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D-Q Theory Based Three Phase Unified Power Flow Controller for Power Quality Improvement

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ABSTRACT

In this project proposes a new algorithm to generate reference voltage for a unified power flow controller (UPFC) operating in voltage control mode. The reference stator current is generated by using D-Q theory which reduce the THD in the source current. The proposed scheme exhibits several advantages compared to traditional voltage-controlled UPFC. The proposed scheme ensures that unity power factor (UPF) is achieved at the load terminal during nominal operation. The UPFC controller compensate the reactive power and also prevent voltage sag problems in the distribution system. The obtained results indicate that the proposed approach maintains sustainable environment with enhanced efficiency. The entire system is validated through a MATLAB simulation.

KEYWORDS: UPFC, D-Q Theory, voltage control, Reactive power, Stator current

1.INTRODUCTION

The economic losses and adverse effects of power quality problems such as voltage fluctuation, sag and short-term interruption on enterprises and society are becoming increasingly prominent. The demand of users for comprehensive management of multi-type power quality is becoming increasingly strong. In order to reduce the economic losses caused by the problem of power supply quality, domestic and foreign scholars have carried out a lot of research, and have obtained a lot of research results and developed corresponding management devices. To improve the power quality of the distribution network sensitive load, a power quality improvement device for medium-voltage distribution network is developed, whose power unit and topology of charging circuit is designed and a fixed voltage slow closed loop control strategy is proposed.Minimum power processing occurs at the voltage operating point at which the most energy is generated, improving the efficiency and the power yield of the PV system [1].Two control methodologies are adopted that is constant DC link voltage based control and a variable DC link voltage based control are employed in the modified dual output cuk converter fed SRM drive [2].PFC based dual output converter is designed to feed the SRM drive and such converter is a combination of Cuk and SEPIC converters. To obtain inherent PFC, a voltage follower approach is adopted [3].The overestimation of the parmeters in all these converters is less influencing than their underestimation. In-depth analysis and evaluation of MPC based MPPT methods applied to various common power converter topologies. [4].To improve the power quality of the distribution network sensitive load, a power quality improvement device for medium-voltage distribution network is developed, whose power unit and topology of charging circuit is designed [5].The series active power filter (APF) is incorporated as the compensating device, for reactive power compensation and harmonic mitigation, at the point of common coupling, near the load bus in the MG [6].The Power electronics controllers are gaining concern to provide the quality of power for both power suppliers and consumers and the custom power devices in order to improve quality of power[7]Theunified power quality conditioner (UPQC) to provide compensation in the distribution system with the purpose of eliminate the current and voltage quality problems. The distribution network delivers power to different classes of non-linear loads [8].The nine switch UPQC acts as two back to back converter as a shunt and series filterwhich reduces the switching stress, less commutation, low losses with less cost [9].A steady-state model for open unified power quality conditioner (UPQC-O) with storage unit to improve the power loss and power quality of radial distribution networks [10]. Here Unified Power Flow Controller (UPFC) is the universal and most flexible FACTS device .It is used to control the power flow in the transmission systems by controlling the impedance, voltage magnitude and phase angle. UPFC consist of two Voltage Supply Inverters, one series converter (SSSC) and one shunt converter (STATCOM). SSSC is used to add controlled voltage magnitude and phase angle in series with the line.While shunt converter STATCOM is used to provide reactive power to the ac system, thus, this project presents the active and reactive power control through a transmission line by placing the UPFC using computer simulation. The UPFC has many possible operating modes: Var control mode, AVC mode, direct voltage injection mode, phase angle shifter emulation mode, Line impedance emulation mode and automatic power flow control mode.

2. PROPOSED SYSTEM

Electric power system regularly face disturbances due to its dynamic nature and also high power quality is the big difficulty due to greater amount of nonlinear loads. So there is need to restrict these disturbances and mitigates the issues of power quality to improve its performance. Flexible Alternating Current Transmission System (FACTS) plays a key role to enhance power handling capability and control of AC transmission systems. D-Q Theory based Unified power flow controller is the latest fact device which combines both series and shunt compensator properties and it is capable of controlling reactive and active power of transmission lines. In this paper, UPFC is used to reduce voltage sags and swells. Circuit model of UPFC is designed on the basis of rectifier and inverter circuits. Real and reactive powers changes at the receiving end by changing the control angle.

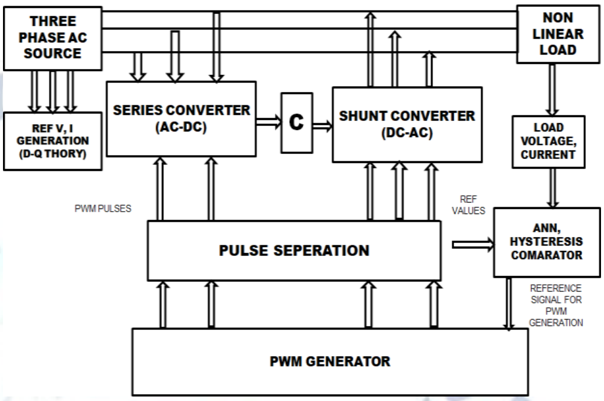

Figure 1: Proposed block diagram

UPFC performs three compensation functions simultaneously which are voltage, phase angle and impedance by varying reactance of line and controlling flow of power in the transmission and distribution lines. UPFC contains dual voltage source converters one is shunt while other is series converter. These converters are merged by a common dc link. Converters are connected with the transmission line through shunt and series transformers.

The real and reactive powers controlled by unified power flow controller are determined by the following equations

$$P = \frac{V_S V_R}{X} \sin(\alpha - \beta) \qquad (1)$$

$$Q = \frac{V_R}{X} \left(V_S - V_R \right) \qquad (2)$$

The influence of dc-link voltage ripple on parallel and series converters, and control strategies are adopted to suppress the influence of dc-link voltage ripple on compensation current and voltage. For parallel converter, the notch filter is introduced in the voltage loop and the specific order harmonic currents compensation is proposed in the inner current loop to decrease the THD of grid current. For the series converter, the dc-link voltage feedback control is introduced to modify modulation signal in real time. The mechanism of dc-link voltage ripple generation and its influences on compensation voltage and current are analysed in this project. To suppress the influence, a control strategy is proposed for the single-phase UPQC.The series compensator is linked in series with the transmission line using a series transformer. This converter converts AC voltage into DC voltage and this voltage is stored in the capacitor. The shunt converter converts stored DC voltage into three-phase alternating voltage. This voltage is fed into non-linear load through the transformer. D-Q theory generates the reference current from input source voltage and current. The hysteresis current controller compares the actual and the reference current to produce a PWM pulse. This pulse is fed into the shunt converter. Similarly, reference voltage and actual voltages are compared and the error is PWM pulses. These pulses are fed into the series converter. The PI controller and fuzzy logic controllers maintain constant DC voltage in the capacitor with the help of the series converter. This UPFC system achieves both voltage and current compensation, i.e., it does both shunt and series compensator work. Opposite harmonics are injected in the PCC through the shunt converter.

A. UPFC SYSTEM DESIGN

The UPFC system consists of two converters, namely the SSSC (Static Synchronous Series Compensator) and the STATCOM (Static Synchronous Compensator) the series compensator is linked in series with the transmission line using a series transformer. This converter converts AC voltage into DC voltage and this voltage is stored in the capacitor. The shunt converter converts stored DC voltage into three-phase alternating voltage. This voltage is fed into non-linear load through the transformer. D-Q theory generates the reference current from input source voltage and current. The hysteresis current controller compares the actual and the reference current to produce a PWM pulse. This pulse is fed into the shunt converter. Similarly, reference voltage and actual voltages are compared and the error is PWM pulses. These pulses are fed into the series converter. The PI controller and fuzzy logic controllers maintain constant DC voltage in the capacitor with the help of the series converter. Figure 1 shows the UPFC block diagram. Here, the UPFC works by voltage control mode. This UPFC system achieves both voltage and current compensation, i.e., it does both shunt and series compensator work. Opposite harmonics are injected in the PCC through the shunt converter.

B. PROPOSED D-Q THEORY MODELING FOR UPFC SYSTEM

The D-Q transformation and 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. 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.

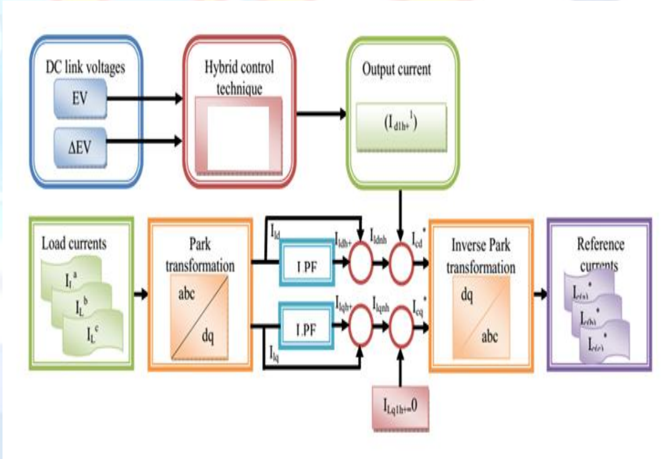

Figure 2: Reference Current Generation Using D-Q Theory

Three-phase AC voltage has been separated into three components, namely positive, negative and zero sequence elements.

$$\begin{bmatrix} V_{Sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = V_a \begin{bmatrix} \cos(\omega t + \phi_0) \\ \cos(\omega t + \phi_0) \\ \cos(\omega t + \phi_0) \end{bmatrix} + V_b \begin{bmatrix} \cos(\omega t + \phi_1) \\ \cos\left(\omega t - \frac{2\pi}{3} + \phi_1\right) \\ \cos\left(\omega t + \frac{2\pi}{3} + \phi_1\right) \end{bmatrix} + V_c \begin{bmatrix} \cos(\omega t + \phi_2) \\ \cos\left(\omega t + \frac{2\pi}{3} + \phi_2\right) \\ \cos\left(\omega t - \frac{2\pi}{3} + \phi_2\right) \end{bmatrix} \quad (2)$$

Where Vsa,Vsb,Vsc are three-phase AC voltages, whereas Va ,Vb ,Vc are zero, positive and negative sequence voltages, respectively.

$$V_S = \begin{bmatrix} V_{Sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} V_{a0} \\ V_{b0} \\ V_{co} \end{bmatrix} + \begin{bmatrix} V_{a1} \\ V_{b1} \\ V_{c1} \end{bmatrix} + \begin{bmatrix} V_{a2} \\ V_{b2} \\ V_{c2} \end{bmatrix} \quad (3)$$

Three-phase source current is represented as follows

$$I_S = \begin{bmatrix} I_{Sa} \\ I_{sb} \\ I_{sc} \end{bmatrix} = \begin{bmatrix} I_{a0} \\ I_{b0} \\ I_{co} \end{bmatrix} + \begin{bmatrix} I_{a1} \\ I_{b1} \\ I_{c1} \end{bmatrix} + \begin{bmatrix} I_{a2} \\ I_{b2} \\ I_{c2} \end{bmatrix} \quad (4)$$

Apparent power is given as

$$S_s = P_s + jQ_s = V_S * I_S^* \quad (5)$$

The D-Q theory general equation is given

$$S_{s012} = S_{1012} + S_{F012}$$

$$S\_1012 = S\_s012 + S\_h012$$

$$S_{1012} = P_{s012}(t) + Q_{Q012}(t) + p_{h012}(t) + q_{1012}(t) \quad (6)$$

The terms P and Q term represent real and reactive power of the transmission system, respectively. Input three-phase voltage and currents are transformed to αβ0 parameters by using Clarke transformation.

$$V_{\alpha\beta o} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{3} & -\frac{\sqrt{2}}{3} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} V_s \quad (7)$$

$$I_{\alpha\beta o} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{3} & -\frac{\sqrt{2}}{3} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} I_s \quad (8)$$

Aβ parameters are calculated from the above equations.

$$V_{\alpha\beta} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{3} & -\frac{\sqrt{2}}{3} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} V_s \quad (9)$$

$$I_{\alpha\beta} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{2}}{3} & -\frac{\sqrt{2}}{3} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} I_s \quad (10)$$

From the positive and negative sequence elements αβ and parameters are calculated.

$$V_{\alpha\beta} = V_1 \begin{bmatrix} \cos(\omega t + \varphi_1) \\ \sin(\omega t + \varphi_1) \end{bmatrix} + V_2 \begin{bmatrix} cos(-\omega t + \varphi_1) \\ \sin(-\omega t + \varphi 1) \end{bmatrix} \quad (11)$$

$$V_{dq1} = V_{\alpha\beta} \begin{bmatrix} cos(\omega t) & sin(\omega t) \\ -\sin(\omega t) & cos(\omega t) \end{bmatrix} \quad (12)$$

$$V_{dq2} = V_{\alpha\beta} \begin{bmatrix} -cos(\omega t) & -sin(\omega t) \\ \sin(\omega t) & -cos(\omega t) \end{bmatrix} \quad (13)$$

$$V_{dq1} = V_1 \begin{bmatrix} cos(\varphi_1) \\ \sin(\varphi_1) \end{bmatrix} + V_2 \begin{bmatrix} cos(\varphi_2) & sin\,\varphi_2 \\ -\sin\varphi_2 & cos(\varphi_2) \end{bmatrix} \begin{bmatrix} cos(2_{\omega t}) \\ \sin(2_{\omega t}) \end{bmatrix} \quad (14)$$

$$V_{dq1} = V_2 \begin{bmatrix} cos(\varphi_1) \\ \sin(\varphi_1) \end{bmatrix} + V_{dq2} \begin{bmatrix} cos(2\omega t) \\ -\sin(2\omega t) \end{bmatrix} + V_{q2} \begin{bmatrix} sin(2\omega t) \\ cos(2\omega t) \end{bmatrix} \quad (15)$$

$$V_{dq2} = V_2 \begin{bmatrix} cos(\varphi_2) \\ \sin(\varphi_2) \end{bmatrix} - V_{dq1} \begin{bmatrix} cos(\omega t) \\ \sin(\omega t) \end{bmatrix} + V_{q1} \begin{bmatrix} sin(2\omega t) \\ -cos(2\omega t) \end{bmatrix} \quad (16)$$

The reference signal from D-Q theories is calculated for UPFC as follows

$$P_0 = \frac{3}{2}\left[V_{d1}\ -V_{q1}\ -V_{d2}\ V_{q2}\right]\begin{bmatrix} I_{q2} \\ I_{d2} \\ I_{q1} \\ I_{d1} \end{bmatrix} \qquad (17)$$

$$Q_0 = P_2 = \frac{3}{2}\left[V_{d1}\ V_{q1}\ V_{d2}\ V_{q2}\right]\begin{bmatrix} I_{q2} \\ I_{d2} \\ I_{q1} \\ I_{d1} \end{bmatrix} \qquad (18)$$

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 other's output.

The reference signals from source voltage and currents are extracted by using Park and Clarke transformations. These reference signals are compared with the actual value by means of a hysteresis comparator. The output of the hysteresis current controller are PWM pulses, which are fed into the series and the shunt converter. PI and fuzzy logic controllers maintain DC link voltage at a constant value. The proposed system results are validated using MATLAB simulation.

3. RESULTS

The simulation results are examined using a software MATLAB/SIMULINK.

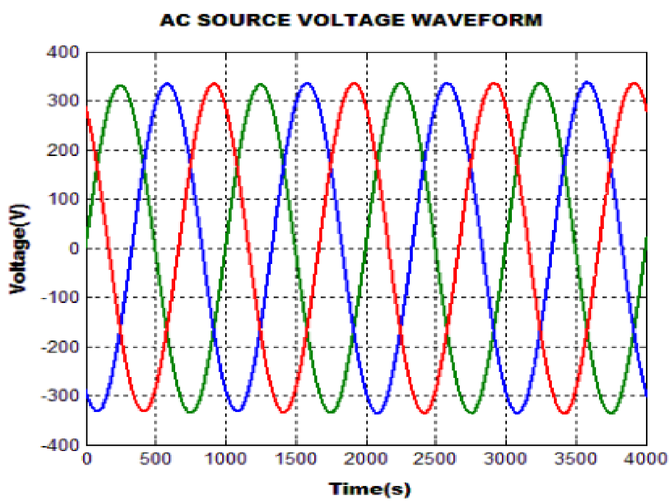

Figure 3: Extended vision of the input voltage waveform

The performance analysis of UPFC with DQ theory has been analyzed by introducing voltage sag at the time period of $2 \times 10^4 to\ 3 \times 10^4$seconds and from the source voltage depiction it has been revealed that the voltage has been reduced and during the remaining time period, voltage is in the range of +320V to -320V.

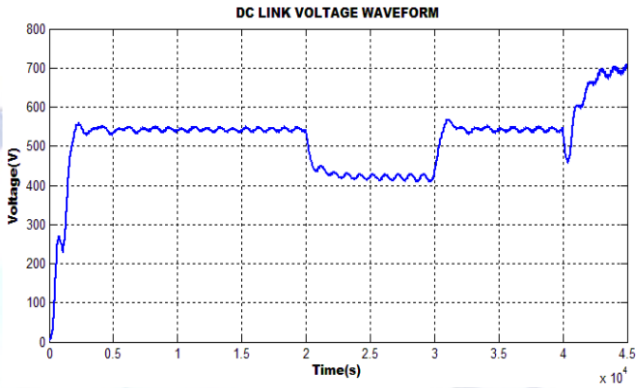

Figure 4: DC-link voltage waveform

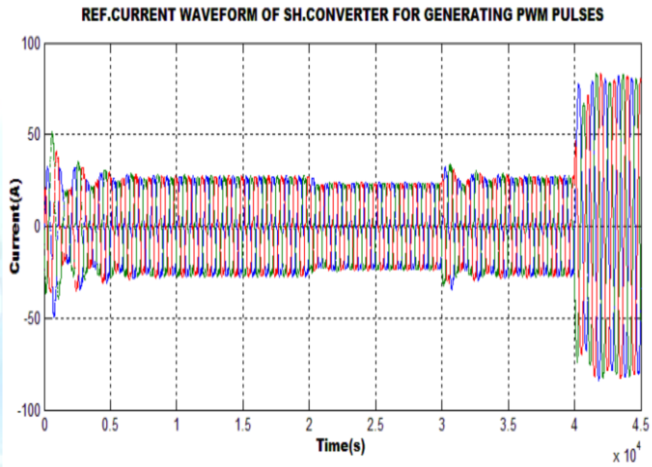

Figure 5: Generated reference current by DDSRF theory

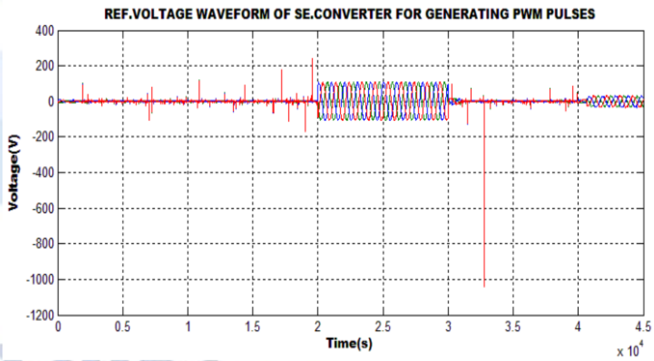

Figure 6: Generated reference voltage by DQ theory

After the implementation of DQ theory, the reference current and the reference voltage has been generated, which is then analogized with the actual current and voltage (Figure 5 and figure 6) thereby generating the PWM pulses for the shunt and the series converter.

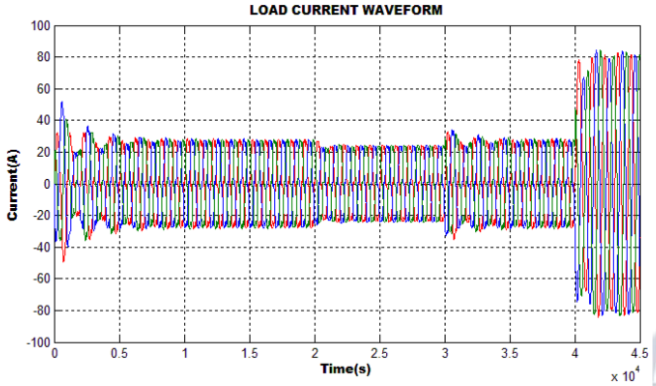

Figure 7: Load current waveform

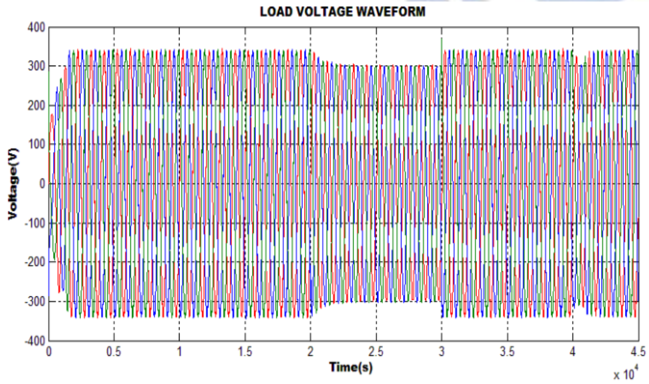

Figure 8: Load voltage waveform

Figure 8 shows the load voltage waveform, voltage is in the range of +320V to -320V.

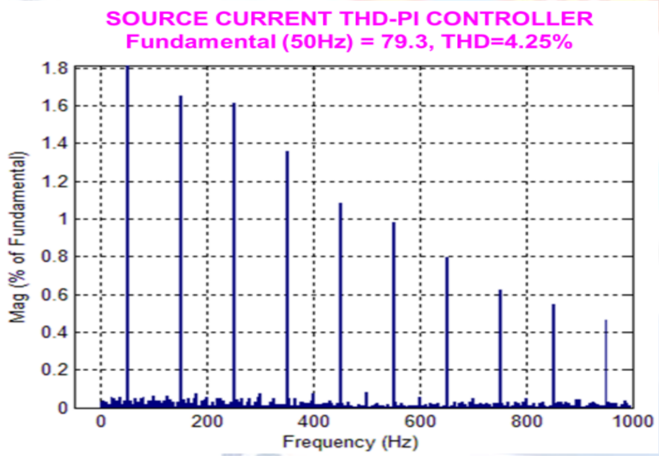

Figure 9: Source current THD using PI controller with theory

4. CONCLUSION

UPFC is able to quickly control the flow of real and reactive power in a transmission line.By implementing D-Q theory 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 oscillationsMoreover, 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. The d-q control system can contribute not only to achieve fast power flow control but also for improvement of stabilizing the transmission systems.The proposed scheme ensures that unity power factor (UPF) is achieved at the load terminal during nominal operation.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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