RELIABILITY EVALUATION OF DVR AND UPQC TO ENHANCE THREE-PHASE DISTRIBUTION SYSTEM POWER QUALITY

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Abstract:
This study presents the use of Unified Power Quality Conditioner (UPQC) and Dynamic Voltage Restorer (DVR) controllers to increase Power Quality (PQ) for a distribution system. Two popular custom devices which are claimed to be used to mitigate voltage sag are DVR and UPQC. One of the primary sources of voltage sag is utility-side problems. In order to provide balanced and controlled output voltages with reduced harmonics across the load terminals, the UPQC and DVR systems are developed. Additionally, reduce the source harmonics which the loads produce. Applying a synchronous reference frame, the Matlab simulation model is shown for both controller types. In order to evaluate the improvement in power quality attained by DVR and UPQC devices, performances are studied under three-phase fault conditions and the outcomes are contrasted.

Keywords:
Voltage Source Converter (VSC), Dynamic Voltage Restorer (DVR), Unified Power Quality Conditioner (UPQC), Custom Power Device (CPD), Power Quality (PQ) and Total Harmonic Distortion (THD).

I. Introduction

For system operators, power quality (PQ) is a major problem. Customers or end users are immediately impacted by low PQ. PQ problems exist when the voltage and current deviate from the sinusoidal waveform, as in [1]. The linked equipment can be in hazard if the PQ problems are not fixed at the source [2]. The increasing presence of power electronic equipment in modern power system is one of the main reasons for poor PQ. However, PQ issues in distribution systems are also being caused by sensitive loads [3]. The other most significant and frequent grid discomforts are voltage droop, swell, and short circuits, which can be caused by faults and transients. One of the main causes of these PQ problems is found to be variations in operating voltage [3]. Voltage sag is the root cause of the majority of PQ issues. A situation known as voltage sag occurs when the magnitude falls below 90% of the nominal voltage. There can be a variety of causes for voltage sag. The primary cause for such being a malfunction in the feeder-connected load [4].

In industrial equipment, voltage sags can lead to unsatisfactory performance and eventual failure, which can result in lost output and financial loss [4-5]. Connected equipment can be vulnerable if PQ problems are not fixed at their origin [1]. The utilities and customers suffer financial losses as a result of these PQ problems, which deteriorate the supply. PQ problems cause the grid current to contain harmonics, which causes the linked equipment to overheat. Insulation deficiency and power loss accordingly increase. Moreover, it produces ripples, which raise motor noise and vibration [6, 7]. Conversely, a high reactive power level causes the power factor to drop, which increases losses.

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The consumer-end power supply must be conditioned to improve system performance under all unfavorable circumstances. When adding a Custom Power Device (CPD) to power distribution systems, the aforementioned problems can be resolved. One of the most efficient and successful strategies for enhancing PQ is through CPDs [7].

In order to reduce deviations related to voltage and current, CPDs are a relatively new gadget that interfaces with consumer appliances and the supply system. Figure 1 depicts the various forms of CPDs which are accessible in the literature.

The Unified Power Quality Conditioner (UPQC) and Dynamic Voltage restorer (DVR) are two of the most popular custom devices among all the available CPDs that are intended to support and mitigate PQ difficulties.

This study uses DVR and UPQC controllers to give a comparative analysis for PQ enhancement for a DS. Research is done on the results for a three-phase distribution system without a controller when there are three-phase faults and non-linear loads. Results of utilizing the DVR and UPQC controller to reduce the PQ difficulties are then shown. A comparison review of the simulation models for the two devices is provided in order to evaluate the improvement in PQ. Two operational conditions one non-linear loading and two voltage sag are studied in relation to the outcomes. Results are compared using the proportion of THD with the controller and with the developed controllers as criterion.

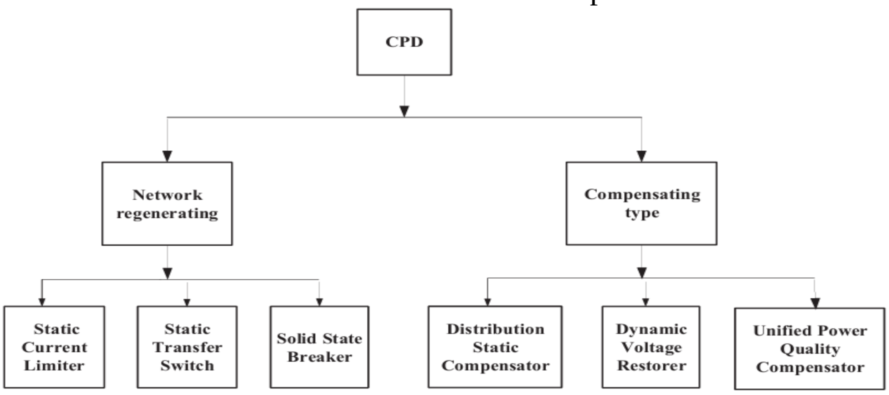

Fig. 1. CPD classification

II. Distribution system

The distribution system (DS), which delivers electricity to end consumers, is at the lowest level in the power system hierarchy, which consists of generation, transmission, sub-transmission and distribution. A substation connection connects the transmission and distribution, lowering the voltage to a level that can be supplied to the customers. At the main level, the voltage level at the distribution end varies between 2KV and 33KV. For three-phase and single-phase systems, it is further reduced to 415 V RMS and 240 V RMS, respectively. Due to rising power usage per consumer, the current distribution infrastructure is overloaded. As a result, supply stability and dependability are impacted. In terms of its effects on reliability, operational technique, power costs and societal aesthetics, DS is the most essential component. In order to protect the connected sensitive equipment and maintain dependability, it must be safeguarded from a variety of PQ issues. As seen in figure 2, a three-phase DS for a 415V RMS is constructed in MATLAB in this study and its performance is evaluated under non-linear loading and three-phase fault conditions.

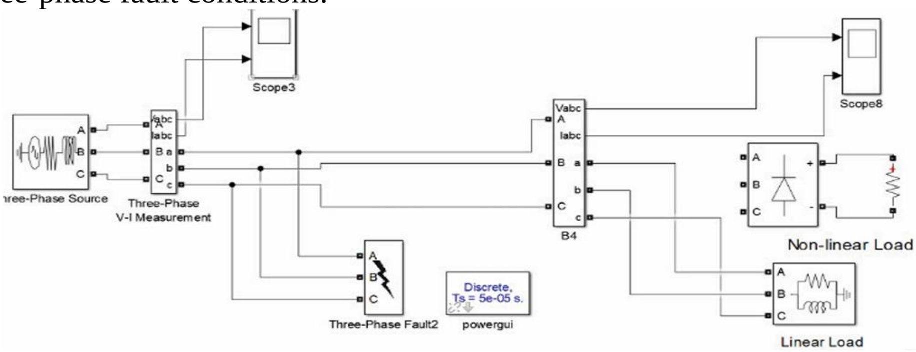

Fig. 2. Distribution system simulation model

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III. DYNAMIC VOLTAGE RESTORER

As seen in Figure 3, the DVR is a CPD which is connected in series with the distribution system [12]. Through power converters, it safeguards the delicate electric load from PQ issues such voltage sag and swell, imbalances, and THD [13]. It controls the load voltage close to the reference value. By injecting reactive power into the distribution network or the sensitive load, the DVR controls the voltage.

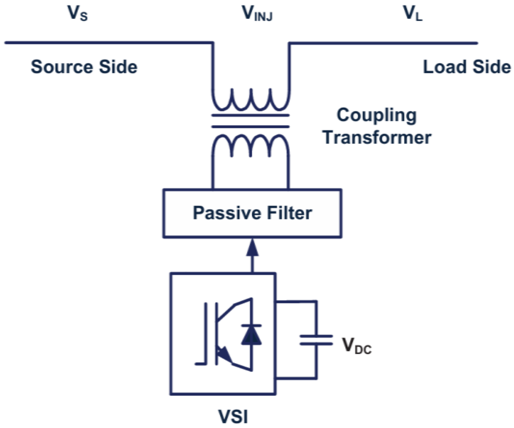

Fig. 3. DVR single line schematic.

The DVR primary parts are a battery storage system, filter element, series voltage source converter (VSC) and coupling transformer with a coordinated control system [14, 15]. The source voltages, VS and VL, are connected in series with the DVR at the load end. It introduces a series voltage VINJ to compensate amends for the voltage imbalance. DC batteries with VDC voltage are used to charge the DVR converter.

IV. UNIFIED POWER QUALITY CONDITIONER

The combination of series-shunt converters can be used to depict the UPQC. The series converter acts as an ideal current source and is linked between the source and the load via an isolation transformer [16]. As an ideal voltage-source converter, the shunt converter is connected in parallel to the load [17]. Figure 4 shows the UPQC circuit architecture. Via the filter element shunt capacitor, the shunt converter in UPQC supports in preserving the balanced sinusoidal voltage. In order to drain the sinusoidal balanced current from the source, the series converter is connected on the source side. The inductor (L), capacitor (C) and resistance (R) are the filter components which assist in reducing the system harmonics. Instead of injecting or absorbing actual power from the system, the UPQC series-shunt converters simply consider provision for reactive power [18].

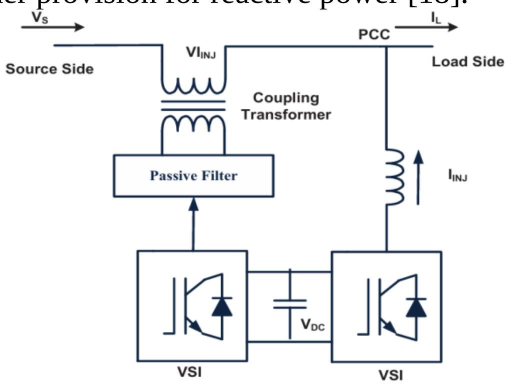

Fig. 4. UPQC single line diagram

The DC-link capacitor is powered by storage devices such as batteries, switch mode supplies, flywheels, etc. in a traditional UPQC architecture. UPQC presents several advantages, primary among being the enhancement of PQ through the reduction of distortion in voltage and current waveforms [19]. Figure 5 illustrates that the controller is built on a synchronous reference frame. The two voltage and current control are features of the UPQC controller. However, DVR contains the ability to regulate both voltage and current simultaneously. This study uses a traditional proportional integral (PI) controller with a PLL block to construct VSC.

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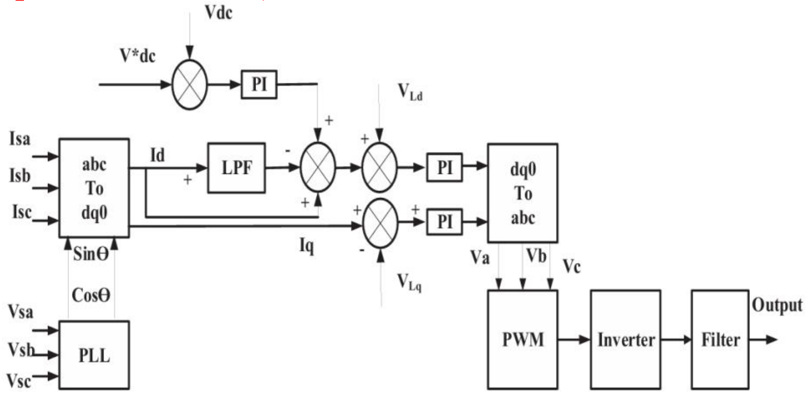

Fig. 5. Converter control.

V. Simulation Results

MATLAB Simulink is used to represent a three-phase DS. Table 1 displays the design parameters. A Simulink block of a three-phase AC source with an RMS of 415V and a frequency of 50 Hz, together with an internal resistance of 0.1 Ω and an internal inductance of 1.58 mH, is used to create the simulation model. Grid parameters and load parameters are measured using two blocks of three-phase VI measurement. Figure 6 displays the voltage and current (V&I) wave-forms of a three-phase linear load that is capable of an active power of 1.5 KW and an inductive reactive power of 100 VAR. Non-Linear Load (NLL) and three-phase fault conditions were specifically studied in the system. A full-bridge diode rectifier connected to a three-phase NLL with a resistance of 40 Ω. The harmonics produced by NLL reflect source side when no compensating devices are used, as seen in figure 7. A Three Phase Fault (TPF) is linked across the grid side for 0.4 to 0.5 seconds, causing a voltage interruption which spreads to the load side as well (see figure 8). Therefore, if the controller is not attached, the source profile is degraded by source voltage conditions and load harmonics. In this work, DVR and UPQC controllers are constructed in Matlab and a comparative study is performed to minimize different PQ difficulties.

Table I: Parameters for UPQC

Parameter	Value
Nominal utility voltages (rms)	415V
Nominal Frequency (ω)	50Hz
DC-link Voltage	140V
Parameters for DVR	
Inverter inductance (L)	45mH
Filter Capacitance (C)	360µF
Switching frequency	3KHz
Parameter for UPQC	
DC link Capacitance (Cdc)	1200µF
Inverter inductance (L)	0.5mH
Filter Capacitance (C)	45µF
Coupling transformer	
Turn ratio	1
Winding: [phase voltage (Vrms), R (pu) X (pu)	415v, 200, 0.05

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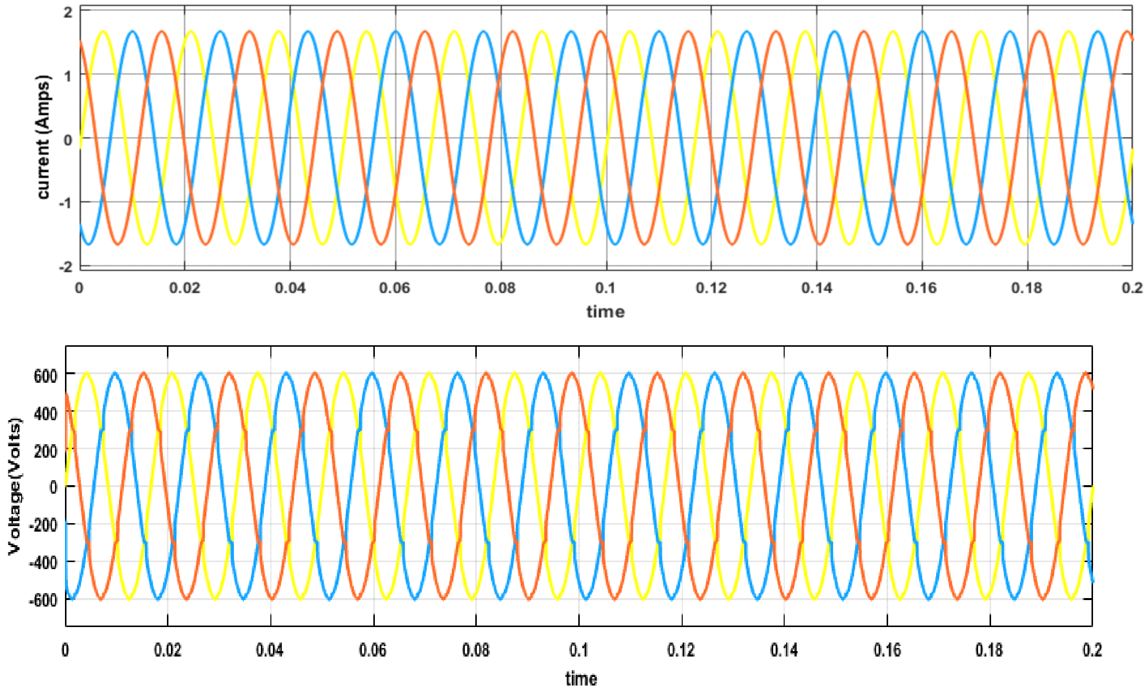


Fig. 6. V&I wave-forms of three phase distribution system under the condition of linear loading

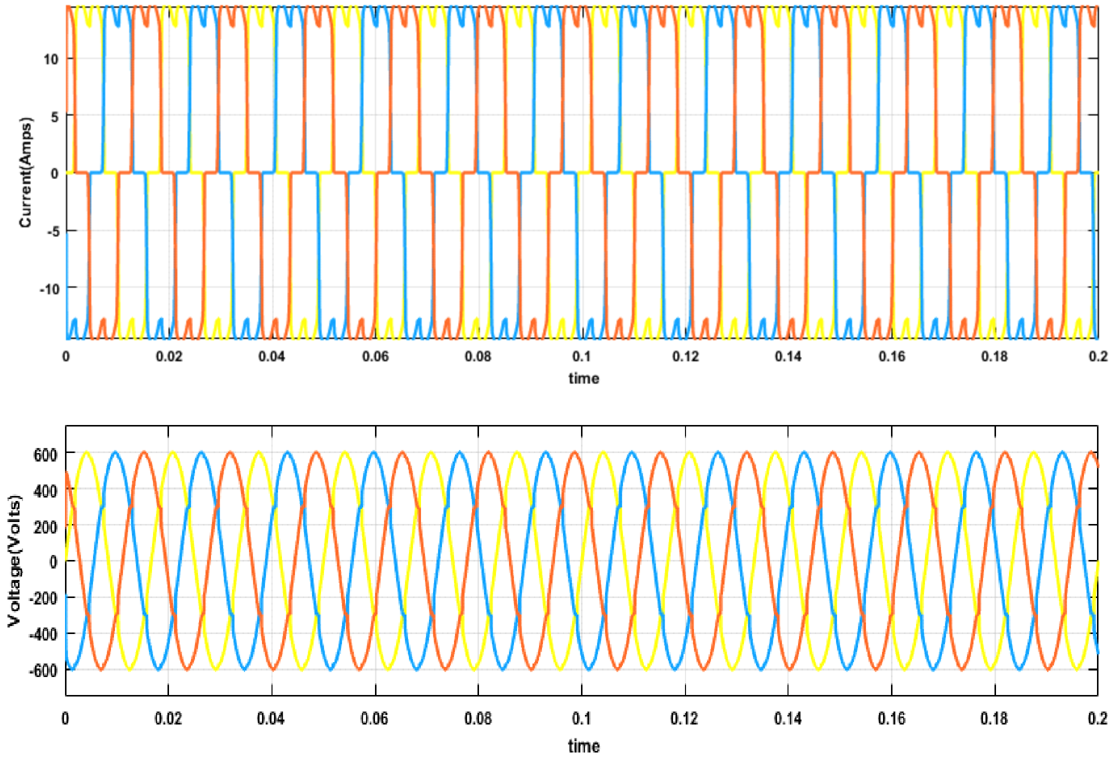
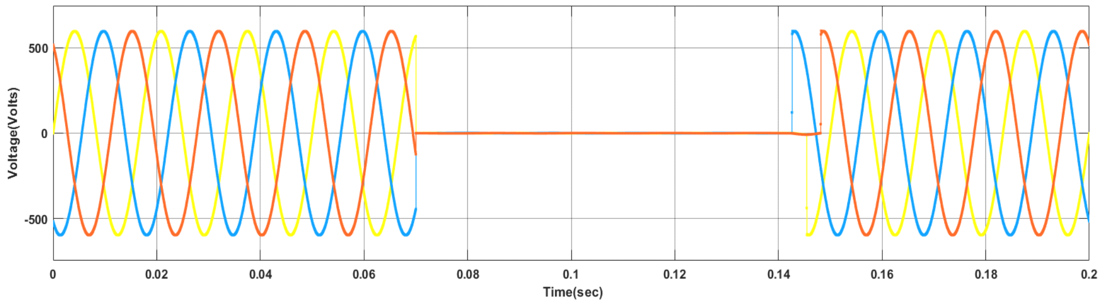


Fig. 7. V&I wave-forms of 3-phase distribution system under the condition of NLL



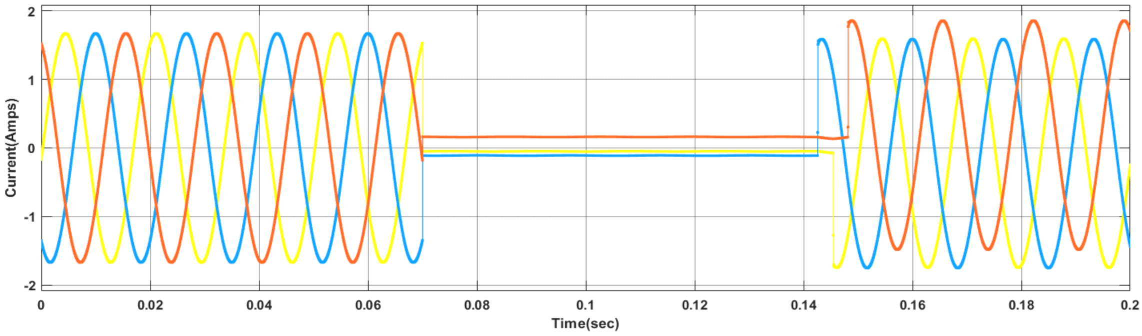


Fig.8. V&I wave-forms of 3-phase distribution system under the condition of LLL-G fault grid side

VSC is constructed in two levels for DVR. The method of sinusoidal pulse width modulation is used to create the gate pulses. VSC control is based on two-axis theory, which uses a PI controller to regulate the direct and quadrature axes [24]. The output produced by the VSC is filtered using an RLC filter to eliminate harmonics, and the VSC is coupled in series using a coupling transformer. In MATLAB-simulink software, the DVR simulation model is shown in Figure 9. Figure 10 displays the V&I waveform of the load side with the DVR attached for non-linear load. Grid side V&I waveform is seen in figure 11. Based on the figures, it is evident that the DVR stops the load current distortion from propagating to the source side whereas the NLL causes it.

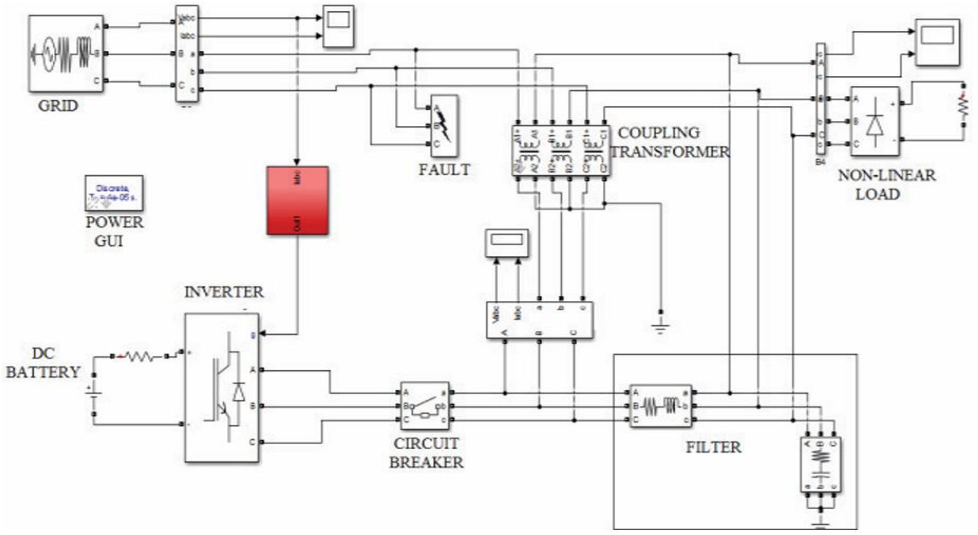


Fig. 9. Simulation model of DVR

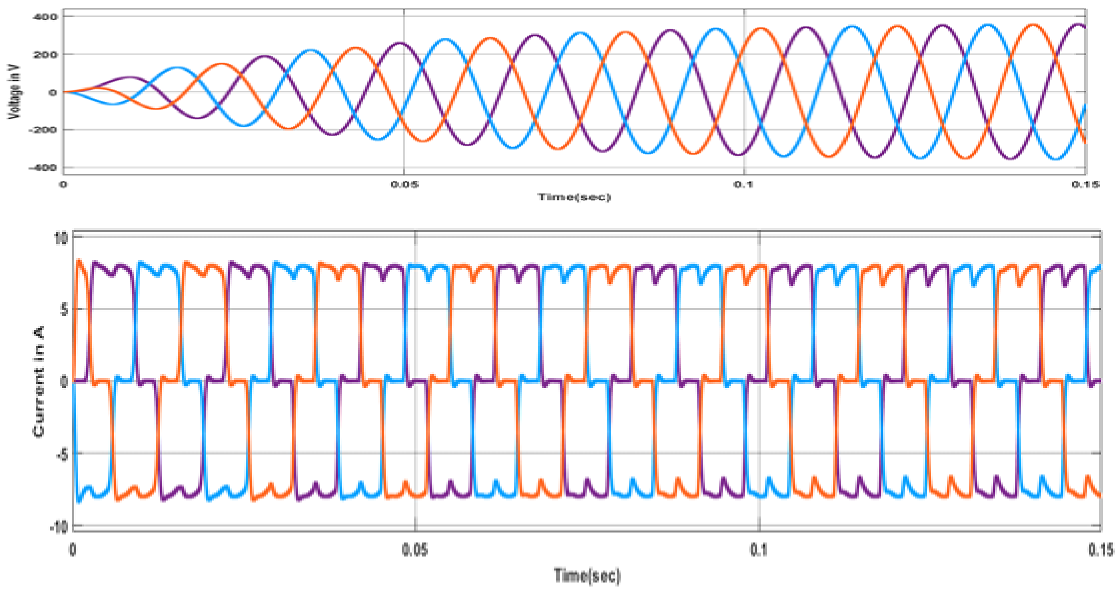


Fig. 10. V&I at load side for NLL

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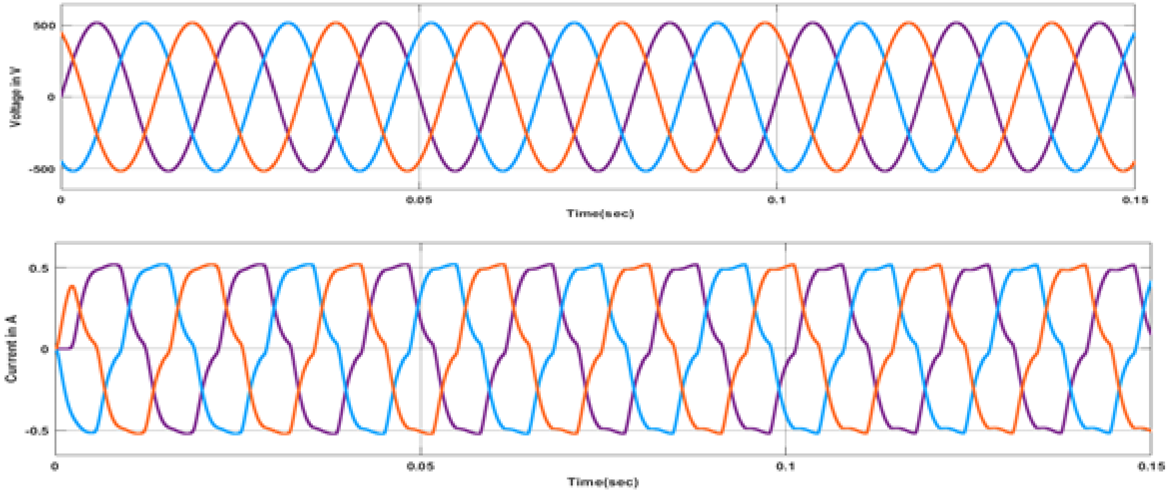

Fig. 11. V&I at grid side for NLL

The system is studied for TPF in addition. The V&I waveform of the grid side containing a fault connected is identical to the DS figure 8. Figure 12 displays the load side with the DVR connected V&I waveform. The figure shows that a grid defect results in a voltage interruption at the grid bus, but the DVR prevents the disturbance from spreading to the load side. Even so, the harmonic content is slightly high.

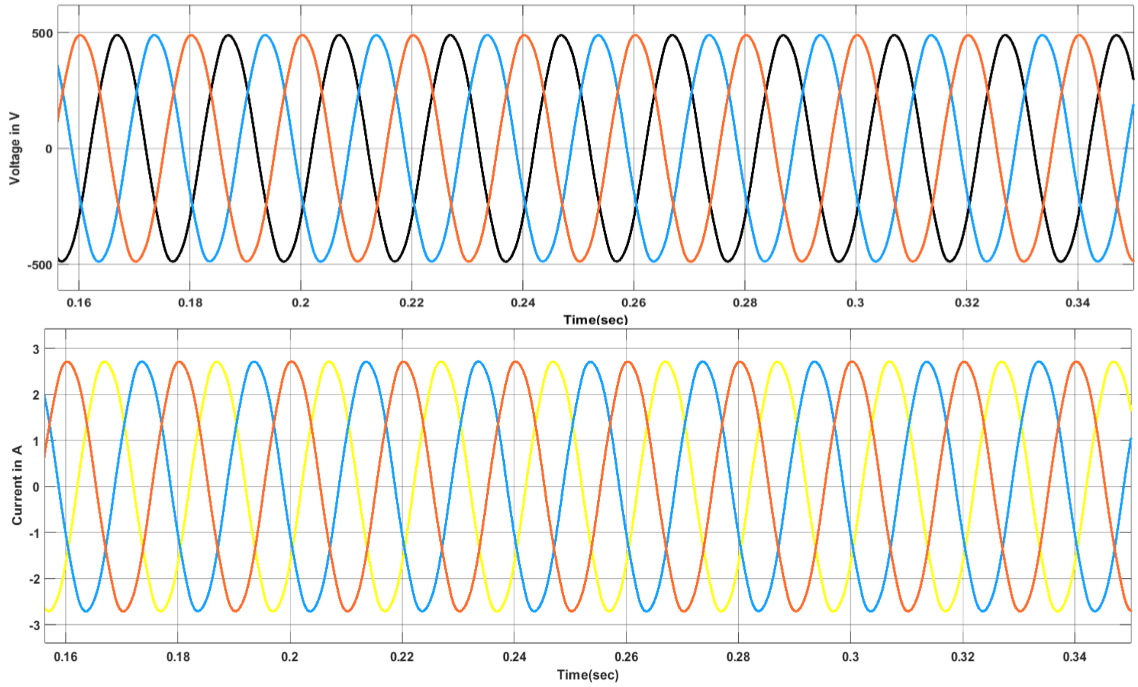

Fig. 12. Load side voltage and current wave-forms of 3-phase distribution system under the condition of TPF with DVR.

As seen in Fig. 13, the UPQC simulation model is developed as well in Matlab. A three-phase voltage source with a 100 MVA short circuit capacity is regarded as an AC bus duplicate of the grid. Two back-to-back DC/AC converters are connected by a DC-link capacitor with a capacitance of one micro farad in order to create a UPQC. The converter contains two connections: one to the grid and a second to the non-linear load. Figure 10 is not replicated in this portion since the V&I wave-form of the load side with UPQC attached for non-linear load is identical to that of DVR or DS. Figure 14 displays the grid side V&I waveform with the DVR attached. It is evident from the figures that the DVR stops the load current distortion from propagating to the source side due to the non-linear load. Three-phase fault analysis is also performed on the system. As seen in figure 8, the grid side voltage and current waveform when UPQC is coupled is identical to that of DS without a controller. Figure 15 displays the load side voltage and current waveform with UPQC attached. The graphic illustrates when a grid

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defect results in a voltage interruption at the grid bus, while UPQC forbids the same from spreading to the load side. Additionally, in the event of a fault, it totally reduces the harmonics at the load side. Consequently, voltage correction is successfully provided.

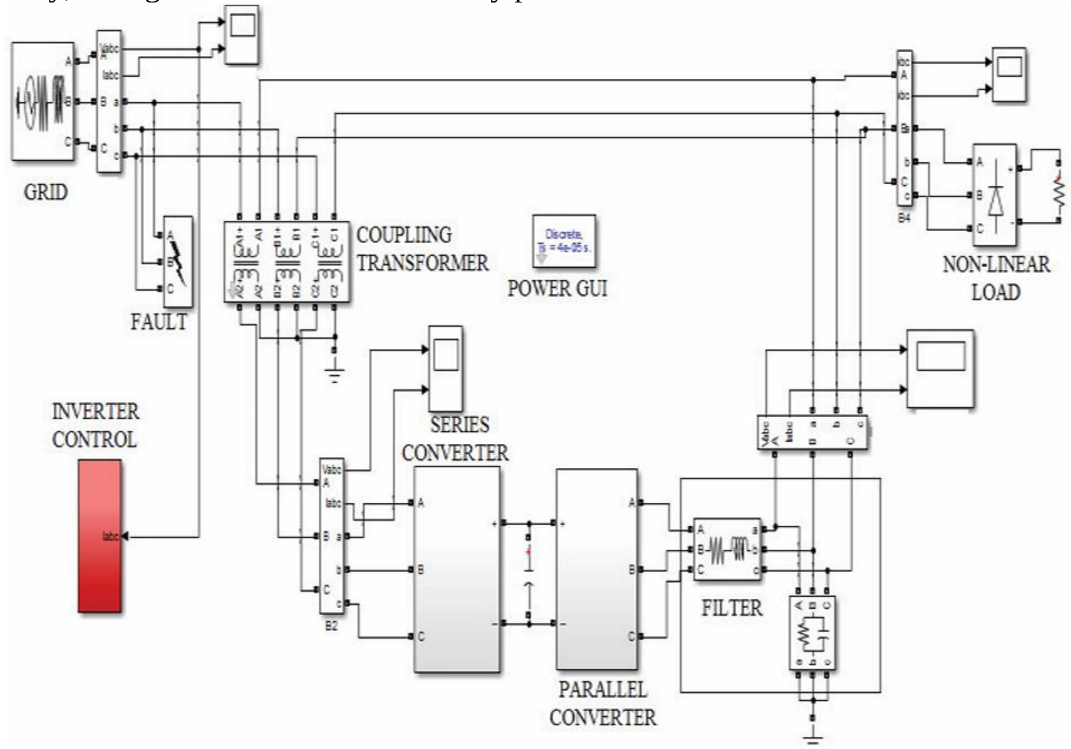

Fig. 13. Simulation model of UPQC

Table II: Harmonics of DVR and UPQC

OPM	Φ-A	Φ-B	Φ-C	Φ-A	Φ-B	Φ-C	Φ-A	Φ-B	Φ-C
THD for grid voltages									
Non- Linear Load	DS			DVR			UPQC		
	4	4	4	1.5	1.5	1.5	0.6	0.6	0.6
Fault	8	8	8	6.6	6.6	6.6	4.7	4.7	4.7
THD for load voltages									
Non- Linear Load	DS			DVR			UPQC		
	4	4	4	2.7	2.7	2.7	1.5	1.5	1.5
Fault	8	8	8	2.3	2.3	2.3	1.5	1.5	1.5

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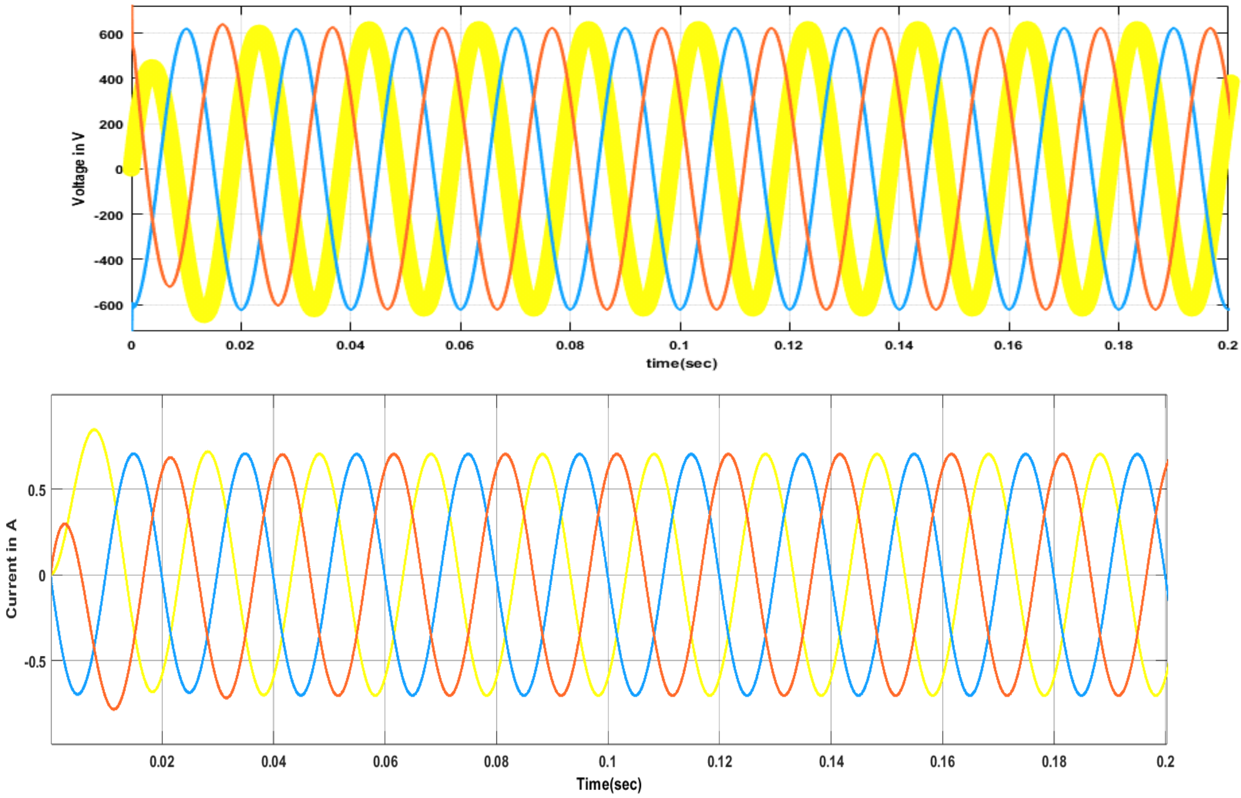

Fig. 14. Grid voltage and current wave-forms of UPQC under the condition of non-linear loading.

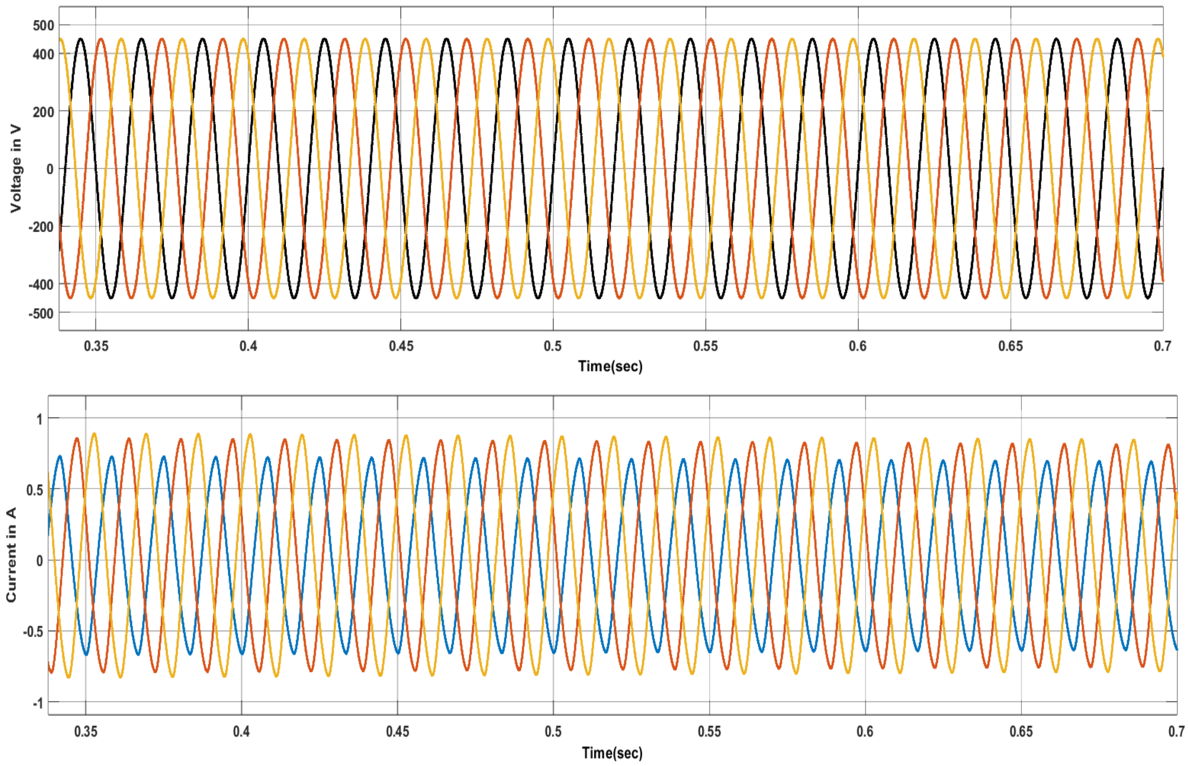

Fig. 15 Load voltage and current wave-forms of three phase distribution system under the condition of LLL-G fault.

VI. COMPARISON

When non-linear loading occurs, it is evident that the very large load current harmonics alter the grid current if the controller is disconnected. UPQC and DVR minimize the harmonics of the load current. When TPF grid side conditions are present, the load voltage also experiences voltage sag if the controller is not attached. The load voltage sag and THD are reduced with DVR and UPQC. Since the waveforms at the load side are smooth and UPQC recovers load voltage in the event of a fault, illustrated in table 2, it performs superior. In comparison to DVR, which is 6.6%, the table shows that the THD percentage for UPQC is extremely low at 1.5% for load voltage and low at around 4.7% for grid voltage.

VII. CONCLUSION

This study analyzes three different operating situations for a three-phase distribution system: normal operation, operation with a non-linear load and three-phase fault. Under fault conditions, voltage sag can be mitigated by the intended DVR and UPQC. Comparative outcomes are provided in order to lessen system harmonics and the load side voltage sag situation. For lowering harmonics in the voltage profile, the simulation results demonstrate that the DVR and UPQC operate satisfactorily in decreasing voltage sags and enhancing power quality. However, UPQC is minimal THD content for both TPF and NLL, as demonstrated by comparative study.

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