



Suppression of Power Quality Problems by using MPC-Based UPQC Technique

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ABSTRACT

The main priority of electrical utilities is to supply their customers with an uninterrupted sinusoidal voltage of constant magnitude and frequency with balanced sinusoidal currents at the AC mains. However, the present day AC distribution systems are facing severe power problems such as voltage sags, voltage swells, reactive power burden, unbalanced loads, currents harmonics, spikes, surges, excessive neutral current, etc. These utilities are not able to procure eternal solutions to these aforementioned problems in the supply voltages across the load ends of the consumers. And these problems when left not overcome, could lead to damage of expensive devices, electric shock or electrocution of the human operators, disruption of important industrial processes, or even the total collapse of the electrical network system. This necessitated the development of different techniques for alleviating these problems to some certain extent. Many works have been done by different researchers and engineers in the realm of power quality improvement. But there still exist the power quality problems in all electrical power systems. In this research thesis, a new technique has been developed to suppress the power quality problems in a more improved way. Model Predictive Control based Unified Power Quality Conditioner is proposed to effectively serve as a single solution to multiple power quality problems. The choice of the UPQC over the other custom devices is because of the fact that it comprises of a series Derivative Voltage Restorer (DVR) which mitigates voltage related problems and a shunt Distributive Static Compensator (DSTATCOM) which handles the disturbances associated with currents. MPC is also selected with high preference over the other controllers due to its preview ability and capability of handling constraints and MIMO systems.

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INTRODUCTION

The demand for stable and qualitative electric power supply has been increasing due to the increase of

sensitive loads. Also, rapid growth of industrial loads, power electronic devices and computer processors leads to the increase in nonlinear loads which

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is one of the major sources of power quality problems. Power distribution systems, ideally should provide customer with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency (Pandya A. 2015). But in practice, distribution systems have nonlinear loads, which affect the purity of waveforms of the supply. Uninterrupted and stable energy supply increases the efficiency of an equipment. On the other hand, unstable power leads to increase in repair of equipment and interruption in production. Due to the high increase of non-linear loads nowadays, significant amounts of harmonics are being injected into power systems causing voltage distortion at a particular frequency.

According to "IEEE standard *Std.1100TM-2005* (Revision of IEEE Std. 1100-1999), power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment. The term electrical power quality is generally used to assess and to maintain the good quality of power at the level of generation, transmission, distribution and utilization of AC electrical power".

Maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency is referred as electric power quality. Voltage unbalance, harmonic content, increased reactive power demand and frequency deviations are the foremost power quality hitches which affect the utility grid (Chitra *et al.* 2015).

Power quality problem is generally defined as any change in power (voltage, current or frequency)

that interferes with the normal operation of electrical equipment. From a customer's perspective, a power quality problem is defined as any power problem manifested in voltage, current or frequency deviations that result in power failure or mal-operation of customer equipment (Hussein M. 2012)

Presently, power quality problems in grid-integrated applications take great interest because of the growing applications in power electronics. The elimination of the harmonics in the grid, eliminating voltage fluctuation and the usage of clean energy resources in the power system applications become a subject of interest worldwide.

The impact of power quality hitches is concerning while linking of micro grid to the main grid and it could become a foremost area to investigate. Therefore, the Distributed Generation (DG) systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network (Medipalli *et al.* 2015).

Generally, power quality problems are not new in power system, but mitigation methodology has increased in recent years. The basic custom power devices which are used for power quality improvement in distribution system are Distribution Static Synchronous Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), Unified Power Quality Conditioner (UPQC), etc. Among these devices, UPQC is the most effective and efficient custom power device because it employs both the DSTATCOM which compensates for currents and DVR that compensates for voltages. (Amandeep 2011). Hence, UPQC, when employed in

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an electric power network, it can compensate for both currents and voltages.

In order to operate the UPQC in an efficient manner, some control strategies have to be investigated and implemented. Model Predictive Control (MPC) is a control algorithm based on a system model, where an optimization procedure is performed in every sampling interval, calculating an optimal control action. During the last decade, the MPC has been proved as a useful control strategy in process industry. It is especially functional since it can handle constraints on control as well as system states and/or output variables. Ability to incorporate economic objectives as a part of control requirements makes it an excellent candidate for the UPQC scheme.

POWER QUALITY PROBLEMS

According to Srinivas *et. al.* (2012), Power Quality problems encompass a wide range of disturbances such as voltage dip, voltage sags/swells, flicker, harmonics distortion, impulse transient and interruptions etc. These problems are briefly explained as follows:

- i. **Voltage dip:** A voltage dip is used to refer to short-term reduction in voltage of less than half a second.
- ii. **Voltage sag:** Voltage sags can occur at any instant of time, with amplitudes ranging from 10 - 90% and a duration lasting for half a cycle to one minute.
- iii. **Voltage swell:** Voltage swell is defined as an increase in r.m.s. voltage or current at the power frequency for durations from 0.5 cycles to 1 min.

- iv. **Voltage spikes, impulses or surges:** These are terms used to describe abrupt, very brief increases in voltage value.
- v. **Voltage transients:** They are temporary undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time.
- vi. **Harmonics:** A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency (50Hz). Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.
- vii. **Flickers:** Visual irritation and introduction of many harmonic components in the supply power and their associated ill effects.

UNIFIED POWER QUALITY CONDITIONER

Unified power quality conditioners are viable compensation devices that are used to ensure that delivered power meets all required standards and specifications at the point of installation. The ideal UPQC can be represented as the combination of a voltage-source converter (injecting series voltage V_c), a current-source converter (injecting shunt current i_c), and a common DC link (connected to a DC capacitor). There are two possible ways of connecting the unit to the terminal voltage (V_t) at PCC (Fuchs & Masoum, 2008):

- i. Right-shunt UPQC (Figure 3.1a), where the shunt compensator (i_c) is placed at the

- right side of the series compensator (V_c).
- ii. Left-shunt UPQC (Figure 3.1b), where the shunt compensator

(i_c) is placed at the left side of the series compensator (V_c).

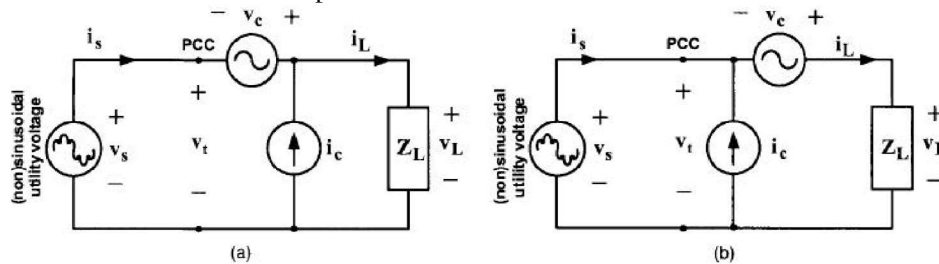


Figure 3.1: Ideal UPQC Structure; (a) The Right-Shunt UPQC (b) The Left-Shunt UPQC

UPQC Structure

These two structures have similar features; however, the overall characteristics of the right shunt UPQC are superior (e.g., operation at zero power injection/absorption mode, achieving unity power factor at load terminals and full reactive power compensation). In this section, a right shunt UPQC configuration is assumed and analyzed.

The detailed structure of the right-shunt UPQC is shown in Figure 3.1. UPQC employs two converters that are connected to a common DC link with an energy storage capacitor. The main components of a UPQC are series and shunt power converters, DC link capacitors, low-pass and high-pass passive filters, and series and shunt transformers.

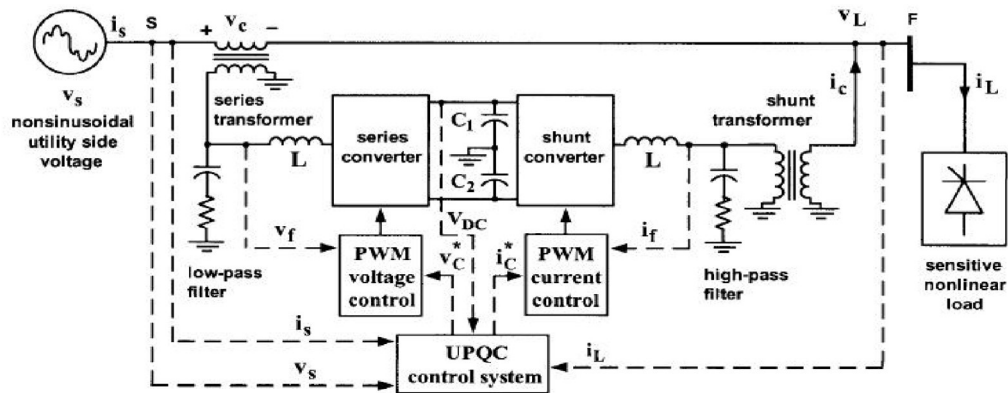


Figure 3.2: Detailed Configuration of the Right-Shunt UPQC (Fuchs & Masoum, 2008).

Operation of UPQC

The shunt converter forces the feeder (system) current to become a balanced (harmonic-free) sinusoidal waveform, while the series converter ensures a balanced, sinusoidal and

regulated load voltage. In most cases, the three-phase system voltages and load currents are unbalanced and contain higher order frequency components (harmonics), and a UPQC unit is used to compensate for both

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types of distortions. The UPQC takes the following two steps to compensate for the imbalance and the distortion of system voltage and line current (Fuchs & Masoum, 2008).

Step 1: Obtaining Balanced Voltage at Load Terminals

$$V_S(t) = V_{S+}(t) + V_{S-}(t) + V_{S0}(t) + \sum V_{Sh}(t) \quad (3.1)$$

where subscripts +, -, and 0 refer to the positive, negative and zero-sequence fundamental components, respectively;

$V_{S+}(t) = V_{S+} \sin(\omega t + \phi_+)$ is the positive-sequence fundamental frequency components.

$V_{S-}(t) = V_{S-} \sin(\omega t + \phi_-)$ is the negative-sequence fundamental frequency components

$V_{S0}(t) = V_{S0} \sin(\omega t + \phi_0)$ is the zero-sequence fundamental frequency components.

$\sum V_{Sh}(t) = \sum V_{Sh} \sin(\omega t + \phi_h)$ represents the harmonics in the system voltage.

ϕ_+, ϕ_-, ϕ_0 correspond the voltage phase angles.

Usually, the voltage at the load at PCC is expected to be sinusoidal with a fixed amplitude V_L :

$$V_L(t) = V_L \sin(\omega t + \phi_+) \quad (3.2)$$

Hence, the series converter will need to compensate for the following components of voltage:

$$\begin{aligned} V_C(t) &= V_L(t) - V_S(t) \\ &= V_L(t) - V_{S+}(t) - V_{S-}(t) - V_{S0}(t) - \sum V_{Sh}(t) \end{aligned} \quad (3.3)$$

The control system should automatically control the series converter so that its generated voltage at its output terminals is $V_C(t)$ (in Fig. 2.2) and matched with Eq. 2-3.

Step 2: Obtaining Balanced System Current through the Feeder

The distorted nonlinear load current (Fig. 2.2) can be expressed as:

$$i_S(t) = i_{L+}(t) + i_{L-}(t) + i_{L0}(t) + \sum i_{Lh}(t) \quad (3.4)$$

where

$i_{L+}(t) = i_{L+} \sin(\omega t + \alpha_+)$ is the fundamental frequency positive-sequence components of the load currents

$i_{L-}(t) = i_{L-} \sin(\omega t + \alpha_-)$ is the fundamental frequency negative-sequence components of the load currents

$i_{L0}(t) = i_{L0} \sin(\omega t + \alpha_0)$ is the fundamental frequency zero-sequence components of the load currents

$\sum i_{Lh}(t) = \sum i_{Lh} \sin(\omega t + \alpha_h)$ is the harmonics of the load current.

$\alpha_+, \alpha_-, \alpha_0$ are the corresponding current phase angles.

The shunt converter is supposed to provide compensation of

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the load harmonic currents to reduce voltage distortion. It should act as a controlled current source and its output current must consist of harmonic, negative-, and zero-sequence currents to cancel the load current distortions. It is

$$\Theta_L = (\alpha_+ + \phi_+) \quad \text{Or:} \quad \alpha_+ = (\phi_+ + \Theta_L) \quad (3.5)$$

Substituting Eq. 2-5 into Eq. 2-4 and simplifying yields

$$i_L(t) = I_{L+} \sin(\omega t + \phi_+) \cos \Theta_L + [I_{L+} \cos(\omega t + \phi_+) \sin \Theta_L + I_{L+}(t) + i_{L-}(t) + i_{L0}(t)] \quad (3.6)$$

It is clear that the output current of the shunt converter should be controlled and must assume a wave shape as specified by the 2nd, 3rd, 4th, and 5th terms of Eq. 2-6. That is;

$$i_c(t) = I_{L+} \cos(\omega t + \phi_+) \sin \Theta_L + i_{L-}(t) + i_{L0}(t) + \sum i_{Lh}(t) \quad (3.7)$$

This will ensure that the system (feeder) current has a sinusoidal waveform:

$$i_s(t) = i_L(t) - i_c(t) = (I_{L+} \cos \Theta_L) \sin(\omega t + \phi_+) \quad (3.8)$$

Equations 2-3 and 2-7 demonstrate the principles of an ideal UPQC. If these equations are dynamically implemented by the UPQC controller, terminal load voltage and system current will be sinusoidal. In addition, system voltage and current will be in phase if $\theta_L = 0$ (e.g., unity power factor), and neither positive nor negative reactive power will be supplied by the source.

The UPQC Control System

Generation, tracking, and observation of the reference signals are performed by the UPQC control system. There are two main classes of UPQC control; the first one is based on the Park's transformation (Fuchs & Masoum, 2008), and the second one on the instantaneous real and imaginary power theory. There are other control techniques for active and hybrid filters.

The Park's transformation will be introduced in the following subsections and use in this work, because among the control methods, the synchronous reference frame (SRF)

usually desired to have a certain phase angle (displacement power factor angle) θ_L , between the positive sequences of voltage and current at the load terminals:

seems to be more appropriate. The fact is that it needs sinusoidal and balanced voltage and is not sensitive to voltage distortions and is relatively simple. In result, the response time of the control system shortens. So it's prior to utilize the SRF theory in UPQC controlling circuit (Mohamadrezapour, Y. *et al*, 2009).

UPQC Control Using the Park's (dq0) Transformation

It is clear that the UPQC should first separate the fundamental positive-sequence component from other components (e.g., derivation of reference signal using either waveform compensation, instantaneous power compensation, or impedance synthesis), and then control the outputs of series and shunt converters (e.g., generation of compensation signal using reference-following techniques). The conventional approach to perform the first task for the UPQC relies on the synchronous *dq0* reference frame (Fuchs & Masoum, 2008).

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General Theory of the Park's (dq0) Transformation

The park's (dq0) transformation is defined as;

$$\begin{bmatrix} X_d \\ X_q \\ X_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos\theta_d & \cos(\theta_d - 2\pi/3) & \cos(\theta_d + 2\pi/3) \\ -\sin\theta_d & -\sin(\theta_d - 2\pi/3) & -\sin(\theta_d + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \quad (3.9)$$

where ω_h is the angular velocity of signals to be transformed and ϕ is the initial angle. The main advantage of the dq0 transformation is that the fundamental (positive-sequence) component of waveform will be transferred to a constant DC term under steady-state conditions. In addition, a harmonic component with frequency ω_t will appear as a sinusoidal signal with frequency of $\omega_t - \omega_h$ in the dq0 domain.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos\theta_d & \cos(\theta_d - 2\pi/3) & \cos(\theta_d + 2\pi/3) \\ -\sin\theta_d & -\sin(\theta_d - 2\pi/3) & -\sin(\theta_d + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_{S_a} \\ V_{S_b} \\ V_{S_c} \end{bmatrix} \quad (3.10)$$

To implement the SRF method and for reference voltage calculation the phase locked loop (PLL) is used to generate the transformation angle (ωt) which presents the angular position of the reference frame. Figure 3.3 (Krupa &

Control of Series Converter Based on the dq0 Transformation

The series APF based on SRF method can be used to solve the voltage related PQ problems. The SRF method is used in series active filter for generating reference voltage signal. The supply voltages V are transformed into dq0 which is given in equation 2-10:

Kaushi, 2015) shows the d-q theory for generating voltage reference signal in series APF. The low pass filter is used to obtain the reference source voltage in dq coordinates.

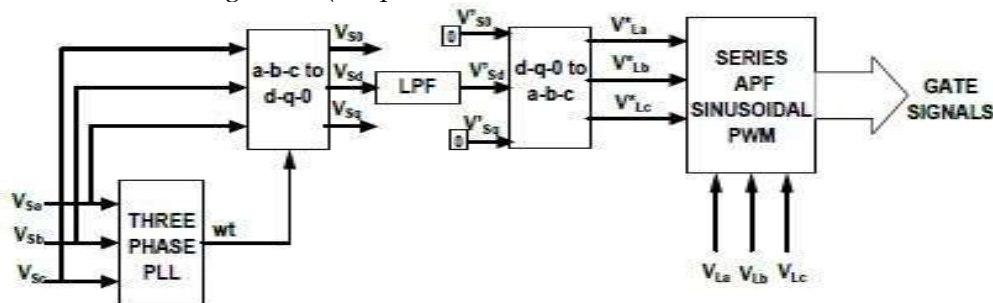


Figure 3.3: Control Block of the UPQC Series Compensator using Park's (dq0)

Transformation. The inverse Park's transformation is used for generating reference voltage signal as

given in equation 3.11. The reference load voltage (V^*_{Labc}) are transform d-q-0 into a-b-c.

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$$\begin{bmatrix} V'L_a \\ V'L_b \\ V'L_c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos\omega t & -\sin\omega t & 1/\sqrt{2} \\ \cos(\omega t - 2\pi/3) & -\sin(\omega t - 2\pi/3) & 1/\sqrt{2} \\ \cos(\omega t + 2\pi/3) & -\sin(\omega t + 2\pi/3) & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \quad (3.11)$$

The reference load voltage (V^*L_{abc}) generated are compared with sensed load voltage (V_{Labc}) in sinusoidal pulse width modulation (PWM) technique. This comparison between reference load voltage and sensed load voltage in sinusoidal PWM technique generate a gating signals for series voltage source converter (VSC). In series voltage source converter as a

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \cos\theta_d & \cos(\theta_d - 2\pi/3) & \cos(\theta_d + 2\pi/3) \\ -\sin\theta_d & -\sin(\theta_d - 2\pi/3) & -\sin(\theta_d + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \quad (3.12)$$

The shunt active filter reference currents in $a-b-c$ frame are obtained with the following expression.

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3/2} \\ -1/2 & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} \cos(\omega t) & -\sin(\omega t) \\ \sin(\omega t) & - \\ \cos(\omega t) & i_{q_ref} \end{bmatrix} \begin{bmatrix} i_{d_ref} \\ i_{q_ref} \end{bmatrix} \quad (3.13)$$

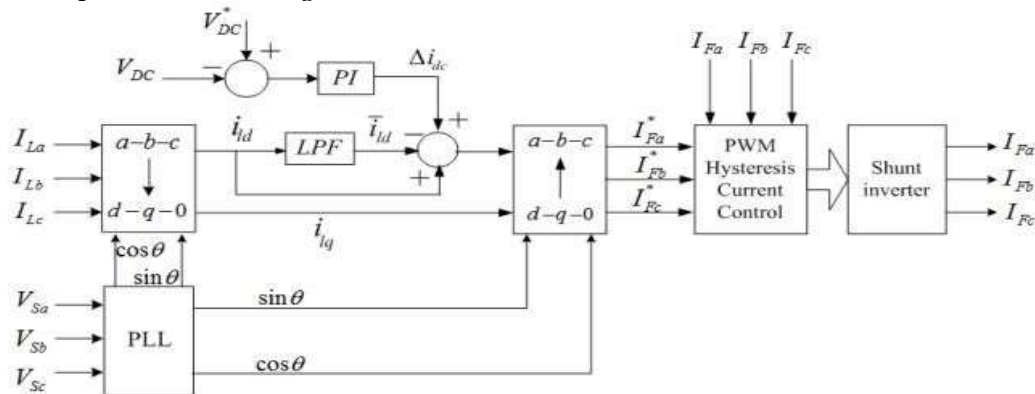
In order to maintain constant DC bus voltage, the error between the reference dc capacitor voltage and the sensed dc bus voltage is given to the PI controller and the output is added to the dc component of I_d to generate I_d^*

switching device use insulated gate bipolar transistor (IGBT) which can compensate all voltage related problems.

Control of shunt converter relying on the dq0 transformation

Similar transformation as employed for voltages can be applied to current waveforms as well:

(Ferdin *et al*, 2014). The signals are fed to the hysteresis controller for generating pulses for the inverter. The control of the shunt compensator based on the dq0 transformation is shown in Figure 2.4.



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Figure 3.4: Control Block of the UPQC Shunt Compensator using Park's (dq0) Transformation.

WORKING PRINCIPLE OF MPC

Model Predictive Controllers are widely applied over process and oil/petrochemical industries due to their capability to deal in an optimal form with input/output process constraints (upper or lower values for a specific variable, for instance); in this sense, one should be able to safely operate their system by restricting it to be conducted in a limited region of operation, such as maximum and minimum liquid level within a distillation column or a maximum opening degree in a valve. Basically, MPC calculations are

performed at each sampling time which can be also set by the control designer; these calculations are based on current measurements and predictions of future output values. Two types of computation are primordial in a MPC controller: set point calculations and control calculations, this last one includes process constraints and other parameters that are able to be manually specified. The main task of a MPC controller is to determine a sequence of control moves in the manipulated variable, so the system can be tracked to its set point in an optimal fashion.

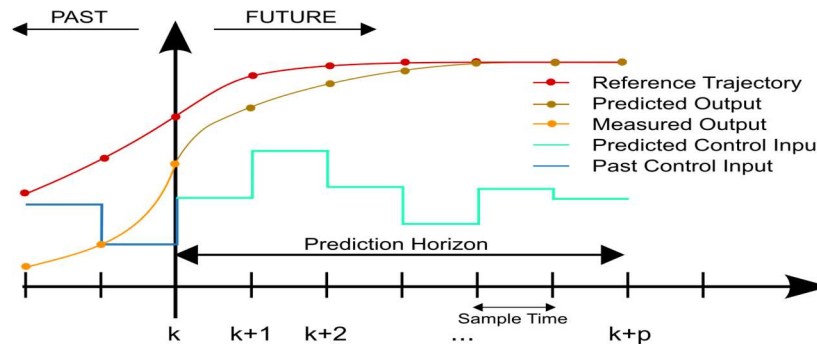


Fig. 3.8: Scheme of MPC (Wikipedia)

The control calculations are based on minimizing the predicted deviations from the reference trajectory. The key idea behind a MPC controller is illustrated in Figure 3.5. When using MPC, an optimization problem is solved at each time step k through an objective function based on output predictions over a prediction horizon of P time steps; this objective function (usually a quadratic one) is minimized by a selection of manipulated variables moves over a control horizon of M control moves. It is important to

emphasize that, even though at each time step a group of M moves is calculated, only the first one y_k is implemented. After this step, the measurement at the next time instant y_{k+1} is obtained, followed by a correction due to model error, and then a new optimization problem is solved again. These procedures are carried out for every time step k .

Before we go in to the MPC equations, it is important to assert the definition of a finite step response (FSR) model; these models are used in almost

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all MPC modeling equations and are obtained by simply introducing a unit step change to a process operating at a steady state. The model coefficients

$(S_1, S_{12}, S_3, \dots, S_N)$ are the output values at each time step.

The predicted output for an instant time k is calculated through the following equation:

$$y_k = \sum_{i=1}^N S_i \Delta u_{k-i} + S_N \Delta u_{k-N} \quad (4.1)$$

The model predicted output is hardly equal to the actual measured output at a certain time step k ; this discrepancy is denoted by:

$$d_k = y_k - y'_k \quad (4.2)$$

The corrected prediction is then:

$$y_k^c = y'_k + d_k \quad (4.3)$$

By combining equations (i), (ii) and (iii), the corrected prediction for the j th step into the future can be demonstrated as:

$$y_{k+j}^c = \sum_{i=1}^j S_i \Delta u_{k-i+j} + S_N \Delta u_{k-N+j} + d_{k+j} \quad (4.4)$$

Equation (iv) can be easily seen as a "compilation" of the effect of future control moves (first term to the right), and past control moves (second and third terms), as well as a correction term d_{k+j} .

Furthermore, the difference between setpoint trajectory and future predictions in j th step, with $j \leq P$, is given by:

$$r_{k+j} - y_{k+j}^c = r_{k+j} - [\sum_{i=1}^j S_i \Delta u_{k-i+j} + S_N \Delta u_{k-N+j} + d_{k+j}] - \sum_{i=1}^j S_i \Delta u_{k-i+j} \quad (4.5)$$

Equation (v) is essential for the optimization problem and can be used in a quadratic objective function for a prediction horizon P and a control horizon of M moves:

$$f_{obj} = \sum_{i=1}^P (r_{k+i} + y_{k+i}^c)^2 w \sum_{i=0}^{M-1} r_{k+i} + \Delta u_{k+1}^2 \quad (4.6)$$

METHODOLOGY

The following steps were followed in carrying out the project.

Running the Network on No-load

The electrical network was designed and simulated in matlab environment. The micro grid is a three

phase, 415V, 50Hz network having a three phase programmable voltage source, three phase RL branch and a three phase V-I measurement. The branch resistance is 0.2 ohms and the inductance is 0.0002H. It was then simulated when no load was connected to it as shown in figure 5.1 below:

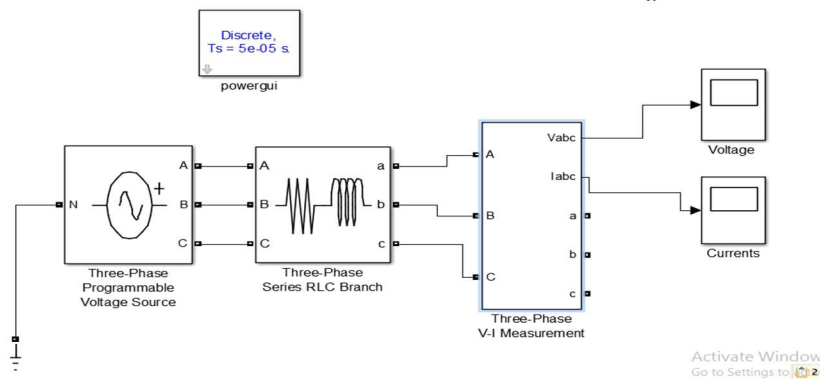


Fig. 5.1: Micro grid without load

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Running the Network with Loads

Two inductive loads with arbitrary specifications were then connected to the network as shown in figure 3.3 below. A circuit breaker with settling time from 0.85 to 0.9s is also connected between the loads and the V-I measurement. The breaker resistance and the snubber resistance are 0.01 ohms and 0.00001 ohms respectively. Load 1

has active power = 25000W, inductive reactive power = 100var, capacitive reactive power = 100var. Load 2 has active power = 450000W, inductive reactive power = 100var, capacitive reactive power = 100var. The network was the run and simulated with the circuit breaker closed and open as shown in the figure below:

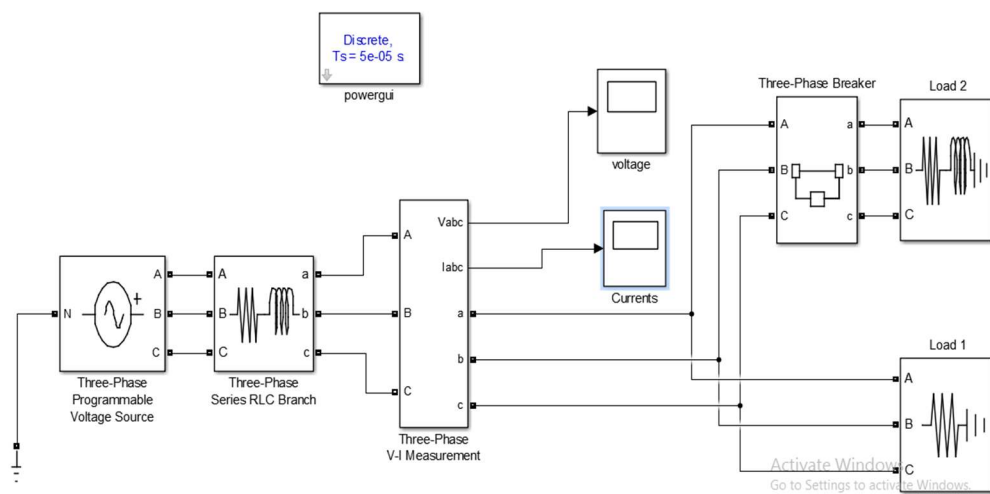


Fig. 5.2: The electrical network with connected loads

Running the Network with MPC-UPQC

Finally, the network was connected with MPC-based UPQC. The UPQC has two voltage source converters, series and shunt, which are power electronic devices. The series converter compensates for the voltage while the shunt converter deals with the currents. The converters have switches which receive signals from the controller, i.e. MPC controller. To control the UPQC means to regulate the gate signals of the device. MPC generates the signals that switch the UPQC converters ON or OFF. The MPC which is placed in feed back form, checks the output or measured voltage

and the reference voltage. The main target is that the output should have zero deviations from the reference voltage, i.e. to have pure sine wave or r.m.s. value of 1 per unit. When the power passes through the UPQC, the controller will check how the voltage or current deviate from the reference, which is set to be zero. It will then try to minimize the difference between the actual voltage or current and the output voltage or current. The controller will use that difference by using quadratic programming to generate a feedback signal that will alter the input or manipulated variables (gate signals) of the system. The signals will then alter

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the switching capabilities of the voltage source converters. This changes the intrinsic characteristics of the UPQC

resulting in improved voltage and current wave form.

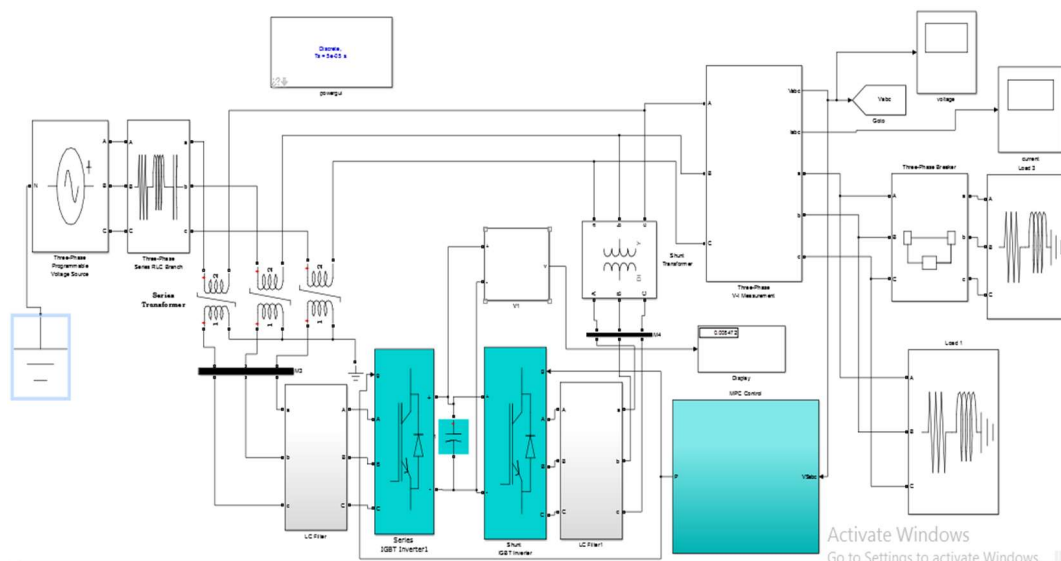


Fig. 5.3: The electrical network with MPC-UPQC

The results and the explanations of the above simulations are presented in the next chapter.

SIMULATION RESULTS AND DISCUSSIONS

This chapter presents the simulation results of micro grid model under different cases, using conventional PID control method and model predictive control method. The system was simulated in Simulink/Matlab environment and the results were presented and compared. The main aim is to evaluate the performance of UPQC with tuned MPC controller.

CASE 1: Network without Load

When no load was connected to the network, no current was drawn as such, there was pure voltage sine wave

with no sag, swell or harmonics. Figures 4.1 and 4.2 below, show the graphs for the voltage and current respectively. The total harmonic distortion was found to be 0% for both the current and voltage.

CASE 2: Network with Connected Loads

When some loads were connected to the micro grid, currents were drawn from the network. Sags were generated when the circuit breaker was closed for the voltage wave form, while swells were obtained when the circuit breaker was set open, and the reverse is the case for the currents wave forms. Figures 6.1, 6.2, 6.3 and 6.4 show the wave forms for voltage sag, voltage swell, current sag and current swell respectively.

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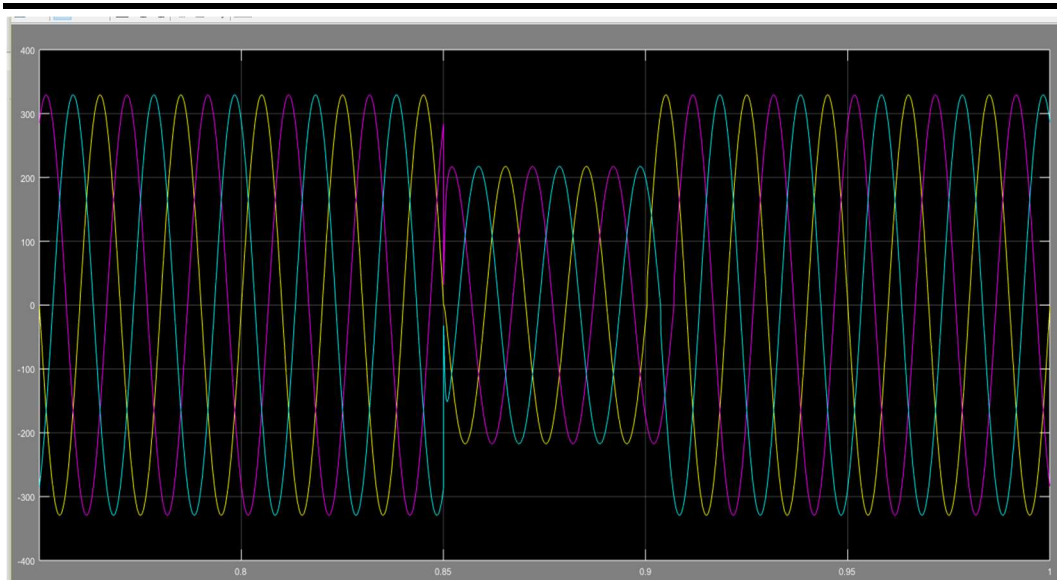


Fig. 6.1: voltage sag

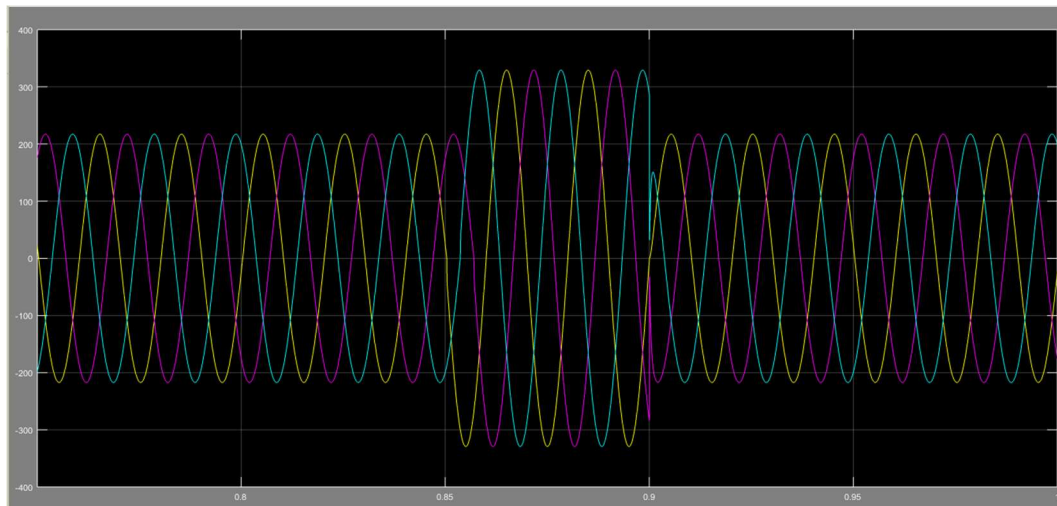


Fig. 6.2: voltage swell

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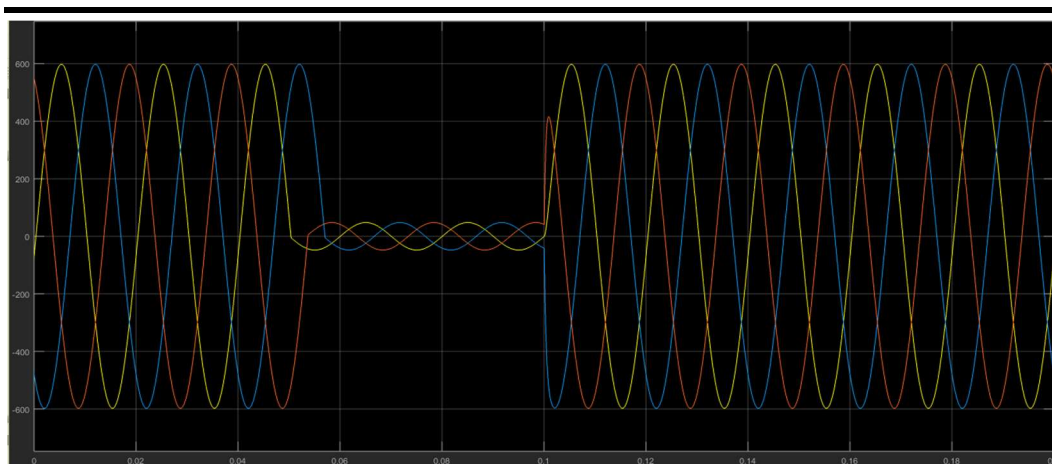


Fig. 6.3: current sag

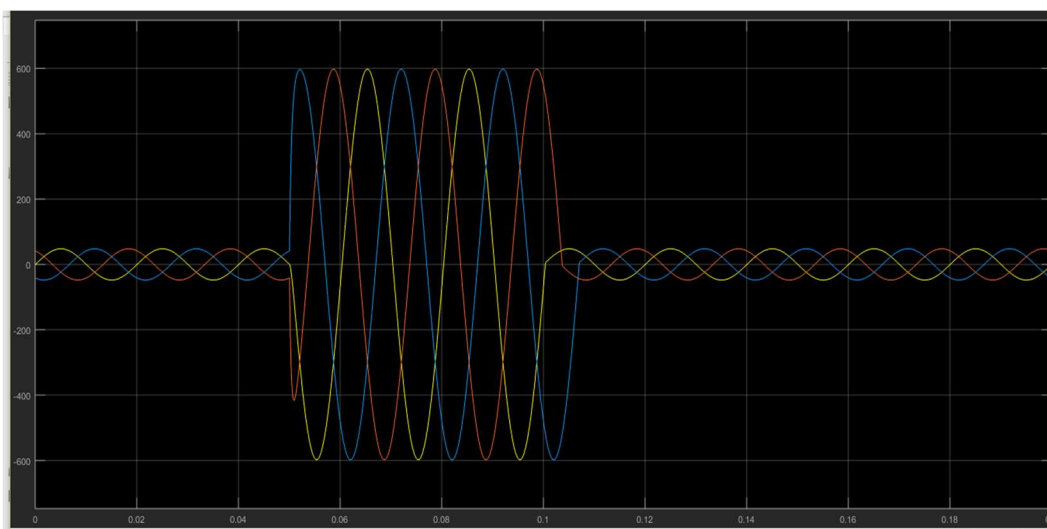


Fig. 6.4: current swell

The total harmonic distortion for the voltage was found to be 14.81% while that of current was 25.85%

CASE 3: Network with MPC-UPQC

An important control technique was then applied to mitigate the ripples generated in the waveforms. The

technique used here was model predictive control-based unified power quality conditioner. When the parameters of the MPC were tuned manually correctly, the technique successfully suppressed the sags and swells of the currents and voltage wave forms.

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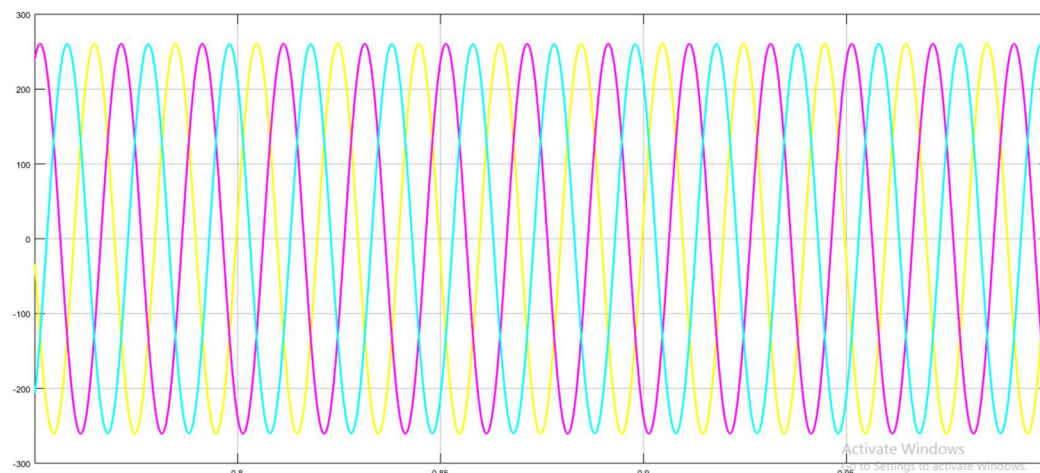


Fig. 6.5: Voltage compensated by MPC-UPQC

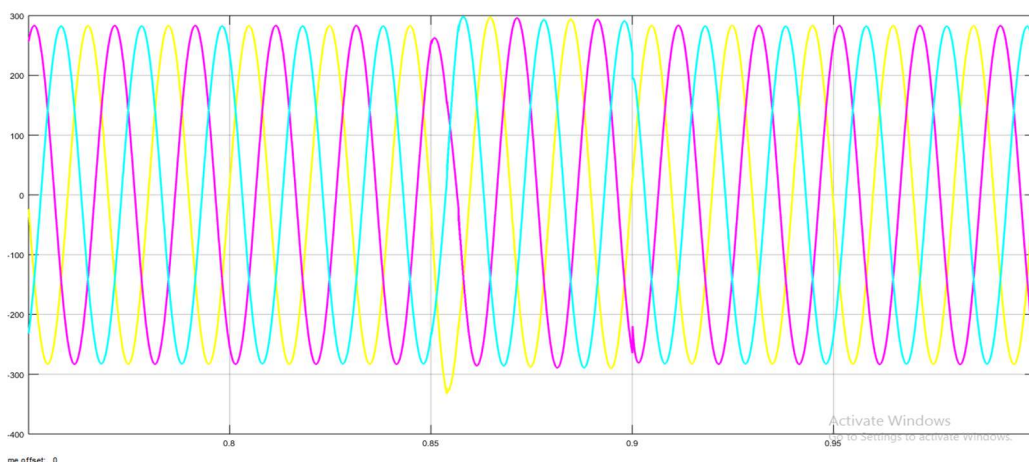


Fig. 6.6: Current compensated by MPC-UPQC

DISCUSSIONS

The electrical network was developed and simulated. When the network was run on no-load, pure sinusoidal voltage waveform and zero current waveform were generated. Also, the total harmonic distortion for both the current and voltage was 0.0%. This is because no current was drawn from the network.

Then, some nonlinear loads were connected to the network which caused

sags and swells of voltage and harmonics of currents. The loads also caused total harmonic distortions of 14.81% for voltage and 25.85% for currents. The values of the loads were adjusted and the nature of the waveforms changed accordingly and also the %THD, indicating the sensitivity of the network with respect to the loads. When the loads were varied, the waveforms and the %THD also varied. But the central aim of loading the network is to create a

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substantial amount of sags and swell which would be suppressed by the proposed control technique. As such, the variation of the loading is not worthy of mention here.

Finally, an MPC controlled UPQC control technique was used to compensate the currents and the voltage. The UPQC, being a combination shunt DSTATCOM and series DVR, gets its signal from the MPC and serves as a single solution for mitigating multiple problems for voltage and currents. The power circuit of the UPQC consists of two voltage source converters joined back to back by a common DC link capacitor. The shunt device is connected in parallel to the consumer loads and compensates reactive power, load balancing and elimination of harmonics. While the series device which is connected in series, keeps the consumer load end voltage insensitive to the supply voltage quality problems such as sags and swells. It injects a compensating voltage between the supply and the consumer load, and restores the load voltage to its reference value.

For the MPC part, the main role of the controller is to calculate the inputs to the plant so that the plant outputs follow the desired reference. It uses the model to predict the future output behavior. It also uses optimizer which ensures that the predicted future plant output tracks the desired reference.

The converters of the UPQC have switches which receive signals from the controller, i.e. MPC controller. To control the UPQC means to regulate the gate signals of the device. MPC generates the signals that switch the UPQC converters ON or OFF. The MPC which is placed in feed back form,

checks the output or measured voltage and the reference voltage. The main target is that the output should have zero deviations from the reference voltage, i.e. to have pure sine wave. When the power passes through the UPQC, the controller will check how the voltage or current deviates from the reference, which is set to be zero. It will then try to minimize the difference between the actual voltage or current and the output voltage or current. The controller will use that difference by using quadratic programming to generate a feedback signal that will alter the input or manipulated variables (gate signals) of the system. The signals will then alter the switching capabilities of the voltage source converters. This changes the intrinsic characteristics of the UPQC resulting in improved voltage and current wave form.

After the correct application of the controller, pure sinusoidal wave forms of both currents and voltages were generated. The voltage and the current THD reduced from the initial 14.81% to 0.0% and from 25.85% to 2.80% respectively.

According to IEEE 519-1992 (1993) standard, the maximum permissible THD is 5% for low voltage and 3% for individual voltage harmonics. This clearly indicate that the proposed MPC control method has performed far better than the conventional PID method. Therefore, the aim of the research work has been achieved.

The FFT analysis of the waveform is presented. The figures below show the graphs for the percentage total harmonic distortions of the different cases explained above.

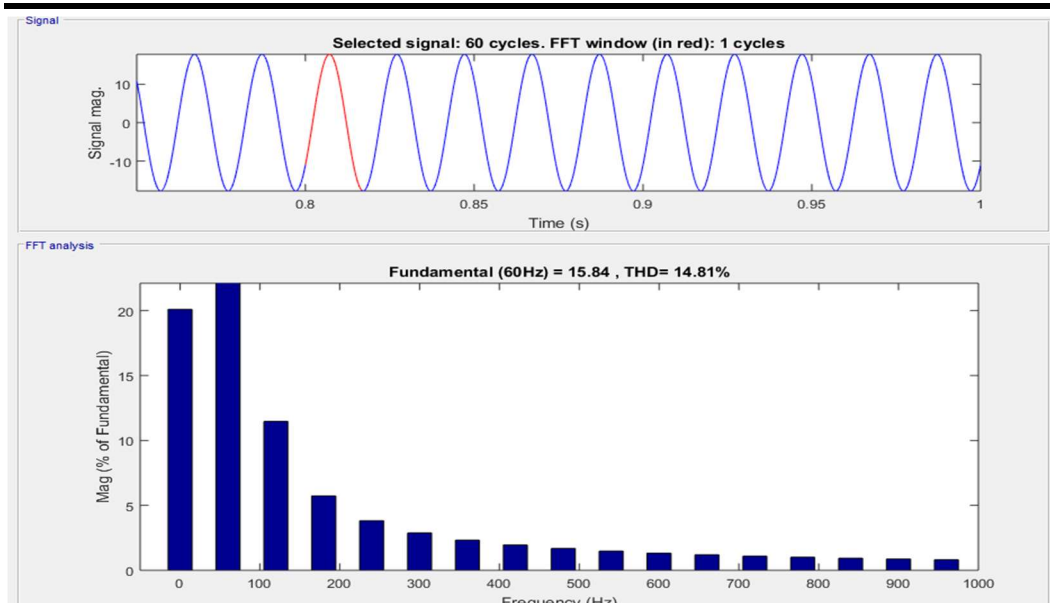


Fig. 6.7: FFT analysis of voltage on load with THD 14.81%

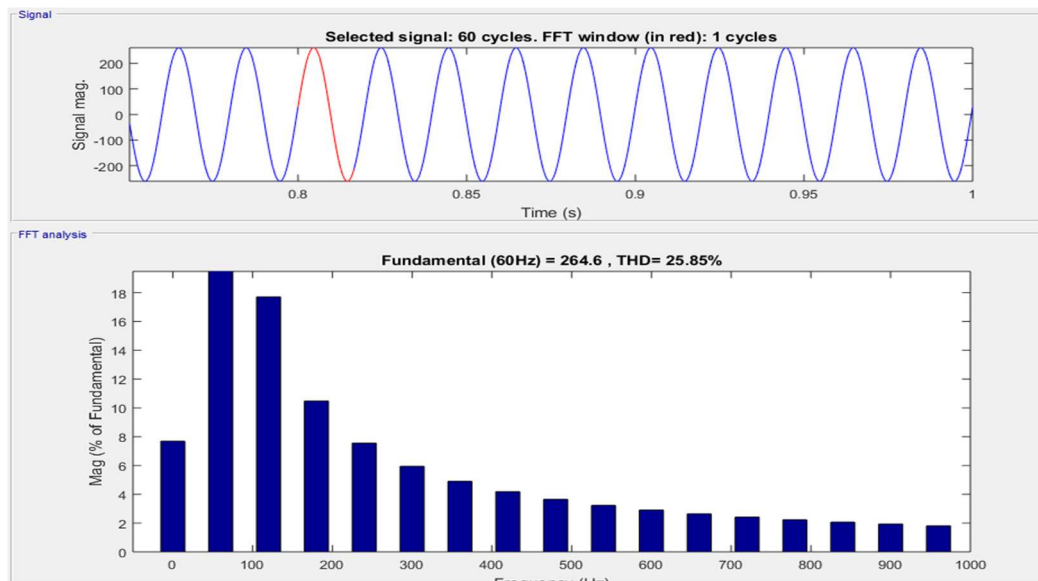


Fig.6.8: FFT analysis of current on load with THD 25.85%

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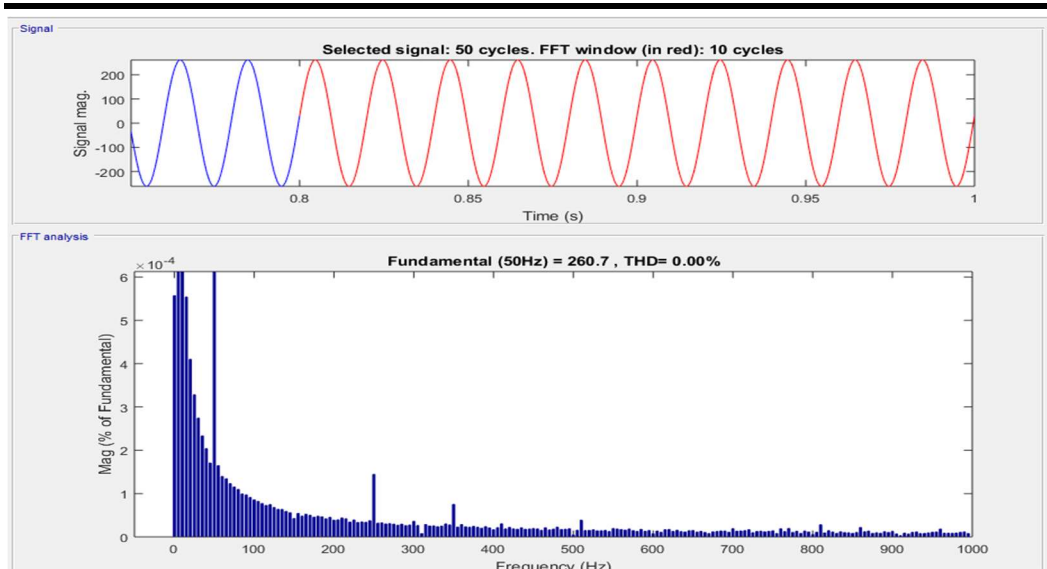


Fig.6.9: FFT analysis of voltage using MPC with THD 0.0%

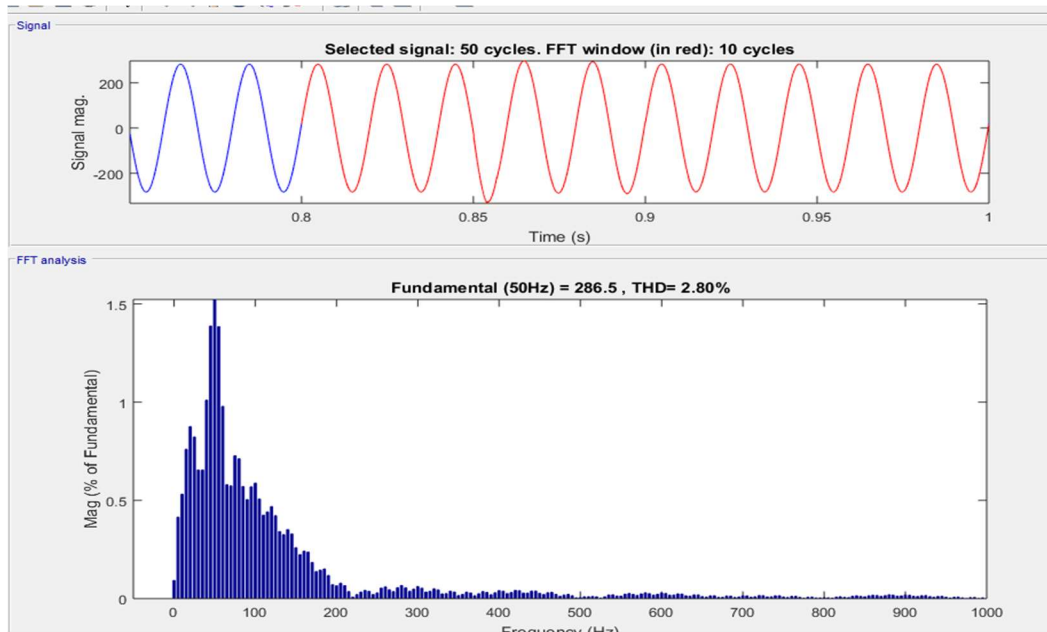


Fig.6.10: FFT analysis of current using MPC with THD 2.80%

CONCLUSION

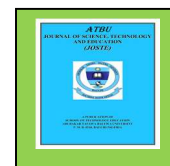
At the end of the project, the performance of MPC based UPQC technique was tested on currents and voltage and the results were analyzed.

The MPC generated excellent results on both the current and voltage. The THD of 0.0% was observed for voltage while 2.80% was for the currents. Since THD is the degree to which waveform deviates

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from its pure sinusoidal value as a result of all the harmonic elements and MPC has reduced it to the accepted level, then, the technique is the best for the task. Therefore, the aim of the research work has been achieved.

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