Efficient Implementaion of Improvement in Power Metrics Using Unified Conditioner Power Quality

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***Abstract*— The importance of electrical power quality holds a significant role in utility systems and various industries. Power quality directly impacts both consumers and suppliers, creating economic consequences. As consumer demands grow, power quality issues become more prevalent. These problems, including voltage sag, swell, harmonics, and interruptions, can lead to substantial technical and economic challenges for many consumers. This paper focuses primarily on UPQC, which combines series and shunt active power filters. The series APF addresses voltage-based distortions, while the shunt APF mitigates current-based distortions. UPQC effectively alleviates both voltage and current-based distortions concurrently and independently. By compensating for harmonics and load current, UPQC enhances power quality, ensuring that source current and load voltage maintain sinusoidal waveforms at the required voltage levels. The modeling of the series APF, shunt APF, and UPQC has been conducted using MATLAB/Simulink.**

Keywords—Power quality, Active power filter, Unified power quality conditioner, Harmonics.

I. INTRODUCTION

Power Quality (PQ) has become increasingly vital for the uninterrupted operation of sensitive equipment, especially as these devices become more interconnected within industrial processes and networks. The significance of PQ has grown with the widespread adoption of power electronics. Many modern devices are susceptible to damage or service disruptions when exposed to poor PQ events. Monitoring PQ becomes essential, particularly for equipment highly sensitive to disturbances (IEEE Standard 1346–1998, 1998). In today's context, the extensive use of non-linear and delicate loads, primarily reliant on power electronic devices within distribution systems, has led to an upsurge in power quality issues. These problems encompass concerns like voltage and current harmonics, voltage flickers, and voltage and current imbalances. Power system issues such as voltage sag/swell can result in malfunctions in digital devices and other sensitive loads.Recent research focused on enhancing power quality has revealed the potential of unified power quality. The Unified Conditioner Power Quality (UCPC) functions by introducing a compensating current into the system to counteract harmonics and stabilize voltage. It relies on voltage and current measurements at the load terminals and utilizes a control algorithm to generate compensatory currents.

The Unified Conditioner Power Quality (UCPQ) represents a comprehensive solution to address both voltage and current-related issues. It was initially introduced in [Year], with the first experimental results showcasing its configuration in 1998.

The UPQC comprises two integral components: a series and a shunt active power filter (APF) that are interconnected via a shared DC link capacitor. The shunt APF, connected in parallel with the load, is employed to mitigate load current harmonics, while the series APF, connected in series with the power supply, serves to regulate the voltage at the load terminals. Operating effectively, the UPQC injects compensating currents into the system, effectively canceling out harmonics and stabilizing voltage levels. By monitoring the voltage and current at the load terminals and employing a control algorithm, it generates compensatory currents.

The UPQC stands as a highly efficient device for enhancing overall power quality, reducing power losses, and enhancing system efficiency. It finds widespread application in industrial and commercial settings where a stable, high-quality power supply is imperative for the smooth operation of equipment. In the present landscape, with the extensive use of non-linear and sensitive loads relying on power electronic devices within distribution systems, power quality issues such as voltage and current harmonics, voltage flickers, and voltage and current imbalances are on the rise. Power system issues like voltage sag/swell can lead to malfunctions in digital devices and other sensitive loads. [References: 1, 2, 3, 10]

II. GENERAL CONFIGURATION OF UPQC AND CONTROL STRATEGY

The fundamental structure of the Unified Power Quality Conditioner (UPQC) involves the incorporation of two active filters, functioning in parallel and series configurations. In Figure 1, the positioning of these filters within the network is illustrated. The series active filter assumes the role of a voltage source integrated in series with the network. It possesses the capability to generate various waveforms as directed by the series controller through the employment of PWM converters. Conversely, the parallel active filter operates as a parallel current source alongside the network, and its operation is governed by the parallel controllers.

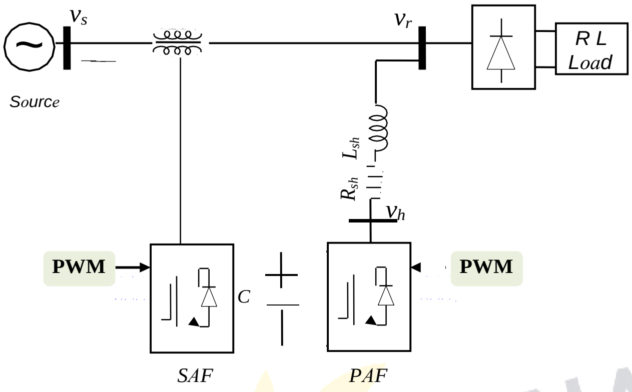


Fig.1. General structure of UPQC in the network.

A. Series Control

The series active power filter (APF) is useful for compensating the voltage because it determines the amount of voltage that has to be induced into the grid in order to make the voltage sinusoidal with the correct voltage magnitude and frequency. The supply voltage must be subtracted from the reference voltage (Vabc*), and after calculating the voltage error and comparing it to the error voltage generated in the lines, The inverter switching pattern is controlled by the hysteresis voltage controller, which also regulates the output voltage of the series APF. Fig. 2.1 depicts the basic schematic of fixed hysteresis band (HB) voltage control. When the sensed output signal deviates from the reference by more than a predetermined amount, the instantaneous value of the output voltage is compared with the reference voltage(Vc*), and the inverter is turned on to lessen the discrepancy. [8] [9] [10]

This indicates that switching happens each time the output voltage crosses the HB value. The Series APF's output voltage signal is provided by:

Vc=Vc* + HB in rising case.

Vc=Vc*- HB in decreasing case.

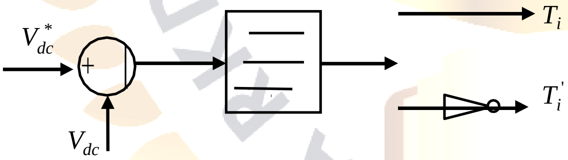


Fig.2 Simplified model for fixed hysteresis-band voltage control

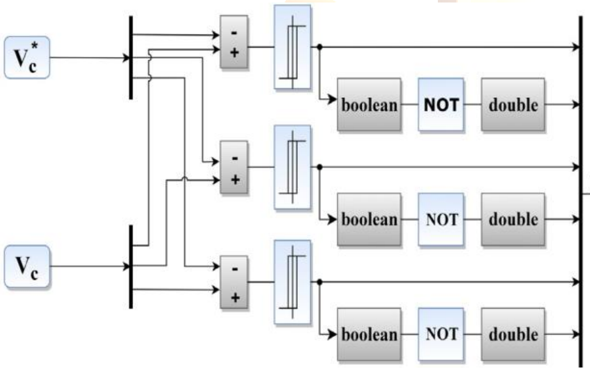


Fig.3 Model of the hysteresis voltage control in Simulink

B. Shunt Control

Active power filters must carefully consider their control technique (APF). The theory of Instantaneous Active and Reactive Power, also known as PQ theory, is utilized to identify harmonic current (shunt APF) and harmonic voltage (series APF), among other important time domain control approaches [5,6]. The key concept is to use Concordia transformation to divide the three-phase system (a-b-c) into two frames (α-β); this can be thought of as an estimation of triphasic measures on a motionless two-axis reference frame [7,10]. Calculations for the currents in the (αβ) frame are as follows: [2] [4]

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \qquad (2)$$

The active, and reactive (instantaneous) power is:

$$p = v_\alpha i_\alpha + v_\beta i_\beta$$
$$q = v_\alpha i_\beta - v_\beta i_\alpha \qquad (3)$$

In the three-phase system (a-b-c) equation (3) can be written as follows:

$$p = v_{sa} i_{la} + v_{sb} i_{lb} + v_{sc} i_{lc}$$
$$q = -\frac{1}{\sqrt{3}} [(v_{sa} - v_{sb}) i_{lc} + (v_{sb} - v_{sc}) i_{la} + (v_{sc} - v_{sa}) i_{lb} \qquad (4)$$

If we put:

$$\Delta = v_\alpha^2 + v_\beta^2 \qquad (5)$$

From expression (3):

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} p \\ q \end{bmatrix} \qquad (6)$$

We can decompose the powers p and q into two parts according to the following equations:

$$p = \bar{p} + \tilde{q} \quad \text{And} \quad q = \bar{q} + \hat{q} \qquad (7)$$

With

$\bar{p}, \bar{q}$: Mean value (fundamental) value active and reactive power.

$\tilde{p}, \tilde{q}$: Alternating (harmonic) value of active and reactive power.

The filtering method used for extracting the alternative power is shown in Figure.2.

Fig.4 Principle of extraction the component alternative of p &q.

If replaced in (6), we find:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \tilde{q} \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \qquad (8)$$

Thus, the reference current will be calculated by the relationship:

$$\begin{bmatrix} i_{ref\,\alpha} \\ i_{ref\,\beta} \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (9)$$

Applying the inverse transformation, we can write:

$$\begin{bmatrix} i_{refa} \\ i_{refb} \\ i_{refc} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{ref\alpha} \\ i_{ref\,\beta} \end{bmatrix} \quad (10)$$

By the same principle, we find the reference voltages injected by the series active filter as follows:

$$\begin{bmatrix} v_{refa} \\ v_{refb} \\ v_{refc} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_{ref\,\alpha} \\ v_{ref\,\beta} \end{bmatrix} \quad (11)$$

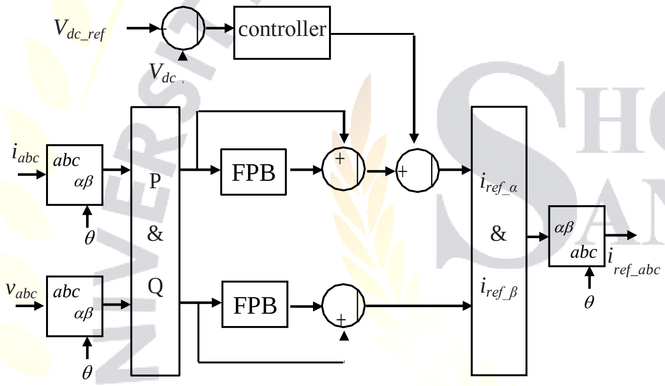


Fig.5.P-Q theory for shunt APF

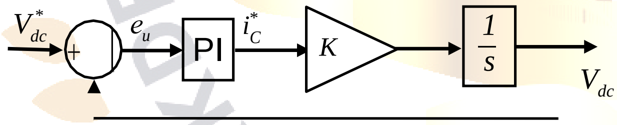


Fig.6 DC bus regulation

III. SIMULATION RESULTS

TABLE I. ARAMETERS OF UPQC STUDIED

Parameter	***value***
Power Source	380v
Line impedance	Rs=0.01Ω Ls=0.1H
DC Voltage	850v
DC capacitor	500µF
Load impedance	R=0.001Ω L=1H
Line frequency	50Hz

Once we have decided on the perturbations to be applied to the networks, in order to test the response of our active filter, simulations under MATLAB/SIMULINK have been performed. These disturbances evolve as shown in the figure7

- From 0 s to 0.2 s normal operation.
- From 0.2 s to 0.4 s source voltage is applied to a harmonic voltage producing non-linear load.
- From 0.4 s to 0.6 s normal operation.
- From 0.6 s to 0.8 s 50% voltage drop.
- From 0.8 s to 1.1 s normal operation
- From 1.1 s to 1.3 s an overvoltage of 50 % is applied
- From 1.3 s to 1.6 s normal operation

TABLE II. VOLTAGE VARIATION

Time (s)	0s to 0.2s	0.2s to 0.4s	0.4s to 0.6s	0.6s to 0.8s	0.8s to 1.1s	1.1s to 1.3s	1.3s to1.6s
voltage	1pu	1pu Harmonic 5+7	1pu	0.5pu	1pu	1.5pu	1pu

A. *Simulation results before filtering*

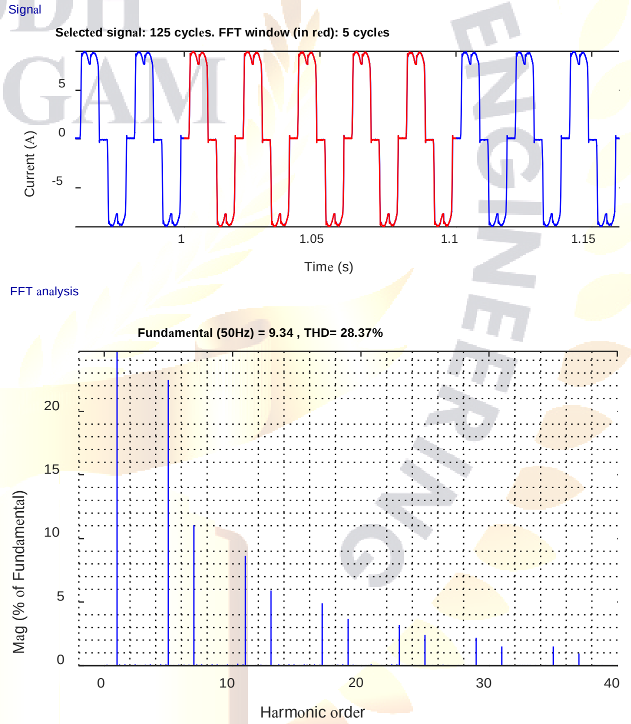


Fig.7 Source and load current and Harmonic Spectrum before filtering

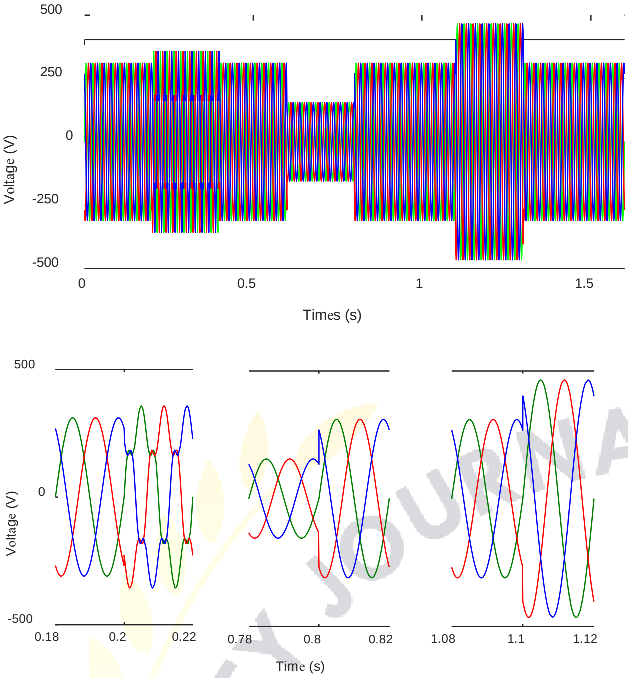
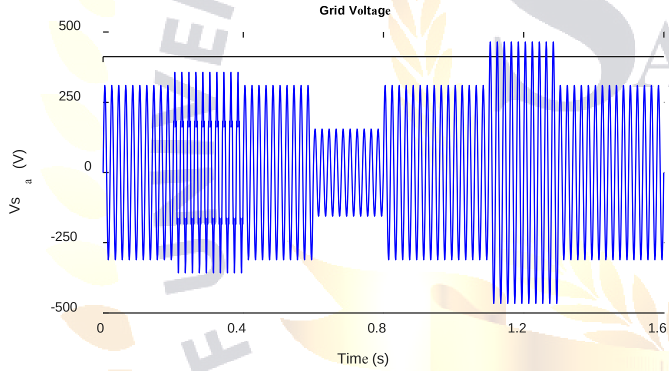
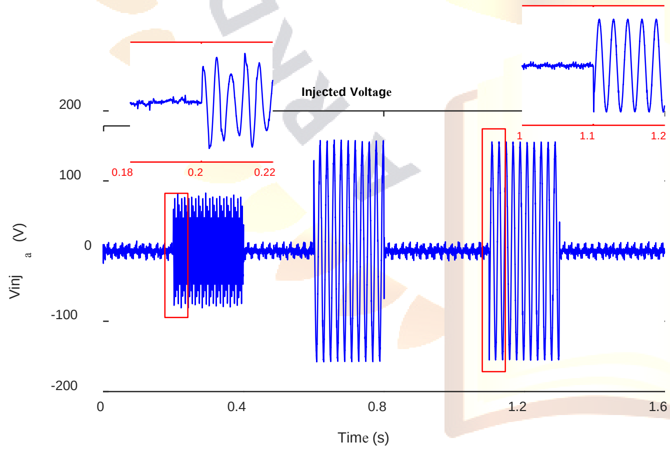


Fig.8 Source and load voltage befor filtering

B. *Simulation results after filtering*





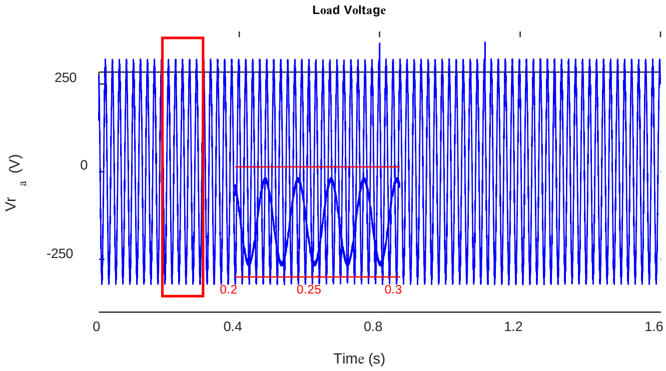


Fig.9 Source, Injection and Load voltage

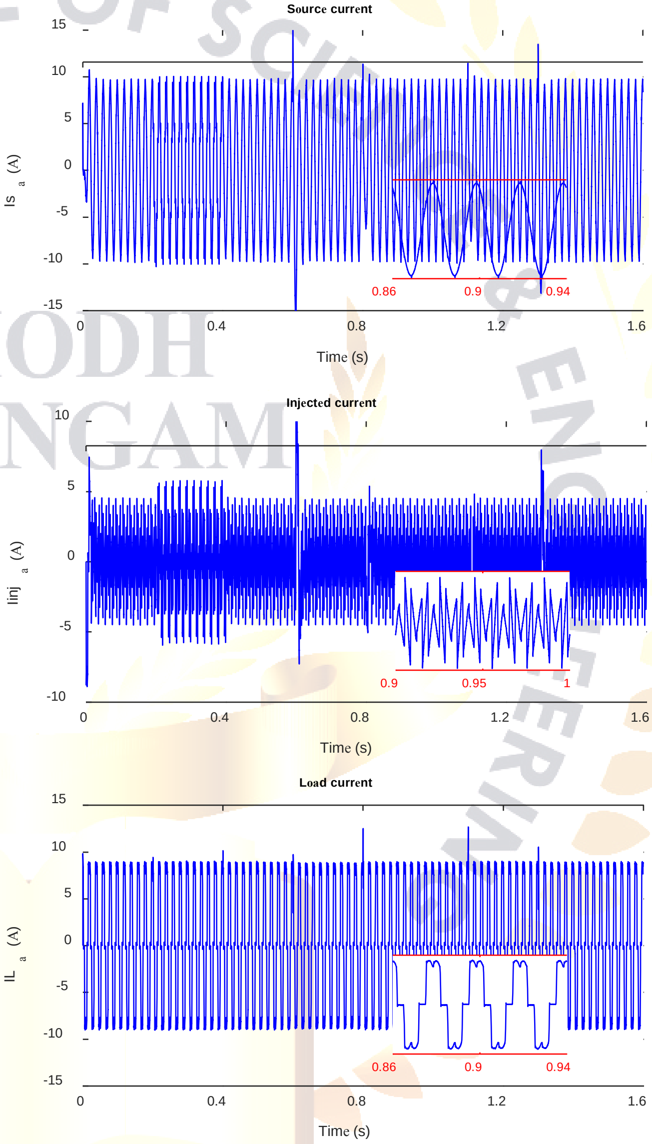


Fig.10 Source, Injection and Load current

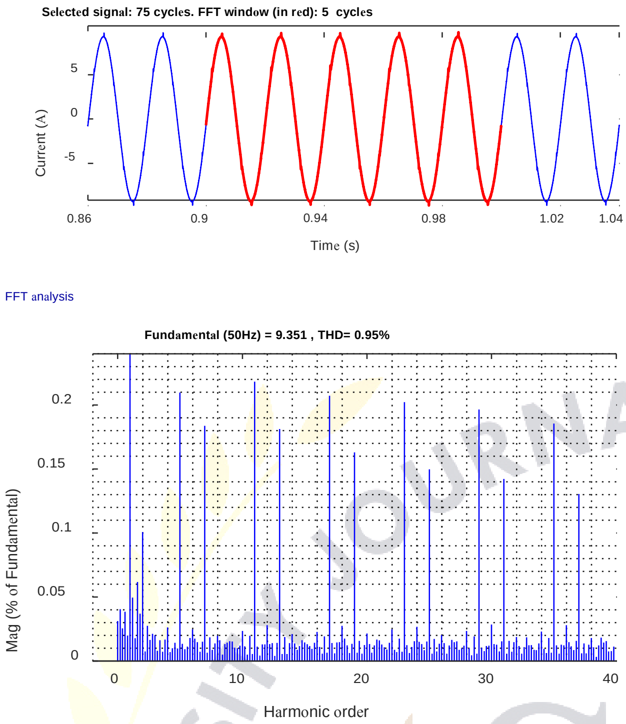


Fig.11 Source current and Harmonic spectum after filtering

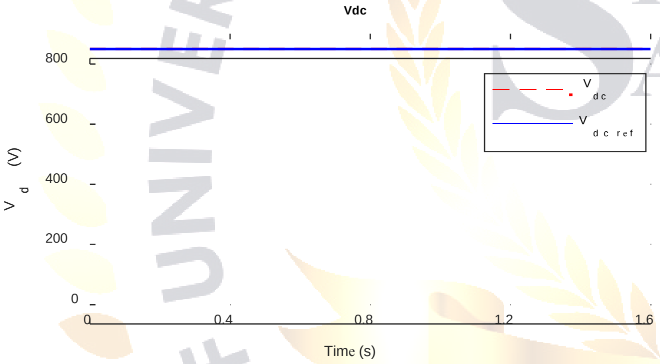


Fig.12 Vdc Voltage and its reference

IV. DISCUSSION

The simulation results obtained before using UPQC

- Figures 7 and 8 show the waveform of load current and voltage, clearly depicting the deformation of their waveform.
- Figure 7 shows the harmonic spectrum of load current, noting a very high rate of total harmonic distortion at 28.37%.

The simulation results obtained after using UPQC

- Figure 9 Voltage sag, between 0.6 and 0.8 seconds, the network voltage drops to 50% of its maximum value. The UPQC quickly detects this sag state and injects the necessary output voltage to supply a steady, sinusoidal voltage to the LED load. This point must be made. In order to make up for the difference between the nominal voltage and the required voltage to be delivered, the series APF is responsible for quickly injecting a voltage in series with the supply voltage through the gate pulses of IGBTs.

Voltage swell from 1.1 to 1.3 seconds, the voltage in the network is increased to 150% of the normal value. It should be emphasized that UPQC detects this swelling condition immediately and absorbs the required amount of output voltage to support a stable, sinusoidal voltage at the load. In order to make up for the difference between the nominal voltage and the voltage needed to supply it, the APF series is in charge of quickly absorbing the voltage in series with the supply voltage through the IGBTs' gate pulses

- Figure 10 The shunt APF injects current harmonics through the capacitor and IGBT gate pulses to make up for the load's distorted current. The basic current must be forced to match the actual input current by the input current controller. The main part of the load current must be determined by the dc link voltage controller.
- After using our proposed device (UPQC), we notice a remarkable improvement in the waveform of the source current, which is becoming almost sinusoidal, as shown in Figure 11 where we noted lower THD values of 0.95% for the current, which is well within the norm.
- The series active power filter works by injecting a compensating voltage that cancels out the sag and swells problem components of the load voltage, resulting in a cleaner sinusoidal waveform.
- Figure 12 shows that the voltage at the terminals of the capacitor follows faithfully the reference voltage Vdc and it comes back to the regulation realized by the PI regulator used.

V. CONCLUSION

This article presents a Unified Power Quality Conditioner (UPQC), the system was designed and modeled successfully using the Matlab / Simulink. The Unified Power Quality Conditioner consists of combined of active power filter series and shunt for simultaneous compensation of harmonic currents and the voltage sag and swells.

The simulation results obtained show good performance of the UPQC for the compensation of harmonic disturbances; we observe a significant decrease of the THD of the current as well as the compensation of the reactive power voltage sag and swell. The performance of the proposed system is verified through simulation.

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