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Contribution of UPQC in Analytic Evaluation of Solar Photovoltaic Systems through Matlab Simulation

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Abstract— **Photovoltaic (PV) module is an electrical device that converts sunlight into electrical DC power. In this paper, the solid-state power DC-AC electronic converters have been used which connect PV array to utility grid. The DC-AC inverter has two major functions: to inject a sinusoidal AC current into the utility grid, and to optimize the operating point of the PV array at Maximum Power Point (MPP). The main objective of this paper is to develop a power conditioning system in which Unified Power Quality Control (UPQC) is implemented to evaluate the quality of electric power. The impact of three phase fault is observed for a double stage solar PV grid connected system. The fault is introduced at the grid side at Point of Common Coupling (PCC). The effect of fault is analysed for the voltage, current and power on Voltage Source Converter (VSC), load and grid side. The function of UPQC as series and shunt filter is described in the mitigation of fault effect during the chosen simulation period. The solar PV array has been connected with grid and the combined system is tested at three phase *RLC* load. As series filter, UPQC injects the extra voltage whereas, as shunt filter, it controls the distorted nature of the three phase current at PCC. It also controls the distorted nature of the voltage, current and power waveforms. It has also been shown that as the load absorbs the reactive power, the positive reactive power demand is completed by three phase Insulated Gate Bipolar Transistor (IGBT) based VSC.**

Index Terms— **UPQC, real, power, control, grid, and solar.**

I. INTRODUCTION

India is forecast to enter the top five countries [1] globally for adding solar power capacity this year, moving up from tenth place last year, according to consultancy firm bridge to India's annual report. Meanwhile, India is likely to become one of the largest solar markets globally in the next three years and is already on track to add more solar capacity than Germany for the year 2015. Photovoltaic (PV) cells depend on the use of semiconductor devices for the direct conversion of the solar radiation into electrical energy. Efficiencies of the typical commercial crystalline PV cells are in the range 12-18% although experimental cells have been constructed that are capable of over 30%. In contrast, solar thermal systems depend on intermediate conversion of solar energy into thermal energy in the form of steam, which in turn is used to drive a turbogenerator. To obtain high temperatures, thermal systems invariably use concentrators either in the form of parabolic troughs or thermal towers.

At present, generation of electricity by either technology is substantially more expensive than traditional means. Studies presented in [2] show that the short fluctuation of solar radiation and cloud cover plays an important role for low-voltage distribution grids with high penetration of PV. Therefore, in this paper, more emphasis has been given to the voltage profile and the power flow on the line. In [3], a model of a solar PV panel emulator is discussed using the power system block set of Matlab-Simulink software. For a real-time implementation, the simulation model of emulator system is developed for testing a controller. The developed model can handle the dependence of variable parameters in the model like change in solar radiation and ambient temperature. In [4], the main power quality problems and challenges which include voltage regulation issues, flicker, and frequency volatility are discussed. The operational challenges include the need for extension of the command-and-control infrastructure to millions of devices anticipated on the low-voltage (service) side of the distribution network. This paper presents an advanced grid-tied inverter controls concept designed to address such challenges.

This study presents an improved dynamic model of grid-connected three-phase renewable energy related inverter [5]. The study shows that the dynamics of the converter change completely when the operating point of as PV generator shifts from the constant current to the constant voltage region. [6] presents a Matlab-Simulink based PV module model that includes a controlled current source and an S-Function Builder. The modeling scheme in S-Function Builder is deduced by some predigested function. The model is practically validated using different array configuration (PV module in series and in parallel) with non-uniform insolation. The simulation results show the *I-V* and *P-V* characteristics under non-uniform insolation conditions. It indicates that output power of PV array get more complex with multiple peaks.

The various parameters which affect the power quality are [7] variations in voltage magnitude, harmonic content in AC power waveform, transient nature of current-voltage and continuity of service. In this paper, the introduction section I summarizes the introduction, scope of renewable energy, solar overview, literature review, and its outcome. Section II 2 presents the introduction and function of Unified Power Quality Control (UPQC). Section III presents the basic explanation of the simulink model in the presence of effect of fault in all the three phases at PCC on grid side. The behaviour of the solar PV grid connected

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system through a three phase transformer is presented. Section IV presents the results and discussion taking into account the function of UPQC in the mitigation of faults.

II. BASIC CONFIGURATION OF UPQC

UPQC'S are viable compensation devices [7] that are used to ensure that delivered power meets all required standards and specifications at the point of installation. The ideal UPQC can be represented as the combination of a VSC (Voltage Source Converter)- (injecting shunt current) and a common DC link (connected to a DC capacitor). UPQC consist of combined series active power filter that compensates voltage harmonics of the power supply, and shunt active power filter that compensates harmonic currents of a non-linear load. This dual functionality makes the UPQC as one of the most suitable devices that could solve the problems of both consumers as well as of utility. UPQC, thus can help to improve voltage profile and hence the overall health of power distribution system. The main components of an open UPQC are series and shunt power converters [8-9], DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers. The major functions performed by UPQC are enumerated below:

- Convert the feeder (system) current is to balanced sinusoids through the shunt compensator, [10].
- Convert the load voltage to balanced sinusoids through the series compensator.
- Ensure zero real power injection (and/or absorption) by the compensators.
- Supply reactive power to the load (reactive power compensation).

III. DESCRIPTION OF COMPUTATIONAL BLOCK DIAGRAM

The block diagram of proposed developed system is shown in Figure 1. A 63 kW solar PV array has been taken using manufacturer data sheet BP Solar SX3190 [11]. This data sheet helps to develop the simulation model more accurately as the validated manufacturer solar data sheets have been used in the proposed system. The manufacturer data for the solar PV array has been given in Table 1. The system is developed using double stage conversion process: first stage is DC-DC converter and second stage is IGBT based DC-AC converter. The DC-DC boost converter is used, which boosts the PV array voltage depending upon the duty ratio of DC-DC converter. The P&O MPPT control is implemented in this converter, which derives the maximum power under the changing conditions. The VSC control is implemented using PI based voltage and current controllers. The chosen parameters are given in Table 1 and Table 2 in Appendix I. The PWM based control is used, which generates the pulse for the operation of DC-AC conversion. A fault is introduced in all the three phases of the Point of Common Coupling (PCC), which affects the voltage and current behaviour at output of VSC, load and utility grid.

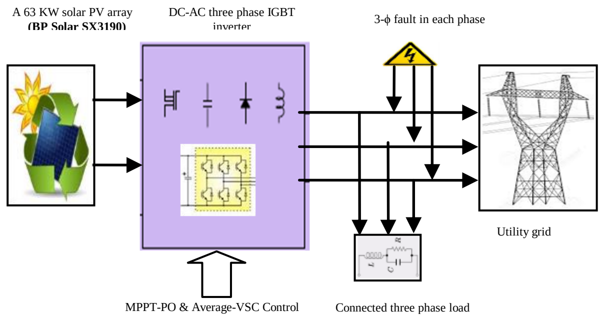


Figure 1 Block diagram of double stage grid connected solar PV system

Maximum Power Point Tracking (MPPT): A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. There are two types of basic MPPT techniques, which have widely been applied in PV grid connected systems:

(i) Perturb & Observe (P&O) technique, and
(ii) Incremental Conductance (IC) technique

From the literature survey, it has been found that P&O MPPT is one of the efficient and commonly used techniques. The approach of the proposed technique is a simple, which calculates the direction in which to perturb the solar PV array's operating point to reach MPP. As shown by flow-chart in Figure 2, the principle of P&O controller is to provoke perturbation by increasing or decreasing the value of PWM duty cycle *D* and observe the resulting change in the output power. The initial value of duty cycle for the DC-DC boost converter is chosen as 0.5. The value of upper limit and lower limit of the duty cycle are 0.52 and 0.42, respectively. The incremental value used to increase and decrease duty cycle is 3×10^{-4}. If the instantaneous solar PV array output power $P_a(k)$ is greater than previously computed solar PV array output power $P_a(k-1)$, then the same direction of duty cycle perturbation is maintained, otherwise the direction is reversed.

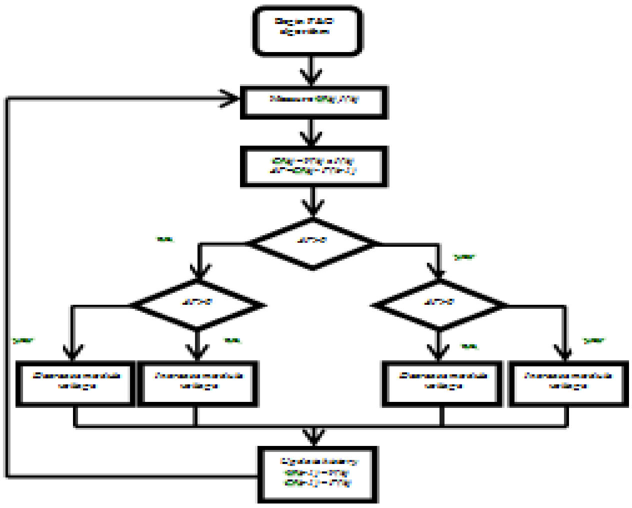
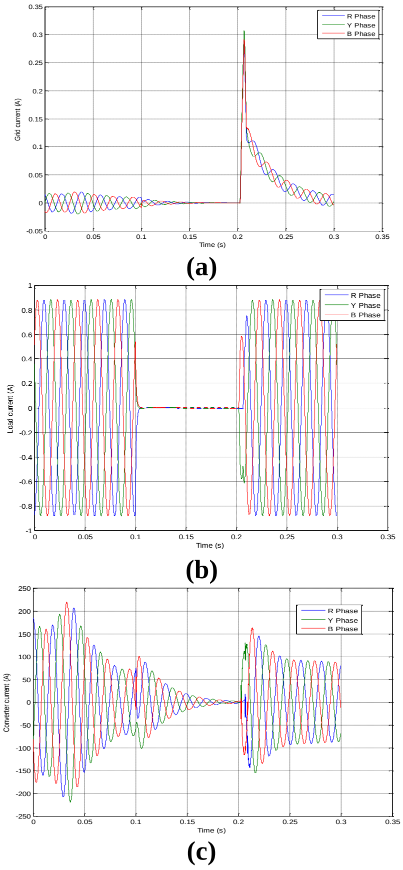


Figure 2 Flowchart of Perturb & Observe MPPT technique

IV. RESULTS AND DISCUSSION

In this section, the proposed system as depicted in Figure 1 has been simulated in Matlab. The simulation period in which the system study is carried out is 0.30 s. The impact of fault in each of three phases is introduced at PCC on grid side. The fault resistance is 0.063 Ω and ground fault resistance is 0.0008 Ω. The fault in each phase is introduced between the time periods 0.1 s to 0.2 s. From the developed system, the voltage and current on grid side is fed to the control system of VSC. The DC link voltage to VSC is also fed to control system of VSC.

From Figure 3 (a), it is observed that there is sine behaviour of grid current till 0.1 s. This behaviour is changed till 0.2 s. A sharp transient can be seen at 0.22 s, which is due to the fault subside at this time. The effect of fault can be seen in all the three phases at PCC on grid side. From Figure 3 (b), it is observed that there is non-sinusoidal behaviour of load current between the time periods 0.1 s to 0.2 s. For all other times, sine behaviour of load current is shown. From Figure 3 (c), it is observed that under changing atmospheric conditions, the DC power from solar PV array converts to AC power at the output of VSC. Non-uniform converter current is shown from 0 s to 0.1 s. The effect of fault diminishes the converter current at 0.2 s in all the three phases of VSC. The sine behaviour is again observed as the effect of fault ends at 0.2 s, thus the VSC sine wave current flows till 0.3 s. Figure 4 (a) shows the real output power of VSC, load and grid. The real power from all the three sides attains zero level during the faulted period. Similarly, Figure 4 (b) shows the reactive output power of VSC, load and grid. The reactive power from all the three sides attains zero level during the faulted period.

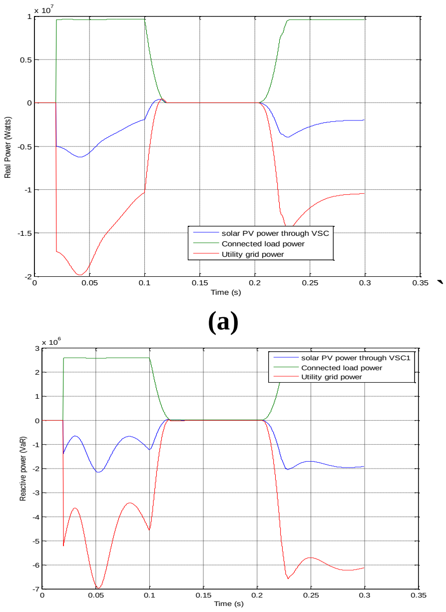


(a)

(b)

(c)

Figure 3 Impact of fault on (a) grid current (b) load current and (c) converter current

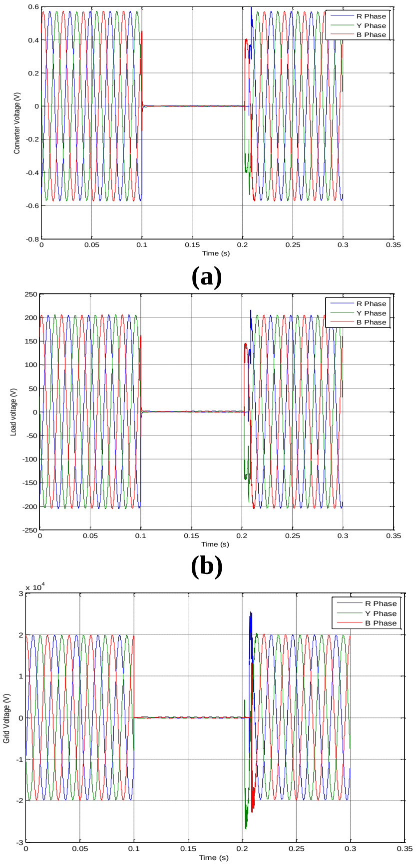


(a)

(b)

Figure 4 Impact of fault on (a) real power (b) reactive power

Figure 5 (a), Figure 5 (b) and Figure 5 (c) shows the sine behaviour of converter voltage, load voltage and grid voltage, respectively, except during the faulted period where there is around zero voltage level at all the three phases. Since the fault effect is more on the grid side, this effect can be seen at 0.2 s by the presence of a sharp transient.



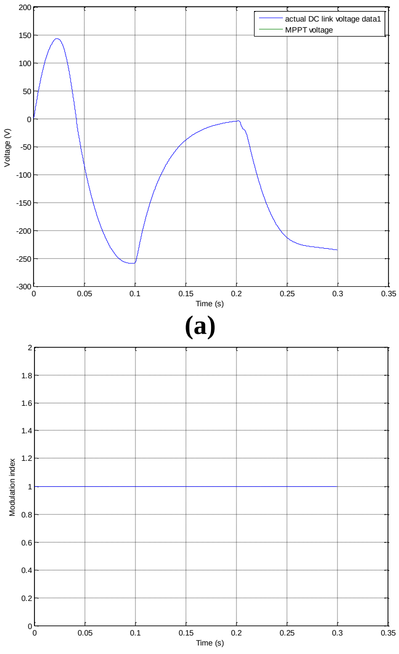
(a)

(b)

(c)

Figure 5 Impact of fault on (a) converter voltage (b) load voltage and (c) grid voltage

Figure 6 (a), and Figure 6 (b) shows the effect of actual DC link voltage and modulation index during the faulted period. The system is operated at the normal modulation as the value of modulation index remains unity at all the times. This modulation index *m* is calculated as, $m=\sqrt{(V_d^2+V_q^2}$ where, V_d and V_q are the direct axis and quadrature axis components of converter voltage.

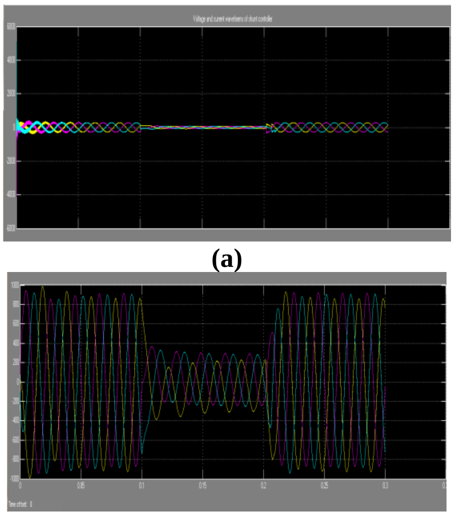


(a)

(b)

Figure 6 Impact of fault on (a) DC link voltage (b) modulation index

Now, the role of UPQC is demonstrated in the presence of a three phase fault. Figure 7 (a) depicts the voltage output of shunt controller, whereas Figure 7 (b) depicts the current output of shunt controller. During the faulted period, it is observed that the voltage and current exists as evident from their sinusoidal behaviour.

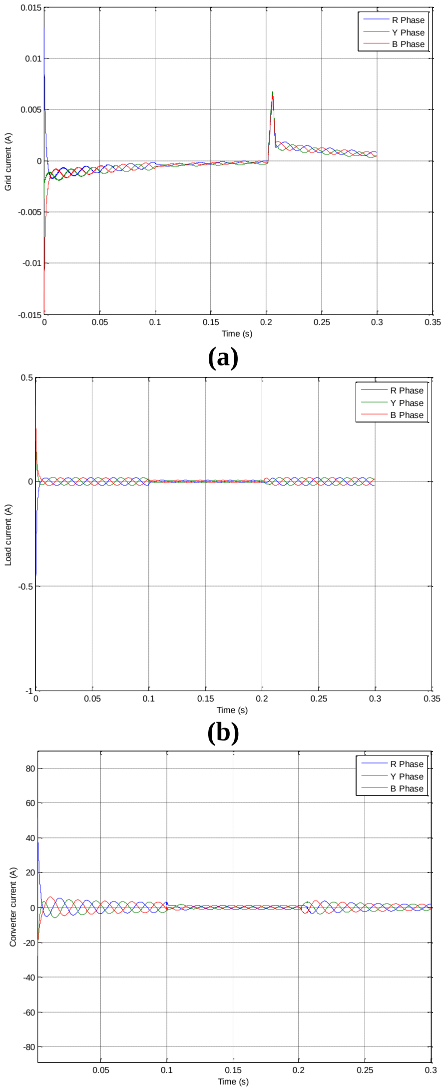


(a)

(b)

Figure 7 (a) Voltage output of shunt controller (b) Current output of shunt controller

Figure 8 (a) shows the flow of grid current particularly during the faulted period. It has been seen that normal value of grid current is obtained in all the three phases at PCC after the injection of current by the shunt controller. The waveform can be made more sinusoidal by changing the parameters of shunt controller. The similar type of effect can be observed from Figure 8 (b) and Figure 8 (c). Figure 8 (b) and Figure 8 (c) shows the behaviour of load current and converter current, respectively.



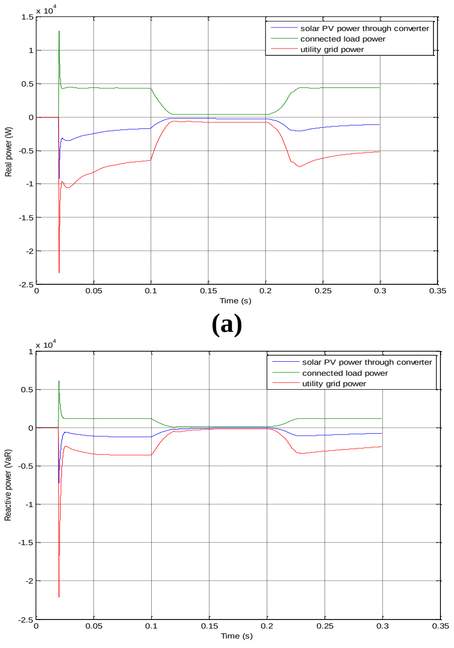
(a)

(b)

(c)

Figure 8 Impact of UPQC on (a) grid current (b) load current and (c) converter current, in the presence of fault

During the faulted period, the real power requirement of the load is reduced to 1 kW (green line), Figure 9 (a). This power demand is met by solar PV array through the IGBT based converter during the faulted period (blue line). However, the real power of grid remains negative (red line) i.e. instead of generation from grid, there is the power absorption by the grid. Figure 9 (b) shows the reactive power being compensated by the converter. As the load absorbs the reactive power, this positive reactive power demand is completed by three phase IGBT based VSC. Some part of the reactive power is met by the generation of power from the grid.

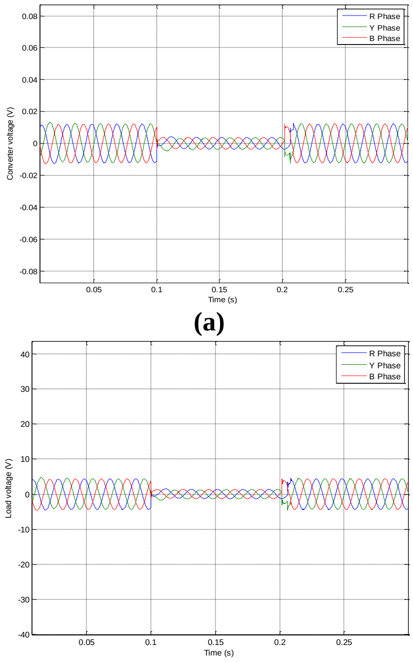


(a)

(b)

Figure 9 Impact of UPQC on (a) real power (b) reactive power, in the presence of fault

Figure 10 (a) depicts the three phase sine behaviour of converter voltage. Figure 10 (b) and Figure 10 (c) shows the load voltage and grid voltage waveforms during the faulted period. These waveforms show the injection of voltage by the series controller of UPQC at grid side. This effect thus controls the load and converter voltage levels also. There are the presence of harmonics in the grid voltage as evident from the darken waveforms in the beginning. This harmonics level can greatly be reduced by operating the UPQC with the help of more advanced controllers likewise neural network, fuzzy logic and neural fuzzy inference system. Figure 11 (a) and Figure 11 (b) shows the behaviour of actual DC link voltage and modulation index. From Figure 11 (a), it is clear that the transient behaviour is controlled by the injection of voltage by the series controller of UPQC.



(a)

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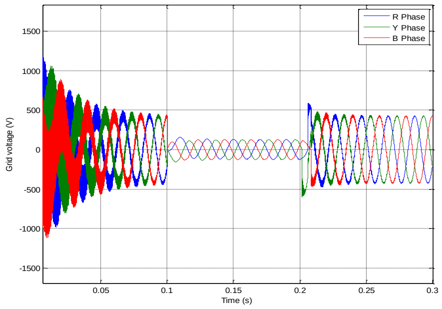
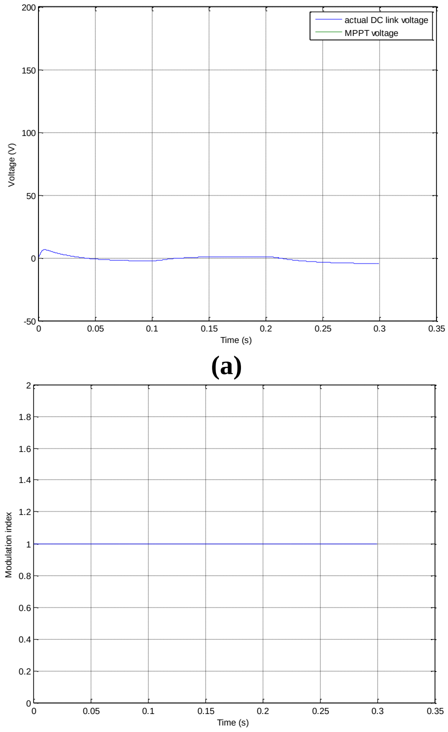


(c)

Figure 10 Impact of UPQC on (a) converter voltage (b) load voltage and (c) grid voltage, in the presence of fault



(a)

(b)

Figure 11 Impact of UPQC on (a) DC link voltage (b) modulation index, in the presence of fault

V. CONCLUSION

In this paper, the solid-state power electronic converters DC-AC have been used, which connect PV array to utility grid. The DC-AC inverter has two major functions: to inject a sinusoidal AC current into the utility grid, and to optimize the operating point of the PV array at MPP. The main objective of this paper is to develop a power conditioning system in which UPQC is implemented to evaluate the quality of electric power. The impact of three phase fault is observed for a double stage solar PV grid connected system. The fault is introduced at the grid side at PCC. The effect of fault is analysed for the voltage, current and power on VSC, load and grid side. It has been found that there is a non-uniformity in the behaviour of current during the faulted period. However, the voltage level remains zero during the faulted period. The real and reactive output power is oscillatory. the function of UPQC as series and shunt filter is described in the mitigation of fault effect during the chosen simulation period. The solar PV array has been connected with grid and the combined system is tested at three phase *RLC* load. As series filter, UPQC injects the extra voltage whereas, as shunt filter, it controls the distorted nature of the three phase current at PCC. It also controls the distorted nature of the voltage, current and power waveforms. It has also been shown that as the load absorbs the reactive power, the positive reactive power demand is completed by three phase IGBT based VSC.

APPENDIX I

Table 1 Specifications adopted for single PV array (BP Solar SX3190)

Name of the system	Specifications
No. of cells per module	50
No. of series connected modules per string	5
No. of parallel strings	66
Module specifications under STC [V_{oc}, I_{sc}, V_{mp}, I_{mp}]	[30.6021 V, 8.51029 A, 24.3003 V, 7.82945 A]
Model parameters for one module [R_s, R_p, I_{sat}, I_{ph}, Q_d]	[0.017514 Ω, 755.51 Ω, 1.0647×10^{-6} A, 8.5158 A, 1.5]
Maximum power P_{mp} per array	66×5×24.3003×7.82945 = 62.785 kW per array

Table 2 Parameters of VSC main controller

Name of the system	Specifications
Nominal DC voltage	200 V
Nominal power and frequency	200 kW, 50 Hz
DC voltage regulator gains (K_p, K_i)	7, 800
Current regulator gains (K_p K_i)	0.30, 20
Sample time	50×10^{-6} s
LC filter (*L*, *C*)	1500 µH, 30 µF
3-φ transformer nominal power and frequency	200 kVA, 50 Hz
Load (V_n, P, Q_l *as positive VAR*)	440 V, 82 kW, 22 kVAR

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