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A Comparative Analysis between UPQC and Dual UPQC (iUPQC) with Improved Controller

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***Abstract*—This paper gives a comparative analysis on the conventional Unified Power Quality Conditioner (UPQC) and interline UPQC (iUPQC). The Interline UPQC is the dual topology of UPQC with back to back connected shunt and series converters which acts as controlled sinusoidal voltage and current source respectively through a common dc link. An extra functionality of STATCOM can be introduced into the iUPQC system so as to provide an additional grid voltage regulation. The iUPQC system performance under nonlinear load condition has been evaluated and compared with conventional UPQC. The MATLAB/SIMULINK based simulation supports the functionality of improved iUPQC System.**

Keywords—UPQC, iUPQC, Static Synchronous Series Compensator(STATCOM), Total Harmonic Distortion (THD)

I. INTRODUCTION

In the recent few decades development of power electronic based equipment has increased tremendously. This drastic increase has greatly affected the quality of the supplied power to consumers of all levels of usage. Like any other goods, services or quality the power quality cannot be measured, since there is no single specified definition for power quality till date. Even though the power electronic equipment has several advantages like high power density, improved controllability etc., they have their inherent disadvantages like harmonics, reactive power disturbances and increased sensitivity to supply voltage etc. These are the reasons why the power system engineers are making a great effort in developing newer control strategies to compensate these power quality problems. [1].

There are several solutions for the growing power quality issues. One of the most promising solution is the Unified Power Quality Conditioner (UPQC) presented by Hirofumi Akagi for the first time in 1995.UPQC consist of shunt and series active filters connected back to back using by a dc link capacitor. UPQC simultaneously compensates the voltage as well as current related power quality issues, hence it isolates the load from all type of disturbances [2].The shunt converter operates in current controlled mode such that it delivers a current required to compensate the load current based on the reference value. The series controller operates in voltage controlled mode which delivers a voltage required to compensate the voltage imperfections. There are several possible configurations of UPQC based on its converter topology, system configurations supply system and voltage sag compensation etc. Interline(UPQC-I), ,Multilevel(UPQC-ML), Right Shunt(UPQC-R),Left Shunt(UPQC-L) are some of the possible UPQC configurations [3].Several research works have been going on in the area of UPQC to implement the most modern as well as relevant controllers and additional functionalities to improve the conventional UPQC system to mitigate the power quality issues more effectively. In literature, enhanced topology of UPQC system with reduced DC link voltage rating is studied. The voltage requirements of the shunt and series compensators are not the same in fact the shunt compensator requires high DC link voltage than the series compensator, so it's a challenging task to optimize the DC link voltage rating without compromising the compensation capabilities [4].Usually the voltage sag/swell problems are short duration voltage interruptions but the load reactive power demand and current harmonics persist for a long time, usually shunt compensator is employed for the reactive power demand. An improved controlling technique to incorporate both shunt as well as series active filters for the reactive power demand is employed. [5]. Interline UPQC (iUPQC), is a dual topology of UPQC that overcomes the conventional disadvantages of UPQC system. While incorporating a UPQC into the power system all the unbalances at the load end will be compensated, still reaming certain unbalances in the utility side. Which results in usage of an additional device like STATCOM for balance the source end. This drawback of UPQC can be mitigated by the improved controller of the iUPQC.

The paper is organized as follows. The basic structure of UPQC and iUPQC is presented in section II .The Dynamic response comparison between UPQC and the iUPQC is done in section III. Section IV describes the new improved control strategy of the iUPQC system. Simulation and results that validates the system performance is detailed in section V. And finally section VI gives the conclusion.

II. STRUCTURE OF UPQC AND IUPQC

A. Basic Configuration of UPQC

The UPQC consist of a shunt active filter and a series active filter connected back to back through a common dc link capacitor as shown in Fig.1. The series APF acts as a controlled voltage source and shunt active filter acts as a controlled current source. Whenever the voltage undergoes Sag/swell, the series compensator will inject a suitable amount of voltage in order to mitigate the voltage imperfections. The shunt active filter mitigates the current related imperfections by injecting the suitable current. Even if the supply voltage remains unbalanced the voltage at the load end will always be

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balanced at the suitable value. Every time the controller has to calculate the compensating voltage and current, hence the requirement of processing as well as synthesizing multiple frequency signals will make the controller design more complicated and has higher switching losses in the converters. These drawbacks of the conventional UPQC system can solved using an iUPQC.

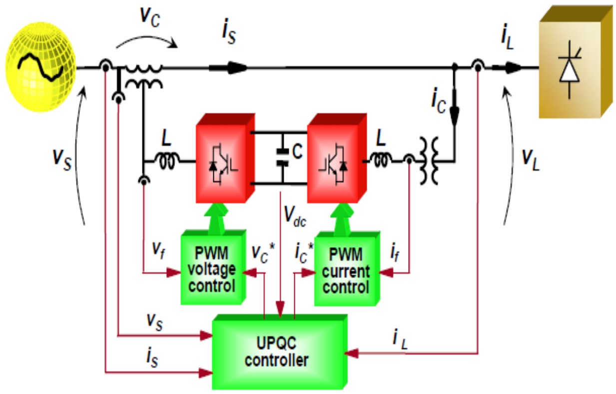

Fig.1. Conventional UPQC Configuration

B. Basic Configuration of iUPQC

In an iUPQC the series active filter acts as a controlled sinusoidal current source and the shunt active filter acts as a controlled sinusoidal voltage source as shown in Fig.2. The compensated load is supplied by a balanced sinusoidal and regulated voltage (v_L) because the iUPQC generates a positive sequence voltage at the nominal value and the series active filter takes a fundamental positive sequence current (i_S) from the source. The magnitude of current (i_S) equals sum of the active power demand of the load and the current components required to meet the internal losses of iUPQC more over the series active filter drains a fundamental positive sequence current component in phase with the supply voltage (v_S).

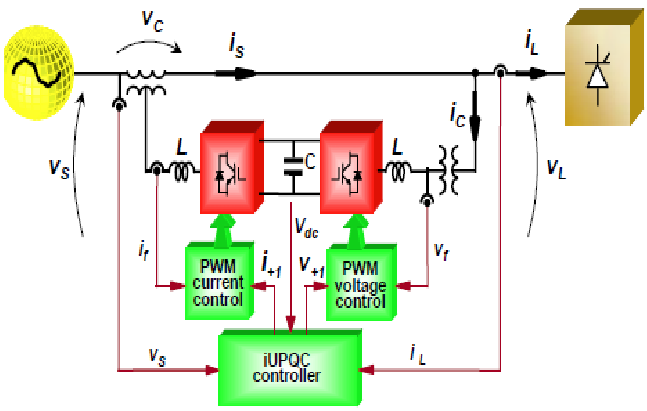

Fig.2. Power Circuit of iUPQC

The shunt active filter offers negligible impedance to the harmonic current, while the series active filter offers an infinite value. Hence the harmonic current injected by the nonlinear load flows through the shunt active filter. [6]

The main difference between the UPQC and iUPQC is the changes in the shunt and series source type i.e., substituting the non-sinusoidal voltage PWM control by a sinusoidal current PWM control in the series converter and The sinusoidal voltage PWM control take the place of non-sinusoidal current PWM control of shunt converter in conventional UPQC.

III. DYNAMIC RESPONSE COMPARISON OF UPQC AND IUPQC

The conventional UPQC system compensates a system disturbance by generating compensation voltage and current depending upon the control algorithm's ability to identify the disturbance and process the reference signals effectively. Hence dynamic response of UPQC depends upon the fast action of the controllers and switching converters. Whereas the iUPQC itself act as a sinusoidal current and voltage source for the load. The Fig.3 represents the dynamic performance of UPQC and iUPQC.

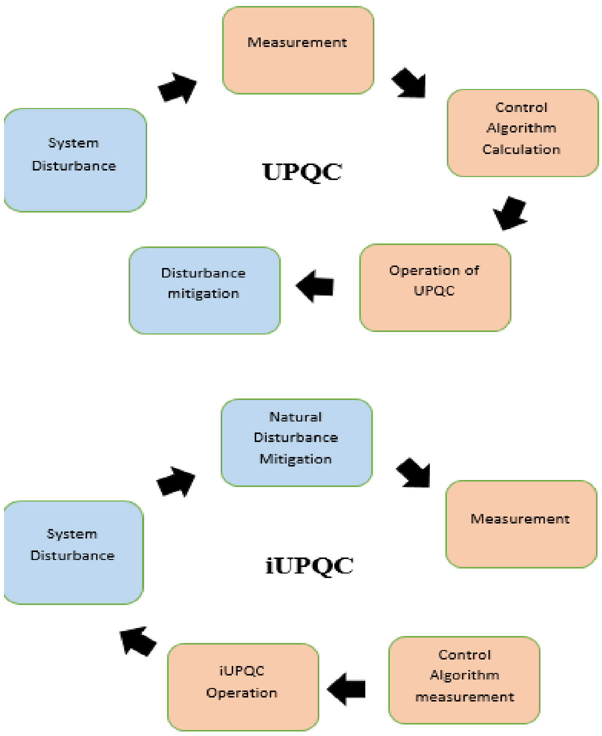

Fig.3. Dynamic Performance of UPQC and iUPQC

For instance, if a nonlinear load is connected at the consumer end then the current has to be measured, synthesized and then finally mitigated in case of UPQC, Conversely in case of iUPQC under same load condition the series converter is a high impedance to the harmonic current which will be drained through the shunt voltage source i.e., without the need of identification by any control algorithm. Hence iUPQC provides more quick dynamic performance than UPQC. Three processes are taking in action in between the system disturbance and its mitigation. Whereas there is no process taking place between the disturbance and mitigation in case of an iUPQC operation.

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IV. IMPROVED CONTROL STRATEGY OF IUPQC

The controller of iUPQC is simpler one which is based on the *p-q Theory*. The improved controller is depicted in Fig.4.

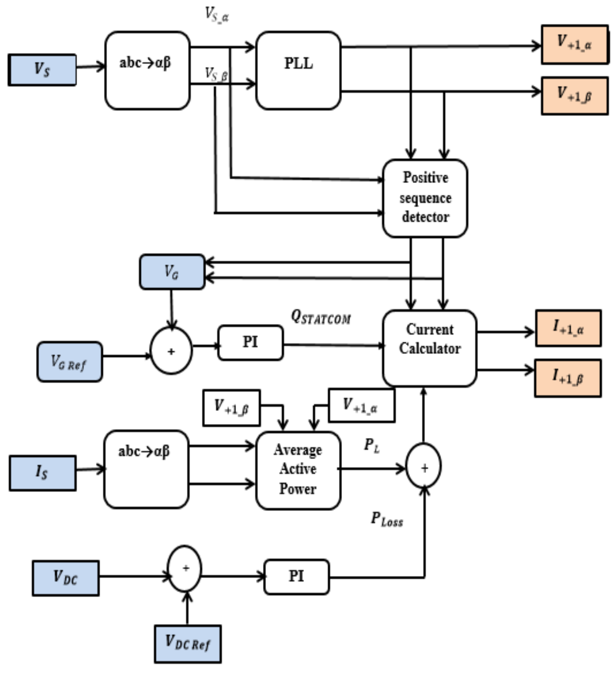

Fig.4. Improved iUPQC controller

The basic part of the controller is the synchronizing control based on Phase Locked-Loop (PLL), that effectively synthesizes the frequency as well as the phase angle of the positive sequence component of the supply voltage (v_S) [7].

If the controller can be modified to include an additional functionality of a STATCOM to provide an additional grid voltage regulation, the imperfections at the consumer end as well as at the utility side can be mitigated. The inputs to the controller are the source and load voltages (v_S,v_L) the load current (i_L) and the dc link voltage (v_{DC}).The outputs obtained from the controller are the current and voltage reference signals for the series and shunt converters respectively. These reference signals are then fed to the PWM controllers. The use of the positive sequence component of the source voltage reduces the circulating power through the shunt and series converters. The current drawn by the series converter is the sum of the average active power requirement of the load plus the power losses in the converter.

$$P_L = V_{+1\_\alpha}\,.i_{L\_\alpha} + V_{+1\_\beta}\,.i_{L\_\beta} \qquad (1)$$

The active power requirement of the load is found as per (1). Here i_{L_α}, i_{L_β} represents the load current and V_{+1_α} ,V_{+1_β} represents the shunt voltage references. $Q_{STATCOM}$ is the additional control signal to incorporate an extra functionality to the iUPQC controller to work it as a STATCOM to provide additional grid voltage regulation.[8], $Q_{STATCOM}$ is the PI controller output whose input variable is the error signal of the actual grid voltage (v_G) and its reference value (v_{G_Ref}). Where v_G is given by

$$v_G=\sqrt{V_{S+1\_\alpha}^2 + V_{S+1\_\beta}^2} \qquad (2)$$

Finally the current references for the series compensator is obtained as

$$\begin{bmatrix} i_{+1\_\alpha} \\ i_{+1\_\beta} \end{bmatrix} = \frac{1}{V_{S+1\_\alpha}^2+V_{S+1\_\beta}^2} \begin{bmatrix} V_{S+1\_\alpha} & V_{S+1\_\beta} \\ V_{S+1\_\beta} & -V_{S+\_\beta} \end{bmatrix} \text{x} \begin{bmatrix} P_L + P_{Loss} \\ Q_{STATCOM} \end{bmatrix} \qquad (3)$$

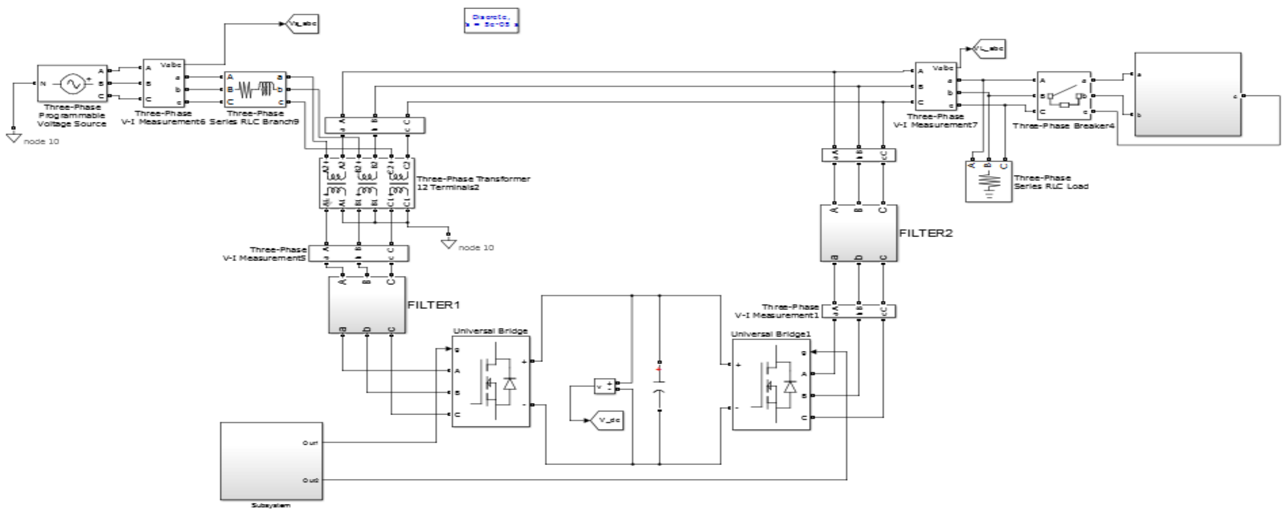

Fig.5. Simulation model of improved iUPQC controller

V. SIMULATION AND RESULTS

In order to verify the improved controller performance over the conventional UPQC the improved iUPQC system has been modelled in MATLAB/SIMULINK environment.

A. Simulation of improved iUPQC

The MATLAB Simulink model of the improved iUPQC system is shown in Fig: 5.It is a three phase three wire system containing two converters one shunt and another series connected back to back through a common dc link. The gating signals are generated based on the reference signals as per the controller in Fig.4.

the load as well as at the source side. Even after the connection of the load at t = 0.25s the voltage are still regulated and the current drawn from the source are almost sinusoidal.

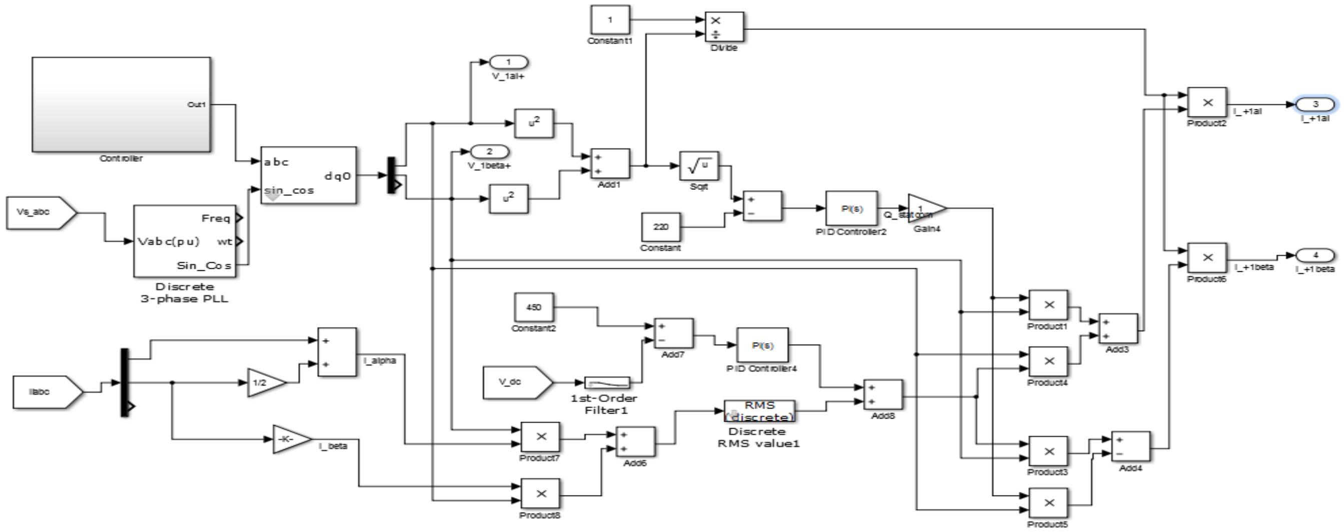

Fig .6. Simulation model of improved iUPQC controller

The system is connected in between source and a nonlinear load. The simulation Parameters are as in table 1.

Table I SIMULATION PARAMETERS

Parameter	value
Voltage	220Vrms
Grid frequency	50Hz
Power rating	5kVA
DC-link Voltage	500Vdc
DC-link Capacitor	9400μF
Shunt Converter Passive filter	L=750μH;R=3.7Ω;C=20μF
Series Converter Passive filter	L=1mH;R=7.5Ω;C=20μF
Sampling Frequency	19440Hz
Switching Frequency	9720Hz
PI Controller(P_{Loss})	K_p=4 ;K_i=250
PI controller(P_L)	K_p=.5 ;K_i=50

B. Simulation Resultss

The system performance is evaluated under nonlinear load (Three phase Diode Rectifier) the simulation outputs of the improved iUPQC system are as shown below, Here the nonlinear load is switched into the system from t = 0.25s onwards. It is evident from the simulation outcomes of improved iUPQC controller that the voltage is regulated at

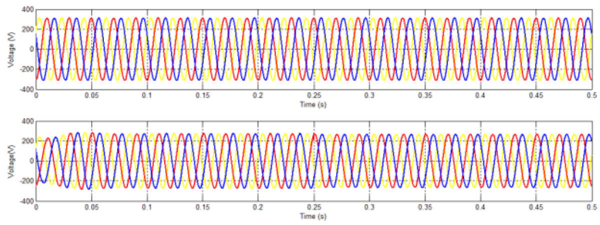

Fig.7. Grid and load Voltages with improved iUPQC

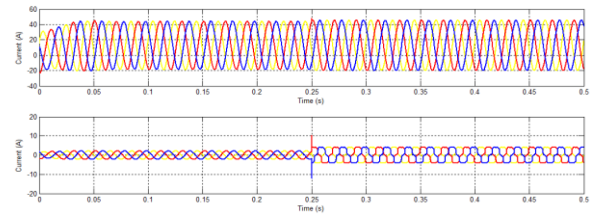

Fig.8. Grid and load Currents with improved iUPQC

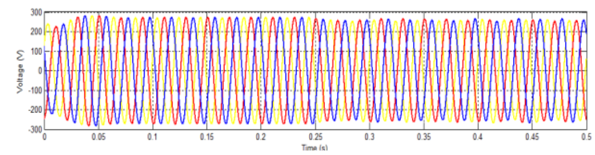

Fig .9. Sinusoidal Shunt Injected Voltage by iUPQC

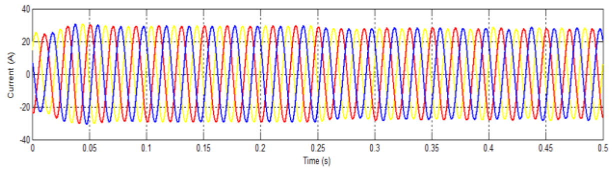

Fig.10es Injected Current by iUPQC

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It is evident from the simulation outputs of the improved iUPQC that the load as well as the source voltages are regulated even after the connection of the nonlinear load at t = 0.25s. Moreover it is clear from Fig 9 and Fig 10,that the shunt and series converters injects a controlled sinusoidal voltage and current respectively even after the connection of nonlinear load at t = 0.25s. Now the improved iUPQC controller can be compared with the conventional UPQC controller output waveforms during the insertion of a nonlinear load at t = 0.25s. The simulation outcomes of conventional UPQC system are as follows. It is observed from the simulation outcomes that the source side remains unregulated even though the load side is regulated. Every time the UPQC has to synthesize and inject the required amount of voltage and current so as to compensate load side, thereby increasing the switching losses in the converter.

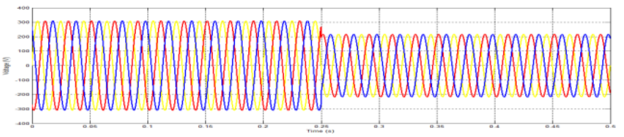

Fig.11. Grid voltage with conventional UPQC

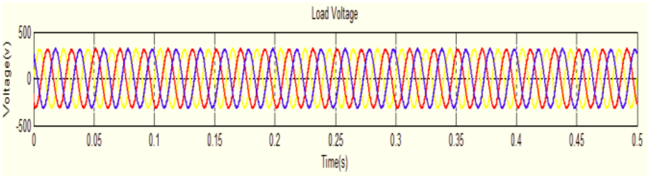

Fig.12. Load Voltage with conventional UPQC

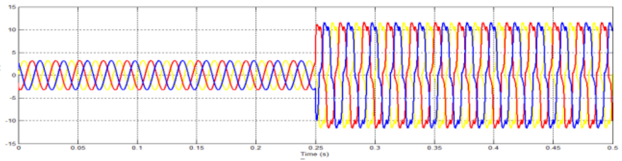

Fig.13. Grid Current with conventional UPQC

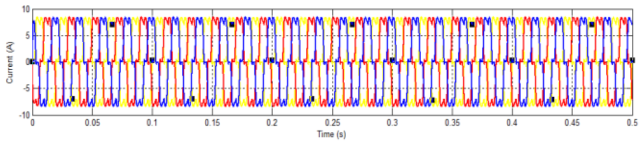

Fig.14. Load Current with conventional UPQC

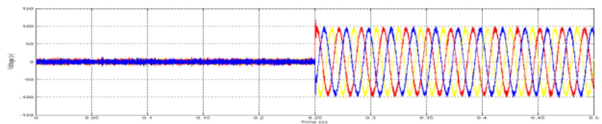

Fig .15. Injected voltage by series converter of UPQC

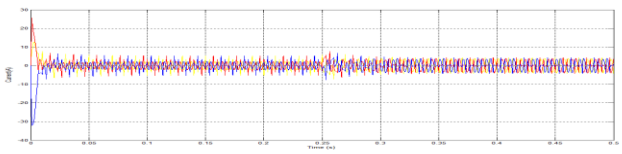

Fig .16. Injected Current by the shunt converter of UPQC

C. THD Analysis

The THD analysis carried out further shows that the improved iUPQC system controller considerably reduced the THD value of both Source as well as load voltages. FFT analysis of iUPQC gives much more prominent result i.e., THD reduced in the source side to 0.07% and in load side up to 0.9%.The THD analysis are shown in Fig 17 and 18 for improved iUPQC.

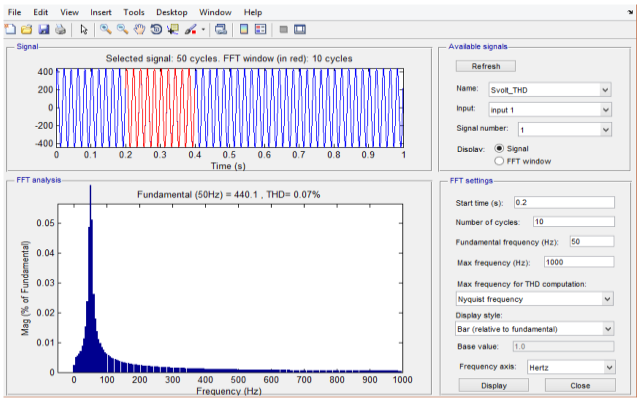

Fig.17. FFT analysis of source voltage with iUPQC

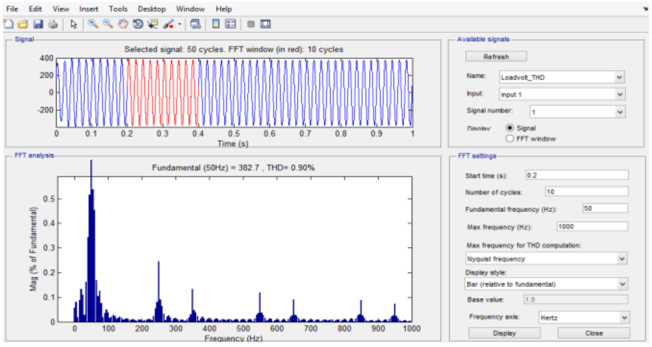

Fig.18. FFT analysis of load voltage with iUPQC

The comparative THD analysis of the conventional UPQC and iUPQC is detailed in Table 2. It is evident that the THD values has reduced considerably in improved iUPQC.

Table II. THD VALUES OFUPQC and iUPQC

	UPQC THD (%)	iUPQC THD (%)
Source Voltage	23.54	0.07
Source Current	23.18	0.90
Load Voltage	4.48	2.79
Load Current	7.92	0.96

VI. CONCLUSION

This paper investigated the performance of improved iUPQC controller over the conventional UPQC. The simulation results shows that the iUPQC can be employed effectively to reduce the distortion level as well as the THD. Furthermore the improved iUPQC reduces the overall cost of the system and promotes its applicability as an iUPQC and as a STATCOM simultaneously. The simulation results substantiated the improved iUPQC goals. The results has demonstrated the voltage regulation can be accomplished at both sides of iUPQC, even during the compensation of harmonics and voltage imbalances.

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