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Performance analysis of Unified Power Quality Conditioner Under Voltage Instability

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Abstract:
The distribution system is highly burdened and undergoes various power quality events. To retain the stability of the system under the conditions of faults which is characterized by sag in voltage or swell due to disconnection of any feeder when faults occurred, power quality conditioner are installed. UPQC is one of the widely adopted power conditioner which maintains the load profile under abnormal operating conditions. Also, it blocks the harmonic current flowing into the system due to heavy non-linear loading. This paper presents the application of UPQC under sag/swell events and high non-linear loading. The design of the controller for controlling the gating of the power switches is designed using grid voltage reference signal in synchronous frame via PI-controller. The PWM is generated using carrier based two-level modulation technique and discrete phase lock loop block synchronize the system.

Key Word*: Active Power Filters (APF), Power Quality Issues (PQI), Unified Power Quality Conditioner (UPQC), Voltage Source Inverter (VSI), harmonic distortion.*

I. Introduction

Power quality is the main concern for stable operation of power system and various equipment connected to it [1]. Faults on transmission lines or switching events at the end user facility are sources of the Power Quality Issues (PQI) [2]. Industrial applications are particularly vulnerable to voltage fluctuations because of the widespread usage of equipment that is sensitive to voltage deviation, such as power electronic converters and switching devices. The sags and swell were identified as the main concern among them [3]. Voltage sags and swell can lead to industrial equipment operating improperly and eventually tripping, which can result in a loss of output and financial loss [4-5]. Hence it has to be mitigated immediately as soon as these events are reported. Active Power Filters (APF), Battery Energy Storage Systems (BESS), Distribution Series Capacitors (DSC), Solid-State Transfer Switches (SSTS), Surge Arresters (SA), Super conducting Magnetic Energy Systems (SMES), Uninterruptible Power Supply (UPS), Static Electronic Tap Changers (SETC), Solid State Fault Current Limiter (SSFCL), Static VAR Compensator (SVC), and Thyristors Switched Capacitors (TSC), unified power-quality conditioner (UPQC), Distribution-STATCOM (DSTATCOM), and dynamic voltage restorer (DVR) are just a few examples of the custom power devices that are available and are made to mitigate power quality-related issues with specific applications. UPQC is one of the efficient ways to safeguard the sensitive loads. Combining series and shunt APFs with a common dc link, a UPQC is designed [6, 7]. This adaptable device can virtually eliminate all PQI, including reactive current, voltage harmonics, voltage imbalance, voltage flickers, voltage sags & swells, and voltage harmonics. Lately, employing UPQC to mitigate voltage swells and sags has received increased attention [8]. Although swells are less frequent than sags, swells can have more disastrous repercussions. For instance, a high overvoltage during a swell scenario may result in equipment or component failure. This paper presents the performance analysis of UPQC under voltage sag/swell conditions when system is operated with heavy non-linear load. The results obtained are validated for both source and load profile. The source load profiles are compared with UPQC when simultaneous sag and swell is occurred at source side. The UPQC also reduces the THD of the source current as well as load voltage with contingencies in the system. The paper is presented in five sections, including first introduction followed by UPQC design and control in second section. Third section presents the simulation model and results are discussed in fourth section. In the last section conclusion is presented.

II. Unified Power Quality Conditioner (UPQC)

In industrial power systems and power distribution, the UPQC can improve PQ at the PCC [9]. A UPQC consists of both series and shunt APFs. Two-level Voltage Source Inverter (VSI) in voltage control mode is used in the design of the APFs in traditional UPQC topology. It may thus synchronise its compensation for both voltage and current. The shunt APF of a UPQC compensates for load-related current difficulties, such as those involving the D-STATCOM, whereas the series APF of the UPQC handles voltage-related issues across the load, such as those involving the DVR. There are numerous benefits to the UPQC for improving PQ. It eliminates the requirement for several devices in the distribution network by handling PQ problems connected to voltage and current as well as filtering harmonics. The UPQC reduces load supply-voltage variations by providing active compensation for current distortion and power factor correction. UPQC has the ability to regulate the voltage on the load and grid sides.

1. In order to provide sinusoidal source current and load voltage at the appropriate voltage level, the UPQC concurrently and independently reduces distortions in both voltage and current [15]. The following are the main components of UPQC [10]:
2. Shunt and series VSIs; By connecting in series with the line, the VSI structure in the series functions as a voltage source. Conversely, the shunt VSI structure connects parallel to the load and serves as a source current.
3. The inverter's network integrator is a shunt coupling inductor.
4. To establish a common DC link, a capacitor could be utilised. The capacitor used to couple the two inverters also maintains a stable and self-sustaining dc bus voltage across them.
5. An LPF-like filter, or LC filter MLI can typically draw input current with minimal distortion.
6. Inverters with multiple levels produce a lower common voltage. It is possible to lower the common mode voltage by utilising advanced mode technologies.
7. An LC filter, which is simply a low-pass passive filter, is used to lessen high-frequency switching-related ripples in an inverter's output voltage.

The series converter is connected to the network by the series injection transformer.

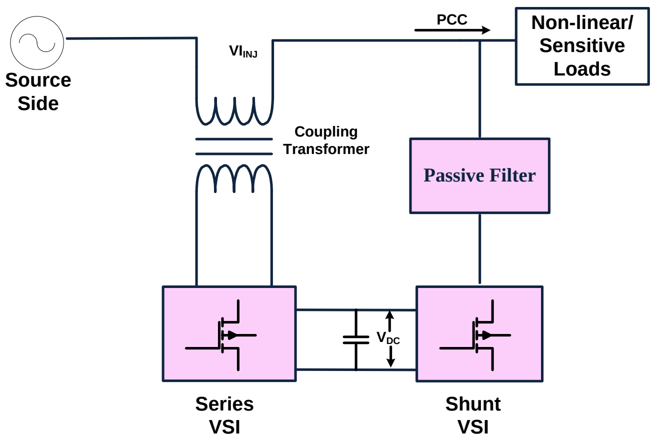

Fig. 1. Schematic of UPQC with right shunted topology

A shunt APF can inject reactive current to balance supply currents, inject zero-sequence and negative components as needed by the load, and inject harmonic current to address load current harmonics. Additionally, it has DC bus voltage control. A series APF isolates the load bus from harmonics in the source voltages by injecting harmonic voltages, controls the magnitude of the load voltage by injecting the required active power components, and adjusts the voltages at the load bus by injecting negative and zero sequence voltages to make up for those in the source [16].

III. MATLAB Simulation

The UPQC with two-level three-phase VSI for 415 V RMS designed using 6 switches is modeled in matlab. The matlab simulation model is shown in figure 2. The control to obtain the gating pulses is designed in synchronous frame with PI controller and Phase Lock Loop (PLL) as shown in figure 3. The carrier-wave with sinusoidal reference/carrier signal method is used for PWM. The discrete PLL synchronize the system at fundamental frequency with the system sampling time. The design parameter for the proposed system is mentioned in table-1. The series side converter of UPQC is connected via coupling transformer of 0.1 MVA rating and shunt converter is connected in parallel at load side through filter unit.

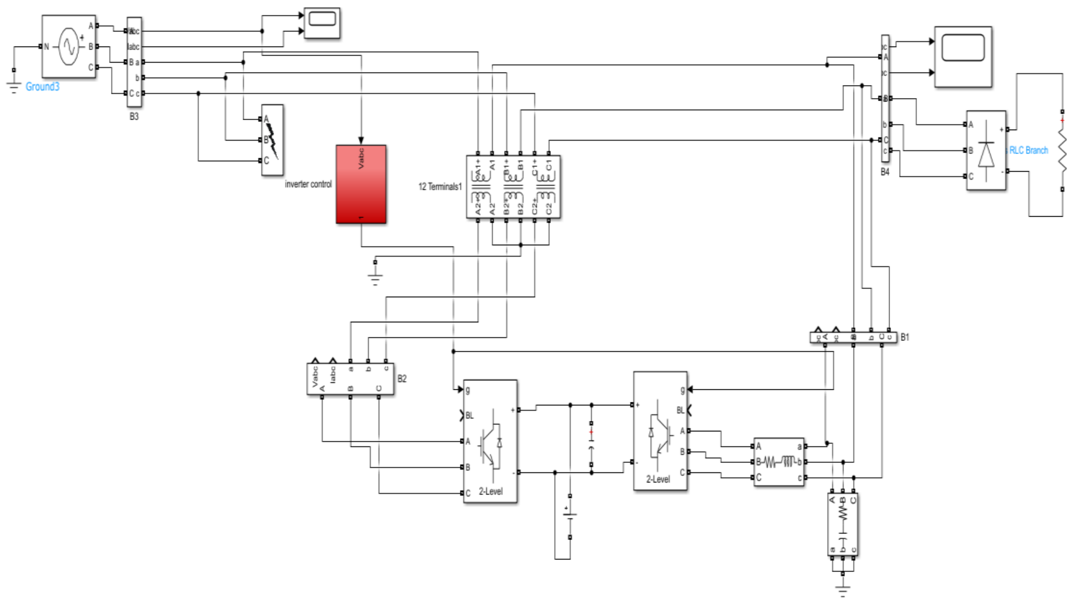

Fig. 2. Simulation model of the UPQC with conventional 2-level converter

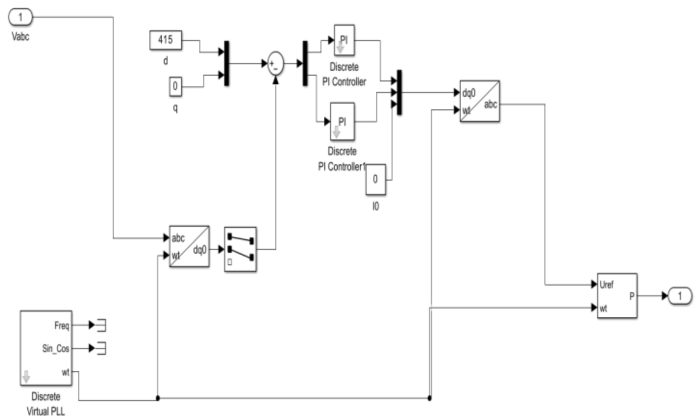

Fig. 3. Voltage controller and PWM topology

Table no 1 Design Parameter

Parameter	**Values selected**
Voltage, RMS (L-L)	415 V
DC-bus voltage	150 V
Source impedance	1.58mH
Frequency	50 Hz
Switching Frequency	7KHz
Filter inductance L_f	310mH
Filter resistance R_f	0.1Ω
Filter capacitor C_f	500 uF
Coupling capacitance	4500 µF
PI gains	0.04, 500
Non-linear load	8KW

IV. Simulation Results

Simulation is performed in three parts. In the first part, control for the gate pulses of VSI is designed. Then the shunt and series converter of UPQC is integrated with the utility system. For this coupling transformer parameters are designed and the filter unit is designed to compute the L and C of the APF. The results are obtained firstly for linear loading and the source and load profile are constant with no harmonics since system is operating under normal conditions as shown in figure 4. Under stable linear loading no harmonics are present and the minor distortion if seen are taken care well by UPQC hence THD of the voltage is negligible within permissible limits as presented in figure 5. Now the designed system is analysed with non-linear load as well as simultaneous sag for 0.1-0.2 sec and swell for 0.3-0.4 sec at source side. UPQC is a power conditioner which can mitigate source as well as load side voltage and current profile. Also, it can eliminate the harmonics. This is justified in figure 6, where source voltage has dip and swell and the load voltage is constant and regulated at the rated voltage and frequency having harmonics 1.19% as shown in figure 7.

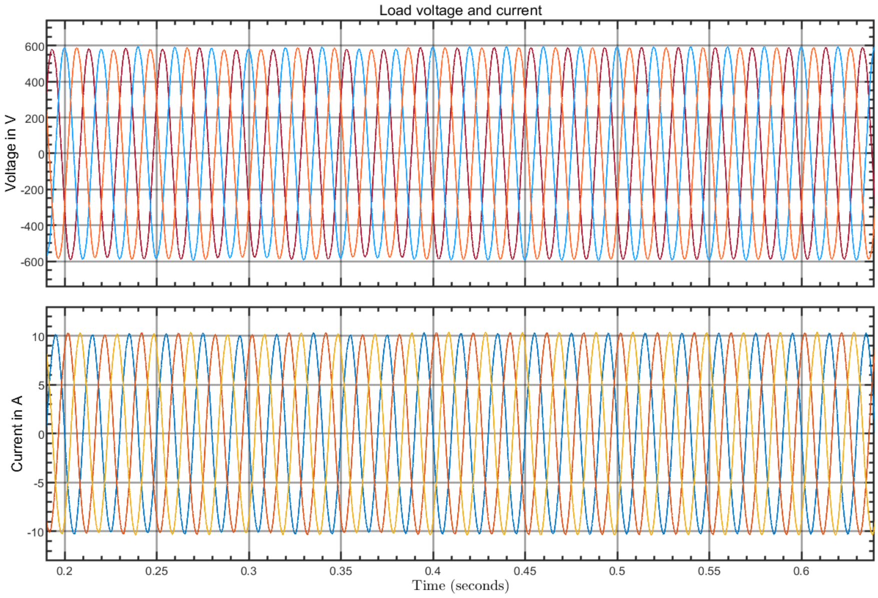

Fig. 4. Simulation results for voltage and current under linear loading.

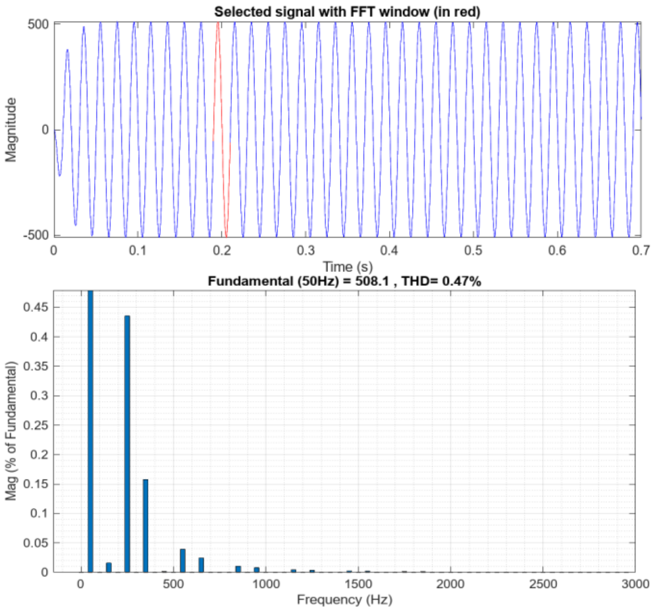

Fig. 5. Harmonic profile for load voltage under linear loading

The source and load currents are shown in figure 8. Since the load is non-linear, therefore load current will be distorted having 29.7 % THD. But UPQC will rule out harmonics from source current, though the source current has high magnitude since high fault currents are flowing. Since sag in the source voltage is created due to three phase ground fault, which will result in high fault current flowing at source side. UPQC also regulate the load current and a constant value is seen. The load current harmonic graph is shown in figure 9 while source current harmonic graph is shown in figure 10.

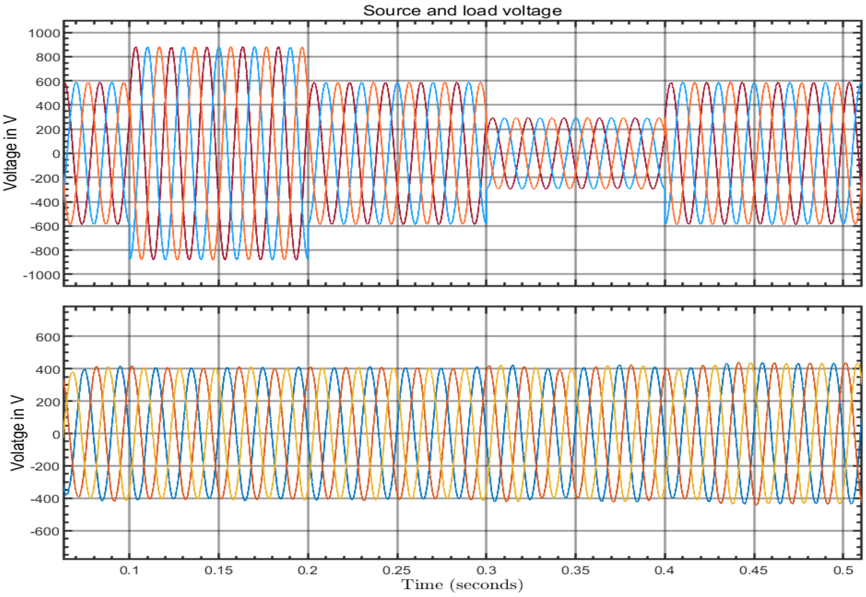

Fig. 6. Source and load voltages under swell/sag event

Fig. 1.

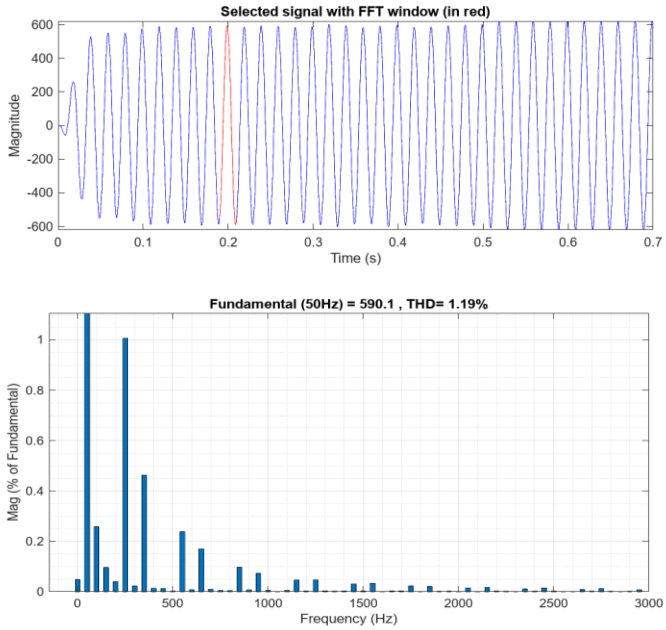

Fig. 7. Load voltage harmonics with sag/swell event

The UPQC injects voltage in order to mitigate both sag and swell conditions. To develop the better understanding for injected voltage against the source side swell and sag event, comparison of source voltages and injected voltages are shown in figure 11. For swell, same magnitude of voltage is injected but in phase opposition. Phase A has highest magnitude in positive direction and injected voltage is in 180^o opposition. Similarly, for phase B', swell event is started and a spike can be seen. The swell has the negative value for phase B' when swell occurs hence a positive spike of same magnitude can be seen. But, the case is different for sag. In case of sag, 50 % of the source voltage is reduced during the complete phenomenon. Same amount of voltage is injected by the UPQC in same phase to compensate for the reduction in voltage.

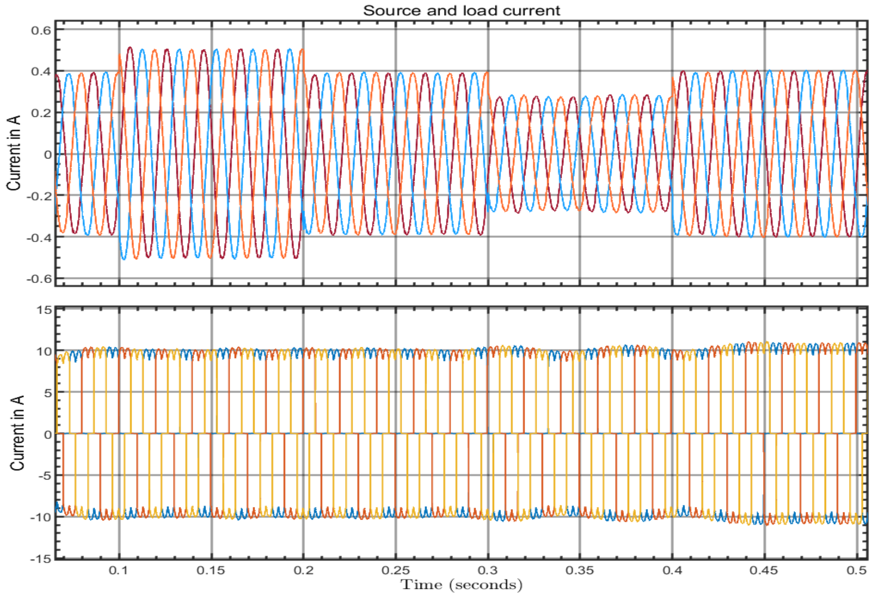

Fig. 8. Source and load current with source side swell/sag and non-linear load.

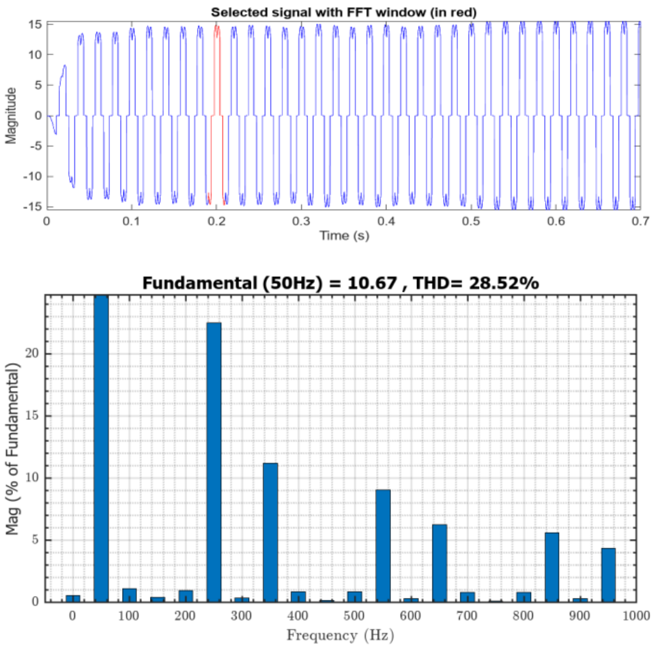

Fig. 9. Harmonic Analysis for the load current

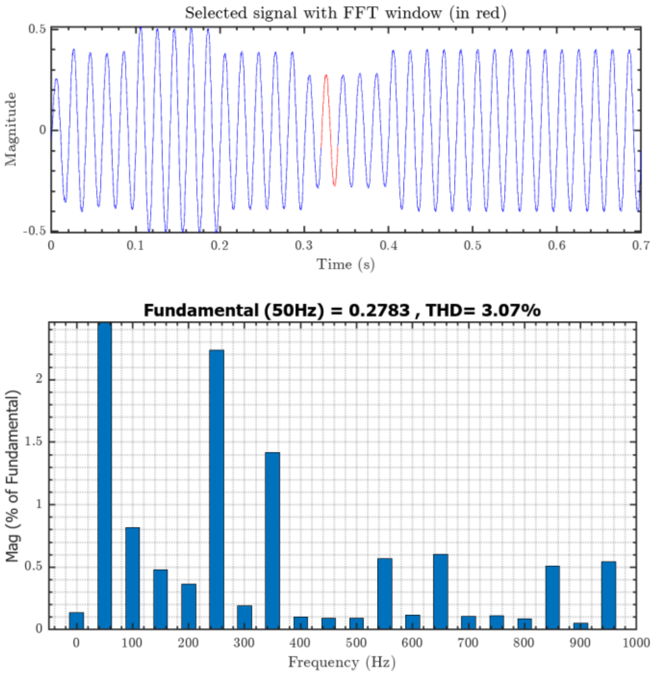

Fig. 10. Source current harmonic with non-linear loading

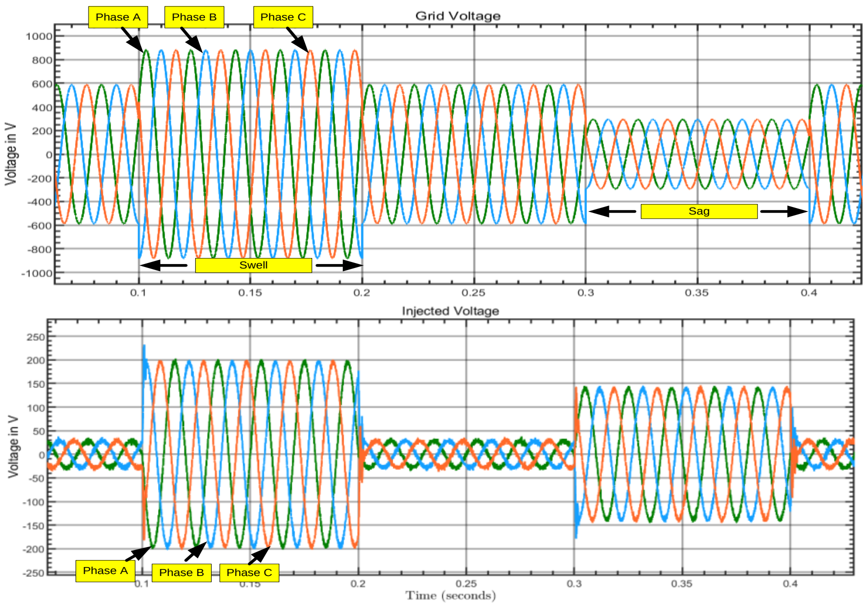

Fig. 11. Source side voltage and respective injected voltage under swell/sag event.

V. Conclusion and Discussion

This work presents the power quality assessment of distribution system operating at 415 V rms under the source distortion condition resulting in simultaneous occurrence of swell and sag event. Also, a heavy non-linear load is connected at load side. The source distortion will affect the voltage sensitive loads connected at the load terminals and heavy non-linear load will affect the other loads connected with the same feeder since high harmonic currents will be injected into the system. UPQC is designed in this paper with modified PI-controller to mitigate the condition of swell and sag simultaneously as well as it also reduces the source and load side harmonics both in voltage and current. This has been validated with the harmonic analysis and the computation of injected voltage by the UPQC converters.

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