NEURO-FUZZY CONTROLLER BASED MULTI CONVERTER UNIFIED POWER QUALITY CONDITIONER WITH PQ THEORY

B. RAJANI, P. SANGAMESWARA RAJU

Abstract- This paper presents a novel structure for a three phase four-wire (3P4W) distribution system utilizing Multi converter unified power quality conditioner (MC-UPQC). The 3P4W system is realized from a three-phase three-wire system where the neutral of series transformer used in series part MC-UPQC is considered as the fourth wire for the 3P4W system. A new control strategy to balance the unbalanced load currents is also presented in this paper. The neutral current that may flow toward transformer neutral point is compensated by using a four-leg voltage source inverter topology for shunt part. Thus, the series transformer neutral will be at virtual zero potential during all operating conditions. The simulation results based on MATLAB/SIMULINK are presented to show the effectiveness of the proposed MC-UPQC-based 3P4W distribution system. The present work study the compensation principle and different control strategies used here are based on PI & Neuro-Fuzzy controller of the MC-UPQC in detail.

Keywords- Active power filter (APF), four-leg voltage-source inverter (VSI) structure, Multi converter unified power quality conditioner (MC-UPQC), three-phase four-wire (3P4W) system.

I. INTRODUCTION

The power electronics-based devices due to their inherent non-linearity draw harmonic and reactive power from the supply. In three phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. In addition to this, the power system is subjected to various transients like voltage sags, swells, flickers etc. These transients would affect the voltage at distribution levels. Excessive reactive power of loads would increase the generating capacity of generating stations and increase the transmission losses in lines. Hence supply of reactive power at the load ends becomes essential. Power Quality (PQ) mainly deals with issues like maintaining a fixed voltage at the Point of Common Coupling (PCC) for various distribution voltage levels irrespective of voltage fluctuations, near unity power factor power drawn from the supply blocking of voltage and current unbalance from passing upwards from various distribution levels, reduction of voltage and current harmonics in the system. To provide a balance, distortion-free, and constant magnitude power to sensitive load and, at the same time, to restrict the harmonic, unbalance, and reactive power demanded by the load and hence to make the overall power distribution system more healthy, the Multi converter unified power quality conditioner (MC-UPQC) is one of the best solutions [11]–[17].

A multi-converter unified power quality conditioner (MC-UPQC) having three VSCs connected back-to-back by a dc link is to compensate both current and voltage imperfections in one feeder
and voltage imperfections in another feeder. As shown in this figure, two feeders connected to two different substations supply the loads L1 and L2. The MC-UPQC is connected to two buses BUS1 and BUS2 with voltages of ut1 and ut2, respectively. The shunt part of the MC-UPQC is also connected to load L1 with a current of il1. Supply voltages are denoted by us1 and us2 while load voltages are ul1 and ul2. Finally, feeder currents are denoted by is1 and is2 and load currents are il1 and il2. Bus voltages ut1 and ut2 are distorted and may be subjected to sag/swell. The load L1 is a nonlinear/sensitive load which needs a pure sinusoidal voltage for proper operation while its current is non-sinusoidal and contains harmonics. The load L2 is a sensitive/critical load which needs a purely sinusoidal voltage and must be fully protected against distortion, sag/swell and interruption. These types of loads primarily include production industries and critical service providers, such as medical centers, airports, or broadcasting centers where voltage interruption can result in severe economical losses or human damages.

A three-phase four-wire (3P4W) distribution system can be realized by providing the neutral conductor along with the three power lines from generation station or by utilizing a delta-star (Δ–Y) transformer at distribution level. The MC-UPQC installed for 3P4W application generally considers 3P4W supply [14]–[17]. This paper proposes a new topology/structure that can be realized in MC-UPQC based applications, in which the series transformer neutral used for series inverter can be used to realize a 3P4W system even if the power supplied by utility is three phase three-wire (3P3W). This new functionality using MC-UPQC could be useful in future MC-UPQC-based distribution systems. The unbalanced load currents are very common and yet an important problem in 3P4W distribution system.

This paper deals with the unbalanced load current problem with a new control approach, in which the fundamental active powers demanded by each phase are computed first, and these active powers are then redistributed equally on each of the phases. Thus, the proposed control strategy makes the unbalanced load currents as perfectly balanced source currents using MC-UPQC.

II PROPOSED 3P4W DISTRIBUTION SYSTEM UTILIZING MC-UPQC

![Fig. 1: Typical MC-UPQC used in a distribution system.](image1)

![Fig. 2. 3P3W MC-UPQC structure.](image2)

![Fig. 3. Proposed 3P4W system realized from a 3P3W system utilizing MC-UPQC.](image3)

The three-phase three-wire MC-UPQC is already installed to protect a sensitive load and to restrict any entry of distortion from load side toward utility, as shown in Fig. 2. If we want to upgrade the system now from 3P3W to 3P4W due to installation of some single-phase loads and if the distribution transformer is close to the plant under consideration, utility would provide the neutral conductor from this transformer.
without major cost involvement. In certain cases, this may be a costly solution because the distribution transformer may not be situated in close vicinity. Recently, the utility service providers are putting more and more restrictions on current total harmonic distortion (THD) limits, drawn by nonlinear loads, to control the power distribution system harmonic pollution. At the same time, the use of sophisticated equipment/load has increased significantly, and it needs clean power for its proper operation. Therefore, in future distribution systems and the plant/load centers, application of MC-UPQC would be common. Fig. 3 shows the proposed novel 3P4W topology that can be realized from a 3P3W system. This proposed system has all the advantages of general MC-UPQC, in addition to easy expansion of 3P3W system to 3P4W System. Thus, the proposed topology may play an important role in the future 3P4W distribution system for more advanced MC-UPQC based plant/load center installation, where utilities would be having an additional option to realize a 3P4W system just by providing a 3P3W supply. As shown in Fig. 3, the MC-UPQC should necessarily consist of three-phase series transformer in order to connect one of the inverters in the series with the line to function as a controlled voltage source. If we could use the neutral of three-phase series transformer to connect a neutral wire to realize the 3P4W system, then 3P4W system can easily be achieved from a 3P3W system (Fig. 3). The neutral current, present if any, would flow through this fourth wire toward transformer neutral point. This neutral current can be compensated by using a split capacitor topology [7], [14], [15] or a four-leg voltage-source inverter (VSI) topology for a shunt inverter [7], [16]. The four-leg VSI topology requires one additional leg as compared to the split capacitor topology. The neutral current compensation in the four-leg VSI structure is much easier than that of the split capacitor because the split capacitor topology essentially needs two capacitors and an extra control loop to maintain a zero voltage error difference between both the capacitor voltages, resulting in a more complex control loop to maintain the dc bus voltage at constant level. In this paper, the four-leg VSI topology is considered to compensate the neutral current flowing toward the transformer neutral point. A fourth leg is added on the existing 3P3W MC-UPQC, such that the transformer neutral point will be at virtual zero potential. Thus, the proposed structure would help to realize a 3P4W system from a 3P3W system at distribution load end. This would eventually result in easy expansion from 3P3W to 3P4W systems. A new control strategy to generate balanced reference source currents under unbalanced load condition is also proposed in this paper and is explained in the next section.

III PROPOSED SHUNT CONTROLLER METHOD USING PQ-THEORY

The control algorithm for series active power filter (APF) is based on unit vector template generation scheme [12], whereas the control strategy for shunt APF is discussed in this section. Based on the load on the 3P4W system, the current drawn from the utility can be unbalanced. In this paper a new control strategy is proposed to compensate the current unbalance present in the load currents by expanding the concept of single phase p—q theory [10], [11]. According to this theory, a signal phase system can be defined as a pseudo two-phase system giving π/2 lead or π/2 lag, that is each phase voltage and current of the original three-phase system can be considered as three independent two phase systems. These resultant two phase systems can be represented in α—β coordinates, and thus, the p—q theory applied for balanced three phase system can also be used for each phase of unbalanced system independently. The actual load voltages and load currents are considered as α—axis quantities whereas the π/2 lead load or π/2 lag voltages and π/2 lead or π/2 lag load currents are considered as β—axis quantities. In this paper π/2 lead is considered to achieve a two phase system for each phase. The major advantage of p—q theory is that it gives poor results under distorted and/or unbalanced input/utility voltages. In order to eliminate these limitations, the reference load voltage signals extracted for series APF are used instead of actual load voltages.

For phase a, the load voltage and current in α—β coordinates can be represented by π/2 lead

\[
\begin{bmatrix}
    v_{La-a} \\
    v_{La-b}
\end{bmatrix} = \begin{bmatrix}
    v_{La}(\omega t) \\
    v_{La}(\omega t + \frac{\pi}{2})
\end{bmatrix} = \begin{bmatrix}
    v_{Lm}\sin(\omega t) \\
    v_{Lm}\cos(\omega t)
\end{bmatrix}
\]  

(1)

\[
\begin{bmatrix}
    i_{La-a} \\
    i_{La-b}
\end{bmatrix} = \begin{bmatrix}
    i_{La}(\omega t) \\
    i_{La}(\omega t + \frac{\pi}{2})
\end{bmatrix} = \begin{bmatrix}
    i_{Lm}\sin(\omega t) \\
    i_{Lm}\cos(\omega t)
\end{bmatrix}
\]  

(2)

\[
\begin{bmatrix}
    v_{La-a} \\
    v_{La-b}
\end{bmatrix} = \begin{bmatrix}
    v_{La}(\omega t) \\
    v_{La}(\omega t + \frac{\pi}{2})
\end{bmatrix} = \begin{bmatrix}
    v_{Lm}\sin(\omega t) \\
    v_{Lm}\cos(\omega t)
\end{bmatrix}
\]  

(3)

\[
\begin{bmatrix}
    i_{La-a} \\
    i_{La-b}
\end{bmatrix} = \begin{bmatrix}
    i_{La}(\omega t) \\
    i_{La}(\omega t + \frac{\pi}{2})
\end{bmatrix} = \begin{bmatrix}
    i_{Lm}\sin(\omega t) \\
    i_{Lm}\cos(\omega t)
\end{bmatrix}
\]  

(4)
\[
\begin{align*}
[i_{La - \alpha}] & = \left[ i_{La} (\omega t + \varphi L) \right] \\
[i_{La - \beta}] & = \left[ i_{La} ((\omega t + \varphi L) + \frac{\pi}{2}) \right] \quad (2)
\end{align*}
\]

Where \(v_{Lm}^* (\omega t)\) represents the reference load voltage and \(v_{Lm}\) represents the desired load voltage magnitude. Similarly for phase b, the load voltage and current in \(\alpha - \beta\) coordinates can be represented by \(\pi/2\) lead as,

\[
\begin{align*}
[v_{Lb - \alpha}] & = \left[ v_{Lb} (\omega t) \right] \\
[v_{Lb - \beta}] & = \left[ v_{Lb} ((\omega t + \frac{\pi}{2}) \right] \\
[v_{Lm}\sin(\omega t - 120^\circ)] & = \left[ v_{Lm}\sin(\omega t - 120^\circ) \right] \\
[v_{Lm}\cos(\omega t - 120^\circ)] & = \left[ v_{Lm}\cos(\omega t - 120^\circ) \right] \quad (3)
\end{align*}
\]

\[
\begin{align*}
[i_{La - \alpha}] & = \left[ i_{La} (\omega t + \varphi L) \right] \\
[i_{La - \beta}] & = \left[ i_{La} ((\omega t + \varphi L) + \frac{\pi}{2}) \right] \quad (4)
\end{align*}
\]

Where \(v_{Lm}^* (\omega t)\) represents the reference load voltage and \(v_{Lm}\) represents the desired load voltage magnitude. Similarly for phase b, the load voltage and current in \(\alpha - \beta\) coordinates can be represented by \(\pi/2\) lead as,

\[
\begin{align*}
[v_{Lb - \alpha}] & = \left[ v_{Lb} (\omega t) \right] \\
[v_{Lb - \beta}] & = \left[ v_{Lb} ((\omega t + \frac{\pi}{2}) \right] \\
[v_{Lm}\sin(\omega t - 120^\circ)] & = \left[ v_{Lm}\sin(\omega t - 120^\circ) \right] \\
[v_{Lm}\cos(\omega t - 120^\circ)] & = \left[ v_{Lm}\cos(\omega t - 120^\circ) \right] \quad (5)
\end{align*}
\]

\[
\begin{align*}
[i_{Lb - \alpha}] & = \left[ i_{Lb} (\omega t + \varphi L) \right] \\
[i_{Lb - \beta}] & = \left[ i_{Lb} ((\omega t + \varphi L) + \frac{\pi}{2}) \right] \quad (6)
\end{align*}
\]

In addition for phase c, the load voltage and current in \(\alpha - \beta\) coordinates can be represented by \(\pi/2\) lead as,

\[
\begin{align*}
[v_{Lc - \alpha}] & = \left[ v_{Lc} (\omega t) \right] \\
[v_{Lc - \beta}] & = \left[ v_{Lc} ((\omega t + \frac{\pi}{2}) \right] \\
[v_{Lm}\sin(\omega t + 120^\circ)] & = \left[ v_{Lm}\sin(\omega t + 120^\circ) \right] \\
[v_{Lm}\cos(\omega t + 120^\circ)] & = \left[ v_{Lm}\cos(\omega t + 120^\circ) \right] \quad (7)
\end{align*}
\]

\[
\begin{align*}
[i_{Lc - \alpha}] & = \left[ i_{Lc} (\omega t + \varphi L) \right] \\
[i_{Lc - \beta}] & = \left[ i_{Lc} ((\omega t + \varphi L) + \frac{\pi}{2}) \right] \quad (8)
\end{align*}
\]

By using the definition of three phase p—q theory, for balanced three-phase system (3), the instantaneous power components can be represented as

\[
\begin{align*}
\text{Instantaneous active power} & = p_{L,abc} = v_{L,abc - \alpha} \cdot i_{L,abc - \alpha} + v_{L,abc - \beta} \cdot i_{L,abc - \beta} \quad (9)
\end{align*}
\]

\[
\begin{align*}
\text{Instantaneous reactive power} & = q_{L,abc} = v_{L,abc - \alpha} \cdot i_{L,abc - \beta} - v_{L,abc - \beta} \cdot i_{L,abc - \alpha} \quad (10)
\end{align*}
\]

Considering the phase a, the phase-a instantaneous load active and instantaneous load reactive powers can be represented by

\[
\begin{align*}
[p_{La}] & = \left[ -v_{La - \alpha} v_{Lb - \beta} \right] \\
[q_{La}] & = \left[ v_{Lb - \alpha} - v_{La - \beta} \right] \quad (11)
\end{align*}
\]

Where

\[
\begin{align*}
p_{La} & = \bar{p}_{La} + \bar{q}_{La} \quad (12)
\end{align*}
\]

\[
\begin{align*}
q_{La} & = \bar{q}_{La} + \bar{q}_{La} \quad (13)
\end{align*}
\]

In (12) and (13), \(\bar{p}_{La}\) and \(\bar{q}_{La}\) represent the DC components that are responsible for fundamental load active and reactive powers, whereas \(\bar{p}_{La}\) and \(\bar{q}_{La}\) represent the ac components that are responsible for harmonic powers. The phase-a fundamental instantaneous load active and reactive power components can be extracted from \(p_{La}\) and \(q_{La}\), respectively by using a low pass filter.

Therefore, the instantaneous fundamental load active power for phase-a is given by

\[
\bar{p}_{La} = \bar{p}_{La} \quad (14)
\]

And Instantaneous fundamental load reactive power for phase-a is given by

\[
\bar{q}_{La} = \bar{q}_{La} \quad (15)
\]

Similarly the fundamental instantaneous load active and the fundamental instantaneous load reactive powers for phases b and c can be calculated as

\[
\begin{align*}
\bar{p}_{Lb,1} = \bar{p}_{Lb} \quad (16)
\end{align*}
\]

\[
\begin{align*}
\bar{q}_{Lb,1} = \bar{q}_{Lb} \quad (17)
\end{align*}
\]

\[
\begin{align*}
\bar{p}_{Lc,1} = \bar{p}_{Lc} \quad (18)
\end{align*}
\]

\[
\begin{align*}
\bar{q}_{Lc,1} = \bar{q}_{Lc} \quad (19)
\end{align*}
\]

Since the load current drawn by each phase may be different due to different loads that may be present inside plant, therefore the instantaneous fundamental load active power and the instantaneous fundamental load reactive power demand for each phase may not be the same. In order to make this load unbalanced power demand, seen from the utility side, as a perfectly balanced fundamental three phase active power, the unbalanced load power should be properly redistributed between utility, MC-UPQC...
NEURO-FUZZY CONTROLLER (NFC)

A neuro-fuzzy system is a fuzzy system that uses a learning algorithm derived from or inspired by neural network theory to determine its parameters (fuzzy sets and fuzzy rules) by processing data samples. NFC is the combination of Fuzzy Inference System (FIS) and NN. The fuzzy logic is operated based on fuzzy rule and NN is operated based on training dataset. The neural network training dataset are generated from the fuzzy rules. The function of NFC is explained in the below section.

A. FUZZY LOGIC CONTROLLER

Fuzzy control system is a control system based on fuzzy logic – a mathematical system that analyzes input variables in terms of logical variables that
Controllers based on fuzzy logic give the linguistic strategies control conversion from expert knowledge in automatic control strategies. Professor Lotfia Zadeh at University of California first proposed in 1965 as a way to process imprecise data its usefulness was not seen until more powerful computers and controllers were available. In the fuzzy control scheme, the operation of controller is mainly based on fuzzy rules, which are generated using fuzzy set theory. Fuzzy controller plays an important role in the compensation of PQ problem the steps involved in fuzzy controller are fuzzification, decision making, and defuzzification. Fuzzification is the process of changing the crisp value into fuzzy value. The fuzzification process has no fixed set of procedure and it is achieved by different types of fuzzifiers. The shapes of fuzzy sets are triangular, trapezoidal and more. Here, a triangular fuzzy set is used. The fuzzified output is applied to the decision making process, which contains a set of rules. Using the fuzzy rules, the input for bias voltage generator is selected from FIS. Then, the defuzzification process is applied and the fuzzified calculated voltage ($V_{dc}$) is determined. The structure of designed FLC is illustrated as follows.

In addition, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. The development of fuzzy logic approach here is limited to the design and structure of the controller. The inputs of FLC are defined as the voltage error, and change of error. Fuzzy sets are defined for each input and output variable. There are seven fuzzy levels (NB-negative big, NM-negative medium, NS-negative small Z-zero, PS-positive small, PM-positive medium, PB-positive big) the membership functions for input and output variables are triangular. The min-max method interface engine is used. The fuzzy method used in this FLC is center of area. The complete set of control rules is shown in Table.1. Each of the 49 control rules represents the desired controller response to a particular situation. Figure 6 shows the block diagram of a fuzzy logic controller. The block diagram presented in Figure 6 shows a FLC controller in the MATLAB simulation. The simulation parameters are shown in Table 1. The performance of degree of membership functions are shown in Figure 8.
**Table 1 Fuzzy Rules**

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

In Figure 8, the input layer, hidden layer and output layer of the network are \( (H_{11}, H_{12}), (H_{21}, H_{22}, \ldots, H_{2N}) \), and \( H_{31} \) respectively. The weight of the input layer to hidden layer is denoted as \( w_{11}, w_{12}, w_{1N}, w_{21}, w_{22}, \ldots, w_{2N} \). The weight of the hidden layer to output layer is denoted as \( w_{211}, w_{221}, \ldots, w_{2N1} \). Here, the Back Propagation (BP) training algorithm is used for training the network. Figure 9 shows the Proposed System NN Structure. Figure 10 shows the NN Performance Plots (i) Regression Analysis, (ii) Network Validation performance and (iii) Training State.

**B. DESIGNING & TRAINING OF ANN**

An artificial neural network (ANN), often just called a "neural network" (NN), is a mathematical model or computational model based on biological neural networks. It consists of an interconnected group of artificial neurons and processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. NN is an artificial intelligence technique that is used for generating training data set and testing the applied input data. A feed forward type NN is used for the proposed method. Normally, the NN consist of three layers: input layer, hidden layer and output layer. Here, the error, change of error, and the regulated output voltage are denoted as \( V_e, V_{\Delta e}, V_{DC}^{\text{NN}} \) respectively. The structure of the NN is described as follows.

V. SIMULATION RESULTS OF PROPOSED 3P4W MC-UPQC STRUCTURE STUDIES

The performance of the simulation model of MC-UPQC in a two-feeder distribution system as in figure 3 is analyzed by using MATLAB/SIMULATION The supply voltages of the two feeders consists of two three-phase three-wire , The BUS1 voltage (ut1) contains the seventh-order harmonic with a value of 22%, and the BUS2 voltage...
(ut2) contains the fifth order harmonic feeder1 load is a combination of a three-phase R-L load (R = 10 Ohms, L = 30μ H) and a three-phase diode bridge rectifier followed by R-L load on dc side (R = 10 Ohms, L = 100 mH) which draws harmonic current. Similarly to introduce distortion in supply voltages of feeder2, 7th and 5th harmonic voltage sources, which are 22% and 35% of fundamental input supply voltages are connected in series with the supply voltages VSC1 and VSC3 respectively. In order to demonstrate the performance of the proposed model of MC-UPQC simulation case studies are carried out.

Simulation is carried out in this case study under distorted conditions of current in feeder1 and supply voltages in feeder1. It is to be noted that the shunt compensator injects compensation current at 0.1s as in Fig.15. The nonlinear load current, its corresponding compensation current injected by VSC2, compensated feeder1 current, and finally, the dc-link capacitor voltage are shown in Fig. 16. The distorted nonlinear load current is compensated very well, and. The Total Harmonic Distortion (THD) of load and source currents is identical before compensation and is observed to be 28.5%. After compensation the source current THD is observed to be less than 5%. Also, the dc voltage regulation loop has functioned properly under all disturbances, such as sag/swell in both feeders. Thus a significant improvement in the frequency spectrum and THD after compensation is clearly demonstrated by MC-UPQC.

VII. COMPENSATION OF VOLTAGE HARMONICS, VOLTAGE SAG/SWELL

The BUS1 voltage (ut1) contains seventh-order harmonics with a value of 22%. The BUS1 voltage contains 25% voltage sag/swell from 0.1s to 0.2s BUS2 voltage (ut2) contains the fifth order harmonic with a value of 35%. The BUS2 voltage contains 35% sag/swell from 0.25s to 0.3s. The nonlinear/sensitive load L1 is a three-phase rectifier load which supplies an RL load of 10 Ω and 30μ H. The MC–UPQC is switched on at t=0.02s. The BUS1 and BUS2 voltages, the corresponding compensation voltages injected by VSC1, and VSC3 and finally load L1 and L2 voltages are shown in figure. 13 & figure.14 respectively.
VIII. UPSTREAM FAULT ON FEEDER2

When a fault occurs in Feeder2 in any form of L-G, L-L-G, and L-L-L-G faults, the voltage across the sensitive/critical load L2 is involved in sag/swell or interruption. This voltage imperfection can be compensated for by VSC2. In this case, the power required by load L2 is supplied through VSC2 and VSC3. This implies that the power semiconductor switches of VSC2 and VSC3 must be rated such that total power transfer is possible. The performance of the MC-UPQC under a fault condition on Feeder2 is tested by applying a three-phase fault to ground on Feeder2 from 0.1s to 0.2s. Simulation results are shown in figures 13 & 14.
<table>
<thead>
<tr>
<th>Order of harmonics</th>
<th>5th &amp; 7th</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITHOUT MCUPQC utility side voltage</td>
<td>0.92</td>
</tr>
<tr>
<td>WITHOUT MCUPQC utility side current</td>
<td>1.276</td>
</tr>
<tr>
<td>MCUPQC with PI controller utility side voltage (with out PQ theory)</td>
<td>0.7201</td>
</tr>
<tr>
<td>MCUPQC with PI controller utility side current (with out PQ theory)</td>
<td>0.42</td>
</tr>
<tr>
<td>MCUPQC with PI controller utility side voltage (with PQ theory)</td>
<td>0.000649</td>
</tr>
<tr>
<td>MCUPQC with PI controller utility side current (with PQ theory)</td>
<td>0.092</td>
</tr>
<tr>
<td>MCUPQC with NEURO-FUZZY controller utility side voltage (with out PQ theory)</td>
<td>0.22</td>
</tr>
</tbody>
</table>
### Neuro-Fuzzy Controller Based Multi Converter Unified Power Quality Conditioner with PQ Theory

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCUUPQC with NEURO- FUZZY controller utility side current (without PQ theory)</td>
<td>0.0409</td>
</tr>
<tr>
<td>MCUUPQC with NEURO-FUZZY controller utility side voltage (with PQ theory)</td>
<td>0.00008113</td>
</tr>
<tr>
<td>MCUUPQC with NEURO- FUZZY controller utility side current (with PQ theory)</td>
<td>0.0115</td>
</tr>
</tbody>
</table>
IX. CONCLUSION

A new 3P4W topology for distribution system utilizing MC-UPQC has been proposed in this paper. This proposed topology would be very useful to expand the existing 3P3W system to 3P4W system where UPQC is installed to compensate the different power quality problems, which may play an important role in future UPQC-based distribution system. A new control strategy to generate the balanced reference source current under unbalanced load condition is also presented in this paper. The MATLAB/Simulink-based simulation results show that the distorted and unbalanced load currents seen from the utility side act as perfectly balanced source currents and are free from distortion. The neutral current that may flow toward the transformer neutral point is effectively compensated such that the transformer neutral point is always at virtual zero potential. A suitable mathematical have been described which establishes the fact that in both the cases of with and without MC-UPQC along with PQ theory and without PQ theory the compensation is done for both PI and NEURO-FUZZY controllers but the response of NEURO-FUZZY controller with PQ theory THD is minimum for both the voltage and current which is evident from the plots and comparison Table 2. Proposed model for the MC-UPQC is to compensate input voltage harmonics and current harmonics caused by non-linear load, and to compensate the supply voltage and load current imperfections such as sags, swells, interruptions. Proposed MC-UPQC can be implemented using simple analog hardware, because it is having PLL and Hysteresis blocks.

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International Electrical Engineering Journal (IEEJ)
ISSN 2078-2365

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AUTHORS BIOGRAPHY

B.Rajani received B.Tech degree in Electrical &Electronics Engineering from
S.I.S.T.A.M college of Engineering, Srikakulam 2002 and M.E degree in Power
Systems and Automation from Andhra university,Visakhapatnam in the year
2008.she presently is working towards her Ph.D degree in S.V.University, Tirupathi.
Her areas of interest are in power systems operation &control and
power quality improvement.

Dr.P.Sangameswararaju received Ph.D from Sri Venkateswara
Univerisity, Tirupathi, Andhra Pradesh.
Presently he is working as professor in the
department of Electrical & Electronics Engineering, S.V. University.Tirupati, Andhra Pradesh .He has about 50
publications in National and International Journals and conferences to his credit.His
areas of interest are in power system operation &control and stability