# Analysis of Unified Power Quality Conditioner

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*Abstract*—**This paper presents a 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. 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.**

*Keywords:* **Active power filter (APF), harmonics, phase locked loop (PLL), power quality (PQ), and synchronous reference frame (SRF), unified power-quality conditioner (UPQC).**

## I. INTRODUCTION

Nowadays, power quality (PQ) issues are becoming more and more significant especially in electrical engineering related fields. PQ can be defined as any problem manifested in voltage, current, or frequency deviation that results in failure or disoperation of customer equipments. As per international standards, the term PQ can be defined as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the user's processes [1]. However, the term PQ issues can have different meanings and significances according to the requirements or environmental condition under which it has been defined. For example, for the utility, it might be the concern of non-linear load causing harmonics on the network, for the consumers, it might be the distortion present in the supplied voltage, etc [2]. In the current power system, there are many types of power quality disturbance such as sag, swell, transient, harmonic, interruption, flicker and voltage unbalance. All these types are caused by load switching, system faults, motor starting, load variations, non-linear loads and furnaces. In order to compensate the power quality disturbance, many devices and expert systems have been developed. Active power filters are widely used to tackle some of the important power quality problems. The increased concern of power quality has resulted in measuring the power quality variations and characteristics disturbances for different customer categories. Recent trends are geared towards the realization of multitasking devices which can tackle several power quality problems simultaneously [3].

One of the interesting proposals within the active filters is the UPQC that has integrated the characteristics of a series filter and a shunt filter. The series-active filter is functioning as a harmonic isolation between a sub transmission system and a distribution system. Furthermore, the series-active filter has the capability of voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). As for the shunt-active filter, it is used to absorb current harmonics, compensate for reactive power and negative sequence current, and regulate the DC-link voltage between both active filters. Integration of the series-active and shunt-active filters is called the UPQC, associated with the unified power flow controller (UPFC) [4, 5 & 6]. It is similar in construction to UPFC. The UPQC, just as in a UPFC, utilizes two voltage source inverters (VSIs) that connected to a DC energy storage capacitor. One of these two VSIs is connected in series with AC line while the other is connected in shunt with the AC system. Similarly, a UPQC also performs shunt and series compensation in a power distribution system. Since a power transmission line generally operates in a balanced, a UPFC must only provide balanced shunt or series compensation. A power distribution system may contain unbalance, distortion and even DC components. Therefore, a UPQC must operate with all these aspects to provide shunt or series compensation.

In this paper, the new 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. The upqc configuration and the load under consideration are discussed in section II. The control algorithm discussed in section III. Results are discussed in section IV. And finally conclution in section V.

## II. SYSTEM DISCRIPTION

The system under consideration is shown in fig-1. The UPQC is connected before the load to make the load voltage free from any distortions and at the same time, the reactive current drawn from source should be compensated in such a way that the currents at source side is, would be in phase with utility voltages. Provisions are made to realize voltage harmonics, voltage sag and swell in the source voltage by switching on/off the three phase rectifier load, R-L load and R-C load respectively. In order to create a voltage dip in source voltage an induction motor is connected suddenly on the load side . The UPQC, realized by using two VSI is shown in fig.2, one acting as a shunt APF while other as a series APF. Both the APFs share a common dc link in between them. Each inverter is realized by using six IGBT switches. The voltage at the source side before UPQC, the load voltage at load, the voltage injected by series APF and dc link voltage between two inverters are represented by $v_s$,$v_L$,$v_F$ and vdc respectively .whereas, the current on the source side ,total current drawn by all the loads and the current injected by shunt APF are represented by $i_s$, $i_l$,and ic respectively. The values of the circuit parameters and load under consideration are given in appendix.

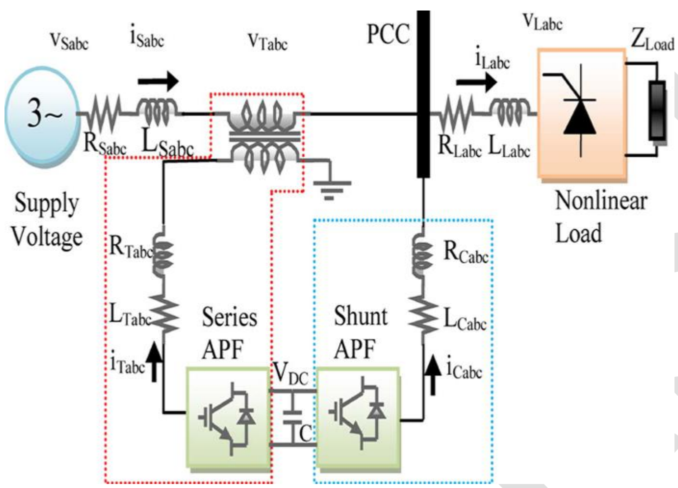


Fig.1 block diagram

## III. CONTOL STRATEGY

The proposed control strategy is aimed to generate reference signals for both shunt and series APFs of UPQC. In the following section an approach based on SRF theory is used to get reference signals for the series and shunt APFs. 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. The proposed SRF control method uses $a-b-c$ to $d-q-0$ transformation equations, filters, 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 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.

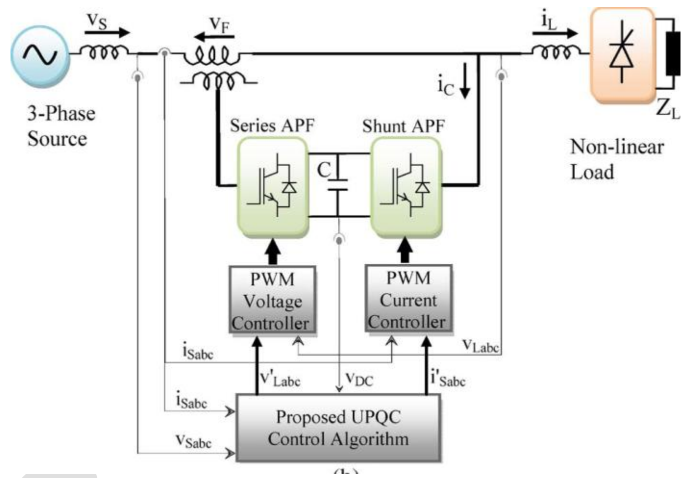


Fig.2 control block diagram of UPQC

### A. *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. 3. In (3), the supply voltages *v*Sabc are transformed $d-q-0$ by using the transformation matrix **T** given in (1). In addition, the modified PLL conversion is used for reference voltage calculation

$$T = \sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin(wt) & \sin(wt-\frac{2\pi}{3}) & \sin(wt+\frac{2\pi}{3}) \\ \cos(wt) & \cos(wt-\frac{2\pi}{3}) & \cos(wt+\frac{2\pi}{3}) \end{bmatrix} \quad .. (1)$$

$$T^{-1} = \sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(wt) & \cos(wt) \\ \frac{1}{\sqrt{2}} & \sin(wt-\frac{2\pi}{3}) & \cos(wt-\frac{2\Pi}{3}) \\ \frac{1}{\sqrt{2}} & \sin(wt+\frac{2\pi}{3}) & \cos(wt+\frac{2\Pi}{3}) \end{bmatrix} \quad .. (2)$$

$$\begin{bmatrix} v_{S0} \\ v_{Sd} \\ v_{Sq} \end{bmatrix} = \mathrm{T} \begin{bmatrix} v_{Sa} \\ v_{Sb} \\ v_{Sc} \end{bmatrix} \quad \text{.......(3)}$$

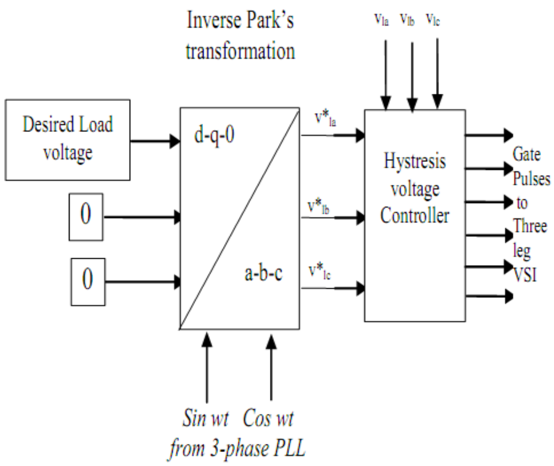


Fig.3 Control Scheme of Series APF

The instantaneous source voltages ($v_{Sd}$ and $v_{Sq}$) include both oscillating components ($v_{Sd}$ and $v_{Sq}$) and average components ($v_{Sd}$ and $v_{Sq}$) under unbalanced source voltage with harmonics. The oscillating components of $v_{Sd}$ and $v_{Sq}$ consist of the harmonics and negative-sequence components of the source voltages under distorted load conditions. An average component component includes the positive-sequence components of the voltages.The zero-sequence part ($v_{S0}$) of the source voltage occur when the source voltage is unbalanced. The source voltage in the *d*-axis ($v_{Sd}$) given in (4) consists of the average and oscillating Components

$$v\mathrm{Sd} = \bar{v}\mathrm{Sd} + \tilde{v}\mathrm{Sd}. \quad (4)$$

The load reference voltages ($v$'Labc) are calculated as given in (5). The inverse transformation matrix $\mathbf{T^{-1}}$ given in (2) is used for producing the reference load voltages by the average component of source voltage and $\omega t$ 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. 3. 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. 3

$$\begin{bmatrix} v'La \\ v'Lb \\ v'Lc \end{bmatrix} = \mathrm{T}^{-1} \begin{bmatrix} 0 \\ vSd \\ 0 \end{bmatrix} \quad \text{..... (4)}$$

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 hysteresis pulse width 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.

*B. 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 (5) and ($\omega t$) 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 negativesequence component of source current ($i$S0) 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 ($i$S0 and $i$S0) in the 0- and *q*-axes of the source currents, in order to compensate harmonics and unbalances in the load

$$\begin{bmatrix} i_{S0} \\ i_{Sd} \\ i_{Sq} \end{bmatrix} = \mathrm{T} \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \quad \text{.......... (5)}$$

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

$$i\mathrm{Sd} = i\mathrm{dloss} + \bar{i}\mathrm{Sd}. \; (6)$$

In the proposed method, the zero- and negative-sequence components of the source current reference ($I'$s0 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 (7) to compensate the harmonics, neutral curre unbalance, and reactive power by regulating the dc-link voltage

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. The proposed SRF-based UPQC control method block diagram is shown in Fig. 4

$$\begin{bmatrix} i'sa \\ i'_{Sb} \\ i'sc \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ i'sd \\ 0 \end{bmatrix} \qquad \text{……… (7)}$$

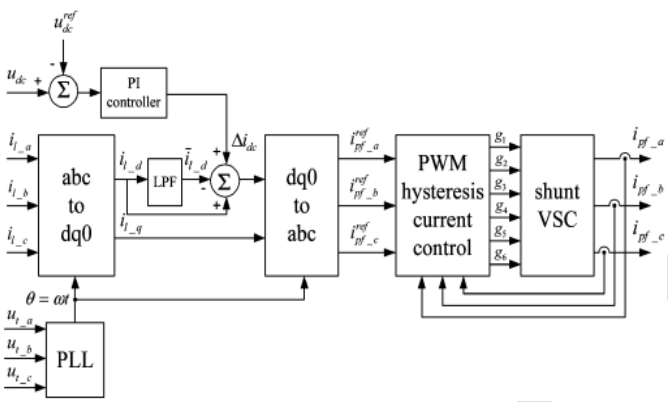


Fig.4. Control block diagram of the shunt APF

## IV. SIMULATION RESULT

In this study, a new control algorithm for the UPQC is evaluated by using simulation results given in Matlab/Simulink software under non-ideal mains voltage and unbalanced load current conditions. In simulation studies, the results are specified before and after UPQC system are operated. The proposed control method has been examined under non-ideal mains voltage and unbalanced load current conditions.

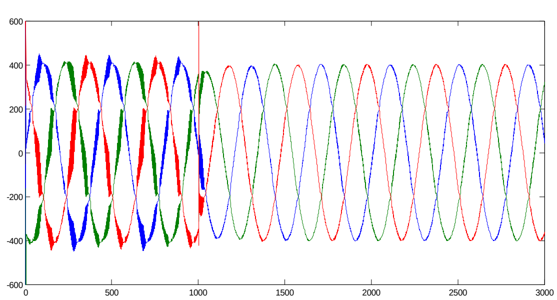

Fig. 5 Supply Voltage

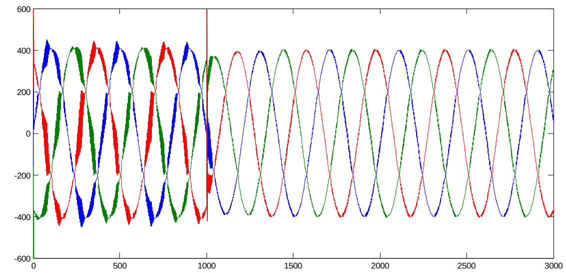

Fig. 6 Load Voltage

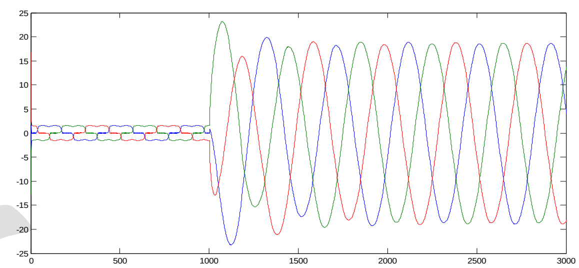

Fig. 7 Source Current

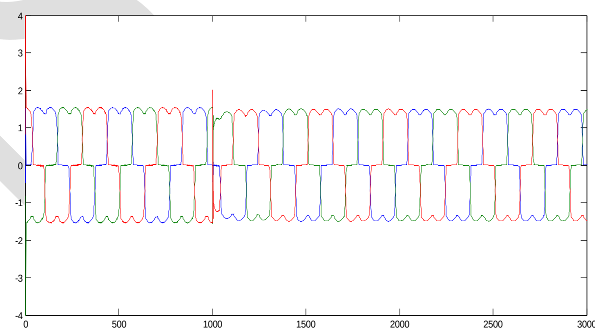

Fig. 8 Load Current

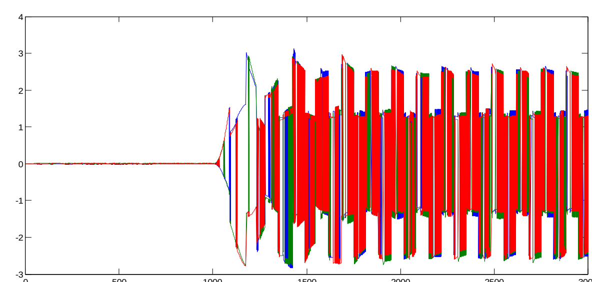

Fig. 9 Injected Transformer Voltages

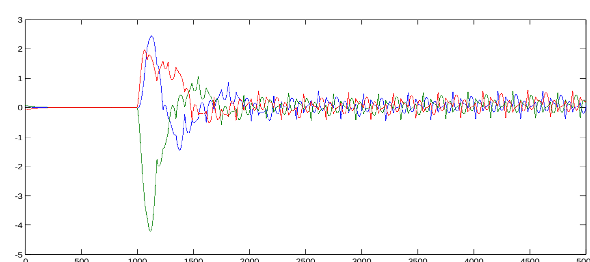

Fig. 10 Compensator Current

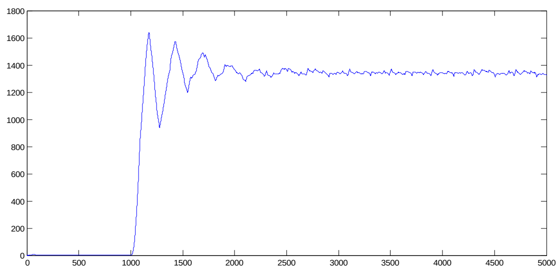


Fig. 11 DC Link Voltage

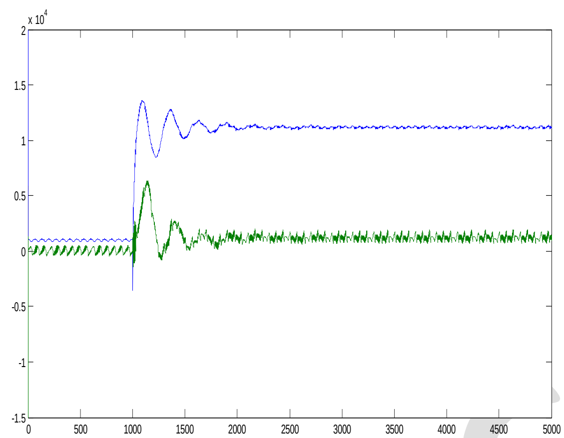


Fig. 12 Active Power & Reactive Power

Before harmonic compensation, the THD of the supply voltage, load voltage, supply current, load current is 15.77%, 15.77%, 28.02%, 26.71% respectively. The obtained results show that the proposed control technique allows the 3.87%, 3.91%, 3.27%, 25.06% respectively mitigation of all harmonic components. As a result, the proposed method is very effective and successful in harmonic compensation under distorted load condition as shown in simulation results.

Parameter for UPQC is as follow:

| PARAMETERS | VALUE |
|---|---|
| **Source:** | |
| Voltage | 415V |
| Frequency | 50Hz |
| 3-phase resistance | 0.001 Ω |
| 3-phase inductance | 10mH |
| **Load resistance** | 100Ω |
| **DC Link:** | |
| Voltage | 2100V |
| Capacitor | 10μF |
| **Series active filter:** | |
| Switching frequency | 12kHz |
| Filter resister | 0.01Ω |
| Filter inductance | 5H |
| Series transformer | 2kVA |
| **Shunt active filter:** | |
| Switching frequency | 1.08kHz |
| AC line inductance | 0.1H |

## V CONCLUSION

This paper describes a new SRF-based control strategy used in the UPQC, which mainly compensates the reactive power along with voltage and current harmonics under nonideal mains voltage and unbalanced load-current conditions. The proposed control strategy uses only loads and mains voltage measurements for the series APF, based on the SRF theory. The conventional methods require the measurements of load, source, and filter currents for the shunt APF and source and injection transformer voltage for the series APF. The simulation results show that, when under unbalanced and nonlinear load-current conditions, the aforementioned control algorithm eliminates the impact of distortion and unbalance of load current on the power line, making the power factor unity. Meanwhile, the series APF isolates the loads and source voltage in unbalanced and distorted load conditions, and the shunt APF compensates reactive power, neutral current, and harmonics and provides three-phase balanced and rated currents for the mains

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