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STATCOM Enabled Modified iUPQC Controller

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Abstract - This paper presents a modified controller for the dual topology of the unified power quality conditioner which helps to bring down the equipment cost. The modified controller is a simplified version of an advanced controller which provides additional functionality such as reactive power compensation at the grid side by providing voltage regulation at the source in addition to the side voltage regulation. The modifications help in providing improvement in smart grid applications and power quality conditioning. A MATLAB simulation is performed to verify its performance.

Key Words: Active filter, Dual topology, Grid-voltage regulation, Power quality conditioner, UPQC.

1. INTRODUCTION

It can be concluded from the vast array of experimental observation and theoretical analysis that, Power Electronic devices have improved the utility and control of Electrical equipments. However, their proliferation has brought in a plethora of Power Quality issues hitherto non-existent. Quite paradoxically, as much as it generates Power Quality disturbances and anomalous harmonic levels, these power electronic devices require superior quality sinusoidal supply voltage to work efficiently. Over the years, researches and studies have developed systems and equipments to combat the impediments of the present Power System scenario. Of the several equipments there are for countering the aforementioned issues, here in this attempt emphasis is placed on bringing in Reactive power compensation at the Grid side, employing Static synchronous Compensator (STATCOM) functionality and Voltage regulation at the load side employing a Unified Power Quality Conditioner (UPQC).

Addition of STATCOM functionality to all the power quality compensation features of a conventional UPQC or an iUPQC, provides new solutions in future scenarios involving smart grids and micro grids, including distributed generation and energy storage systems to better deal with inherent variability of renewable resources such as solar and wind power. Further it reiterates that the cost and expensive nature of conventional UPQC systems can be better justified by the added capability of including STATCOM functionality. This system promotes the utilization and applicability of iUPQC in combating power quality issues of critical systems where the necessity is not exclusively of iUPQC or of a STATCOM, but both, simultaneously. Despite addition of one more power quality compensation feature, the grid-voltage regulation reduces the inner-loop circulating power in iUPQC, allowing lower power rating for series converter. Firstly the major advantages of iUPQC are the sinusoidal currents and voltages references synthesized by the series and shunt compensators respectively. This reduces the switching losses and simplifies the control development. The iUPQC and the UPQC power flow behavior are the same for each power quality issues. Consequently, it was verified that an internal power flow occurs when a sag/swell is present in the voltage source. The theoretical dynamic analysis shows that, the iUPQC has better dynamic performance than the UPQC. The iUPQC avoids disturbances that directly affect the system, through natural mitigation.

2. DEVICE CONFIGURATION

Although several independent equipments exist with the objective of improving the power quality, it is however observed that an improvement in Unified Power Quality Conditioner as an interline UPQC or iUPQC adds two distinctive features which are to be explored within this section.
The primary feature that iUPQC adds is, the dual topology or configuration and the latter being a derivative of the primary feature e which incorporates natural mitigation of current harmonics. Their comparative study is presented herein.

2.1 UPQC CONFIGURATION

The conventional method of improving power quality was by using the active and passive Power filters. UPQC comes under active power filter family. Shunt APF mitigates any current related power quality issues while the series APF mitigates any voltage related power quality issue. Thereafter several research works has been done in this field to introduce newer technologies and devices to mitigate power quality issues more accurately. UPQC is a combination of the shunt and series APFs used for the mitigation of all current as well as voltage related power quality issues. Traditionally, shunt converter of the UPQC behaves as a controlled current source that compensates the load current. Likewise, the series active filter behaves as a controlled voltage source to compensate the voltage imperfections as shown in Fig. 1. Hence the power that reaches the load is balanced and distortion free, which means under any non linear load current or any distorted mains voltage conditions, the UPQC eliminates the effect of distortion and unbalances of the supply at the load terminal.

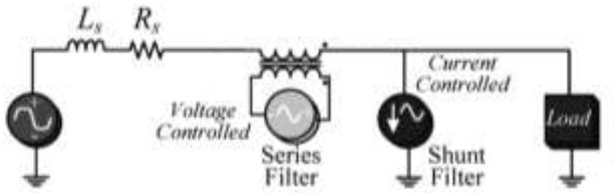

Fig -1: UPQC Configuration

2.2 *The interline UPQC Configuration*

In traditional UPQC configuration, the series active filter synthesizes three phase voltage compensation and shunt active filter synthesizes three phase current compensation. Thus a drawback of this is the requirement of high frequency switching required for the production of compensation reference signal. In iUPQC as shown by Fig. 2 follows a dual topology approach, where the series power conditioner synthesizes a three-phase current compensation and the shunt power conditioner synthesizes a three-phase voltage compensation. By the Kirchhoff's laws, the load current and the source voltage disturbances (that must be compensated) will naturally be directed to the shunt and series converters, respectively. It is important to highlight that the iUPQC and the UPQC hardware configurations are the same, with a back-to-back power converter used to work as the series and shunt power conditioners. In order to obtain sinusoidal load bus voltage (V_L) and source current (I_S), the main controller has to generate the references based on the fundamental positive-sequence component of the voltage source bus and the average power demanded by the load. Furthermore, the PWM controller has to guarantee that the fundamental positive sequence component of the series current and shunt voltage synthesized are equal to the output references of the main controller. In this way, this paper proposes a new PWM controller that uses d-q reference frame and proportional-integral (PI) technique. There are several advantages for the iUPQC over the conventional UPQC.

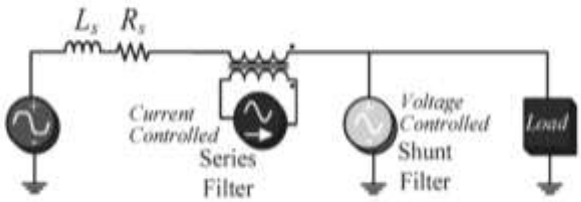

Fig -2: iUPQC Configuration

That is, using the fundamental positive sequence components of the current and voltage references for the series and shunt compensators, while in conventional UPQC, the non-sinusoidal compensating voltages and currents are used.

3. MODIFIED iUPQC CONTROLLER

The improved iUPQC controller as shown in Fig. 3 provides additional grid voltage regulation as STATCOM at the grid side. This functionality is provided by incorporating a $Q_{STATCOM}$ component in the controller. The controller calculations are based on the Park's transformation (dq0) transformation. With the Park's transformation, the direct axis and quadrature axis component of both the voltage and current are obtained. The direct and quadrature axis component of voltage is directly given as the voltage reference for the shunt active filter. . The current reference for the series active filter is based on quantities such as reactive power requirement at source, the average active power requirement at the load and the power loss in the unified power quality conditioner.

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3.1 THE MAIN CONTROLLER

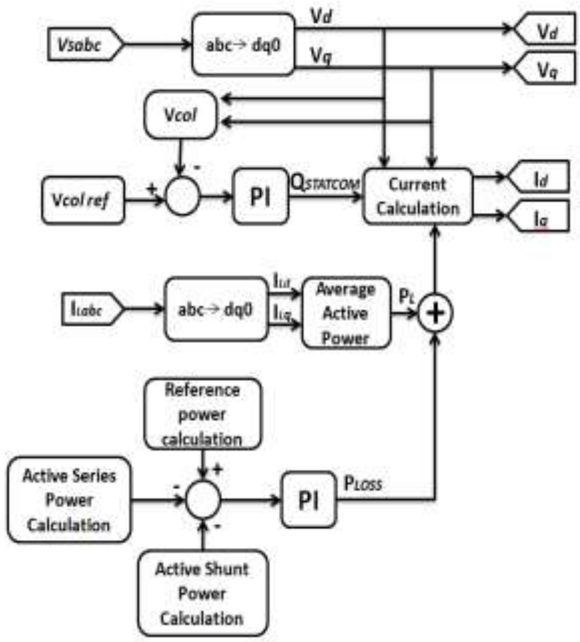

Fig -3: iUPQC Controller

The controller inputs are the voltages at buses A and B, the current demanded by bus B (IL), and the voltage Vdc of the common dc link. The outputs are the shunt voltage reference and the series current reference to the pulse width modulation (PWM) controllers.

First, the simplified Park's transformation is applied to the measured variables. As example of this transformation, the grid voltage in the -reference frame can be calculated as,

$$\begin{bmatrix} d \\ q \\ 0 \end{bmatrix} = 2/3 \begin{bmatrix} sin(\theta) & sin(\theta - 2\pi/3) & sin(\theta + 2\pi/3) \\ cos(\theta) & cos(\theta - 2\pi/3) & cos(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

The series converter synthesizes the current drawn from the grid bus (bus A). In the original approach of iUPQC, this current is calculated through the average active power required by the loads P_L plus the power P_{Loss}. The load active power can be estimated by:

$$P_L = V_d * I_d + V_q * I_q$$

Where I_d, I_q are the load currents, and V_d, V_q are the voltage references for the shunt converter. A low-pass filter is used to obtain the average active power (PL). P_{Loss} is determined by a proportional integral (PI) controller by comparing energy drawn from the shunt and series active filter and with the energy stored in the capacitor.

$$P_{Loss} = (V_c * I_s + V_s * I_c) - (V_{dc} * I_{dc})$$

The additional control loop to provide voltage regulation like a STATCOM at the grid bus is represented by the control signal $Q_{STATCOM}$. This control signal is obtained through a PI controller, in which the input variable is the error between the reference value and the actual aggregate voltage of the grid bus, given by,

$$V_{col} = \sqrt{(V_d^2 + V_q^2)}$$

The sum of the power signals P_L and P_{Loss} composes the active-power control variable for the series converter of the iUPQC. Likewise, $Q_{STATCOM}$ is the reactive power control variable. Thus, the current references I_d and I_q of the series converter are determined by,

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = 1/ V_d^2 + V_q^2 \begin{bmatrix} V_d & V_q \\ V_q & -V_d \end{bmatrix} * \begin{bmatrix} P_l + P_{loss} \\ Q_{statcom} \end{bmatrix}$$

3. THE SIMULATION MODEL

Fig. 5 shows the simulink model of a modified iUPQC system. The system defines a series and parallel path for current and voltage compensation respectively. Apart from the conventional iUPQC, the topology of the system is changed so as to provide a low impedance path through the shunt connection for current harmonic compensation. This introduces an additional functionality to the normal UPQC as it improves the power quality to a better standard. A back to back converter is provided as the heart of the system. The converter segments are interconnected via a DC link of sufficient value. The DC link acts as a source for providing the additional energy for mitigating wave form distortion. The DC link is designed using a capacitor of sufficient rating and a resistor in series to it.

Table -1: iUPQC simulation parameters

Parameters	Specifications
Voltage	220V
Grid frequency	50 Hz
DC link voltage	450V
DC link capacitance	94 Farad
Shunt convertor passive filter	L=90mH, R=37 K ohm, C=460 mF
Series convertor passive filter	L=20 mH, C= 700mF
Switching Frequency	9720 Hz
Sampling Frequency	19440 Hz
PI controller	Kp=4, ki= 250

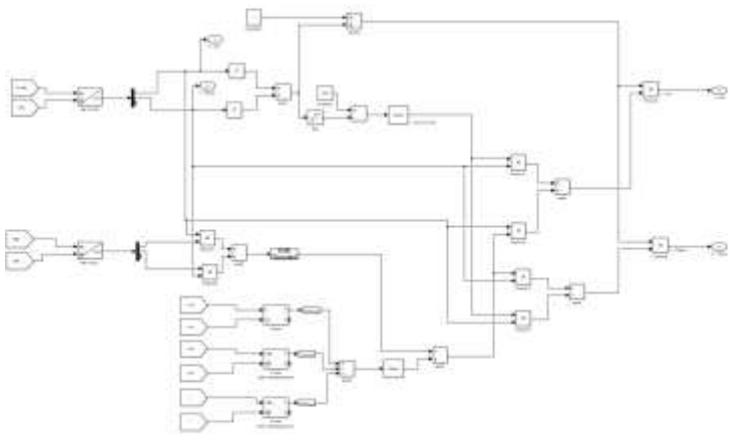

Fig -4: Simulation Model of modified iUPQC controller

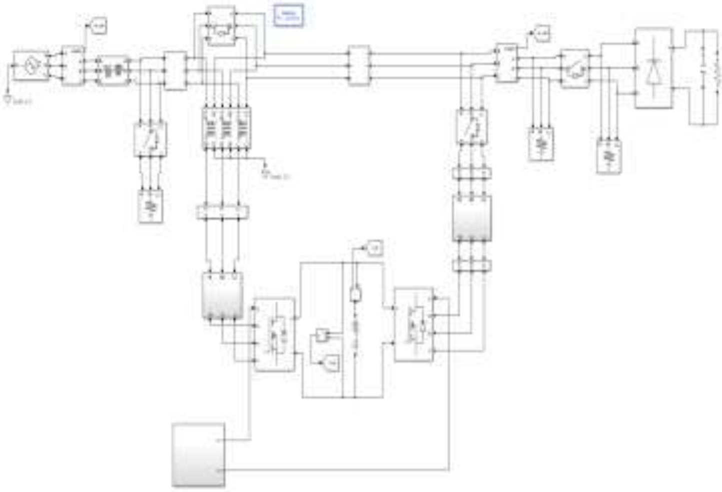

Fig -5: Simulation Model of Modified iUPQC

4. OUTPUT WAVEFORMS

In the simulation, initially the iUPQC is disconnected from the system. At t=0.25s, a voltage sag and non-linear load is introduced at the load side of the system which is seen in the voltage waveform. At t=0.5s, the iUPQC is connected back to the system. As seen in the waveform, the sag has been compensated and the load voltage brought back to the nominal value.

As shown in figure 7, the grid side regulation is also achieved by using reactive power injection in the series active filter, thus obtaining the STATCOM functionality as discussed. Figure 8 shows the load side compensation of iUPQC. Therefore, the grid side as well as load side voltage compensation is obtained. Similarly the load current and source current is shown in fig. 9 and 10 respectively. It is seen that the sag causes a rise in the voltage. When the iUPQC is inactive, the current drawn from the source is highly distorted due to harmonics. When the iUPQC is activated, the source current is sinusoidal without any harmonic content is observed. Hence the source current is regulated as well as the load voltage.

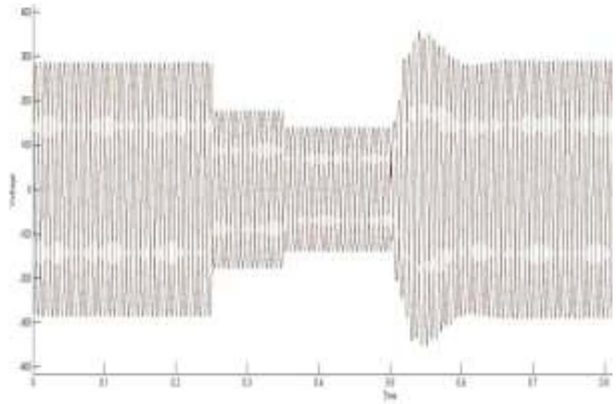

Fig -6: Grid voltage regulation with improved iUPQC

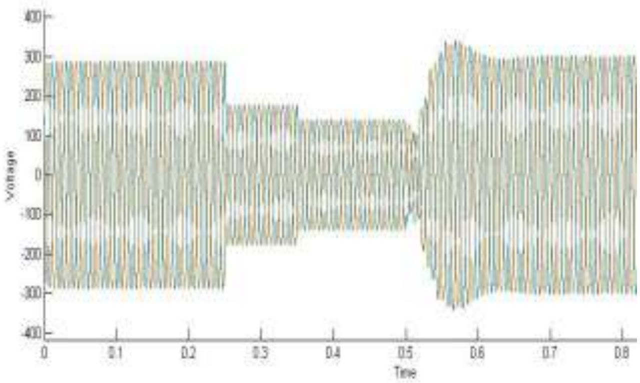

Fig -7: Load voltage regulation with improved iUPQC

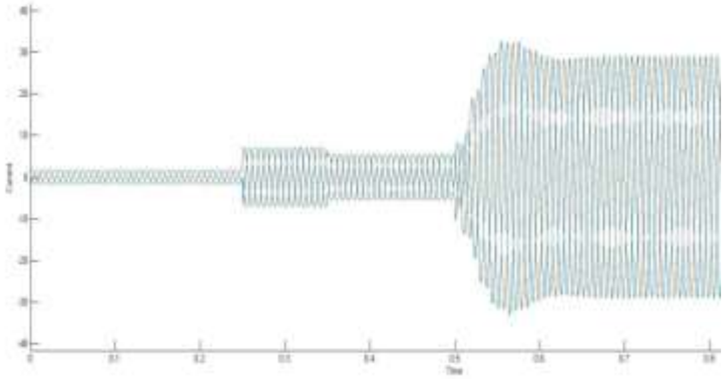

Fig -8: Source Current

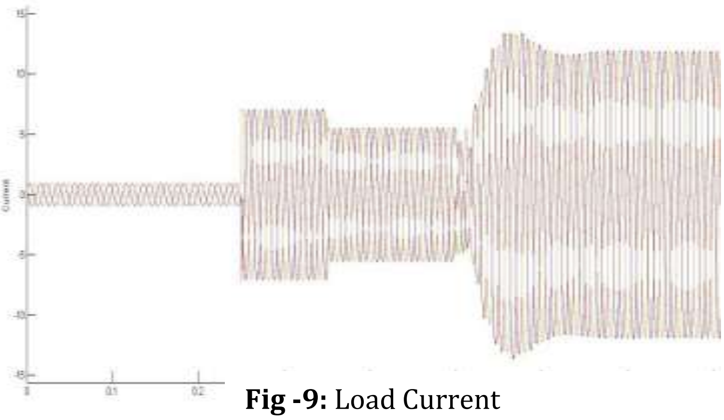

Fig -9: Load Current

5. CONCLUSION

The improved iUPQC controller design introduces both grid side and load side voltage regulation at a lower budget. Besides the monetary benefits, it also introduces a simpler controller design with fewer number of components compared to its older counter-part. In addition to these distinctive features, it also introduces improvement in the power quality of the system, thereby providing better utilization of the apparent power. Current harmonic mitigation is also achieved at the source side using the improved iUPQC controller, providing better quality of the power delivered.

The unique features in the controller design puts forth varied opportunities for iUPQC in the modern field including micro grids, distributed energy systems and renewable energy systems. As the need for iUPQC systems become more persistent with the highly rising energy demand with superior power quality requirement, the improved controller offers a better alternative to its older version in both technical and monetary basis.

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