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Power Quality Improvement using UPQC with Single and Three-Phase Non-linear Loads in Countryside Areas

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Abstract**: — *This paper is intended to simulate a power quality conditioning device, Unified Power Quality Conditioner (UPQC), in countryside areas for non-linear loading. From past decades there is much increase in the requirement of the good quality electrical power in single phase distribution grids established in these locations. Due to technical advancement, three-phase loads are practiced more than single phase loads so that the demand for three phase distribution grids is growing. But the installation process of three-phase grids, at countryside areas, is not an economic option and to get access to these systems is a very challenging task. So a neighbouring three-phase distribution system is required to be established at the location, where single-phase to three-phase UPQC with single wire earth return is appropriate for the end user due to economic considerations. A dual compensation strategy is implemented to obtain the reference quantities for controlling the converters. The proposed idea is accomplished to eliminate voltage harmonics and mitigate further instabilities and power quality problems. This system allows the balanced and regulated voltage with lower harmonic content. Synchronous Reference Frame (SRF) based controllers are considered to organize the input grid current and the load voltages of the UPQC. The present prototype under consideration analyses and validates the compensation and controlling techniques using PI controller. The control strategies are simulated using MATLAB/SIMULINK.***

Keywords**: *UPQC, Synchronous Reference Frame, Power Quality, Dual Compensation.***

I. INTRODUCTION

Now days there are immense importance of electrical power because life cannot be imagined without it. For the efficient functioning of the system at the user’s end it is very important to supply power which must be continuous and of good quality. The majority of the marketable and industrialized loads necessitate good quality power. All the consumers whether it may be Industrial, commercial or residential, are deteriorating power quality because of the incorporation of the amplified amount of non-linear loads’ presence in the power system. Thus it is essential priority to attain improved and clear power in electric power systems.

There is a great significance of power electronics devices in distribution and transmission of electrical power due to the fact that these power equipments process electricity very efficiently and also these devices are very economic. Power electronic equipments are incorporated in the system gradually which is the sign of many problems associated with. As they create non-linear characteristics showing serious impact on the power quality and power supply continuity. The non-linear characteristics pose certain restrictions such as harmonics generation, reactive power generation [2].There is numerous power quality defects such as voltage sag or swell, voltage unbalance due to various types of faults occurred in power system network taken under consideration. The extensive application of non-linear load is responsible for generating harmonics and reactive power disturbances in network. These types of power quality defects must be removed as soon as possible to avoid further degradation in the quality of the system.

There are so many ways to overcome these power quality issues by using active power quality conditioners such as shunt [18], series [18] and hybrid active power filters (APFs), dynamic voltage restorers [16], unified power quality conditioners (UPQC) [13] and others. The integration of series APF & shunt APF is acknowledged as Unified power quality conditioner which simultaneously suppresses the power quality defects related to voltage and current. The UPQC provides reactive power to the system and mitigate harmonics to get better system power factor [2]. In the UPQC circuit all current related issues are solved by shunt APF such as current harmonics compensation, reactive power compensation etc. and series APF is allowed to mitigate voltage based power quality problems such as a voltage sag/swell, flickers etc., to maintain the voltage regulated.

The cost involved in extending the main grid to supply remote and rural area is extremely high. In rural and remote areas of Brazil, Australia or New Zealand, single-phase distribution lines are commonly used to supply load due to the fact that single-phase lines involved lower establishment and maintenance costs in comparison of three-phase electrical power distribution systems. Rural areas which are characterized by low load density and sparse load needs a low cost electrification method; and electrification using Single wire earth return distribution has revealed to be the most economic option as it uses earth as return path.

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The extensive use of three-phase loads deteriorates the quality of electrical power day by day due to the increased involvement of nonlinear devices which poses non-linear characteristics.

In paper, a single-phase to three-phase unified power quality conditioner system, which converts single-phase power into three-phase power using single wire earth return to obtain series-parallel power quality conditioning [11], is considered.

In bulk of the UPQC-based systems, non-sinusoidal control references for the control of series and parallel APFs are implemented. Uninterruptible power supply (UPS) systems [3], [14] based applications uses dual compensation approach which need sinusoidal voltage and current control references. In this way, the control references are simpler to achieve, and require easier method [11].

Synchronous Reference Frame (SRF) based controllers are applied, to obtain lesser steady-state errors with Proportional-Integral (PI) controllers [15] [6].

II. POWER QUALITY ISSUES

In today's life, both electrical utilities and consumers of electrical energy are fetching more and more attention towards the quality of electric power. There is a large variety of power quality issues regarding power systems [1]. The deficiency of power quality affects end users in various ways; many outer and inner features influence the quantity and quality of power being delivered.

Now a day's integrated circuit-based controls and power electronic devices used in load instruments are more susceptible to power quality deviations in comparison to the instruments used in the past.

Today's electricity consumer has much more realization of the power quality issues occurred at each end of the system. Utility customers are more knowledgeable regarding quality aspects of the power such as voltage and current imbalances, harmonics and switching transients and are demanding to enhance the quality of power transferred to the client side.

Due to more concern about the overall regulation and productivity of the power system, many devices are employed with increased performance. These highly efficient devices may raise harmonics in the system. Incessant development of the high performance devices is more susceptible to power quality disturbances.

In a power system plenty of instruments or devices are interconnected that means dependent on each other. If any component is unable to work properly, further it may lead to any significant consequences or the system malfunction**.** In some situations, every part of equipment in system was possibly experienced at the plant for appropriate performance, but when these parts are installed as one, power quality disturbances are created and turn into the total system out of order [7].

Sources of poor power quality are as follows [8]:

- Switching power supplies
- Arc furnaces
- Power electronic appliances
- Lightening strike
- Electrolytic refining
- Telecom systems
- Adjustable-speed drives
- L-G faults

On the basis of time power quality variations can be classified into short duration voltage variation and long duration voltage variation. If supply voltage variation exceeds one minute then it is termed a short duration voltage variation. Whereas short duration variations have three types such as voltage sags, voltage swells and interruptions. Long duration variations are rms variations in the supply voltage exceeding 60 seconds and are categorized into over voltages, under voltages and sustained interruptions. Voltage fluctuation and transients also serve as the reason for power quality distortion [9].

So many procedures are invented to compensate these power quality defects, nullified by utilizing active power filters, unified power quality conditioners etc. In this paper to mitigate PQ variations a dual compensation topology is owned within UPQC. The UPQC with dual compensation is same as conventional UPQC except the controlling technique. Different from the conventional UPQC, in dual compensation sinusoidal references are generated for controlling the UPQC, which will automatically reduce the complex calculations.

III. SINGLE-PHASE TO THREE-PHASE UPQC

A basic UPQC circuit diagram is shown in fig 1. Basically two active power conditioners, sharing same dc-link, connected in series and parallel with the system. Here Shunt Active power filter (APF), which is connected in parallel to the system, is intended to apply as a controlled current source and draws unwanted current component, generated by the load i.e. current harmonics, forming source current absolutely sinusoidal by compensating harmonics and distortions. Series APF, which is connected in series with the line, is employed to suppress voltage unbalances and disturbances, exists on the source side to make load side voltage fully balanced and regulated.

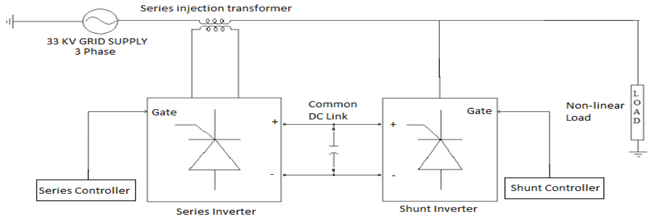

Fig. 1: Conventional UPQC circuit diagram

A single-phase to three-phase UPQC shown in fig. 2, is basically the combination of two active power same as conventional UPQC. Four half bridge PWM converters, simultaneously connected through a DC-link, contribute in the formation of the UPQC 1–ph-to-3-ph. Here a split-capacitor pattern is implemented for DC-link and its mid-point is linked with the load system's neutral wire.

As stated above four half bridge PWM converters are used, of which one of the half bridge converter is introduced as series APF (S-APF), functions in the system as a current source which is controlled and having sinusoidal behavior, in identical phase with the source voltage.

And the remaining three half-bridge converters are connected together to work as parallel APF (P-APF), obviously connected in parallel of the load. P-APF is voltage controlled, having sinusoidal behavior, by using which the system voltage harmonics are automatically suppressed following the reason that series coupling transformer retain the harmonics injected by the load. Therefore, No extra effort or additional calculating methods are required to get the control references [10] [11].

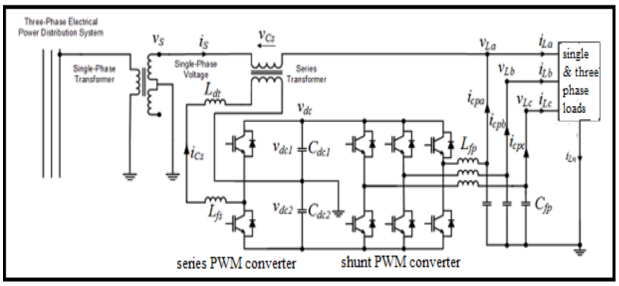

Fig. 2: UPQC 1-ph-to-3-ph

IV. DUAL COMPENSATION

The drawback of the basic unified power quality conditioner is that it poses complicated calculation of reference generation of current [7]. This limitation can be resolved by using the dual strategy based UPQC presented in this paper. Both in Dual configuration and in conventional configuration the basic structure of formation is same, the difference is in the manner the both of the filters are regulated and controlled.

Dual compensation strategy is dissimilar from the traditional power quality filtering strategy in a way that it uses sinusoidal references which are easy to control rather than non-sinusoidal references. Pulse Width Modulated Converters can be easily controlled by the application of sinusoidal references. The process of generating control references is much easier to perform, and uses simpler algorithms to fulfill the desired aim.

Synchronous Reference Frame based controllers are allowable to manage the input current from the grid. Series converter controller functions as a current source acting sinusoidal. Current harmonics exist in the electrical network experiences a high impedance path i.e. impedance must be sufficient to cut off the harmonic currents which are introduced by the non-linear loads. Parallel filtering is implemented by the parallel converter. Parallel converter is intended to employ as a controlled sinusoidal voltage source as current harmonics introduced due to the application of non-linear load experience low impedance path i.e. its impedance must be satisfactorily s0mall for drawing off the harmonic currents from the load. For generating control references, Phase-Locked Loop (PLL) system [12] is applicable to provide projected phase angle.

The load harmonic voltages and voltage instability are nullified by considering sinusoidal and balanced references, after their application to the converters by producing gate signal. The series coupling transformers are responsible for discarding all the voltage disturbances automatically. Due to the fact the dual compensation is much striking than the traditional or basic UPQC controlling technique [6].

V. CONTROL

The proposed unified power quality conditioner control is comprised in the union of the control of series and parallel active power filters [7]. Control reference generation and controllers are as following:

A. Series Converter Current Reference Generation

A single phase current reference is generated in the rotating frame for controlling purpose. To fulfill this aim three phase load currents, presently exist in stationary reference frame (abc -axes) are observed. Load currents are converted into the rotating frame (d-q axes) [11].

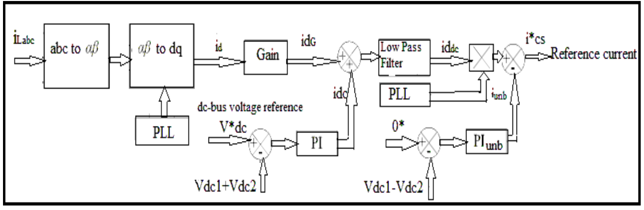

Fig. 3: Current Reference generation

During realization of 1ph-to-3ph UPQC system, for measuring the value of reference current (i^*_{cs}), condition is that single-phase input power and three-phase output power must be equal ($P_s = P_L$) assuming that three-phase output voltages and grid voltage are equal. We get:

Single-phase peak current $I_p = \sqrt{6} id_{dc}$;

Where id_{dc} is direct axis voltage ac component and gain is $\sqrt{6}$.

In series converter controller circuit two control loops are considered such as:

- voltage control loop for dc-bus
- voltage unbalance control loop

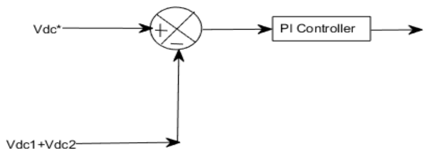

Fig. 4: PI voltage control

In voltage control loop, proportional-integral (PI) controller is used to maintain the magnitude of the reference current in case of occurrence of voltage amplitude variations in the system. It also provides dc-bus voltage regulation. A low pass filter is used for filtering application of the obtained reference current.

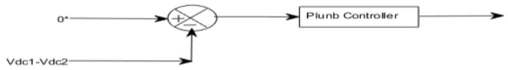

Fig. 5: voltage unbalances PI control

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In voltage unbalance controller loop again a proportional-integral (PI) controller is implemented to maintain the voltage level to be balanced by eliminating the voltage unbalance generated by dc-bus capacitors.

B. Series Converter Controller

Series converter control can be obtained from the following function:

$$\frac{i_{cs}}{i^{*}_{cs}} = \frac{K_{pwm}\left(\frac{V_{dc}}{2}\right)(K_{ps}S + K_{is})}{L_{eq}S^2(K_{ps}SK_{pwm}\left(\frac{V_{dc}}{2}\right) + R_{eq})S + K_{is}K_{pwm}\frac{V_{dc}}{2}}$$

This is required to generate PWM signal for series converter operation.

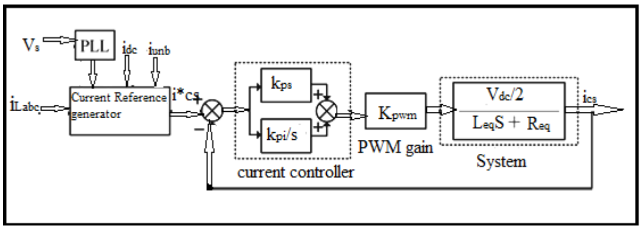


Fig. 6: controller for series converter

C. Parallel Converter Voltage Reference Generation

The output voltage references are given as:

$V^*_a = V_p\sin\theta$;
$V^*_b = V_p\sin(\theta - 120°)$;
$V^*_c = V_p\sin(\theta - 240°)$

Where V_p is the required voltage magnitude of the load and θ is the projected phase angle [11].

D. Parallel Converter Controller

There are two controller loops consisted in the parallel filter control block diagram such as:

One Proportional-integral (PI) and one Proportional (P) controllers are implemented in this parallel converter controller. P controller forms the current controller loop i.e. inner loop. PI controller forms the voltage controller loop i.e. outer loop.

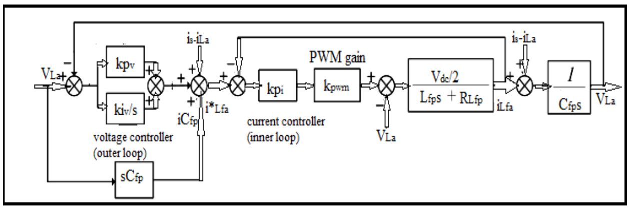


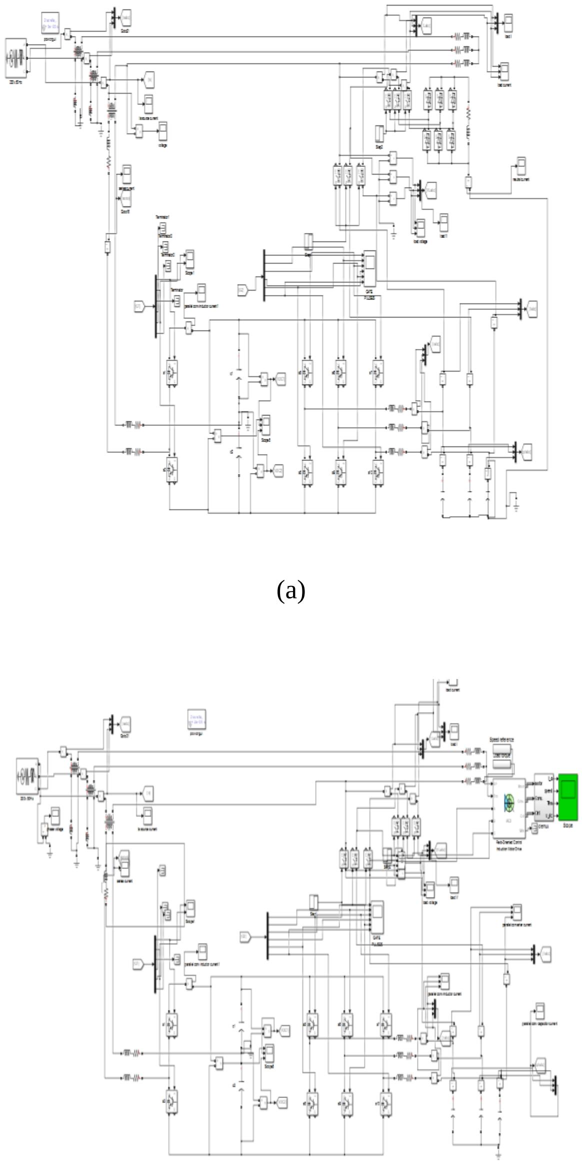
Fig. 7: Voltage controller

Transfer function for the above diagram is written as:

$$\frac{V_{La}(S)}{V^{*}_{La}(S)} = \frac{A(X_1S^2 + X_2S + X_3)}{(Y_1S^3 + Y_2S^2 + Y_3S + Y_4)}$$

VI. SIMULINK MODEL

From the MATLAB model it was feasible to construct and investigate proposed UPQC system and to optimize their performance before implementation on the genuine experimental equipment. This enabled rapid development and the opportunity to explore control. For the controller design purpose, model verification and response were modeled in MATLAB using SIMULINK. Figure 8 shows the MATLAB Simulation of Dual unified power quality conditioner having series and shunt active power filters with IGBTs.



(a)

(b)

Fig. 8: UPQC simulation model (a) three-phase full-bridge rectifier load, (b) FOC induction drive load

Here different loads are fed by a single phase power. These loads create several fault conditions, resulting in current harmonics in the system current. During this time, Active power filters of UPQC starts injecting compensating current and voltages in the system to compensate voltage & current unbalance, and harmonics restoring both the load voltages and the source current.

A. Series Converter Controller

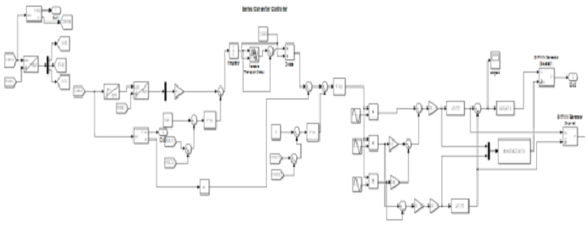


Fig. 9: Series converter controller simulation diagram

B. Parallel Converter Controller

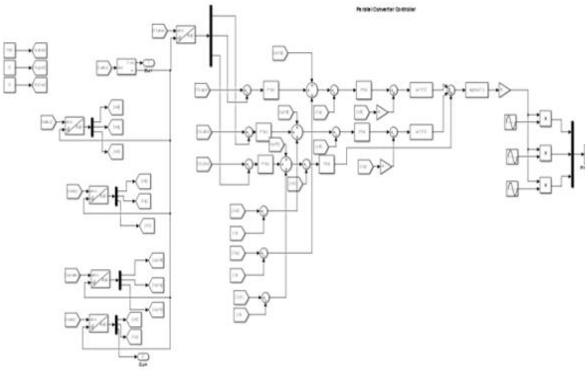


Fig.10: Parallel converter controller simulation diagram

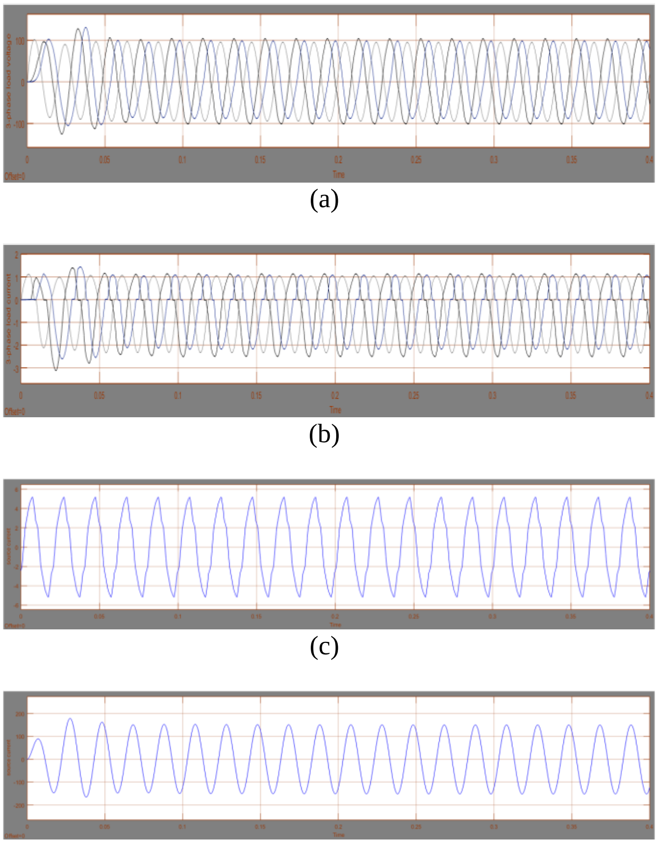
C. Parameters used in Simulation

Table- I: Parameters

single phase grid rms voltage Vrms	Vs = 230V
3-phase load voltage (rms)	V = 230V
Grid frequency	fs = 50 hz
Inverters' switching frequency	fch = 10 khz
Parallel converter inductances	Lfpabc = 10mH
Parallel converter capacitances	Cfpabc = 50µF
Series converter inductances	Lfabc = 2mH, Rfs = 0.2 Ω
Series transformer	Ldt = 0.2mH, Rdt = 0.2Ω, N=1
3-ph load1	R = 50Ω, L = 20mH
3-ph load2	1860VA
1-ph load1	R=20Ω, L=200mH
1-ph load2	R=40Ω, L=346mH
1-ph load3	R=30Ω, L=400mH
DC-bus voltage	1000V
DC-bus capacitance	8600µF

With above specifications, simulation is performed for different loads as follows: (i) three-phase full bridge rectifier with R-L load, (ii) 3 single-phase full wave rectifier with R-L load, and (iii) Three-phase field-oriented induction motor drive as load.

VII. SIMULINK RESPONSE



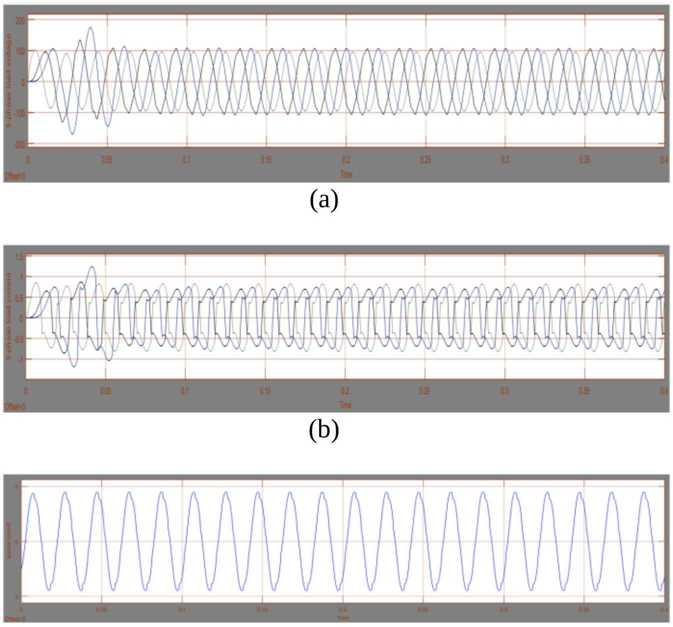
(a)

(b)

(c)

(d)

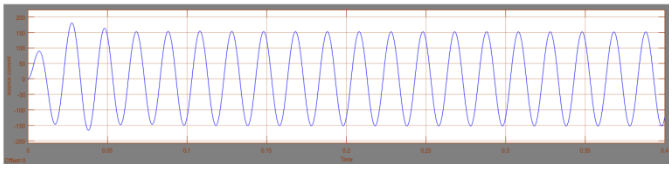
Fig. 11: three-phase full bridge rectifier load (a) Three-Phase output load voltages, (b) three-phase output load currents after compensation, (c) & (d) source current before and after compensation



(a)

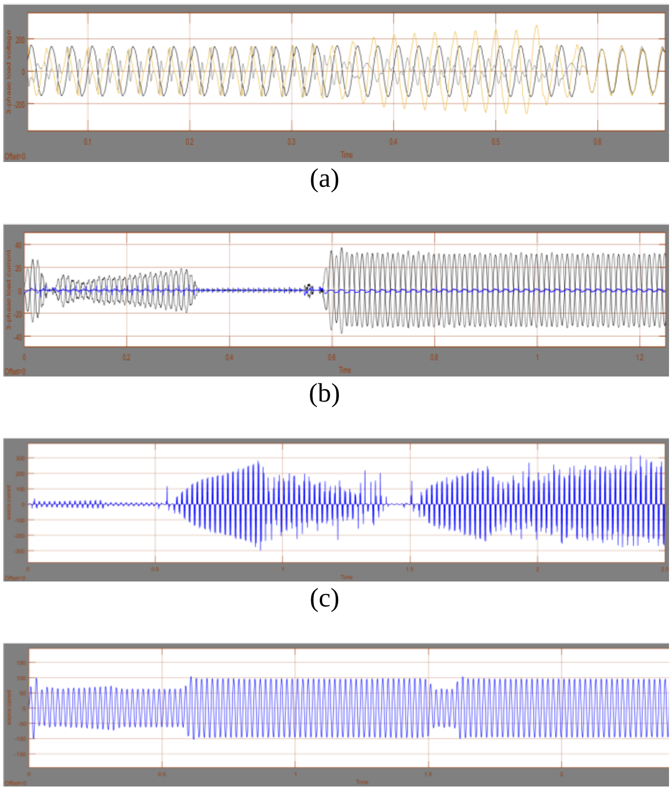
(b)

(c)



(d)

Fig. 12: 3- single-phase loads (a) Three-Phase output load voltages, (b) three-phase output load currents after compensation, (c) & (d) source current before and after compensation



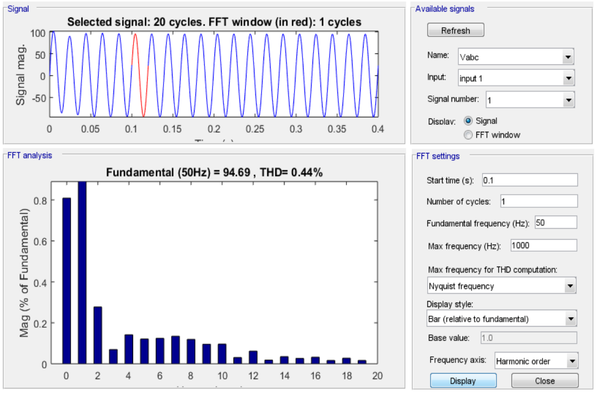
(a)

(b)

(c)

(d)

Fig. 13: three-phase FOC induction motor drive load (a) Three-Phase output load voltages, (b) three-phase output load currents after compensation, (c) & (d) source current before and after compensation

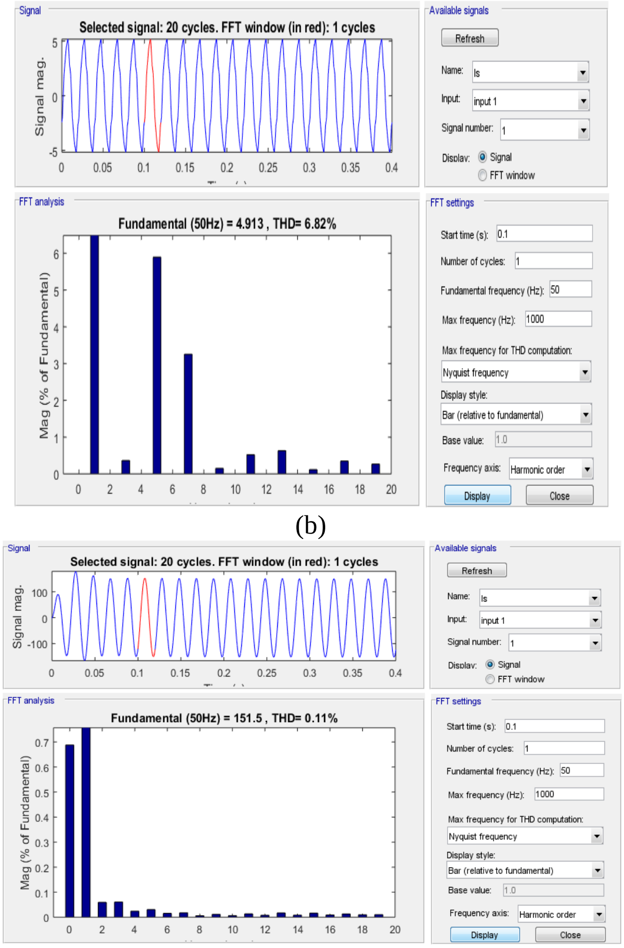


Selected signal: 20 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 94.69 , THD= 0.44%

Name: Vabc
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

(a)



Selected signal: 20 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 4.913 , THD= 6.82%

Name: Is
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

(b)

Selected signal: 20 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 151.5 , THD= 0.11%

Name: Is
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

(c)

Fig. 14: THD of the (a) three-phase output (b) source current before compensation, (c) source current after compensation

After compensation, the lower level of total harmonic distortion as well as three-phase sinusoidal and balanced output in load voltages, load currents and source currents has been achieved.

VIII. CONCLUSION

Unified power quality conditioner having non-linear loads, in rural areas, was considered and examined in this paper for power quality fortification. Proposed UPQC is simulated using series and parallel converters. Both series and shunt converters' reference generation and their controlling techniques are developed and simulated. UPQC 1-ph-to-3-ph overcomes both voltage and current related power quality problems concurrently. After compensation, UPQC is capable of reducing the total harmonic distortion level in grid source current, load voltages and currents in different load conditions generating harmonics and also able to feed both single-phase as well as three-phase loads. The recommended Dual unified power quality conditioner is able to satisfy the nonlinear load currents and also ensure the sinusoidal voltage for the load in all three phases. The major benefit of the projected control in comparison of other expected strategies is the application of sinusoidal references for the control operation of filters excluding the need of complex calculations.

FUTURE SCOPE

The proposed UPQC model can be modified to overcome the power quality problems in an electrical power distribution system. In future UPQC 1-ph-to-3-ph can be simulated on another platform other than MATLAB simulink and more superior controllers such as fuzzy controllers or artificial neural network can also be employed to make the proposed system more efficient. The load in the simulation can be replaced by some other loads i.e. turbine load, electric furnace.

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Shuchi Vishnoi received degree of B.Tech. in Electrical and Electronics Engineering in the year 2007 from UP Technical University, India. Presently she is pursuing her Master’s Degree in Power System from Rajasthan Technical University, Kota, India. Formerly, she has worked as a Lecturer in Electrical and Electronics Engineering department in SRMS CET, India. She has published research papers in national level conferences. Her present researches involve power electronics, power quality conditioning etc.