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Enhancing Electric Power Quality Using Dual Unified Power Quality Conditioner

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Abstract — **Due to increasing complexity in the power system, power quality problems are most significant problems. If the power quality problem exceeds, then manufacturing systems making use of sensitive electronic equipments are likely to be affected leading to major problems. It ultimately leads to wastage of resources as well as financial losses. The increasing competition in the market and the declining profits has made it pertinent for the industries to realize the significance of high-power quality. This project tends look at the solving the problems by using custom power devices by Dual Unified Power Quality Conditioner (iUPQC). In iUPQC there is no need of coordinate transformation this reduces the complex calculation. This work describes the techniques of correcting the power quality problems in the distributed system. The proposed system can able to compensate the nonlinear load condition and also ensure the sinusoidal voltage for the load in all three phases. This results in the better power quality. It is important to emphasize that the existing UPQC topologies does not have this capability. The simulation result is verified using MATLAB/SIMULINK.**

Index Terms - **Dual Unified Power Quality conditioner (iUPQC), active and reactive power control, power quality problems, coordinate transformation.**

I. INTRODUCTION

The usage of power quality conditioners in the distribution system network has increased during the past years due to the steady increase of nonlinear loads connected to the electrical grid. The current drained by nonlinear loads has a high harmonic content, distorting the voltage at the utility grid and consequently affecting the operation of critical loads. By using a unified power quality conditioner (UPQC), it is possible to ensure a regulated voltage for the loads, balanced and with low harmonic distortion and at the same time draining undistorted currents from the utility grid, even if the grid voltage and the load current have harmonic contents. The UPQC consists of two active filters, the series active filter (SAF). The PAF is usually controlled as a non sinusoidal current source, which is responsible for compensating the harmonic current of the load, while the SAF is controlled as a nonsinusoidal voltage source, which is responsible for compensating the grid voltage. Both of them have a control reference with harmonic contents, and usually, these references might be obtained through complex methods. The aim of this paper is to propose a simplified control technique for a dual three phase topology of a unified power quality conditioner (iUPQC) is to be used in the utility grid connection. The proposed control scheme is developed in ABC reference frame and allows the use of classical control theory without the need for coordinate transformers and digital control implementation. The references to both SAF and PAFs are sinusoidal, dispensing the harmonic extraction of the grid current and load voltage.

II. DUAL UPQC

The conventional UPQC structure is composed of a SAF and a PAF, as shown in Fig. 1. In this configuration, the SAF works as a voltage source in order to compensate the grid distortion, unbalances, and disturbances like sags, swells, and flicker. Therefore, the voltage compensated by the SAF is composed of a fundamental content and the harmonics. The PAF works as a current source, and it is responsible for compensating the unbalances, displacement, and harmonics of the load current, ensuring a sinusoidal grid current. The series filter connection to the utility grid is made through a transformer, while the shunt filter is usually connected directly to the load, mainly in low-voltage grid applications. The conventional UPQC has the following drawbacks: complex harmonic extraction of the grid voltage and the load involving complex calculations, voltage and current references with harmonic contents requiring a high bandwidth control, and the leakage inductance of the series connection transformer affecting the voltage compensation generated by the series filter. In order to minimize these drawbacks, the iUPQC is investigated in this paper, and its scheme is shown in the Fig.2. The scheme of the iUPQC is very similar to the conventional UPQC, using an association of the SAF and PAF, diverging only from the way the series and shunt filters are controlled. In the iUPQC, the SAF works as a current source, which imposes a sinusoidal input current synchronized with the grid voltage. The PAF works as a voltage source imposing sinusoidal load voltage synchronized with the grid voltage. In this way, the iUPQC control uses sinusoidal references which is derived from transfer function for both series and shunt active filters.

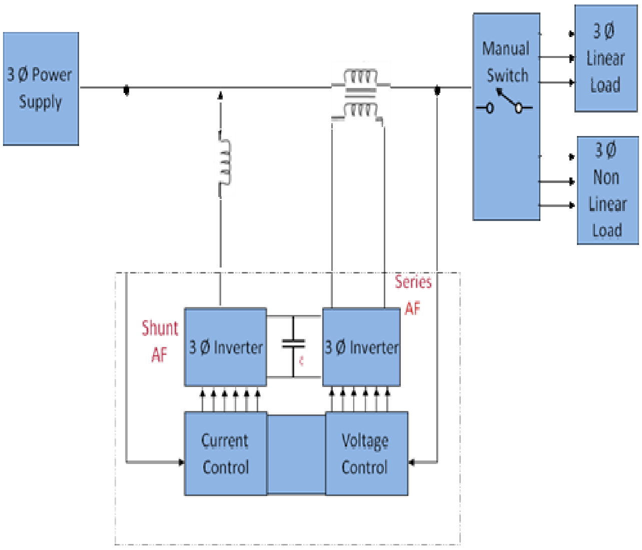


Fig. 1. Conventional UPQC

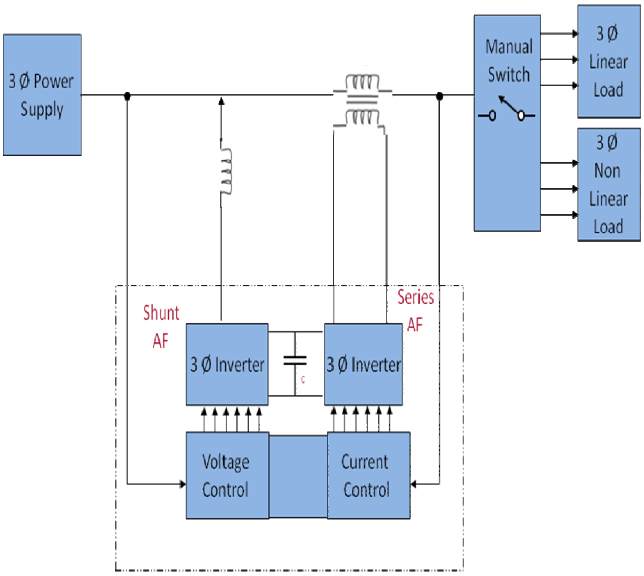


Fig. 2. Dual UPQC (iUPQC).

III. PROPOSED CONTROL SCHEME

The proposed iUPQC control structure in an ABC reference frame based control, where the SAF and PAF are controlled in an independent way, shown in Fig. 3.

In the proposed control scheme, the power calculation and harmonic extraction are not needed since the harmonics, unbalances, disturbances, and displacement should be compensated.

The Series Active Filter (SAF) has a current loop in order to ensure a sinusoidal grid current synchronized with the grid voltage. The PAF has a voltage loop in order to ensure a balanced regulated load voltage with low harmonic distortion.

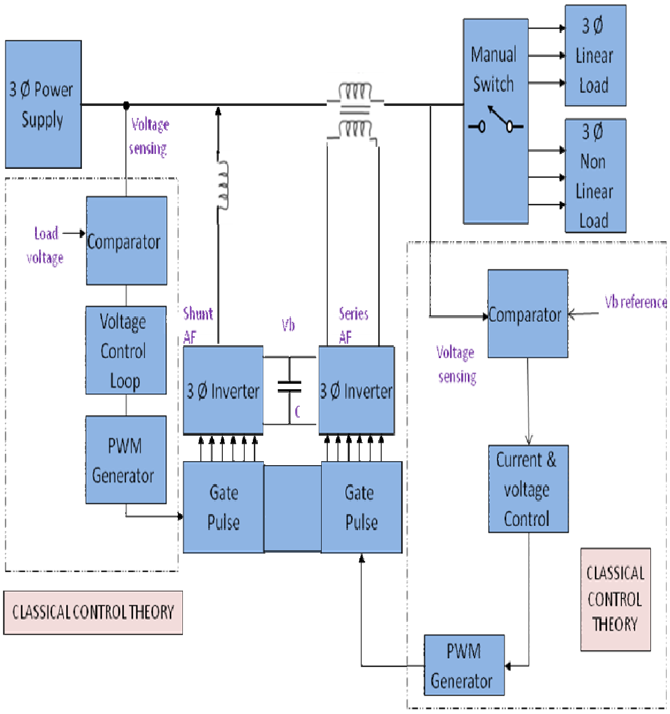


Fig. 3 Control of Dual UPQC (iUPQC).

These control loops are independent from each other since they act independently in each active filter. The dc link voltage control is made in the SAF, where the voltage loop determines the amplitude reference for the current loop, in the same mode of the power factor converter control schemes. The sinusoidal references for both SAF and PAF controls are generated by a digital signal processor, which ensure the grid voltage synchronism using a phase locked loop.

A. SAF Control

The SAF control scheme consists of three identical grid current loops and two voltage loops. The current loops are responsible for tracking the reference to each grid input phase in order to control the grid current independently. One voltage loop is responsible for regulating the dc link voltage, and the other is responsible for avoiding the unbalance between the dc link capacitors shown in the Fig. 4.

The total dc voltage control loop has a low-frequency response and determines the reference amplitude for the current loops. Thus, when the load increases, overcoming the input grid current, the dc link supplies momentarily the active power consumption, resulting in a decrease of its voltage. This voltage controller acts to increase the grid current reference, aiming to restore the dc link voltage.

In the same way, when the load decreases, the voltage controller decreases the grid current reference to regulate the dc link voltage. Considering the three phase input current, sinusoidal and balanced, the voltage loop transfer function is obtained through the method of power balance analysis.

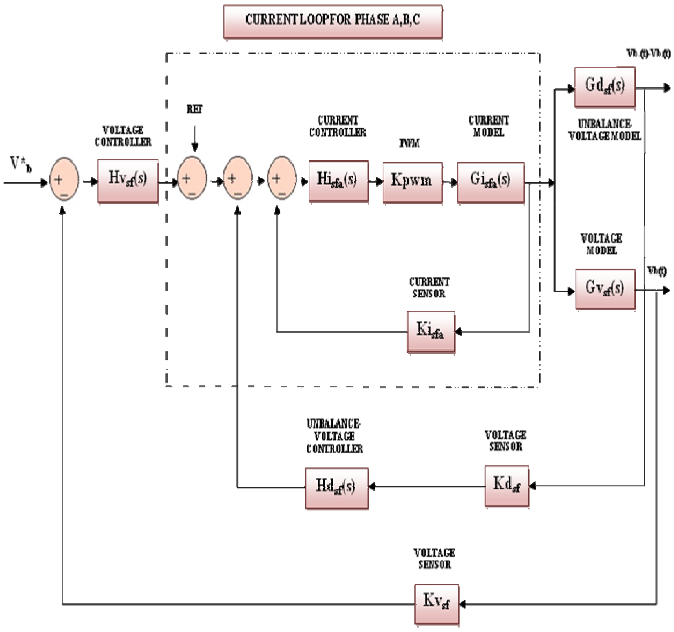
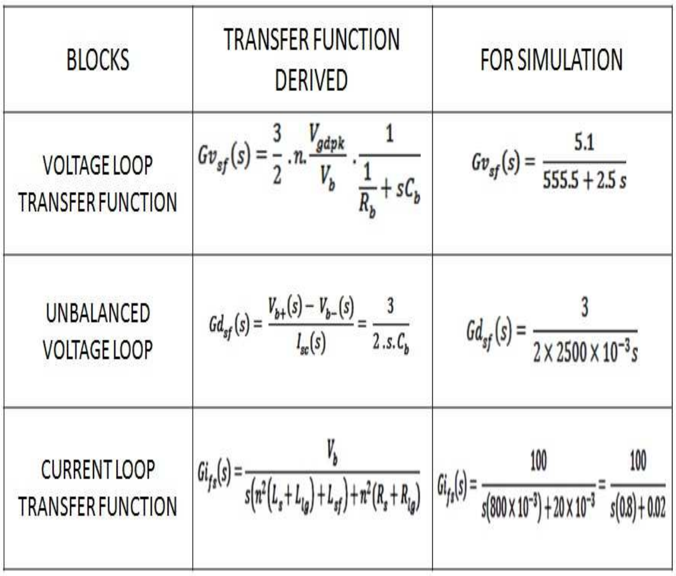


Fig. 4 Control of SAF

The transfer function derived for Series Active Filter (SAF) is tabulated and given below table 1.



BLOCKS	TRANSFER FUNCTION DERIVED	FOR SIMULATION
VOLTAGE LOOP TRANSFER FUNCTION	$Gv_{sf}(s)=\frac{3}{2}.n.\frac{V_{gdpk}}{V_b}.\frac{1}{\frac{1}{R_b}+sC_b}$	$Gv_{sf}(s)=\frac{5.1}{555.5+2.5\,s}$
UNBALANCED VOLTAGE LOOP	$Gd_{sf}(s)=\frac{V_{b+}(s)-V_{b-}(s)}{I_{sc}(s)}=\frac{3}{2.s.C_b}$	$Gd_{sf}(s)=\frac{3}{2\times2500\times10^{-3}s}$
CURRENT LOOP TRANSFER FUNCTION	$Gi_{fs}(s)=\frac{V_b}{s\left(n^2\left(L_s+L_{lg}\right)+L_{sf}\right)+n^2\left(R_s+R_{lg}\right)}$	$Gi_{fs}(s)=\frac{100}{s\left(800\times10^{-3}\right)+20\times10^{-3}}=\frac{100}{s(0.8)+0.02}$

Table. 1 Transfer function of SAF

B. PAF Control

The PAF control scheme is formed by three identical load voltage feedback loops, except for the 120° phase displacements from the references of each other. The voltage loops are responsible for tracking the sinusoidal voltage reference for each load output phase in order to control the load voltages independently shown in Fig. 5.

The voltage loop transfer function is obtained through the analysis of the single-phase equivalent circuit shown in Fig. 17. The dynamic model is obtained through the circuit analysis using average values related to the switching period. Through small signal analysis by using Laplace transformation.

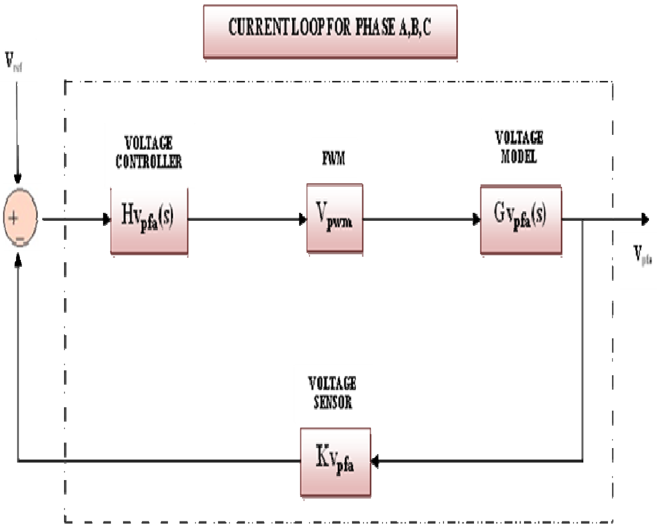
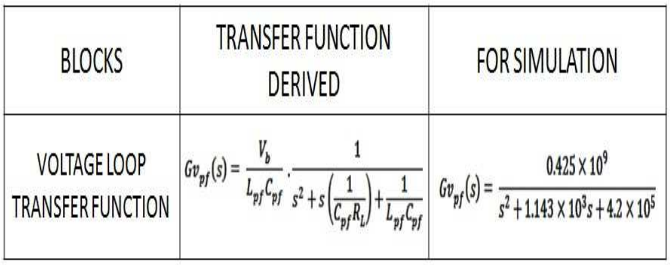


Fig. 5 Control of PAF

The transfer function derived for Shunt Active Filter (PAF) is tabulated and given below table 2.



BLOCKS	TRANSFER FUNCTION DERIVED	FOR SIMULATION
VOLTAGE LOOP TRANSFER FUNCTION	$Gv_{pf}(s)=\frac{V_b}{L_{pf}C_{pf}}.\frac{1}{s^2+s\left(\frac{1}{C_{pf}R_L}\right)+\frac{1}{L_{pf}C_{pf}}}$	$Gv_{pf}(s)=\frac{0.425\times10^9}{s^2+1.143\times10^3s+4.2\times10^5}$

Table. 2 Transfer function of PAF

IV. SIMULATION TOOLS

The Simulink developed by Math Works, is a data flow graphical programming language tool for modelling, simulating and analyzing multidomain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multidomain simulation and Model-Based Design.

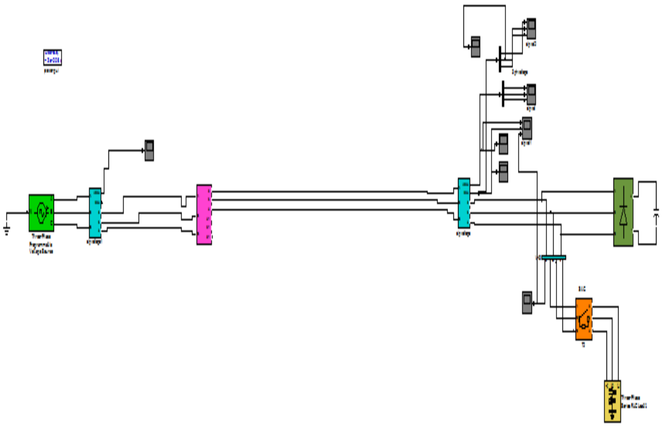


Fig. 6 Simulation for without compensation

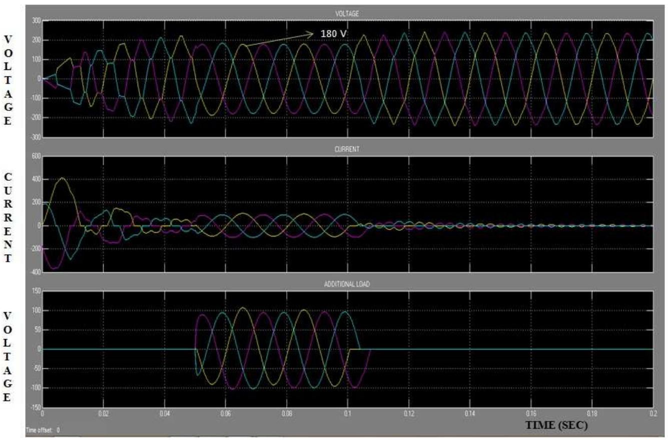
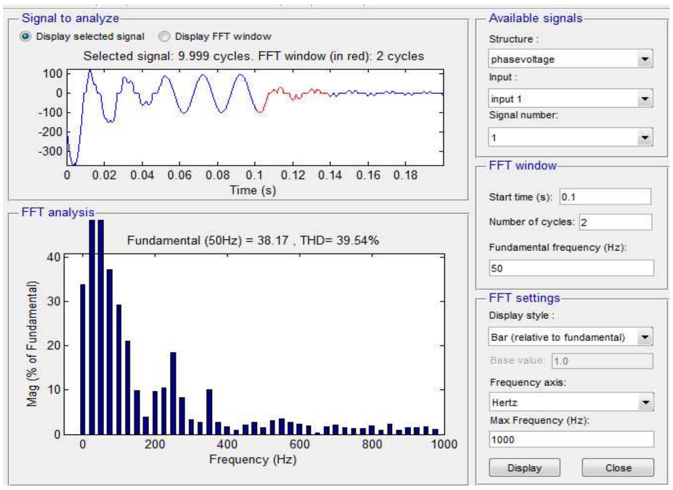


Fig. 7 Output for without compensation



Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 9.999 cycles. FFT window (in red): 2 cycles

FFT analysis
Fundamental (50Hz) = 38.17 , THD= 39.54%

Available signals
Structure : phasevoltage
Input : input 1
Signal number: 1

FFT window
Start time (s): 0.1
Number of cycles: 2
Fundamental frequency (Hz): 50

FFT settings
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig. 8 THD for without compensation

When additional load is added in the load side at the time period of 0.05 to 0.6 t the output current in the load side will be increased so the output voltage is reduced which is shown in the above simulation result Fig 7.

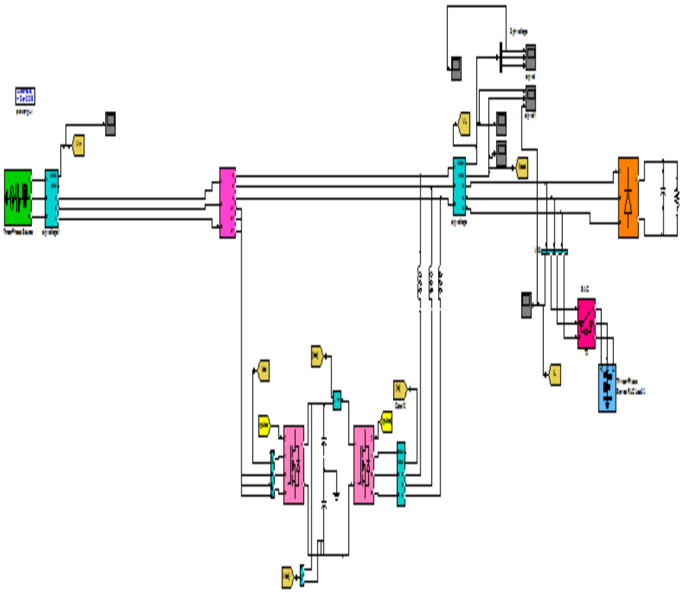


Fig. 9 Simulation of Unified Power Quality Conditioner

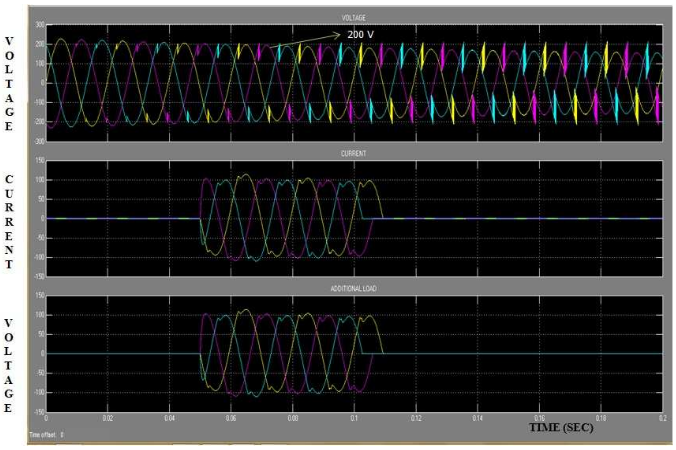
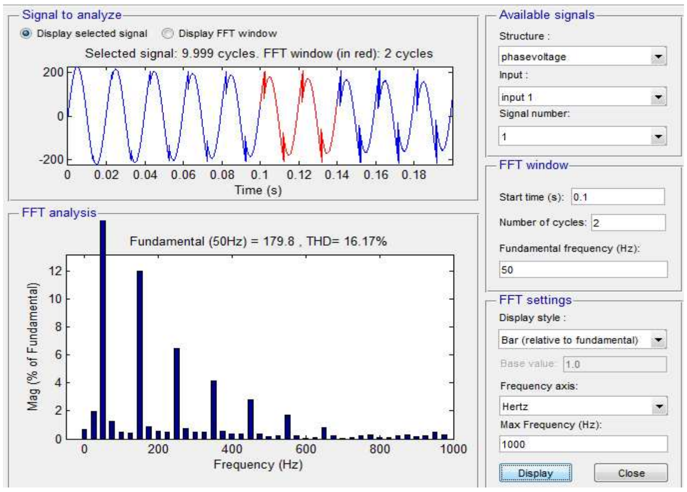


Fig. 10 Output for Unified Power Quality Conditioner (UPQC)



Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 9.999 cycles. FFT window (in red): 2 cycles

FFT analysis
Fundamental (50Hz) = 179.8 , THD= 16.17%

Available signals
Structure : phasevoltage
Input : input 1
Signal number: 1

FFT window
Start time (s): 0.1
Number of cycles: 2
Fundamental frequency (Hz): 50

FFT settings
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

Fig. 11 THD for UPQC

When additional load is added in the load side at the time period of 0.05 to 0.6 t the output current in the load side will be increased so the output voltage will be reduced but here unified power quality conditioner is used so voltage is compensated but it has harmonics 16.17%

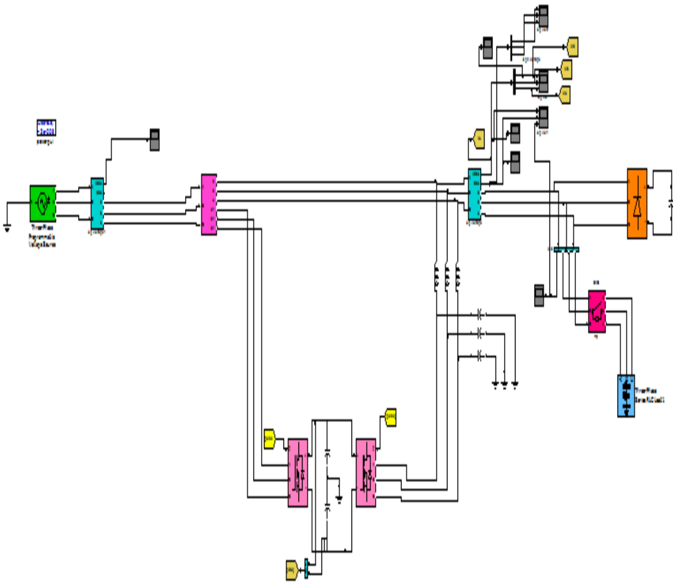


Fig. 12 Simulation of iUPQC

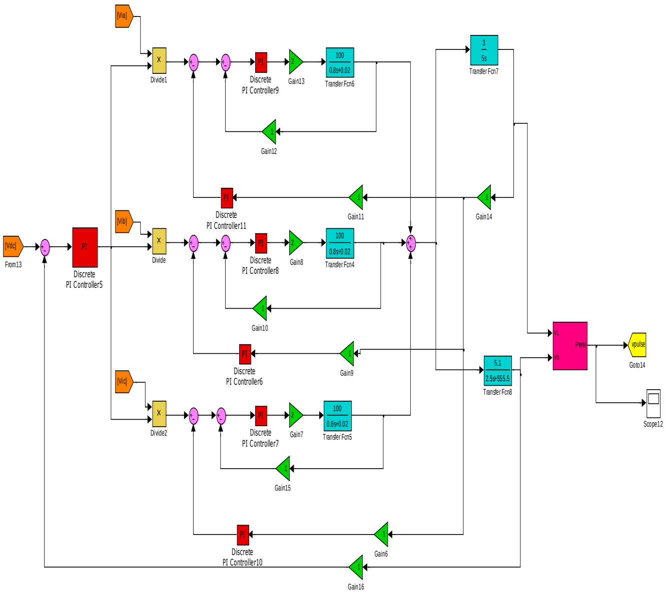


Fig. 13 Simulation of SAF controller

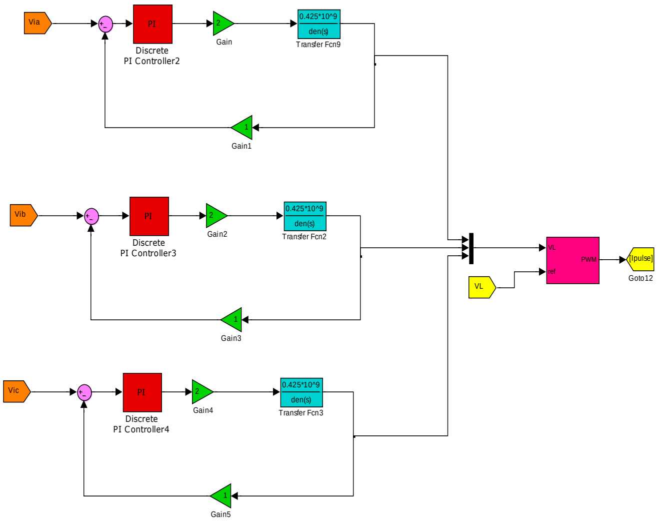


Fig. 14 Simulation of PAF controller

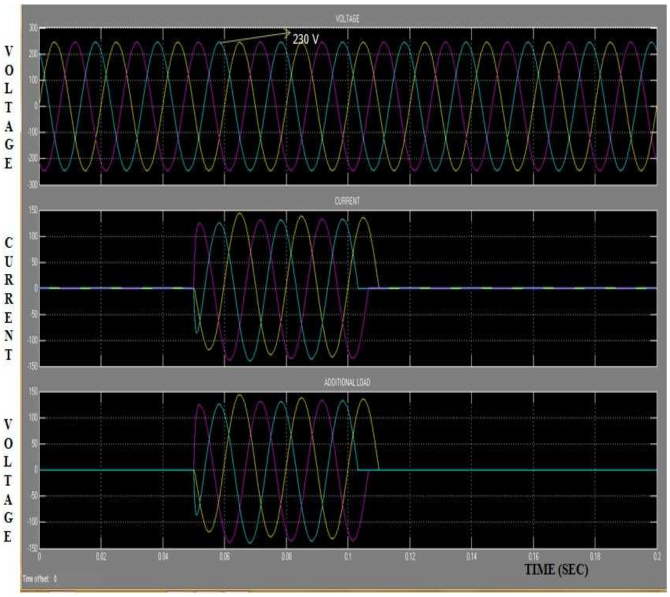
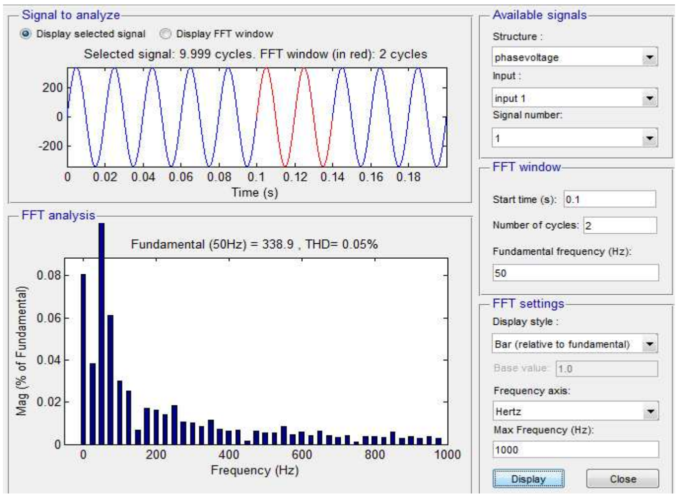


Fig. 15 Output for iUPQC

When additional load is added in the load side at the time period of 0.05 to 0.6 t the output current in the load side will be increased so the output voltage will be reduced but here Dual unified power quality conditioner is used so voltage is compensated and the harmonics is reduced to 0.05%.



Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 9.999 cycles. FFT window (in red): 2 cycles

FFT analysis

Fundamental (50Hz) = 338.9 , THD= 0.05%

Available signals

Structure : phasevoltage

Input : input 1

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 2

Fundamental frequency (Hz): 50

FFT settings

Display style : Bar (relative to fundamental)

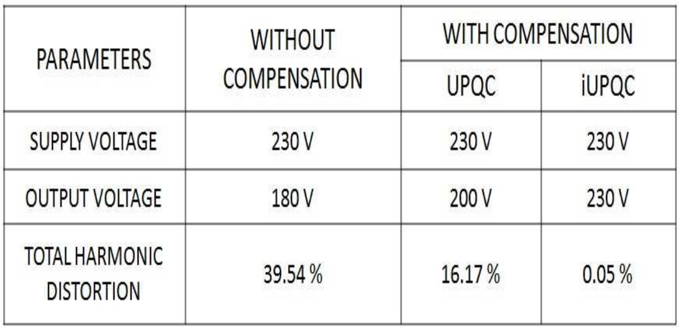
Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000

Fig. 16 THD of iUPQC

The comparison of with compensation and without compensation is tabulated and given below table 3.



PARAMETERS	WITHOUT COMPENSATION	WITH COMPENSATION	
		UPQC	iUPQC
SUPPLY VOLTAGE	230 V	230 V	230 V
OUTPUT VOLTAGE	180 V	200 V	230 V
TOTAL HARMONIC DISTORTION	39.54 %	16.17 %	0.05 %

Table. 3 Comparison of with and without compensation

V. CONCLUTION

The proposed iUPQC confirms that the ABC reference frame based control works very well and that it was able to compensate the nonlinear load currents and also ensure the sinusoidal voltage for the load in all three phases. The control also had a great performance during the load steps and voltage disturbances at the source.

The main advantage of the proposed control in relation to other proposed schemes were the utilization of sinusoidal references for both series and shunt active filter controls without the need for complex calculations or coordinate transformations.

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