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Harmonics Reduction In Non Linear Sensitive Loads Using Pi-Fuzzy Based Ipqc

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Abstract

One of the major concerns in electricity industry today is power quality. It becomes especially important with the introduction of advanced and complicated devices, whose performance is very sensitive to the quality of power supply. Power Quality (PQ) has become an important issue to electricity consumers at all levels of usage. The PQ issue is defined as “Any power problem manifested in voltage, current, or frequency deviations that results in failure of customer equipment.” The development of power electronic based equipment has a significant impact on quality of electric power supply. Power Quality (PQ) has become an important issue to electricity consumers at all levels of usage. The main causes of a poor power quality are harmonic currents, poor power factor, supply-voltage variations, etc. To mitigate power quality problems, we have various equipments like active filter, passive filter, unified power flow controller and unified power quality conditioner etc. Among from them unified power quality conditioner was widely studied by many researchers as an eventual method to Improve power quality of electrical distribution System. The proposed IPQC has ultimate capability to improve the power quality at the point of installation on power distribution systems and industrial power systems. Artificial intelligence based gain scheduling is an alternative technique commonly used in designing controllers for non-linear systems. Fuzzy system transforms a human knowledge into mathematical rule base. The conventional performance of UPQC is improved using the optimization method like Fuzzy Logic. The performance of the proposed system was analyzed through simulations with MATLAB software.

Keywords—UPQC, Power Quality, Shunt Inverter Control, Series Inverter Control, Voltage harmonics, Current harmonics, PI controller, Fuzzy Controller.

Introduction

Power quality is the set of limits of electrical properties that allows electrical system to function in proper manner without significant loss of performance Like flexible ac transmission system, the term custom power use for distribution system. The present power distribution system is usually configured as a three-phase three-wire or four-wire structure featuring a power-limit voltage source with significant source impedance, and an aggregation of various types of loads. The extensive use of non-linear loads in modem power system is becoming highly vulnerable to power quality and contributing to increased power quality issues. The main causes of a poor power quality are harmonic currents, poor power factor, supply voltage variations, etc. In recent years the demand for the quality of electric power has been increased rapidly. Power quality problems have received a great attention nowadays because of their impacts on both utilities and customers. Voltage sag, swell, momentary interruption, under voltages, over voltages, noise and harmonics are the most common power quality disturbances. There are many custom power devices. The devices either connected in shunt or in series or a combination of both. The devices include D-STATCOM, DVR and UPQC etc. Many efforts have been taken by utilities to fulfill consumer requirement, some consumers require a higher level of power quality than the level provided by modern electric networks. This implies that some measures must be taken so that higher levels of Power Quality can be obtained.

Active power filters (APF) have been proposed as efficient tools for power quality improvement. Active power filters can be classified as series or shunt according to their system configuration. The series APF generally takes care of the voltage based distortions, while shunt APF mitigates current based distortions. The combination of series and shunt active power filter is called the unified power-quality compensator (UPQC). UPQC mitigates the voltage and current based distortion simultaneously as well as independently. Series active power filter working as a sinusoidal current source, in phase with the mains voltage. The amplitude of the fundamental current in the series filter was controlled through the error signal generated between the load voltage and a pre-established reference. The control allows an effective correction of power factor, harmonic distortion, and load voltage regulation

Power quality of sensitive loads can be improved by a unified power quality conditioner (UPQC) which consists of back-to-back connected series and shunt active filters, and is modeled using state-space-averaging technique to analyze its behavior. The UPQC is modeled with reference to a synchronously rotating d-q-0 reference axes. Compared to the traditional low pass filtering methods, the proposed method is seen to result in a more rapid dynamic response. The proposed UPQC used to compensate for various voltage disturbance of the power supply, to correct any voltage fluctuation and to prevent the harmonic load current from entering the power system. The proposed direct compensation control method used in the series active filter and the moving window current calculation method used in the shunt active filter make the UPQC response very quickly to any sudden voltage change.

The Power Quality

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.” The power quality problem is defined as any problem manifested in voltage, current or frequency deviations that result in mal-operation of customer equipment. The power quality problem causes the deterioration of performance of various sensitive electronic and electric equipments. The voltage should be balanced in all three phases. Supply should be reliable i.e. continuous availability without interruption. For a sensitive load, there must be a deviation from the above statement. Sensitive electrical equipments susceptible to power quality or more appropriately to lack of power quality would fall within a wide range. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. These electrical devices might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or most of the household appliances.

Power quality problems are associated to an extensive number of electromagnetic phenomena in power systems with a broad range of time. For instance, it includes impulsive transients (in the range of nanoseconds) as well as frequency deviations (in the range of some seconds). The classification takes the voltage into account, as the quality of the voltage is the addressed issue in most of the cases. However, it is well known that there is always a close relationship between voltages and currents in a power system. Specifications regarding current are applied to dimensioning equipment or in the case of harmonics. There are a number of different types of power quality disturbances and also a number of different ways to define and categorize them.

Unified Power Quality Conditioner

Unified Power Quality Conditioner (UPQC) is a multifunction power conditioner that can be used to compensate various voltage disturbance of the power supply, to correct voltage fluctuation, and to prevent harmonic load current from entering the power system. It is a custom power device designed to mitigate the disturbances that affect the performance of sensitive and/or critical loads. UPQC has shunt and series compensation capabilities for (voltage and current) harmonics, reactive power, voltage disturbances (including sag, swell, flicker etc.), and power-flow control. The series and shunt active power filter couples together through the DC-link energy storage capacitors. Normally, a UPQC consists of two voltage-source inverters with a common dc link designed in single-phase, three-phase three-wire, or three phase four-wire configurations. One inverter is controlled as a variable voltage source in the series active power filter (APF). The other inverter is controlled as a variable current source in the shunt active power filter (APF). The series APF compensates for voltage supply disturbances (e.g., including harmonics, imbalances, negative and zero sequence components, sag, swell, and flickers). The shunt APF converter compensates for load current distortions (e.g., caused by harmonics, imbalances) and reactive power, and perform the dc link voltage regulation.

In this study, the power supply is assumed to be a three-phase, three-wire system. The two active filters are composed of two 3-leg voltage source inverters (VSI). Functionally, the series filter is used to compensate for the voltage distortions while the shunt filter is needed to provide reactive power and counteract the harmonic current injected by the load. Also, the voltage of the DC link capacitor is controlled to a desired value by the shunt active filter. There can be negative and zero sequence components in the supply when a voltage disturbance occurs. The DC link capacitor bank is divided into two groups connected in series. The neutrals of the secondary of both transformers are directly connected to the dc link midpoint. In this way, as the connection of both three phase transformers is Y/Yo, 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 when the voltage disturbance occurs. Assuming that the load is non-linear, the power system model considered can be divided into following units: the power supply system, series active filter and shunt active filter. These constituent members of the UPQC are modeled separately in this section. First consider the power supply system. By Kirchhoff‘s law:

$$V_{if} = e_i - L_s\frac{diis}{dt} - R_s i_{is} - V_{sh} \qquad \text{.......................................(i)}$$

$$i_{is} = i_{iL} - i_{ih} \qquad \text{.......................................(ii)}$$

Where, subscript i refers to a, b and c phases in the power system; Ls and Rs are the inductance and resistance of the transmission line; e_i is source voltage; v_{ih} is the output voltage of the series active filter; i_{is} is the line current; i_{iL} is the load current and i_{is} is the output current of the shunt of the shunt active filter respectively. For the series active filter,

$$V_{ih} = L_1\frac{diis}{dt}+R_1 i_{is} = d_{1i}V_{c1}+ (1-d_{1i})V_{c2}$$

Where, L_l and R_l are the leakage inductance and resistance of the series transformer, Vc1 and Vc2 are the voltages of dc link capacitors; d_{li} is the switch duty ratio of the series active filter. Without loss of generality, the turn‘s ratio of the transformer is assumed to be unity.

For shunt active filter:

$$L_2\frac{diih}{dt} = R_2 i_{ih} - V_{if} +d_{2i}V_{c1}+ (1-d_{2i})V_{c1} \qquad \text{...(iii)}$$

Where L_2 and R_2 are the leakage inductance and resistance of the shunt-connected transformer, d2i is the switch duty ratio of the shunt active filter. The turn‘s ratio of this transformer is also assumed to be unity

UPQC Control Model Design Using Dq0 Transformation

Control strategy plays the most significant role in any power Electronics based system. It is the control strategy which decides the behaviour and desired operation of a particular system. The effectiveness of a UPQC system solely depends upon its control algorithm. The UPQC control strategy determines the reference signals (current and voltage) and, thus, decides the switching instants of inverter switches, such that the desired performance can be achieved. There are several control strategies/technique available in the existing paper those have successfully applied to UPQC systems.

The control system has four major elements, which are a positive sequence detector, a shunt inverter control, a series inverter control, and a DC/DC converter control. Fig. 2 shows the control system of the proposed UPQC, including the power circuit.

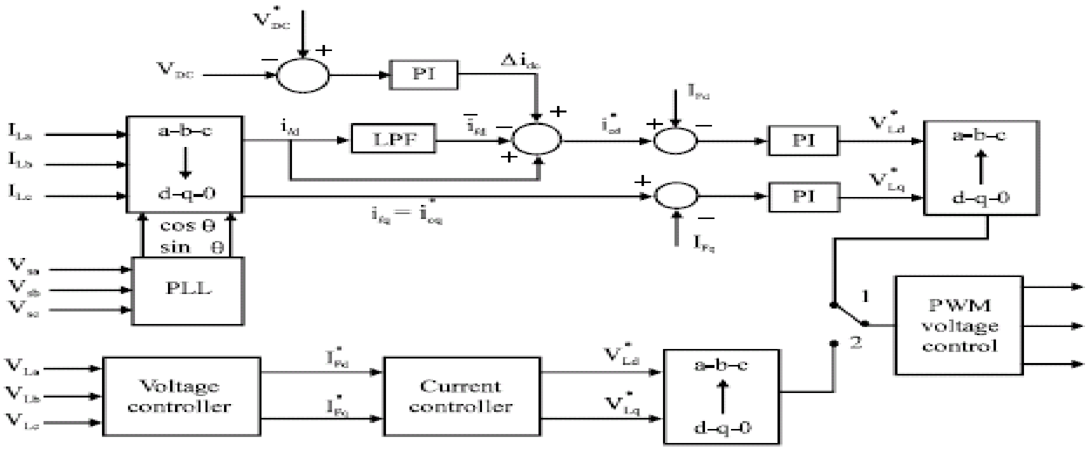

Figure 2: Proposed UPQC control system

The positive-sequence detector extracts the positive sequence component from the disturbed three-phase source voltage. This detector derives the transformed reference voltages based on the α −β − 0 transform. The measured source voltage passes through the PLL (Phase- Locked Loop) and the sine wave generator to calculate the fundamental component of the A-B transformed current.

Shunt Inverter Control

The control strategy for shunt APF is based on the utilization of closed loop PI controllers. These PI controller are used to get the amplitude of the in-phase components of reference supply currents (Im), The PI controller is realized on the sensed and reference values of DC bus voltage of back-back VSI capacitor of UPQC. To regulate the voltage at PCC the three-phase reference supply currents have component and this component of reference supply currents in-phase with the voltage at PCC. It is very essential to feed active power to the load and the losses of UPQC. The second component is in quadrature component which is quadrature with the voltage at PCC.

Active filters are implemented using a combination of passive and active (amplifying) components, and require an outside power source. Operational amplifiers are frequently used in active filter designs. These can have high Q, and can achieve resonance without the use of inductors. However, their upper frequency limit is limited by the bandwidth of the amplifiers used. Multiple element filters are usually constructed as a ladder network. These can be seen as a continuation of the L,T and π designs of filters.

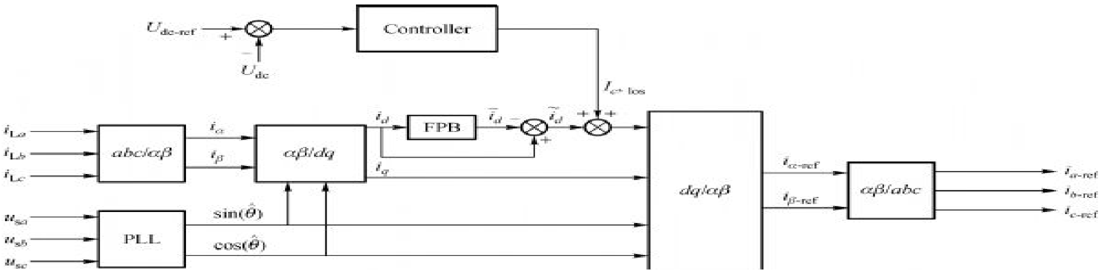

Figure 3: Shunt Active Power Filter block Diagram

Series Inverter Control

Series active power filters were introduced by the end of the 1980s and operate mainly as a voltage regulator and as a harmonic isolator between the nonlinear load and the utility system. The series connected filter protects the consumer from an inadequate supply voltage quality. This type of approach is especially recommended for compensation of voltage unbalances and voltage sags from the ac supply and for low power applications and represents economically attractive alternatives to UPS, since no energy storage (battery) is necessary and the overall rating of the components is smaller. The series active filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side.

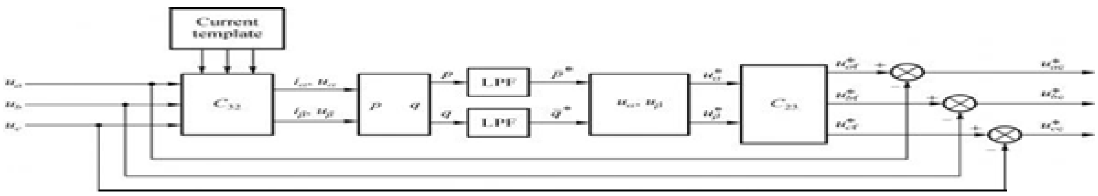

Figure 4: Series Active Power Filter block Diagram

Intelligent Power Quality Conditioner(Ipqc)

To verify the operating performance of the proposed IPQC, a 3-phase sensitive electrical system, with reference signal generation method is designed for IPQC and compared its performance with conventional electrical system as well as normal UPQC and the graphs are plotted. The Harmonic Distortion is plotted for output current and voltage. The proposed algorithm has been tested in simulation, using the SimPowerSystems BlockSet from MatLab. The IPQC is designed using a conventional PI controller combined with the fuzzy logic. The rule base is developed in Matlab. The logic of an approximate reasoning continues to grow in importance, as it provides an in expensive solution for controlling know complex systems.

PI controller

A PI controller is selectrd to controlthe UPQC while connectd to the nonlinear sensitive loads. The linear load voltage is sensed and forwarded through a sequence analyzer. To eliminate zero sequence components from abc components is the advantage of abc to dqo transformation. The d- coordinate and q-coordinate have separate PI controller. The PI controller is a feedback controller which controlled by the summation of the error and integral of that values as shown in figure 5.

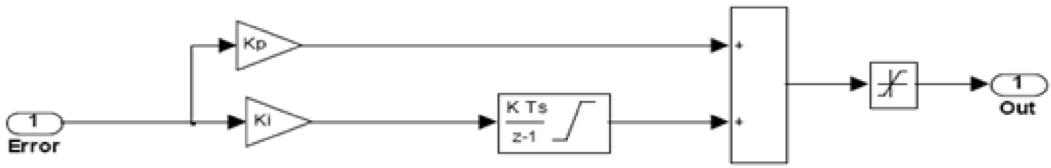

Figure 5: PI controller

Fuzzy Logic Pi Controller

The structure of a complete fuzzy control system is composed from the following blocs: Fuzzification, Knowledge base, Inference engine, Defuzzification. The fuzzification module converts the crisp values of the control inputs into fuzzy values. A fuzzy variable has which are defined by linguistic variables (fuzzy sets or subsets) such as low, Medium, high, big, slow where each is defined by a gradually varying membership function. In fuzzy set terminology, all the possible values that a variable can assume are named universe of discourse, and the fuzzy sets (characterized by membership function) cover whole universe of discourse. The shape fuzzy sets can be triangular, trapezoidale, etc. To verify the performance of UPQC the system was simulated using Simulink Power System Blockset in Matlab. The performance of Fuzzy logic controller is well documented for improvements of both transient and steady State performances. The function of fuzzy logic controller is very useful since exact mathematical model of it is Not required. The fuzzy logic control system can be divided into four main functional blocks namely Knowledge base, Fuzzification, Inference mechanism and Defuzzification, Rule base. In this study, a fuzzy logic based feedback controller is employed for controlling the series and shunt filters and the energy storing sections.

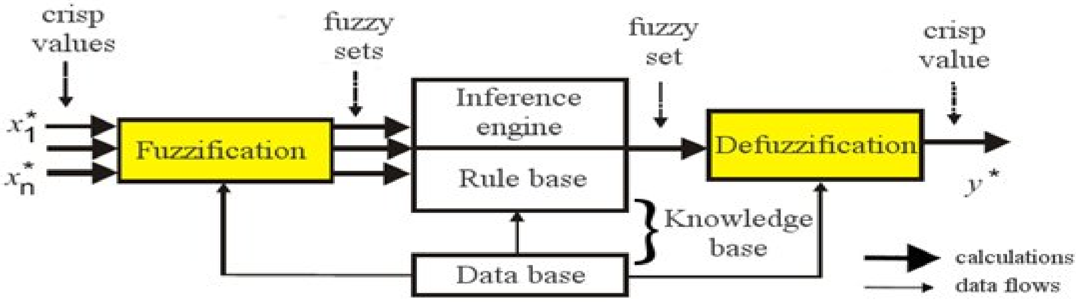

Figure 6: Fuzzy controller block diagram

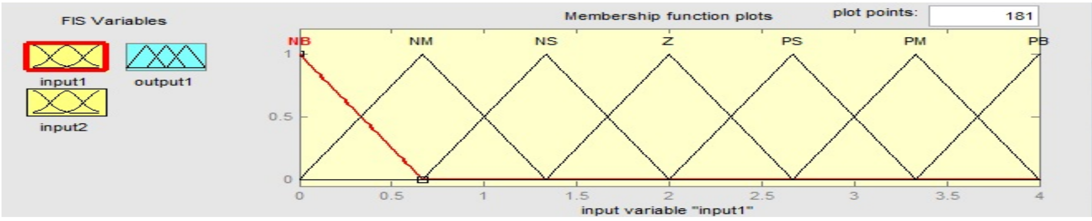

Figure 7: fuzzy rule base for error input, 'e'

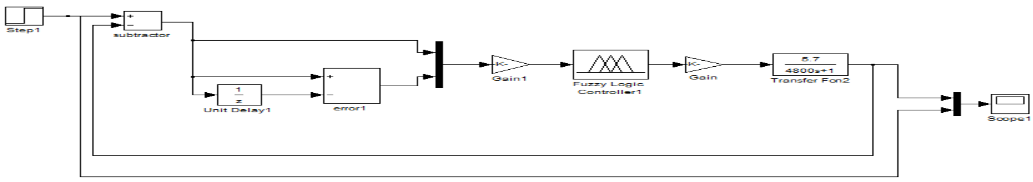

Figure 8: Fuzzification Simulink Connection

The harmonics and unbalanced components are compensated in case of unbalanced and distorted current and voltage at the PCC. Simulation results show that the proposed control strategy compensates harmonic components as well as most of the other unbalanced load current distortions. It is shown that the IPQC can compensate the voltage and current problems simultaneously. In this study, the proposed SRF-based control algorithm for the UPQC is evaluated by Matlab/Simulink software under Unbalanced and distorted load-current and source-voltage conditions. The UPQC system parameters used in this study are given in Table 1

Table 1: UPQC system parameters for design

SYSTEM PARAMETERS	No disturbance	With disturbance
Source voltage of phase A	230 V	200 V
Source voltage of phase B	230V	230 V
Source voltage of phase C	230 V	230 V
Smoothing resistance	0.1 Ω	0.1 Ω
Smoothing reactance	0.15 mH	0.15 mH
DC link capacitor	2 mF	2 mF
Sample interval	0.00001 S	0.00001 S
Normal load resistance	175 Ω	175 Ω
Normal load reactance	200 mH	200 mH
Increased load resistance	175 Ω	175 Ω
Increased load reactance	300 mH	300 mH
Step input	0.5 S	0.5 S
FIS type for FLC	Mamdani	Mamdani
Membership function for	7X7 Triangular	7X7 Triangular

FLC		
Implication for FLC	Min	Min
Deffuzification	Centroid	Centroid

Table 1:- UPQC system parameters for design

The simulation is carried out using MATLAB software and the various results are plotted. It is observed that the designed UPQC can able to eliminate the current and voltage harmonics to a considerable level. The output voltage and current wave forms are given below,

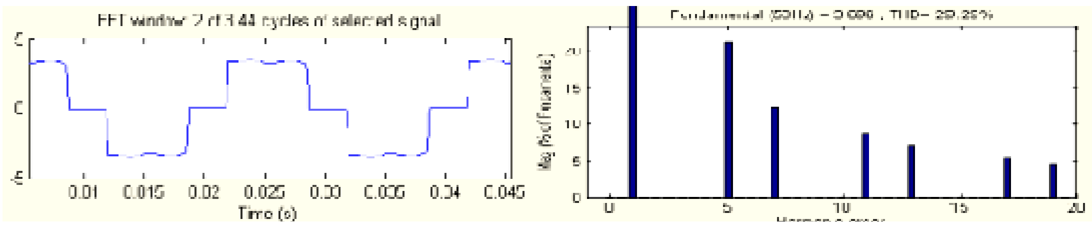

Figure 9: Load Current Harmonic Analysis for a system with UPQC

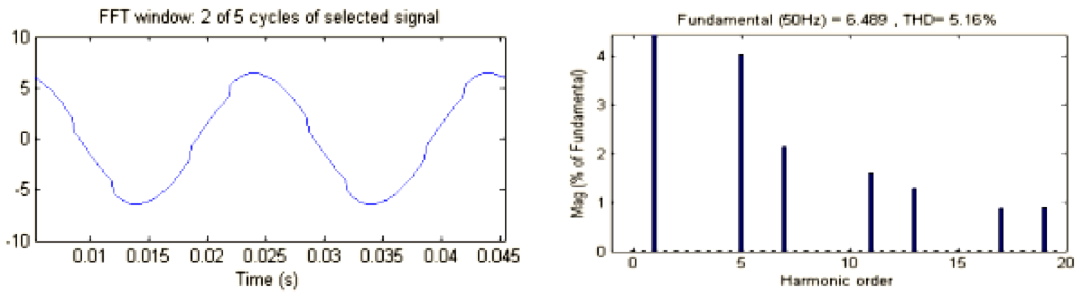

Figure 10: Load Current Harmonic Analysis for a system with UPQC and PI

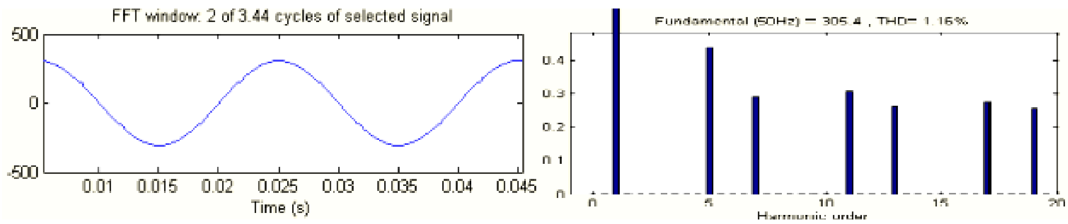

Figure 11: Load Voltage Harmonic Analysis for a system with UPQC and FLC

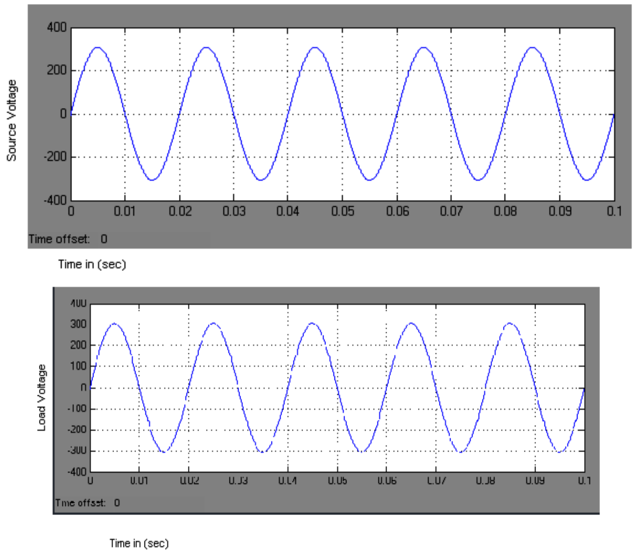

Figure 12: Source and load voltages UPQC and FLC

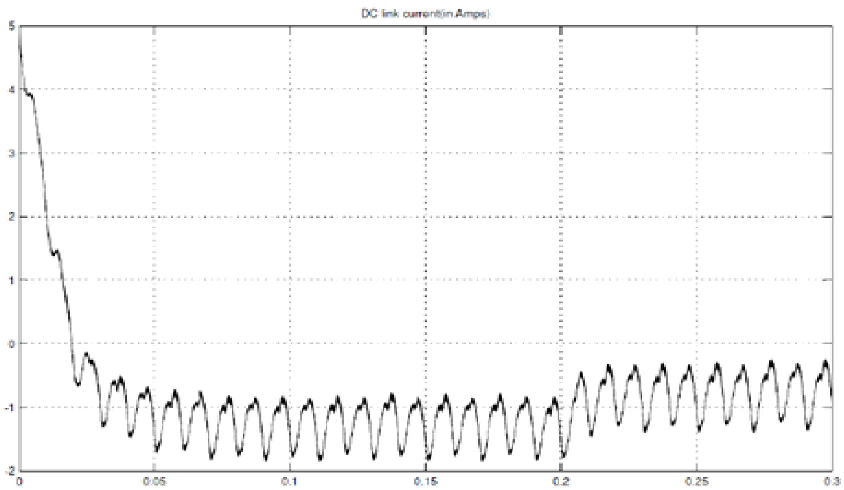

Figure 13: performance plot of the designed IPQC with Fuzzy PI controller for sensitive laod

The spectrum analysis is generated using the Simulink for all harmonics upto 25th order is also viewed. It is observed that the after compensation, the THD level of the load voltage is approximately 1.16% and the source current is approximately 01.19%.

Conclusions

UPQC performance mainly depends upon how accurately and quickly reference signals are derived. In the present work two controllers, PI controller and Fuzz logic controllers are used to control the UPQC which is used to compensate the current harmonics. The simulation results showed that, even if the supply voltage is unbalanced (non-ideal) the performance of SHAF using FLC with triangular MF comfortably outperformed the results obtained using SHAF with PI controller. The THD value offered by the SHAF when controlled by FLC (with triangular MF) is much less as compared to the THD value obtained using PI controller. The obtained results of the simulations show that the IPQC is sensible equipment able to compensate all disturbances of voltage and/or current with a great efficiency.

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