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Practical Implementation Of UPQC Under Non-Linear Loading Condition

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Abstract: Non-linear load adversely affect the voltage stability of the distribution system. If not checked at time the generated harmonics may propagate further and can severely damage the supply system. Non-linearity of load generates harmonics which if not filtered out may damage the connected equipments. In this paper dual compensation based unified power quality conditioner has been proposed to rule out the harmonics of the system. The controller is designed using sinusoidal current as well as voltage source converter which take care of both voltage as well as current control. The steady state error is removed using PI controller.

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I. INTRODUCTION

The use of non-linear loads is increasing making up a large percentage of demand. Inverters, rectified input, heavy variable drives, banking machines, switching power supplies, equipments of communication and electronic lighting ballasts are the most commonly used non-linear loads. Harmonic generated by non-linear loads which are connected phase-to-neutral in a three phase four wire system, are third order, zero sequence harmonics (the third harmonic and its odd multiples – 3rd, 9th, 15th, 21st, etc., phasors displaced by zero degrees). These third order harmonics do not cancel but add up arithmetically on the neutral bus, creating a primary source of excessive neutral current. These harmonics may propagate further and damage the equipments connected to the system also these are the primary source of voltage and frequency instability. Reliability and power quality issues of the distribution system can be improved using an advanced power electronics controller devices which have been launched over last decades. The evolution of power electronics controller devices has given to the birth of custom power devices (CPD).Custom power is technically designed to convene the requirement of industrial and commercial consumers. The concept of the CPD is tools of application of power electronics controller devices into power distribution system to enhance the quality of power, demanded by the specified users. These power electronics controller devices are also called custom power devices because through these valuable powers is applied to the customers. They perform well at medium distribution levels and most are available as commercial products. The concept behind CPD is to add value to the power that is offered to the customer aiming to improve power quality and reliability. In literature numerous CPDs are available such as; Active Power Filters (APF), Surge Arresters (SA), static transfer switch, Super conducting Magnetic Energy Systems (SMES), Current Limiter (SSFCL), Solid-State Transfer Switches (SSTS), Static VAR Compensator (SVC), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Distribution Static synchronous Compensators (DSTATCOM) and Uninterruptible Power Supplies (UPS) , Unified power quality conditioner(UPQC). Among these UPQC [1] – [17] is widely used which is designed using two APFs; shunt [18]–[24] and series [25]. Shunt APFs are placed in parallel with nonlinear loads, and controlled to operate as a sinusoidal current source. Series APF is connected between nonlinear load and the utility through a coupling transformer mitigating load harmonic currents. With the help series and parallel APFs UPQC is able to adopt dual compensating strategy that means it can perform both series and parallel power line conditioning simultaneously. The conventional UPQC is designed with non-sinusoidal reference frame which is very difficult to be synthesized by pulse width-modulated (PWM) converters and require an additional effort in order to achieve good performance. While sinusoidal reference frame (SRF) are easy to implement and has better performance. The scope of the research is to design a CPD having dual compensation strategy. The CPD is connected with series APF which is controlled as sinusoidal current source with high impedance to block the load harmonic current to enter into the supply system and parallel converter is controlled as sinusoidal voltage source with low impedance to absorb the load harmonic currents. The proposed topology employ sinusoidal synchronous frame which is different from the conventional conditioning strategy, which uses non-sinusoidal control references, the dual compensating strategy uses only sinusoidal references to control the PWM converters.

II. UNIFIED POWER QUALITY CONDITIONER (UPQC)

The main concern of power engineer is to maintain sinusoidal voltage and current at point of common coupling and also to supply harmonic free power to the consumer. The increased connectivity of non-linear loads had raised the demand of power conditioning devices. UPQC is one of the advance configurations of hybrid filter. In some literature it is also termed as universal filter [17].UPQC is a multifunction power conditioner employed to compensate voltage disturbances of the utility system, as a remedial for voltage fluctuation, and barricade the harmonic load current from entering the power system. It is designed by integrating series active filter and shunt active filter. The UPQC is accepted as one of the most powerful filter to large capacity loads sensitive to supply voltage flicker/imbalance. At the distribution side/ industrial load UPQC can improve power quality at the point of installation. Since last two decades it has been under research to improve voltage profile at distribution side. The state of the art of design of UPQC is to make the load equal to a resistance which done by inserting a series voltage proportional to the line current As the UPQC is a combination of series and shunt active filters, two active filters have different functions. The series active filter suppresses and isolates voltage-based distortions. The shunt active filter cancels current-based distortions. At the same time, it compensates reactive current of the load and improves power factor. The general configuration of UPQC is shown in Figure 1.

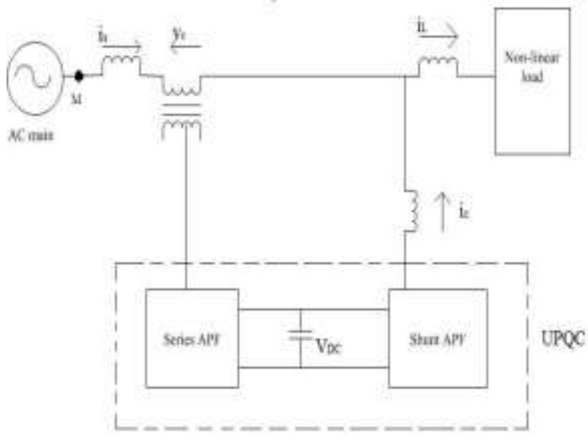


Figure 1 Schematic of UPQC

UPQC is crafted to protect the sensitive load at the point of installation connected to distorted distribution systems by correcting any of the following shortcomings:

- harmonic distortions (of source voltage and load current) at the utility--consumer PCC,
- voltage disturbances (sags, swells, flickers, imbalances, and instability),
- voltage regulation,
- reactive power flow at fundamental and harmonic frequencies,
- neutral and negative-sequence currents, and
- harmonic isolation (e.g., between a sub-transmission and a distribution system).

III. CONTROL STRATEGIES FOR UPQC

The PCC voltage unbalance compensation at distribution side can be achieved with flexible and coordinated control of UPQC. The UPQC is capable of steady-state and dynamic series and/or shunt active and reactive power compensations at fundamental and harmonic frequencies. UPQC is only concerned about the quality of the load voltage and the line current at the point where it is installed. However it cannot improve the power quality of the entire system. The control configuration of UPQC is shown in figure 2. The converter connected in series with the power line is a series converter designed as a voltage-source converter which acts as a voltage source mitigating voltage distortions. The flickers of the supply or imbalance due to non-linear loading are eliminated by series converter. It also forces the shunt branch to absorb current harmonics generated by the nonlinear load. Control of the series converter output voltage is usually performed using sinusoidal pulse-width modulation (SPWM).A three phase; six pulses; two level converter is triggered by the comparison of a fundamental voltage reference signal with three phase supply voltage.

Shunt converter is a voltage-source converter connected in shunt with the same AC line and acts as a current source to cancel current distortions, to compensate reactive current of the load, and to improve the power factor. It also performs the DC-link voltage regulation reducing the rating of the DC capacitor. The output current of the shunt converter is adjusted (e.g., using a dynamic hysteresis band) by controlling the status of semiconductor switches such that output current follows the reference signal and remains in a predetermined hysteresis band.

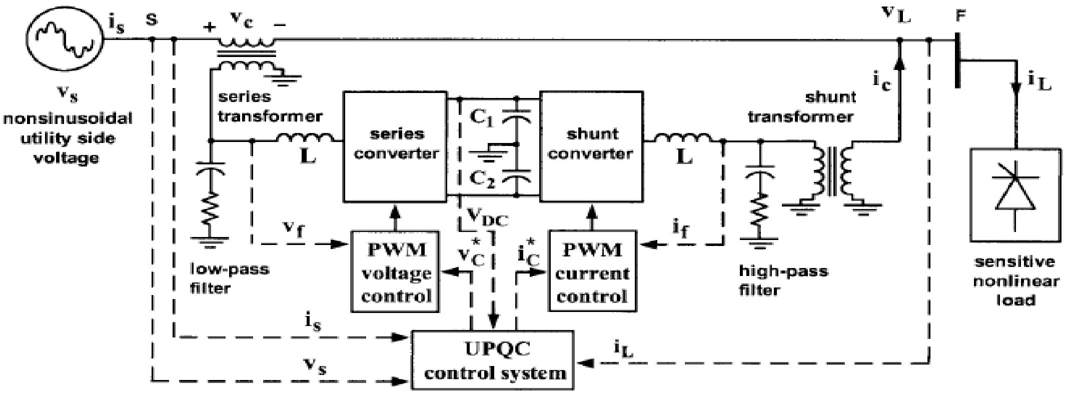


Figure 2 Control Loop Design for UPQC

1) Control Loop Design;

The accurate compensation calculation and the reference for voltage unbalance factor can be accurately obtained by properly designing controller.

The function of the controller can be defined with the following blocks;

i) The PCC voltage control block is used to track the VUF reference with a PI controller.
ii) The negative sequence current sharing block is used to produce the weighting factor for the output of the PCC voltage control block.
iii) The feed forward block is used to improve the dynamic response when the VUF reference steps rapidly.

IV. PROPOSED WORK

In this paper the practical implementation of the UPQC connected to the three phase distribution system under various operating conditions is present. The work has been carried out in three parts;Firstly; modeling of UPQC in matlab using simulink toolbox is carried out. The parameters chosen are mentioned in table 1. For modeling two converters one connected in series working as voltage converter and another connected in parallel with the supply system acting as current controller is designed. The series APF is triggered by generating control signal with PI controller whose gains are given in table 1. Series converter references are extracted from supply voltage which is first transformed using parks transformation than PI controller generates the control signal which is again converted from dqo-abc reverse parks transformation. The shunt converter forces the feeder (system)current to become a balanced (harmonic-free) sinusoidal waveform, while the seri es converter ensuresa balanced, sinusoidal, and regulated load voltage.

Secondly; the modeled UPQC is connected in the three phase distribution system. Three types of non-linear loadingis connected to check the performance of the modeled UPQC. Also condition of voltage sag is created to analyze the system under emergency state. The results are presented in next section. The scope of the research is to eliminate current harmonics load side generated due to non-linear loading and voltage sag. To regulate the load voltage and prevent it propagating further hence to safeguard the voltage sensitive equipments.

Table 1 Simulation model parameters

Effective nominal voltage of the utility (line to neutral))	Vs a , b , c = 127 V
Nominal utility grid frequency	fs = 50 Hz
Series filter inductance and capacitance	11H, 28e-6H
Inductance, resistance and Capacitances of the parallel	13e-6H, 10 ohm, 50e-6F
Transformation ratio of the series coupling transformers	n = 1
dc-bus voltage	Vd c = 400 V
dc-bus capacitance	Cd c = 9400 µF

Table 2 Various operating conditions

Unbalanced three phase loads	**Phase A**	**Phase B**	**Phase C**
Three single phase rectifier with RL loading	R=8.1 ohm L=380mH	R=10.12 ohm L=346mH	R=8.1 ohm L=357mH
Three single phase rectifier with RLC loading	R=13.5 ohm C=940 micro F	R=10.12 ohm L=346mH	R=8.1 ohm L=380mH
Balanced loading connected via three phase full wave rectifier	R=17 ohm		
Voltage sag	Three phase fault with ground resistance 0.001ohm persisting for 0.3seconds		

V. Simulation results

The system under study is shown in figure 3 which has been modeled in matlab simulink 2013a. For analyzing the performance of the system the three cases of operation of three phase three wire distribution system has been considered. The weak grid suffers from the problem of voltage unbalance which has been removed by designing controller which is placed between distribution system and the load terminal. The controller consists of two converter one controls the grid voltage unbalance and another stabilize the load current harmonics. The simulation results for system have been discussed below;
Case 1; non-linear load connected to distribution system without UPQC.
Case 2; non-linear load connected to distribution system with UPQC.
Case 3; condition of voltage sag on distribution system without and with UPQC.

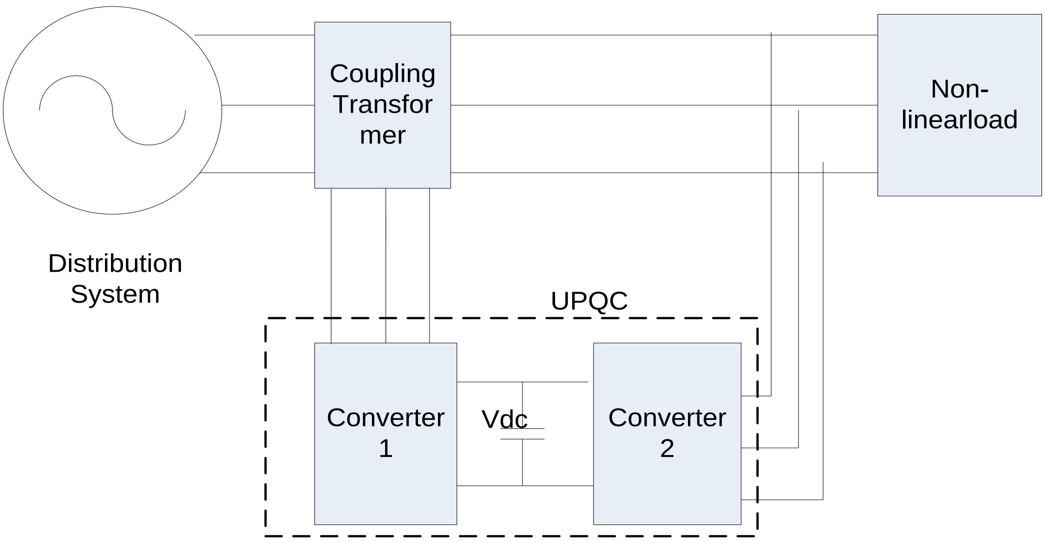


Figure 3 System under study.

Distribution system performance under non-linear loading without UPQC

It can be seen from the figures 5-8 that though the source voltage is stable under non-linear loading but source current is distorted a lot which may damage the other load or equipment connected to the same system.
The harmonic content of the source and load current are mitigated to a very extent employing UPQC whose results are presented in next section.

Distribution system performance under non-linear loading with UPQC

This section presents the distribution system performance with UPQC. All the three non-linear loading behavior with UPQC connected are presented in figures 9 and 10. The comparisons of THD percentage and the level of mitigation of harmonic both in source as well as load side is presented in tables 1and 2.

Voltage sag

A condition of voltage sag is created which last for 0.2 seconds by applying three phase fault. The results of voltage sag with and without UPQC is presentedinfigure11.

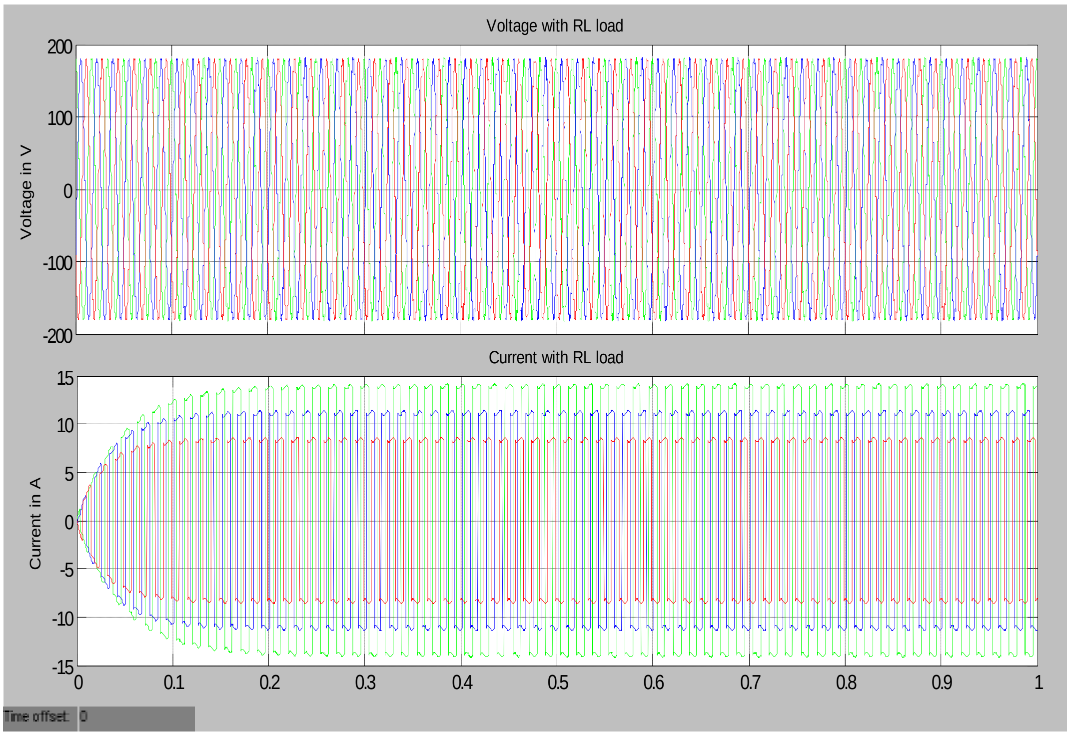


Figure 4 RL load without UPQC Source side

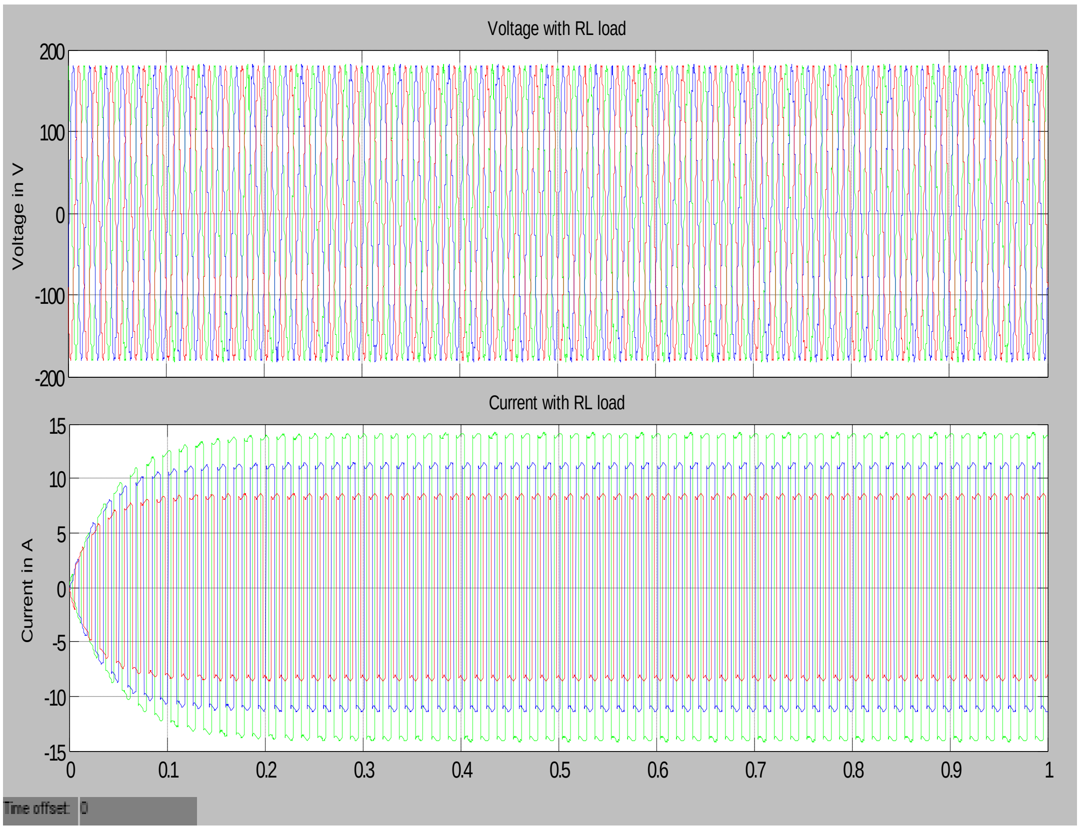


Figure 5 RL load without UPQC load side

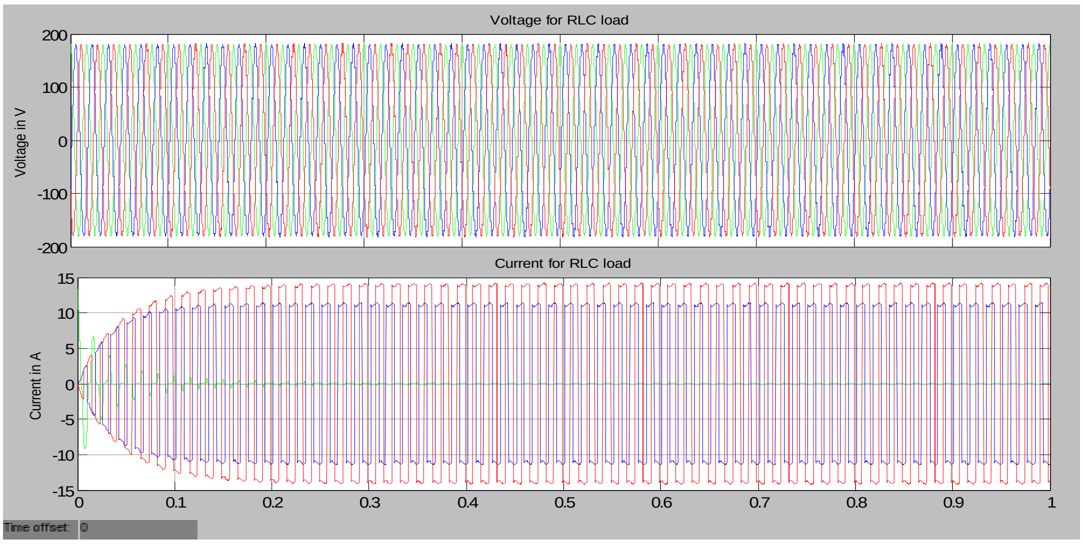


Figure 6 RLC load without UPQC source side

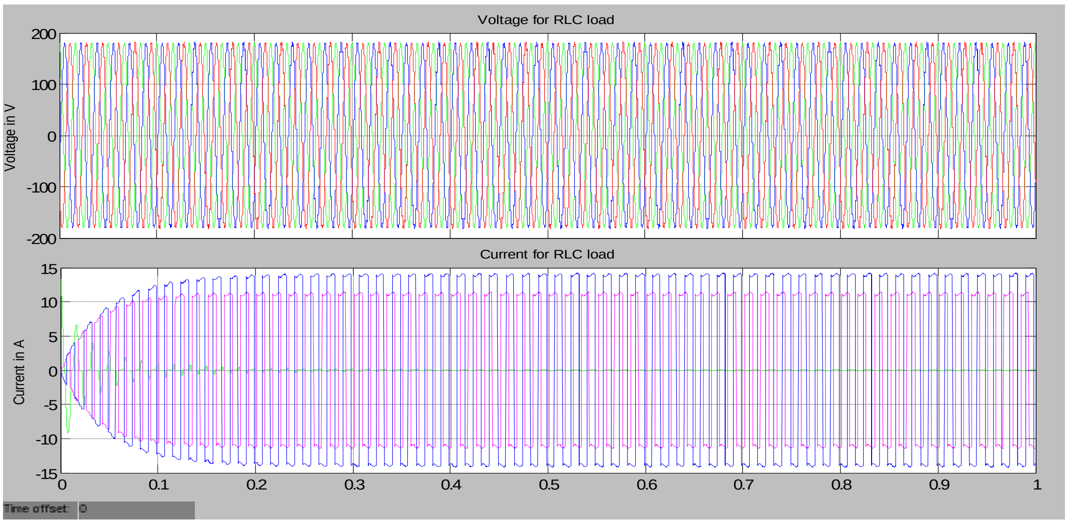


Figure 7 RLC load without UPQC load side

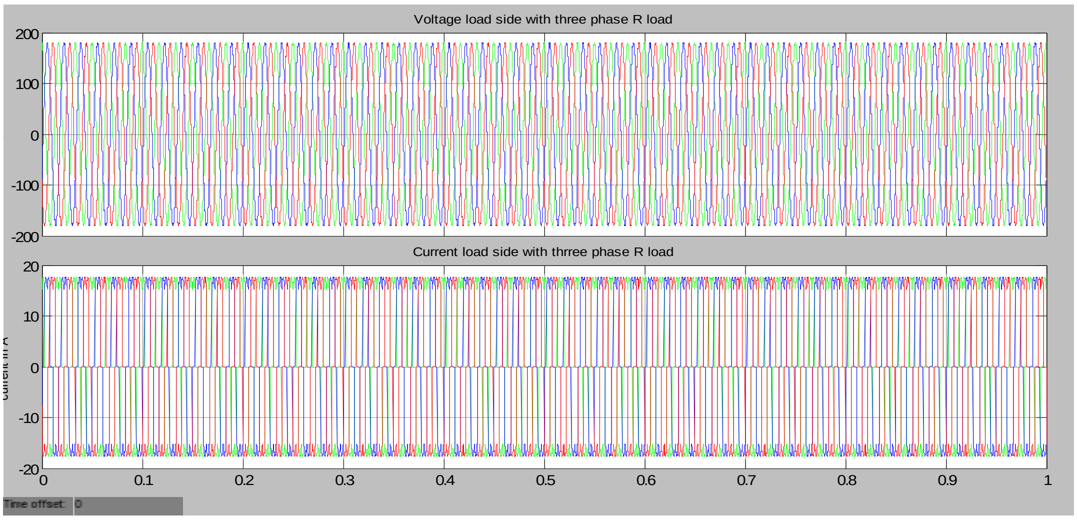


Figure 8 balanced three phase R load without UPQC load side

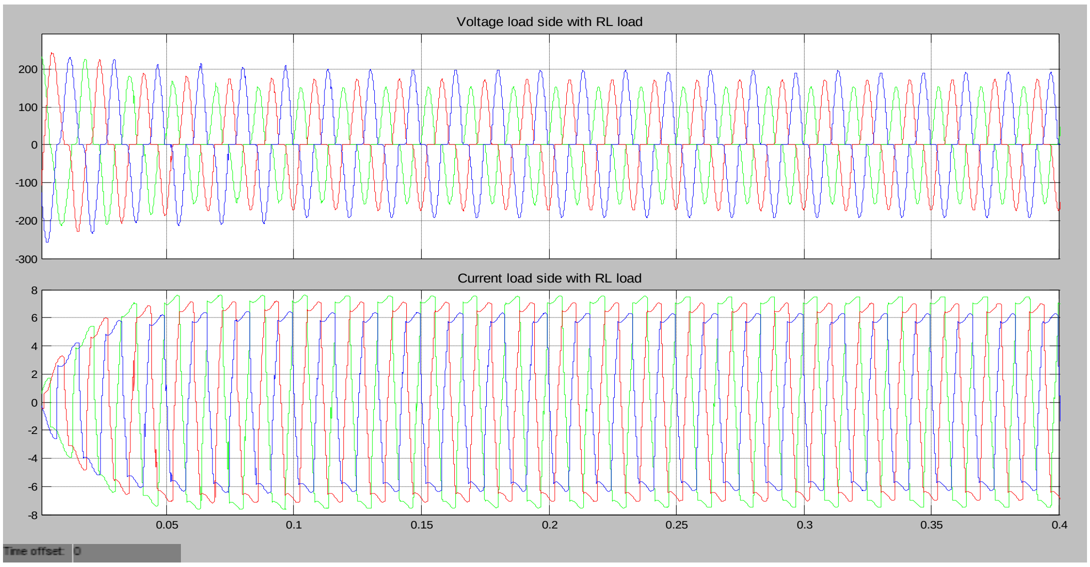


Figure 9 RL load with UPQC load side

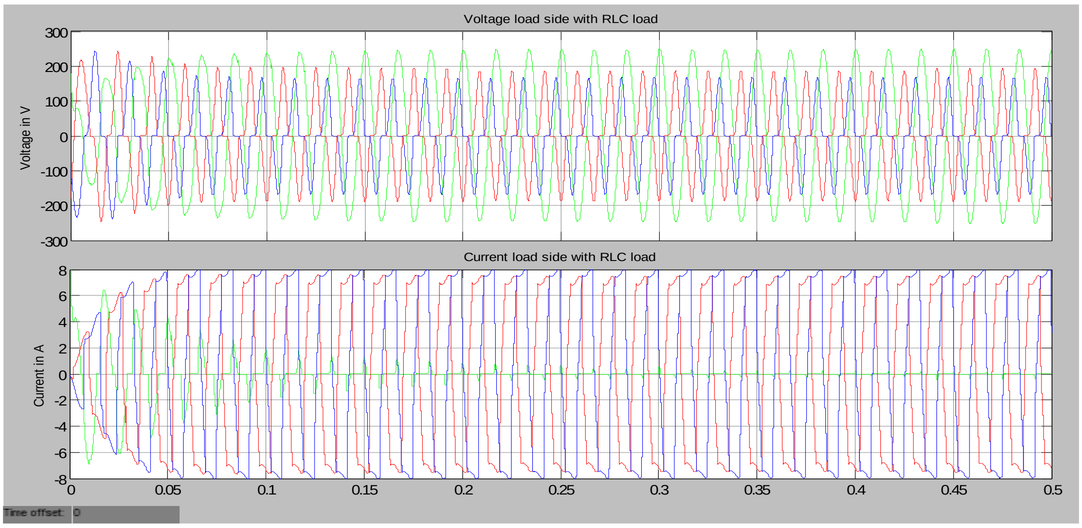
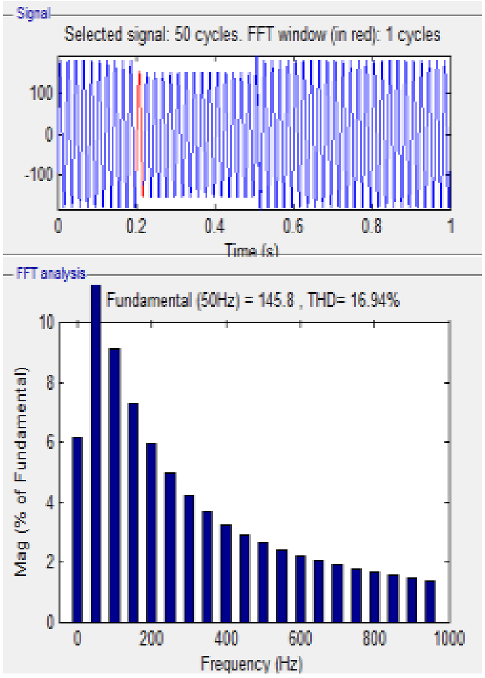


Figure 10 RLC load with UPQC Load side

Table 4 Comparison of Load Current THD with and without UPQC

Loading condition	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
	Without UPQC			With UPQC		
Three single-phase full-wave rectifiers (unbalanced load 1)	51	40	55	41	30	34
Three single-phase full-wave rectifiers (unbalanced load 2)	46	40	57	21	23	25
Balanced three-phase load(17.7 ohm) Three-phase full-wave Rectifier	28	28	28	24	24	24

Without upqc For RCL loading source current Phase A



With UPQC For RCL loading source current Phase A

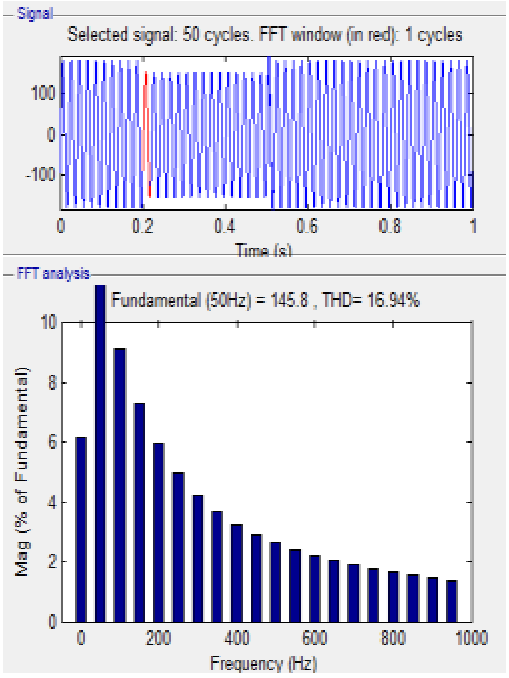


Figure 11 comparison of THD for fundamental waveform of source current for RCL loading

VI. CONCLUSION

A flexible compensation strategy for distribution system under various balanced and unbalanced non-linear loading as well as for the condition of voltage sag is presented in this paper. The proposed dual compensatory UPQC topology successfully mitigates the load current harmonics and protects the supply system from voltage flickers. With the help of series and parallel active filters input and output currents are balanced, and regulated. The system has been analyzed under various nonlinear loading conditions. Also the behavior of the proposed UPQC custom power device is studied under the condition of voltage dip.

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