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Performance analysis of UPQC in alleviation of voltage and current related distortions

KNV Sai Tejaswi[1], K V Kumar Kavuturu[2], K Baby Shamili[3], I Revathi[4]

[1-4]Asst Professor, Dept. of EEE, Vasireddy Venkatadri Institute of Technology, Guntur, India
[1]tejaswi.konidena@vvit.net
[2]vasishta.kavuturu@vvit.net
[3]shamilikuraganti@vvit.net
[4]revathi.issarapu@vvit.net
[1]Corresponding author: K V Kumar Kavuturu*

ABSTRACT

In recent days, most of the equipment is based on power electronics and often leads to power quality problems. Conventional equipments for power quality enhancement are not sufficient to meet the increasing applications and so it is very essential to develop a unique solution for majority of power quality issues. Hence, to mitigate both voltage imperfections and load current abnormalities one of the custom power quality device named as unified power quality conditioner (UPQC) is employed. It comprises the arrangement of both series and shunt voltage source converters associated with a typical dc interface capacitor. This paper presents the simulation of UPQC through synchronous reference theory for the converters control. The simulation case studies are carried out with the help of MATLAB software and the results are described under distorted source conditions, voltage sag and swells conditions.

Index terms—*UPQC, synchronous reference frame theory (SRFT), sinusoidal pulse width modulation (SPWM), PQ theory, point of common coupling (PCC).*

1. INTRODUCTION

It is evident that a large portion of the power sector loads have non linear behavior when operated on AC power supply. Because they draw different types of harmonic currents like unbalanced current, fluctuating current, reactive component of current, characteristic and non-characteristic current harmonics from AC supply. Majority of the rotating machines and magnetic devices are behaves with non linear nature due to its saturation, geometry and asymmetry in airgap. The nonlinear loads comprising of solid state converters and they can draw considerable amount of harmonic current from the supply. In 3-phase SYSTEMS, THESE NONLINEAR LOADS CAN CAUSE UNBALANCE IN LOAD VOLTAGE AND SOMETIMES DRAWS EXCESSIVE NEUTRAL current under the system with 3-phase, 4-wire supply.

Generally power quality problems are classified into two classes: a) due to poor quality of current drawn from non linear loads and b) due to disturbances in voltages that can cause power system faults and the cumulative process may lead to voltage collapse. The very common but critical power quality problems are voltage dips, surges and harmonic currents. These issues may lead from temporary interruption to permanent shutting down of the sensitive equipment connected to the system.

The review on the different types on UPQC is available in [1]. The sag/swell and harmonic mitigation in the two feeders is possible with Multi-Converter UPQC (MC-UPQC). The UPQC optimal location is

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determined based on a hybrid algorithm GA-DA in [2] for the power quality enhancement in terms of UPQC cost and power loss in IEEE33 and 69 test systems. The source current compensation and voltage compensation and THD level measurement in an isolated power system by using UPQC device and hybrid generation is proposed in [3]. A comparative study on measurement of power consumption losses by using UPQC variants as UPQC-P, UPQC-Q and UPQC-Q shows the best device among the three in minimization of power loss [4]. Double loop control topology for UPQC is experimented in [5] towards harmonic suppression and voltage sag mitigation. A 20 switch 3-level cascaded H-bridge UPQC is used for alleviation of current/voltage harmonics, current/voltage unbalances in [6]. The power from solar cell can be extracted from fractional open circuit algorithm which provides both current and voltage compensation by the converters of UPQC. A comparison between UPQC and open-UPQC (O-UPQC) in addressing the voltage sag and unbalanced current conditions and proves O-UPQC shows the better performance than normal UPQC [7]. Fuzzy based UPQC is incorporated into the system for attenuating current and voltage harmonics in [8]. Several voltage variation problems faced by Mufindi Paper mill are addressed by SRF based UPQC is presented in [9]. Many control algorithms such as unit vector template (UVT) and PQ theory are used for the two converters of UPQC for addressing the voltage and current deformity issues. Recent research efforts are mostly concentrating on the full utilization of UPQC for all the current, voltage power quality abnormalities. UPQC is a flexible custom device similar to Unified Power Flow Controller (UPFC) but differs in control objectives and applications.

2. MODELLING OF UPQC

The basic model of UPQC with two voltage source converters being used as filters, one is in series conjunction and the other is shunt conjunction with the 3-phase feeder as presented in Fig 1. The shunt active filter is used to compensate all the current related issues and the series filter can able to recompense voltage related issues. Two active filters are connected by a dc coupling capacitor.

The series voltage source converter is used for voltage inclusion into the feeder and the shunt voltage source converter provides a path for current insertion into the line.

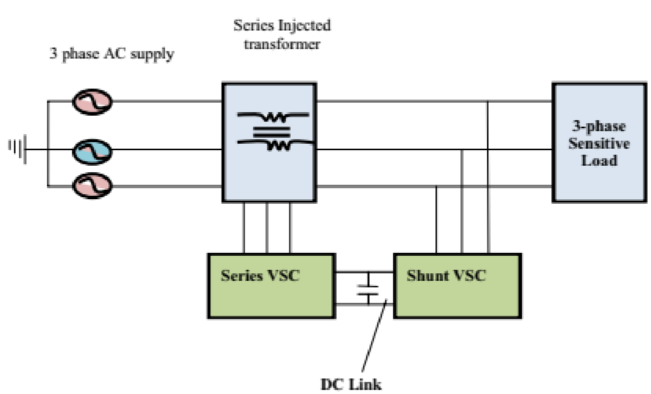

Fig.1 Schematic Layout of UPQC

3. CONTROLLING METHODS

The shunt filter can do the following functions:

1. The balanced 3-phase source currents are obtained by injecting negative and zero sequence components.
2. The shunt converter able to compensate the load current harmonics.
3. Due to the injection of reactive currents, the power factor is improved.
4. The voltage of dc capacitor voltage is regulated.

The series filter can do the following functions:

1. The load bus voltages are balanced by adding sequence voltages other than positive sequence.
2. The voltages at sensitive or non-linear loads are regulated by feeding the real and reactive components.
3. The supply power factor can be controlled by series converter.

The UPQC series filter is governed by using SRFT and its simulation model is shown in Fig 2. The pulses for series filter are obtained when the distorted source voltage V_{abc_dist} is compared with the reference supply voltage $V_{abc\_ref.}$ Afterwards these two voltages are transformed into d-q-0 reference frame as V_{dq0_dist} and V_{dq0_ref} and compared to generate an error signal. This error signal is converted back to a-b-c reference frame and given as $V'_{abc.}$ This reference voltage is applied to the pulse generator for generation of necessary gate pulses to the series converter.

According to SRFT, the *abc* source voltages can be transformed into *dq0* by using the equation (1).

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin\theta & \cos\theta \\ \frac{1}{\sqrt{2}} & \sin(\theta-120) & \cos(\theta-120) \\ \frac{1}{\sqrt{2}} & \sin(\theta+120) & \cos(\theta+120) \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

(1)

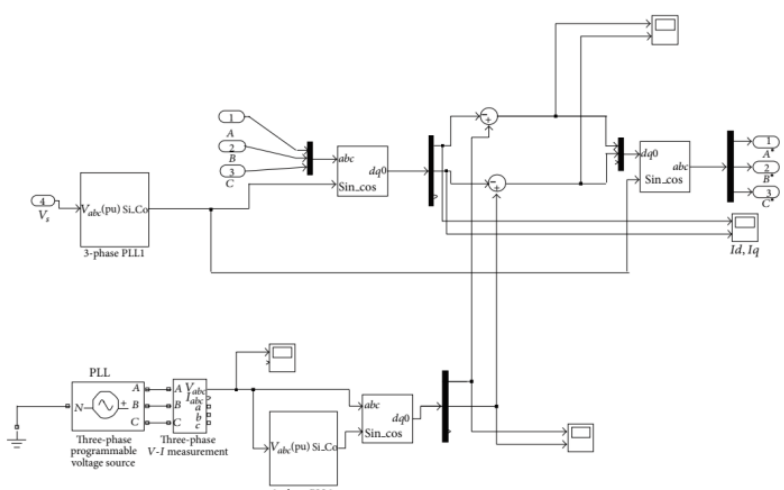

Fig.2 Control topology for series converter

Both the voltages V_d and V_q consists of dc component and ac harmonic component. This harmonic component can be eliminated by using this series power filter and the steady state error can be eliminated

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with the help of PI controller. Once the harmonics are eliminated, the voltages in *dq0* frame are converted back to *abc* frame to get the series converter reference generate the reference vector to the filters. This conversion is given in equation (2).

$$\begin{bmatrix} V_a' \\ V_b' \\ V_c' \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin\theta & \sin(\theta-120) & \sin(\theta-120) \\ \cos\theta & \cos(\theta-120) & \cos(\theta+120) \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \quad (2)$$

The simulated diagram for shunt voltage source converter based on SRF theory is presented in Fig 3. Here also, the *abc* reference load currents can be transformed into *dq0* frame and filtered with low pass filters to mitigate harmonics and then again the two currents I_d and I_q are transformed back into *abc* frame to produce the reference current signal. This signal is applied to pulse generator for the production of gate pulses to the shunt filter.

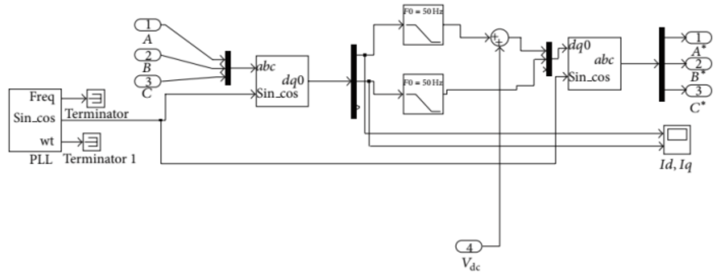

Fig.3 Control topology for shunt filter

The capacitor voltage at dc link is measured and compared with a constant voltage 730V as shown in Fig 4. The comparison yields the error signal and it is processed by the PI controller to maintain the constant voltage.

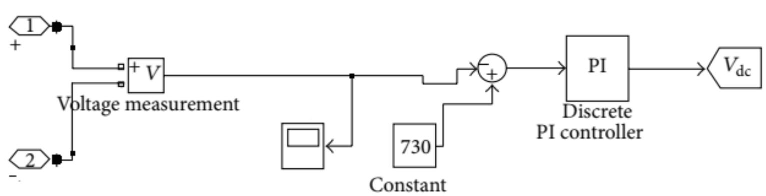

Fig.4 Voltage at dc link

4. SIMULATION RESULTS

This paper manifests the simulation of UPQC for compensation of voltage and current related problems have been addressed by using MATLAB simulation tool.

a. Simulation results for current related issues

The load current due to non-linear loads consisting of harmonic content is shown in Fig 5(a). Because of non-linearity, the source current also distorted and consists of harmonics is presented Fig 5(b). The source current harmonics are shown till the time 0.2sec. The shunt filter mitigates this harmonic current

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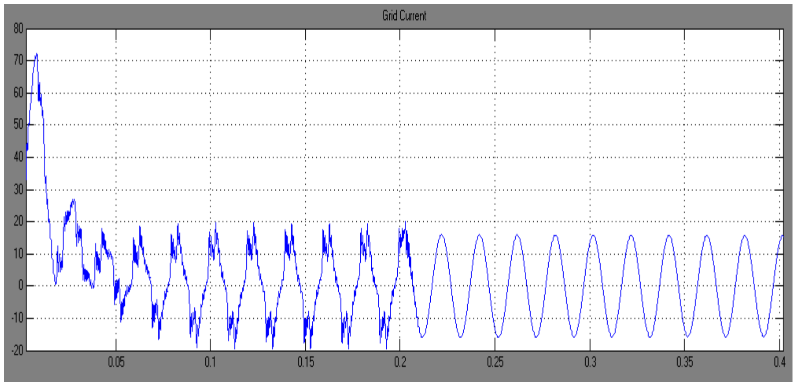
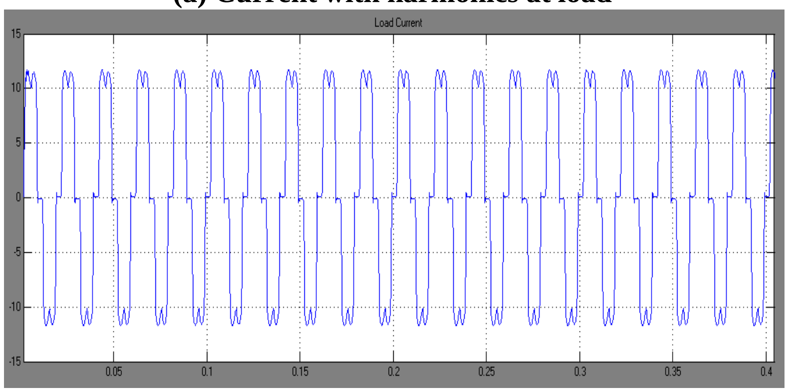
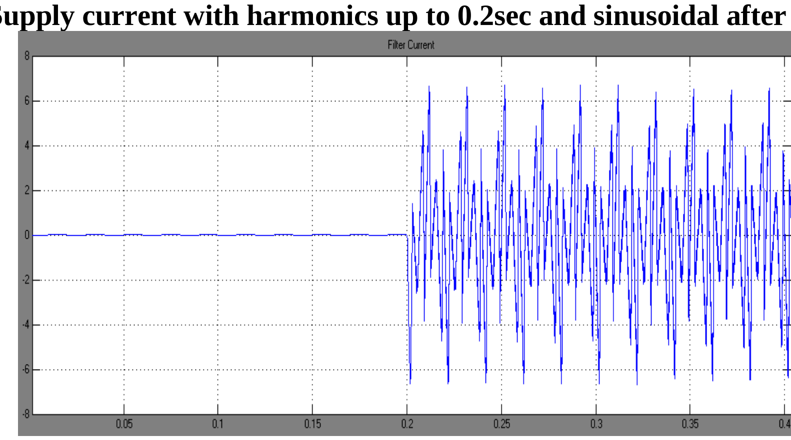
from the time 0.2seconds which is shown in Fig 5(c). Due to shunt current compensation the source current becomes sinusoidal as shown in Fig 5(b) after time 0.2sec.



(a) Current with harmonics at load



(b) Supply current with harmonics up to 0.2sec and sinusoidal after 0.2sec



(c) Current compensated by shunt filter

Fig.5 Simulation of Current related problems

The total harmonic distortion (THD) level for the phase-a current without the shunt filter is observed as 28.49% which is shown in Fig 6(a). After incorporating of shunt filter of UPQC, the THD level is reduced to 0.41% as depicted in Fig 6(b).

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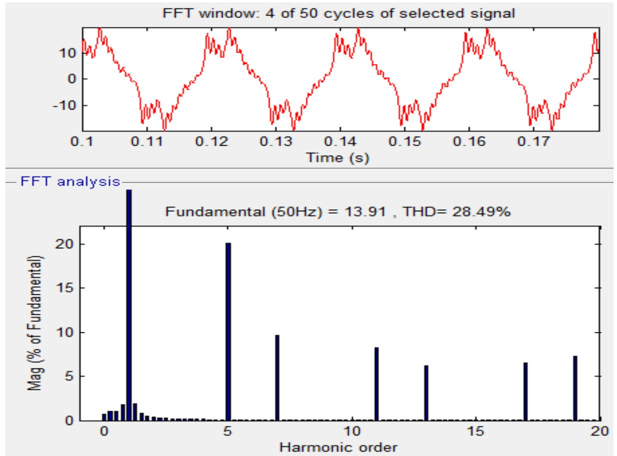
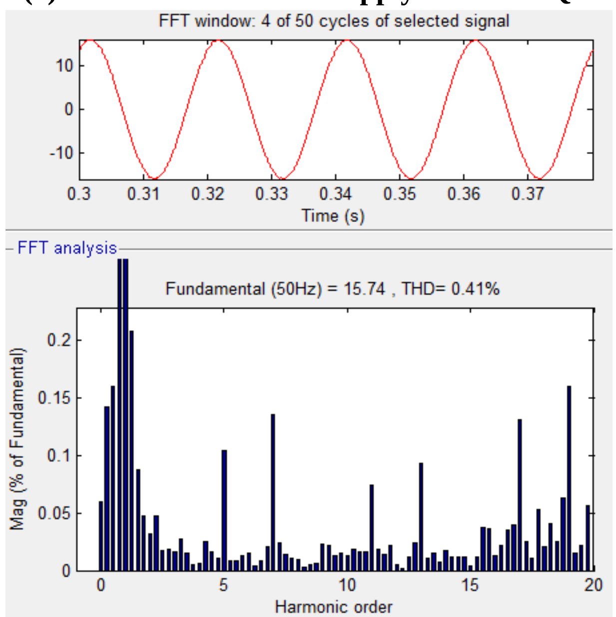


(a) Harmonic current at supply before UPQC



(b) Harmonic current at supply after UPQC

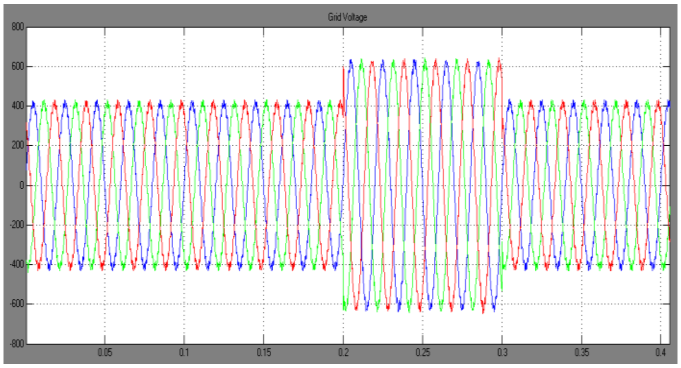
Fig.6 THD levels before and after UPQC placement

b. Simulation results for voltage related issues

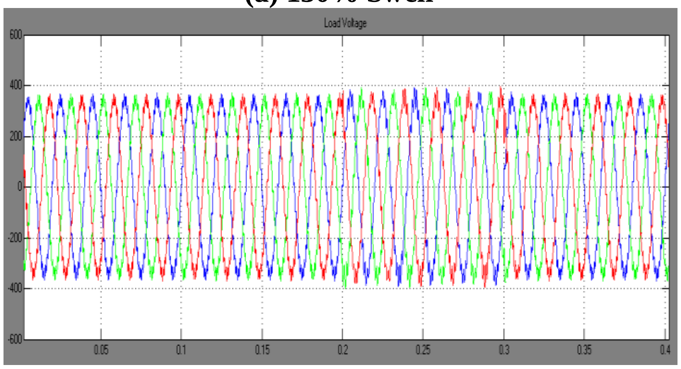
To test the UPQC in mitigating the voltage related problems, a voltage sag and swell created in the system as shown in Fig 7. A voltage swell with 130% peak is created from the time 0.2sec to 0.3sec as shown in Fig 7(a). After incorporating UPQC into the system, the series filter clips the surge voltage to normal level which is shown in Fig 7(b).

Similarly, a voltage is clipped to 50% level as shown in Fig 7(c) during time 0.2sec to 0.3sec. Now the series filter injects the missing voltage via injection transformer and maintain the line voltage to normal level as shown in Fig 7(d).

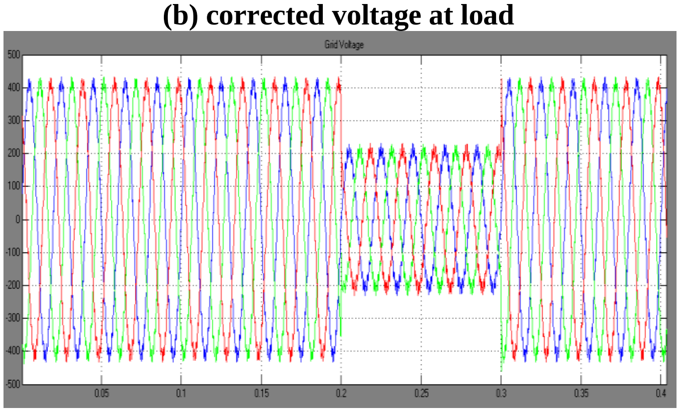
5. CONCLUSION



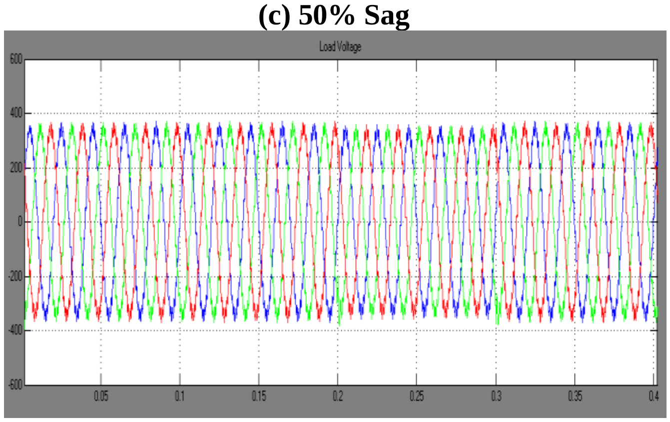
(a) 130% Swell



(b) corrected voltage at load



(c) 50% Sag



(d) Corrected voltage at load

Fig.7 Simulation of Voltage related problems

In this paper, the two converters of UPQC can be considered as two active filters for mitigation of voltage and current related quality issues. Both the filters are governed by SRF theory and pulses are generated to control and maintain constant voltage under sag and surge situations. The created voltage sag with 50% and voltage swell by 130% has been regulated to normal levels by using series filter of UPQC. In addition, the current harmonics in the supply are mitigated by using shunt filter and the THD levels for the compensated source current is also presented in this paper. The shunt filter supplied the harmonic current which maintain the source current as sinusoidal and THD level is reduced to a value of 0.41% from 28.49%.

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