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Analysis the Performance of New Control Strategy for Single Phase Unified Power Quality Conditioner

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Abstract--This paper presents enhancement of Unified Power Quality Conditioner (UPQC) using Hysteresis Controller. The proposed controller is capable of reducing total harmonic distortion and to provide constant switching frequency and it has the capability of improving power quality at the point of installation on power distribution systems or industrial power system. Power quality is the set of limits of electrical properties that allows electrical systems to function in their intended manner without loss of performance or life. The power quality problems such as voltage sag, swell including system harmonics in the supply voltage and load current has been compensated. The results were obtained for different types of typical signals which is compared with existing methods. Simulation will be carried out using Matlab/Simulink.

Index Terms – Series Active Filter, Shunt Active Filter, Unified Power Quality Conditioner, Hysteresis Controller.

I.INTRODUCTION

Nowadays, The increasing use of nonlinear power electronic loads in industries has led to harmonics generation. This causes voltage sag/swells in the supply voltage and poor power factor at the supply side. Some of the compensating devices that are able to resolve these power quality problems include dynamic voltage restorers [1],[2], uninterruptible power supplies[3], active power filters[4] and unified power quality conditioner[5]. Generally, the UPQC isclassified into two categories, namely single phase and three phase UPQC [6],[7]. However, there are no many applications of UPQC in single-phase systems.

The active power filters (APFs) are one of the significant power quality enhancement devices it is simply called as custom power devices[8].The APFs are broadly classified as shunt APF, series APF and hybrid APF. The UPQC, a type of hybrid APF[9], is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously. Recently, a lot of attention has been given to tackle power quality problems in single-phase systems using a UPQC [10-12]. The current harmonics, voltage harmonics, voltage sag and voltage swell are the most significant power quality issues for a single-phase system.

A simple control algorithm which have been developed and control approach uses a phase locked loop (PLL) and proportional-integral (PI) to generate the reference signals for both shunt and series active filters of UPQC[13].

This paper is based on power quality compensation in single-phase system utilizing a single phase UPQC using hysteresis controller.

II.UPQC MODEL

UPQC is one of the custom power devices used at the electrical power distribution systems to improve the power quality of distribution system customers. UPQC could be used to cancel current harmonics, to eliminate voltage harmonics, to correct voltage sag or swell. A UPQC consists of both shunt and series filters. A shunt filter is used to cancel the disturbances in current whereas series filter is used to cancel disturbances in voltage. The configuration of a single-phase UPQC as shown in Fig.1. It consists of two H-bridge inverters (four semiconductor devices per inverter) connected back to back through a common DC-link capacitor. Inverter-1 is connected across the load and acts as a shunt APF. This inverter is controlled as a variable current source such that the load current related power quality problems do not appear at source terminal. Furthermore, the shunt inverter plays an important role in maintaining a constant and self-supporting DC bus voltage across two inverters.

Inverter-2 is connected in series with the line through a series transformer and it act as a series APF. This inverter is controlled as a variable voltage source and it isolates the load bus voltage from the disturbances in the voltage at the point of common coupling (PCC). Both the inverters are coupled with the network using interface inductorsL_{Sh} and L_{Sr}. In order to minimize the presence of higher order harmonics from the injected series APF voltage, a ripple capacitor C_{rf} is utilized. The interface inductor L_{Sh} and ripple capacitor C_{rf} forms a low pass filter to eliminate the higher order harmonics. In a single-phase system, control of shunt and series inverters can compensate the load current harmonics, voltage harmonics, and voltage sag/swell.

III. CONTROL STRATEGY

In this section, a control strategy for UPQC based on unit vector template generation (UVTG)[14] scheme is developed for single-phase system.

A. Generation of reference voltage signal for Series Active Filter

The major function of series part of UPQC is to maintain the voltage at load bus sinusoidal and at the rated value. Therefore the simplest approach to generate reference signals for series inverter would be directly imposing the load bus voltage to be perfect sinusoidal. On a particular system, the standard magnitude of voltage being supplied is fixed, for example, a typical household consumer is supplied by single-phase 230 VAC/50 Hz voltage.Therefore two important factors to maintain the precise regulation at load bus, especially for sensitive loads to be protected are (i) perfect sinusoidal voltage at rated fundamentalfrequency (such as 50Hz) and (ii) fixed load voltage magnitude. The supply voltage can be distorted and may show some dips or rise in voltage due to undesirable conditions on the same feeder, for example, switching ON/OFF of high rated load, capacitor banks and so on. Under such events, if the load voltage is forced to be perfectly sinusoidal and at fixed load voltage magnitude, the unwanted events/problem can be solved easily.

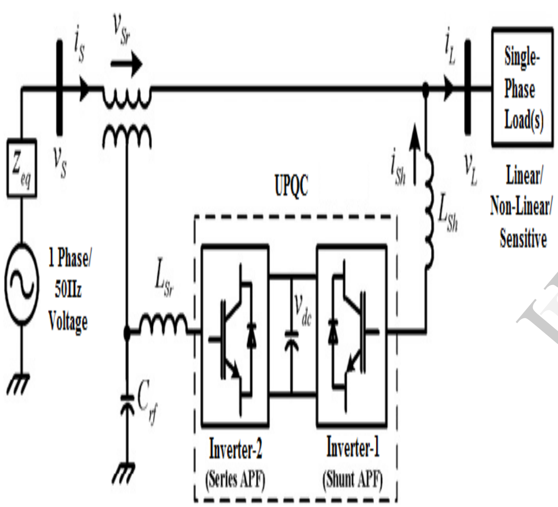


Fig.1. Single-phase UPQC block diagram

Assuming the voltage available at PCC (V_S) is distorted, this distorted voltage can be decomposed as sum of fundamental (V_{Sf}) and harmonics components (V_{Sh}) and mathematically represented as,

$$V_S(\omega t) = V_{Sf} + V_{Sh} \qquad (1)$$

The harmonics term can be further expressed as,

$$V_{S\,a,h} = \sum_{n=2}^{\infty} V_{Sa,n} \sin(n\omega t + \theta_{na}) \qquad (2)$$

Where,

$V_{S\,a,h}$ - Amplitude of harmonic component voltage

$V_{Sa,n}$ - Amplitude of nth harmonic voltage

n - Order of harmonics

θ_{na} - Phase angle of nth harmonics

For a single-phase system to be perfectly sinusoidal only the fundamental component should be presented and harmonics component should be necessarily zero. A PLL-based simple procedure is explained to define the load voltage as fundamental component. First, the supply voltage is sensed and multiplied by a gain equal to $1/V_p$, where V_p represents the peak amplitude of supply voltage under consideration. This gives an approximate unity source voltage profile. This unity source voltage signal is then processed by a single-phase PLL. The PLL gives output in terms of sin and cos functions with fundamental frequency set by the user, in this case 50 Hz. Furthermore, the output sin and cos signals have unity magnitude. The sin term represents the perfect sinusoidal unity voltage signal. The unit vector template for single-phase system can be given as,

$$U = \sin(\omega t) \qquad (3)$$

As discussed previously, for a particular application, the load bus voltage magnitude is a known quantity. By multiplying V_{Lp} with generated unit vector template of eqn.(3), the required profile of desired load voltage at load bus can be generated easily. This desired reference load voltage can be expressed as,

$$V_L^*(\omega t) = V_{Lp} U = V_{Lp} \sin(\omega t) \qquad (4)$$

Where,

V_{Lp} - Peak amplitude of load voltage

$V_L^*(\omega t)$ - Reference load voltage

Using eqn.(4), the voltage at load bus can be regulated by forcing the series inverter to maintain it at reference load voltage. Thus, the power quality problems associate with supply voltage, such as voltage harmonics, voltage sag/swells will get compensated indirectly.

B. Generation of reference current signal for Shunt Active Filter

The unit vector templates generated for series part can also be used to generate reference current signals for shunt inverter. The major function of shunt inverter is to compensate current harmonics and reactive power by maintaining the DC bus voltage at constant level. The simplest way to compensate the abovementioned problems associated with the load is to force the source current to be sinusoidal. To achieve the aforementioned tasks, the DC-link voltage is sensed and compared with the reference DC-link voltage shown in Fig.2. The error is then processed by a PI controller. The output of the PI controller can be represented as I_p, which should be drawn from the supply in order to maintain DC-link voltage at constant level and to supply losses associated with UPQC. Thus, by multiplying I_p, with unit vector template of eqn.(3), gives the reference source current signal that the source should supply.

$$i_s^* = I_p Ua = I_p \sin(\omega t) \qquad (5)$$

Where,

i_s^* - Reference source current

I_p - Peak amplitude of fundamental input current

The significant advantage of this approach is that it does not require complex transformations and it is easy to implement for practical hardware applications.

IV. HYSTERESIS CONTROLLER

The actual load voltage is compared with the reference load voltage given by eqn.(4) and the error is given to the hysteresis controller to carry out the pulse width modulation (PWM) operation and produced pulse is given to the first leg upper switch and the same pulse is given to the second leg upper switch with 180° delay. The upper switches pulses are inverted and given to the lower switches. This is the switching scheme of series active filter.

The generated reference source current signal is then compared with actual source current to perform PWM operation and produced pulses are given as it is same for series active filter.

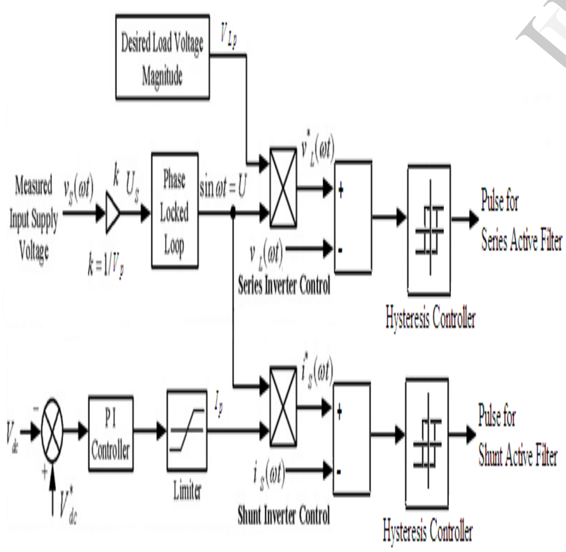


Fig.2. Block diagram of Hysteresis controller based on single-phase UVTG approach for UPQC

The complete block diagram of Hysteresis controller[15] based on single-phase UVTG approach for UPQC is shown in Fig. 2.

V. SIMULATION RESULTS

Simulations of the Single phase UPQC were carried out using Matlab/Simulink. The combination of rectifier and RL load used for simulation.

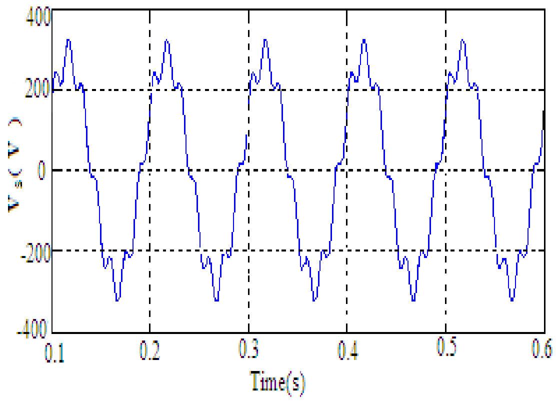
Table. l. Simulation parameters

System parameters	Values
Supply voltage	230V
Series filter inductance, capacitance, resistance	3.3mH,220µF,10Ω
Shunt filter inductance	1mH
DC-link capacitance	1000µF
Hysteresis band width	±0.01
RL Load	10Ω,1mH

The simulation parameters are given in the table.1. based on that values the simulation model of UPQC is developed. The non-linear load is considered as a diode bridge rectifier load and RL load is also connected with the non-linear load.The important simulated cases are (i) distorted condition, (ii) voltage sag condition and (iii) voltage swell condition.

1) Distorted condition

Distortion is the change of shape of sinusoidal that is it contains harmonics. Non-linear loads can draw current that is not perfectly sinusoidal Since the current waveform deviates from a sine wave, voltage distortions are created.Fig.3&4. shows simulation results of non-linear load under distorted supply voltage. The total harmonics distortion (THD) values of source voltage and load current are 13.9% and 22.25% respectively. The series inverter injects the harmonics present in the source voltage such that the source voltageis maintained as pure sinusoidal. At the sametime, the shunt inverter also injects the harmonics generatedby the non-linear load. Thissimulation case demonstrates that UPQC can be utilised tosolve the harmonics-related problems.UPQC with developedsingle-phase UVTG approach reduces THD in load voltageand source current to 1.92% and 3.42% respectively.



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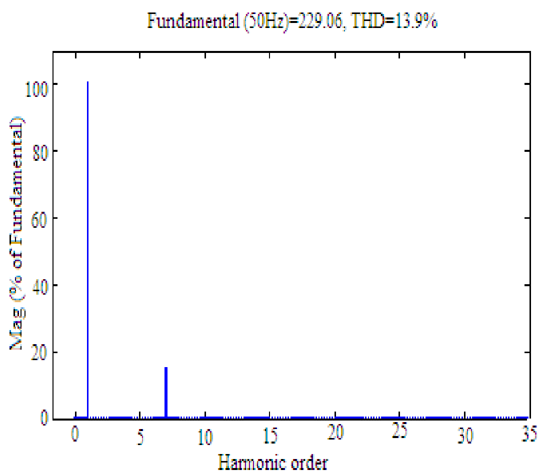

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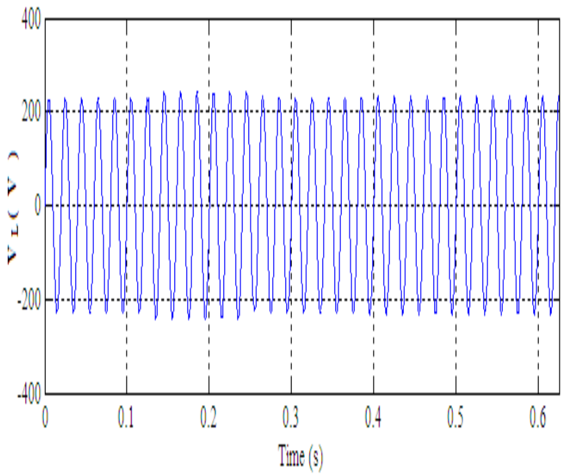

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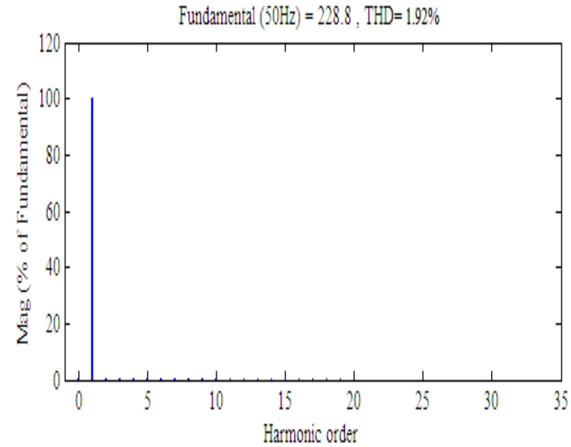
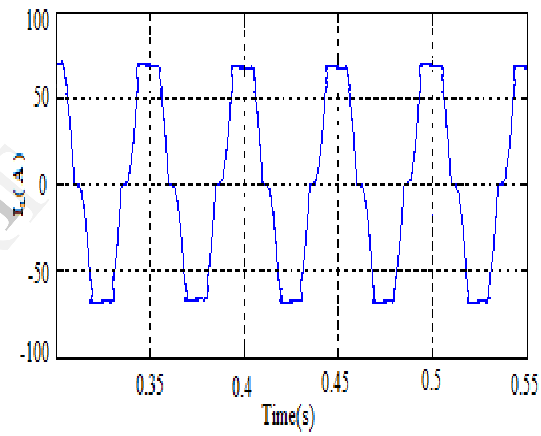


(d)

Fig.3. voltage waveforms: (a) supply voltage (b) FFT analysis of supply voltage (c) load voltage (d) FFT analysis of load voltage



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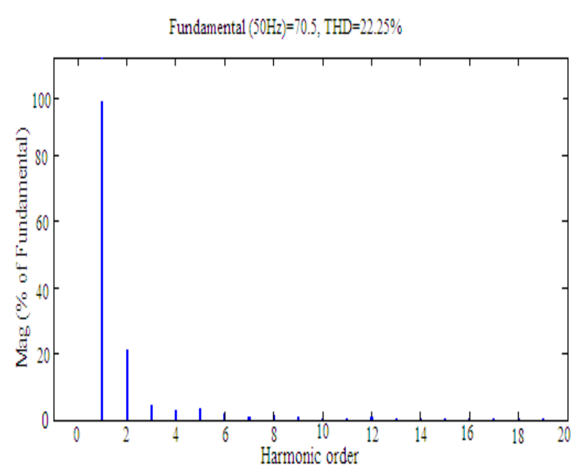

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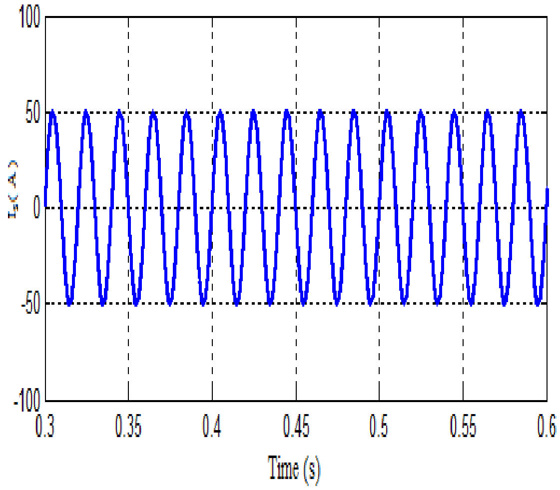

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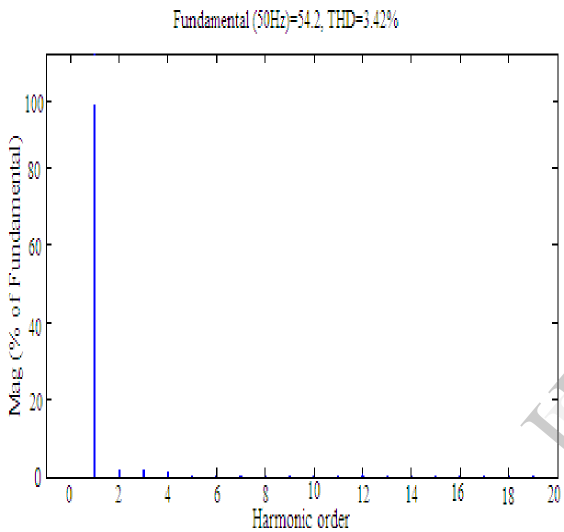


(d)

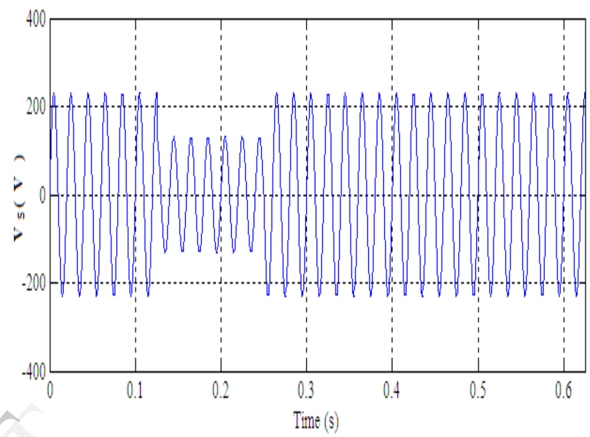
Fig.4. current waveforms: (a) load current (b) FFT analysis of load current(c) source current (d) FFT analysis of source current

2) Voltage sag and Swell

When the rms voltage is below the nominal voltage by 10 to 90% for half cycle to 1 minute the event is called voltage sag. The swell is opposite to sag when the rms voltage exceeds the nominal voltage by 10 to 80% for half cycle to 1 minute, the event is called voltage swell.

For 0.15≤t<0.25s, V_S experiencing a sag of 45% on the system.During this condition, the series inverter injects an in-phase voltage thus helps to maintain the load voltage at desired level such that the sag in source voltage does not appear at the load terminals. The shunt inverter draws necessary fundamental current component to maintain the DC bus voltage at constant level.

For 0.375≤t<0.5s, V_S experiencing a swell of 45% on the system.During this condition, the series inverter injects out of phase voltage thus the UPQC cancels the increased source voltage and maintains the load voltage at desired level. The shunt inverter injects fundamental out-of-phase current component to maintain the DC-link voltage at constant level.The voltage and current waveforms for these conditions are shown in Fig.5 and 6.The simulation demonstrates the UPQC to compensate voltage sag, swell and get the sinusoidal load voltage and source current.



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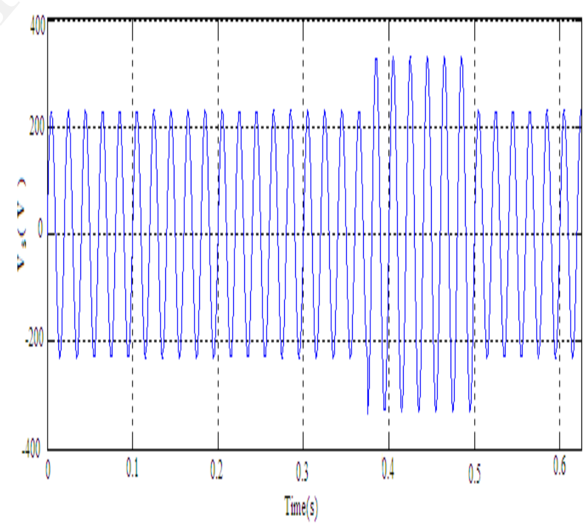

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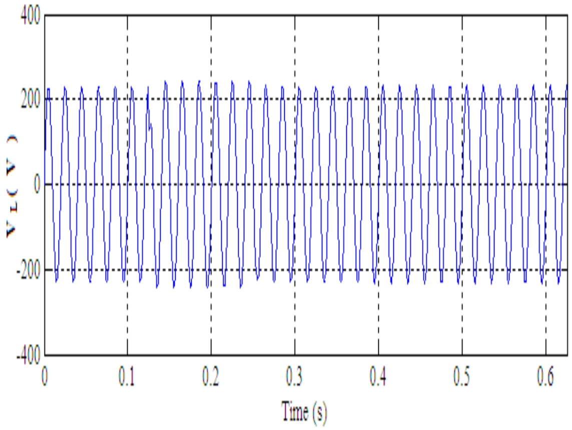
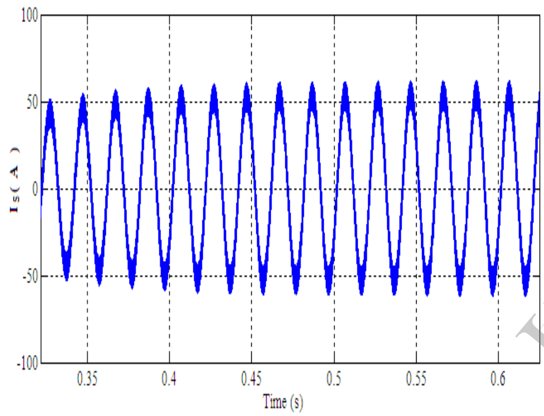


(c)

Fig.5.Voltage waveform: (a) supply voltage when sag occurs (b) supply voltage when swell occurs (c) load voltage after compensation of sag and swell



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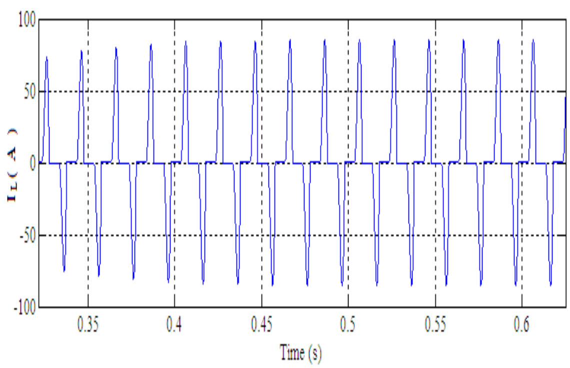

(b)

Fig.6. Current waveform: (a) source current for sag and swell condition (b) load current for sag and swell condition

The voltage across dc-link is shown in Fig.7.this waveform is used to know whether the dc-link voltage reaches a constant level to minimise current problems in the system.

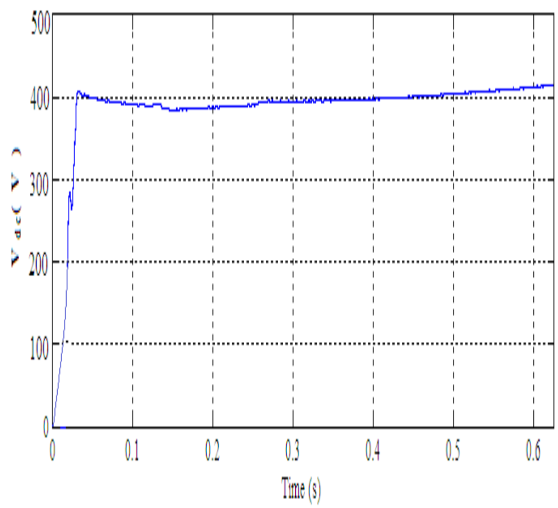

Fig.7. DC-Link Voltage

CONCLUSION

In this paper, Hysteresis controller based on single-phase UVTG approach for UPQC is developed and simulated by three cases such as distorted condition, voltage sag and swell condition. The simulation results show that the input voltage harmonics and the current harmonics caused by non-linear load can be compensated and it maintains IEEE std.519 because the THD is less than 5%.The proposed UPQC also compensate voltage sag and swell and maintains close to rated value at the load terminal.

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