# PI CONTROLLER BASED OF MULTI-LEVEL UPQC USING DQ0 TRANSFORMATION TO IMPROVE POWER QUALITY IN DISTRIBUTION SYSTEM

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## Abstract

*The aim of this paper is to improve power quality in the source side of distribution system using unified power quality conditioner (UPQC) by realization of cascaded multilevel inverter (MLI). The UPQC is an integration of series and shunt active power filters via common dc link which can mitigates various power quality issues like voltage sag, swell, harmonics, interruptions etc. The cascaded MLI offers low THD in the output waveform and flexible circuit layout. The sinusoidal pulse width modulation (SPWM) switching scheme is employed for better operation of MLI. The control mechanism of UPQC is derived from dq0 transformation which is simple in its design and gives better control characteristics. The PI controller can efficiently reduce the steady state error and this can be used in UPQC controller for better response. The regulation of source voltage in the distribution system using multilevel UPQC under nonlinear load condition is analyzed in MATLAB/SIMULINK environment.*

***Keywords:*** *UPQC, series APF, shunt APF, cascaded multilevel inverter, dq0 transformation, SPWM switching scheme PI controller, nonlinear load.*

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## 1. INTRODUCTION

The power quality becomes a very important issue due to rapid growth in use of nonlinear loads. The recent advancements in power electronic equipment attract the users due to saving of electricity bills, user friendly, good performance and safety. The power quality is simply a sinusoidal voltage and currents waveforms exactly in phase with constant frequency. If there are any deficiencies in voltage or current waveform then there exists a problem on power quality. The various power quality problems are voltage sag, swell, harmonics, transients, interruptions, notches etc. voltage sag and harmonics are dominant and severe impact on the power system. The loss of production due to voltage sag is very high in the recent years. The harmonics are severe impact on sensitive equipment, motors, transformers, cables etc. the source need to supply harmonic component in addition with fundamental component, this makes the production cost high. The source voltage gets distorted due to nonlinear load connected at the point of common coupling which can affect the other linear loads connected to the source because the linear load draws nonlinear current due to non uniform voltage.

There are many solutions available to improve power quality like DVR, D-STATCOM, series APF, Shunt APF, UPQC etc. Here UPQC is a series and shunt active power filters (APF) devices through common dc link which can solve both voltage and current related problems. The design and modelling of UPQC is explained in later sections. MATLAB/SIMULINK software is used to design and analyze the performance of UPQC with PI controller.

## 2. UNIFIED POWER QUALITY CONDITIONER (UPQC)

UPQC is a combination of series and shunt compensating devices connected through a capacitor which is used for energy storing device. The value of capacitance is based on the peak voltage ripple and rated filter current. The design and operation series and shunt APF are discussed in section 2.4. The regulation of voltage source can be done by series APF but some of the current harmonics are missing and this can affect the source voltage this can be avoided by shunt APF. The basic circuit of UPQC is shown in fig.2.1.

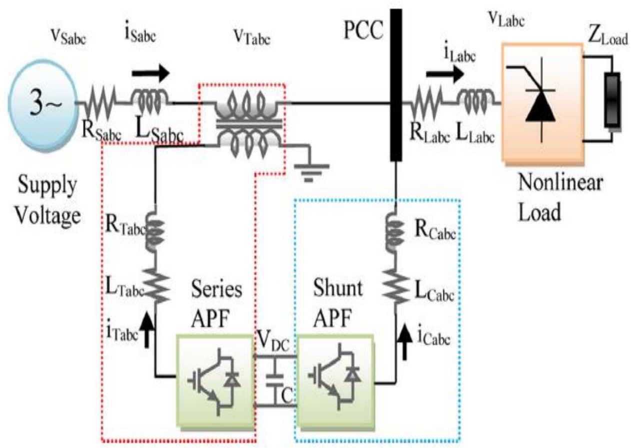



**Fig 2.1** block diagram of UPQC.

## 2.1 Series APF

Series APF is a series element which can act as a controlled voltage source. It injects voltage of negative harmonics through injection transformer. The basic circuit circuit of series APF is shown in fig.2.2.The capacitor is energy storage with self supporting i.e. with reactive power exchange. If we use a fixed dc source then there exists only a real power exchange through voltage source inverter. the design of controller for generating pulses explained in section 2.3.

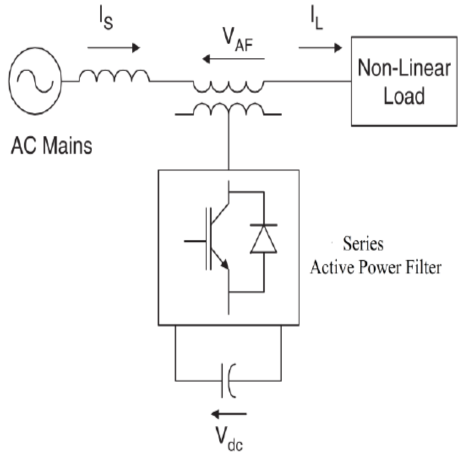



**Fig.2.2** Basic circuit of series APF

## 2.2 Shunt Active Power Filter

Shunt active power filter is a shunt connecting device which can be acts as controlled current source. It injects negative current harmonics to solve current related problems. The purpose of capacitor is same as series APF. The basic circuit of shunt APF and its basic function is explained in fig 2.3. The controller for generating pulses is explained in section 2.3. The functions of shunt APF are dc link voltage regulation, improvement of power factor by controlling reactive power.

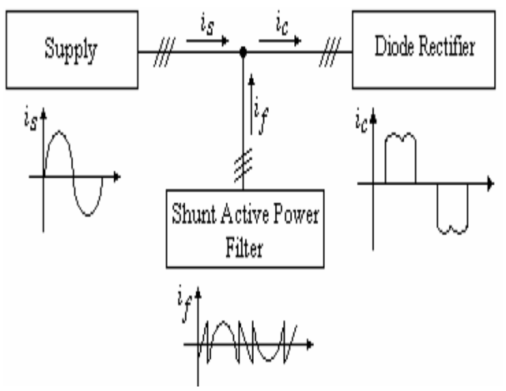



**Fig.2.3** Basic circuit of shunt APF

## 2.3 Multi Level Inverter

Voltage source inverter (VSI) is main component of the compensator which converts dc to ac voltage. In recent years the applications of multilevel inerter in power quality becomes very popular. The multilevel inverter has many advantages over 3-level inverter like low harmonic distortions, better quality of output and many more. There are three types of MLIs they are diode clamped, flying capacitor, and cascaded multilevel inverters. In particularly the cascaded MLI has a circuit layout flexibility, no need of extra clamping diodes, balancing capacitors etc., low voltage stresses on the switches and exactly suitable for integration of renewable energy resources to grid. The circuit topology of cascaded MLI is shown in fig.2.4

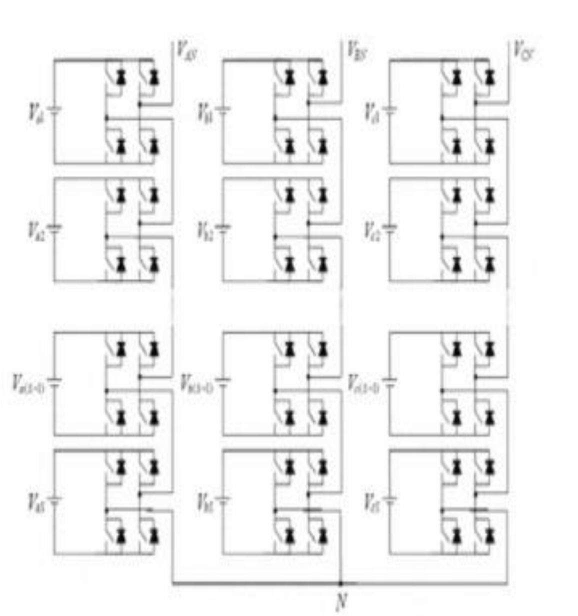



**Fig.2.4** The circuit layout of cascaded H bridge inverter

There are 2N+1 output levels in the in the output voltage waveform, here N represents number of dc sources or half bridges. Based on the required ratings, the addition or subtraction of H bridges can be done this is the main advantage of its circuit flexibility.

### 2.3.1 Carrier Shifted Sinusoidal Pulse Width Modulation Scheme

This is the best switching scheme for VSI. In this scheme all the pulses are varied in sinusoidal fashion to give better output of the inverter. The average value of output is depends upon the value of modulation. The carriers are shifted by an angle of ø =360/k, here k = number of H bridges for better rejection of harmonics. The basic generation of pulses by intersection of sine wave (voltage) with triangular carrier as shown in fig.2.5

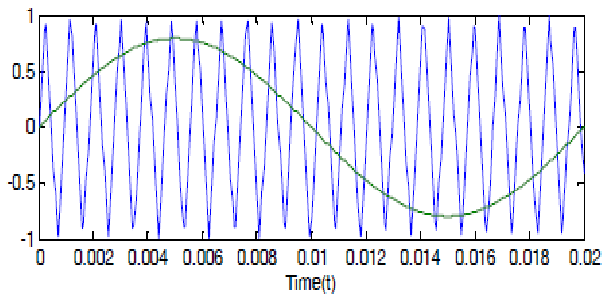



**Fig.2.5** The SPWM switching scheme

If the carrier is low the output low and if the carrier goes high the output will low. If we consider three H bridges the generation of pulses as shown in fig

The output of cascaded MLI with SPWM scheme as follows

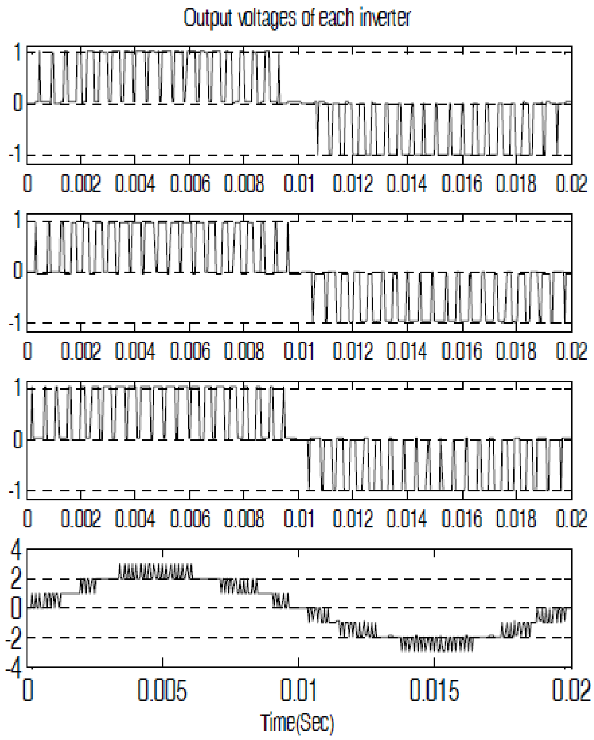



**Fig.2.6** the output of cascaded MLI using SPWM logic.

## 2.4 DESIGN of CONTROLLERS using dq0 Transformation

### 2.4.1 Series Controller

The series controller actively mitigates voltage related problems the compensation of series APF is the difference between source voltage and load voltage ($V_{se}=V_{source}-V_{load}$). The design of controller is based on dq0(synchronous dq0) algorithm. Firstly the source and load voltages Vsabc, Vlabc is converted into $V_{dq0}$ by using parks transformation see equation (1, 2). The second order low pass filter (LPF) is used to filter the higher order harmonics. The sequence of designing controller as follows.

$$V_{sabc}=T*V_{sdq0} \quad (1)$$

$$V_{labc}=T*V_{ldq0} \quad (2)$$

$$T = \begin{matrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ sinwt & \sin(wt-120) & \sin(wt+120) \\ coswt & \cos(wt-120) & \cos(wt+120) \end{matrix}$$

Here T refers to parks transformation matrix.The zero sequence component in both voltages must be zero because under unbalanced condition the zero sequence component is not zero which is undesired.

The instantaneous voltages ($V_{ld}$, $V_{lq}$, $V_{sd}$, $V_{sq}$) are passed through LPF in order to suppress oscillating components and is compared as follows.

$$V_{compd}=K(V_{sd}-V_{ld}) \quad (3)$$

$$V_{compq}=K(V_{sq}-V_{lq}) \quad (4)$$

Here K is PI the controller. The values of $K_p$, $K_i$ are taken based trial and error method and the results are discussed in later sections.

The compensated direct and quadrature axis components are equation (3, 4) are converted back to a-b-c quantities by applying inverse parks transformations follows

$$V_{comp(abc)=}T^{-1*}V_{comp(dq0)} \quad (5)$$

Here $T^{-1}$ is inverse park transformation matrix

$$Tinv = \begin{matrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ sinwt & \sin(wt-120) & \sin(wt+120) \\ coswt & \cos(wt-120) & \cos(wt+120) \end{matrix}$$

This compensating voltage equation (5) is given to SPWM scheme to generate requied pulses to operate multilevel inverter

### 2.4.2 Shunt Controller

Shunt controller actively mitigates current harmonics and other related problems the basic idea of deriving compensating currents.

$$I_{sabs}=I_{sh}+I_{labc} \quad (6)$$

$$I_{sh}=I_{sabc}-I_{labc} \quad (7)$$

Here $I_{sabc}$ is source current, $I_{sh}$ is shunt compensator current, $I_{labc}$ is load current. The mechanism of generation of required compensating currents is same as series controller. The generated compensating current is given to SPWM scheme to generate pulses for inverter.

## 3. SIMULATION STUDY

The performance of multilevel UPQC is analyzed in MATLAB/SIMULINK software. A source voltage of 415V 50Hz is connected to a load of 100Ω, 1mH. A rectifier load of 50Ω, 30mH is switched from 0.2 to 0.3 which acts as a nonlinear load. Due to sudden switching of inductive load a voltage sag is created.

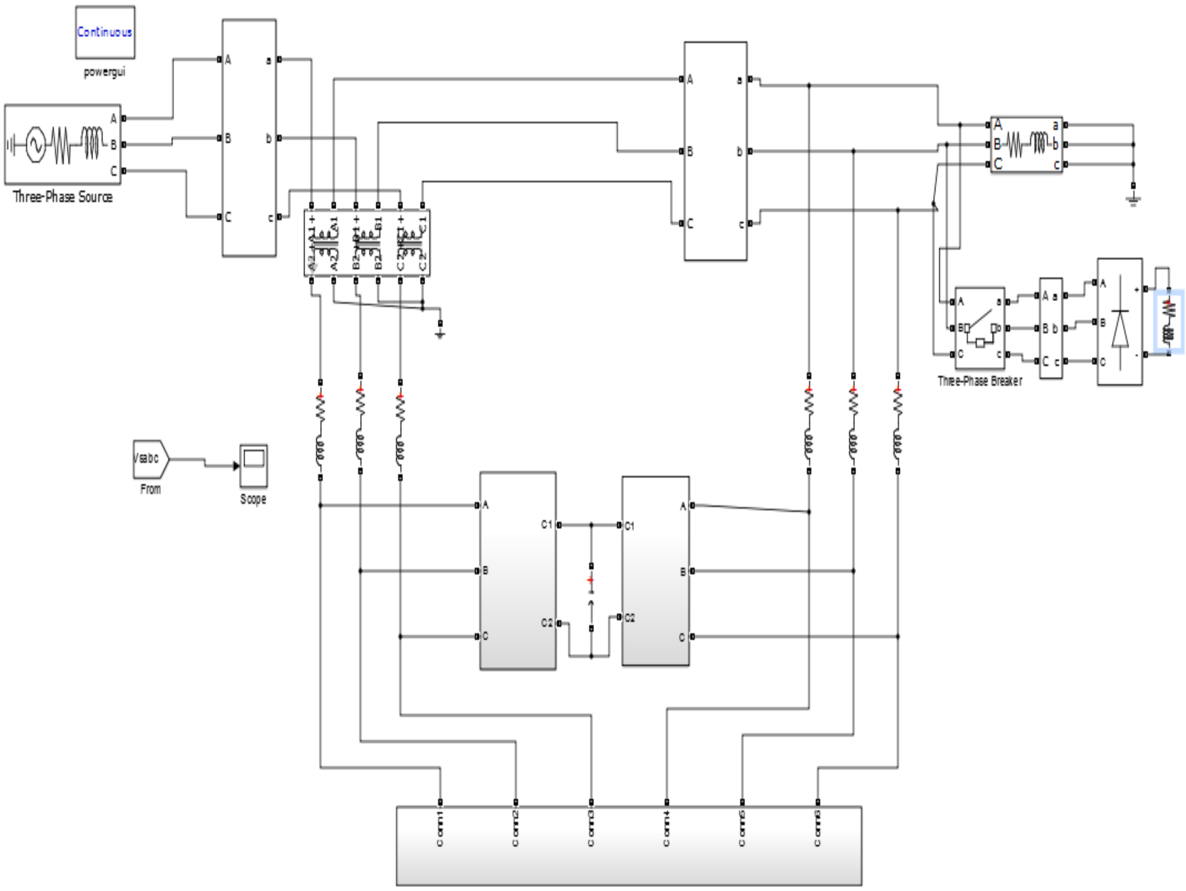
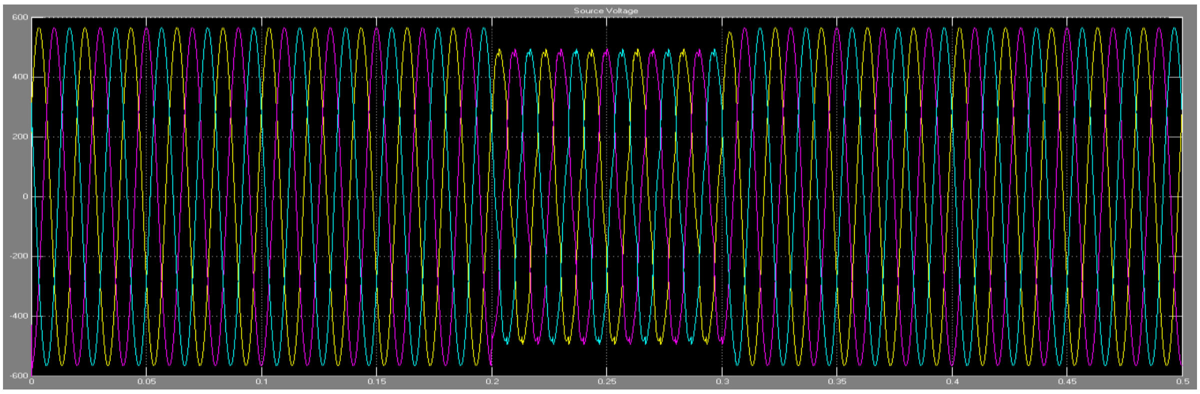



**Fig 3.1** simulation diagram of UPQC

**Table 1.**The circuit parameters for overall system

| S.No. | Name | Specifications |
|---|---|---|
| 1 | Source voltage | 415V |
| 2 | System frequency | 50Hz |
| 3 | Linear load | 100Ω, 1mH |
| 4 | rectifier load | 50Ω, 30mH |
| 5 | Filter resistance | 10Ω |
| 6 | Filter inductance | 200mH |
| 7 | Switching frequency | 1080Hz |
| 8 | Injection transformer Turns ratio | 1:1 |
| 9 | Dc link capacitance | 1µH |
| 10 | PI controller | Kp=0.025 Ki=0.5 |

The source voltage before and after compensation is shown in fig.3.2



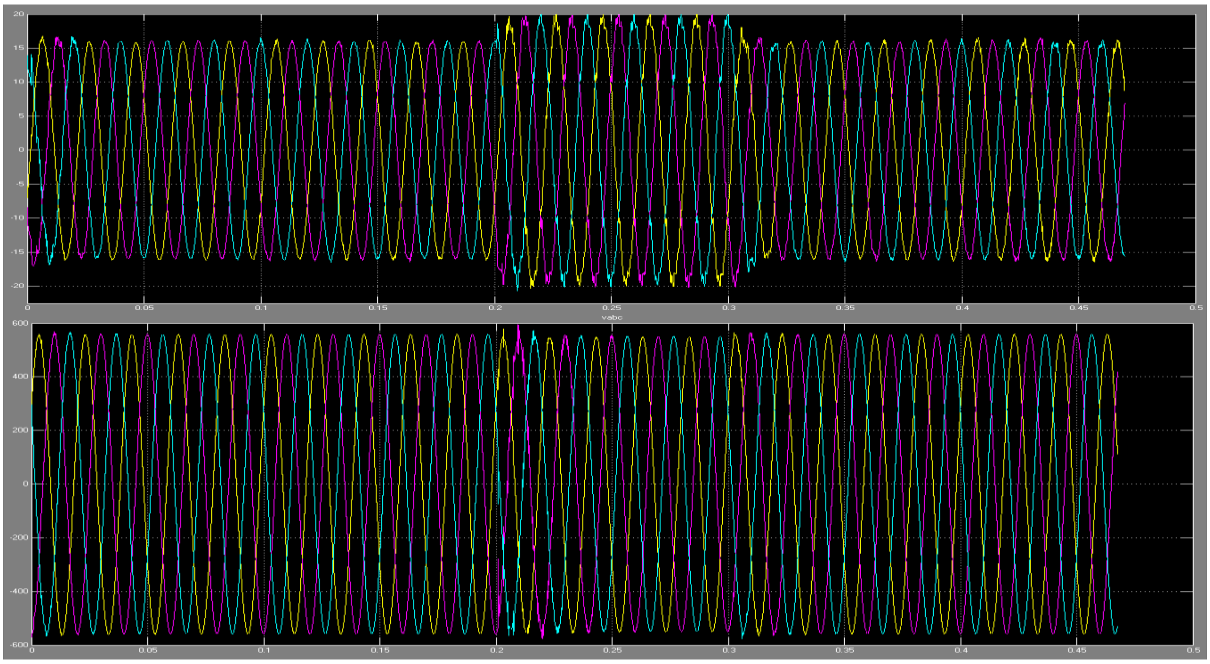


**Fig. 3.2** source voltage a) before compensation b) injected voltage c) after compensation

The FET analysis for computing THD in voltage waveform before and after compensation

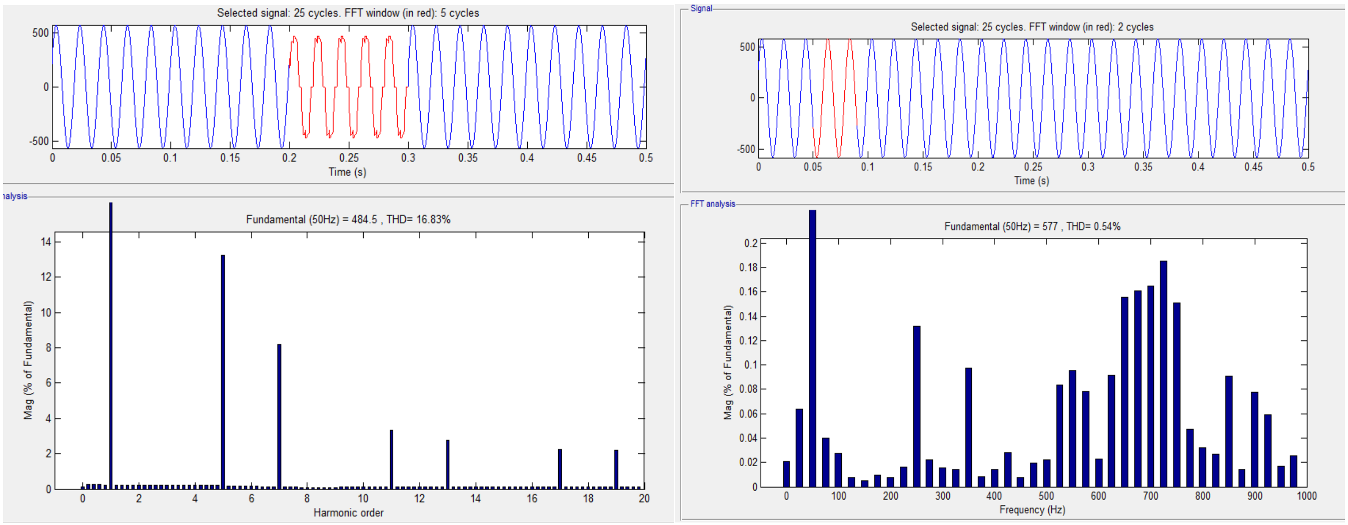



**Fig.3.3** FET analysis for source voltage before and after compensation

The UPQC can actively mitigate voltage sag as well as harmonics. The summary of results as follows

**Table 2** harmonics analysis

| S.NO | Parameter | Before compensation | After compensation |
|---|---|---|---|
| 1 | Harmonics(THD) | 16.8% | 0.54% |

## 4. CONCLUSIONS

The performance of UPQC with PI controller under voltage sag and harmonics are analyzed in MATLAB. The controller design for UPQC using dq0 transformation gives satisfactory results. The use multilevel inverter reduces the filter requirement due to THD in the output. The harmonics in source voltage is reduced from 16% to 0.54% and voltage sag is also mitigated based on the simulation results.

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## BIOGRAPHIES

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