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VOLTAGE REGULATION OF A GRID WITH IUPQC USING PI & FUZZY LOGIC CONTROLLER

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Abstract — The paper presents the control and simulation of the improved unified power quality conditioner (iUPQC) on microgrid applications. On providing conventional UPQC compensations at the load or microgrid side, the iUPQC will work as a static synchronous compensator (STATCOM). This enhances the power quality of the system. The PI and Fuzzy controller are used to regulate the voltage and their performance is compared interms of total harmonic distortion (THD) for the grid current. The three phase diode rectifier is used as a load with non linear nature. The simulation is perforemed using MATLAB Software

Keywords — iUPQC, microgrids, power quality, static synchronous compensator (STATCOM), unified power quality conditioner (UPQC), Fuzzy control.

I. INTRODUCTION

Power-electronics devices have brought about great technological improvements. However, the increasing number of power-electronics-driven loads used generally in the industry has brought about uncommon power quality problems. In contrast, power-electronics-driven loads generally require ideal sinusoidal supply voltage in order to function properly, whereas they are the most responsible ones for abnormal harmonic currents level in the distribution system. In this scenario, devices that can mitigate these drawbacks have been developed over the years. Some of the solutions involve a flexible compensator, known as the unified power quality conditioner (UPQC)

The power circuit of a UPQC consists of a combination of a shunt active filter and a series active filter connected in a back-to-back configuration. This combination allows the simultaneous compensation of the load current and the supply voltage, so that the compensated current drawn from the grid and the compensated supply voltage delivered to the load are kept balanced and sinusoidal.

The STATCOM has been used widely in transmission networks to regulate the voltage by means of dynamic reactive power compensation. Nowadays, the STATCOM is largely used for voltage regulation [9], whereas the UPQC and the iUPQC have been selected as solution for more specific applications. Moreover, these last ones are used only in particular cases, where their relatively high costs are justified by the power quality improvement it can provide, which would be unfeasible by using conventional solutions. By joining the extra functionality like a STATCOM in the iUPQC device, a wider scenario of applications can be reached, particularly in case of distributed generation in smart grids and as the coupling device in grid-tied microgrids.

The performance of the iUPQC and the UPQC was compared when working as UPQCs. The main difference between these compensators is the sort of source emulated by the series and shunt power converters. In the UPQC approach, the series converter is controlled as a non-sinusoidal voltage source and the shunt one as a non-sinusoidal current source. Hence, in real time, the UPQC controller has to determine and synthesize accurately the harmonic voltage and current to be compensated. On the other hand, in the iUPQC approach, the series converter behaves as a controlled sinusoidal current source and the shunt converter as a controlled sinusoidal voltage source. This means that it is not necessary to determine the harmonic voltage and current to be compensated, since the harmonic voltages appear naturally across the series current source and the harmonic currents flow naturally into the shunt voltage source.

In actual power converters, as the switching frequency increases, the power rate capability is reduced. Therefore, the iUPQC offers better solutions if compared with the UPQC in case of high-power applications, since the iUPQC compensating references are pure sinusoidal waveforms at the fundamental frequency. Moreover, the UPQC has higher switching losses due to its higher switching frequency.

II. Power Quality Problems and Power Conditioner

We can define power quality problems as:Any power problem that results in failure or miss-operation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment.' When applied to the container crane industry, the power issues which degrade power quality include:

- Power Factor
- Harmonic Distortion
- Voltage Transients
- Voltage Sags or Dips
- Voltage Swells

A power conditioner (also known as a line conditioner or power line conditioner) is a device intended to improve the quality of the power that is delivered to electrical load equipment. While there is no official definition of a power conditioner, the term most often refers to a device that acts in one or more ways to deliver a voltage of the proper level and characteristics to enable load equipment to function properly. In some usages, power conditioner refers to a voltage regulator with at least one other function to improve power quality (e.g. power factor correction, noise suppression, transient impulse protection, etc.). The terms "power conditioning" and "power conditioner" can be misleading, as the word power" here refers to the electricity generally rather than the more technical electric power. Conditioners specifically work to smooth the sinusoidal A.C. wave form and maintain a constant voltage over varying loads.

A. Design of Power Conditioner

A good quality power conditioner is designed with internal filter banks to isolate the individual power outlets or receptacles on the power conditioner. This eliminates interference or "crosstalk" between components. If the application is a home theatre system, the noise suppression rating listed in the technical specifications of the power conditioner will be very important. This rating is expressed in decibels (db).

The higher the db rating, the better the noise suppression. Good units start at a rating of about 40-60db for noise filtering. If a device does not state the db rating in its specs it may be better to move on to a different model or manufacturer.

The power conditioner will also have a "joule" rating. A joule is a measurement of energy or heat required to sustain one watt for one second, known as a watt second. Since electrical surges are momentary spikes, the joule rating indicates how much electrical energy the suppressor can absorb at once before becoming damaged itself. The higher the joule rating, the greater the protection.

B. Interline Unified Power Quality Conditioner (Iupqc)

The IUPQC shown in Fig.1 below consists of two VSCs (VSC- 1 and VSC-2) that are connected back to back through a common energy storage dc capacitor. Let us assume that the VSC-1 is connected in shunt to Feeder-1 while the VSC-2 is connected in series with Feeder-2. Each of the two VSCs is realized by three H-bridge inverters. In its structure, each switch represents a power semiconductor device (e.g., IGBT) and an anti-parallel diode. All the inverters are supplied from a common single dc capacitor Cdc and each inverter has a transformer connected at its output. The complete structure of a three-phase IUPQC with two such VSCs is shown in figure. The secondary (distribution) sides of the shunt-connected transformers (VSC-1) are connected in star with the neutral point being connected to the load neutral. The secondary winding of the series-connected transformers (VSC-2) are directly connected in series with the bus B-2 and load L-2. The ac filter capacitors Cf and Ck are also connected in each phase to prevent the flow of the harmonic currents generated due to switching. The six inverters of the IUPQC are controlled independently. The switching action is obtained using output feedback control. An IUPQC connected to a distribution system is shown in the figure. In this figure, the feeder impedances are denoted by the pairs (Rs1, Ls1) and (Rs2, Ls2). It can be seen that the two feeders supply the loads L-1 and L-2. The load L-1 is assumed to have two separate components—an unbalanced part (L-11) and a non-linear part (L-12). The currents drawn by these two loads are denoted by il1 and il2, respectively. We further assume that the load L-2 is a sensitive load that requires uninterrupted and regulated voltage. The shunt VSC (VSC-1) is connected to bus B-1 at the end of Feeder-1, while the series VSC (VSC-2) is connected at bus B-2 at the end of Feeder-2. The voltages of buses B-1 and B-2 and across the sensitive load terminal are denoted by Vt1, Vt2 , and Vl2, respectively.

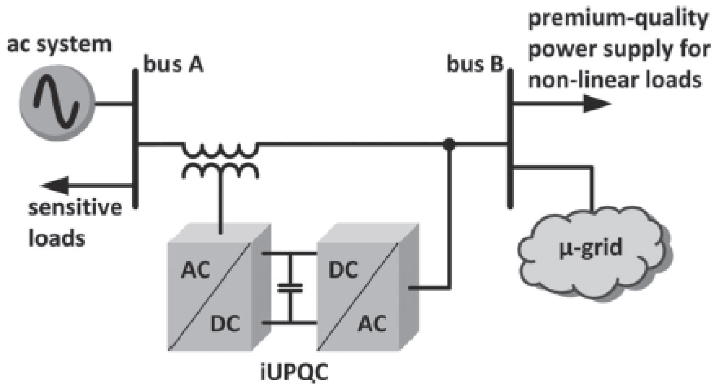

Fig. 1 Electrical System with two buses.

C. *Modified IUPQC*

The application of the improved iUPQC controller can be explained with the help of Figure 1 which depicts an electrical system with two buses i.e., bus A and bus B. Bus A is considered as the critical bus of the power system that supplies sensitive loads and it serves as the point of coupling of a microgrid. Bus B acts as a bus of the microgrid, B must be regulated, so that there is a proper supply to the sensitive loads and the nonlinear loads. The effects caused by the harmonic currents drawn by the nonlinear loads should be mitigated, in order to avoid the harmonic voltage propagation to bus A. The use of a STATCOM alone to guarantee the voltage regulation at bus A is not enough because the harmonic currents drawn by the nonlinear loads are not mitigated only with the STATCOM. Instead, a UPQC or an iUPQC between bus A and bus B can not only compensate the harmonic currents of the nonlinear loads but also compensate the voltage at bus B, in terms of voltage harmonics, unbalance, and sag/swell. However, this is still not enough to guarantee the voltage regulation at bus A. Therefore, to achieve all the desired goals, a STATCOM at bus A and a UPQC (or an iUPQC) between buses A and B should be employed. But, the cost of this solution would be unreasonably high. An alternate solution would be the use of a modified iUPQC controller to provide the reactive power support to bus A. The modified iUPQC serves as an intertie between the buses A and B. Moreover, the microgrid connected to the bus B could be a complex system comprising distributed generation, energy management system, and other control systems.

The modified iUPQC can provide the following functionalities:

a) "Smart" circuit breaker as an intertie between the grid and the microgrid.
b) Energy and power flow control between the grid and the microgrid.
c) Reactive power support at bus A of the power system.
d) Voltage/frequency support at bus B of the microgrid.
e) Harmonic voltage and current isolation between bus A and bus B.
f) Voltage and current imbalance compensation.

The configuration of modified iUPQC is shown in Figure 2.

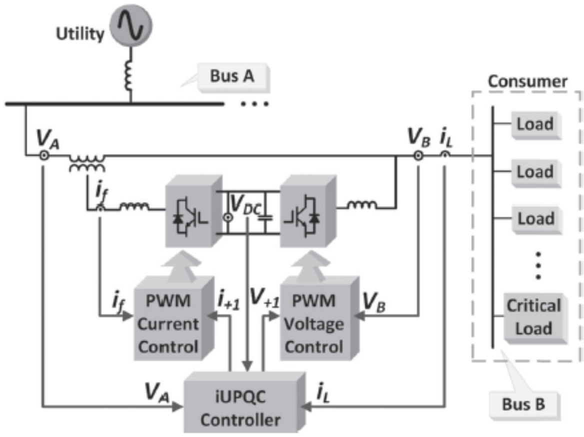

Figure 2 Modified iUPQC

D. IMPROVED iUPQC CONTROLLER

The iUPQC hardware and the measured units of a three-phase three-wire system are used in the controller. Figure 3 bus B (*iL*), and the voltage V_{DC} of the common dc link. The outputs are the shunt-voltage reference and the series current reference to the pulse width modulation (PWM) controllers. The voltage and current PWM controllers can be simply employed, or be improved further so as to deal better with voltage and current imbalance and harmonics. The voltage at bus Bis imposed by the shunt converter. Therefore, it is necessary to synthesize sinusoidal voltages with nominal amplitude and frequency. Consequently, the signals sent to the PWM controller are the phase-locked loop (PLL) outputs whose amplitude is equal to 1 p.u.

In the iUPQC approach as presented, the voltage reference of the shunt-converter can be either the PLL outputs or the fundamental positive-sequence component *VA*+1 of the grid voltage. The use of *VA*+1 in the controller is to minimize the power that is circulating through the series and the shunt converters, under normal operation, while the amplitude of the grid voltage is kept within an acceptable range of magnitude. However, this is not the case here, in the modified iUPQC controller, since the grid voltage will also be regulated by the modified iUPQC. In other words, both buses will be regulated independently so that their reference values can be tracked.

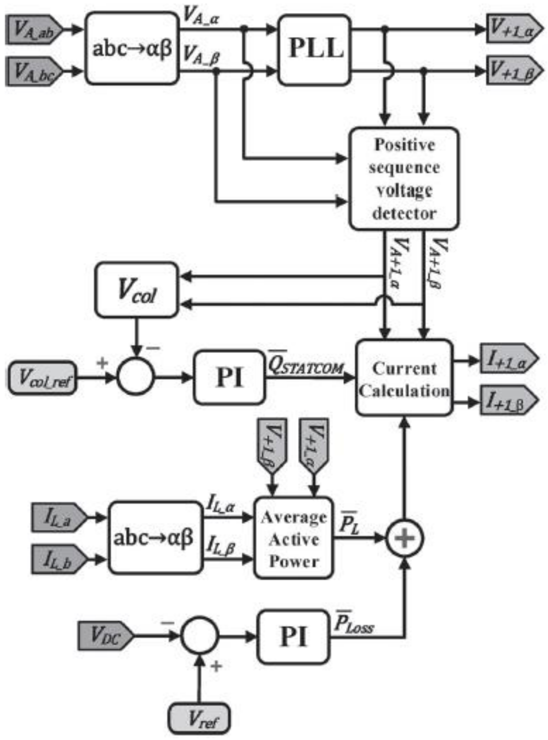

Figure 3 Improved iUPQC controller.

III. PI CONTROLLER

The main goal of the controller is to maintain constant voltage magnitude at sensitive load during supply disturbances. This control method is based on comparing source and load voltage. The three phase voltage is transformed to dqo, using park transformation. After converting the voltage is constant with d-voltage is 1 in p.u and q-voltage is 0 in p.u under the normal and balanced condition but varies under abnormal condition. After comparison d-voltage and q-voltage with the desired voltage, the difference in voltage is enhanced by PI controller, after it go through dqo to abc transformation to convert into abc component which is the main signal to generate switching pulses of voltage source PWM inverter. The significant role of controller is to detect the voltage sag, swell, harmonics & faults, inject voltage deviation and turn off inverter, when voltage sag event in the system is removed. Fig.5 represents the PI controller placed in feed back path.

The input of the controller come from the Sensitive load voltage, VSL measured by three-phase V-I measurement at Sensitive Load in p.u. VSL is then transformed in dq term. The voltage sag is detected by measuring the error between the dq voltage and the reference values. Such error is processed by a PI controller. The d-reference is set to rated voltage as unity in p.u while q-reference is set to zero.

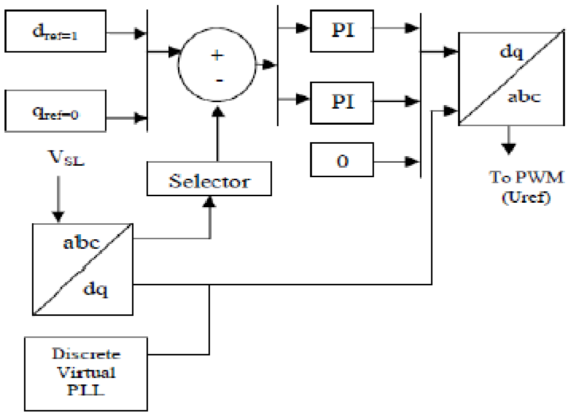

Figure.5 PI-Controller

IV. FUZZY LOGIC CONTROL

FLC determined by the set of linguistic rules. The mathematical modeling is not required in fuzzy controller due to the conversion of numerical variable into linguistic variables. FLC consists of three part:

a. Fuzzification
b. Interference engine
c. Defuzzification.

The fuzzy controller is characterized as; for each input and output there are seven fuzzy sets. For simplicity a membership functions is Triangular. Fuzzification is using continuous universe of discourse. Implication is using Mamdani's "min" operator. Defuzzification is using the "height" method. FLC block diagram as shown in figure 6.

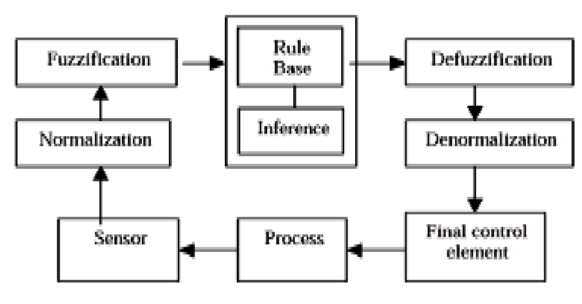

Figure.6 Fuzzy logic-Controller

a. Fuzzification

Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small),PM(Positive Medium) and PB (Positive Big). The partition of fuzzy subsets and the shape of membership function adapt the shape up to appropriate system. Input error *E(k)* and change in error *CE(k)* of values which is normalized by an input scaling factor as shown in table 1.

Table 1 Membership Function

PARAMETERS	VALUES
Voltage	220V rms
Grid frequency	50 Hz
power rate	5 kVA
DC-link voltage	450 V dc
DC-link capacitors	C=9400μF
Shunt converter passive filter	L=700μH R=5Ω C=20.0μF
Series converter passive filter	L=1.0mH R=10Ω C=20.0μF
Sampling frequency	19440Hz
Switching frequency	9720Hz
PI controller(P*loss*)	Kp=4.0 Ki=250.0
PI controller(Q*statcom*)	Kp=0.5 Ki=50.0

In this system the input scaling factor is between -1 and +1 has design. The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset is shown in fig7.

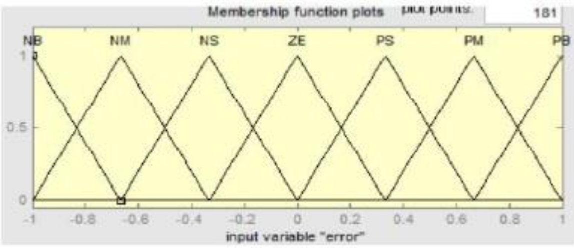

Figure.7 membership function

e / Δe	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 2: iUPQC Parameters

The IUPQC consists of two-voltage source converters that are connected to back-to-back through common energy storage DC capacitor. One Voltage Source Converter (VSC-2) is connected in series with the feeder-2 i.e., DVR and another voltage source converter is connected in shunt with the feeder-1 i.e., DSTATCOM. Two separate load components are connected in feeder-1 i.e. unbalanced and nonlinear loads. The sensitive load is connected in feeder-2. Here simulation results have taken under individual abnormal conditions & in combined cases with PI & FLC controllers acting one at a time in the IUPQC system.THD in the system with FLC controller is observed less compared to system with PI controller. In, Sags and Harmonics are mitigated with IUPQC connection using conventional PI controller. Parameter values are shown in table 2.

In under abnormal conditions performance of DVR connected to a single feeder system is investigated with PI and FLC controllers. Here, with IUPQC system operated with PI is investigated first for abnormal and dangerous conditions like sags, swells, harmonics, symmetrical and asymmetrical faults. Then the same IUPQC system with Mamdani based FLC is investigated for above faulty conditions. Using MATLAB/Simulink software the IUPQC connected. Fig [8]-[9].

V. SIMULATION RESULTS

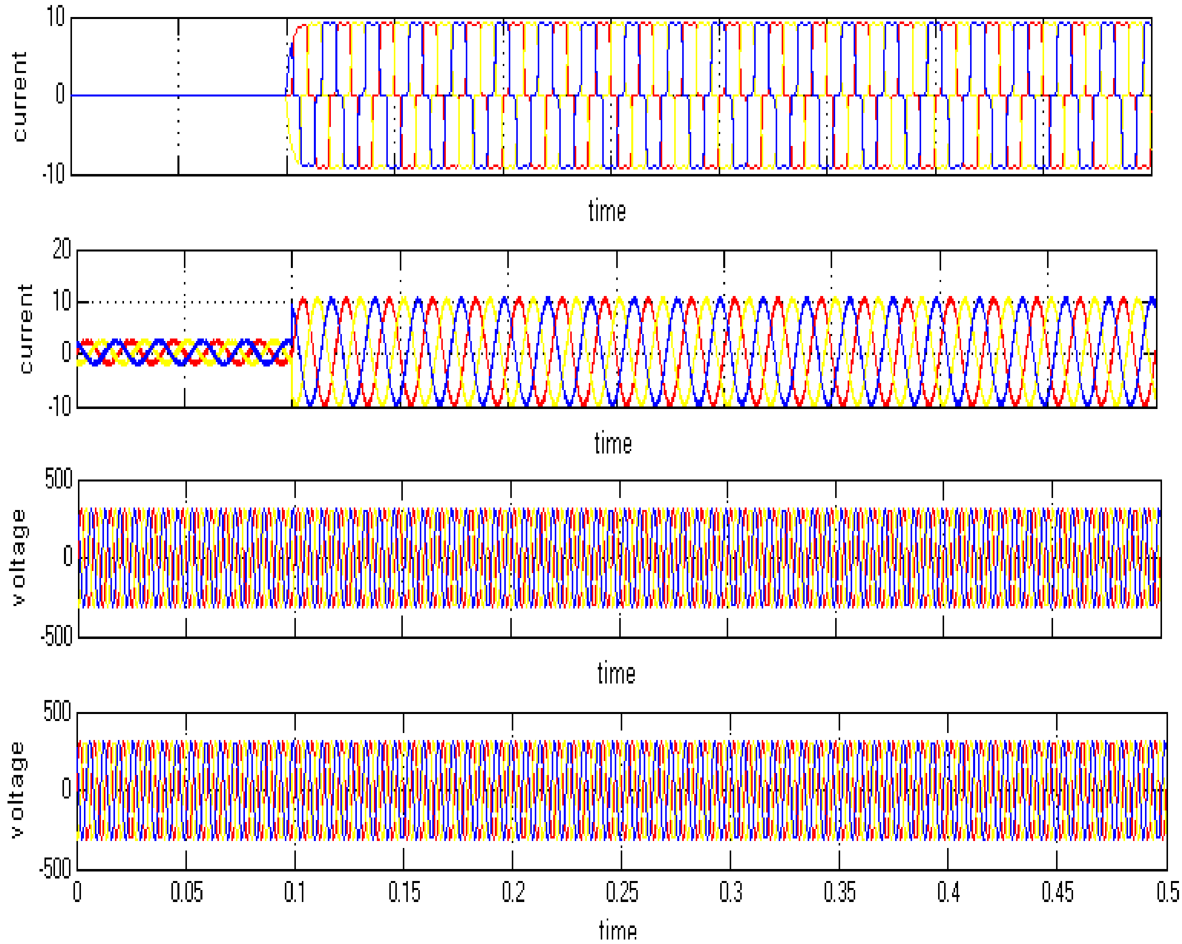

fig:8 load current, grid current, load voltage, grid voltage for iUPQC response using PI controller

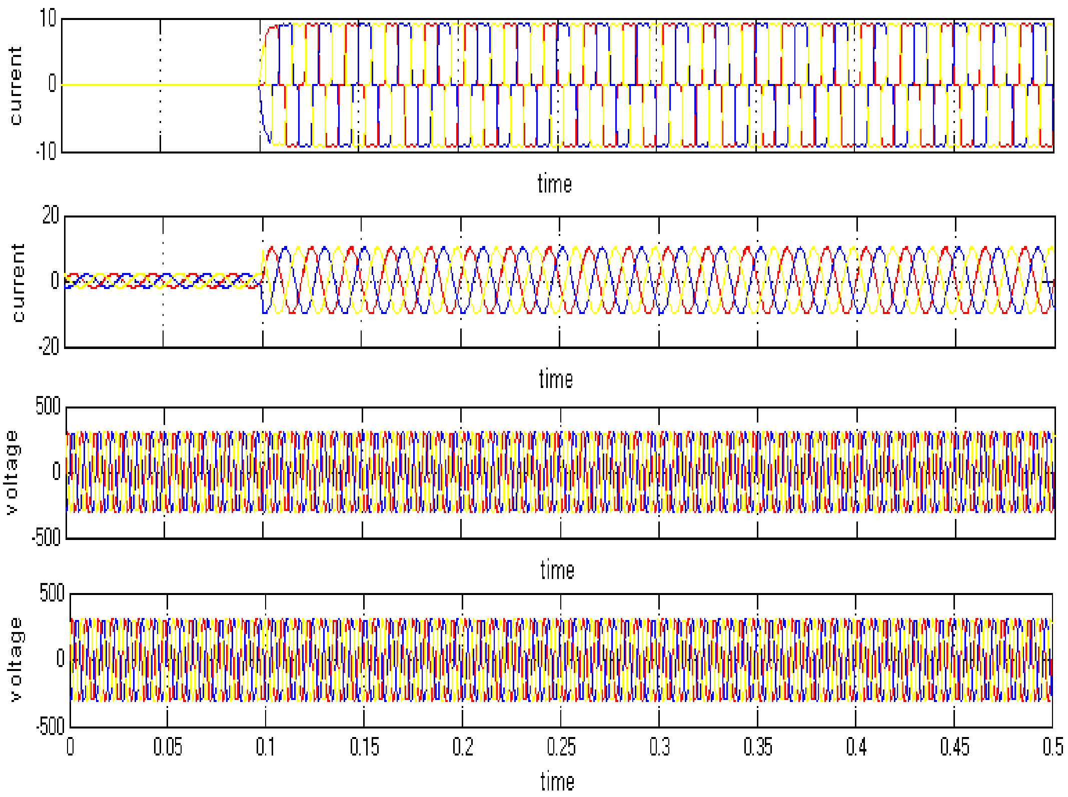

fig:9 load current, grid current, load voltage, grid voltage for iUPQC response using fuzzy logic controller

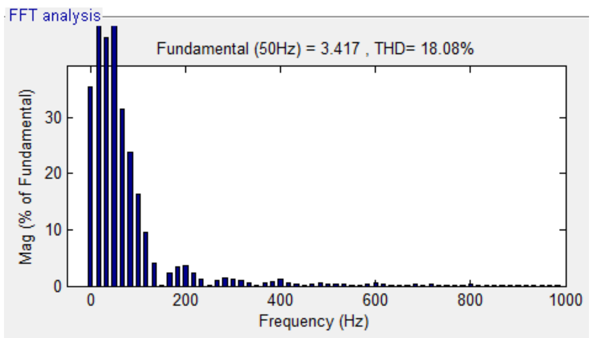

Fig 10: THD without using controller

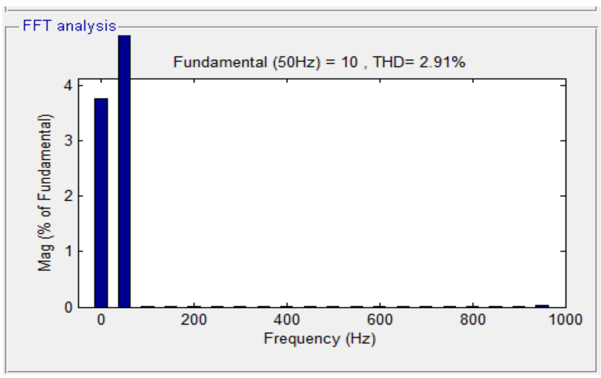

Fig11: THD using PI controller

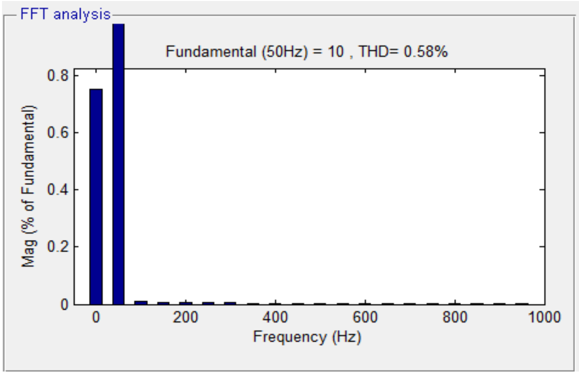

Fig12: THD using fuzzy logic controller

Table 3. Shows THD comparison

CONTROLLER	THD%
Without controller	18.08
PI controller	2.91
Fuzzy Logic controller	0.58

VI. Conclusion

The simulation of non-linear load with iUPQC is successfully accomplished using PI controller and Fuzzy logic controllers. The fuzzy logic controller gives better response with THD of (0.58) % in the grid current compared to THD of (2.91) % in the case of PI controller and also the THD of (18.08) % without controller in the grid current.In the future analysis another controller can be used such as Neuro-fuzzy for better performance.

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