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# A Control Method for UPQC Based on SRF Theory Under Unbalanced and Distorted Load Conditions

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## ABSTRACT

*This paper introduces another synchronous-reference frame (SRF)- based control strategy to compensate power quality (PQ) issues through a three-stage four-wire Unified PQ conditioner (UPQC) under distorted and unbalanced load conditions. The proposed UPQC framework can enhance the power quality at the point of common coupling on power distribution systems under unbalanced and distorted load conditions. The reproduction comes about in light of Matlab/Simulink are examined in detail to bolster the SRF-based control strategy displayed in this paper. The proposed approach is additionally approved through test consider with the UPQC equipment model.*

***KEYWORDS:*** *Active power filter (APF), harmonics, phase-locked loop (PLL), power quality (PQ), synchronous referenceframe (SRF), unified power-quality (PQ) conditioner (UPQC).*



## I. Introduction

UNIFIED POWER-QUALITY (PQ) conditioner (UPQC) is used for the elimination of disturbances which affects the critical loads performances in the power system and researchers find it as the most eventual method so is expected to be the most effective solution to large capacity loads sensitive to supply voltage imbalance distortions.It has two inverters that share one DC link,to compensate the voltage sag and swell and the current and voltage harmonics and also controls the power flow and voltage stability. It has shunt APF which compensates all the current related problems ,such as power factor improvement, current harmonic compensation,reactive power compensation,dc-link voltage regulation and load unbalances which is connected across the load. The series APF compensates the voltage related problems such as voltage harmonics,voltage swell, voltage sag,flickers etc..,and is connected in series with the line through series transformer(ST).

The numbers of current measurements are reduced and the system performance is improved as the UPQU system is optimized by the synchronous reference frame method(SRF) based control method without using transformer voltage, load, and filter current measurement.

## II. UPQC

This UPQC is generally connected at the PCC for harmonic elimination and simultaneous compensation of voltage and current, which improves the PQ. The basic configuration of general

UPQC consists of series and shunt APF's. Harmonic isolation between load and supply is obtained by series APF and it has a capability of compensating the voltage imbalance, voltage regulation and compensating the harmonics at PCC. The current harmonics are adsorbed by shunt APF and reactive power is compensated and regulates the dc-link voltage between both the APF's.

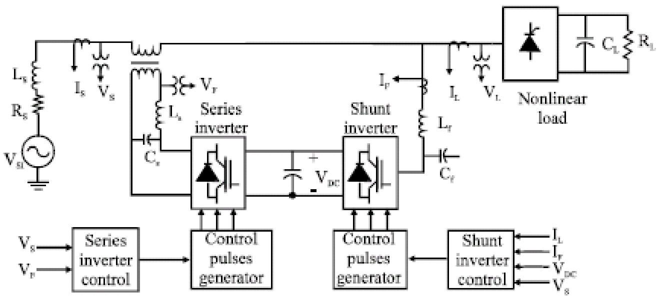


***Fig.2. UPQC Basic system configuration***

## III. SRF

The conventional SRF algorithm which is also known as $d-q$ method which is proposed for the active filter compensation transforms $a-b-c$ to $d-q-0$ which is park transformation, this is used for extracting the harmonics in the supply voltages or current. The distorted currents, by using $\alpha-\beta$ transformation are firstly transferred into two-phase stationary coordinates and then stationary frame quantities are transferred into synchronous rotating frames by the help of sinus and cosine functions from phase locked loop (PLL) which help to maintain synchronization with supply voltage and currents, for current harmonic compensation. The harmonics and fundamental components are separated by the help of filters and are again transferred back to $a-b-c$ frame as reference signals for the filter.

The voltage and current signals are transformed into conventional rotating frame (d-q-0) and the angular position of reference frame, which is rotating at a constant speed in synchronism with the three-phase ac voltage and is represented by the transformation angle ωt. The harmonics and currents with same magnitude and reverse phase are produced and injected to the power system. In SRF, $\alpha-\beta-0$ coordinates are stationary where as the $d-q-0$ coordinates rotate synchronously with the supply voltages and the angular position of SRF is shown by the supply voltage vector. In 3P4W system d coordinate component current $i_d$ which is the positive sequence current is in phase with the voltage and $i_q$ the component current in q coordinate which is the negative sequence reactive current is orthogonal to $i_d$. $i_0$the zero sequence component current which is orthogonal to $i_d$ and $i_q$. When the load has capacitive reactive power then the $i_q$ component of the current is negative and is positive when the load has inductive reactive power. Both the average ($\bar{i}_d$ and $\bar{i}_q$) which corresponds to harmonic currents and oscillating($\tilde{i}_d$ and $\tilde{i}_q$) component currents which corresponds active and reactive power respectively are present in $i_d$ and $i_q$ in 3P4W nonlinear power systems.

$i_d = \tilde{i}_d + \bar{i}_d i_q = \tilde{i}_q + \bar{i}_q$. (1)

In the three phase systems which are balanced and linear there will be only the positive sequence component current and voltages whereas; there will be fundamental positive-, negative-, zero-sequence components in unbalanced and non-linear load conditions. The positive sequence components of signals are needed to be separated in APF applications in order to compensate the harmonics.

## IV. PROPOSED SRF-BASED CONTROL ALGORITHM

Excellent characteristics are produced by the SRF method but it requires decisive PLL techniques. This paper used the modified PLL technique.

The $a-b-c$ $to$ $d-q-0$ transformation equations, filters, and the modified PLL algorithm are used by SRF control method. This proposed SRF control method reduces the current measurements and thus is easy to implement and is simple and can run effectively in DSP platforms.

Thus the UPQC's performance is highly improved by this control method under unbalanced and distorted conditions.

### *A.Modified PLL*

The conventional PLL circuit gives low performance for highly distorted and unbalanced system voltages. The positive sequence components of system voltage signal are got determined by modified PLL and this improves the UPQC filtering performance in highly distorted and unbalanced conditionsand in this condition the output ($\omega t$) of modified PLL has low oscillations which gives good performance than the conventional PLL.

In order to determine the transformation angle ($\omega t$) of the system supply voltage the three phase instantaneous source line voltage $\vartheta s_{ab}$ and $\vartheta s_{cb}$($\vartheta s_{ab} = \vartheta s_a - \vartheta s_b$;$\vartheta s_{cb} = \vartheta s_c - \vartheta s_b$),is applied to the modified PLL circuit to calculate the three phase auxiliary total power.

To the modified PLL circuit the measured three phase line voltages are inputs and transformation angle ($\omega t$) is the output signal. The measured line voltages are multiplied by the auxiliary ($iax_1$ and $iax_2$) feedback currents with unity amplitude and one of them leads 120° to another to obtain three-phase auxiliary instantaneous active power ($P3_{ax}$) .

To stabilize the output 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.

By integrating the calculations the auxiliary transformation angle ($\omega t$) is obtained which leads 90° to the system fundamental frequency. In order to reach system fundamental (-$\pi/2$) is added to the output of the integrator. When the 3-Ø auxiliary instantaneous active power ($P3_{ax}$) become zero or has low frequency oscillation. The PLL circuit arrives a stable operating point.

The output transformation angle ( $\omega t$ ) of modified PLL circuit reaches the fundamental positive sequence component of line voltages. $\sin\omega t$ in modified PLL output and fundamental positive sequence component of measured source voltages ($v_{Sa}$) are in phase.

When PI gains in PLL algorithm are tuned accordingly there will be a satisfactory operation of the modified PLL.

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

To tackle the PQ issues related with source-voltage harmonics, unbalanced voltages, and voltage sag and swell, the proposed SRF-based UPQC control algorithms can be used at a similar time for series APFs. The reference value which is to be injected by ST's is got calculated by the series APF controllers by comparing the positive sequence component of source voltages with load side line voltages .The series APF reference-voltage signal generation calculation is shown in Z$v_{Sabc}$ are transformed to d-q-0 in (4) . In reference voltage calculation the modified PLL conversion is used.

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

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

$$\begin{bmatrix} v_{S0} \\ v_{Sd} \\ v_{Sq} \end{bmatrix} = T \begin{bmatrix} v_{Sa} \\ v_{Sb} \\ v_{Sc} \end{bmatrix} \quad (4)$$

Under unbalanced source voltage with harmonics, the instantaneous source voltages ( $_{Sd}$ and $_{Sq}$) contains both oscillating components ( $_{Sd}$ and $_{Sq}$) and average components ( $_{Sd}$ and $_{Sq}$).

Under distorted load conditions the harmonics and negative-sequence components of the source voltages are comprised in the oscillating components of $_{Sd}$ and $_{Sq}$ .The positive-sequence components of the voltages are incorporated in average component. When the source voltage is unbalanced the zero-sequence part ($v_{S0}$) of the source voltage occurs. The source voltage in the d-axis ($v_{Sd}$) given in (5) comprises of the average and oscillating components.

$v_{Sd} = \bar{v}_{Sd} + \tilde{v}_{Sd}$.(5)

(6) is used to calculate the load reference voltages ($v^1_{Labc}$).The reference load voltages are produced by using the inverse transformation matrix $T^{-1}$ by the average component of source voltage and ωt produced in the modified PLL algorithm. LPF is used to calculate the average source voltage positive sequence value ($v_{sd}$) in d-axis and is shown in Fig.5.In order to compensate the load voltage harmonics, unbalance, and distortion the Zero and negative sequences of source voltages are set to zero as in Fig.5.

$$\begin{bmatrix} v'_{La} \\ v'_{Lb} \\ v'_{Lc} \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ \bar{v}_{Sd} \\ 0 \end{bmatrix}. \qquad (6)$$

In order to produce insulated gate bipolar transistor(IGBT) switching signals the produced load reference voltages ($v^{1}_{La,}v^{1}_{Lb},v^{1}_{Lc}$) and load voltages ($v_{La}$,$v_{Lb}$,$v_{Lc}$) are compared in the sinusoidal pulsewidth modulation controller to compensate the problems at PCC which are related to voltage such as voltage sag, swell, harmonics,unbalance,etc.

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

In order to compensate the current harmonics generation in non-linear load and reactive power the shunt APF is utilized. The source voltages, source current, and dc-link voltages are only used in the proposed SRF-based shunt APF reference-source- current signal-generation algorithm as given in (7)and (1) the source currents are got transformed into d-q-0 coordinates and (ωt)coming from the modified PLL . Both oscillating ($i_{Sd}$ and $i_{Sq}$) and average components ($i_{Sd}$ and $i_{Sq}$) are present in the instantaneous source currents in the 3P4W systems and nonlinear load conditions. The harmonic and negative-sequence components of source are present in the oscillating components .Corresponding to the reactive currents the positive sequence currents are present in the average components. Under the unbalanced load conditions the source currents negative sequence component ($i_{S0}$) appears. In order to compensate harmonics and unbalances in load , the positive sequence average component in d-axis and the zero and negative sequence component in 0 and q-axis of source currents are got employed by the proposed SRF-based method

$$\begin{bmatrix} i_{S0} \\ i_{Sd} \\ i_{Sq} \end{bmatrix} = T \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \quad (7)$$

To compensate active power losses of UPQC power circuit the power system is got injected with active power which reduces DC link voltage. As to regulate DC link voltage some active power is absorbed by shunt APF. The reference valve ($v'_{DC}$)and the DC link voltages are compared and required active current ($i_{dloss}$) is obtained by PI controller. By adding the required active current and source current average component ($\bar{i}_{Sd}$) the source current fundamental reference component is obtained by LPF,s

$$i'_{Sd} = i_{dloss} + \bar{i}_{Sd}. (8)$$

The harmonics,unbalance, distorted and reactive power in source currents are compensated by setting the zero and negative sequence component of the source current reference ($i'_{S0}$ and $i'_{Sq}$) in 0-and q-axis are set to zero and source current references are calculated by (9).

$$\begin{bmatrix} i'_{Sa} \\ i'_{Sb} \\ i'_{Sc} \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ i'_{Sd} \\ 0 \end{bmatrix}. \qquad (9)$$

To compensate all current related problems, the produced reference- source current ($i'_{Sa}$ ,$i'_{Sb}$ ,$i'_{Sc}$) and measured source currents ($i_{Sa}$, $i_{Sb}$, $i_{Sc}$) are compared and by a hysteresis band current controller for producing IGBT switching signals.

## V. SIMULATION RESULTS

In this paper,the algorithm that is used for UPQC is evaluated by Matlab/Simulink. As distorted and unbalanced load currents are very common problem in 3P4W distribution systems. The parameters used for UPQC is given in the table1.

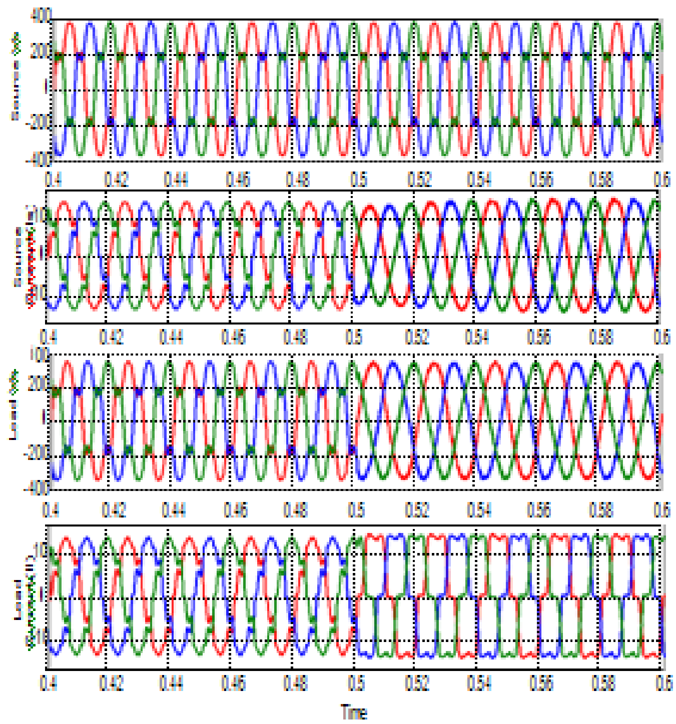


***Fig. 3.Supply currents and load voltages before and after compensation without voltage sag and swell.***

TABLE1
EXPERIMENTAL AND SIMULATION PARAMETERS FOR **UPQC**

| | **Parameters** | | **Value** |
|---|---|---|---|
| **Source** | Voltage | $V_{sabc}$ | $380V_{rms}$ |
| | Frequency | f | 50HZ |
| **Load** | 3-phase AC line inductance | $L_{Labc}$ | 1.47 mH |
| | 1-phase AC line inductance | $L_{La1}$ | 0.75 mH |
| | 3-phase DC inductance | $L_{dc3}$ | 11.5 mH |
| | 3- phase DC resistor | $R_{dc3}$ | 30Ω |
| | 1- phase DC resistor | $R_{dc1}$ | 100Ω |
| | 1- phase DC capacitor | $C_{dc1}$ | 75μF |
| **dc link** | Voltage | $V_{DC}$ | 700 V |
| | Two series capacitor | $C_1,C_2$ | 2200μF |
| **Shunt APF** | AC line inductance | $L_{Cabc}$ | 3 mH |
| | Filter Resistor | $R_{Cabc}$ | 5Ω |
| | Filter Capacitor | $C_{Cabc}$ | 4.7μF |
| | Switching frequency | $f_{pwm}$ | ~15 kHZ |
| **Series APF** | AC line inductance | $L_{Tabc}$ | 1.5 mH |
| | Filter Resistor | $R_{Tabc}$ | 5Ω |
| | Filter Capacitor | $C_{Tabc}$ | 26μF |
| | Switching frequency | $f_{pwm}$ | 12 kHZ |
| | Three series transformer | S | 5.4 KVA |

The results are separated before and after the operation UPQC .When the UPQC was operated the dynamic response of the system was tested. Then the proposed method has been evaluated under unbalanced source voltage and load currents and here we use passive RC filters are used to eliminate the ripples in the voltage and current waveforms. Table 2 represents the simulation results and total harmonic distortion (THD) levels.

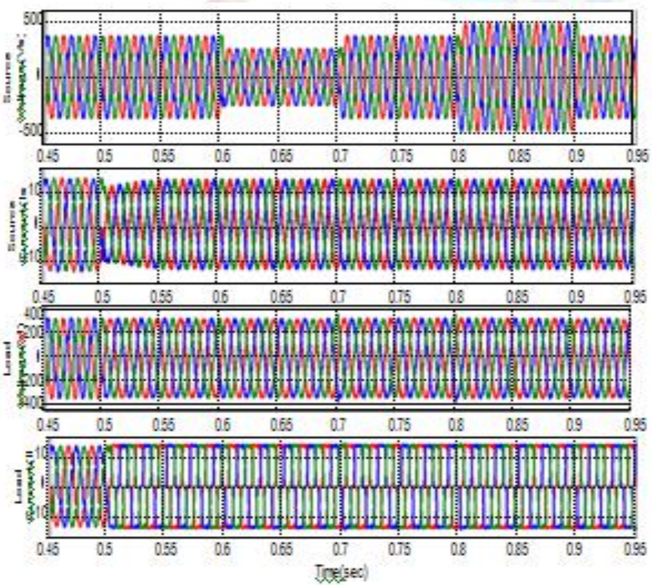

***Fig. 4.Supply currents and load voltages before and after compensation with voltage sag and swell.***

TABLE2
COMPARING CONVENTIONAL AND PROPOSED **UPQC** CONTROL METHODS FOR SIMULATION RESULTS AND **THD** LEVELS OF VOLTAGE AND CURRENT WAVEFORMS AT THE **PCC**

| **System Voltage condition** | | **BeforeUPQC** | | After UPQC control method with | | | |
|---|---|---|---|---|---|---|---|
| | | | | conventional | | Proposed | |
| | **phase** | **Current(A)** | **Voltage(V)** | **Current(A)** | **Voltage(V)** | **Current(A)** | **Voltage(V)** |
| Balanced THD(%) | A | 35.4 | 0.1 | 6.7 | 0.8 | 2.7 | 0.7 |
| | B | 26.2 | 0.1 | 3.6 | 0.9 | 3.5 | 0.9 |
| | C | 27.6 | 0.1 | 3.7 | 1.0 | 3.5 | 0.9 |
| Unbalanced THD(%) | A | 35.4 | 0.1 | 4.2 | 0.6 | 3.3 | 0.8 |
| | B | 26.2 | 0.1 | 2.7 | 0.6 | 3.4 | 0.8 |
| | C | 27.6 | 0.1 | 2.8 | 0.6 | 3.9 | 0.9 |
| Balanced with distorted THD(%) | A | 35.4 | 19.7 | 6.8 | 2.3 | 3.1 | 1.1 |
| | B | 26.2 | 22.7 | 4.1 | 2.7 | 3.1 | 1.4 |
| | C | 27.6 | 19.7 | 4.0 | 2.9 | 3.4 | 1.3 |
| Unbalanced with distorted THD(%) | A | 35.4 | 22.4 | 6.6 | 3.7 | 3.2 | 1.4 |
| | B | 26.2 | 24.2 | 3.7 | 2.6 | 3.5 | 1.6 |
| | C | 27.6 | 19.7 | 4.1 | 2.9 | 3.4 | 1.3 |
| RMS | A | 15.3 | 187 | 3.8 | 210 | 14.3 | 221 |
| | B | 12.7 | 205 | 15.3 | 211 | 14.1 | 220 |
| | C | 12.5 | 219 | 15.3 | 211 | 14.2 | 221 |
| | N | 2.4 | - | 0.09 | - | 0.05 | - |

These (THD) levels are compared between conventional and proposed SRF. The results show that proposed control method brings THD levels of load voltage of phase a from 20.2% to 1.4% and the source current from 31.4% to 3.0% to compensate the distortions.

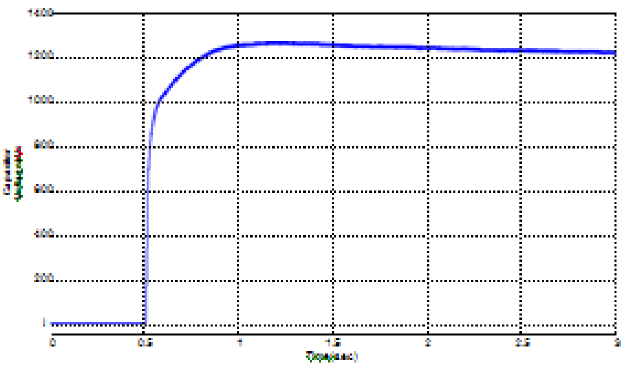

***Fig.5.Voltage across capacitor during capacitor voltage balancing.***

In this the mains current (isabc) and voltages (vsabc) are measured to calculate the reference current for shunt APF and mains and load voltage (Vlabc) are used for series APF.

Proposed UPQC compensates both the harmonics and reactive power of the load and the neutral current is completely eliminated. It is concluded that UPQC can compensate voltage and currents problems simultaneously.

## VI. EXPERIMENTAL RESULTS

The arrangement APF is associated in arrangement in series by means of an RC filter, RT and CT and a coordinating ST. The dc connections of both shunt and arrangement APFs are associated with two basic arrangements 2200-μF dc capacitors under 700-V dc in split capacitor topology. A three-stage and a single-stage diode connect rectifier are utilized as nonlinear loads, also, the impact of progress in load current is recorded.

The greater part of the circuit parameters and experimental conditions are set up nearly simulation conditions.The experimental outcomes demonstrate that the control targets are fulfilled. Despite the fact that the proposed SRF-based control conspire can't be considered for uneven mains voltage conditions by reason of research center case, an ideal control can be intended to take out this issue tentatively, which has been talked about as a future work.

The shunt APF was tried under dynamical and steady-state stack conditions under load evolving.Exploratory outcomes for voltages previously, then after the fact channel operation in three-stage frame at the PCC. Test comes about for the source streams $(i_{Sabc})$ and the impartial current $(i_{Sn})$ under adjusted and uneven load-current conditions.

## VII. CONCLUSION

This paper depicts another SRF-based control procedure utilized in the UPQC, which predominantly compensates the reactive power along with voltage and current harmonics under non-ideal mains voltage and unbalanced load-current conditions. The proposed control technique utilizes just loads and mains voltage measurements for the series APF, in view of the SRF theory. The conventional techniques require the measurements of load, source, what's more, filter currents for the shunt APF and source and injection transformer voltage for the series APF. The simulation outcomes demonstrate that, when under unbalanced and nonlinear load-current conditions, the previously mentioned control algorithm eliminates the effect of contortion and unbalance of load current on the power line, giving unity power factor. In the meantime, the series APF isolates the loads and source voltage in unbalance and distorted load conditions, and the shunt APF compensates reactive power, neutral current, and harmonics and gives three-phase balanced and rated currents for the mains. Test outcomes about acquired from a research center model of 10 kVA, alongside a hypothetical investigation, are appeared to check the suitability and effectiveness of the proposed SRF-based UPQC control technique.

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