POWER QUALITY ENHANCEMENT by UPQC using VERSATILE CONTROL SCHEME

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***Abstract*—With the wide application of nonlinear and electronically switched devices in distribution systems, the Power Quality problem becomes more serious. A new advanced Custom Power Device (CPD) - Unified Power Quality Conditioner (UPQC) which is realized using two voltage source inverters (VSI) connected back to back, to a common dc link capacitor. Basically, it consists of combined series active power filter (APF) that compensates voltage harmonics of the power supply, and shunt active power filter that compensates harmonic currents of a non-linear load.**

In this paper the reference signals for the shunt and series APFs of UPQC are derived from the versatile control strategies to generate switching signals for shunt and series APFs. This control technique has been evaluated and tested under dynamical and steady state load conditions.

The performance of the proposed topology of UPQC is analysed through simulation results using MATLAB software with its SIMULINK.

***Index Terms* -- UPQC, CPD, VSI, APF, PQ, MATLAB, SIMULINK**

I. Introduction

In the present market, the main objective of the electric utility companies is to deliver quality power to their consumers. One of the serious problems in electrical systems is the increasing number of electronic components of devices that are used by industry as well as residences. These nonlinear loads degrade electric power quality, the quality degradation leads to low power-factor, low efficiency and so on [1].

The power electronic based power conditioning devices can be effectively utilized to improve the quality of power supplied to customers [2].These issues are gaining significant attention these days as an increasing range of equipment that are sensitive to distortions or dips in supply voltages are used [3]**.**For the power quality different standards are governed such as the IEEE-519 standard and IEEE Std. 141, 1993[4].

Active filters can resolve this problem. However, the cost of active filters is high. They are difficult to implement in large scale. Nowadays equipment made with semiconductor devices appears to be as sensitive and polluting as ever.

One modern solution that deals with both load current and supply voltage imperfections is the Unified Power Quality Conditioner [9], which was first presented in 1995 by Hirofumi Akagi. Such a solution can compensate different power quality phenomena, such as: sags, swells, voltage imbalance, flicker, harmonics and reactive currents.

Unified Power Quality Conditioner (UPQC) device combines a shunt active filter together with a series active filter in back -to- back configuration, to simultaneously compensate the supply voltage and the load current such that improved power quality can be made available at the point of common coupling. The operation of UPQC combines the operations of a distribution static compensator (DSTATCOM) and dynamic voltage restorer (DVR) together.

UPQC can be used to attenuate current harmonics by inserting a series voltage proportional to the line current. Alternatively, the inserted series voltage is added to the voltage at the point of common coupling such that the device can provide a buffer to eliminate any voltage dip or flicker. It is also possible to operate it as a combination of these two modes. In either case the shunt device is used for providing a path for the real power to flow to aid the operation of the series connected VSI.

The structure of UPQC is detailed in second part of this paper. Control strategies are covered in the third part. Simulation results in fourth part illustrate the successful implementation of UPQC using MATLAB/SIMULINK. Finally, conclusion has given in fifth part.

II. Basic Structure of UPQC

The unified power quality conditioner (UPQC) employs two voltage source inverters (VSIs) that are connected to a common DC energy storage capacitor. One of these two VSIs is connected in series with the feeder and the other is connected in parallel to the same feeder. They are applicable to power distribution systems, being connected at the point of common coupling of loads that generate harmonic currents. The figure.1 shows block diagram of UPQC.

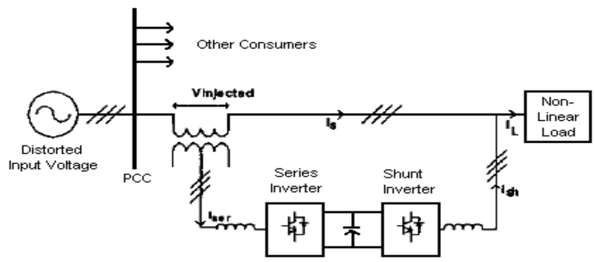

Fig.1 Block diagram of UPQC

A. Series APF:

The series APF injects a voltage in series with the line which feeds the polluting load through a transformer. The injected voltage will be mostly harmonic with a small amount of sinusoidal component which is in-phase with the current flowing in the line. This filter compensates current system distortion caused by non-linear load by imposing a high impedance path to the harmonic current.

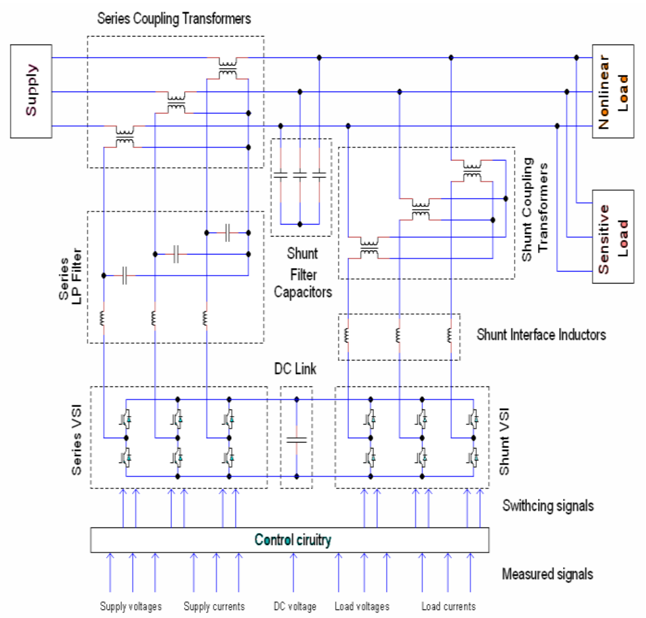

Fig.2. Power circuit diagram of a three-phase UPQC

The above fig.2 represents the power circuit diagram of a three-phase UPQC. It compensates the source voltage disturbances, such as harmonics, dips or over-voltages, which might deteriorate the operation of the local load. The compensation goals are achieved by injecting voltages in series with the supply voltages such that the load voltages are balanced and undistorted, and their magnitudes are maintained at the desired level. This voltage injection is provided by the dc storage capacitor and the series VSI. Based on measured supply and/or load voltages the control scheme generates the appropriate switching signals for the series VSI switches. The output voltages of the series VSI do not have the shape of the desired signals, but contain switching harmonics, which are filtered out by the series low pass filter. The amplitude, phase shift, frequency and harmonic content of injected voltages are controllable.

B. Shunt APF:

The active power filter is connected in parallel with the load being compensated. Therefore the configuration is often referred to as an active parallel or shunt filter. The voltage source inverter used in the active filter makes the harmonic control possible [13]. This inverter uses dc capacitors as the supply and can switch at a frequency to generate a signal that will cancel the harmonics from the non-linear load. The control algorithm for series APF is based on unit vector template generation scheme [8]. This is responsible for power factor correction and compensation of load current harmonics and unbalances. Also, it maintains constant average voltage across the DC storage capacitor.

The shunt part of the UPQC consists of a VSI connected to the common DC storage capacitor on the dc side and on the ac side it is connected in parallel with the load through the shunt interface inductor and shunt coupling transformer. The shunt interface inductor, together with the shunt filter capacitor is used to filter out the switching frequency harmonics produced by the shunt VSI. The shunt coupling transformer is used for matching the network and VSI voltage.

III. CONTROL STRATEGY

The control strategy is presented to extract the compensating signals for the control of the proposed system [6]. The UPQC has the prominent capability of improving the quality of voltage and current at the point of installation on power distribution systems. Therefore, UPQC is expected to be one of the most powerful solutions to the load which is considered as very important or sensitive to supply voltage to customers steadily due to the limitation of power storage [8].

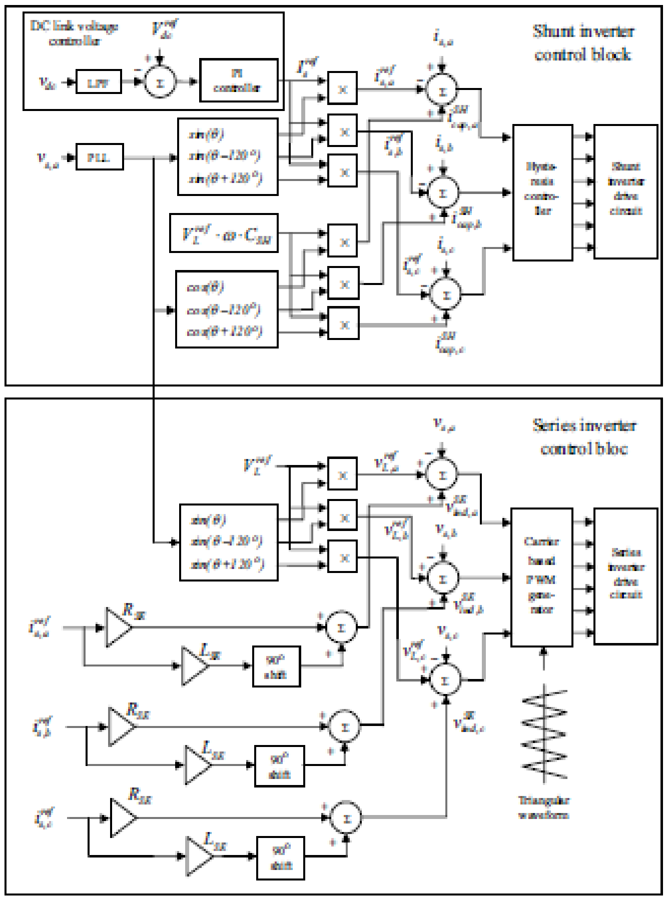

Fig.3 Block diagram of the UPQC overall control scheme

The effectiveness of an APF depends basically on the design characteristics of the current controller, the method implemented to generate the reference template and the modulation technique used. The block diagram of UPQC overall control scheme is shown in figure.3.

A. The shunt active power filter controller

The shunt APF attenuates the undesirable load current. Moreover, the shunt APF must control the dc-bus voltage in order to ensure the compensation capability of the UPQC. The hysteresis controller appears to be the most preferable for it. Therefore, in the UPQC simulation model, this controller has been used. The hysteresis control method has simpler implementation, enhanced system stability, increased reliability and response speed [13].

B. The series active power filter controller

The series component of UPQC is controlled to inject the appropriate voltage between the point of common coupling and load, such that the load voltages become balanced, distortion free and have the desired magnitude.

Two UPQC terms are defined in depending on the angle of the injected voltage: UPQC-Q and UPQC-P.

In the first case (UPQC-Q) the injected voltage is maintained 90 degrees in supply current, so that the series compensator consumes no active power in steady state. In this case, quadrature voltage injection the series compensator requires additional capacity, while the shunt compensator VA rating is reduced as the active power consumption of the series compensator is minimized and it also compensates for a part of the load reactive power demand.

In second case (UPQC-P) the injected voltage is in phase with both the supply voltage and current, so that the series compensator consumes only the active power, which is delivered by the shunt compensator through the dc link. In this case the series compensator does not compensate for any part of the reactive power demand of the load, and it has to be entirely compensated by the shunt compensator. Also the shunt compensator must provide the active power injected by the series compensator. Thus, in this case the VA rating of the shunt compensator increases, but that of the series compensator decreases.

In this case when UPQC-P control strategy is applied, the injected voltage is in phase with the supply voltage; hence the load voltage is in phase with the supply voltage and there is no need for calculating the angle of the reference load voltage. Thus, the reference load voltage is determined by multiplying the reference magnitude with the sinusoidal template phase-locked to the supply voltage. Then, the reference series filter voltage is obtained.

Comparing the techniques for calculating the reference voltage of the series compensator, presented above, it can be concluded that the UPQC-P algorithm has the simplest implementation. In the UPQC-P case the voltage rating of the series compensator is considerably reduced. Also, the UPQC-Q compensation technique does not work in the case when the load is purely resistive. Therefore, the UPQC-P control strategy has been used in the UPQC simulation model. PI controller has been used for dc link voltage control in the UPQC simulation model.

IV. Simulations and Results

The UPQC simulation model as shown in figure.4 has been developed in MATLAB/SIMULINK to investigate waveforms under the dynamic and steady-state condition.

The following typical case studies have been simulated and the results are presented.

1. Steady state source voltage and load current under three phase fault condition without and with UPQC

2. Source voltage and load current under dynamic load and three phase fault condition without and with UPQC.

3. DC link voltage regulation for the above conditions is also verified.

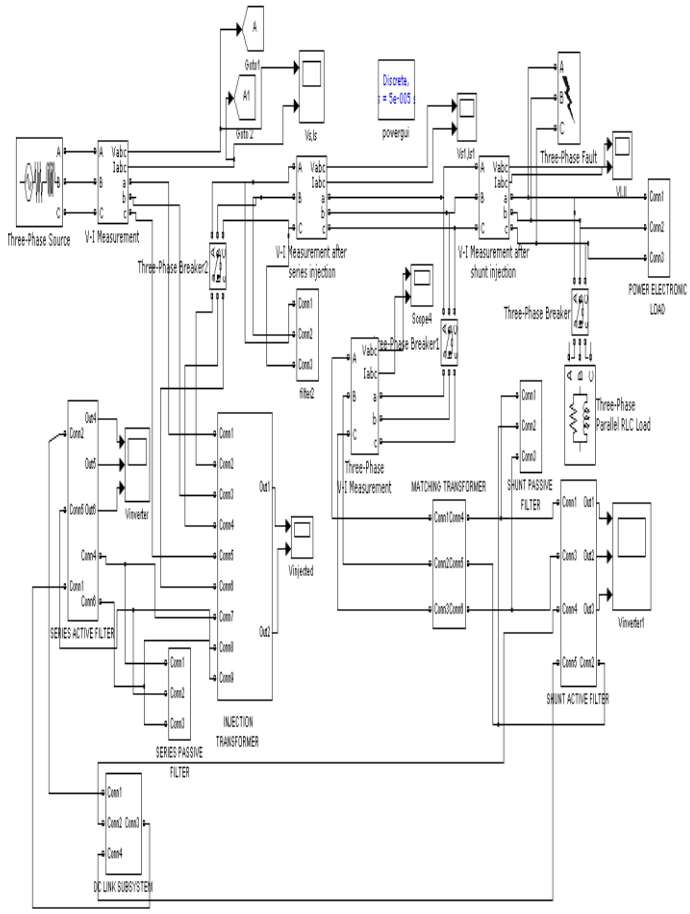

Fig.4 UPQC simulation systems

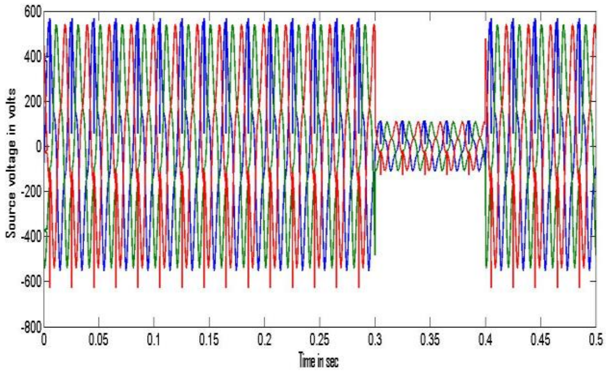

Fig.5. Source voltage when a three phase fault is introduced from 0.3 to 0.4 seconds. (Without UPQC) (THD: 25.81%).

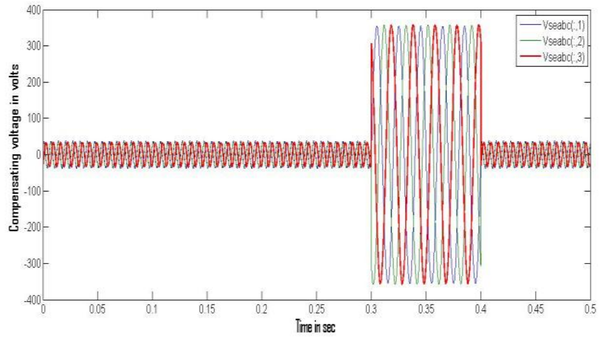

Fig 6.Compensating voltage injected by series active filter

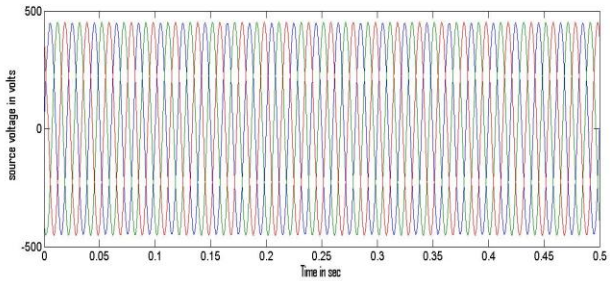

Fig.7 Source voltage when a three phase fault is introduced from 0.3 to 0.4 seconds(with UPQC) (THD: 0.96%).

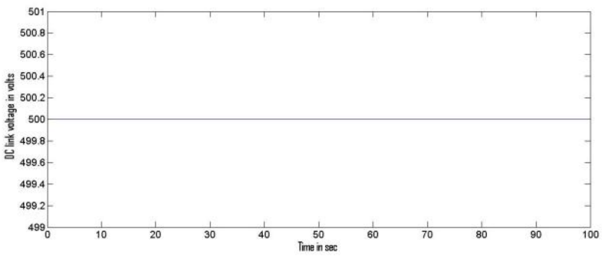

Fig.8 Steady state DC link voltage (500V)

Figure 5-8 shows the simulation results when a three phase fault is introduced. The series active filter (DVR) injects the compensating voltage so that the source voltage is maintained constant. This shows that voltage imperfections are compensated by the series part of UPQC.

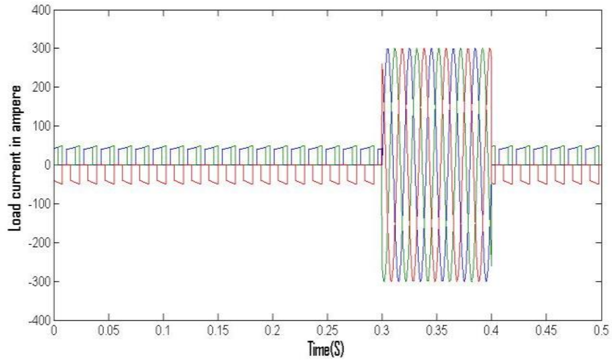

Fig 9. Load current when a three phase fault is introduced from 0.3 to 0.4 seconds.(withoutUPQC)

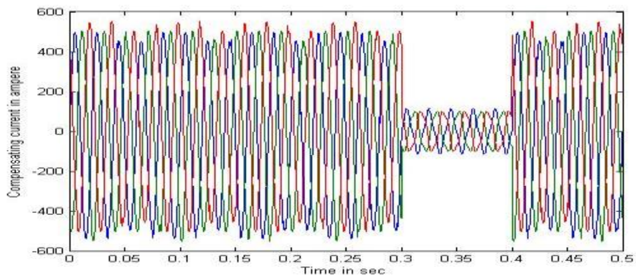

Fig 10. Compensating current injected by shunt active filter

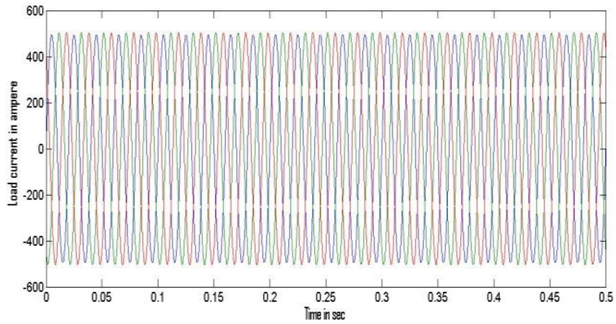

Fig 11. Load current when a three phase fault is introduced from 0.3 to 0.4 seconds. (with UPQC)

Figure 9-11 shows that when there is a current distortion, the shunt part (D-STATCOM) maintains balance and filters out harmonics.

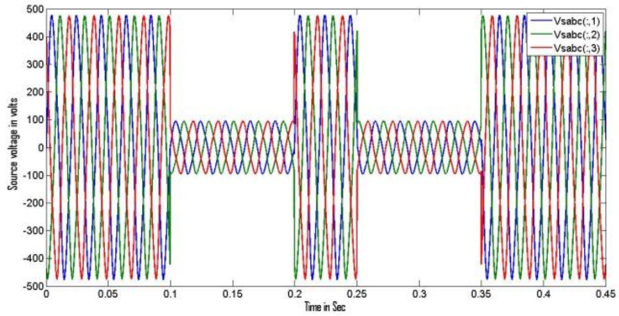

Fig.12 Source voltage when a three phase fault is introduced from 0.1 to 02 seconds and RLC load from 0.25 to 0.35 seconds (without UPQC).

Fig.12 shows the transient case where both fault and dynamic load is introduced at different time instants.

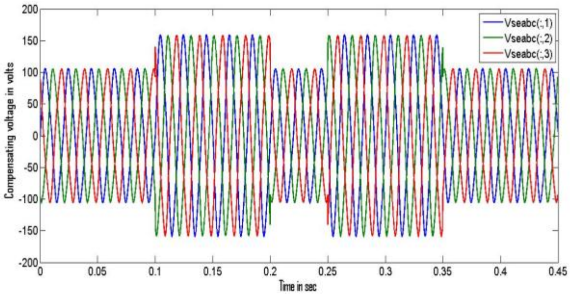

Fig.13 compensating voltage injected by series active filter.

DVR compensates for the sag by injecting more voltage when sag occurs in the system.

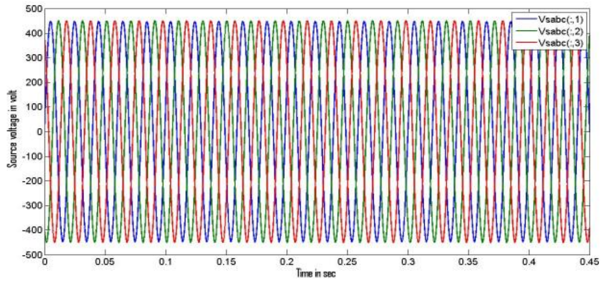

Fig.14 Source voltage when a three phase fault is introduced from 0.1 to 0.2 seconds and an RLC load from 0.25 to 0.35 seconds (with UPQC)

Thus the source voltage is regulated and maintained constant by the UPQC.

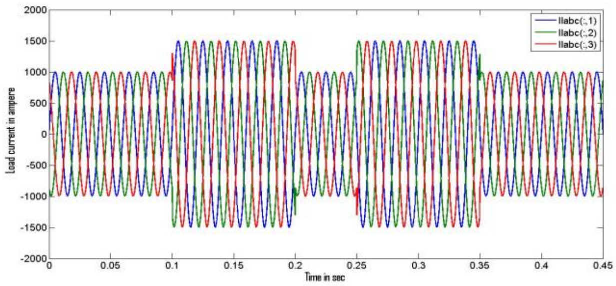

Fig.15 Load current when a three phase fault is introduced from 0.1 to 0.2 seconds and an RLC load from 0.25 to 0.35 seconds (without UPQC)

Fig.15 shows the case when the load current is distorted and unbalanced.

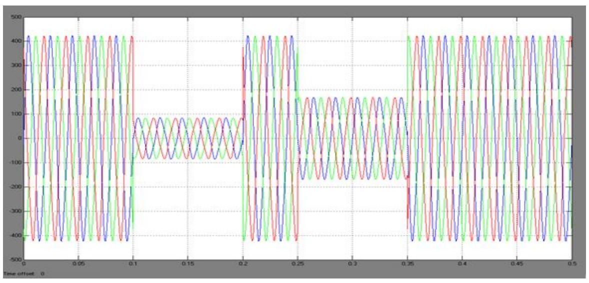

Fig.16 Compensating current injected by shunt active filter

D-STATCOM injects current waveforms of opposite polarity and mitigates the swell in current.

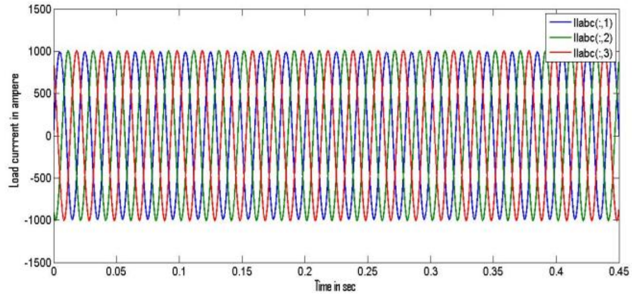

Fig 17 Load current when a three phase fault is introduced from 0.1 to 0.2 seconds and an RLC load from 0.25 to 0.35 seconds. (With UPQC).

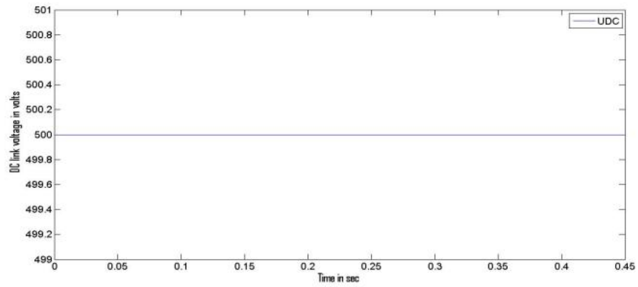

Fig18. DC link voltage when a three phase fault is introduced from 0.1 to 0.2 seconds and an RLC load from 0.25 to 0.35 seconds. (With UPQC).

UPQC gives enhanced performance when compared to DSTATCOM and DVR. The results show that UPQC mitigates deeper sags, harmonic compensation is better. It does better load regulation and balancing for dynamic loads and can tolerate long duration fault conditions effectively. Finally, gives better performance.

V. CONCLUSION

The performance of the UPQC has been found to be satisfactory for various power quality improvements like mitigation of voltage sag, swell and voltage dip. In addition to this the performance of UPQC has been found satisfactory during transient conditions. Custom power devices like DVR, D-STATCOM, and UPQC can enhance power quality in the distribution system.

The objectives laid down have been successfully realized through software implementation in MATLAB/SIMULINK.

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