ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.2, Pages : 39-44 (2013)
Special Issue of NCRTECE 2013 - Held during 8-9 February, 2013 in SMK Fomra Institute of Technology, OMR, Thaiyur, Kelambakkam,Chennai

POWER QUALITY IMPROVEMENT OF THE CUSTOM POWER DEVICE WITH PROTECTION OF INVERTER FROM SHORT CIRCUIT FAULT

M.REKHA[1] M.E. (PED) , C. OORVASI[2] M.E. (PED)
[1]Assistant Professor, Department of Electrical and Electronics Engineering, Christ College of Engineering and Technology
[2]Assistant Professor, Department of Biomedical Engineering, Rajiv Gandhi College of Engineering and Technology

***ABSTRACT*-- This paper presents a new synchronous-reference frame (SRF)-based control method to compensate power-quality (PQ) problems through a three-phase four-wire unified PQ conditioner (UPQC) under unbalanced and distorted load conditions. The proposed UPQC system can improve the power quality at the point of common coupling on power distribution systems under unbalanced and distorted load conditions. An addition of fault protection circuit at the series transformer. The simulation results based on Matlab/Simulink are discussed in detail to support the SRF-based control method presented in this paper. The proposed approach is also validated through experimental study with the UPQC hardware prototype.**

Index Terms—Active power filter (APF), harmonics, phase locked loop (PLL), power quality (PQ), synchronous reference frame (SRF), unified power-quality (PQ) conditioner (UPQC).

I.INTRODUCTION

Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive power electronic equipment and non-linear loads are widely used in industrial, commercial and domestic applications leading to distortion in voltage and current waveforms

UNIFIED POWER-QUALITY (PQ) conditioner (UPQC) systems were widely studied by many researchers as an eventual method to improve the PQ in electrical distribution systems. The aim of a UPQC is to eliminate the disturbances that affect the performance of the critical load in power systems. The UPQC, therefore, is expected to be one of the most powerful solutions to large-capacity loads sensitive to supply-voltage-imbalance distortions. The UPQC, which has two inverters that share one dc link, can compensate the voltage sag and swell and the harmonic current and voltage, and it can control the power flow and voltage stability.
Moreover, the UPQC with the combination of a series active power filter (APF) and a shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link.

The shunt APF is usually connected across the loads to compensate for all current-related problems, such as the reactive power compensation, power factor improvement, current harmonic compensation, neutral current compensation, dc-link voltage regulation, and load unbalance compensation, whereas the series APF is connected in series with a line through a series transformer (ST). It acts as a controlled voltage source and can compensate all voltage-related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc..

The proposed synchronous-reference-frame (SRF)-based control method for the UPQC system is optimized without using transformer voltage, load, and filter current measurement, so that the numbers of the current measurements are reduced and the system performance is improved. In the proposed control method, load voltage, source voltage, and source current are measured, evaluated, and tested under unbalanced and distorted load conditions using Matlab/Simulink software. The proposed SRF-based method is also validated through experimental study.

II. UPQC

The UPQC for harmonic elimination and simultaneous compensation of voltage and current, which improve the PQ, offered for other harmonic sensitive loads at the point of common coupling (PCC). In almost all of the papers on UPQC, it is shown that the UPQC can be utilized to solve PQ problems simultaneously. Fig. 1 shows a basic system configuration of a general UPQC with series and shunt APFs. The main aim of the series APF is to obtain harmonic isolation between the load and supply. It has the capability of voltage imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer PCC. The shunt APF is used to absorb current harmonics, to compensate for reactive power, and to regulate the dc-link voltage between both APFs.

III. SRF

The conventional SRF method can be used to extract the harmonics contained in the supply voltages or currents. For current harmonic compensation, the distorted currents are first transferred into two-phase stationary coordinates using $\alpha-\beta$ transformation (same as in $p-q$ theory). After that, the stationary frame quantities are transferred into synchronous rotating frames using cosine and sinus functions from the phase-locked loop (PLL). The sinus and cosine functions help to maintain the synchronization with supply voltage and current. Similar to the $p-q$ theory, using filters, the harmonics and fundamental components are separated easily and transferred back to the $a-b-c$ frame as reference signals for the filter. The conventional SRF algorithm is also known as $d-q$ method, and it is based on $a-b-c$ to $d-q-0$ transformation (park transformation), which is proposed for active filter compensation. Several APF and UPQC application works presented in the literature are about improving the performance of the compensator.

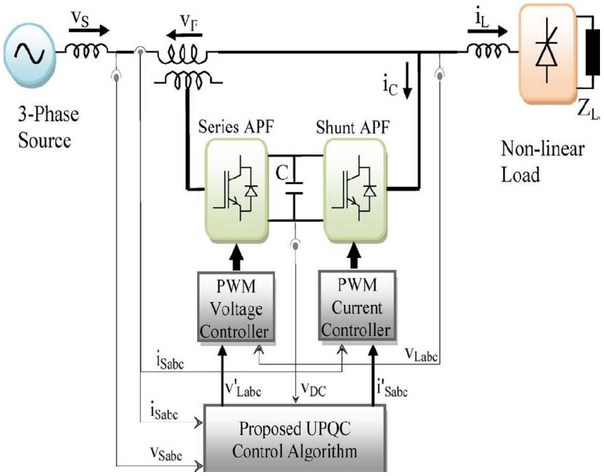

Fig 1: SRF based UPQC system

In the SRF-based APF applications in three-phase four-wire (3P4W) systems, voltage and current signals are transformed into the conventional rotating frame ($d-q-0$). In the SRF method, the transformation angle (ωt) represents the angular position of the reference frame which is rotating at a constant speed in synchronism with the three-phase ac voltage. In nonlinear load conditions, harmonics and reactive currents of the load are determined by PLL algorithms. Then, currents with the same magnitude and reverse phase are produced and injected to the power system in order to compensate neutral current, harmonics, and reactive power. In the stationary reference frame, $\alpha-\beta-0$ coordinates are stationary, while in the SRF, $d-q-0$ coordinates rotate synchronously with supply voltages. Thus, the angular position of the supply voltage vector shows the angular position of the SRF.

In 3P4W systems, since the *id* component of the current in the "*d*" coordinate is in phase with voltage, it corresponds to the positive-sequence current. However, the *iq* component of the current in the "*q*" coordinate is orthogonal to the *id* component of the current, and it corresponds to the negative sequence reactive current. The *i*0 component of the current, which is orthogonal to *id* and *iq*, corresponds to the zero sequence component of the current. If the *iq* component of the current is negative, the load has inductive reactive power. If it is positive, the load has capacitive reactive power. In 3P4W nonlinear power systems, the *id* and *iq* components of the current include both oscillating components (*id* and *iq*) and average components (*id* and *iq*), as shown in

$$i_d = \tilde{\iota}_d + \bar{\iota}_d \qquad (1)$$
$$i_q = \tilde{\iota}_q + \bar{\iota}_q$$

The oscillating components (_*id* and_*iq*) of the current correspond to harmonic currents, and the average components of the current correspond to the active (*id*) and reactive (*iq*) currents. In the balanced and linear three-phase systems, the load voltage and current signals generally consist of fundamental positive-sequence components. However, in unbalanced and nonlinear load conditions, they include fundamental positive-, negative-, and zero-sequence components. In APF applications, the fundamental positive-sequence components of the signals should be separated in order to compensate the harmonics.

IV. PROPOSED SRF-BASED CONTROL ALGORITHM

Among the several APF control methods presented in the literature, the SRF-based control method is one of the most conventional and the most practical methods. The SRF method presents excellent characteristics but it requires decisive PLL techniques. This paper presents a new technique based on the SRF method using the modified PLL algorithm and compares its performances with that of the conventional SRF method under unbalanced and distorted load conditions.

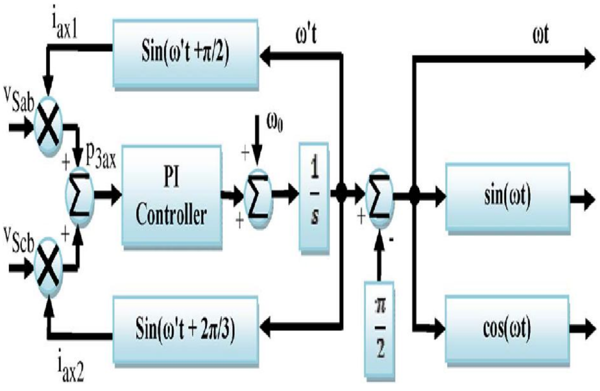

Fig 2: Proposed SRF Control Method

The proposed SRF control method uses $a-b-c$ to $d-q-0$ transformation equations, filters, and the modified PLL algorithm shown in Fig. 2. The sensing of only the source current to realize an SRF-based controller or another type of controller for shunt APF is not new, and this kind of controller can be found in literature. The proposed SRF-based controller with modified PLL for the UPQC under 3P4W topology and particularly the SRF-based controller for the series APF part is not presented in the literature. The proposed method is simple and easy to implement and offers reduced current measurement; therefore, it can be run efficiently in DSP platforms. Hence, the proposed modified PLL algorithm efficiently improves the performance of the UPQC under unbalanced and distorted load conditions.

A. *Modified PLL*

Some PLL algorithms were used with SRF and other control methods in APF applications. The conventional PLL circuit works properly under distorted and unbalanced system voltages. However, a conventional PLL circuit has low performance for highly distorted and unbalanced system voltages. In this paper, the modified PLL circuit shown in Fig. 2 is employed for the determination of the positive sequence components of the system voltage signals. The reason behind making a modification in conventional PLL is to improve the UPQC filtering performance under highly distorted and unbalanced voltage conditions. The simulation results according to the transformation angle (ωt) waveform for, first, the conventional PLL and, second, the modified PLL algorithms are shown in Fig. 3. The modified PLL has better performance than that of the conventional PLL, since the output (ωt) of the modified PLL has a low oscillation under highly distorted and unbalanced system voltage conditions.

The modified PLL circuit calculates the three-phase auxiliary total power by applying three-phase instantaneous source line voltages, i.e., vSab and vScb (vSab = vSa − vSb; vScb = vSc −vSb), in order to determine the transformation angle (ωt) of the system supply voltage. The modified PLL circuit is designed to operate properly under distorted and unbalanced voltage waveforms. The three phase line voltages are measured and used as inputs, and the transformation angle (ωt) is calculated as output signal of the modified PLL circuit. The measured line voltages are multiplied by auxiliary ($i$ax1 and $i$ax2) feedback currents with unity amplitude, and one of them leads 120◦ to another to obtain three-phase auxiliary instantaneous active power (p3ax).

The reference fundamental angular frequency ($\omega 0 = 2\pi f$) is added to the output of the proportional–integral (PI)(P = 0.05; I = 0.01) controller to stabilize the output. The auxiliary transformation angle (ω_t) is obtained by the integration of this calculation, but the produced ω_t leads 90◦ to the system fundamental frequency; therefore, the $-\pi/2$ is added to the output of the integrator in order to reach system fundamental frequency.

The proposed method has an effective response under distorted and unbalanced load conditions. The proposed control strategy is capable of extracting most of the load-current and source-voltage distortions successfully.

B. *Reference-Voltage Signal Generation for Series APF*

The proposed SRF-based UPQC control algorithm can be used to solve the PQ problems related with source-voltage harmonics, unbalanced voltages, and voltage sag and swell at the same time for series APFs. In the proposed method, the series APF controller calculates the reference value to be injected by the STs, comparing the positive-sequence component of the source voltages with load-side line voltages. The series APF reference-voltage signal-generation algorithm is shown in Fig. 5. In (4), the supply voltages vSabc are transformed $d-q-0$ by using the transformation matrix **T** given in (2). In addition, the modified PLL conversion is used for reference voltage calculation

$$\mathrm{T} = \begin{bmatrix} V_{s0} \\ V_{sd} \\ V_{sq} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin(\omega t) & \sin(\omega t - 2\frac{\pi}{3}) & \sin(\omega t + 2\frac{\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - 2\frac{\pi}{3}) & \cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \tag{2}$$

$$\mathrm{T}^{-1} = \sqrt{2/3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(\omega t) & \cos(\omega t) \\ \frac{1}{\sqrt{2}} & \sin(\omega t - 2\frac{\pi}{3}) & \cos(\omega t - 2\frac{\pi}{3}) \\ \frac{1}{\sqrt{2}} & \sin(\omega t + 2\frac{\pi}{3}) & \cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} V_{s0} \\ V_{sd} \\ V_{sq} \end{bmatrix} = \mathrm{T} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{4}$$

The instantaneous source voltages (vSd and vSq) include both oscillating components (vSd and vSq) and average components (vSd and vSq) under unbalanced source voltage with harmonics. The oscillating components of vSd and vSq consist of the harmonics and negative-sequence components of the source voltages under distorted load conditions. An average component includes the positive-sequence components of the voltages. The zero-sequence part (vS0) of the source voltage occurs when the source voltage is unbalanced. The source voltage in the d-axis (vSd) given in (5) consists of the average and oscillating components

$$\mathrm{V}_{\mathrm{sd}} = \bar{V}_{sd} + \tilde{V}_{sd} \tag{5}$$

The load reference voltages (*v*_ Labc) are calculated as given in (6). The inverse transformation matrix $\mathbf{T-1}$ given in (3) is used for producing the reference load voltages by the average component of source voltage and *ωt* produced in the modified PLL algorithm. The source-voltage positive-sequence average

value (*v*Sd) in the *d*-axis is calculated by LPF, as shown in Fig. 5. Zero and negative sequences of source voltage are set to zero in order to compensate load voltage harmonics, unbalance, and distortion, as shown in Fig. 5

$$\begin{bmatrix} V'_{La} \\ V'_{Lb} \\ V'_{Lc} \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ \overline{V}_{sd} \\ 0 \end{bmatrix}$$

The produced load reference voltages (*v* La, *v* Lb, and *v* Lc) and load voltages (*v*La, *v*Lb, and *v*Lc) are compared in the sinusoidal pulsewidth modulation controller to produce insulated-gate bipolar transistor (IGBT) switching signals and to compensate all voltage-related problems, such as voltage harmonics, sag, swell, voltage unbalance, etc., at the PCC.

C. Reference-Source-Current Signal Generation for Shunt APF

The shunt APF described in this paper is used to compensate the current harmonics generated in the nonlinear load and the reactive power. The proposed SRF-based shunt APF reference source- current signal-generation algorithm uses only source voltages, source currents, and dc-link voltages. The source currents are transformed to $d-q-0$ coordinates, as given in (7) using (1) and (*ωt*) coming from the modified PLL. In 3P4W systems and nonlinear load conditions, the instantaneous source currents (*i*Sd and *i*Sq) include both oscillating components (_*i*Sd and_*i*Sq) and average components (*i*Sd and *i*Sq). The oscillating components consist of the harmonic and negative-sequence components of the source currents. The average components consist of the positive-sequence components of current and correspond to reactive currents. The negative sequence component of source current (*iS*0) appears when the load is unbalanced. The proposed SRF-based method employs the positive-sequence average component (*i*Sd) in the *d*-axis and the zero- and negative-sequence component (*iS*0 and *iS*0) in the 0- and *q*-axes of the source currents, in order to compensate harmonics and unbalances in the load

$$\begin{bmatrix} i_{s0} \\ i_{sd} \\ i_{sq} \end{bmatrix} = T \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \qquad (7)$$

The active power is injected to the power system by the series APF in order to compensate the active power losses of the UPQC power circuit, which causes dc-link voltage reduction. Some active power should be absorbed from the power system by the shunt APF for regulating dc-link voltage. For this purpose, the dc-link voltage is compared with its reference value (*v*_ DC), and the required active current (*i*dloss) is obtained by a PI controller. The source current fundamental reference component is calculated by adding to the required active current and source current average component (*i*Sd), which is obtained by an LPF, as given in

$$i'_{sd} = i_{dloss} + \overline{i}'_{sd} \qquad (8)$$

In the proposed method, the zero- and negative-sequence components of the source current reference (*i*_ *s*0 and *i* Sq) in the 0- and *q*-axes are set to zero in order to compensate the harmonics, unbalance, distortion, and reactive power in the source current. The source current references are calculated as given in (9) to compensate the harmonics, neutral current, unbalance, and reactive power by regulating the dc-link voltage

$$\begin{bmatrix} i'_{sa} \\ V'_{sb} \\ V'_{sc} \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ i'_{sd} \\ 0 \end{bmatrix} \qquad (9)$$

The produced reference-source currents (*i*_ Sa, *i*_ Sb, and *i*_ Sc) and measured source currents (*i*Sa, *i*Sb, and *i*Sc) are compared by a hysteresis band current controller for producing IGBT switching signals to compensate all current-related problems, such as the reactive power, current harmonic, neutral current, dc-link voltage regulation, and load-current unbalance.

V. FAULT PROTECTION CIRCUIT

The proposed protection scheme is a controlled crowbar, which is connected across the secondary of the series transformer and short circuits it when an overvoltage occurs across the transformer secondary. Because a short circuit on the load side of UPQC usually results in an overvoltage across the secondary of the series transformer, the protection operates and the large short-circuit current flowing from the supply side is diverted from the series inverter switches to the thyristors of the protection scheme. The inverter switches are simultaneously protected from both overvoltage and overcurrent during such a fault.

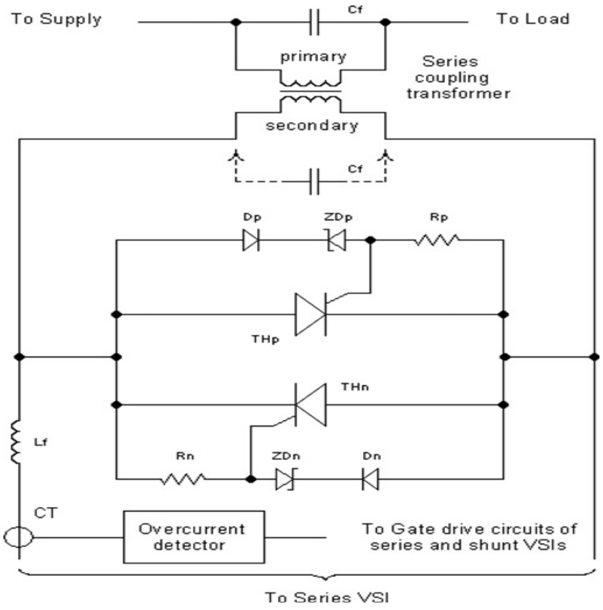

Fig 3: Fault protection circuit.

The operating principle of the scheme is explained for the positive half cycle of the voltage waveform (thyristor THp is forward biased). From Fig. 3 we can see that the voltage across the thyristors is also the same as the voltage applied to their control circuits. Although the voltage across the thyristor THp is of forward polarity, but not greater than the rated breakdown voltage of the Zener diode ZDp, the latter is not conducting and the voltage across the resistor Rp is of a very low value and is insufficient to turn on the thyristor.

VI. SIMULATION RESULTS

In this study, the proposed SRF-based control algorithm for the UPQC is evaluated by Matlab/Simulink software under unbalanced and distorted load-current and source-voltage conditions since the unbalanced load currents are very common and, yet, an important problem in 3P4W distribution systems [34]. The UPQC system parameters used in this study are given in Table I. In the simulation studies, the results are specified before and after the operation of the UPQC system.

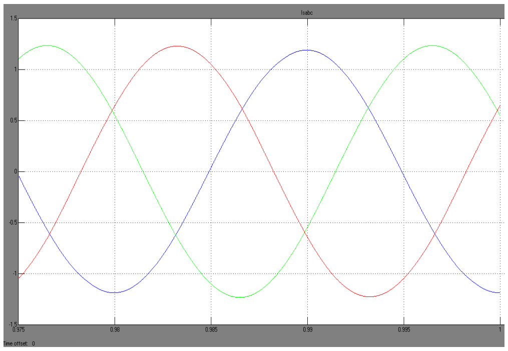

Fig 4: Voltage waveform.

In addition, when the UPQC system was operated, the load methods. The obtained results show that the proposed control method allows THD levels of 3.0% current and 1.4% voltage by mitigation of all harmonic components. The proposed control strategy is capable of extracting most of the load-current and source-voltage distortions successfully.

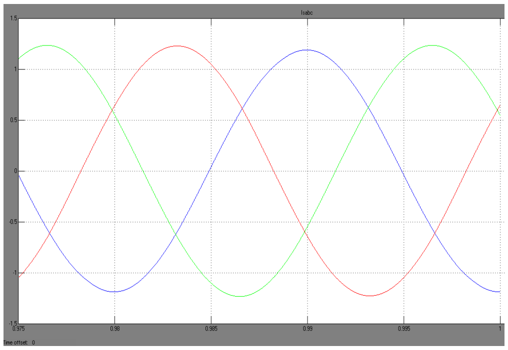

Fig 5: Current Waveform

In the proposed SRF-based control algorithm, the mains currents (*i*Sabc) and voltages (*v*Sabc) are measured to calculate the shunt APF reference current, and the mains and load voltages (*v*Labc) are used in the series APF controller are the proposed UPQC control method simulation results for the following conditions: 1) unbalanced and distorted mains voltages; 2) injected transformer voltages; 3) load voltages; 4) unbalanced and nonlinear load currents; 5) injected compensator currents; 6) source currents; 7) load neutral current; 8) injected compensator current; 9) source neutral current; and 10) reactive power compensation. The proposed UPQC control algorithm has the ability of compensating both the harmonics and reactive power of the load, and the neutral current is also eliminated.

VII REFERENCES

[1] H. Fujita and H. Akagi, “The unified power quality conditioner: The integration of series and shunt-active filters,” IEEE Trans. Power Electron.,Mar. 1998.

[2] D. Graovac, V. Katic, and A. Rufer, “Power quality problems compensation with universal power quality conditioning system,” IEEE Trans. Power Del,Apr. 2007.

[3] B. Han, B. Bae, H. Kim, and S. Baek, “Combined operation of unified power- quality conditioner with distributed generation,” IEEE Trans. Power Del., Jan. 2006.

[4] F. Z. Peng, J. W. McKeever, and D. J. Adams, “A power line conditioner using cascade multilevel inverters for distribution systems,” IEEE Trans. Ind. Appl., Nov./Dec. 1998.

[5] M. Aredes, H. Akagi, E. H. Watanabe, E. V. Salgado, and L. F. Encarnacao, “Comparisons between the p–q and p–q–r theories in three-phase four- wire systems,” IEEE Trans. Power Electron., Apr.2009.

[6] K. H. Kwan, Y. C. Chu, and P. L. So, “Model-based H∞ control of a unified power quality conditioner,” IEEE Trans. Ind. Electron., Jul.2009.

[7] A Novel Control Method for Unified Power Quality Conditioner (UPQC) Under Non-Ideal Mains Voltage and Unbalanced Load Conditions. Metin Kesler.

[8] Metin Kesler and Engin Ozdemir, *Senior Member, IEEE* “Synchronous-Reference-Frame-Based Control Method for UPQC Under Unbalanced and Distorted Load Conditions”.

[9] Enhanced Dynamic Response of SRF-PLL System for High Dynamic Performance during Voltage Disturbance Hyeong-Jin Choi, Seung-Ho Song†, Seung-Gi Jeong, Ju-Yeop Choi, and Ick Choy.