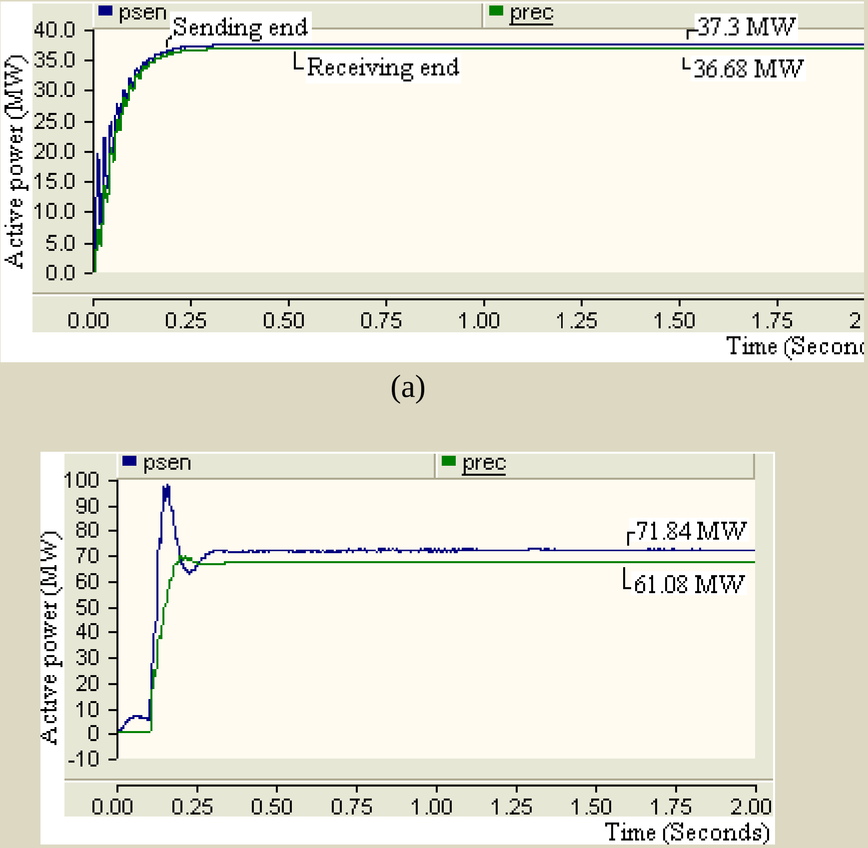


Fig.2 Mathematical model of UPFC

In this model, we have considered the UPFC is placed at the centre of a 100km transmission line. The equations for sending end active and reactive power can be obtained from the real and imaginary powers of power equation. The maximum limit of δ is chosen according to the stability margin [9]. The variation of sending end active and reactive powers by varying δb and δ is obtained through MATLAB



(a)

(b)

Fig. 12 sending end and receiving end active power
(a) Without UPFC (b) With UPFC

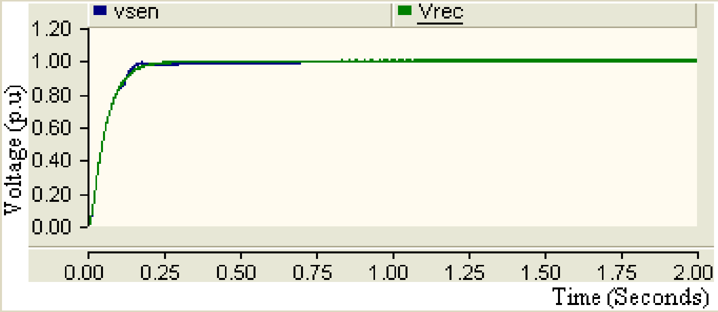
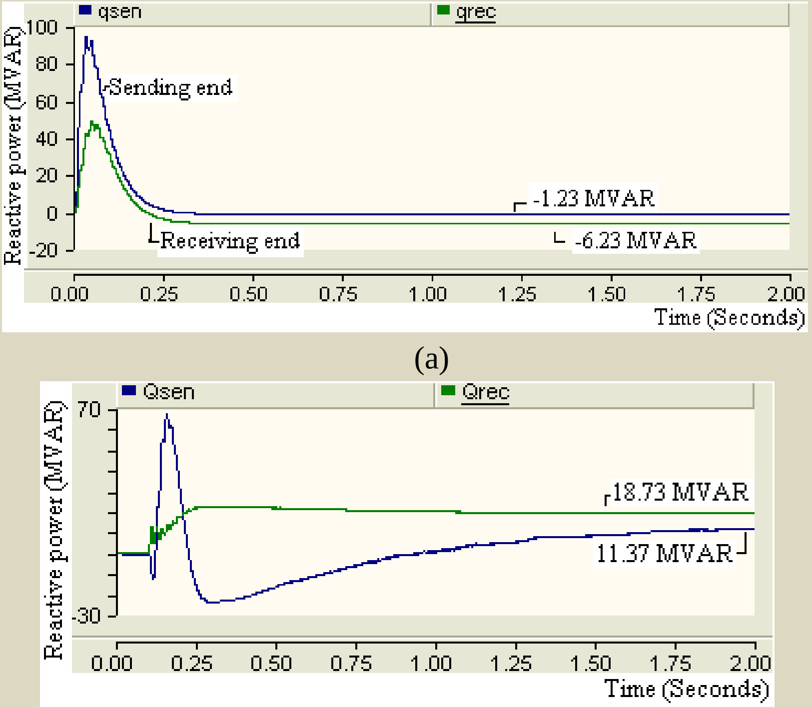


Fig. 10 Sending end and receiving end voltages
(a) Without UPFC (b) With UPFC



(a)

(b)

Fig. 13 Sending end and receiving end reactive power
(a) Without UPFC (b) With UPFC

III. OPTIMAL POWER OSCILLATION DAMPING CONTROLLER

The dynamic characteristics of a system can be influenced by location of eigenvalues, for a good system response in terms of overshoot/undershoot and settling time, a particular location for system eigenvalues is desired depending upon the operating conditions of system. The damping power and the synchronizing power are related respectively, to real part and imaginary part of eigenvalue that correspond to incremental change in the deviation of rotor speed and the deviation of rotor angle[14], this eigenvalue is known as electromechanical mode. Power oscillation damping can be improved if real part of eigenvalue associated with mode of oscillation can be shifted to left-side in complex s-plane as desired. This paper presents an optimal controller such that the closed loop designed system will have a desired degree of stability .

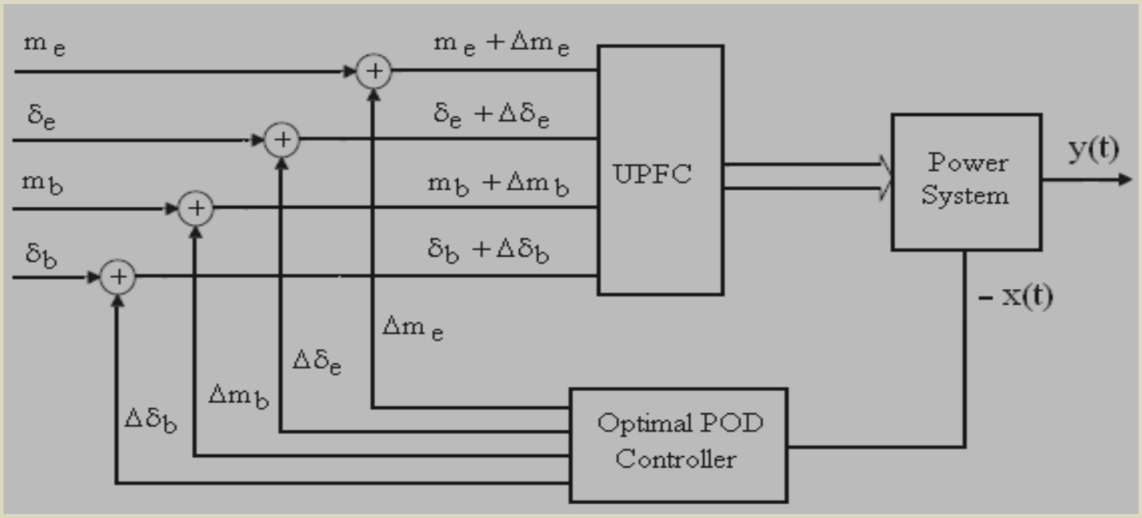


Fig. 3 UPFC based optimal POD controller

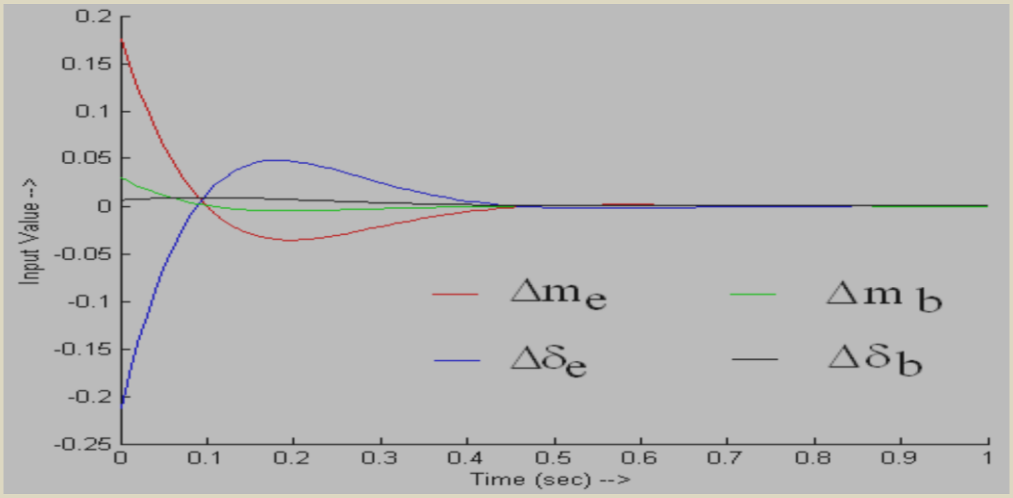


Fig. 5 Variation of modulation input control parameters in SMIB (1.0 pu load)

The change in operating conditions of power system is common phenomenon, e.g., line loading varies over a wide range and also length of line may change, sometimes. For a good design of damping controller, besides the maximum effectiveness of the controller, the robustness of damping controller to the variations of power system operating conditions is an equally important factor to be taken under consideration. Hence, it is desirable for UPFC optimal POD controller that it must be able to respond for changes in operating point along with satisfactory performance.

Therefore, it is extremely important to investigate the effect of load variations and effect of change in line length on the performance of the designed controller. In view of this, the performance of UPFC optimal POD controller at following operating conditions are studied (i) 20 percent decrease in line loading (ii) 20 percent increase in line loading (iii) 10 percent decrease in line length at normal loading condition (iv) 10 percent increase in line length at normal loading condition. For performing such investigations, the parameters of damping controllers are computed at each operating point, i.e., a method being named individual point tuning of controllers parameters is adopted. Figs. 6 to 9 show the response of system states of SMIB power network, at different operating conditions (i) to (iv), as discussed above, and Figs. (10) to (13) show the variations of modulation input control parameters for UPFC optimal POD controller for the same operating conditions as above.

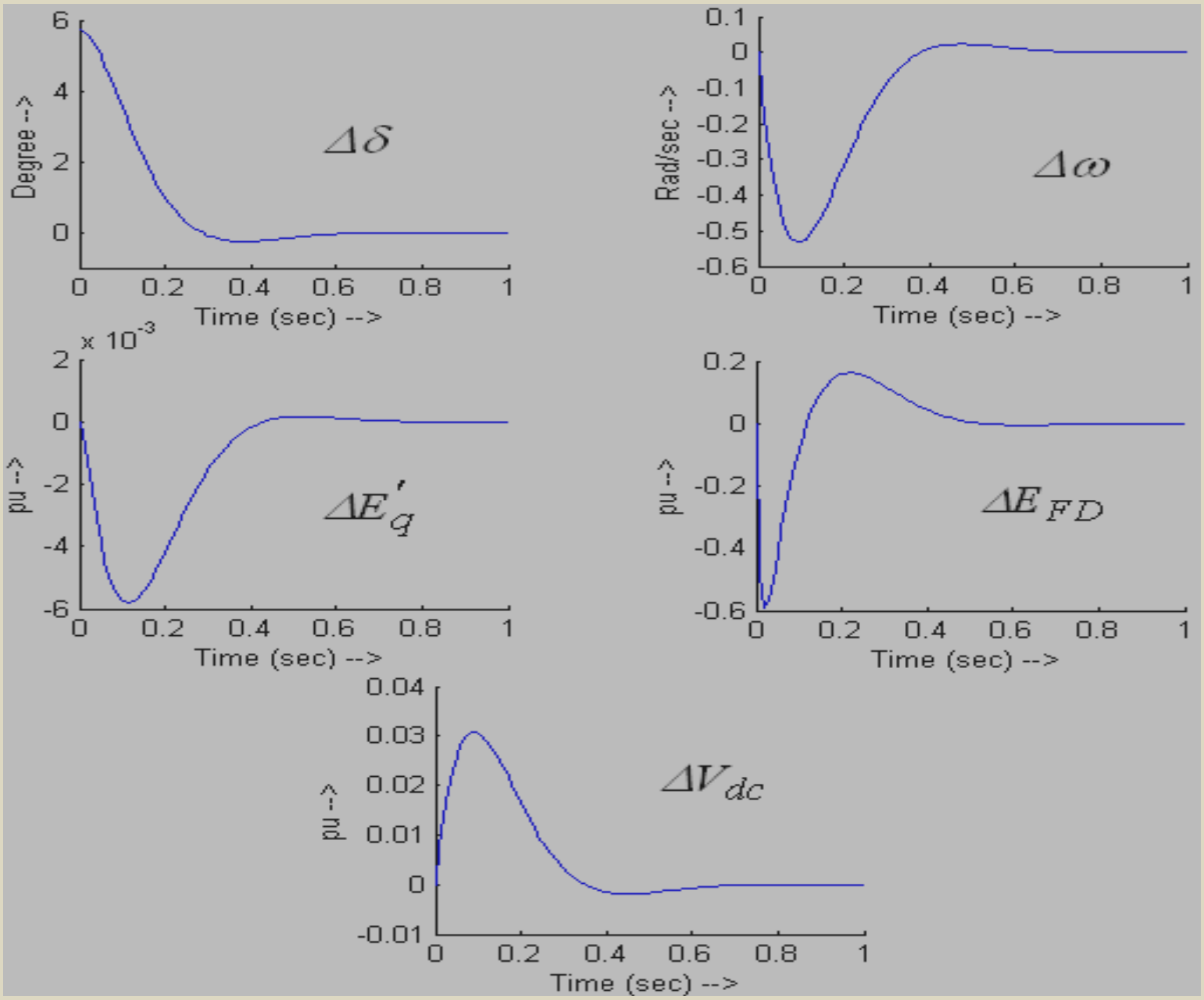


Fig. 6 Variation of system states in SMIB (0.8 pu load)

The model has been used to design optimal damping controller with the concept of eigenvalue assignment technique. The controller designed has been widely studied for variety of system loading and also changing the transmission line length. This has been observed while analyzing the effectiveness of the controller in damping the power oscillations that the controller so designed meets all performance indices of good controller. Moreover, the peak overshoot/undershoot along with the settling time is reasonable within acceptable constraints. This approach provides the relaxation from arbitrary selection of weighting matrix Q with the proper formulation of control strategy. Also, optimal damping controller with UPFC so designed proves to be robust over the wide range of variations in operating conditions.

D-Q CONTROL STRATEGY FOR UPFC :

Power electronic systems have the capability of providing faster response compared to traditional mechanically based power system controls. Therefore to obtain the maximum capability out of the UPFC, a control system with an equally faster response is required. It would be advantageous, if the time-varying equations can be transformed to a time invariant set. This would result in the simplification of the calculations both for steady and transient conditions especially when we are considering a huge power system. R.H.PARK introduced the d-q transformation. This paper presents operation of UPFC using a control strategy which is based on d-q axis control theory. This d-q axis control system enables the UPFC to follow the changes in reference values like AC voltage, DC link voltage, real and reactive powers through the line. By implementing a d-q axis controller it is possible to produce a relatively fast response and to reduce the interaction between real and reactive power flow. In this control system, the transformation of a three phase system to d-q and d-q to 3-phase quantities is done according to Park’s transformation, through which real and reactive power can be controlled individually, while also regulating the local bus voltage. Ooi *et al.*, [3] suggested a control system for the UPFC which is based on the principle that the real power is influenced by the phase angle whereas reactive power is dependent on the voltage magnitude. Therefore to control the real power flow in the transmission line the series UPFC controller adjusts the angle of the series compensation voltage while to regulate the reactive power flow, the amplitude of the series voltage is controlled. As was presented in [3], the real and reactive power flows in the transmission line are influenced by both the amplitude and the phase angle of the series compensating voltage. Therefore, the real power controller can significantly affect the level of reactive power flow. The reactive power controller then adjusts the series voltage magnitude to regulate the reactive power but in turn also changes the real power flow. Thus both controllers reacting to each others output. To improve the performance and to reduce the interaction between real and reactive power control system for a UPFC based on d-q axis theory was presented by Yu *et al.,* [4 and 5]. In [5], cross coupling controller using d-q axis theory is applied to the series converter of the UPFC. In this paper, cross coupling controller using d-q axis theory is applied to the shunt controller of the UPFC.

Shunt inverter control circuit :

Shunt inverter can be controlled in two different modes, viz. VAR control mode and Automatic voltage control mode. In var control mode, the shunt inverter control translates the var reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. In voltage control mode, the shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. As in [5], the crossing gain of a power transmission line is much larger than its direct gain. The cross-coupling controller uses the q-axis voltage Vq, to control the d-axis current Id and the d-axis voltage Vd, to control the q-axis current Iq. This makes it possible to control both active and reactive powers independently. In this simulation, the shunt inverter operates in voltage control mode. Figure-3 shows the DC voltage control circuit. DC link voltage is measured (Vdcm) and compared with the reference value (Vdcref), whose error is fed to PI controller and related quadrature axis voltage, Vq is developed. Id and Iq are obtained through Park's transformation of transmission line current.

The generated Vd and Vq signals are used to develop firing pulses for the six GTOs in the inverter, as shown in the Figure-5, in PSCAD environment. A generalized sinusoidal pulse width modulation switching technique is used for pulse generation. H-L (high-low) logic in PSCAD is used to generate firing pulses. Two sets of signals, reference and triangular ones are needed, one set for turning-on and the other for turning-off the GTOs. Deblock option is available, which is made 0.1 seconds during this simulation.

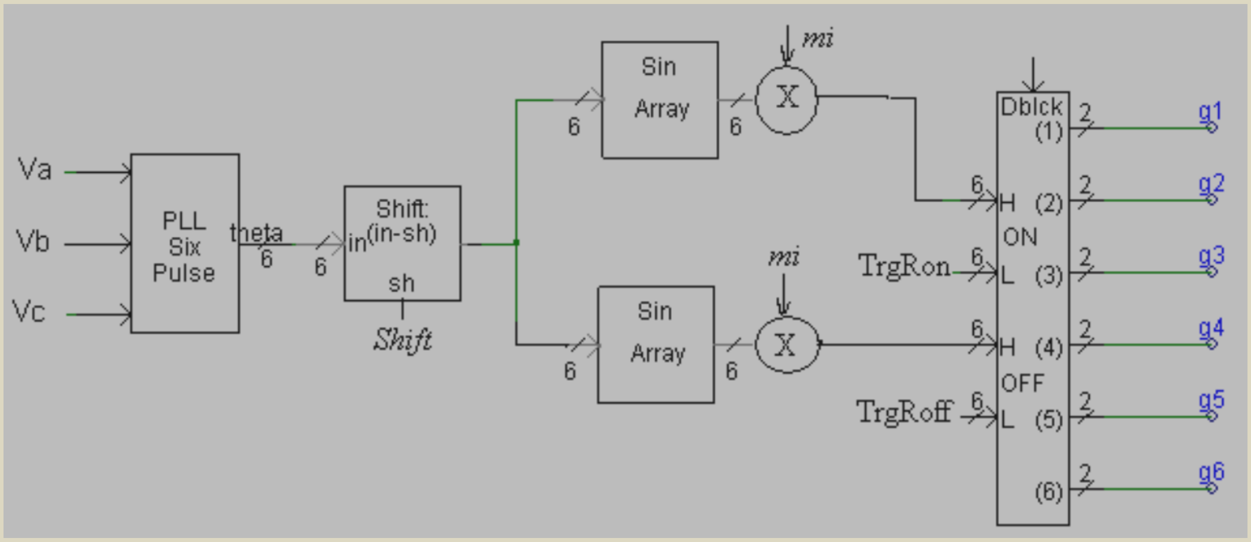


Fig. 8 Circuit for firing pulse generation

Series Inverter Control Circuit:

In this case, the series inverter operates in the direct voltage injection mode. The series inverter simply injects voltage as per the theta order specified. Fig. 9 shows the series inverter control circuit, which is an open loop phase angle controller, generates modulation index, *mi* and *shift.* The *mi* and *shift* signals are used to develop firing pulses as shown in fig. 8.

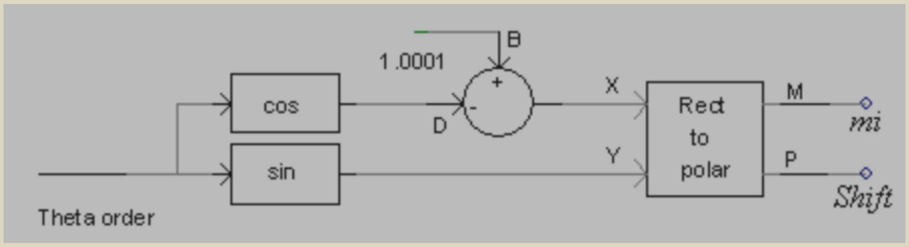


Figure-6. Series inverter open-loop phase angle controller.

UPFC is placed in series with the transmission line at the sending end. For each of the controller, a simulation model is created which includes the required PWM, filters and digital controllers. Different types of faults were simulated and applied to the transmission line at 1.0 second and cleared at 1.05 seconds using timed fault logic. When the line is without UPFC, the fault current is about 14kA, voltage drop across the line is very high during the fault. When the UPFC is placed in the transmission line for the same fault, the fault current is reduced to 5kA as per the simulation results. Figure-8 shows the simulation results when L-G fault is applied to the transmission line. Figure-9 shows the simulation results when LL-G fault is applied at the sending end of the transmission line. Figure 10 shows the simulation results when LLL-G fault is applied to the transmission line. Voltage regulation is highly improved by the variation of the series injected voltage during the fault as shown in Figure-8. The DC link voltage is maintained at 38kV by DC voltage controller. The variation in direct axis current, direct axis voltage, quadrature axis current and quadrature axis voltage are shown in Figure-8. Simulation results show that the q-axis voltage Vq controls d-axis current Id which affects the real power flow through the transmission line.

Active power transmitted through the line is 90 MW. Similarly, the d-axis voltage Vd controls q-axis current Id which affects the reactive power flow through the transmission line. The performance of the transmission line is highly improved by placing the UPFC at the sending end. The cross coupling controller also shows very good performance. The response time of the control system is very less (less than 100 ms) and the interaction between the real and reactive power is minimal.

CONCLUSION:

A UPFC is able to quickly control the flow of real and reactive power in a transmission line. In this paper, a cross coupling controller based on d-q axis theory conventional PI controller with a response as slow as 100ms has the difficulty in suppressing the power variations caused by the faults. Moreover, a conventional controller may cause an over current after finishing the fault, due to the slow response of the integral gains in the control loop. By implementing d-q controller with cross coupling, to the series converter results good transient response and reduced oscillations. By implementing a d-q axis cross coupling controller to the shunt converter of UPFC, it is possible to produce relatively fast response and to reduce the interaction between real and reactive power flow. The simulation results show good transient response with less overshoot and reduced oscillations. The d-q control system can contribute not only to achieve fast power flow control but also improvement of stabilizing the transmission systems.

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