A 3P4SW Based UPQC to Improve Power Quality in Medium Voltage Distribution System

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Abstract. The adverse effect of power quality issues on power distribution system due to power electronics based controllers has tremendously increased in the modern power system; therefore, it is highly desired to design a novel power quality conditioner with a minimum number of switches to compensate voltage and current distortions. This proposed configuration reduces switching losses and also effectively alleviates the performance of the power quality conditioner. This paper introduces a configuration of 3P4SW (Three Phase Four Switch) UPQC (Unified Power Quality Conditioner) for both shunt and series APF (Active Power Filter) which can be implemented in medium voltage power grid. The major challenge of phase balance with only four switches in UPQC is accomplished by adaptive Self-tuning PID using neuro-fuzzy logic control and adaptive reference current generation scheme. This controller improves sag and swells compensation with better angle control via shunt and series converter performance and passive components design. The efficacy of proposed topology is tested on MATLAB/Simulink software and results are compared with the existing three phase six switch configuration (3P6SW).

1. Introduction
There are many configurations of UPQC of which a three phase four wire topology effectively compensates power factor and voltage distortions. The damping algorithms generates the reference voltages and currents by the both series and shunt converters [1]. The various control algorithms are studied to generate the reference signals for the shunt and series inverters to compensate the voltage or current unbalances [2][3]. The fuzzy based control algorithms eliminates voltage and current harmonics more precisely and also the Total Harmonic Distortion (THD) would be less than 1% compared to conventional control algorithms. The cost of the controller can be greatly reduced by reducing the number of the switches without compromising the performance of the power quality conditioner. In addition to this, design of passive components enhances the performance of the controller [4]. The addition of a capacitor, in series with a parallel active filter reduces the DC-link voltage, due to which a lower rating UPQC can be used for the power quality mitigation. The multilevel converter based UPQC provides sufficient sub-modules to utilize it for low and medium voltage applications. It effectively balances the intra-arm voltages at the multi-converter sub-modules [5]. The improvement of power quality problem in medium voltage power grid is obtained using a multi converter[6] based UPQC, this leads to use of low rating power electronics devices to medium voltage distribution systems. If the filter parameters are carefully designed, then the UPQC can compensate the load with higher efficiency at a low DC-link voltage [7]. The synchronous reference frame theory gives better results for compensating three-phase network [8].
2. Mathematical Model of UPQC

Fig. 1 shows the schematic of a UPQC, the main objective is to maintain the magnitude of the voltage and the waveform to be sinusoidal at the distribution system[9]. In this section, the selection of various parameters of the UPQC is discussed. The voltage on the VSI to be maintained as double the peak phase voltage.

\[ V_{dc} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \]  

(1)

Where, VLL – grid line voltage and m – modulation index.

The rating of the switch can be defined as

\[ V_{SW} = V_{dc} + V_{d} \]  

(2)

\[ I_{SW} = 1.25*I_{crpp} + I_{peak} \]  

(3)

Where Icrpp is the ripple current of 10%.

The value of DC-link capacitance is calculated by the following expression,

\[ C_{dc} = \frac{P_{dc}/V_{dc}}{2\omega V_{dcr}} \]  

(4)

3. Proposed 3P4SW UPQC System

The medium voltage distributed system incorporates the 3P4SW topology to efficiently absorb the maximum power from the photovoltaic cell to maintain the DC-link voltage for VSI and this is obtained by self-tuning fuzzy based PID controller [1]. Whereas the SAPF is regulated by the park transformation reference current generation[10]. The SPAF is to minimize the voltage unbalances such as sag and swell, the PAPF is to compensate the current harmonics[11].

Figure 1. The schematic Equivalent circuit of UPQC.

Figure 2. Block diagram of proposed 3P4SW UPQC.
3.1. An Overview of Self Tuning PID Control

The four switch three-phase configuration is implemented to compensate and also to enhance source and load side power quality problems. To minimize the switching losses and to improve the efficiency of the grid system a four switch configuration is introduced. The major drawback in the proposed topology is that the phase balancing problem. However, this is overcome by self-tuning fuzzy based PID controller.

The proposed PID controller is implemented at the DC-link capacitor to balance the power and to regulate the voltage unbalances and the harmonics. In the given system the PWM is compared against the space vector modulation. SVPWM (Space Vector Pulse Width Modulation) technique reduces the total harmonic distortion and also it reduces the switching losses. This is more suitable for unbalanced voltage condition.

The reference vector generated by the following formula,

\[ V_{\text{ref}} = \sqrt{V_d^2 + V_q^2} \]  

(5)

3.2. Switching Control Algorithm of VSI

The switching algorithm mainly focuses on generating the gating pulses. The synchronous reference frame theory is implemented to generate the reference current signals [10].

![Figure 3. SRF based reference current generation.](image)

The three-phase source currents are denoted as \(i_a, i_b, i_c\) and these are compared with the load currents \(i_a, i_b, i_c\). The difference is generated as reference current signals for the shunt active filter are following as \(i_{a, r}, i_{b, r}, i_{c, r}\). These unit current vectors are utilized to compensate the harmonics. Similarly, the source voltages are represented as \(v_a, v_b, v_c\) and are compared with the load voltages \(v_{la}, v_{lb}, v_{lc}\). The resultant series unit vectors \(v_{sra}, v_{srb}, v_{src}\) are represents the voltage to be injected into the line to compensate voltage sag and voltage swell with respect to the series active power filter.

4. Simulation Results

A 13KW Permanent Magnet Synchronous grid connected Generator is used as a three-phase supply for the proposed medium voltage distribution system. By inducing fault on the given system the voltage quality issues such as sag and swell being created. A 10-20% of the supply voltage is considered to simulate sag and swell. The power is extracted and being injected into the line during a swell and the sag.
Figure 4. Simulink circuit model of (a) proposed 3P4SW UPQC controller and (b) conventional 3P6SW UPQC controller.

The MATLAB simulation carried out on the proposed 3P4SW controller and 3P6SW UPQC. The results are compared on both the topologies under balanced and unbalanced conditions.

4.1. Voltage Sag under balanced condition
The three-phase fault is induced at the source side to obtain voltage sag and it is effectively analyzed for both 3P4SW AND 3P6SW UPQC configurations. From the waveform, it is observed that the amplitude of supply voltage is decreased by about 25% from its nominal voltage. By implementing the
UPQC based algorithm, the voltage sag is compensated and their performance is described. The injected source voltages are illustrated in fig. 5 (b).

![Source Voltage](image1)

![Compensated Source Voltage](image2)

![DC-link Capacitor Voltage](image3)

**Figure 5.** Analysis of (a) source voltage and (b) compensated source voltage (c) DC-link capacitor voltage for proposed 3P4SW topology.

![THD Analysis](image4)

![THD Analysis](image5)

**Figure 6.** THD analysis of (a) Balanced and (b) unbalanced condition of the proposed method.
Figure 7. Analysis of (a) source voltage and (b) compensated source voltage (c) THD analysis of Balanced and (d) unbalanced condition of 3P6SW UPQC.
From the results, it is observed that the load voltage is kept at the nominal by means of a 3P4SW based UPQC. When it is compared with the 3P6SW module, the voltage sag is compensated more effectively by the proposed method.

Figure 8. Analysis of (a) source voltage and (b) DC-link capacitor voltage for proposed 3P4SW topology

Figure 9. THD analysis of (c) Balanced and (d) unbalanced condition of 3P4SW UPQC
Figure 10. Swell analysis of (a) source voltage and (b) compensated source voltage (c) THD analysis of (c) Balanced and (d) unbalanced condition of 3P6SW UPQC.
5. %THD Comparative analysis
The effectiveness of the proposed topology is compared with the conventional 3P6SW UPQC in medium voltage power grid in terms of Total Harmonic Distortion (THD). The following table presents the analysis of mitigation of voltage sag and swells under the balanced and unbalanced condition of source voltage against the conventional three-phase six switch configuration.

| S.NO | Six Switch Three Phase UPQC | Four Switch Three Phase UPQC |
|------|----------------------------|-----------------------------|
|      | Balanced                   | Balanced Unbalanced         |
| 1    | 3.71                       | 4.45                        |
|      | Balanced                   | Balanced Unbalanced         |
| 1    | 3.81                       | 7.05                        |

6. Conclusion
The main objective of this paper is to propose a UPQC configuration which results with an optimum number of switching devices and hence reduced switching losses compared to conventional UPQC topology. Moreover, the suggested topology should not compromise only with the nominal functions of the controller but also fulfill the economic constraints such as the cost of the converter and the presence of active elements. The control pulses for the proposed 3P4SW UPQC is generated using Space Vector Pulse Width Modulation (SVPWM) to diminish the power quality problems such as voltage sag and swell. The comparative analysis of optimized controller with the conventional UPQC is presented based on SVPWM technique and self-tuned fuzzy based PID controller. The simulations are carried out for both balanced and unbalanced condition. Also, the THD percentage is maintained well within the IEEE standard with a lesser number of control switches. Thus, the proposed system can be implemented for medium voltage distributed system with improved power quality.

7. References
[1] A.K. Dr. A.H.Bhat Shubhendra Pratap Singh 2016 J. Electr. Eng., Performance Evaluation of Fuzzy Logic Controlled Voltage Source Inverter Based Unified Power Quality Conditioner for Mitigation of Voltage and Current Harmonics vol 14(20) p 207–212.
[2] L. F. C. Monteiro J. G. Pinto J. L Afonso M.D. Bellar. A 2012 Proc.Intl. Conf. on IEEE Industrial Electronics Society Three-Phase Four-Wire Unified Power Quality Conditioner Without Series Transformers p 168–173.
[3] A. Teke L. Saribulut and M. Tumay. A 2011 IEEE Trans. Power Delivery Novel reference signal generation method for power-quality improvement of unified power-quality conditioner vol26(4) p 2205–2214.
[4] Q. N. Trinh and H. H. Lee 2014 Proc.Intl. Conf. on Symp. Ind. Electron A low-cost high-performance UPQC for current and voltage harmonics compensations p 341–346.
[5] P. Converters B. B. Ambati and V. Khadkikar. 2014 IEEE Trans. Power Delivery Optimal Sizing of UPQC Considering VA Loading and Maximum Utilization of power Electronic converters vol 29(3) p 1490–1498.
[6] Q. Xu, F. Ma A. Luo, Z. He and H. Xiao 2016 IEEE Trans. Power Electronics Analysis and Control of M3C based UPQC for Power Quality Improvement in Medium/High Voltage Power Grid vol 99(3) p1-6.
[7] B. Karanki N. Geddada M. K. Mishra and B. K. Kumar. 2013 IEEE Trans. Ind. Electron A modified three-phase four-wire UPQC topology with reduced DC-link voltage rating vol 60(9) p 3555–3566.

[8] A. Chebabhi M. K. Fellah A. Kessal and M. F. Benkhoris. 2015 Proc. Intl. Conf. ICCE. on Power quality improvement using a Three Dimensional Space Vector Modulation with SRF theory for three levels neutral point clamped four leg shunt active power filter controlling in dq0 axes

[9] F. Mekri M. Machmoum N. a. Ahmed and B. Mazari 2008 Proc. Intl. Conf. on 34th Annu. Conf. IEEE Ind. Electron A fuzzy hysteresis voltage and current control of a Unified Power Quality Conditioner p 2684–2689.

[10] A. Pigazo V. M. Moreno and E. J. Estébanez. 2009 J. IEEE Trans. Power Electronics A recursive park transformation to improve the performance of synchronous reference frame controllers in shunt active power filters vol 24(9) p 2065–2075.

[11] Y. Zhao Y. Ren M. Zho, and G. Li 2012 IEEE Trans. Power Electron Design and Simulation of Multiple Terminal Unified Power Quality Conditioner vol12(3)p 6-12.