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MODELING AND IMPLEMENTATION OF D-QCONTROL SYSTEM FOR A UNIFIED POWER FLOW CONTROLLER

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Abstract **-The Unified Power Flow Controller (UPFC) can provide simultaneous control of all basic power system paramaters (transmission voltage, impedance and phase angle). The controller can fulfill functions of reactive shunt Compensation, series compensation and phase shifting, meeting multiple control objectives. From a functional perspective, the objectives are met by appliying a cross coupling control strategy which is based on d-q axis theory is presented by simulation. In this control system, the transformation of a three phase system to the d-q, 2 axis system is done through which real and reactive power can be controlled individually, also regulating the local bus voltage. The performance of the proposed control system is checked by applying various faults across a transmission line to which UPFC is connected. A generalized pulse width modulation switching technique is used to generate firing pulses for both the converters of the UPFC. Simulation was carried out using Matlab/ Simulink software to validate the performance of the UPFC connected to a transmission line with different faults. Simulation results show that the proposed control scheme is effective in damping the power swings in transient states.**

Index Terms- **Unified power flow controller, optimal power flow, d-q axis control, power flow control, angle stability, power system oscillations.**

I. INTRODUCTION

The concept of the flexible AC transmission system (FACTS) envisages the use of solid state controller to achieve flexibility of power system operation by fast and reliable control. One of the greatest advantages of using a FACTS device in a power transmission system is to enhance the transient stability performance of the system by controlling the real and reactive power flow of the line during fault conditions. The unified power flow controller (UPFC) is one of the most versatile of the FACTs controllers [1]and its main function is to inject a controllable series voltage (both in magnitude and phase angle) with respect to the bus where it is located) thereby modulatin the line reactance and controlling the power flow in the transmission line.

Two voltage source inverters connected by a capacitor charged to a DC voltage realize the UPFC. The converter number one, which is a shunt converter, draws real power from the source and exchanges it (minus the losses) to the series converter. The power balance between the shunt and series converters is maintained, to keep the voltage across the DC link capacitor constant.

As the UPFC can provide a smooth control response, an analytical model that neglects the swtiching details is adequate to study low frequency electromechanical oscillations. To control the magnitude and phase and

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quadrature component of the voltage (with reference to the line current) are controlled using PI regulator (conventional control) [2]. The real and reactive power references are used for this control and are derived from steady state power flow requirements. The shunt converter of the UPFC may be controlled to provide the DC capacitor voltage constant along with the bus voltage regulation. This is achieved by controlling the in-phase and quadrature components of the shunt current (with respect to the system bus voltage where the UPFC is located) using PI regulators.

II. OPERATING PRINCIPLE OF UPFC

A simplified schematic of a UPFC is shown in Figure-1. The main features are, it has two inverters, one connected in series with the line through a series insertion transformer and another connected in shunt with the line through a shunt coupling transformer. Primarily, the series-connected inverter is used to inject a controlled voltage in series with the line and thereby to force the power flow to a desired value. In general, the series inverter may exchange both real and reactive power while performing this duty. A voltage sourced-inverter is able to generate the needed reactive power electronically at its ac terminals, but is incapable of handling real power exchange unless there is an appropriate power source connected to its dc terminals. Consequently the series-connected inverter has its dc terminals connected to those of the shunt-connected inverter, which performs its primary function by delivering exactly the right amount of real power to meet the real power needs of series inverter. It obtains this real power from its connection to the ac bus. The shunt inverter can also perform a secondary function by electronically generating reactive power for regulation of the local ac bus voltage. The UPFC thus offers the unique capability of independently regulating the real and reactive power flows on the transmission line, while also regulating the local **bus voltage.**

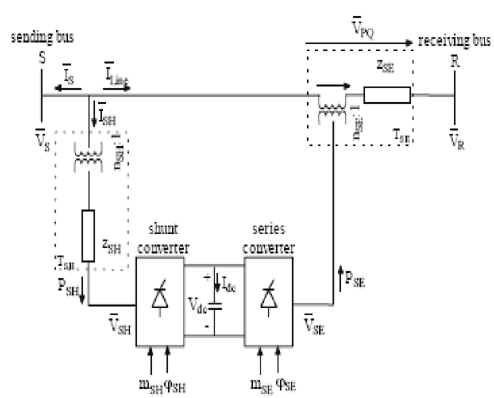

Fig. 1. Fundamental frequency model of UPFC

III. D-Q CONTROL SYSTEM FOR A UPFC

The D-Q transformation and Operation of UPFC using a control strategy which is based on d-q axis control theory as shown Fig.2. 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

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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. [4] 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

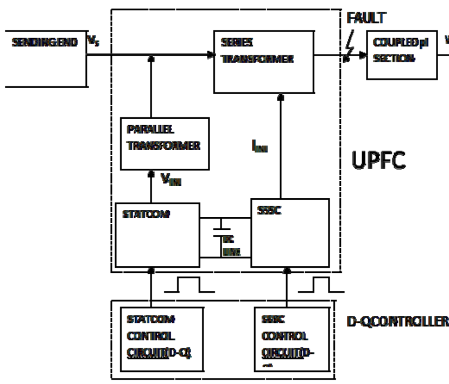

Fig.2. Block Diagram: Setup of UPFC

flow, the amplitude of the series voltage is controlled.

A. Real and Reactive Power Flow Control

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.*,.[8] In 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.

B. Pulses Generation

The generated V_d and V_q signals are used to develop firing pulses for the six GTOs in the inverter, as shown in the Figure-3, in MATLAB environment. A generalized sinusoidal pulse width modulation switching technique is used for pulse generation. H-L (high-low) logic in MATLAB is used to generate firing pulses [1]. 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.

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C. Series inverter control circuit

The series inverter controls the magnitude and angle of the voltage injected in series with the line. Main objective of this voltage injection is to influence the power flow on the line.

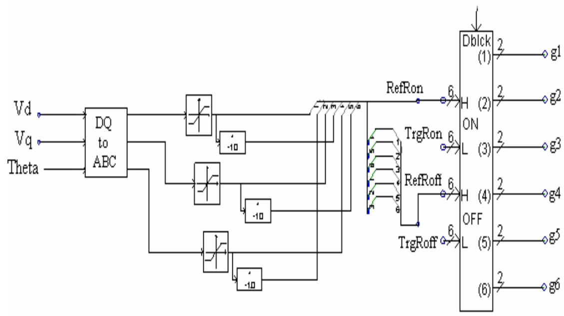

Fig. 3. Circuit for Pulse Generation

The actual value of the injected voltage can be obtained in several ways, viz. direct voltage injection mode, phase angle shifter emulation mode, line impedance emulation mode and automatic power flow control mode. In this simulation, the series inverter operates in the direct voltage injection mode. The series inverter simply injects voltage as per the theta order specified. By varying the theta order input to this controller power flow through the transmission line can be varied. Figure-4 shows the series inverter control circuit, which is an open loop phase angle controller, generates modulation index, mi and shift, as per the theta order specified.

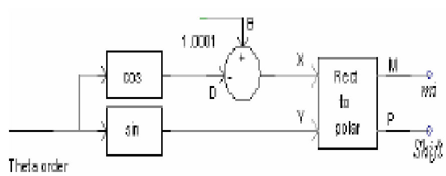

Fig.4. A Series inverter open-loop phase angle controller.

The modulation index, mi and shift signals are used to develop gate pulses as shown in Figure-5, using same H-L logicunit. Two signals are developed, one to turn on and the other to turn off the GTO.

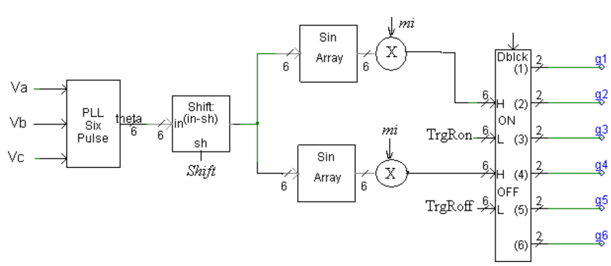

Fig.5. Circuit for Pulse Generation

IV. UPFC POWER INJECTION MODEL

So far no work has been reported in open literature for the optimal location of UPFC considering the effects on economical cost and voltage stability margin under both normal and contingency circumstances[10]. Reference focuses on STATCOM as a dynamic VAR source Providing voltage support in a power system.

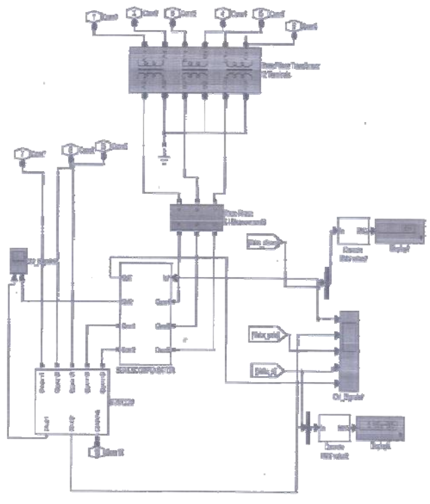

Fig. 6. UPFC Power Injection Model

Both static voltage stability margins based on P-V curve and time domain dynamic simulation are carried out and compared to verify the agreement between the two study methods.

The series transformer by universal bridge circuit. The series device injects real and reactive power through series injection transformer. The amount of power injection is depending on the reference set value and actual. The twosignals given to comparator that out put is feeding to the firing circuit.

The Fig.6 shows the UPFC power injection model. The required power is injected to the STATCOM supply reactive power and receives real power that feed to the DC- link capacitor. Capacitor gives real and reactive power to series inverter circuit. Both are combinely working to reduce the fault current, transient behaviors and damping in dynamicperformance.

Even though one method is static analysis and the other is dynamic analysis, the two different methods lead to the same result. For example, voltage collapse in time – domain simulation reflects on P_V curve as the operating point out of the range of maximum load- capability.

V. SIMULATION OF D-Q CONTROL SYSTEM FOR AUNIFIED POWER FLOW CONTROLLER

A. Simulation setup

Figure7 and 8 shows the setup of without and with UPFC used for simulation and analysis using

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MATLAB. The circuit parameters are shown in Table-1. The main circuit of the series device (SSSC) consists of a three phase PWM inverter, the ac terminals of which are connected in series to a transmission line through three single phase transformers. The shunt device (STATCOM) consists of a three phase PWM inverter, the ac terminals of which are connected in parallel with the transmission line via a three phase star-delta transformer[1]. A transmission line of a simple power system with parameters given in Table-1 is considered. 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 as shown in Fig.9. Different types of faults were simulated and applied to the transmission line at 0.1second and cleared at 0.15 seconds using timed fault logic.

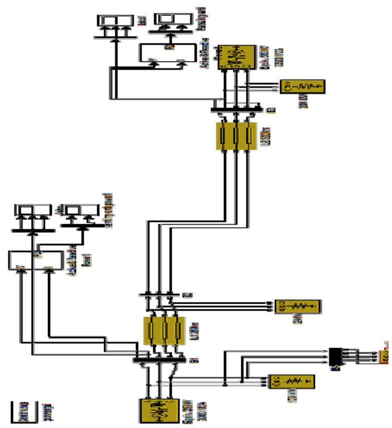

Fig.7. Simulation Setup: Transmission line without UPFC

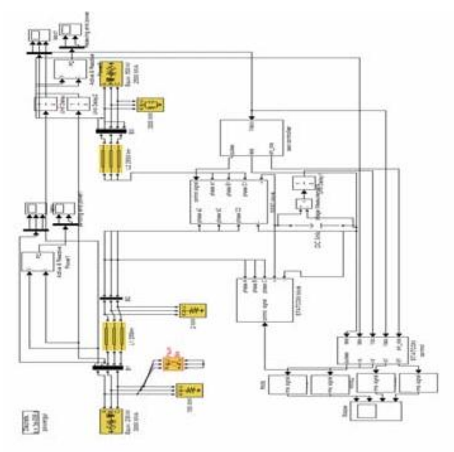

Fig.8. Simulation Setup: Transmission line with UPFC

PWM inverter, the ac terminals of which re connected in series to a transmission line through three single phase transformers.

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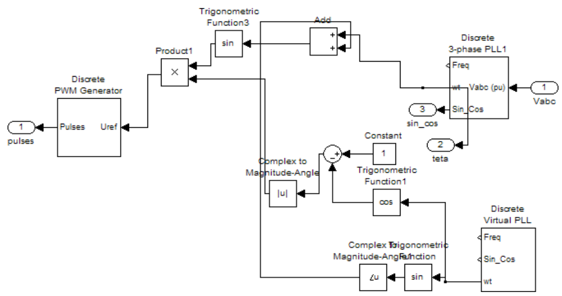

Fig. 9 Series device (SSSC) in UPFC

The shunt device (STATCOM) consists of a three phase PWM inverter, the ac terminals of which are connectedin parallel with the transmission line via a three phase star- delta transformer.

A transmission line of a simple power system with parameters given in table – 1 is considered. UPFC is placed in series with the transmission line at the sending end. For each ofthe controller,

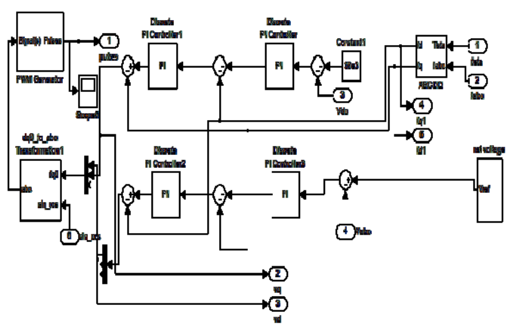

Fig. 10. Shunt device (STATCOM) in UPFC

A simulation mode is created which includes the required PWM, filters and digital controllers. Different types of faults were simulated and applied to the transmission at 0.10 second to 0.15 second using timed fault logic.

VI. SIMULATION PARAMETERS

A transmission line of a simple power system with parameters given in Table-1 is simulated.

TABLE- I TRANMISSION LINE PARAMETERS

Line to line voltage	230 kV
Frequency	60 Hz
Transmission rating	100 MVA

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Capacitance of DC link Capacitor	750000□ F
DC link voltage	38 kV
Length of the transmission line	300km
Resistance of the line	32□□ /m
Inductive reactance of the line	388.3 □□ /m
Capacitive reactance of the line	241.1 M-m

UPFC is placed in series with the transmission line at the sending end as shown in Fig.10. 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 0.1 second and cleared at 0.15 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, as in [10]. 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.

RESULTS AND DISCUSSION

Figure-11(a-d)-13(a-d) shows the simulation results of various faults are 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-13(c-d). 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-13(a-d). Simulation results show that the q- axis voltage V_q controls d-axis current I_d which affects the real power flow through the transmission line. Active power transmitted through the line is 90 MW. Similarly, the d-axis voltage V_d controls q-axis current I_d 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[12]. 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.

L-G FULT SIMULATION RESULTS

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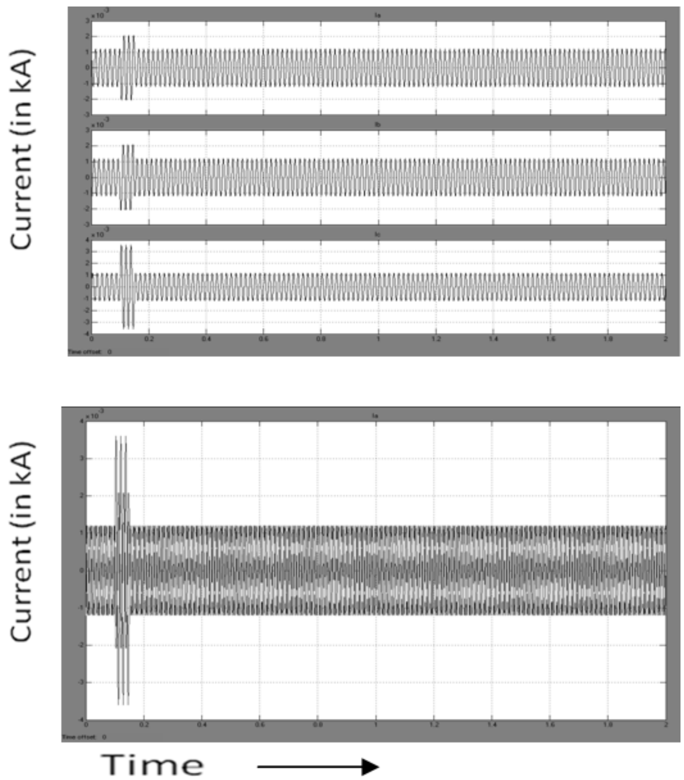

Fig. 11 (a). L-G fault is applied to the transmission line. (Ia, Ib, Ic)

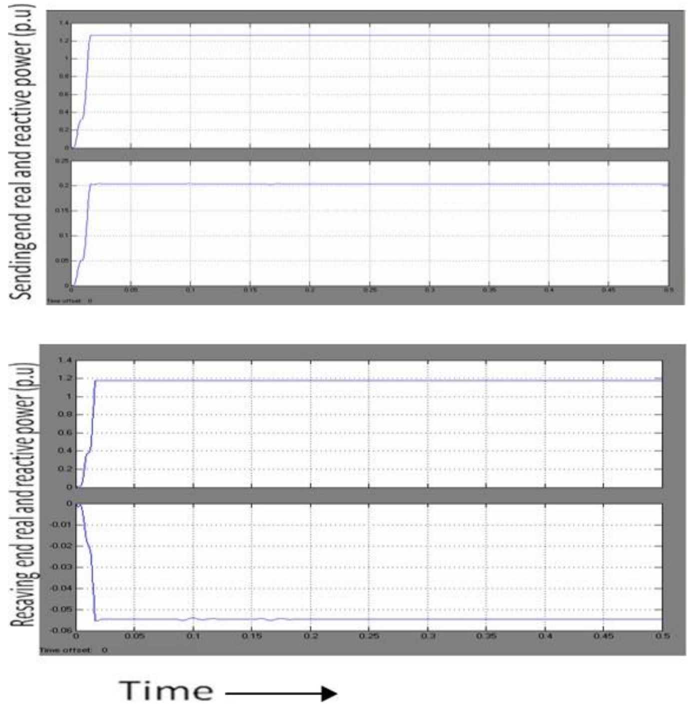

Fig.11 (b). L-G fault is applied to the transmission line without UPFC

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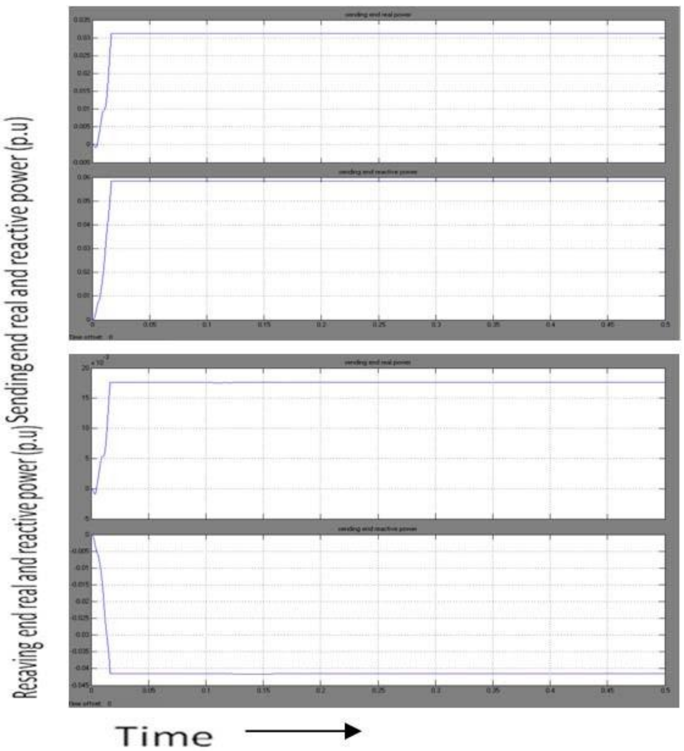

Fig.11 (c). L-G fault is applied to the transmission line with UPFC

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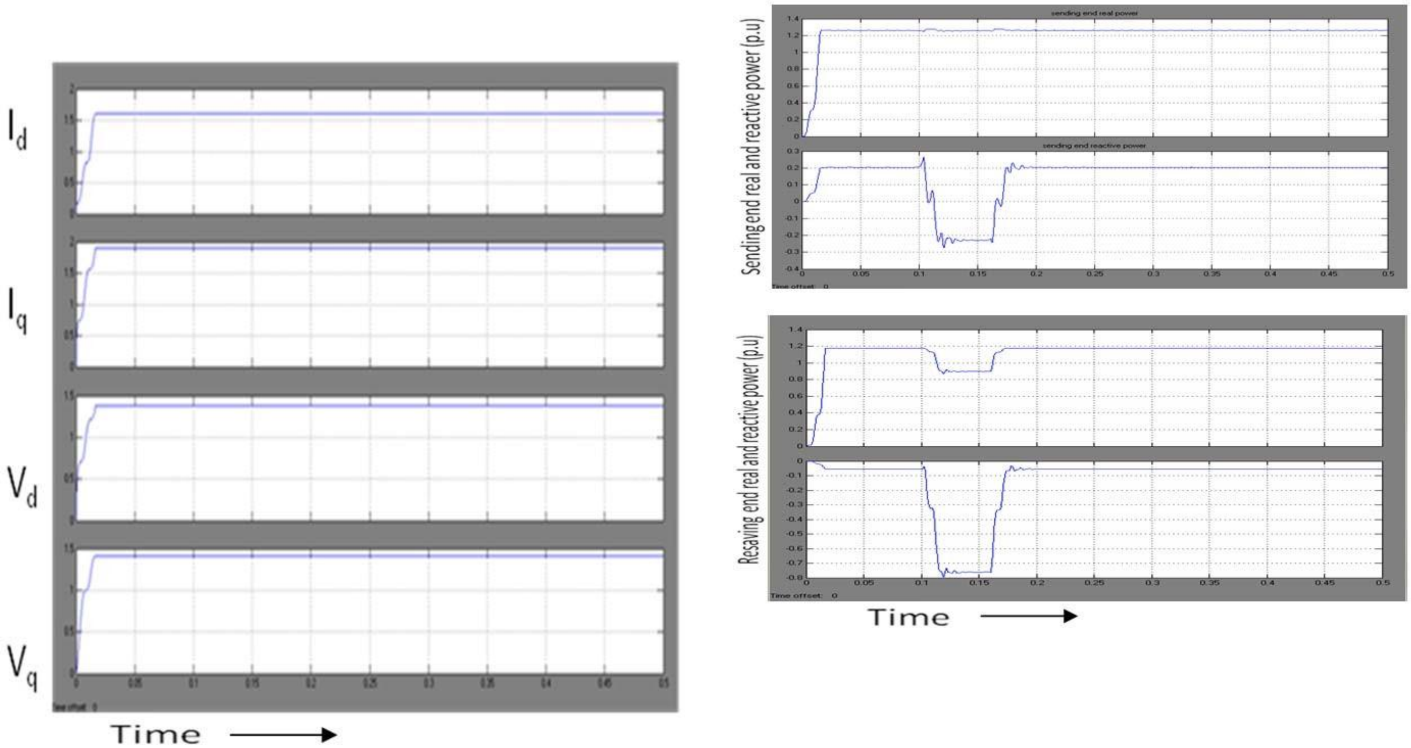

Fig.11 (d). L-G fault is applied to the transmission line with UPFC (V_q, V_d, I_q, I_d)

LL-G FAULT SIMULATION RESULTS

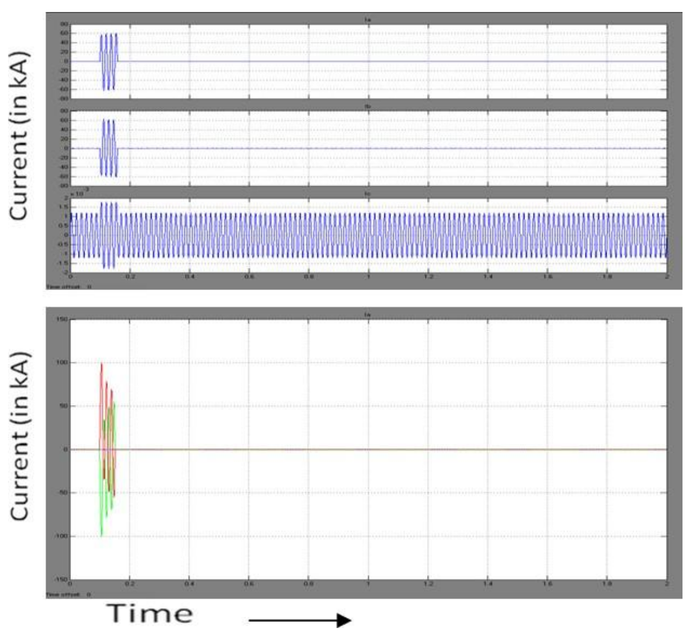

Fig. 12 (a). LL-G fault is applied to the transmission line. (I_a, I_b, I_c)

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Fig. 12 (b). LL-G fault is applied to the transmission line without UPFC

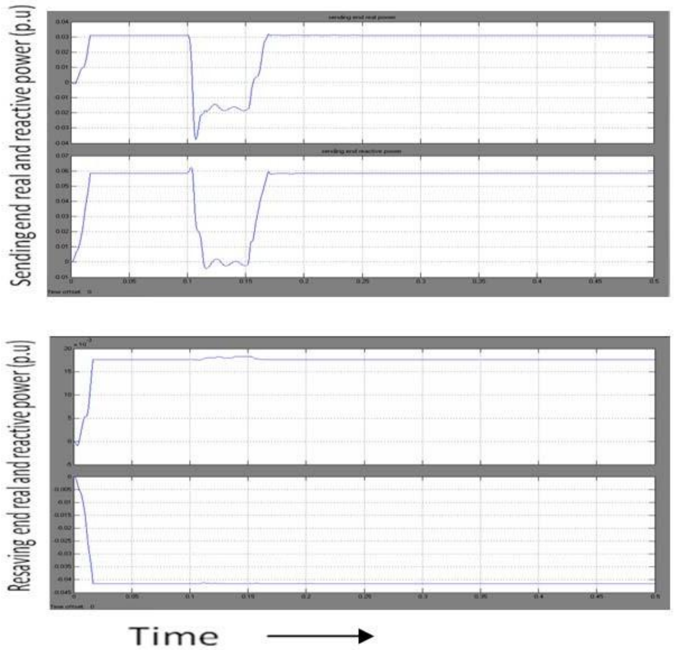

Fig. 12 (c). LL-G fault is applied to the transmission line with UPFC

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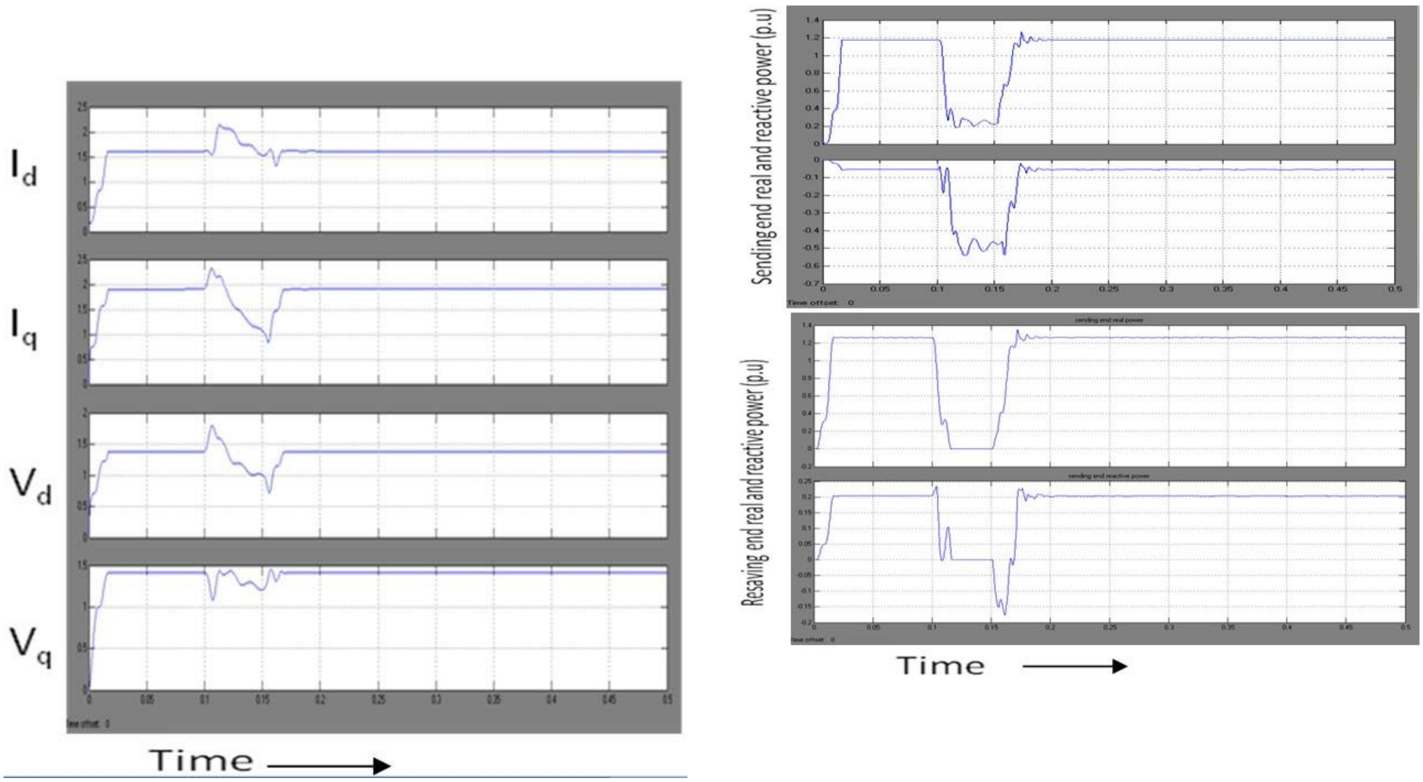

Fig. 12 (d). LL-G fault is applied to the transmission line with UPFC (V_q, V_d, I_q, I_d)

LLL-G FAULT SIMULATION RESULT

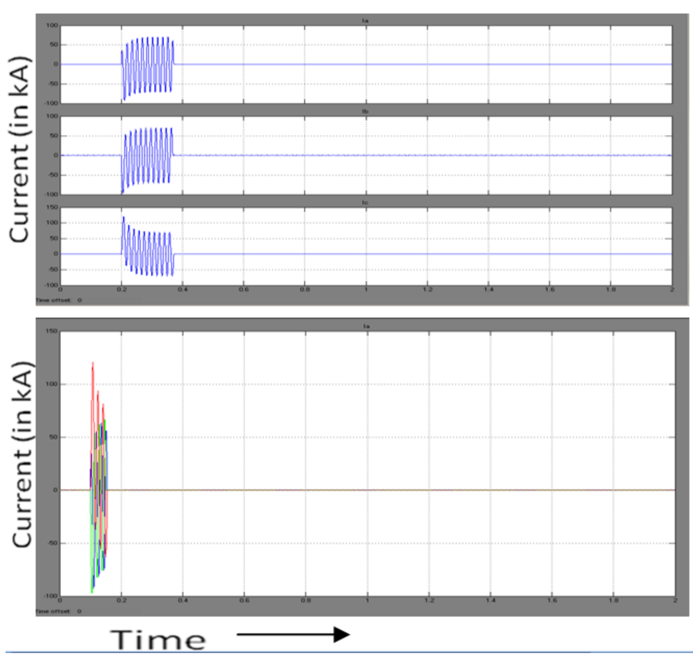

Fig. 13 (a). LLL-G fault is applied to the transmission line. (I_a, I_b, I_c)

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Fig- 13 (b) LLL-G fault is applied to the transmission line without UPFC

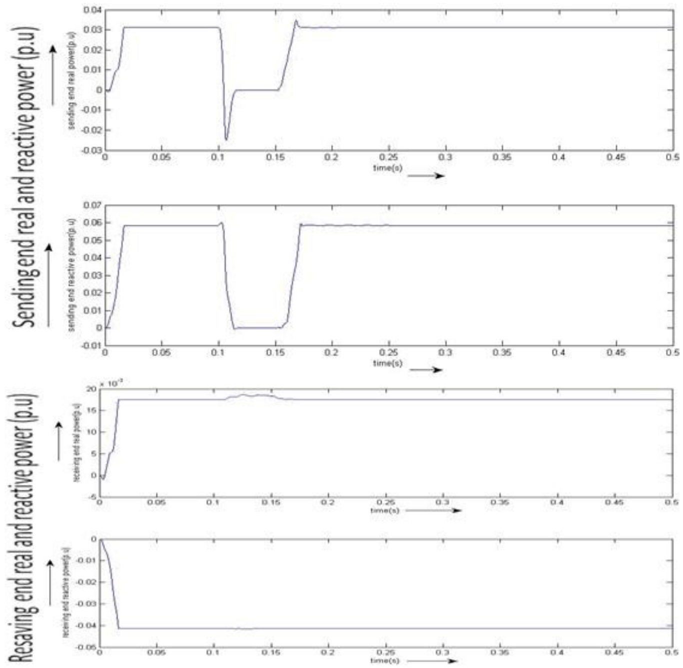

Fig.13 (c). LLL-G fault is applied to the transmission line with UPFC

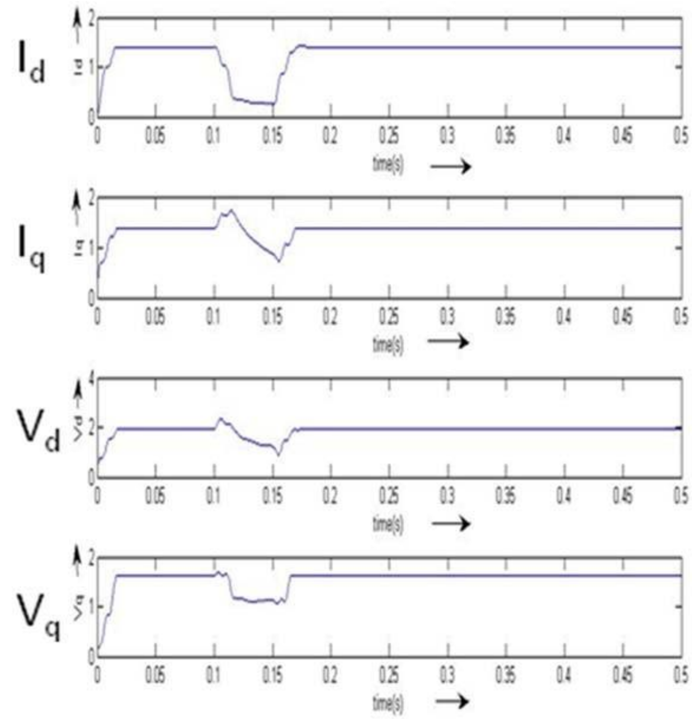

Fig- 13 (d) LLL-G fault is applied to the transmission line with UPFC (V_q, V_d, I_q, I_d)

CONCLUSIONS

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 is presented and performance of the UPFC connected to a transmission line under different fault conditions is studied through simulation. The three faults, L-G, LL-G and LLL-G are applied to the transmission line. A UPFC with a conventional PI controller with a response as slow as 100ms has the difficulty in suppressing the power variations caused by the faults [12]. 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 [5] 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 for improvement of stabilizing the transmission systems.

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