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An Multi-Objective Approach for Power Quality Improvement: UPQC

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Abstract: This paper presents a multi-objective control strategy for power quality issues. With increasing applications of nonlinear and semi-conductor devices in distribution systems and industries, power-quality (PQ) problems, such as harmonics, neutral current elimination, voltage sag, voltage swell reactive power has become an unavoidable issue. Due to the changing trends and restructuring of power systems, the consumers are looking forward to the quality and reliability of power supply at the load centers. The aim therefore, in this work, is to identify the prominent concerns in the area and thereby to recommend measures that can enhance the quality of the power, keeping in mind their economic reliability and technical consequences. The Unified power quality conditioner (UPQC) is an effective custom power device for the enhancement of power quality due to its quick response, high reliability and nominal cost.

Keywords: Reactive power control, Unified power quality conditioner (UPQC), Active power filter (APF), Load compensation, Linear and Non- Linear loads, Voltage profile improvement.

I. Introduction

Power Quality is an important issue in electric power systems, involving operational, economical and quality of service aspects. Consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. Active power is converted into useful energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile. The achievement of these aims depends on the sizing and allocation of shunt capacitors (sources of reactive power). Since operational, economical and quality of service aspects are at stake, these multiple, conflicting, and evaluation aspects must be explicitly addressed by the mathematical model [1]. Therefore, a multi-objective model has been developed incorporating the objectives of distinct nature that are weighed by decision-makers / planning engineers to select acceptable solutions having in mind their practical implementation. Multi-objective models enable to grasp the conflicting nature of the objectives and the trade- offs to be made in order to identify satisfactory compromise solutions by providing a basis to rationalize the comparison between non-dominated solutions. A non-dominated solution is a feasible solution for which no improvement in all objective functions is simultaneously possible; that is, an improvement in an objective function can only be achieved by degrading. A large range of models and methodological approaches has been proposed in the scientific literature devoted to the reactive power compensation problem. Broadly in chronological order, approaches to tackle this problem have ranged from analytical methods to mathematical programming algorithms, whose characteristics are well-suited for solution representation in networks loss minimization in distribution systems has assumed greater significance recently, Since the trend towards distribution automation will require the most efficient operating scenario for economic .The quality degradation leads to low power factor, low efficiency, overheating of transformers, and so on. Moreover, in case of the distribution system, the overall load on the system is hardly balanced, causing excessive neutral currents in a three phase, four-wire distribution system. Overheating of the neutral conductor occurs because of the fundamental and high-frequency contents in the neutral current. With the application of sophisticated and more advanced software and hardware for the control systems, power quality has become one of the most important issues for power electronics engineers. To control power quality problems, many standards are proposed by different agencies, such as the IEEE-519 standard ideally, voltage and current waveforms are in phase, the power factor of load equals unity, and the reactive power consumption is zero. This situation enables the most efficient transport of active power, leading to the attainment of the cheapest distribution system. In the past, the solutions to mitigate these identified power quality problems were through conventional passive filters. However, their limitations, such as fixed compensation, resonance with the source impedance, and difficulty in tuning time dependence of filter parameters, have ignited the need for active and hybrid filters.viability variations. Studies have indicated that as much as 13% of total power generated is wasted in the form of losses at the distribution level. To reduce these losses, shunt capacitor banks are installed on distribution primary feeders. The [4] FACTS devices and Custom power devices are introduced to electrical system to improve the power quality of the electrical power. DVR, DSTATCOM, ACTIVE

FILTERs, UPQC etc are some of the devices used to improve the power quality of the voltage and current. With the help of these devices we are capable to reduce the problems related to power quality [2] & [3]. Although all devices can improve the power quality but in this the focus is on UPQC. UPQC is a power electronic device consisting of both DVR and D-STATCOM, former is connected in series and latter is connected in parallel to protect the sensitive load from all disturbances. Even as harmonic distortion and power Factor issues surfaced, no one was really prepared. Even today, crane builders and electrical drive System vendors avoid the issue during competitive bidding for new cranes. Rather than focus on Awareness and understanding of the potential issues, the power quality issue is intentionally or unintentionally ignored. Power quality problem solutions are available. Although the solutions are not free, in most cases, they do represent a good return on investment. However, if power quality is not specified, it most likely will not be delivered.The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. Low power factor loads can also affect the voltage stability which can ultimately result in detrimental effects on the life of sensitive electronic equipment or even intermittent malfunction. Voltage transients created by DC drive SCR line notching, AC drive voltage chopping, and high frequency harmonic voltages and currents are all significant sources of noise and disturbance to sensitive electronic equipment. In other words, the reactive power oscillates between the ac source and the capacitor or reactor, and also between them, at a frequency equals to two times the rated value (50 or 60 Hz). For this reason it can be compensated using VAR generators, avoiding its circulation between the load (inductive or capacitive) and the source, and therefore improving voltage stability of the power system. Power quality has different meanings to different people. Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 [5] defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” A simpler and perhaps more concise definition might state: “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.” This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. As appropriate as this description might seem, the limitation of power quality to “sensitive electronic equipment” might be subject to disagreement. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment”. There is a broad range of power quality problems associated with power systems based on time such as long duration variations, short duration variations and other disturbances. In this paper a new control algorithm for the UPQC system is optimized without measuring transformer voltage, load and filter current, so that system performance is improved [6]. The proposed control technique has been evaluated and tested under non-ideal mains voltage and unbalanced load conditions using Matlab/Simulink software.

II. Linear and Non Linear Loads

1) Linear Loads: AC electrical loads where the voltage and current waveforms are sinusoidal and the current at any time proportional to voltage are treated as linear loads. If pure sinusoidal voltage is passed through the resistive element, then the shape of the current wave form will be purely sinusoidal without distortions. Voltage and current waveform in a circuit involving inductor makes voltage to lead current. On the other hand for a circuit involving capacitor, current leads voltage.

2) Non-Linear Loads: AC loads where the current is not proportional to the voltage are considered as nonlinear loads. Non-linear loads generate harmonics in the current waveform that leads to distortion of the voltage waveform; under these conditions the voltage is no longer proportional to the current. The table below shows the examples of linear and non-linear loads and comparison between them.

Table 1: Comparison between Linear and Non-Linear loads

S.No.	Linear Loads	Non- Linear Loads
1	Ohms law is valid here.	Ohms law is not valid.
2	Load current does not contain harmonics.	Load current contain all odd harmonics.
3	Could be either Inductive or capacitive.	Can’t be categorized as leading or lagging loads.
4	Zero neutral current, If 1-phase loads are equally balanced on 3-phase mains (Vector sum of line current).	Even if single phase are equally balanced on three phase neutral current 2.8 times the line current.
5	Linear Loads may not demand for high in-rush currents while starting.	High in-rush current is drawn approximately for one cycle.
6	Examples; Power factor improvement Capacitor, Heaters, Incandescent lamps etc.	Examples; SMPS, UPS, Computers, Laser Printers, Refrigerators etc.

III. Unified Power Quality Conditioner

The provision of both series active power filter (APF) and shunt active power filter can control the power quality of the source current and the load bus voltage. In addition, if the series and shunt active power filters are connected on the DC side, the DC bus voltage can be regulated by the shunt connected active power filter while the series active power filter supplies the required energy to the load in case of the transient disturbances in source voltage. The configuration of such a device (termed as Unified Power Quality Conditioner (UPQC)) [7]. This is a versatile device similar to a UPFC. However, the control objectives of a UPQC are quite different from that of an UPFC.

1) Control Objectives of UPQC

The shunt connected converter has the following control objectives:

A) To balance the source currents by injecting negative and zero sequence components required by the load.

B) To compensate for the harmonics in the load current by injecting the required harmonic currents.

C) To control the power factor by injecting the required reactive current (at fundamental frequency).

D) To regulate the DC bus voltage.

The series connected converter has the following control objectives:

A) To balance the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source.

B) To isolate the load bus from harmonics present in the source voltages, by injecting the harmonic voltages

C) To regulate the magnitude of the load bus voltage by injecting the required active and reactive components (at fundamental frequency) depending on the power factor on the source side.

D) To control the power factor at the input port of the UPQC (where the source is connected. Note that the power factor at the output port of the UPQC (connected to the load) is controlled by the shunt converter.

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 devices, which need high-quality energy to work properly, at the same time, are the most responsible ones for injections of harmonics in the distribution system [8]. Therefore, devices that soften this drawback have been developed.

2) Basic configuration of UPQC

The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers:

a) Series converter: It is a voltage-source converter connected in series with the AC line and acts as a voltage source to mitigate voltage distortions. It is used to eliminate supply voltage flickers or imbalance from the load terminal voltage and forces the shunt branch to absorb current harmonics generated by the nonlinear load. Control of the series converter output voltage is usually performed using Hysteresis band controller [9]. The gate pulses required for converter are generated by the comparison of a fundamental voltage reference signal with a high-frequency triangular waveform.

b) Shunt converter: It is a voltage-source converter connected in shunt with the same AC line and acts as a current source to cancel current distortions, compensate reactive current of the load, and improve the power factor. It also performs the DC-link voltage regulation, resulting in a significant reduction of the DC capacitor rating. The output current of the shunt converter is adjusted using a dynamic hysteresis band by controlling the status of semiconductor switches so that output current follows the reference signal and remains in a predetermined hysteresis band.

c) Midpoint–to-ground capacitor bank: It is divided into two groups, which are connected in series. The neutrals of the secondary transformers are directly connected to the DC link midpoint. As the connection of both three-phase transformers is Y/Yo, the zero-sequence voltage appears in the primary winding of the series-connected transformer in order to compensate for the zero-sequence voltage of the supply system. No zero-sequence current flows in the primary side of both transformers. It ensures the system current to be balanced even when the voltage disturbance occurs.

d) Low pass filter: It is used to attenuate high frequency components at the output of the series converter that are generated by high-frequency switching.

e) High pass filter: It is installed at the output of shunt converter to absorb current switching ripples.

f) Series Shunt transformers: These are implemented to inject the compensation voltages and currents, and for the purpose of electrical isolation of UPQC converters. The UPQC is capable of steady-state and dynamic series and/or shunt active and reactive power compensations at fundamental and harmonic frequencies. However, the UPQC is only concerned about the quality of the load voltage and the line current at the point of its installation, and it does not improve the power quality of the entire system.

The proposed UPQC control block diagram is shown as below;

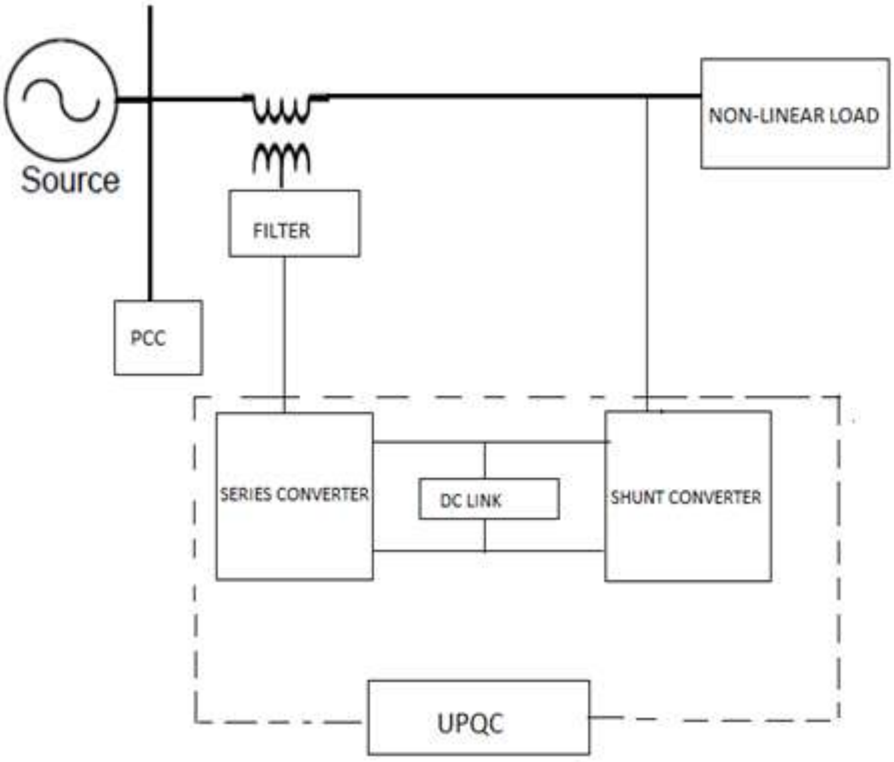

Fig 1. Block configuration of UPQC

The dc-link storage element (either inductor or dc-bus capacitor) is shared between two current-source or voltage-source bridges operating as active series and active shunt compensators. It is used in single-phase as well as three-phase configurations. It is considered an ideal AF, which eliminates voltage and current harmonics [10] & [11] and is capable of giving clean power to critical and harmonic-prone loads, such as computers, medical equipment, etc. It can balance and regulate terminal voltage and eliminate negative-sequence currents. Its main drawbacks are its large cost and control complexity because of the large number of solid-state devices involved.

IV. Matlab model of UPQC

The Fig 2 below shows the MATLAB model of the Unified Power Quality Conditioner (UPQC). Firstly the reference voltages and the reference currents are generated and then the reference voltages are compared with the actual load voltages and the reference currents are compared with the actual source currents and then the error signals are given to the hysteresis controllers for generating the switching signals for the switches of series active power filter and the shunt active power filter. And the generated pulses are then given to the series and shunt APF’s and accordingly the switches are turned on and off to compensate for the voltage and current harmonics. [12]

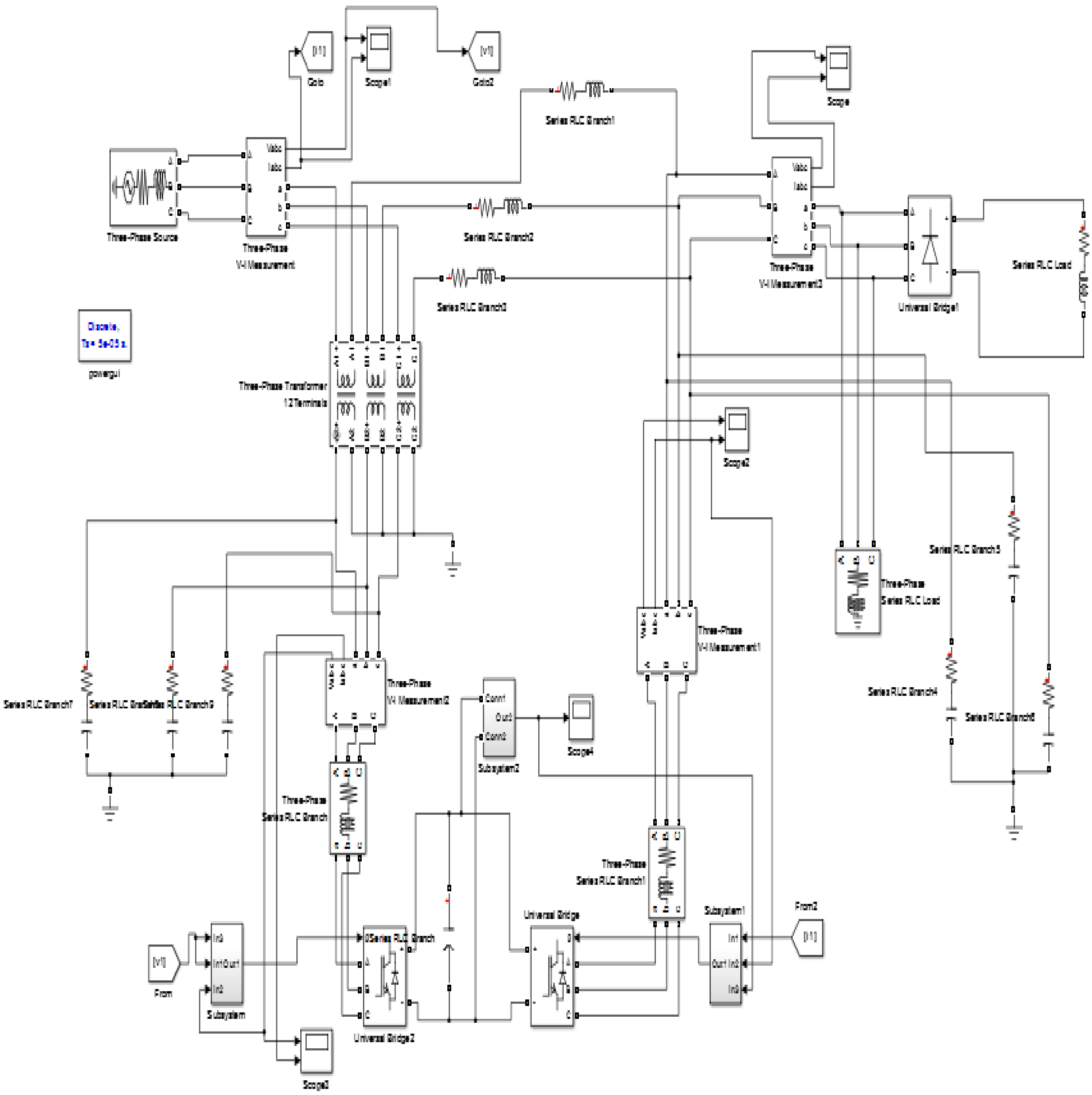

Fig 2. Matlab model of UPQC

- **System parameters**

System voltage	230 V
System Frequency	50 Hz
Load side (Linear & Non-Linear)	1KW ; 450W
Line parameters (Resistance & Inductance)	0.01 ohm; 3mH
Passive filters (Resistance & Capacitance)	0.01 ohm; 15micro farad
DC side Voltage	600V
DC capacitor Voltage	2100 micro farad

V. Simulink Results

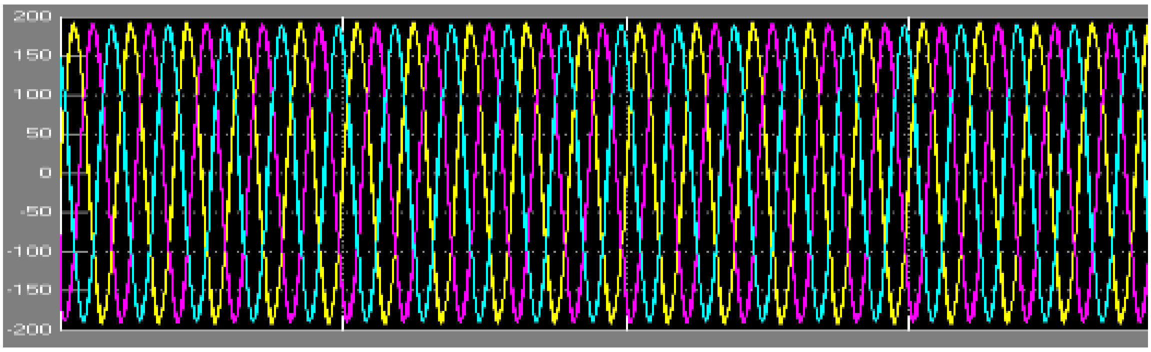

Fig 3 a). Grid Side & Voltage Waveform a, b, c (Without Compensation)

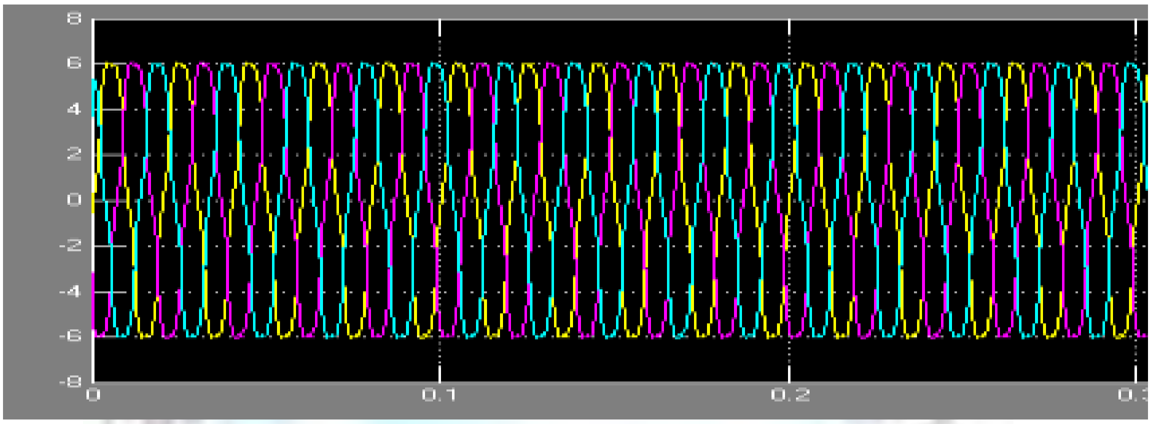

Fig 3 b). Grid Side Current Waveform (Without Compensation)

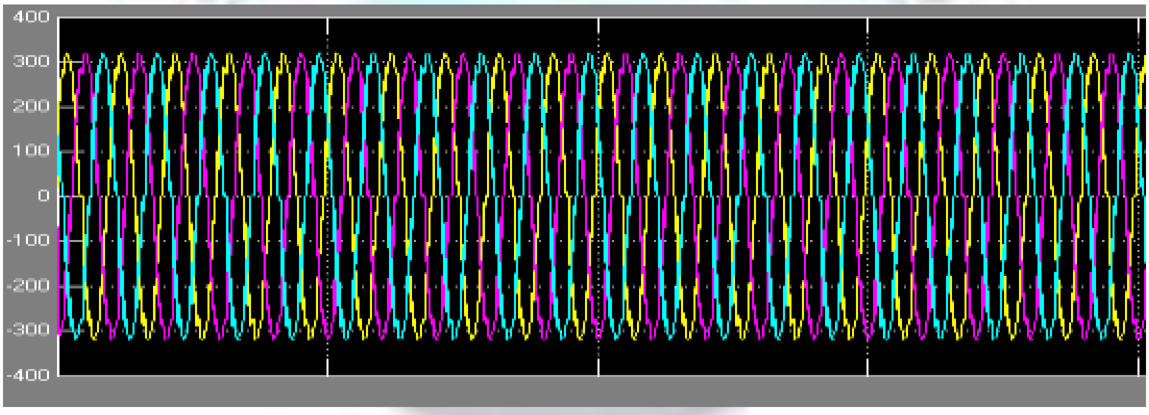

Fig 4 a). Load Side Current Waveform a, b, c (Without Compensation)

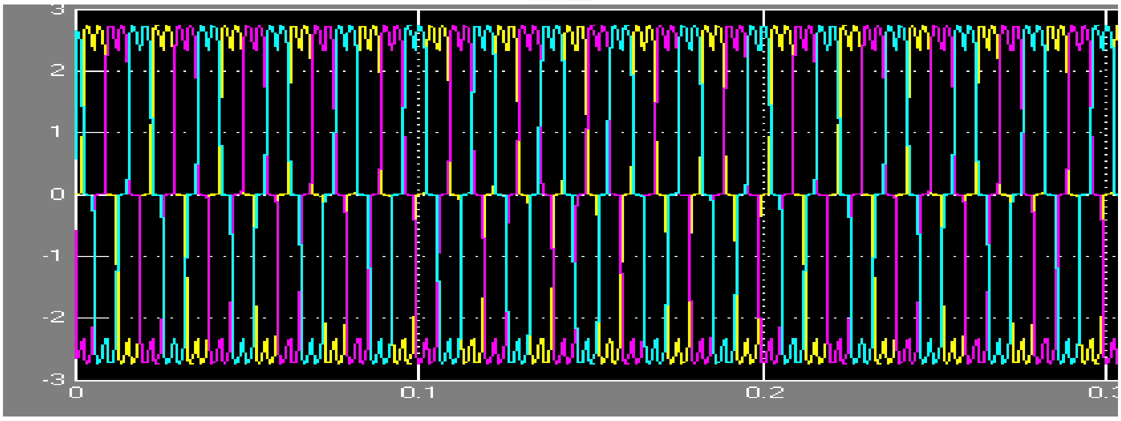

Fig 4 b). Load Side Current Waveform (With Compensation)

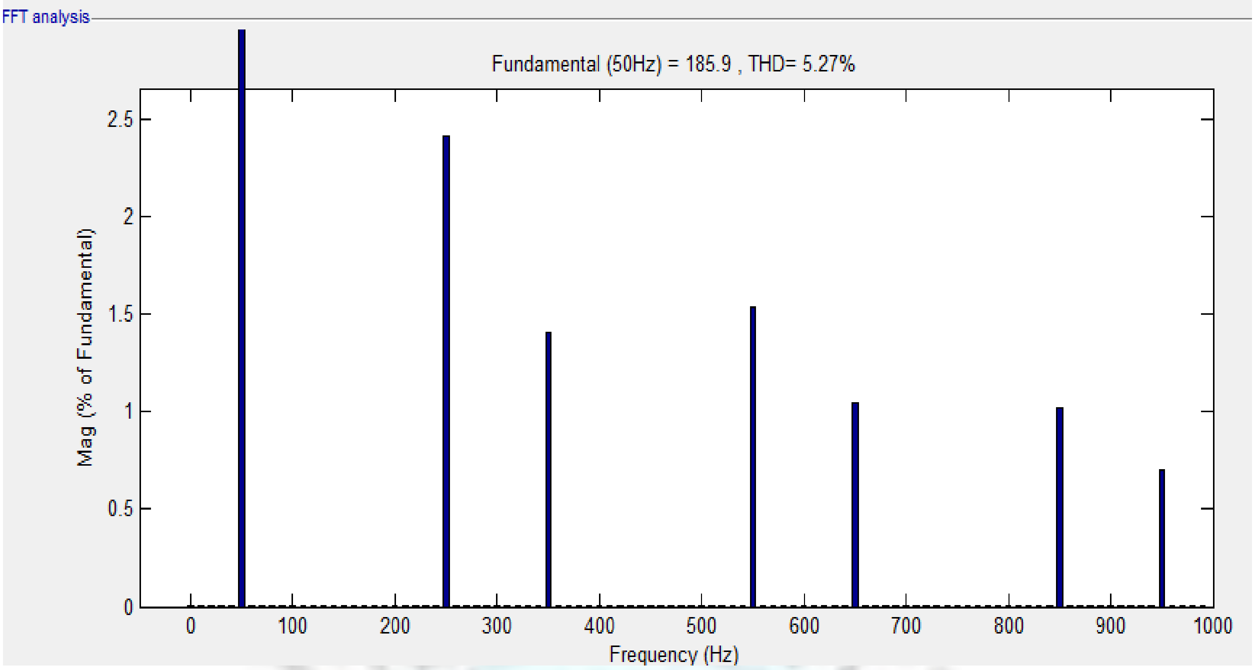

Fig 5 a) THD Analysis of Grid Side Voltage (Without Compensation)

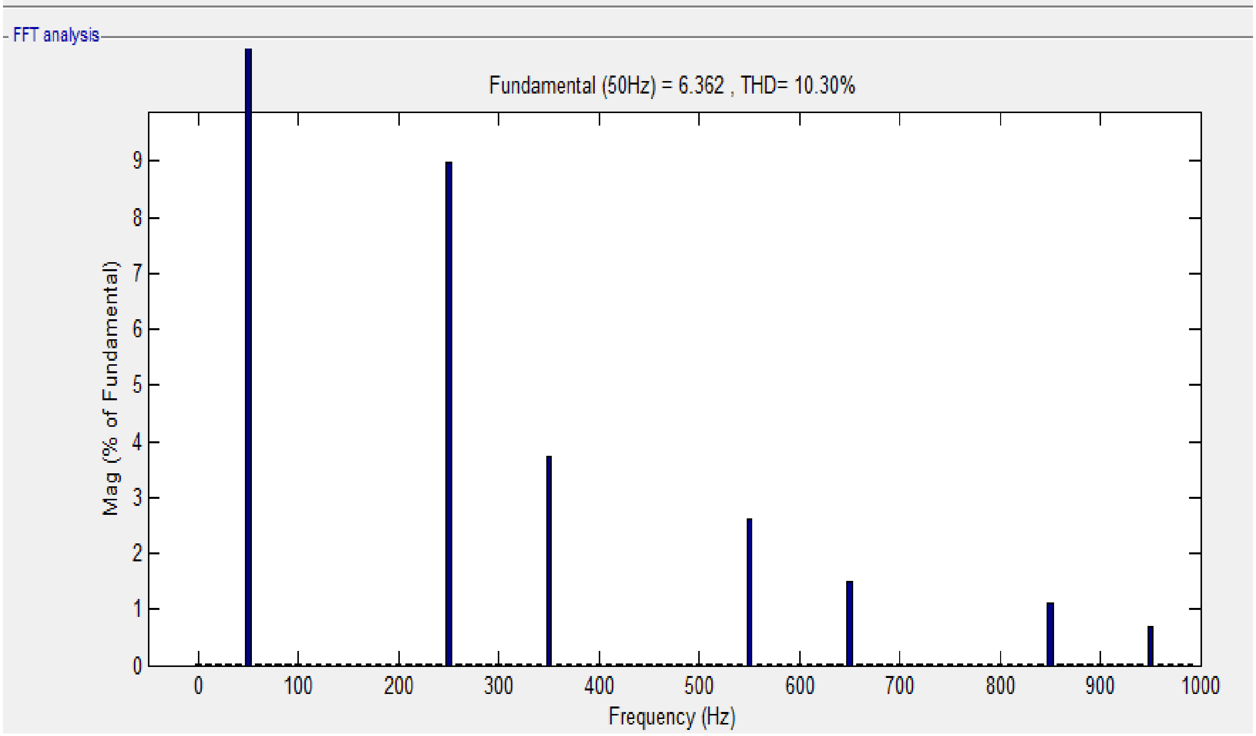

Fig 5 b) THD Analysis of Grid Side Current (Without Compensation)

By injecting the required amount of current to the system the source current become sinusoidal as shown in Figure 5 a). With the proposed control algorithm the source current improves with the THD of 3.58% which is well within the standard. In order to perform the above task the capacitor voltage should have to be maintained, and must be regulated by the algorithm.

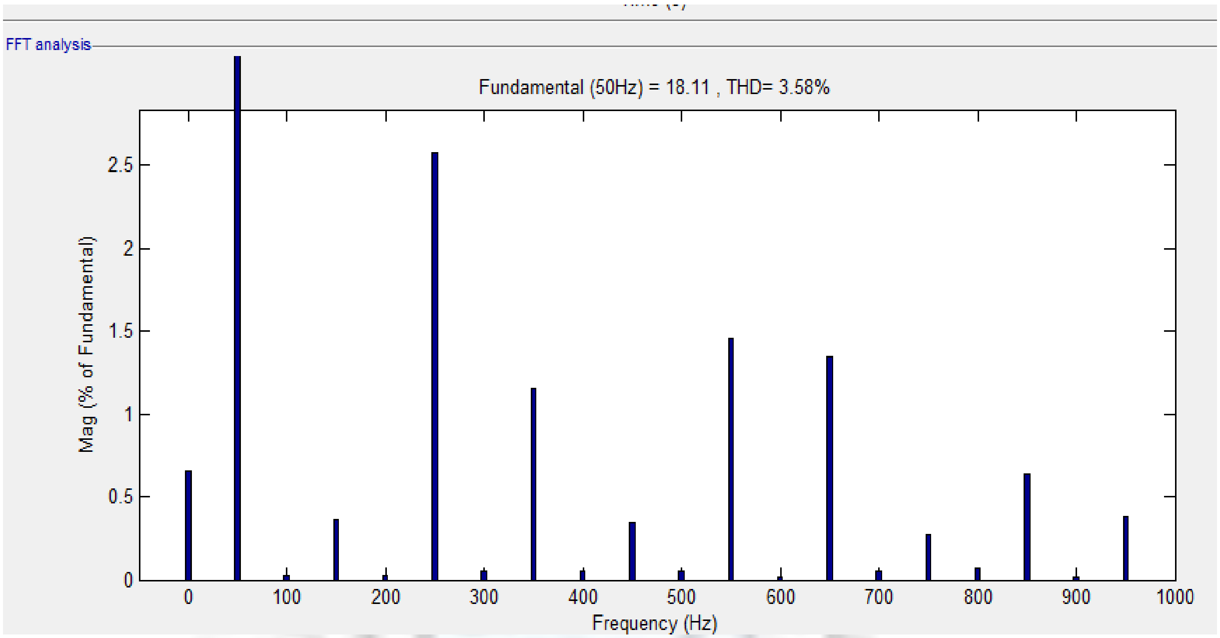

Fig 7 a) THD Analysis of Grid Side Current (With Compensation)

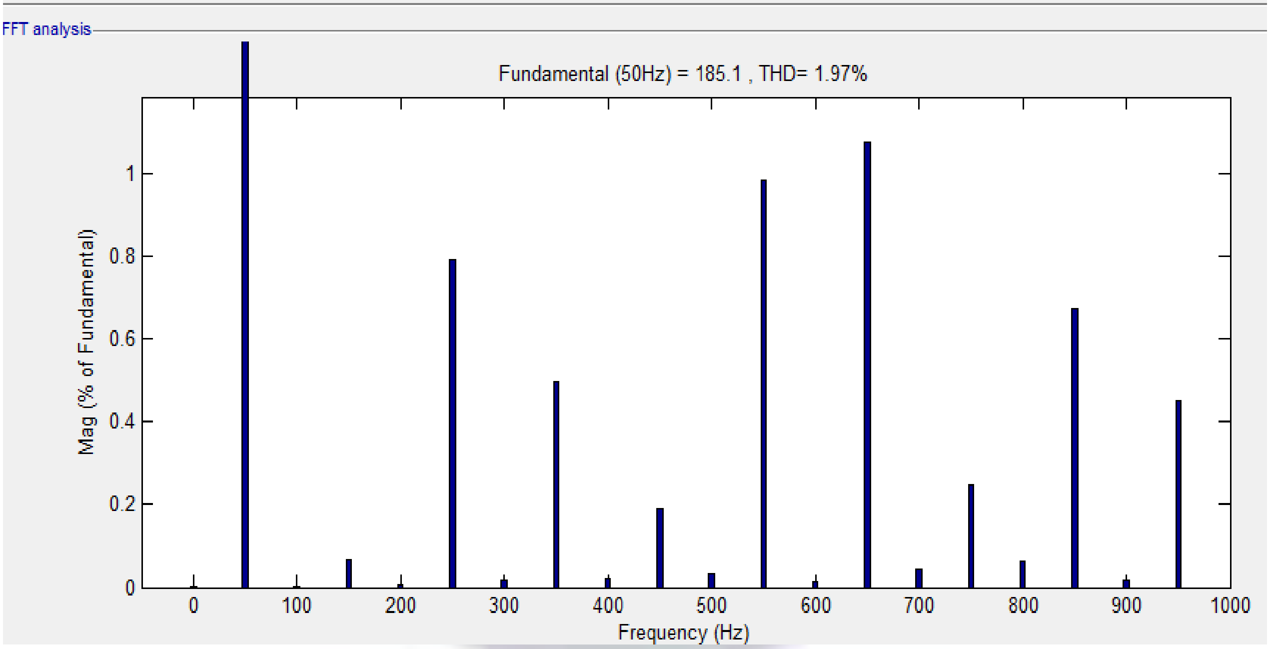

Fig 7 b): THD Analysis of Grid Side Voltage (With Compensation)

The tabular column shown below indicates the difference in the system having system with UPQC and without UPQC.

Tabular Column: Comparison of THD between with and without UPQC

	Without UPQC		With UPQC	
	Values	THD	Values	THD
V source	230 V	5.27%	230 V	1.97%
I source	6.362 A	10.30%	18.11A	3.58%
V load	230 V	7.49%	230 V	5.93%
I load	2.847 A	26.34%	5.328 A	10.82%

VI. CONCLUSION

Hereby Custom power devices like UPQC can enhance power quality in the distribution system. Based on the power quality problem at the load or at the distribution system, there is a choice to choose particular custom power device with specific compensation. Unified Power Quality Conditioner (UPQC) is the combination of series and shunt APF, which compensates supply voltage and load current imperfections in the distribution system. In this paper we are able to compensate the harmonics caused by a three phase uncontrolled diode rectifier and it provides positive results by reducing the percentage of THD of the line current. In fact, the distortion of the power supply current was diminished to a satisfactory level with THD =3.58 %. As a conclusion, the objectives of this paper have been achieved by reducing the harmonic components that exist in a power system with a chosen combination of Linear and Non-linear load.

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