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SIMULATION OF D-Q CONTROL SYSTEM FOR A UNIFIED POWER FLOW CONTROLLER

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ABSTRACT

The Unified Power Flow Controller (UPFC) is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission system. This paper presents a control system which enables the UPFC to follow the changes in reference values like AC voltage and DC link voltage. Operation of UPFC using 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, while also regulating the local bus voltage. The performance of the proposed control system is checked by applying different 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. Simulations were carried out using PSCAD 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.

Keywords: power, flow, DC, AC, voltage regulation, transmission system, FACTS, PWM converters, UPFC.

1. INTRODUCTION

The power transfer capability of long transmission lines is usually limited by thermal capability, dielectric strength and a number of stability issues. Economic factors, such as high cost of long lines and revenue from the delivery of additional power, give strong incentives to explore all economically and technically feasible means of raising the stability limit. On the other hand, the development of effective ways to use transmission systems at their maximum thermal and dielectric capability has caught much research attention in recent years. Fast progression in the field of power electronics has great influence on the power industry. One direct outcome of its influence is the concept of Flexible AC Transmission Systems (FACTS), which improves stability to increase usable power transmission capacity to its thermal limit. The family of FACTS devices makes use of gate turn-off thyristors (GTOs) in high power converter conurations that can be controlled to behave as three phase sinusoidal voltage sources, to provide fast control of active and reactive power through a transmission line. The family of FACTS devices includes the 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. Most researches have emphasized the effect of UPFCs on power flow control and stability improvement. However, a little literature has been published on dynamic performance and transient behaviour of UPFCs.

This paper presents a control scheme and comprehensive analysis for a UPFC through computer simulation. In this control scheme, the transformation of a three phase system to d-q, two axis system is used through which real and reactive power can be controlled individually. The performance of the above said control scheme is tested by applying different faults across a transmission line to which it is connected. It concludes that the proposed control scheme is characterized by successfully damping power swings in transient states.

2. BASIC 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.

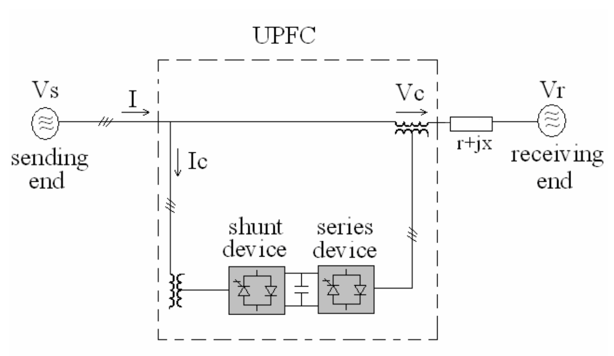

Figure-1. Schematic of UPFC.

3. 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.

4. SIMULATION SETUP

Figure-2 shows the setup of the UPFC used for simulation and analysis using PSCAD. 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. 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. 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.

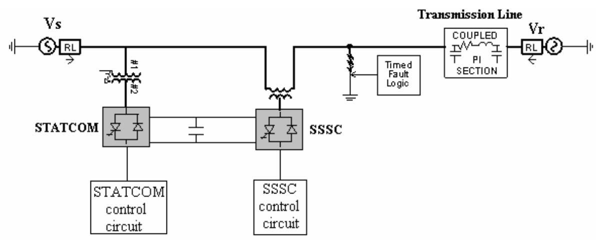

Figure-2. Setup of UPFC.

4.1. 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.

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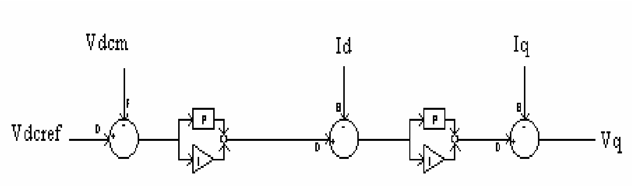

Figure-3. DC Voltage control circuit.

Similarly, AC voltage from the sending end bus feeding shunt coupling transformer is measured in p.u (Vpum) and compared with the AC voltage set point (here 1.0 p.u), whose error is fed to PI controller to generate the related direct axis voltage, Vd. Figure-4 shows the AC voltage control circuit for the shunt inverter.

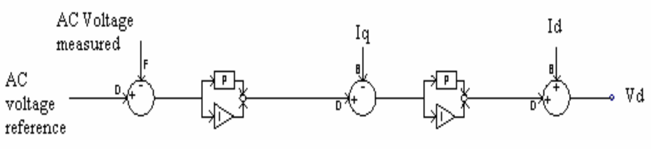

Figure-4. AC Voltage control circuit.

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.

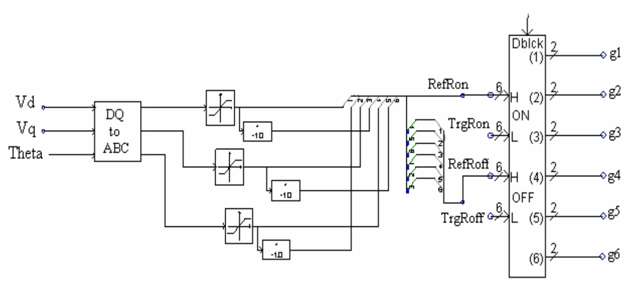

Figure-5. Circuit for pulse generation.

4.2 Series inverter control circuit

The series inverter controls the magnitude and angle of the voltage injected in series with the line. Main objective this voltage injection is to influence the power flow on the line. 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 powerflow 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-6 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.

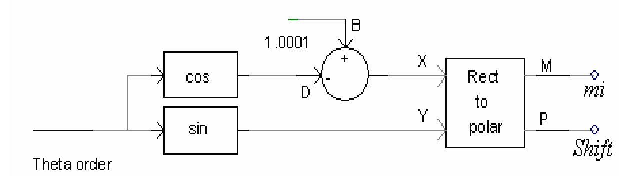

Figure-6. Series inverter open-loop phase angle controller.

The modulation index, mi and shift signals are used to develop gate pulses as shown in Figure-7, using same H-L logic unit. Two signals are developed, one to turn on and the other to turn off the GTO.

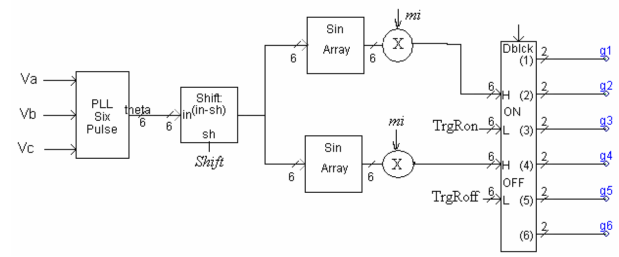

Figure-7. Circuit for pulse generation.

5. SIMULATION RESULTS

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

Table-1. System parameters.

Line to line voltage	230 kV
Frequency	60 Hz
Transmission rating	100 MVA
Capacitance of DC link Capacitor	2000μF
DC link voltage	38kV
Length of the transmission line	500 km
Resistance of the line	32 μΩ/m
Inductive reactance of the line	388.3 μΩ/m
Capacitive reactance of the line	241.1 MΩ-m

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, 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. 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

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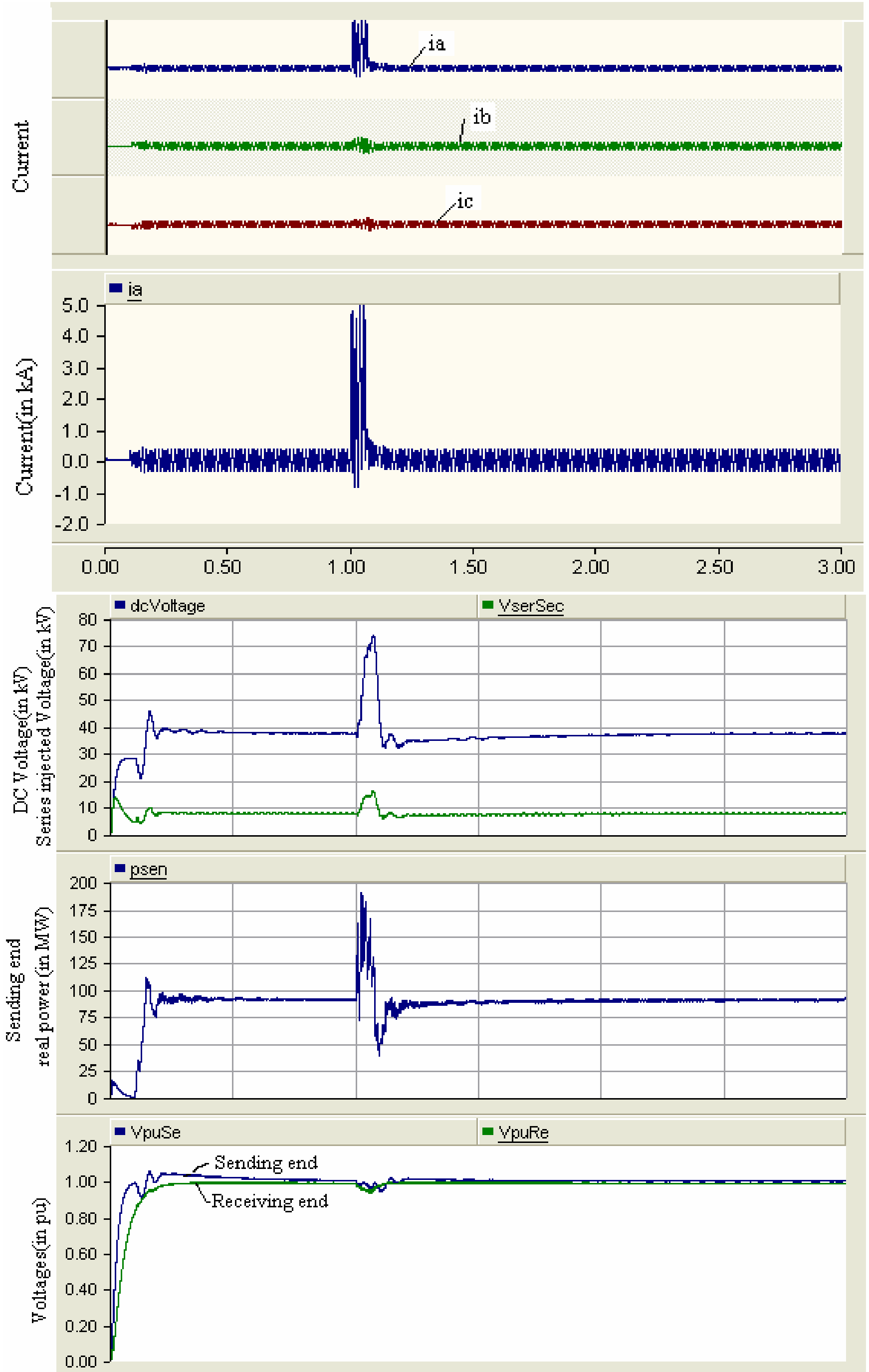
transmission line. Figure-10 shows the simulation results when LLL-G fault is applied to the transmission line. Voltage regulation is highly improved by the variation of the series injected voltage during the fault as shown in Figure-8. The DC link voltage is maintained at 38kV by DC voltage controller. 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.



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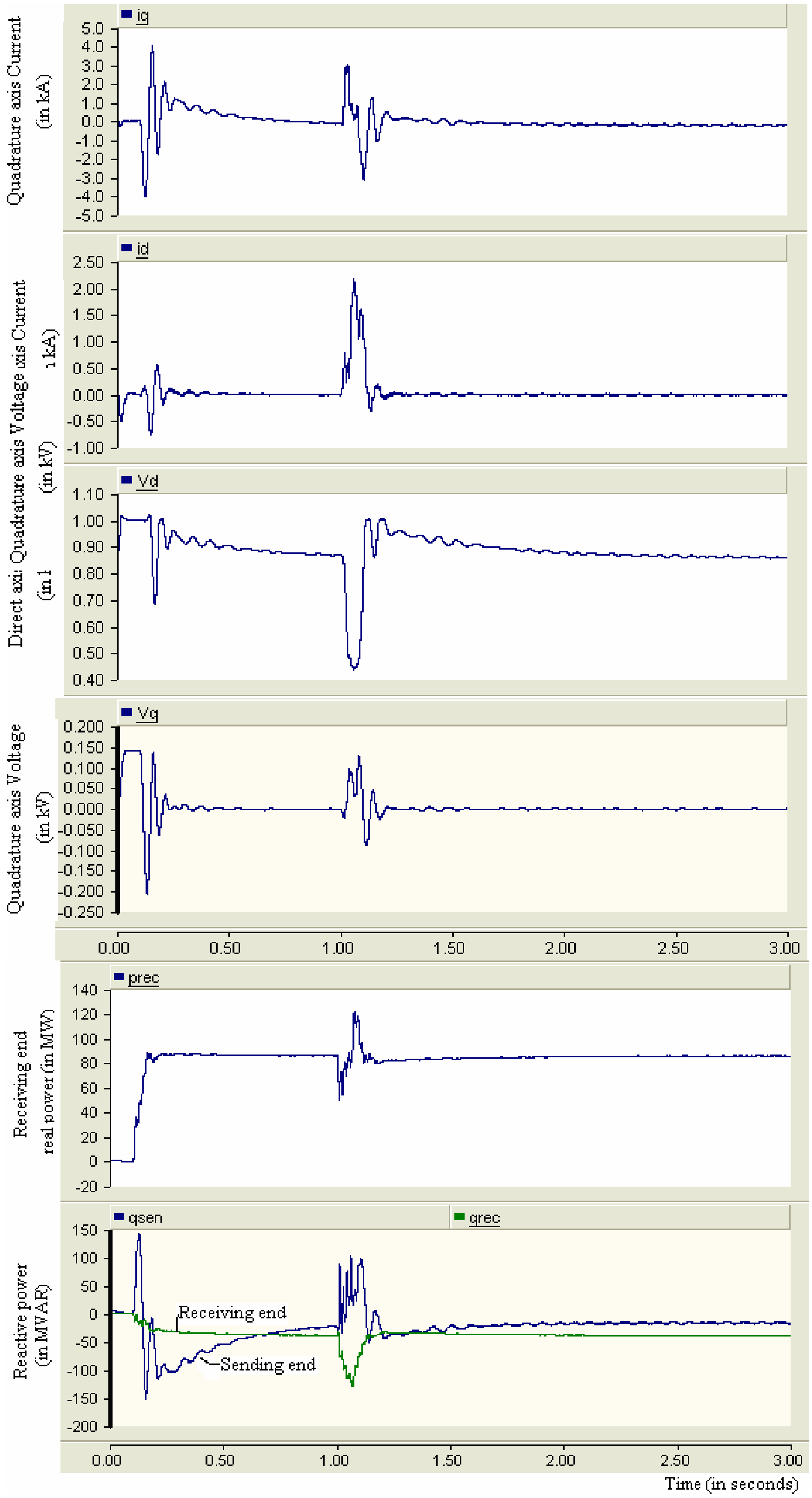

Figure-8. Simulation results when L-G fault applied to the transmission line.

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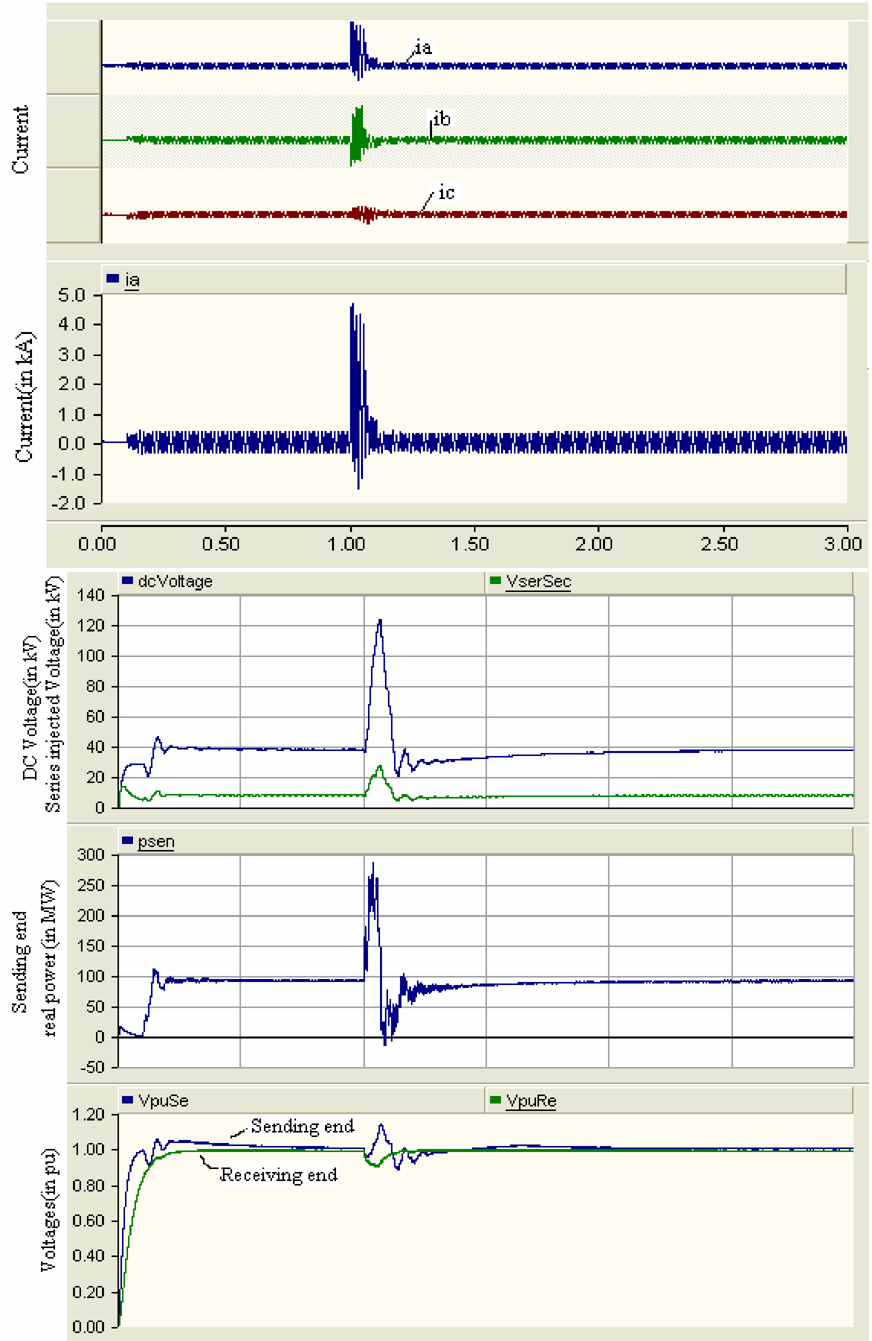

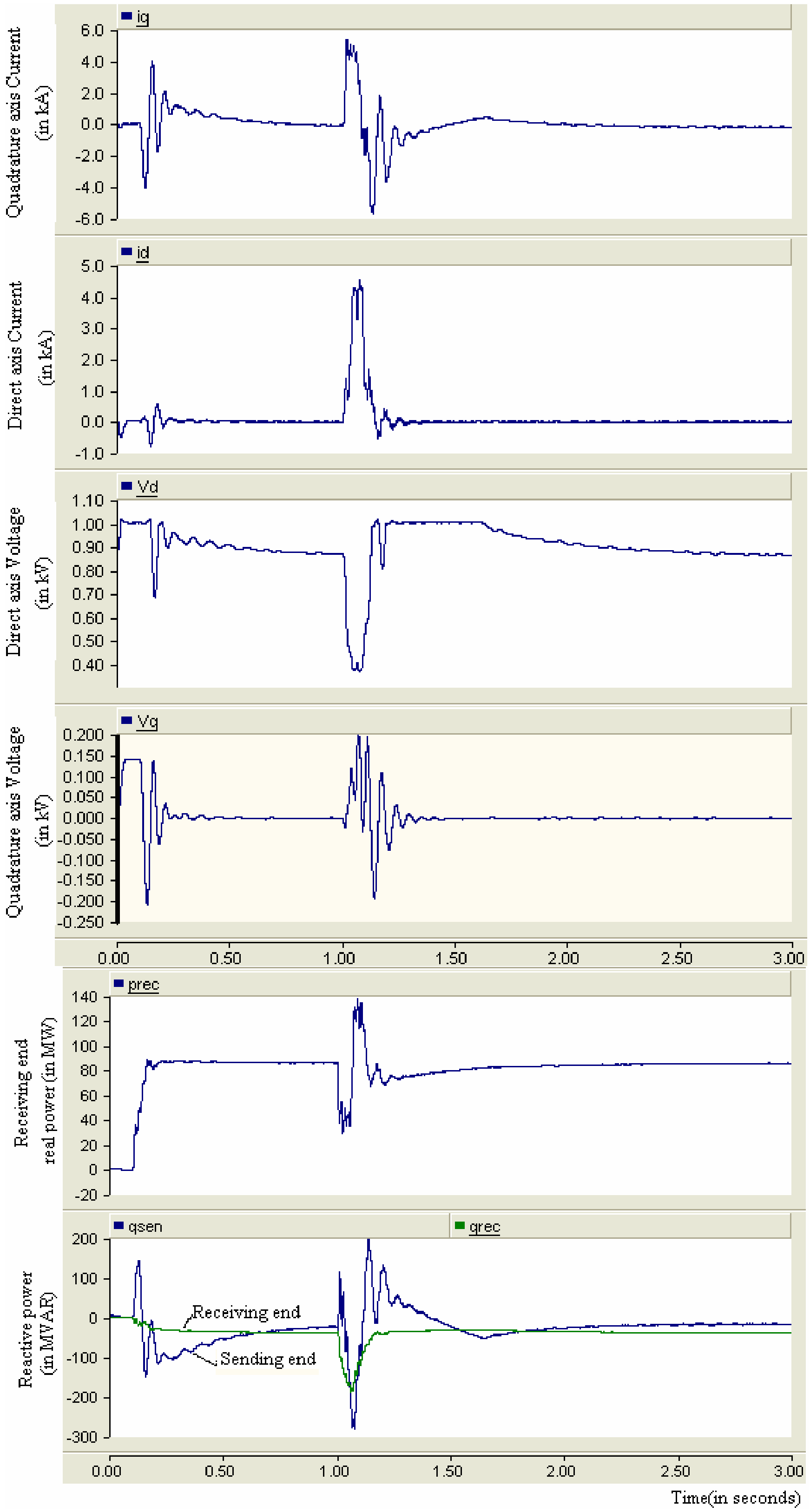

Figure-9. Simulation results when LL-G fault applied to the transmission line.

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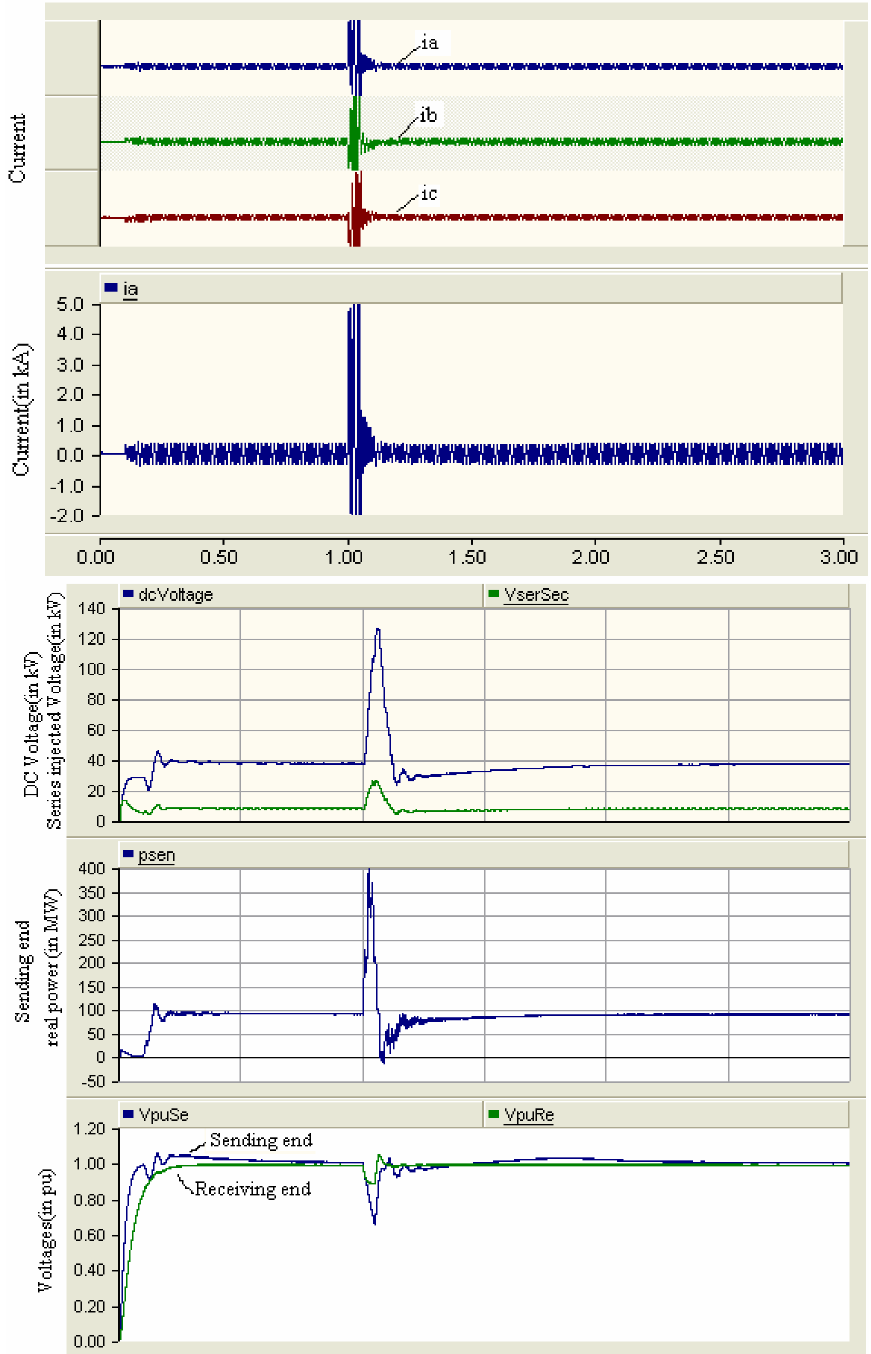

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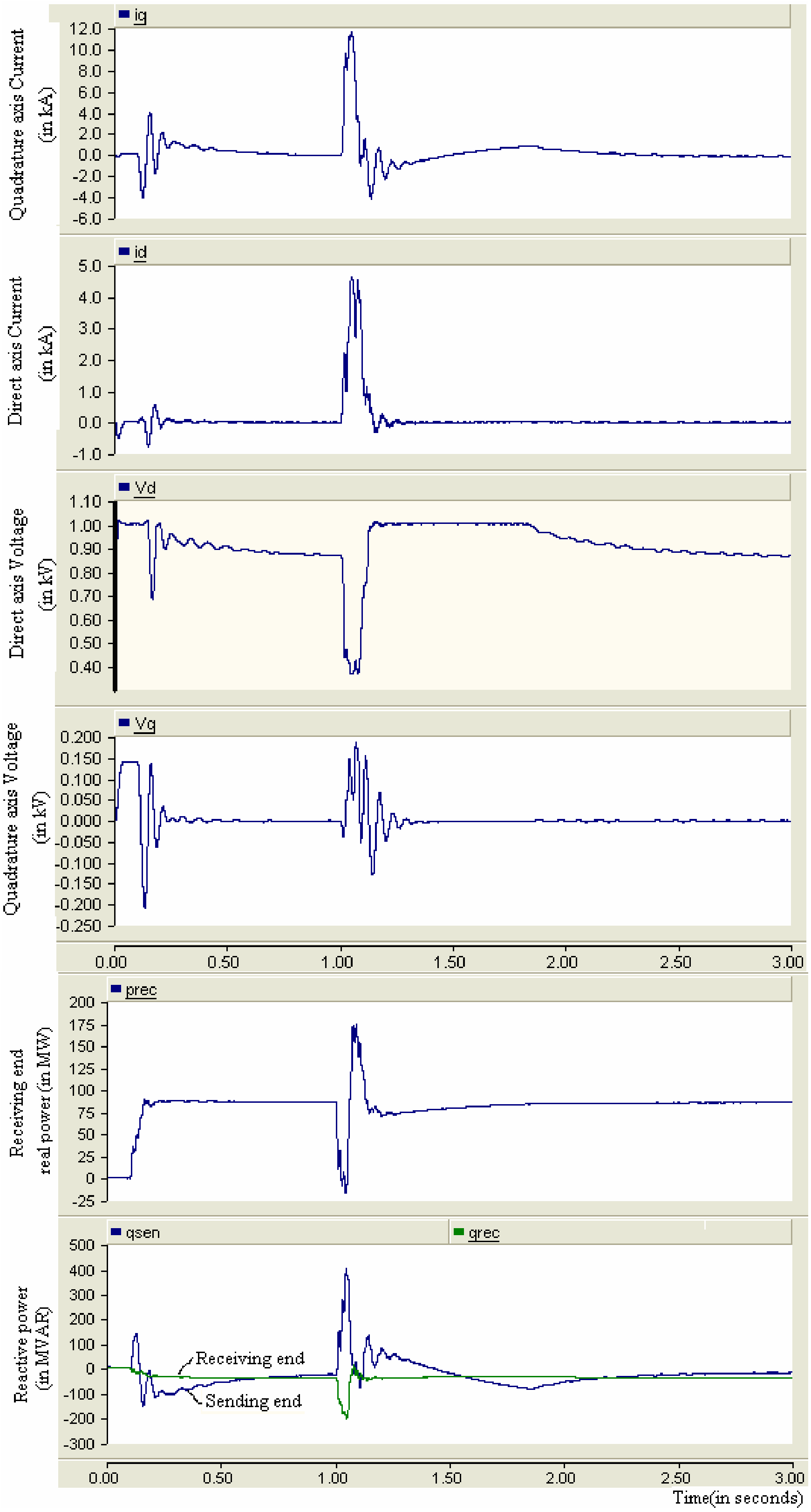

Figure-10. Simulation results when LLL-G fault applied to the transmission line.

6. 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 improvement of stabilizing the transmission systems.

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