

Power Quality Enhancement and Low Voltage Ride Through Capability in Hybrid Grid Interconnected System by Using D-Fact Devices



T. Joshiram and S. V. R. Laskhmi Kumari

Abstract One of the major difficulties detected in the distribution system in present days has been power quality. These days, most individuals are utilizing the urbane electrical devices which are dependent on the semiconductor devices, these devices humiliate the power quality. Hence, there is a need to recover the voltage profile. In this paper, the photovoltaic (PV) plant and the wind turbine generator (WTG) are connected to the same point of common coupling (PCC) with a nonlinear load. The unified power quality conditioner (UPQC) [1] is familiar as the best solution for moderation of voltage sag associated problems in the highly taped distribution system. This effort grants the simulation modeling and analysis of innovative UPQC system for solving these problems. UPQC to increase the power quality and recover the low voltage ride through (LVRT) capability of a three-phase medium voltage network connected to a hybrid distribution generation (DG) system. UPQC associated to same PCC. Unlike fault condition setups are tested for improving the efficiency and the quality of the power supply and compliance with the requirements of the LVRT grid code. It inserts voltage in the distribution line to reserve the voltage profile and guarantees constant load voltage. The simulations were led in MATLAB/Simulink to show the UPQC-based future approach's usefulness to smooth the distorted voltage due to harmonics [2].

Keywords Active power · DC link voltage DFIG · Unified power quality conditioner · LVRT · Power factor · Photovoltaic voltage stability · Reactive power · Reactive components · Total harmonic distortion · Sag · Swell · D-FACTS

1 Introduction

Power Quality—The Problem

If possible, the goal of power industry is to supply a purely sinusoidal voltage at fixed amplitude and fixed frequency [1, 2]. Whereas it is the responsibility of the dealer to deliver a nearly sinusoidal voltage with smaller amount variation in amplitude and

T. Joshiram · S. V. R. Laskhmi Kumari (✉)
VR Siddhartha Engineering College, Kanuru, Vijayawada, Andhra Pradesh 520007, India

frequency, the customer additionally has a section to play in making such a situation [3]. At the PCC, both the service organization and the client have a few components to conform to. To overcome these constraints and assurance the stability of the electric power system related with a great deal of variable energy resources, the executives of energy system have relied upon examining distinctive particular courses of action [4]. Quite possibly the main grid code necessities are the low voltage ride through (LVRT) capacity, which means that the renewable energy power change system should remain associated during grid faults and supply reactive power to help the grid [5].

The prospects of power generation from hybrid energy systems are winding up being incredibly promising and dependable [2]. A DFIG and flywheel energy storage system was premeditated in [3] and the future control system was planned to ensure that the grid power is remote from wind power output fluctuations. To boost the LVRT capability of a grid-integrated DFIG-based wind farm [3]. Additional devices usually used in distribution networks to defend grave loads counter to voltage disturbances are known as D-FACTS and comprise: DSTATCOM (Static Dispensing Compensator), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) [1]. Unified power quality conditioner (UPQC) is one of the most prevalent solutions cast-offs currently [5]. The UPQC as isolated device in as quick control device to control the active power and reactive power and it keeps the sensitive load from preeminent disturbances [5]. The UPQC incorporates of joined activity of (DSTATCOM) and dynamic voltage restorer (DVR) [1]. The DSTATCOM is compensating the reactive power and harmonics in the load side and DVR mitigates the voltage sags/swell in the source side [5]. From this future method the foremost disturbances are condensed and too the control voltage sag instigating from the supply side [5]. To reimburse for the harmonics in the load current by injecting the required harmonic currents. To normalize the power factor by injecting the required reactive current [6]. This paper dowries a simulation study to regulate the worth of the UPQC to restrained voltage disturbances, reduce their effect on the total stability of the transmission and distribution network, and recover the LVRT capability when the network is connected to a hybrid PV-wind system [7].

2 Future Simulated Methods and Explanation

The ideal of photovoltaic energy or wind turbine or together relies upon the availability of the sustainable asset after some time and furthermore is bounty at the spot of establishment [4]. The future topography is displayed in Fig. 1. It contains of a 500 kW PV farm interconnected to a distribution system through a 3 phase PWM inverter with a 3 phase AC choke filter and a move forward transformer. The DFIG has a negligible produce power of 500 kW and is associated with the matrix at the PCC through a move step-up transformer and providing the heap. Therefore, the appraised total power delivered by the hybrid system is 1 MW [2] (Fig. 2).

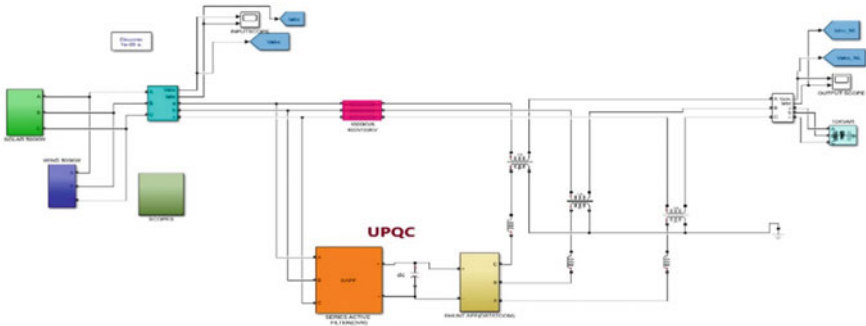


Fig. 1 MATLAB simulation with UPQC and a load connected to grid

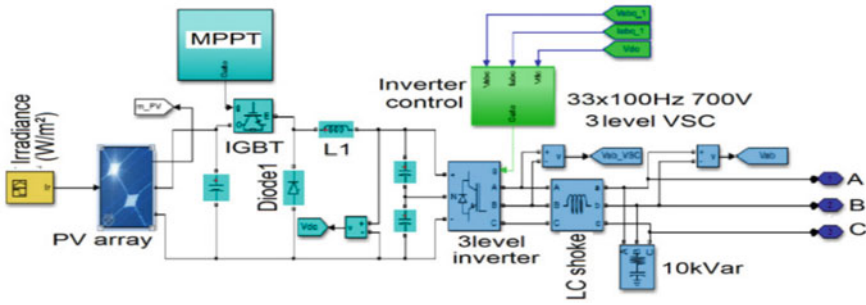


Fig. 2 PV farm of 500 kW connected to grid via an inverter associated to 500 kVA – 400 V/30 kV transformer [2]

The PV farm is exposed to the solar irradiance shown in Fig. 3 and the WTG is consecutively with a wind speed of 12 m/s throughout the simulation time of 5 s additional information required by the volume editor [1].

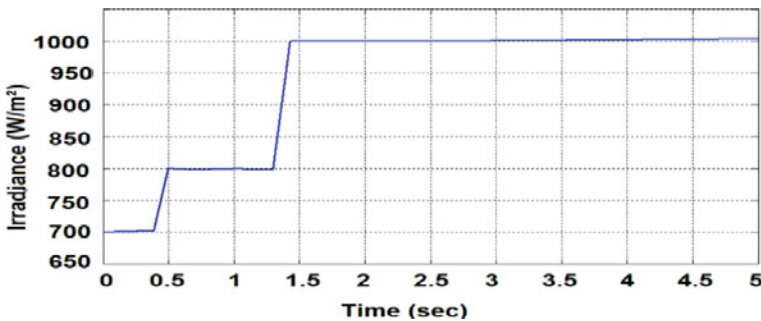


Fig. 3 Solar irradiance at 25 °C [5]

2.1 Photovoltaic Installations

The PV plant array contains of 16 series modules and 102 parallel strings (model: SunPower SPR-305-WHT) [2].

The PV model castoff in the paper is created on the 2-diode equivalent circuit revealed in Fig. 4. The PV cell total current in the equivalent circuit revealed in Fig. 4 is stated by [2].

$$I = I_{Ph} - I_{Ph} \left(e^{q \frac{v+IR}{nkt}} - 1 \right) - I_{s1} \left(e^{q \frac{v+IR}{nkt}} - 1 \right) \frac{v+IR}{R_p} \tag{1}$$

where n is the idealist factor. Presumptuous that all the cells are equal and working under the similar operating circumstances [8].

$$R_{p,field} = \frac{G_s}{G_p} R_{p,cell} \tag{2}$$

The PV power transformation control is made on maximum power point tracker (MPPT) which endures high efficiency power transfer and be dependent upon together the solar irradiance and the electrical qualities of the load [9]. Figure 5 displays the $I-V$ and $P-V$ characteristics of the PV module for different stages of solar irradiance [5].

As depicted in Fig. 5, the most extreme force is positive by the significant square shape region, $PMP = VMPIMP$, reachable from the $I-V$ trademark. The synchronizes of the VMP are start [8].

$$\left. \frac{dP}{dE} \right|_{E=Emp} = \left. \frac{d(IE)}{dE} \right|_{E=Emp} = \left(1 + \frac{dI}{dE} \right) \Big|_{E=Emp} = 0 \tag{3}$$

Then I_{MP} is resolute by evaluating Eq. 1 at $E = E_{MP}$ [10].

The PV array model is mounted to contain 12 series modules and 102 equal strings sought after to ship 500 kW at an irradiance of 1000 W/m² and a DC voltage of VDC

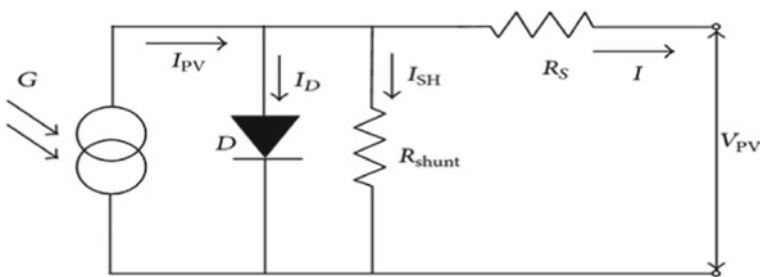


Fig. 4 PV cell circuit model [2]

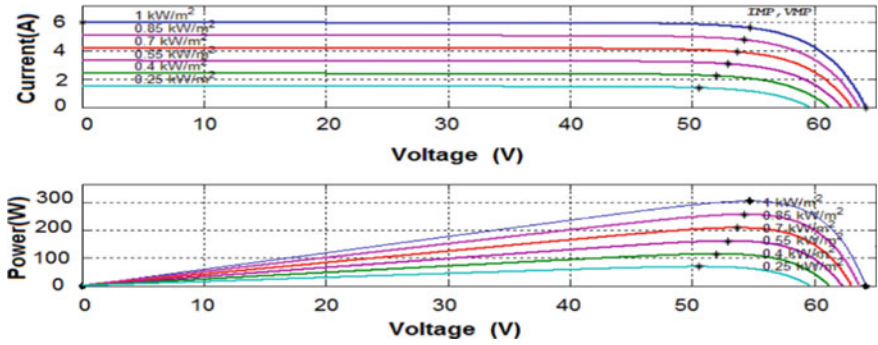


Fig. 5 $V-I$ and $P-V$ characteristic of PV module under dissimilar solar irradiance and at 25 °C with MPPT points in strings [5]

= 896 V applied to the boost converter as uncovered in Fig. 7. There are various MPPT control techniques future underway, some of them are a lot of the same in relations of their functioning rule [9] (Fig. 6).

The INC strategy can be seen as a superior kind of the Perturb and Observe (P and O) [11]. The point of the power bend is gotten from:

$$\frac{dP_{PV}}{dE_{PV}} = 0 \Rightarrow \frac{dI_{PV}}{dE_{PV}} = -\frac{I_{PV}}{E_{PV}} \tag{4}$$

$$\frac{dP_{PV}}{dE_{PV}} = \frac{d(I_{PV} E_{PV})}{dE_{PV}} = I_{PV} + E_{PV} \frac{dI_{PV}}{dE_{PV}} \tag{5}$$

Multiplying 2 sides of Eq. (5) by $1/E_{PV}$ gives:

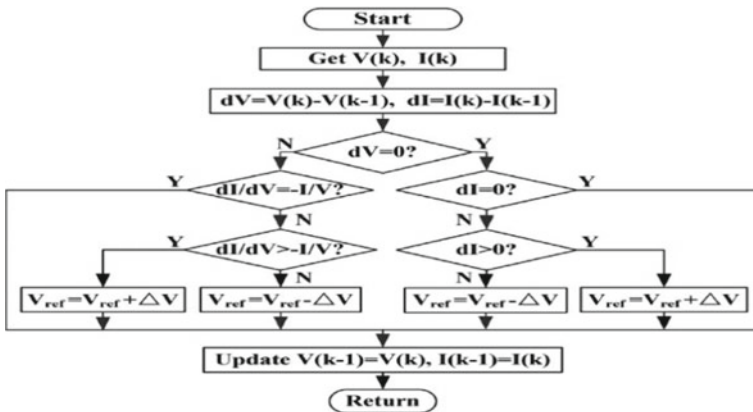


Fig. 6 Flowchart of the incremental conductance algorithm [2]

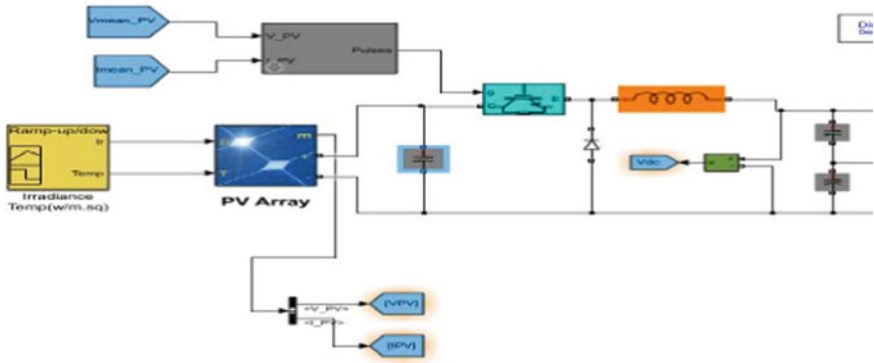


Fig. 7 Displays the circuit model of the DC–DC boost converter used in this effort [7]

$$\frac{1}{E_{PV}} \frac{dP_{PV}}{dE_{PV}} = \frac{I_{PV}}{E_{PV}} + \frac{dI_{PV}}{dE_{PV}} = G_{PV} + dG_{PV} \tag{6}$$

where G and dG mean the conductance and gradual conductance correspondingly. A flowchart identifying with the INC calculation is uncovered in Fig. 6. The calculation can follow the MPP and remains there till an adjustment of $[dI]_{(PV)}$ or $[dV]_{(PV)}$ occurs because of a modification in climatic conditions [11].

The grave upsides of the inductor and capacitances of the expected lift converter are: $L_1 = 30$ mH, $C = 100$ μ F, $C_1 = C_2 = 120$ mF. To affirm greatest force reflection from the PV source, the converter interfacing the PV framework to the network should be cultivated of self-changing its own limitations progressively. The 3-level voltage source inverter topology revealed in Fig. 8 is simulated in this work [9].

The Vdc boost converter orientation output voltage is customary at 714 V and the IGBT 3-level inverter uses PWM technique, (3.3 kHz carrier frequency) converting DC power from 714 Vdc source to 400 Vac, 50 Hz. The grid is connected to the inverter through an inductive grid filter and a low frequency transformer to step-up the voltage from 0.4 to 30 kV in order to reduce losses when PV energy is transmitted to the grid [9] and to filter out harmonic frequencies. The 12 pulses required by the inverter are generated by the discrete three phase PWM generator [14] (Fig. 9).

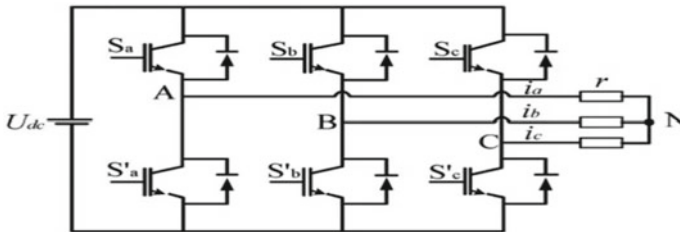


Fig. 8 3-level inverter topology [25]

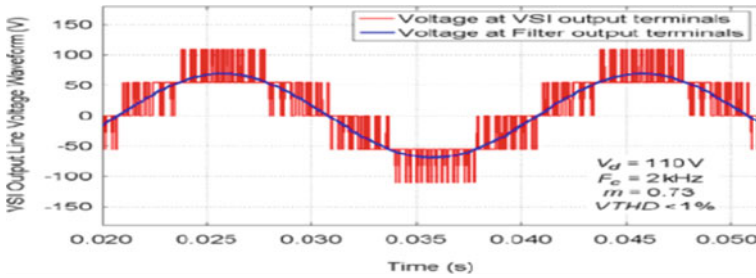


Fig. 9 Output three-level inverter unfiltered and filtered voltage waveforms [5]

2.2 Modeling of Wind Plant

1. Aerodynamic modeling of the wind turbine

The unique energy from the wind is caught by the wind turbine and changed over to mechanical force P_m [9, 12]. The wind power plant involves of a solitary DFIG-based wind turbine delivering 500 kW with 400 Vac produce voltage. The energy or power of a wind turbine might be indefatigable by various means [27]. The force P_m captured by the wind turbine is a control of the sharp edge sweep, the pitch point, and the rotor speed [7] (Fig. 10).

The power or torque of a wind turbine may be resolute by numerous income. The power P_m taken by the wind turbine is a purpose of the blade radius, the pitch angle, and the rotor speed [13]. Figure 13 displays the simulated power curves for dissimilar wind speeds [5] (Figs. 11 and 12).

$$P_m = \frac{1}{2} \pi \rho C_p(\lambda, \beta) R^2 v^3 \tag{7}$$

$$C_p(\lambda, \beta) = 0.22 \left(\frac{116}{\lambda_i} - 0.4\beta - 5 \right) e^{\frac{21}{\lambda_i}} \tag{8}$$

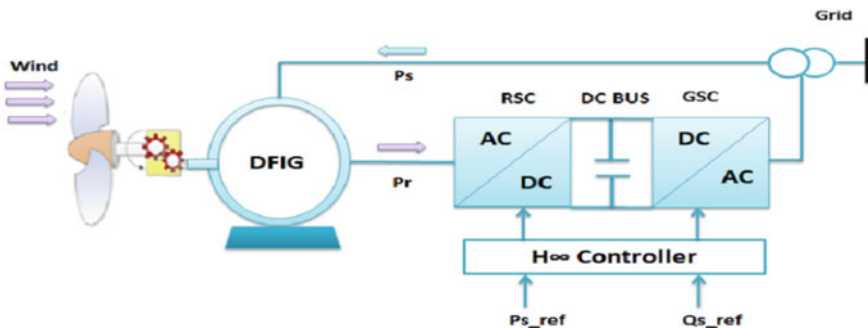


Fig. 10 Doubly fed induction generator [3]

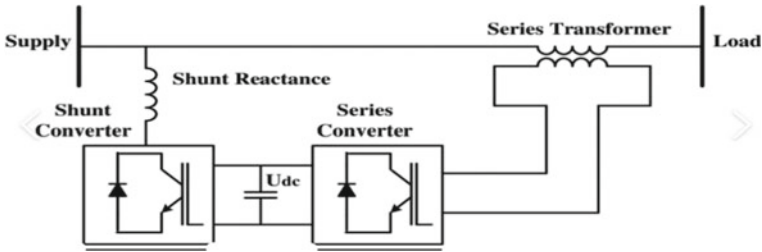


Fig. 11 Basic schematic representation of the UPQC

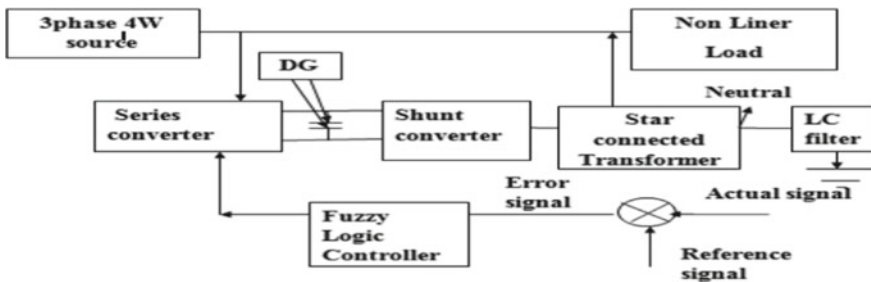


Fig. 12 Proposed UPQC model [8]

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^2 + 1} \tag{9}$$

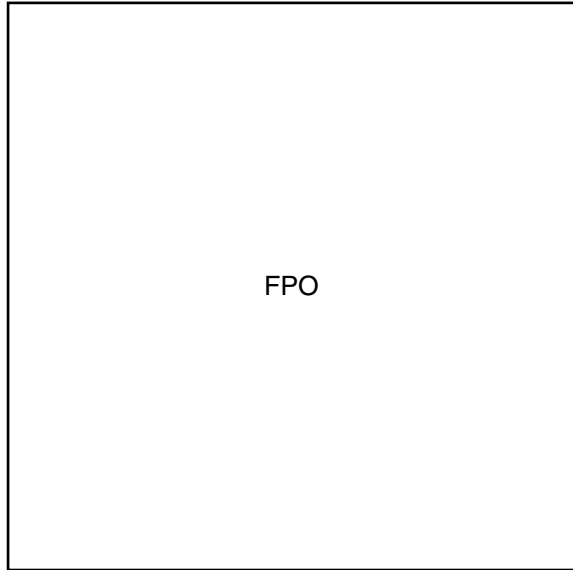
2.3 Double Fed Induction Generator (DFIG) Modeling

The Doubly Fed Induction Generator (DFIG)-based wind turbine with variable-speed variable-pitch control game plan is the most extreme common wind power generator in the wind power industry. This machine can be worked also in grid associated or independent mode. In this task an exhaustive electromechanical model of a DFIG-based wind turbine associated with power grid or just as independently worked wind turbine system with incorporated battery energy stockpiling is set up in the MATLAB/Simulink area and its adjusting generator and turbine control erection is executed. Natural [8].

Model of DFIG

The DFIG contains of stator winding and the rotor twisting outfitted with slip rings. The stator is giving 3-stage protected windings produce up a picked post plan and is associated with the matrix through a 3-stage transformer. The same to the stator, the rotor is additionally worked of 3-stage protected windings. The rotor windings

Fig. 13 FLC-based series converter controller



are associated with an outside fixed circuit through a bunch of slip rings and brushes [11].

3 UPQC Topology

The arrangement of the both DSTATCOM and DVR can handle the power quality of the source current and the load bus voltage. Furthermore, if the DVR and DSTATCOM are associated on the DC side, the DC bus voltage can be managed by shunt associated on the DSTATCOM while the DVR supplies the necessary energy to the load if there should arise an occurrence of the transient’s disturbance in source.

The setup of such a device is displayed in Fig. 11. The DG is related in among the dc connection of the UPQC. The recreation of the arranged method has been endorsed out by MATLAB/SIMULATION [11].

4 Formation of Hybrid UPQC

The arranged technique embraces of the consolidated rating star connected transformer-based UPQC appended with DG. The 3 phase source is taken from the 1 MW system. The series converter is associated through the series reactor from the line correspondingly through the shunt reactor is shunt converter. The series and

shunt converter is connected with common DC link connection and capacitor. The arranged UPQC model is displayed in Fig. 12 [13].

4.1 Series Converter Control

The various disturbances like switching operation and different faults occur in the distribution system causes voltage sags and swell. It influences the customer equipment cruelly. The series converter compensates the voltage sags and swells in the distribution system. The fuzzy logic controller-based series converter controller is displayed in Fig. 13. The DC link limited voltage is contrasted and the reference voltage by comparator [7]. The blunder signal acquired from the comparator is handled with FLC 1. The real worth of voltage in phase a, b, c is prepared with the magnitude of the injected voltage in series converters. The real value of voltage in phase a, b, c is handled with the magnitude of the injected voltage in series converters. This output value is contrasted and output of FLC 1 by comparator. The amplitude of voltage is utilized for reference current estimation [7].

4.2 Shunt Converter Control

Because of expanding in nonlinear load and power electronic equipment in distribution system causes harmonics. This harmonic and is compensate by the shunt converter. The dc link voltage is detected and contrasted with reference voltage [11]. The error signal is handled and it considered as the magnitude of the 3 phase supply current references. The reference current is determined by utilizing the unit vector in phase, with the real supply voltage the 3 phase unit vector in phase is inferred as in [12].

$$u_{sa} = \frac{v_{sa}}{v_{sm}}, u_{sb} = \frac{v_{sb}}{v_{sm}}, u_{sc} = \frac{v_{sc}}{v_{sm}} \quad (10)$$

where v_{sm} is the amplitude of supply voltage. v_{sa} , v_{sb} , v_{sc} are the three phase supply voltage. u_{sa} , u_{sb} , u_{sc} are the multiplication of three phase unit current vectors. The 3 phase shunt current for compensation of harmonics as shown in 10 [12]. The design of UPQC depends on the parameter specification of the distribution system. The 1 MW grid is considered in the system. The fifth, seventh and eleventh order harmonics are made in this plan. The decreased rating star connected transformer is connected with the UPQC, whereas the industrial and domestics loads are associated in close to the shunt converter side [7] (Fig. 14).

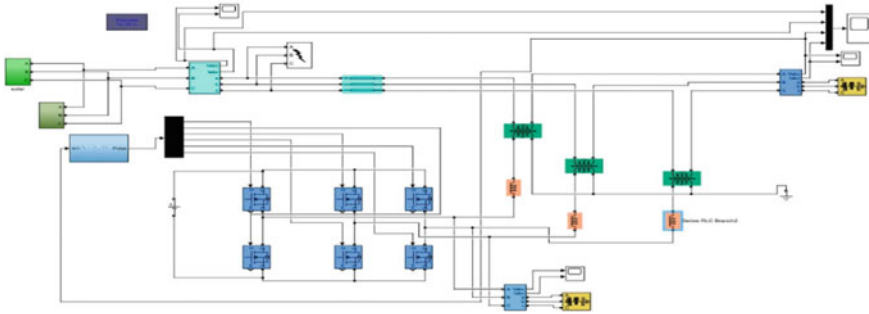


Fig. 14 MATLAB Simulink model of the DVR [2]

5 Results and Discussion

The UPQC has simulated using the proposed hybrid UPQC with DG. The source voltage waveform before and after connecting the UPQC are analyzed. It noticed that the source voltage is distorted before connecting the UPQC and it becomes sinusoidal after connecting the UPQC. The voltage waveform on source side without UPQC is shown in Fig. 15 and with UPQC is shown in Fig. 16. It has clearly shown that the voltage sag and swell present in the waveform is compensated after connecting the UPQC. The voltage sags and swell present in the load side are also reduced, due to source side compensation [9]. Hence, the power quality of the system can be improved (Figs. 17, 18 and 19; Table 1).

DVR is proved to compensate voltage levels under faulty conditions. Voltage harmonics has been reduced considerably. Harmonics generated at source side has THD of 30.5% which has been compensated to 3.6% at load end. Even the voltage sag during fault duration has also been compensated to a desired level [1]. UPQC is proved to compensate current and voltage levels under faulty conditions. Voltage and current harmonics have been reduced considerably. Current harmonics generated

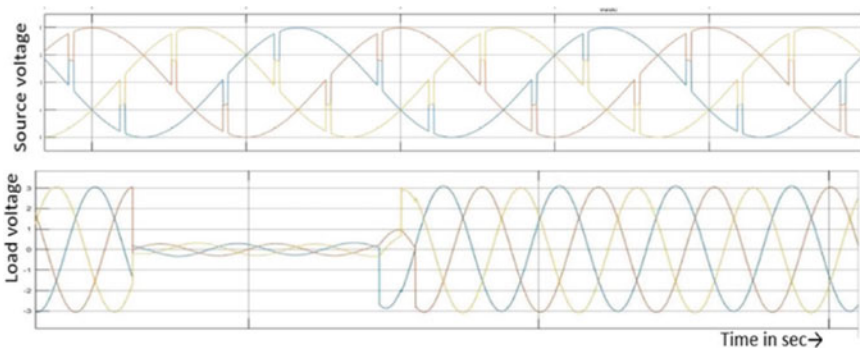


Fig. 15 Load voltage waveform without UPQC

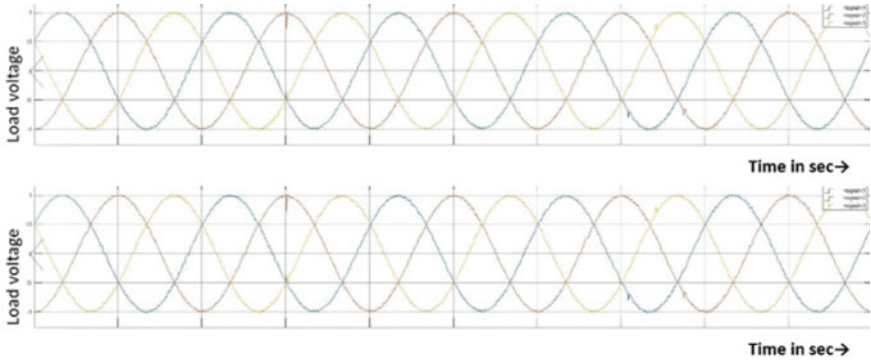


Fig. 16 Load voltage waveform with UPQC and DVR [2]

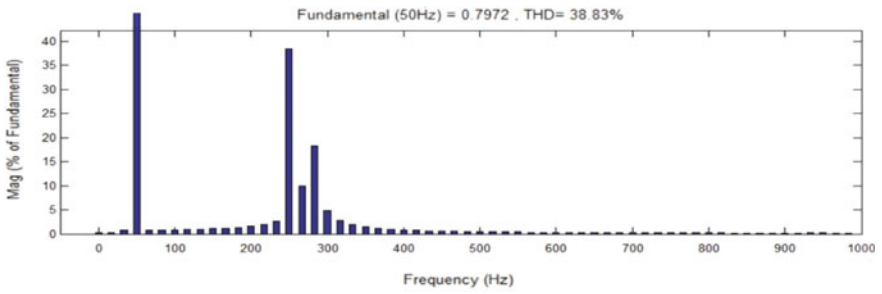


Fig. 17 THD without UPQC in load side [6]

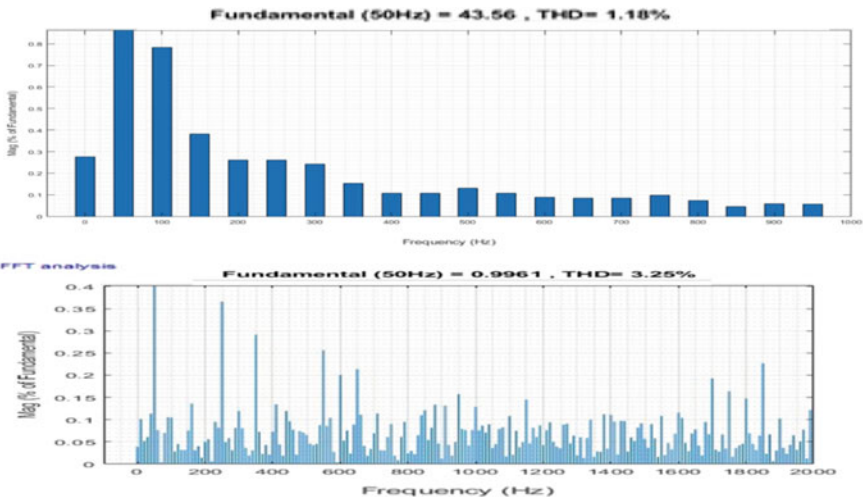


Fig. 18 THD with UPQC and DVR on load side

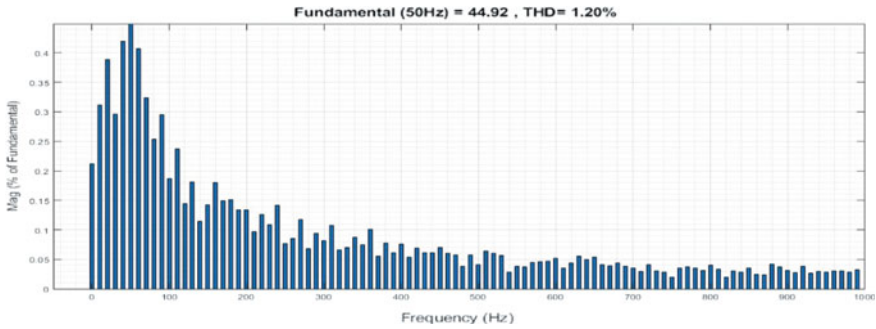


Fig. 19 THD with UPQC in source side

Table 1 THD % comparison with and without D-FACTS

Location	Without UPQC (%)	With DVR (%)	With DSTATCOM (%)	With UPQC (%)
THD in source side	30.5	30.5	30.5	1.1
THD in load side	38.83	3.69	4.12	1.21

at load side has THD of 30.24% which has been compensated to 1.21% at PCC. Voltage harmonics generated at source side has THD of 1.45% which has been compensated to 1.06% at load end [2]. The power quality is improved and the power oscillation overshoot reduction control of rotor speed and preventing the system from having a DC link overvoltage and thus increasing the stability of the power system in accordance with LVRT requirements [2].

Table 2 shows the system parameters.

Table 2 System parameter [2]

	Parameters	Values
MV grid	Grid <i>L-L</i> voltage	30 kV
	Frequency [2]	50 Hz
DFIG	Power	500 kW
	Frequency	50 Hz
	Nominal <i>L-L</i> voltage	400 V
Photovoltaic	Plant capacity	500 kW
	V _{dc}	896 V
	Parallel strings	102
	Series modules	12
UPQC	Capacitances	1100 uF
	Filter inductance	30 mH
	Filter capacitances	28 uF
	Star connected transformer	20 kV

6 Conclusion

This paper presents a hybrid UPQC and DVR in distribution systems for simultaneous compensation of load current harmonics, voltage sag/swell and source neutral current. The performance of proposed UPQC and DVR has been investigated through extensive simulation studies. From these studies it is observed that the proposed scheme completely compensated the source current harmonics, load current harmonics, voltage sag/swell and neutral current [2]. Even the current and voltage level during fault duration has also been compensated to a desired level [3]. Future scope. The more advanced controllers such as fuzzy controller, artificial neural network, AUPF, ISCT, AGCT, IGCT theories can also be used with UPQC to make the system more effective [9].

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