Power Quality Improvement using Nine Switch UPQC

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Abstract: *This paper aims to reduce the switching stress commutation, Switching losses with the help of nine switch unified power quality conditioner. Active power filters are mainly used for power quality improvement in the distribution system than the passive filter because of the drawbacks such as large size and the effect of source impedance on its performance. Active power filters can either be connected in series (series active filter) or in parallel (shunt active filter).*

This nine switch UPQC acts as two back to back converter as a shunt and series filter. The control scheme used for the nine switch converter has been done by pulse width modulation (PWM) technique. The performances were analyzed with the help of MATLAB/ SIMULINK environment for nonlinear loads.

The reduced switch count nine switch converter structure has been used to reduce 33% of the conventional converter. Therefore the nine switch conditioner is taken as a perfect topology since it would be completely used at both series and parallel sides without sacrificing its performance.

Keywords: *Nine Switch UPQC, Custom Power devices, Switching losses, MATLAB/SIMULINK*

1. INTRODUCTION

In today’s world there is great importance of electrical energy as most of the applications are massively relying on it. Many of the commercial and industrial loads require high quality undisturbed and stable power. Thus maintaining the qualitative power is very important in today’s world.

Due to power electronic devices there are serious effects on power quality like flicker, harmonics and voltage fluctuations etc. There also exist PQ problems such as voltage rise/dip due to network faults, lightning, switching of capacitor banks. With the excessive use of non-linear load (computer, lasers, printers, rectifiers) there are reactive power disturbances and harmonics in the power distribution system. It is very essential to overcome these types of problems as its effect may increase in future and cause adverse effects.

Traditionally passive filters were used for reactive power disturbances and harmonics generation but there are many problems with them like large size, resonance problem and effect of source impedance on performance. Active Power Filters, used for power quality enhancement are of two types, series and shunt. UPQC is formed by combining both series APF and shunt APF connected back to back on the DC side. Thus, UPQC eliminates the voltage and current distortions together.

The power electronic devices causes major power quality problems in the distribution system. But the loads driven by power electronic components require sinusoidal supply. To mitigate power quality issues, power quality mitigation equipments should be installed in the distribution side to overcome current/voltage harmonics, voltage sag/swell and voltage unbalances. A modern expertise in the application of power electronics makes comfort to the client or group of clients is referred as “custom power" devices. Conventional UPQC designed for single phase, three phase three wire and four wire configurations consist of two voltage source converters connected side by side with a common dc link capacitor. Each voltage source inverter consists of six switches. Thus totally twelve switches are present in conventional conditioner which increases the circuit complexity. In this paper nine switch converter structure with reduced switches has been proposed and the switch count has been reduced by 33% than the conventional converter.

Therefore the nine switch conditioner is taken as a perfect topology since it would be completely used at both series and parallel sides without sacrificing its performance.

A nine-switch power converter having two sets of output terminals was recently proposed in place of the traditional back-to-back power converter that uses twelve switches in total[1]. The nine-switch converter has already been proven to have certain advantages, in addition to its component saving topological feature. Despite these advantages, the nine-switch converter has so far found limited applications due to its many perceived performance tradeoffs like requiring an oversized dc-link capacitor, limited amplitude sharing, and constrained phase shift between its two sets of output terminals. Instead of accepting these tradeoffs as limitations, a nine-switch power conditioner is proposed here that virtually “converts” most of these topological short comings into interesting performance advantages. With an appropriately designed control scheme then incorporated, the nine-switch converter is shown to favorably raise the overall power quality in experiment, hence justifying its role as a power conditioner at a reduced semiconductor cost.

The UPQC model consists of thyristor controlled capacitor banks, series-active filter and shunt active filter. The series-active and shunt-active filters mainly compensate negative-sequence current and harmonics and the thyristor controlled capacitor banks is used to compensate the reactive power of power frequency[4]. With the increase of non-linear loads in electric power systems, power quality distortion has become a serious issue in recent years. Power quality problems have received a great attention nowadays because of their economic impacts on both utilities and customers. Unified power quality conditioner (UPQC) was designed, modeled and simulated by synchronous reference frame theory which can compensate the Voltage sags and swells[5].

This paper presents a novel nine-switch integrated power conditioner in place of conventional twelve switch converter i.e. back-to-back converter for improving the power quality. In a nine-switch power converter, the suitable carrier-based pulse-width modulation technology is introduced. The advantages of the proposed converter are reduction of components, commutation, switching losses, semiconductor cost etc. The novelty of this proposed scheme is like middle switch of the converter is shared by the inverter and rectifier, thereby reducing the switching is compared with traditional twelve switch back-to-back converter. The control scheme is also incorporated with nine switch converter, which is helpful for raising the power quality with minimization of voltage sag and voltage swell.

2. Proposed Topology

The nine-switch converter is formed by tying three semiconductor switches per phase, giving a total of nine for all three phases. The nine switches are powered by a common dc link, which can either be a micro source or a capacitor depending on the system requirements under consideration. Like most reduced component topologies, the nine-switch converter faces limitations imposed on its assumable switching states, unlike the fully decoupled back-to-back converter that uses 12 switches. Those allowable switching states can conveniently be found in Table 1, from which, it is clear that the nine-switch converter can only connect its two output terminals per phase to either Vdc or 0 V, or its upper terminal to the upper dc rail P and lower terminal to the lower dc rail N . The last combination of connecting its upper terminal to N and lower terminal to P is not realizable, hence constituting the first limitation faced by the nine-switch converter.

In this paper a right shunt UPQC (UPQC-R) is used. The dc link voltage can be supplied from a micro source or by a capacitor depending upon the system requirement. Figure 1 shows the nine switch converter.

In nine switch converter, two three phase output can be taken from the terminals A, B, C and R, Y, W. This converter is either operated in Fixed Frequency (FF) mode or in Variable Frequency (VF) mode. In this paper, Fixed Frequency mode has been used. The upper three switches and the middle three switches act as converter 1 whereas the middle three switches and the lower three switches act as converter 2. Thus intermediate three switches have been used for both shunt and series action. Though with reduced topologies, this nine switch converter has constraints on the switching states which means that the inverter output voltage should not be higher than that of converter output. These are the major constraints that should be taken into account in designing the switching signals. The per phase switching states is shown in Table 1.

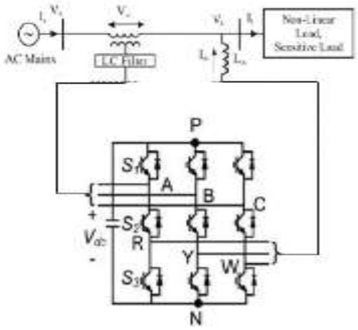

Figure 1 Nine switch UPQC

Table 1 Per phase switching states

Switching state	S1	S2	S3	V_{AN}	V_{RN}
I	close	close	open	Vdc	Vdc
II	open	close	close	0	0
III	close	open	close	Vdc	0

The output of the two converters can be controlled separately through the middle switch. In order to overcome the constraints the shunt reference signal should always be greater than the series reference signal shown in Figure 2.

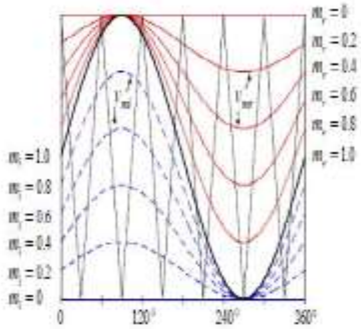

Figure 2 Modulating reference signal

Control scheme used in shunt APF is instantaneous reactive power theory which is also known as "p-q theory". It was introduced by Akagi et al in 1983. The instantaneous reactive power theory is based on time domain transformations, here abc phases are transformed into αβ0 coordinates. The coordinate 0 corresponds to a zero sequence component. "p-q theory" corresponds to an algebraic transformation which is known as Clarke's transformation. Advantages of "p-q theory" is it is simple as it only requires algebraic operations. It is applicable for steady state and transient state operation. In this theory abc phases are converted to $\alpha\beta 0$ are given below.

Clarke’s transformation is given as

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Inverse Clarke’s transformation is given as

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{pmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} * \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \qquad \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} * \begin{pmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} * \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}$$

For a three phase three wire system the neutral/ ground is neglected so there is no zero sequence component.
Clarke’s transform

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Inverse Clarke’s transform

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} \qquad \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

By Clarke’s transform we have converted the abc phase into $\alpha\beta0$ coordinates and by inverse Clarke’s transform $\alpha\beta0$ coordinates to abc phases. In this case the voltages are source voltage and currents are load currents. The equation below shows the separation of real power and imaginary power from apparent power

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} * \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Real/active power is (p) = $\bar{p}$ + p

Reactive/imaginary power (q) = $\bar{q}$ + q

Here the $\bar{p}$ denotes fundamental component of real power i.e direct component of instantaneous real power and $\tilde{p}$ denotes the alternating component of real power. And $\bar{q}$ denotes the fundamental i.e. direct component of instantaneous imaginary power and $\tilde{q}$ denotes the alternating component of imaginary power. The direct components have the fundamental component of voltages and current & alternating components contain harmonic contents of voltage and current. In Shunt APF compensation of reactive power is done and harmonic contents of real power are removed. There is no zero sequence power as it is a three phase three wire system.

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \bar{p}_{loss} \\ \bar{q} \end{bmatrix}$$

A $p\overline{loss}$ is calculated by using DC capacitor, a certain reference voltage is kept for capacitor this reference capacitor voltage is compared with actual DC voltage across capacitor and is given to PI controller for calculation of $p\overline{loss}$. The gain of the PI controller is chosen appropriately to minimize steady state error.

The above equation is reference compensation current in $\alpha{-}\beta$ coordinates it is converted in reference compensation current in a-b-c axis by inverse Clarke's transformation given below.

$$\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix}$$

The power loss across the DC capacitor is found with the help of the PI controller. Power which is to be compensated is the harmonic component of real power and whole imaginary power. Then after this current is calculated in $\alpha{-}\beta$ coordinates. These currents in $\alpha{-}\beta$ coordinates are transformed into $a{-}b{-}c$ axis by inverse Clarke's transformation. This is the reference compensating current. It is given to hysteresis current controller along with shunt APF actual output current. In current calculation low pass filter is used to remove higher order harmonics of power

Hysteresis controller is used as it is simple, it has fast transient response, it enhances stability, & has good accuracy. Hysteresis current controller is used for producing switching signals by comparing the error present in the current in a fixed tolerance band. Here comparison is done between the actual current & reference current within a fixed tolerance band. It is different for different phases. Hysteresis current controller is used to compare current so as to generate switching signals for Shunt APF. Here the reference current $ic*$ is compared with actual current ic of shunt APF within a given hysteresis band. A hysteresis band is a boundary of actual current.

When $ica<(ica*-HB2)$ then the upper switch is ON and lower switch is OFF and the current is allowed to decay in phase a it is similar for phase $b\&c$. When $ica>(ica*+HB2)$ then upper switch is OFF and lower switch is ON.

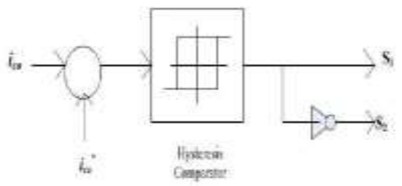

Figure 3 Hysteresis current controller

3. Simulation & Results

3.1 SIMULINK Model:

The nine switch UPQC is simulated using MATLAB/SIMULINK. The SIMULINK model is as shown in Figure 4.

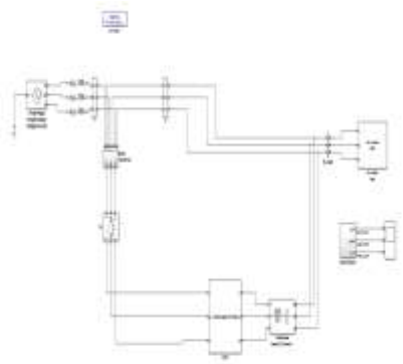

Figure 4 SIMULINK Model of Nine Switch UPQC

3.2 Results:

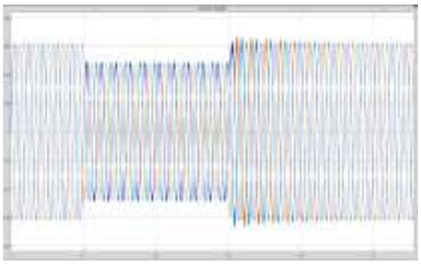

Figure 5 Load Voltage with Voltage Sag

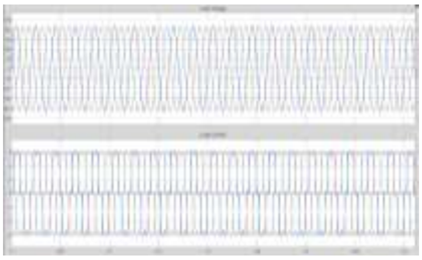

Figure 6 Load Voltage and Load Current after Sag compensation

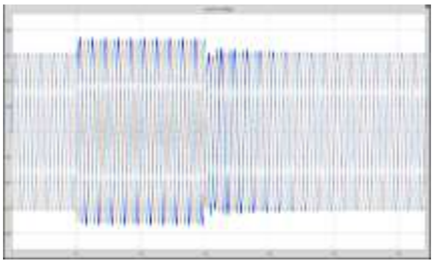

Figure 7 Load Voltage with Voltage Swell

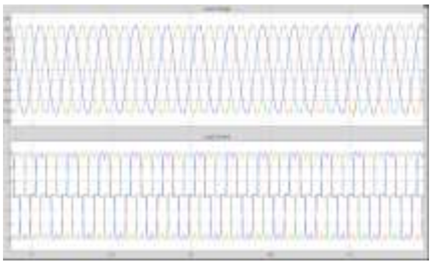

Figure 8 Load Voltage and Current after Swell Compensation

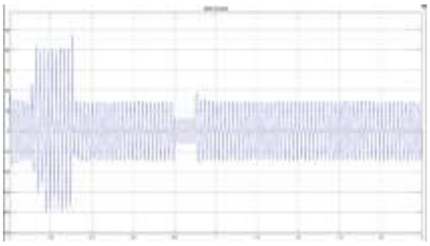

Figure 9 Source Current with Harmonics

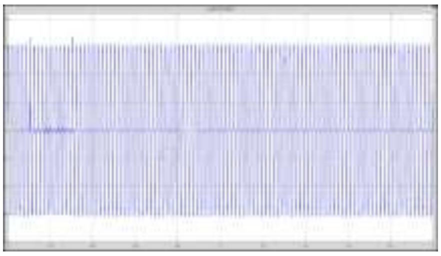

Figure 10 Load Current

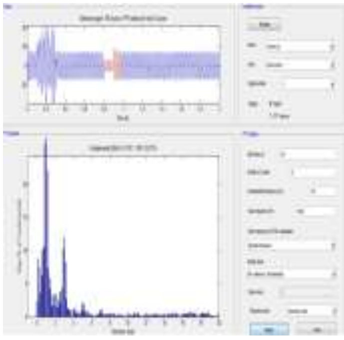

Figure 11 FFT Analysis of Source Current

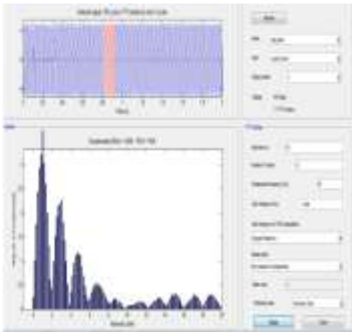

Figure 12 FFT Analysis of Load Current

4. Conclusion

Unified Power Quality conditioner using nine switches has been studied and it is proved that the nine switch power quality conditioner is well suited to perform shunt and series action than the conventional 12 switch converter. The newly proposed nine switch converter, with a better understanding developed, the conclusion drawn is that the nine switch converter is not an attractive alternative for replacing back-to-back converters with two shunt bridges.

Instead, the nine-switch converter is more suitable for replacing back-to-back converters in “series–shunt” systems, where one good example is the UPQC. As a further performance booster, a modified 120° discontinuous modulation scheme is presented for reducing the overall commutation count by 33%. The simulation done using MATLAB Simulink environment validates its performance and Voltage sag, Voltage swell and Current Harmonics are mitigated using nine switch power conditioner.

5. References

5.1 Journal Articles

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