UPQC CONTROL UNDER UNBALANCED AND DISTORTED MAINS VOLTAGE WITH FUZZY LOGIC CONTROLLER

NAIDU SHRAVANI  
M.Tech Student,  
Dept. of EEE, SNIST,  
Hyderabad,  
Telangana State,  
India.

Sriram Ramu  
Associate Professor,  
Dept. of EEE, SNIST,  
Hyderabad,  
Telangana State,  
India.

Ch.V. Seshagiri Rao  
Associate Professor  
Dept. of EEE, SNIST,  
Hyderabad,  
Telangana State,  
India.

Dr. K. Sumanth  
Principal and HOD,  
Dept. of EEE, SNIST,  
Hyderabad,  
Telangana State,  
India.

Abstract - This paper presents a synchronous-reference frame (SRF)-based control method to mitigate power-quality (PQ) problems through a three-phase four-wire unified PQ conditioner (UPQC) under unbalanced and distorted load conditions using fuzzy logic controller (FLC). In FLC, basic control action is shown by a set of linguistic rules. Here we are using fuzzy logic controller instead of using other controllers. UPQC has the capability of improving the power quality at the point of installation on power distribution systems or industrial power systems. The proposed UPQC system can enhance the power quality at the point of common coupling on power distribution systems under unbalanced and distorted load conditions. A trend that is growing in visibility relates to the use of fuzzy logic in combination with neuro computing and genetic algorithms. The simulation results of the SRF-based control method are shown in this paper by using Matlab/Simulink.

Index terms – Active power filter (APF), harmonics, phase locked loop (PLL), power quality (PQ), synchronous reference frame (SRF), unified power-quality (PQ) conditioner (UPQC), Fuzzy logic controller (FLC).

1. INTRODUCTION

Unified Power-quality (PQ) conditioner (UPQC) systems has been studied by researchers as an eventual method to enhance the PQ in electrical distribution systems. The main purpose of a UPQC is to compensate supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics. In other words, the UPQC can improve the power quality at the point of installation on power distribution systems or industrial power systems. More generally, fuzzy logic, neuro computing, and genetic algorithms may be viewed as the principal constituents of what might be called soft computing. Unlike the traditional, hard computing, soft computing accommodates the imprecision of the real world. The guiding principle of soft computing is: exploit the tolerance for imprecision, uncertainty and partial truth to achieve tractability, robustness and low solution cost. In the future, soft computing could play an increasingly important role in the conception and design of systems who’s MIQ (Machine IQ) is much higher than that of systems designed by conventional methods.

The UPQC is one of the most powerful solutions to large capacity loads which are sensitive to supply voltage flicker/imbalance. The UPQC, has two inverters and by sharing a dc link, will mitigate the voltage sag, swell, harmonic current and voltage and controls the power flow and voltage stability. The main aim of UPQC is to mitigate the disturbances which affects the critical load performance in power systems. The UPQC with the combination of a series active power filter (APF) and a shunt APF will also mitigate the voltage interruption only if the dc link has some energy storage or battery.

In the proposed synchronous-reference-frame (SRF)-based control method of the UPQC system has been optimized without using the transformer voltage, load and measurement of the filter current and so that the current measurements will be reduced and the system performance will be enhanced. The proposed SRF-based method is validated even in experimental study. The shunt APF is connected across the load to mitigate the current-related problems which are the improvement of power factor, compensation of the reactive power, current harmonic and the neutral current, dc-link voltage regulation and unbalance load compensation. The series APF has been connected in series in a line through the series transformer (ST). And it will act as a controlled
voltage source and compensates voltage harmonics, voltage sag and the swell, flicker.

II. PROPOSED DEVICES

A. UPQC

The UPQC eliminates the harmonics and simultaneously compensates the voltage and current, which improves the PQ, from other harmonic sensitive loads at the point of common coupling (PCC). In most of the papers, the UPQC is used to solve PQ problems. Fig. 1 is a basic system configuration of a UPQC with series and shunt APFs.

![Fig.1 Basic system configuration of UPQC.](image)

The aim of the series APF is the harmonic isolation between the load and supply. It is capable of mitigating the voltage imbalance, voltage regulation and also compensates the harmonics at the PCC. The shunt APF absorbs the current harmonics and regulates the dc-link voltage between the both APFs.

B. SRF

This method is used to extract the harmonics of the supply voltages and the currents. In current harmonic compensation, the distorted currents will be transferred into two-phase stationary coordinates by using the α–β transformation. Then, the stationary frame quantities will be transferred into synchronous rotating frames by using cosine and sinus functions which are obtained from the phase-locked loop (PLL). Same as in the p–q theory, by using filters, harmonics and the fundamental components will be separated and transferred to the a–b–c frame as the filter reference signals. The conventional SRF algorithm is the d–q method and it is the a–b–c to d–q–0 transformation (park transformation), which is the active filter compensation. Many APF and UPQC application works in the literature are used for enhancing the compensator performance. In SRF-based APF applications i.e. in three-phase four-wire (3P4W) systems, the voltage and current signals will be transformed into conventional rotating frame (d–q–0). In SRF method, the transformation angle (ot) is the angular position of the reference frame which will rotate at a speed which is constant and is in synchronism with the three-phase ac voltage.

In stationary reference frame, α–β–0 coordinates will be stationary, where as in the SRF method, d–q–0 coordinates will rotate synchronously with the supply voltages. Then, the angular position of the supply voltage vector will show the SRF angular position. In the 3P4W systems, the id component of the current will be in the “d” coordinate and it is in phase with voltage and is the positive-sequence component of the current. And the iq component of the current will be in the “q” coordinate and it is orthogonal to the id component of the current, and it is the negative sequence reactive current. The i0 component of the current, which is orthogonal to id and iq components of current, is the zero sequence component of the current. The iq component of the current is negative, then the load has inductive reactive power. And if the iq component of the current is positive, then the load has capacitive reactive power. In 3P4W nonlinear power systems, the id and iq components of the current has the oscillating components (id and iq) and average components (ìd and ıq), such that

\[
i_d = ï_d + î_d \\
i_q = ï_q + î_q
\] (1)

The oscillating components of the current (ìd and ıq) will correspond to the harmonic currents where as the average components of the current will correspond to the active current (ìd) and the reactive current (ıq). In the linear three-phase and balanced systems, the load voltage and current signals will consist of fundamental positive-sequence components. Whereas, in the unbalanced and nonlinear load conditions, fundamental positive, negative- and zero-sequence components are included. The fundamental positive-sequence components of the signals are separated to mitigate the harmonics in the applications of the APF.

III. PROPOSED SRF-BASED CONTROL ALGORITHM

Among the APF control methods, the SRF-based control method is the most conventional and the practical method.
The SRF method gives characteristics but it needs the techniques of the decisive PLL. In this paper a new technique based on the SRF method is obtained by using the modified PLL algorithm and its performance is compared with the conventional SRF method under unbalanced and distorted load conditions. In the proposed SRF control method, a−b−c to d−q−0 transformation equations, filters and the modified PLL algorithm which is shown in Fig. 2 are used. The source current is sensed in order to realize an SRF-based controller or any other type of controller for shunt APF and thus already exists in the literature. The proposed SRF-based controller with the modified PLL for the UPQC under 3P4W topology and the SRF-based controller for the series APF part are not found. Thus, the proposed modified PLL algorithm of the UPQC under unbalanced and distorted load conditions performance is improved.

A. Modified PLL

Some PLL algorithms are used with SRF and other control methods in the applications of APF. The conventional PLL circuit will work properly under the distorted and unbalanced system voltages. But, the conventional PLL shows a low performance under the distorted and unbalanced system voltages. The modified PLL circuit is shown in Fig. 2 is used for finding the positive sequence components of the system voltage signals. Fig. 3 shows the simulation results of the conventional PLL and the modified PLL algorithms with the transformation angle (ωt). The modified PLL performance is better than the conventional PLL, because under highly distorted and unbalanced system voltage conditions the output (ωt) of the modified PLL show low oscillations.

![Fig. 2 Modified PLL circuit block diagram.](image)

The modified PLL circuit will calculate the three-phase auxiliary total power by using three-phase instantaneous source line voltages, i.e., Vsab and Vscb (Vsab = vsa − Vsb; Vsb = Vsc − Vsb), to know the transformation angle (ωt) of the system supply voltage. The modified PLL circuit will operate properly under the distorted and unbalanced voltage waveforms. The measured line voltages will be multiplied by the auxiliary feedback currents (iax1 and iax2) with the amplitude of unity, and one leads 120° to another to get the three-phase auxiliary instantaneous active power (p3ax). The output is stabilized by adding the reference fundamental angular frequency (ω0 = 2πf) to the output of the proportional–integral (PI) controller (P = 0.05; I = 0.01). By integrating we get the auxiliary transformation angle (ωt), but this will lead the system fundamental frequency by 90°; and hence, to obtain the system fundamental frequency we add −π/2 to the integrator output.

![Fig. 3 Transformation angle (ωt) waveforms for the (a) conventional and (b) modified PLL algorithms.](image)

The proposed modified PLL circuit is arranged in the proposed SRF-based UPQC control method, which can be used directly and it is known as simple, fast and robust for the utility applications and with special weight of operation under the unbalanced and distorted load and supply voltage conditions. Fig. 4 shows the control block diagrams of the conventional and the proposed UPQC models. Fig. 4(a) shows the conventional control method, the reference switching signals in the UPQC are computed by sensing of three-phase source current and voltages, load current, shunt APF filter current and series
APF injected voltages in transformers along with a dc-link voltage. Fig. 4(b) shows the proposed method but the sensing of three phase source current, voltages and load voltages along with a dc-link voltage will become excess to compute the reference switching signals in the UPQC.

B. Reference-Voltage Signal Generation for Series APF

The proposed SRF-based UPQC control algorithm is used to solve the PQ problems which are related to source-voltage harmonics, unbalanced voltages, voltage sag and swell and at the same time for series APFs also. In this method, the series APF controller will calculate the reference value to be injected to the STs, and the positive-sequence component of the source voltages with the load-side line voltages are compared. Fig. 5 shows the algorithm of series APF reference-voltage signal-generation. In the equation (4), the supply voltages Vsabc are transformed to d-q-0 by using the equation (2) transformation matrix T. And, the modified PLL conversion is used for calculating the reference voltage.

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

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

$$\begin{bmatrix} V_{So} \\ V_{Sd} \\ V_{Sq} \end{bmatrix} = T^{-1} \begin{bmatrix} V_{Sa} \\ V_{sp} \\ V_{sc} \end{bmatrix}$$ (4)

Under the distorted load conditions, the oscillating components of Vsd and Vsq contains the harmonics and the source voltage negative-sequence components. And the average component has the voltage positive-sequence components. When there is unbalanced source voltage, the zero-sequence (Vs0) is occurred. The source voltage in the d-axis is (Vsd) and it has the average and oscillating components which is mentioned in the equation (5).

$$V_{sd} = \bar{V}_{sd} + \tilde{V}_{sd}$$ (5)

Equation (6) shows the calculation of the load reference voltages (V'Labc). Equation (3) has the inverse transformation matrix T^{-1} and it produces the reference load voltages by the source voltage average component and \omega t is produced from the modified PLL algorithm. Fig. (5) shows the calculation of the average value of the positive-sequence component of the source-voltage i.e. (V'Sd) in the d-axis and it is calculated by LPF. Fig. 5 shows the compensation of the load voltage harmonics, unbalance and the distortion where the zero and negative sequence components of the source voltage are set to zero.

$$\begin{bmatrix} \bar{V}_{La} \\ \bar{V}_{Lb} \\ \bar{V}_{Lc} \end{bmatrix} = T^{-1} \begin{bmatrix} 0 \\ \bar{V}_{sd} \\ 0 \end{bmatrix}$$ (6)

To compensate the voltage related problems, voltage harmonics, sag, swell, voltage unbalance, etc., at the PCC and to produce the switching signals of the insulated-gate bipolar transistor (IGBT); the sinusoidal pulse width modulation controller should compare the produced load reference voltages (V'Lac, V'Lbc and V'Lc) and the load voltages (V'Lac, V'Lbc and V'Lc).
C. Reference-Source-Current Signal Generation for Shunt APF

The current harmonics which are generated in the nonlinear load and the reactive power are compensated by the shunt APF. The signal-generation algorithm of the proposed SRF-based shunt APF reference source-current will use the source voltages, source currents and the dc-link voltages. The oscillating components contains the negative-sequence components of the source current and the harmonics. And the average components contains the positive-sequence components of current and they will correspond to the reactive current. When the load is unbalanced, the negative sequence component of source current i.e. \( i_s^q \) will appear. To compensate the harmonics and load unbalances, the proposed SRF-based method will employ the d-axis positive-sequence average component \( i_s^d \) and the zero and negative-sequence components in the 0 and q-axes of the source currents \( i_s^0 \) and \( i_s^q \) respectively.

\[
\begin{bmatrix}
  i_{s0} \\
  i_{sd} \\
  i_{sq}
\end{bmatrix}
= T
\begin{bmatrix}
  i_{sa} \\
  i_{sb} \\
  i_{sc}
\end{bmatrix}
\tag{7}
\]

For the dc-link voltage reduction cause, the active power will be injected into the power system with the help of the series APF to compensate the active power losses in the UPQC power circuit. For the dc-link voltage regulation, some active power is absorbed from the power system with the help of shunt APF. For this sake, the dc-link voltage will be compared with its reference value \( V^{DC} \) and from the PI controller we get the active current \( i_{dloss} \) which is required.

\[
i_{sd} = i_{dloss} + i_{sd}
\tag{8}
\]

To compensate the harmonics, unbalance, distortion and the source current reactive power in the proposed method, the zero and the negative-sequence components of the reference source current \( (i_s^0 \) and \( i_s^q \)) in the 0 and the q-axes will be set to zero. And to compensate the harmonics, neutral current, unbalance and the reactive power by regulation of the dc-link voltage; the source current references will be calculated by using the equation (9).

\[
\begin{bmatrix}
  i_{s0}' \\
  i_{sd}' \\
  i_{sq}'
\end{bmatrix}
= T^{-1}
\begin{bmatrix}
  0 \\
  i_{sd}' \\
  0
\end{bmatrix}
\tag{9}
\]

The produced reference-source currents \( (i_s'a, i_s'b \) and \( i_s'c \)) and the measured source currents \( (i_a, i_b \)

\[and \ i_c) \] will be compared by a hysteresis band current controller to produce the IGBT switching signals which compensates the current-related problems, reactive power, current harmonic, neutral current, dc-link voltage regulation and the load-current unbalance. Fig. 5 shows the block diagram of the proposed SRF-based UPQC control method.

IV. FUZZY LOGIC CONTROLLER

In FLC, a set of linguistic rules determines the basic control action. The system determines these rules. Since the numerical variables can be converted into the linguistic variables, so mathematical modeling of the system is not required. The FLC consists of three parts: fuzzification, interference engine and defuzzification. The FLC is classified as

i. There are seven fuzzy sets for each input and output.
ii. Triangular membership functions are used for the simplicity.
iii. Fuzzification using continuous universe of discourse.
iv. Implication using Mamdani’s, ‘min’ operator.
v. Defuzzification using the height method.

![Fig.6 (a) Fuzzy logic controller]

**Fuzzification:** Membership function values will be assigned to the linguistic variables, by using the seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big). The partition of the fuzzy subsets and the shape of membership function CE(k) E(k) adapts the shape to the appropriate system. Input scaling factor will normalize the value of input error and change in the error are normalized by an input scaling factor.
The system’s input scaling factor is designed such that input values lies between -1 and +1. The arrangement of triangular shape of the membership function shows that for any particular E(k) input there is one dominant fuzzy subset. The input error for the FLC is:

\[
E(k) = \frac{\text{ph}(k) - \text{ph}(k-1)}{\text{V}(k) - \text{ph}(k-1)} \quad (10)
\]

\[
CE(k) = E(k) - E(k-1) \quad (11)
\]

<table>
<thead>
<tr>
<th>Change in error</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>PB</td>
<td>PB</td>
<td>PB</td>
<td>PM</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
</tr>
<tr>
<td>NM</td>
<td>PB</td>
<td>PB</td>
<td>PM</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>NS</td>
<td>PB</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NB</td>
</tr>
<tr>
<td>Z</td>
<td>PB</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NB</td>
</tr>
<tr>
<td>PS</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
</tr>
<tr>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
</tr>
<tr>
<td>PB</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
</tr>
</tbody>
</table>

Fig.6 (b) Membership functions

**Inference Method:** Some composition methods like the Max–Min and Max-Dot are proposed in the literature. Here we are using the Min method. The output of the membership function for each rule is given by the minimum operator and maximum operator. Table 1 shows the FLC rule base.

**Defuzzification:** A defuzzification stage is needed, when a plant generally requires a non-fuzzy value of control. For computing the output of the FLC, the "height method" is used and the FLC output will modify the control output. And, the output of FLC will control the inverter switch. The UPQC requires the active power, reactive power, terminal voltage of the line and capacitor voltage and they should be maintained. To control these parameters, they are sensed and compared with the reference values. To obtain this, the membership function of FLC are the error, change in error and output. The set of FLC rules will be derived from the equation (12).

\[
u = -[\alpha E + (1-\alpha)C] \quad (12)
\]

Where \( \alpha \) is self-adjustable factor which regulates the whole operation. And \( E \) is the error of the system, \( C \) is the change in the error and \( u \) is the control variable. A large value of the error \( E \) will indicate that the system is in the unbalanced state. If the system is in the unbalanced state, the controller will enlarge its control variables to balance the system as soon as possible. The set of FLC rules are made in the Fig. 6 (b) by using the Table 1.

**V. SIMULATION RESULTS**

Here, the UPQC proposed SRF-based control algorithm has been evaluated by using the Matlab/Simulink software under unbalanced, distorted load-current and source-voltage conditions because the unbalanced load currents are common and it is one of the problem in 3P4W distribution systems. Table 2 shows the UPQC system parameters which are used. The simulation results shows the operation of the UPQC system by using fuzzy logic controller (FLC). And when the UPQC system is operated, the load will be changed and the dynamic response of the system is tested. In the simulation, the proposed control method under the nonideal mains voltage and unbalanced load current is examined. The R and C passive filters will remove the switching ripples in the current and the voltage waveforms. The simulated results shows the proposed control method allows the THD levels as 3.0% and 2.5% for the current and voltage respectively by mitigating all the harmonic components. The proposed control method will extract the load current and the source voltage distortions.

In this proposed SRF-based control algorithm, the mains currents ( \( \text{isabc} \) ) and voltages ( \( \text{Vsabc} \) ) will be calculated by the shunt APF reference current and the series APF controller uses the mains and the load voltages ( \( \text{VLabc} \) ).

The proposed UPQC control algorithm will compensate both harmonics and the reactive power of the load and also eliminates the neutral current. This proposed method is evaluated and tested under the steady-state and dynamic load conditions. Fig. 8 shows load changing simulation results. In this, the UPQC system will be operated at 0.15 sec and the load current amplitude increases nearly by 100% at 0.2 sec. In the proposed control method, the output voltage will show almost invisible transient when there is 100% load change. From fig. 7 the dynamic performance is clearly seen.

**Table I Fuzzy Rules**

<table>
<thead>
<tr>
<th>Change in error</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>PB</td>
<td>PB</td>
<td>PB</td>
<td>PM</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
</tr>
<tr>
<td>NM</td>
<td>PB</td>
<td>PB</td>
<td>PM</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>NS</td>
<td>PB</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NB</td>
</tr>
<tr>
<td>Z</td>
<td>PB</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NB</td>
</tr>
<tr>
<td>PS</td>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
</tr>
<tr>
<td>PM</td>
<td>PS</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
</tr>
<tr>
<td>PB</td>
<td>Z</td>
<td>NS</td>
<td>NM</td>
<td>NM</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
</tr>
</tbody>
</table>

IJPRES
### TABLE II: UPQC EXPERIMENTAL AND SIMULATION PARAMETERS OF VOLTAGE AND CURRENT WAVEFORMS AT THE PCC

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>$V_{abc}$ 380 V</td>
</tr>
<tr>
<td>Frequency</td>
<td>$f$ 50 Hz</td>
</tr>
<tr>
<td>3-Phase AC Line Inductance</td>
<td>$L_{abc}$ 1.47 mH</td>
</tr>
<tr>
<td>1-Phase AC Line Inductance</td>
<td>$L_{a}$ 0.75 mH</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td></td>
</tr>
<tr>
<td>3-Phase DC Inductance</td>
<td>$L_{dc}$ 11.5 mH</td>
</tr>
<tr>
<td>3-Phase DC Resistor</td>
<td>$R_{dc}$ 30 Ω</td>
</tr>
<tr>
<td>1-Phase DC Resistor</td>
<td>$R_{dc}$ 100 Ω</td>
</tr>
<tr>
<td>1-Phase DC Capacitor</td>
<td>$C_{dc}$ 75 µF</td>
</tr>
<tr>
<td><strong>dc Link</strong></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>$V_{dc}$ 700 V</td>
</tr>
<tr>
<td>Two series capacitor</td>
<td>$C_1C_2$ 2200 µF</td>
</tr>
<tr>
<td>AC Line Inductance</td>
<td>$L_{abc}$ 3 mH</td>
</tr>
<tr>
<td><strong>Shunt APF</strong></td>
<td></td>
</tr>
<tr>
<td>Filter Resistor</td>
<td>$R_{abc}$ 5 Ω</td>
</tr>
<tr>
<td>Filter Capacitor</td>
<td>$C_{abc}$ 4.7 µF</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>$f_{sw}$ 15 kHz</td>
</tr>
<tr>
<td>AC Line Inductance</td>
<td>$L_{abc}$ 1.5 mH</td>
</tr>
<tr>
<td><strong>Series APF</strong></td>
<td></td>
</tr>
<tr>
<td>Filter Resistor</td>
<td>$R_{abc}$ 5 Ω</td>
</tr>
<tr>
<td>Filter Capacitor</td>
<td>$C_{abc}$ 26 µF</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>$f_{sw}$ 12 kHz</td>
</tr>
<tr>
<td>Three Series transformer</td>
<td>$S$ 5.4 kVA</td>
</tr>
</tbody>
</table>

![Waveform Images](a) (b) (c) (d) (e)
Fig. 7 Simulation results of the proposed UPQC control method for (a) unbalanced and distorted mains voltages, (b) injected transformer voltages, (c) load voltages, (d) unbalanced and nonlinear load currents, (e) injected compensator currents, (f) source currents, (g) load neutral current, (h) injected compensator current, (i) source neutral current and (j) reactive power compensation.
Fig. 8. Simulation results for operational performance of the UPQC system. (a) Load voltages, (b) injected transformer voltages, (c) load currents, (d) source currents, (e) injected compensator currents, (f) source neutral current, (g) instantaneous active power, (h) instantaneous reactive power, (i) load voltage and source current for phase a, and (k) dc-link voltage.
At the PCC, in order to create the sinusoidal waveforms the current and voltage with distortion are compensated. Before compensating, the THD level of the load voltage in phase c is 25.98% and the source current is 8.12%; but after compensating, the THD level of the load voltage is nearly 2.5% and the source current is nearly 3.0%. At the PCC, in case of the unbalanced and distorted current and voltage; the harmonics and unbalanced currents will be compensated. Simulation results shows that the proposed control strategy will compensate the harmonics and the unbalanced load current distortions. It shows that the UPQC compensates the voltage and the current harmonics and it also compensates when the unbalance components occurs in the 3P4W electric power systems.

The simulation results show that the proposed UPQC control technique with the modified PLL circuit has the better performance.

Table 3. Simulated results by using fuzzy logic controller

<table>
<thead>
<tr>
<th>Signal</th>
<th>Before UPQC (0.1 to 0.15 sec)</th>
<th>After UPQC under balanced load condition (0.1 to 0.3 sec)</th>
<th>After UPQC under unbalanced load condition (0.2 to 0.4 sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i_b)</td>
<td>8.41</td>
<td>0.55</td>
<td>0.59</td>
</tr>
<tr>
<td>(i_b/fuzzy)</td>
<td>8.41</td>
<td>0.52</td>
<td>0.59</td>
</tr>
<tr>
<td>(i_c)</td>
<td>8.12</td>
<td>1.31</td>
<td>2.81</td>
</tr>
<tr>
<td>(i_c/fuzzy)</td>
<td>8.12</td>
<td>1.28</td>
<td>1.27</td>
</tr>
<tr>
<td>(v_{la})</td>
<td>25.82</td>
<td>1.64</td>
<td>1.69</td>
</tr>
<tr>
<td>(v_{la}/fuzzy)</td>
<td>25.82</td>
<td>1.57</td>
<td>1.62</td>
</tr>
<tr>
<td>(v_{lc})</td>
<td>25.98</td>
<td>1.71</td>
<td>2.03</td>
</tr>
<tr>
<td>(v_{lc}/fuzzy)</td>
<td>25.98</td>
<td>1.55</td>
<td>1.55</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In this a new SRF-based control strategy has been used in the UPQC, which will compensate the reactive power with voltage and current harmonics under the non-ideal mains voltage and the unbalanced load current conditions. Based on the SRF theory, the proposed control strategy will use the loads and mains voltage measurements for the series APF. And by using fuzzy we are improving the performance of the system better than the PI controller. In the FLC, a set of linguistic rules determines the basic control action. The conventional method requires the measurements of load, source and filter currents for the shunt APF and the source and injection transformer voltages for the series APF. The simulation results shows under the unbalanced and nonlinear load current conditions, the control algorithm will eliminate the impact of distortion and unbalance of load current on the power line till the power factor becomes unity. The series APF will isolate the loads and the source voltage in the unbalanced and distorted load conditions and the shunt APF will compensate the reactive power, neutral current and the harmonics and thus provides three phase balanced and the rated currents for the mains.

REFERENCES


AUTHORS

NAIDU SHRAVANI  M.Tech (Electrical Power Engineering) in SNIST, Hyderabad, Telangana State, India.

SRIRAM RAMU presently working as an Associate Professor in SNIST, Hyderabad, Telangana State, India.

CH.V.SESHAGIRI RAO presently working as an Associate Professor in SNIST, Hyderabad, Telangana State, India.

DR.K.SUMANTH presently working as a Professor and HOD (EEE), in SNIST, Hyderabad, Telangana State, India.