Performance Analysis of DVR and UPQC for Mitigating Voltage Sag in a Distribution System

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ABSTRACT
In this paper Power Quality (PQ) improvement for a distribution system is presented using Dynamic Voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC) controllers. DVR and UPQC are widely adopted custom devices that are reported for mitigation of voltage sag. Voltage sag is a result of the faults in the power system. The designed UPQC and DVR systems help in obtaining regulated and balanced output voltages with reduced harmonics across the load terminals. Also, they suppress the source harmonics generated by the loads. The Matlab simulation model is presented for both the types of controllers using synchronous reference frame. Their performances have been analyzed under 3-phase fault condition and the results are compared to assess the improvement achieved in power quality by DVR and UPQC devices.

Keywords— Power Quality, Photo Voltaic, Unified Power Quality Conditioner (UPQC), Dynamic Voltage Restorer (DVR).

I INTRODUCTION

Power quality (PQ) is a serious concern for system operators. Poor PQ directly affects the end-users or consumers. Power quality phenomena or power quality disturbance may be defined as the deviation of the voltage and the current from their ideal waveform i.e. sinusoidal in power systems [2-4]. If the PQ issues are not rectified at source, then they may threaten the connected equipment [1]. These PQ problems are classified by five main events; sags, swells, harmonics, interruptions, and transients. These events can cause degradation in service which may cost monetary losses to utility as well as consumers.

Most of the PQ problems are related to voltage sag. Voltage sag refers to a condition when, magnitude drops lower than 90% of the nominal voltage. There may be lot of reasons for the occurrence of voltage sag. Mainly it occurs due to fault in the load connected to the feeder [5].

In this paper, grid connected DVR and UPQC controllers are presented to minimize the voltage sag which could be the result of system faults [6]. The basic function of the DVR is to inject a dynamically controlled voltage V_{DVR} generated by a forced commutated converter in series with the bus voltage [7-10]. On the other hand, UPQC has been reported for simultaneous mitigation of both the current and voltage related power quality impacts [11]. The simulation model for both the devices is presented with comparative analysis to assess improvement in PQ. The results mainly focus on the voltage sag. The criteria for comparison of about voltage sag are the percentage of voltage restoration and THD during the fault.

II DYNAMIC VLTAGE RESTORER

The DVR is a custom power device that is connected in series with the distribution system as shown in Fig 1 [12]. It protects the sensitive electric load against PQ problems such as voltage sags, swells, unbalances, and distortion through power electronic controllers that use voltage source converters (VSC) [13]. It regulates the load voltage near to set reference value. The voltage is regulated by the injection of reactive power into the sensitive load or the distribution network by the DVR. The main components of the DVR consist of a coupling transformer, passive filter, series VSC, and energy storage and control system [14, 15].

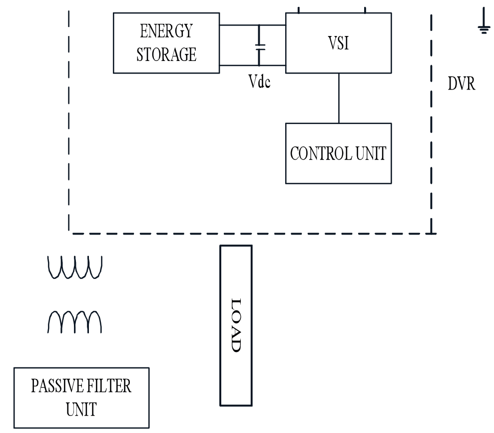

Fig. 1 Schematic of DVR connected to a distribution network

III UNIFIED POWER QUALITY CONDITIONER

The UPQC can be represented as the combination of series-shunt converters. The series converter is connected between the source and load via isolation-transformer and behaves as an ideal current source [16]. The shunt converter is connected in parallel to the load which behaves as an ideal voltage-source converter [17]. The circuit topology of the UPQC is given in Fig. 2. In UPQC, shunt converter helps in maintaining the balanced sinusoidal voltage via the shunt capacitor of the filter element. The series converter is connected on a source side via coupling transformer and hel draining sinusoidal balanced current from source filter elements LCR help in suppressing harmoni the system. The series-shunt converters of U ensure no injection or absorption of real power fro system but only compensates for reactive power 20]. In conventional UPQC topology, the DC capacitor is energized with storage devices batteries, switch mode supply, flywheel, etc. [21 UPQC offers numerous benefits, mainly improvement in PQ by its ability to minimiz distortion in voltage and current waveforms. [23].

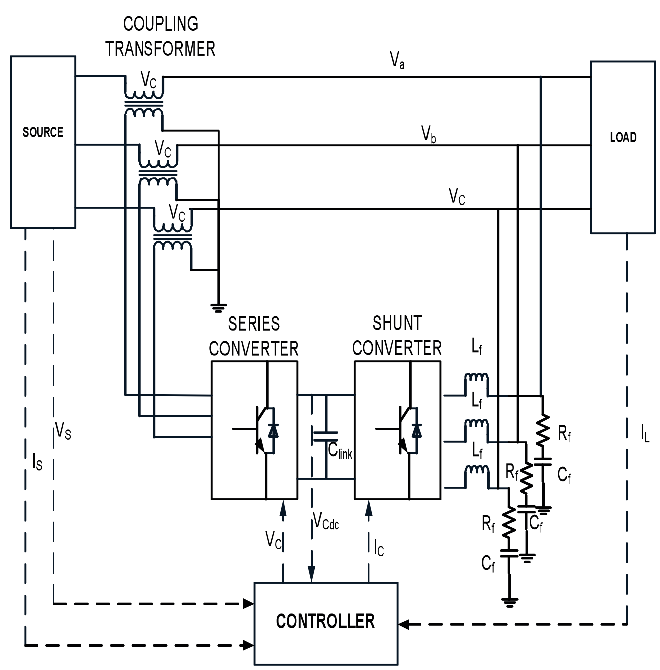

Fig.2 Detailed configuration of the UPQC

IV SIMULATION AND MODELLING OF DVR AND UPQC

To analyze the performance of the DVR, a 415 V, 3-phase distribution system has been modeled in MATLAB Simulink toolkit of Sim-power system as shown in Fig. 3. DVR is designed using two-level VSC. The gate pulses are generated using the sinusoidal pulse width modulation technique. The control for VSC is based on two-axis theory i.e. direct and quadrature axis employing Proportional Integral (PI) controller [24]. The VSC is series connected via coupling transformer and the output generated through VSC is filtered to remove harmonics using RLC filter. The parameters considered for DVR are given in Table 1.

Table 1
Parameters considered

Parameter	Value
Nominal utility voltages (rms)	415 V
Nominal Frequency (ω)	50Hz
DC-link Voltage	1200
Parameters for DVR	
Inverter inductance (L)	45mH
Filter Capacitance (C)	360 µF
Parameters for UPQC	
Inverter inductance (L)	0.5mH
Filter Capacitance (C)	45 µF
Non-linear resistive load is connected via three-phase bridge rectifier	

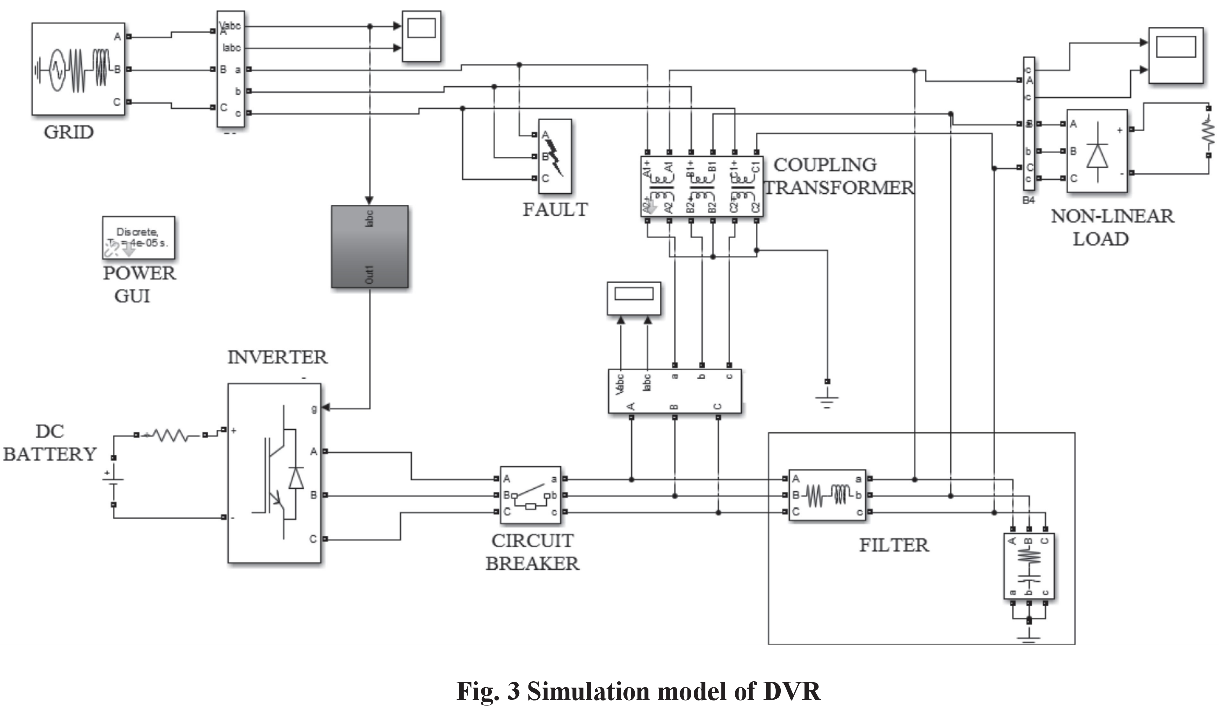

Fig. 3 Simulation model of DVR

The simulation model of the designed UPQC system is shown in Figure 4. Three phase voltage source is considered as an AC bus replica of the grid with short circuit capacity of 100 MVA. To design a UPQC, two back to back DC/AC converters are connected through a DC-link capacitor of 1 micro farad capacitance. One side of the converter is connected to the non-linear load and another side to the grid. The system is synchronized with the grid using PI-controller and Phase Lock Loop [25]. The performance of the designed DVR and UPQC analysed for three phase fault and the results are provided in the next section.

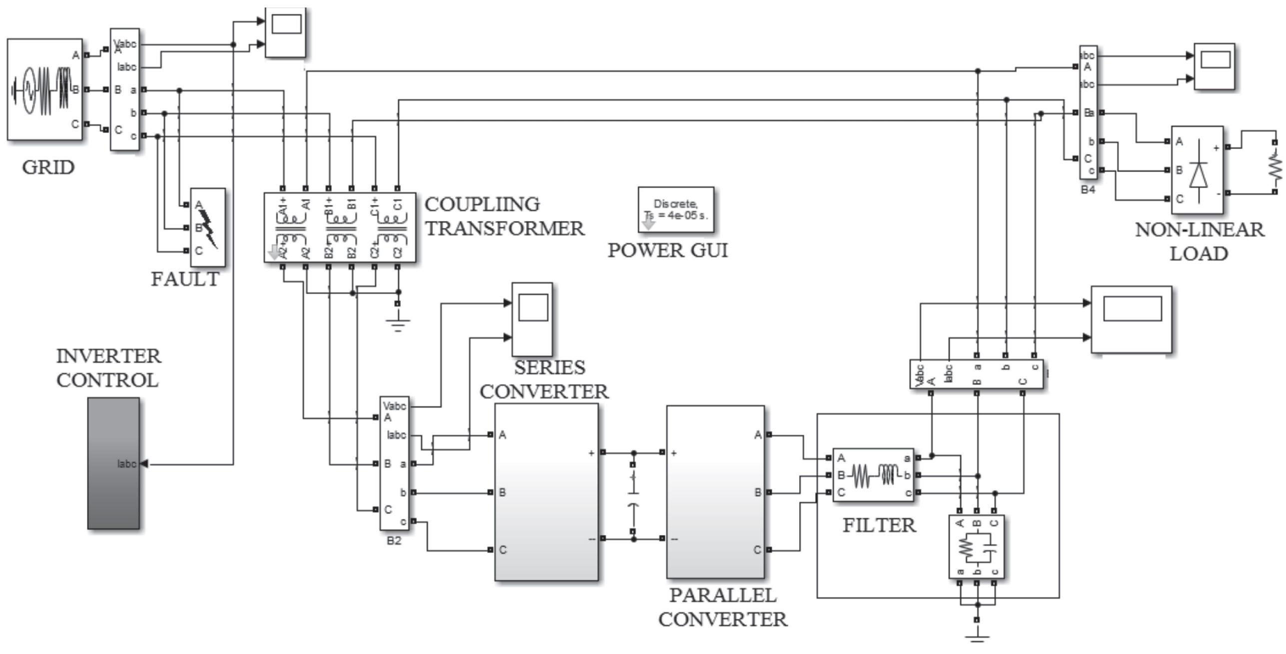

Fig. 4 Simulation model of

V RESULTS AND DISCUSSION

Among the various PQ problems, voltage sags are the most severe disturbances, which are caused by the fault in power systems. If a fault occurs due to the short circuit at the source side in a power network, it results in the voltage sag in the load connected to the power network. The distortion in voltage waveforms load side due to sag is analysed. Both DVR and UPQC successfully mitigate the voltage sag, by injecting the required amount of reactive power at the time of fault to restore the load voltage.

The fault occurs at grid side and its effect is analysed on grid as well as load side. Fig. 5 presents the grid side voltage and current when a three phase to ground fault occurs at 0.5 sec. and cleared at 0.6 sec. But it results in the 50% voltage sag. This dip in voltage propagates to the load bus and may cause severe damage to the sensitive loads connected. Also, it will increase the grid current upto 50% which results in over current. The distortion in grid voltage will also be increased as shown in Fig. 6, the THD due to the fault is 25% which is very high. Fig. 7 shows the load voltage and current profile with DVR connected in series with the source using a coupling transformer. From the figure, it can be seen that DVR mitigates the voltage sag successfully by restoring about 90% system voltage when the sag occurs. Also, it reduces the THD of the load voltage to 3.08% which is well within the permissible limit (IEEE 519-1992) allowing THD of 5% in voltage. Fig. 8. presents the THD graph of load voltage at fundamental frequency.

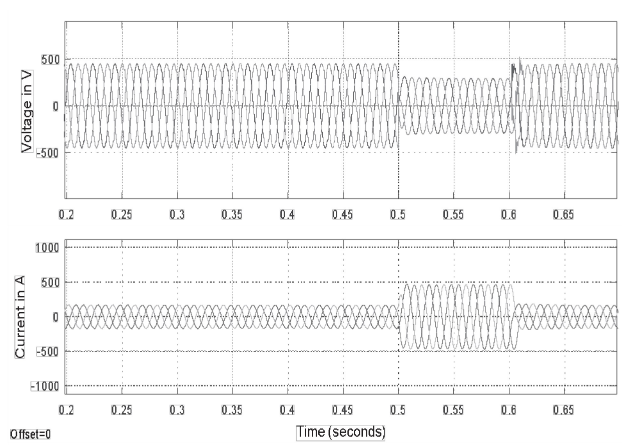

Fig. 5 Grid side voltage and current waveforms under three phase fault

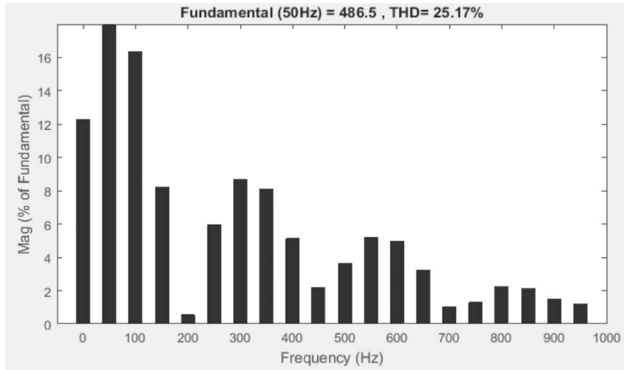

Fig. 6 THD of grid voltage

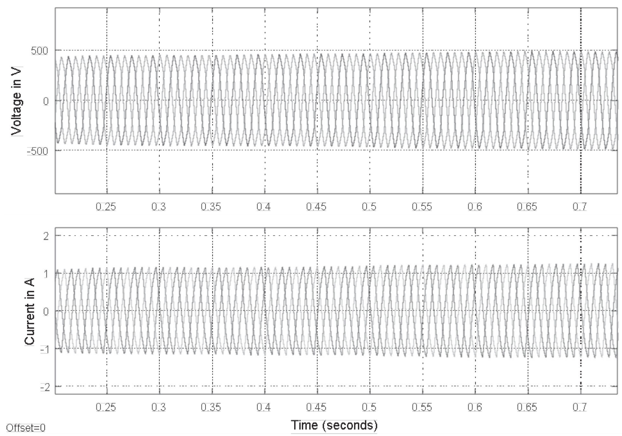

Fig. 7 Load side voltage and current under three phase fault load side with DVR

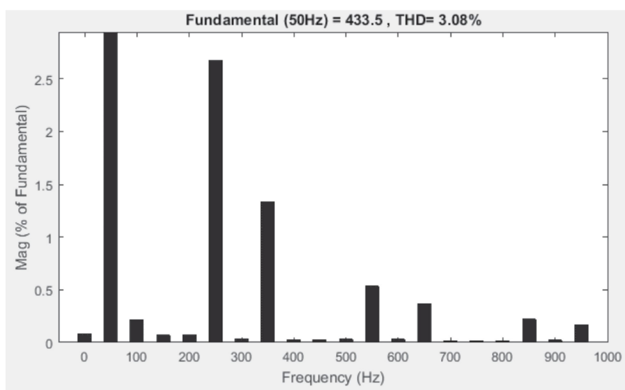

Fig. 8 THD of load voltage with DVR

Fig. 9 presents the load voltage and current profile with UPQC. From the figure it can be seen that UPQC mitigates the voltage sag successfully. And restores the 100% system voltage. Also, it reduces the THD of the load voltage to 0.21% which is very nominal. Fig. 10. presents the THD graph of load voltage at fundamental frequency.

Fig. 10 THD of load voltage with UPQC

VI CONCLUSION

The modeling and simulation of a DVR and UPQC are presented using MATLAB/SIMULINK toolkit. A control system based on the synchronous reference frame technique is used. The simulation results show that the DVR and UPQC performance are satisfactory in mitigating voltage sags as well as improving the power quality by reducing harmonics in the voltage profile. From the result, it can be seen that, though both DVR and UPQC are capable of mitigating the voltage sag. With the designed controller, DVR restores about 90% of voltage after the occurrence of fault whereas UPQC restores 100%. Further, THD is lower in case of UPQC in comparison to DVR. The authors have also noted from the research papers that the performance of UPQC is superior to that of DVR. The authors have also concluded the same.

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