Fuzzy Logic Controller Based Unified Power Quality Conditioner (UPQC) 
By Mitigation of Power Quality Problems

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Abstract: Wide spread application of power electronic based loads in industry has increased the importance and application of power quality studies. Sensitive power electronic equipment’s with nonlinear loads are broadly used in domestic, commercial and industrial applications causing for distortion in current and voltage waveforms. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems like voltage dips, voltage sags, voltage flickers, harmonics and load unbalance etc. At present, a wide range of use of flexible controllers, that capitalizes for available new power electronics components, which are emerging for tailored power applications. Power electronic devices based custom power devices can be used to mitigate these power quality problems. In this paper the power quality improvement is done by mitigating harmonics using the custom power devices like UPQC. UPQC consists of combination of series and shunt active filters. Series filter inject voltage which gets added at the point of common coupling and hence the voltage at the load end gets unchanged with the voltage disturbances. Shunt active filter compensates the load reactive power demand and hence mitigates the harmonics from supply current and also maintains the DC link voltage. This paper accentuates improvement of power quality by using Unified power quality conditioner with fuzzy logic controller device. The performance and behavior of the proposed controllers has been evaluated through Matlab/Simulink.

Keywords: Power Quality, Active Power Filter, Modeling of UPQC, Harmonics, Fuzzy Logic Controller.

I. INTRODUCTION

Power quality is very sensitive due to nonlinear loads, such as rectifier equipment, adjustable speed drives, domestic appliances and arc furnaces. These nonlinear loads draw non-sinusoidal currents from ac mains and cause a type of current and voltage distortion called as ‘harmonics’. These harmonics causes various problems in power systems and in consumer products such as equipment overheating, capacitor blowing, motor vibration, transformer over heating excessive neutral currents and low power factor [1-2]. Common Power quality problems are most of commercial, industrial and distributed networks. The most frequent cause of power quality problems are natural phenomena such as lighting, switching phenomena resulting in oscillatory transients in the electrical supply. Hence for all these reasons, from the consumer point of view, power quality issues will become an increasingly important factor to consider in order satisfying good productivity. To address the needs of energy consumers trying to improve productivity through the reduction of power quality [3-4] related process stoppages and energy suppliers trying to maximize operating profits while keeping customers satisfied with supply quality, innovative technology provides the key to cost-effective power quality enhancements solutions. However, with the various power quality solutions available, the obvious question for a consumer or utility facing a particular power quality problem is which equipment provides the better solution [5-7].

Previously the solutions to mitigate are as fixed compensation, resonance with the source impedance, very difficult in tuning the filter parameters, these are through conventional passive filters which have limitations to ignite the need of active and hybrid filters. This paper presents a fuzzy logic control based unified power quality conditioner to mitigate all the power quality problems and compares both results. Unified power quality conditioner is the combination of series and shunt active filter [8-10]. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Control schemes of UPQC based on fuzzy controller has been widely reported [11]. The PI control based techniques are simple in design and reasonably. However, the tuning of the PI controller is a tedious job. Further, the control of UPQC based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows [12]. In this work, the conventional PI controller has been replaced by a fuzzy logic controller. The fuzzy logic controller has been used in APFs in place of conventional PI controller for improving the dynamic performance [13]. The FC is basically nonlinear and adaptive in nature. The results obtained through FC are superior in the cases where the effects of parameter variation of controller are also taken
The proposed system has many advantages such as fast controllability, efficient design and reduced switching losses over conventional neutral clamped UPQC systems or four-leg shunt active filter UPQC systems [15-16]. MATLAB/Simulink is used to verify the results of the proposed system.

II. UPQC CONTROL STRATEGY

The detailed structure of UPQC is described in Fig.1. The UPQC comprises two voltage source inverters connected through a common dc link capacitor. The series inverter coupled to the line in series compensates for the voltage related problems such as voltage sag/swells, voltage flickers and voltage harmonics. The shunt inverter is treated as current source and is connected in shunt with the same AC line to mitigate problems related to current such as current harmonics, load reactive power and control of the dc link capacitor voltage. The DC link capacitor expedites the sharing of active power among the two inverters.

A. Control Of Series APF

A simple algorithm is used to control the series filter. The concept of unit vector template (UVT) as proposed in [4] is used as control strategy of series APF. The UVT is extracted from the distorted supply. The extraction process is shown in Fig.2. The objective is to make the voltage at the load terminal \( V_{La}, V_{Lb}, V_{Lc} \) perfectly balanced and sinusoidal with desired amplitude. In order to carry this out the series filter injects voltages opposite to the distortion and/or unbalance present in the source voltage and these voltages cancels each other resulting in a balanced and required magnitude voltage at the load side. The load reference voltage obtained by this control strategy is compared with the load voltage signals and the error is fed to a hysteresis controller which generates the required gating signal for the series inverter. This is shown in Fig.2. The hysteresis controller as described in [5] has been used. The hysteresis band controller decides the pattern of switching in the inverters. This operation of the hysteresis controller is dependent on the error signal generated on comparing the load reference voltage and the instantaneous load voltage signals.

B. Shunt Active Power Filter

Instantaneous reactive power theory, also known as p-q theory [3], is utilized to generate the reference signals for the shunt APF. Fig.3 describes the control strategy of the shunt APF. According to this theory the three phase voltages and currents are measured instantaneously and by the use of equation (1) and (2) are converted to \( \alpha-\beta-0 \) coordinates [3].

\[
\begin{align*}
    v_{\alpha} &= \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix} v_{\alpha} \\
    v_{\beta} &= \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix} v_{\beta} \\
    i_{\alpha} &= \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix} i_{\alpha} \\
    i_{\beta} &= \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{1}{2} & -\frac{1}{2} \end{bmatrix} i_{\beta}
\end{align*}
\]

Equation (3) shows the computation of the real power \( p_s \), imaginary power \( q_s \) and the zero sequence components drawn by the load. The real power and imaginary power are measured instantaneously. Equation (4) shows the presence of oscillating and average components in instantaneous power.

\[
\begin{align*}
    p_s &= p_{dc} + p_{ac} \\
    q_s &= q_{dc} + q_{ac}
\end{align*}
\]

Where \( p_{dc} = \) direct component of real power; \( p_{ac} = \) fluctuating component of real power; \( q_{dc} = \) direct component of imaginary power; \( q_{ac} = \) fluctuating component of imaginary power.

The total imaginary power \( q_s \) and the fluctuating component of real power are selected as power references and current references and are utilized through the use of equation (5) for compensating harmonic and reactive power. There will be no zero sequence power \( p_0 \) as the load is considered to be balanced.
Fuzzy Logic Controller Based Unified Power Quality Conditioner (UPQC) By Mitigation of Power Quality Problems

The signal $\bar{p}_{\text{loss}}$, is obtained from the voltage regulator and is utilized as average real power [6]. It can also be specified as the instantaneous active power which corresponds to the resistive loss and the switching loss of the UPQC [7]. The error obtained on comparing the actual DC-link capacitor voltage with the reference value is processed in proportional-integral controller (PI), engaged by the voltage control loop as it minimizes the steady state error of the voltage across the DC link to zero. The compensating currents ($i_{\text{com}}^* + i_{\text{com}^β}$) required to meet the power demand of load are shown in equation (5). These currents are represented in $α−β$ coordinates. Equation (6) is used to acquire the phase current ($i_{\text{com}}^* + i_{\text{com}^β}$) required for compensation. These phase currents are represented in a-b-c axis obtained from the compensating current in the $α−β$ coordinates.

$$\begin{align*}
\begin{bmatrix}
i_{\text{com}^α} \\
i_{\text{com}^β}
\end{bmatrix} &= \frac{1}{\sqrt{3}} \begin{bmatrix}
1 & \frac{1}{2} & -\frac{1}{2} \\
\frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix} \begin{bmatrix}
i_{\text{com}}^α \\
i_{\text{com}}^β
\end{bmatrix}
\end{align*}$$

(6)

Fig.3. Control block diagram of shunt APF.

The control strategy observed in Fig.3 using p-q theory is applicable for ideal 3-phase systems but is inappropriate for non-ideal mains voltage cases. Under non-ideal voltage circumstances, $(v_{\text{in},α}^2 + v_{\text{in},β}^2)$ is inconstant and current and voltage harmonics will be introduced in the instantaneous real and imaginary powers. As a result, compensation current equal to current harmonics will not be generated by shunt APF. To overcome these limitations, instantaneous reactive and active powers have to be calculated after mains voltages have been filtered. Voltage harmonic filter is used as shown in Fig.4. In this method instantaneous voltage is first transformed to d-q coordinates (Park transformation) as shown in equation (7).

$$\begin{align*}
\begin{bmatrix}
v_{\text{in},d} \\
v_{\text{in},q}
\end{bmatrix} &= \frac{1}{\sqrt{2}} \begin{bmatrix}
\sin(\omega t) & \sin(\omega t + \frac{2\pi}{3}) & \sin(\omega t + \frac{4\pi}{3}) \\
\cos(\omega t) & \cos(\omega t + \frac{2\pi}{3}) & \cos(\omega t + \frac{4\pi}{3})
\end{bmatrix} \begin{bmatrix}
v_{\text{in},α} \\
v_{\text{in},β}
\end{bmatrix}
\end{align*}$$

(7)

Fig.4. Voltage harmonic filtering block diagram.

The reference currents as computed by control algorithm are provided to the power system by controlling the switching action of inverter. The reference currents are compared with the instantaneous line currents. The result is fed to a hysteresis band PWM control which generates the switching pattern of the VSI. The basis of this hysteresis current controller depends on the error signals between the current injected and the reference current of the shunt APF.

III. FUZZY LOGIC CONTROLLER

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers. Furthermore, 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. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig.5. and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

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The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers as shown in Fig. 6.

**B. Fuzzy Logic Rules**

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table I as per below:

<table>
<thead>
<tr>
<th>(e)</th>
<th>NB</th>
<th>NS</th>
<th>ZO</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>(de)</td>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>PS</td>
<td>PS</td>
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<tr>
<td></td>
<td>NB</td>
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<td></td>
<td>PS</td>
<td>ZO</td>
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**IV. SIMULATION RESULTS**

Simulation results of this paper is as shown in bellow Figs. 10 to 24.

**Case 1: Voltage and current harmonic Compensation**

![Simulink model of UPQC](image-url)
Fuzzy Logic Controller Based Unified Power Quality Conditioner (UPQC) By Mitigation of Power Quality Problems

Fig. 11. (a) Source voltage (b) series injected voltage (c) Load voltage.

Fig. 12. (a) Source Voltage (b) Source Current (c) Load Current (d) D-Statcom Current.

Fig. 13. Power factor angle between Voltage and Current.

Fig. 14. Source Voltage THD.

Fig. 15. Load Voltage.

Fig. 16. Load current THD.

Fig. 17. Source current THD for PI Controller.

Case 2: Voltage Sag and Current Harmonic Compensation

Fig. 18. (a) Source Voltage (b) DVR Voltage (c) Load Voltage.
Fig. 19. (a) Source Voltage (b) Source Current (c) Load Current (d) D-Statcom Current.

Fig. 20. Power factor angle between Voltage and Current.

Case 3: Voltage Swell and Current Harmonic Compensation

Fig. 21. (a) Source Voltage (b) DVR Voltage (c) Load Voltage.

Fig. 22. (a) Source Voltage (b) Source Current (c) Load Current (d) D-Statcom Current.

Fig. 23. Power factor angle between Voltage and Current.

Fig. 24. Source Current THD for Fuzzy logic controller.

V. CONCLUSION

Unified power quality conditioner is made to mitigate all types of power quality disturbances like voltage sag and swells, voltage harmonics, voltage unbalance, current
Fuzzy Logic Controller Based Unified Power Quality Conditioner (UPQC) By Mitigation of Power Quality Problems

harmonics, reactive power problem and poor power factor. Unified Power Quality Conditioner (UPQC) is one of the promising power electronic circuit modules to overcome voltage sag and total harmonic distortion problems, as the circuit is modeled using both series-active and shunt-active power filters. Thus the benefits of both the power filters are integrated for better power quality mitigation is realized. This paper considers the advantages of the fuzzy logic and proposes a new control scheme for the Unified Power Quality Conditioner (UPQC) for minimizing the voltage sag and total harmonic distortion in the distribution system. The reference signal generated by the fuzzy logic controller was given as input to the UPQC switching module. The proposed fuzzy logic controller is better in improving the power quality by minimizing the voltage sag and total harmonic distortion when compared to the conventional PI controller. To enable this, a systematic approach for creating the fuzzy membership functions is carried out by using an ant colony optimization technique for optimal fuzzy logic control.

VI. REFERENCES