An improved grid-voltage regulation as a statcom by using iUPQC

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ABSTRACT: This paper presents a simplified control technique for a dual three-phase topology of a unified power quality conditioner—iUPQC. The iUPQC is composed of two active filters, a series active filter and a shunt active filter (parallel active filter), used to eliminate harmonics and unbalances.. By using this controller, beyond the conventional UPQC power quality features, including voltage sag/swell compensation, the iUPQC will also provide reactive power support to regulate not only the load-bus voltage but also the voltage at the grid-side bus. In other words, the iUPQC will work as a static synchronous compensator (STATCOM) at the grid side, while providing also the conventional UPQC compensations at the load or microgrid side.

Index Terms—iUPQC, microgrids, power quality, static synchronous compensator (STATCOM), unified power quality conditioner (UPQC).

I. INTRODUCTION

Certainly, power-electronics devices have brought about great technological improvements. However, the increasing number of power-electronics-driven loads used generally in the industry has brought about uncommon power quality problems. In contrast, power-electronics-driven loads generally require ideal sinusoidal supply voltage in order to function properly, whereas they are the most responsible ones for abnormal harmonic currents level in the distribution system. In this scenario, devices that can mitigate these drawbacks have been developed over the years. Some of the solutions involve a flexible compensator, known as the unified power quality conditioner (UPQC) and the static synchronous compensator (STATCOM).

The power circuit of a UPQC consists of a combination of a shunt active filter and a series active filter connected in a back-to-back configuration. This combination allows the simultaneous compensation of the load current and the supply voltage, so that the compensated current drawn from the grid and the compensated supply voltage delivered to the load are kept balanced and sinusoidal. The dual topology of the UPQC, i.e., the IUPQC, was presented in the shunt active filter behaves as an ac-voltage source and the series one as an ac-current source, both at the fundamental frequency. This is a key point to better design the control gains, as well as to optimize the LCL filter of the power converters, which allows improving significantly the overall performance of the compensator.

The STATCOM has been used widely in transmission networks to regulate the voltage by means of dynamic reactive power compensation. Nowadays, the STATCOM is largely used for voltage regulation, whereas the UPQC and the IUPQC have been selected as solution for more specific applications. Moreover, these last ones are used only in particular cases, where their relatively high costs are justified by the power quality improvement it can provide, which would be unfeasible by using conventional solutions. By joining the extra functionality like a STATCOM in the IUPQC device, a wider scenario of applications can be reached, particularly in case of distributed generation in smart grids and as the coupling device in grid-tied micro grids. In the performance of the IUPQC and the UPQC was

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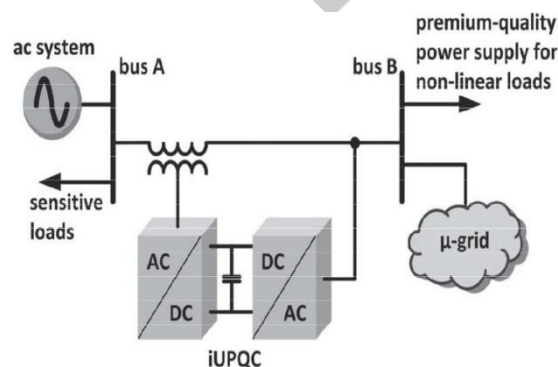
The provision of both DSTATCOM and DVR can control the power quality of the source current and the load bus voltage. In addition, if the DVR and STATCOM are connected on the DC side, the DC bus voltage can be regulated by the shunt connected DSTATCOM while the DVR supplies the required energy to the load in case of the transient disturbances in source voltage. The configuration of such a device (termed as Unified Power Quality Conditioner (UPQC)) is shown in Fig.2.1-2.2. This is a versatile device similar to a UPFC. However, the control objectives of a UPQC are quite different from that of a UPFC.
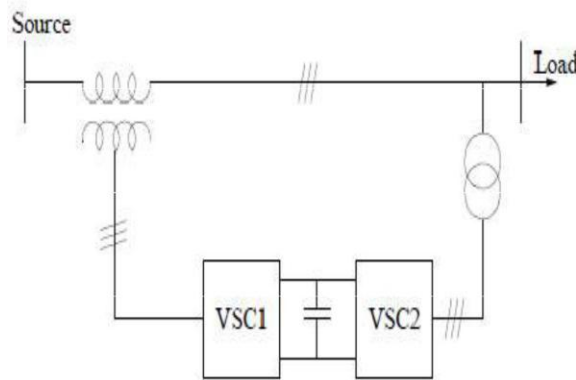

Fig 2.1: Block diagram of upqc

CONTROL OBJECTIVES OF UPQC

The shunt connected converter has the following control objectives

To balance the source currents by injecting negative and zero sequence components required by the load
The compensate for the harmonics in the load current by injecting the required harmonic currents
To control the power factor by injecting the required reactive current (at fundamental frequency)
To regulate the DC bus voltage.
The series connected converter has the following control objectives

1. To balance the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source.
2. To isolate the load bus from harmonics present in the source voltages, by injecting the harmonic voltages
3. To regulate the magnitude of the load bus voltage by injecting the required active and reactive components (at fundamental frequency) depending on the power factor on the source side
4. To control the power factor at the input port of the UPQC (where the source is connected. Note that the power factor at the output port of the UPQC (connected to the load) is controlled by the shunt converter.
Operation of UPQC
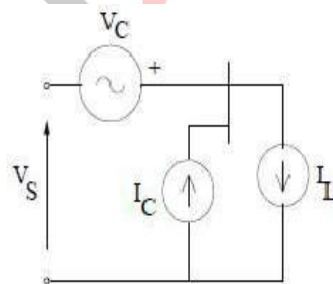
The operation of a UPQC can be explained from the analysis of the idealized equivalent circuit shown in Fig. 2.2. Here, the series converter is represented by a voltage source VC and the shunt converter is voltages and currents may contain negative and zero sequence components in addition to harmonics. Neglecting losses in the converters, we get the relation

Represented by a current source IC. Note that all the currents and voltages are 3 dimensional vectorswhere X, Y denote the inner product of two vectors, defined by

$$\langle V_L, I_C \rangle + \langle V_C, I_S \rangle = 0$$

$$\langle X, Y \rangle = \frac{1}{T} \int_0^T X^t(\tau) Y(\tau) d\tau.$$

Let the load current IL and the source voltage VS be decomposed into two Components given by

$$I_L = I_L^{1p} + I_L^r$$

$$P_L = \langle V_L, I_L \rangle = \langle V_L, I_L^{1p} \rangle$$

$$P_L = |V_L^* \, I_S^*| \cos \phi_l = |V_S^{1p} I_S^*| \cos \phi_s$$

and balanced. If the reference current (I¤C) of the shunt converter and the reference voltage (V ¤ C) of the series converter are chosen as

with the constraint

$$I_C^* = I_L^*, \quad V_C^* = -V_S^r + V_C^{1p}$$

$$\langle V_C^{1p}, I_S^* \rangle = 0$$

we have,

$$I_S^* = I_L^{1p}, \quad V_L^* = V_S^{1p} + V_C^{1p}$$

desired source current, I¤S . It is easy to derive that The above equation shows that for the operating conditions assumed, a UPQC can be viewed as a inaction of a DVR and a STATCOM with no active power flow through the DC link

However, if the magnitude of V ¤ L is to be controlled, it may not be feasible to achieve this by injecting only reactive voltage. The situation gets complicated if V 1p S is not constant, but changes due to system disturbances or fault. To ensure the regulation of the load bus voltage it may be necessary to inject variable active voltage (in Phase with the source current). If we express

$$I_S = I_S^* - \Delta I_C, V_L = V_S^{1p} + V_C^{1p} + \Delta V_C$$

$$\langle I_S, \Delta V_C \rangle + \langle V_L, \Delta I_C \rangle = 0$$

In deriving the above, we assume that

$$\langle I_S, V_C^* \rangle = 0 = \langle V_L, I_C^* \rangle$$

SIMULATION RESULTS

The improved IUPQC controller, as shown in Fig.5.1, was verified in a 5-kVA prototype, whose parameters are presented in Table I. In order to verify all the power quality issues described in this paper, the IUPQC was connected to a grid with a voltage sag system, as depicted in Fig. 6. The voltage sag system was composed by an inductor (LS), a resistor (RrmSag), and a breaker (SSag). To cause a voltage sag at bus A, SSag is closed. At first, the source voltage regulation was tested with no load connected to bus B. In this case, the IUPQC behaves as a STATCOM, and the breaker SSag is closed to cause the voltage sag. To verify the grid-voltage regulation the control of the QSTATCOM variable is enabled to compose (4) at instant t = 0 s. In this experimental case, LS = 10 mH, and RSag = 7.5 Ω. Before the QSTATCOM variable is enabled, only the dc link and the voltage at bus B are regulated, and there is a voltage sag at bus A, as shown in Fig. 7. After t = 0s, the IUPQC starts to draw reactive current from bus A, increasing the voltage until its reference value. As shown in Fig. 7, the load voltage at bus B is maintained regulated during all the time, and the grid-voltage regulation of bus A has a fast response.
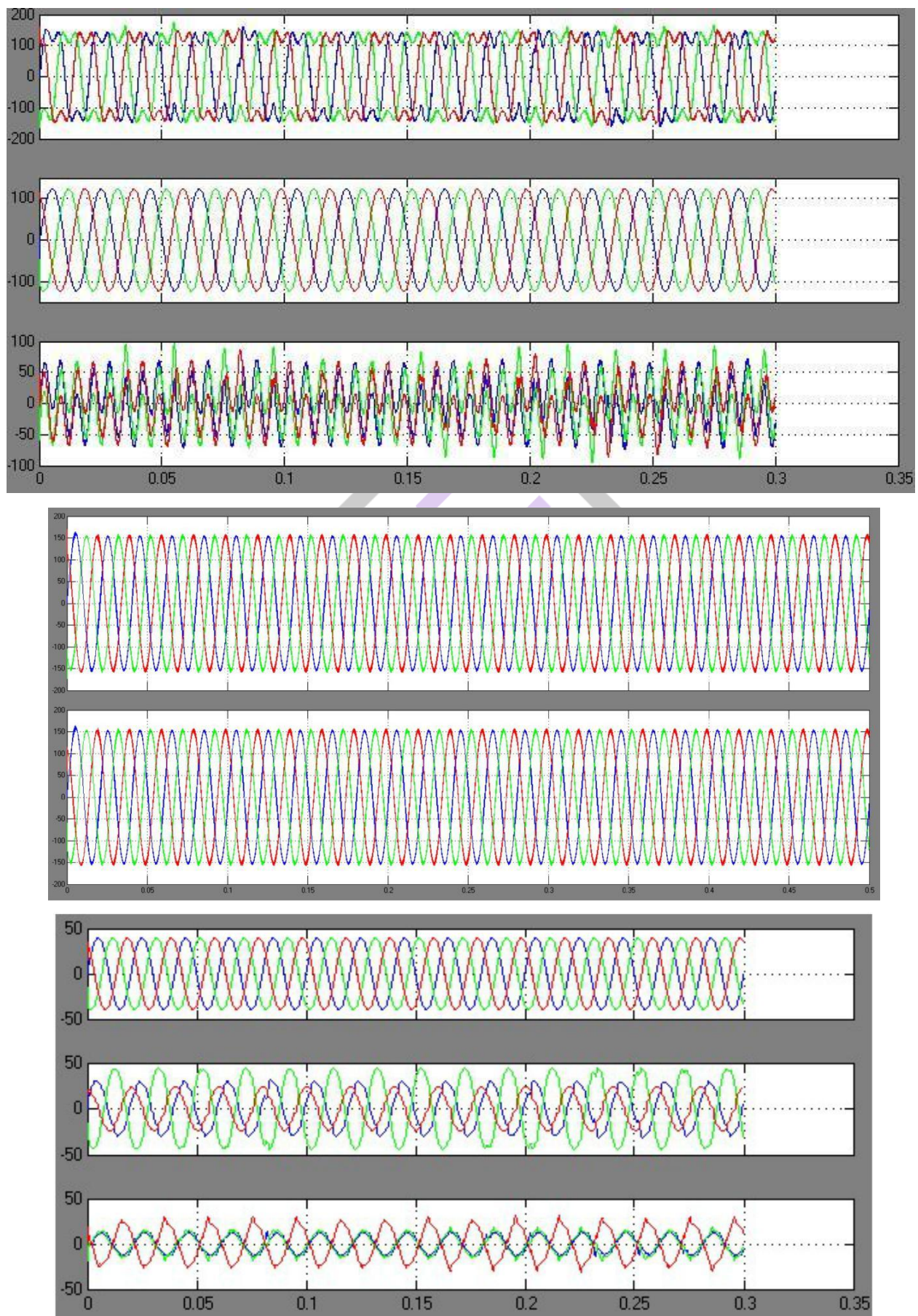
Fig.5.1: IUPQC response at no load condition: (a) grid voltages VA, (b) load voltages VB, (c) gird current

Fig.5.2: IUPQC transitory response during the connection of a threephase diode rectifier: (a)gird voltage, (b) load voltage, (c) grid currents, (d) load currents,

The load is a threephase diode rectifier with a series RL load at the dc link (R = 45 Ω and L = 22 mH), and the circuit breaker SSag is permanently closed, with a LS = 10 mH and a RSag = 15 Ω. In this way, the voltage-sag disturbance is increased due to the load connection. In Fig. 5.2 it is possible to verify that the IUPQC is able to regulate the voltages at both sides of the IUPQC, simultaneously. Even after the load connection, at t = 0 s, the voltages are still regulated, and the currents drawn from bus A are almost sinusoidal.

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IUPQC transitory response during the connection of a two- phase diode rectifier: (a) load currents, (b) source currents, (c) load voltages, and (c) source voltages

These are almost sinusoidal. Hence, the IUPQC can perform all the power-quality compensations, as mentioned before, including the grid-voltage regulation. It is important to highlight that the grid-voltage regulation is also achieved by means of the improved IUPQC controller, as introduced in Section III.

Finally, the same procedure was performed with the con- section of a two-phase diode rectifier, in order to better verify the mitigation of power quality issues. The diode rectifier has the same dc load (R = 45 Ω and L = 22 mH) and the same voltage sag (LS = 10

An improved IUPQC controller to provide additional gird-voltage regulation as a statcom mH and RrmSag = 15 Ω). Fig.5.3 depicts the transitory response of the load connection. Despite the two- phase load currents, after the load connection at t = 0 s, the three-phase current drained from the grid has a reduced unbalanced component. Likewise, the unbalance in the voltage at bus A is negligible. Unfortunately, the voltage at bus B has higher unbalance content. These components could be mitigated if the shunt compensator works as an ideal voltage source, i.e., if the filter inductor could be eliminated. In this case, the unbalanced current of the load could be supplied by the shunt converter, and the voltage at the bus B could be exactly the voltage synthesized by the shunt converter. Therefore, without filter inductor, there would be no unbalance voltage drop in it and the voltage at bus B would remain balanced. However, in a practical case, this inductor cannot be eliminated, and an improved PWM control to compensate voltage unbalances, as mentioned in Section III, is necessary

CONCLUSION

In the improved IUPQC controller, the currents synthesized by the series converter are determined by the average active power of the load and the active power to provide the dc-link voltage regulation, together with an average reactive power to regulate the grid-bus voltage. In this manner, in addition to all the power-quality compensation features of a conventional UPQC or an IUPQC, this improved controller also mimics a STATCOM to the grid bus. This new feature enhances the applicability of the IUPQC and provides new solutions in future scenarios involving smart grids and microgrids, including distributed generation and energy storage systems to better deal with the inherent variability of renewable resources such as solar and wind power. Moreover, the improved IUPQC controller may justify the costs and promotes the IUPQC applicability in power quality issues of critical systems, where it is necessary not only an IUPQC or a STATCOM, but both, simultaneously. Despite the addition of one more power-quality compensation feature, the grid-voltage regulation reduces the inner-loop circulating power inside the IUPQC, which would allow lower power rating for the series converter. The experimental results verified the improved IUPQC goals. The grid-voltage regulation was achieved with no load, as well as when supplying a three-phase nonlinear load. These results have demonstrated a suitable performance of voltage regulation at both sides of the IUPQC, even while compensating harmonic current and voltage imbalances.

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