

Enhancement of Power Quality in a Grid by using PV/iUPQC

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Abstract: *This paper presents an improved PV based controller for the dual topology of the unified power quality conditioner (iUPQC) extending its applicability in power-quality compensation, as well as in microgrid applications. 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 volt- age at the grid-side bus. In other words, the PV based 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. Experimental results are provided to verify the new functionality of the equipment.*

Keywords: *Micro Grid; iUPQC; PV.*

1. INTRODUCTION

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) [1]–[7] and the static synchronous compensator (STATCOM) [8]–[13].

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 [14]–[19], where 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 LC L filter of the power converters, which allows improving significantly the overall performance of the compensator [20].

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 [9], whereas the UPQC and the iUPQC have been selected as solution for more specific applications [21]. 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 microgrids.

In [16], the performance of the iUPQC and the UPQC was compared when working as UPQCs. The main difference between these compensators is the sort of source emulated by the series and shunt power converters. In the UPQC approach, the series converter is controlled as a nonsinusoidal voltage source and the shunt one as a nonsinusoidal current source. Hence, in real time, the UPQC controller has to determine and synthesize accurately the harmonic voltage and current to be compensated. On the other hand, in the iUPQC approach, the series converter behaves as a controlled sinusoidal current source and the shunt converter as a controlled sinusoidal voltage source. This means that it is not necessary to determine the harmonic voltage and current to be compensated, since the harmonic

voltages appear naturally across the series current source and the harmonic currents flow naturally into the shunt voltage source.

In actual power converters, as the switching frequency increases, the power rate capability is reduced. Therefore, the iUPQC offers better solutions if compared with the UPQC in case of high-power applications, since the iUPQC compensating references are pure sinusoidal waveforms at the fundamental frequency. Moreover, the UPQC has higher switching losses due to its higher switching frequency.

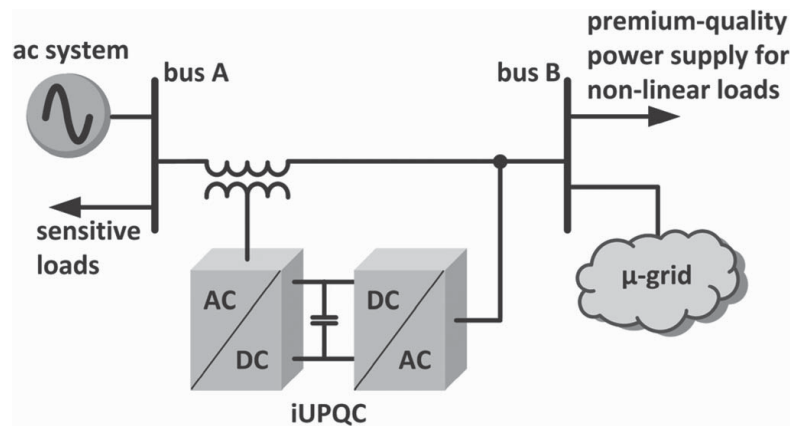


Fig1. Example of applicability of iUPQC.

This paper proposes an improved PV based controller, which expands the iUPQC functionalities. This improved version of iUPQC controller includes all functionalities of those previous ones, including the voltage regulation at the load-side bus, and now providing also voltage regulation at the grid-side bus, like a STATCOM to the grid. Experimental results are provided to validate the new controller design.

2. APPLICABILITY OF PROPOSED MODEL

In order to clarify the applicability of the improved iUPQC controller, Fig. 1 depicts an electrical system with two buses in spotlight, i.e., bus A and bus B. Bus A is a critical bus of the power system that supplies sensitive loads and serves as point of coupling of a microgrid. Bus B is a bus of the microgrid, where nonlinear loads are connected, which requires premium-quality power supply. The voltages at buses A and B must be regulated, in order to properly supply the sensitive loads and the nonlinear loads. The effects caused by the harmonic currents drawn by the nonlinear loads should be mitigated, avoiding harmonic voltage propagation to bus A.

The use of a STATCOM to guarantee the voltage regulation at bus A is not enough because the harmonic currents drawn by the nonlinear loads are not mitigated. On the other hand, a UPQC or an iUPQC between bus A and bus B can compensate the harmonic currents of the nonlinear loads and compensate the voltage at bus B, in terms of voltage harmonics, unbalance, and sag/swell. Nevertheless, this is still not enough to guarantee the voltage regulation at bus A. Hence, to achieve all the desired goals, a STATCOM at bus A and a UPQC (or an iUPQC) between buses A and B should be employed. However, the costs of this solution would be unreasonably high.

An attractive solution would be the use of a modified iUPQC controller to provide also reactive power support to bus A, in addition to all those functionalities of this equipment, as presented in [16] and [18]. Note that the modified iUPQC serves as an intertie between buses A and B. Moreover, the microgrid connected to the bus B could be a complex system comprising distributed generation, energy management system, and other control systems involving microgrid, as well as smart grid concepts [22]. In summary, the modified iUPQC can provide the following functionalities:

- “smart” circuit breaker as an intertie between the grid and the microgrid;
- energy and power flow control between the grid and the microgrid (imposed by a tertiary control layer for the microgrid);
- reactive power support at bus A of the power system;
- voltage/frequency support at bus B of the microgrid;

- e) harmonic voltage and current isolation between bus A and bus B (simultaneous grid-voltage and load-current active- filtering capability);
- f) voltage and current imbalance compensation.

The functionalities (d)–(f) previously listed were extensively explained and verified through simulations and experimental analysis [14]–[18], whereas the functionality (c) comprises the original contribution of the present work. Fig. 2 depicts, in detail, the connections and measurements of the iUPQC between bus A and bus B.

According to the conventional iUPQC controller, the shunt converter imposes a controlled sinusoidal voltage at bus B, which corresponds to the aforementioned functionality (d). As a result, the shunt converter has no further degree of freedom in terms of compensating active- or reactive-power variables to expand its functionality. On the other hand, the series converter of a conventional iUPQC uses only an active-power control variable p , in order to synthesize a fundamental sinusoidal current drawn from bus A, corresponding to the active power demanded by bus B. If the dc link of the iUPQC has no large energy storage system or even no energy source, the control variable p also serves as an additional active-power reference to the series converter to keep the energy inside the dc link of the iUPQC balanced. In this case, the losses in the iUPQC and the active power supplied by the shunt converter must be quickly compensated in the form of an additional active power injected by the series converter into the bus B.

The iUPQC can serve as: a) “smart” circuit breaker and as b) power flow controller between the grid and the microgrid only if the compensating active- and reactive-power references of the series converter can be set arbitrarily. In this case, it is necessary to provide an energy source (or large energy storage) associated to the dc link of the iUPQC.

The last degree of freedom is represented by a reactive-power control variable q for the series converter of the iUPQC. In this way, the iUPQC will provide reactive-power compensation like a STATCOM to the bus A of the grid. As it will be confirmed, this functionality can be added into the controller without degrading all other functionalities of the iUPQC.

3. IMPROVED iUPQC CONFIGURATION

Fig. 2 depicts the iUPQC hardware and the measured units of a three-phase three-wire system that are used in the controller. Fig. 3 shows the proposed controller. The controller inputs are the voltages at buses A and B, the current demanded by bus B (i_L), and the voltage v_{DC} of the common dc link. The outputs are the shunt-voltage reference and the series-current reference to the pulsewidth modulation (PWM) controllers. The voltage and current PWM controllers can be as simple as those employed in [18], or be improved further to better deal with voltage and current imbalance and harmonics [23]–[28].

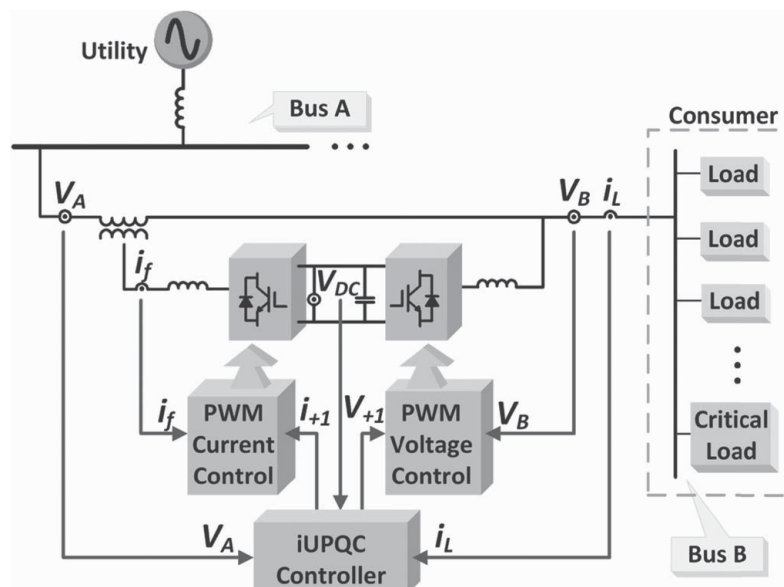


Fig2. Modified iUPQC configuration

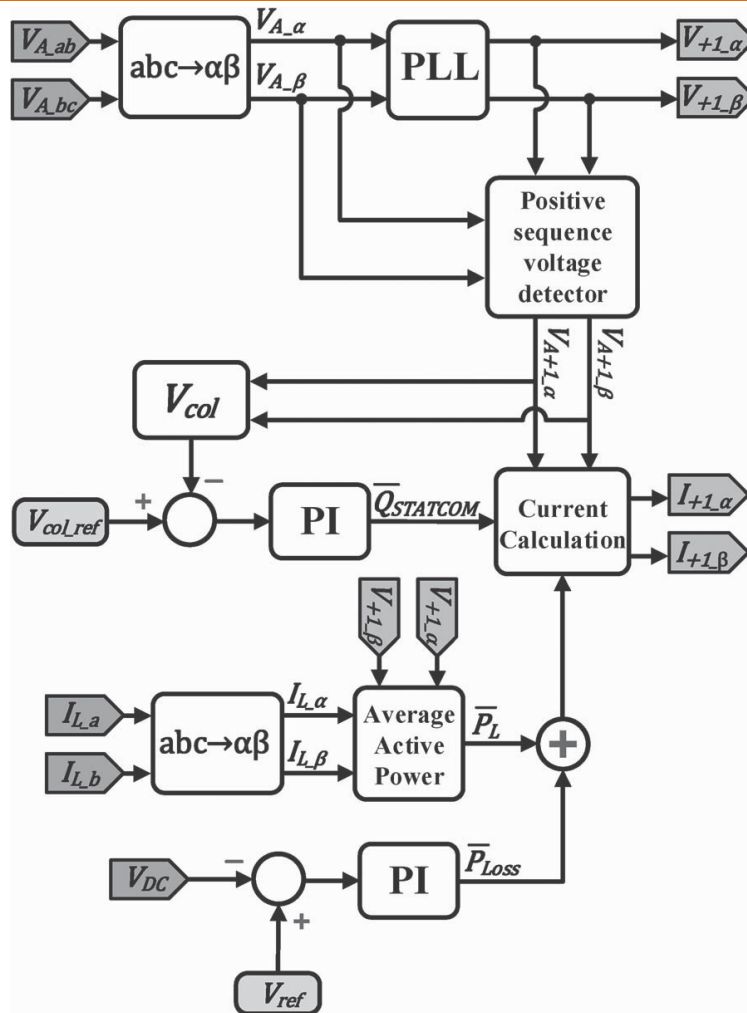


Fig3. Novel iUPQC controller.

4. SIMULATION RESULTS

Case: 1. Conventional iUPQC

A. iUPQC with NO-Load:

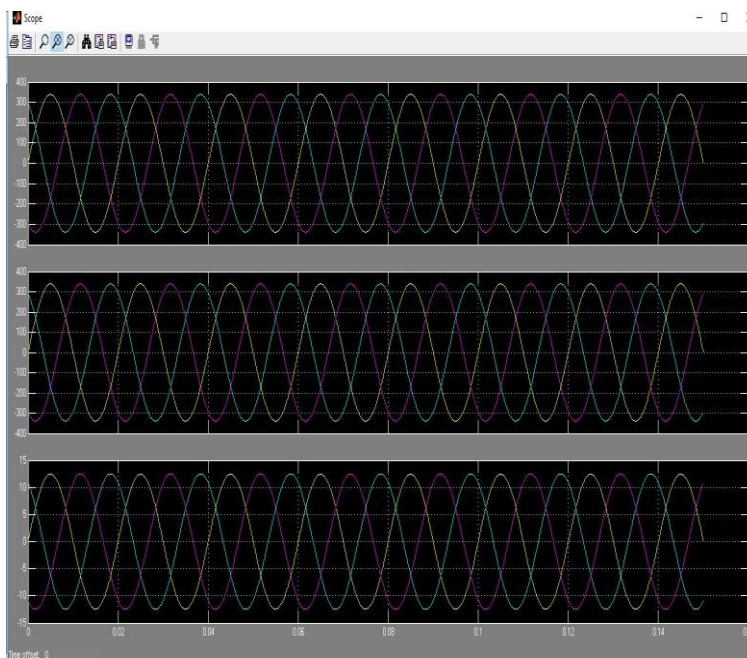


Fig4. (a) grid voltages V_A , (b) load voltages V_B , and (c) grid currents.

B. iUPQC with 2-Arm Rectifier

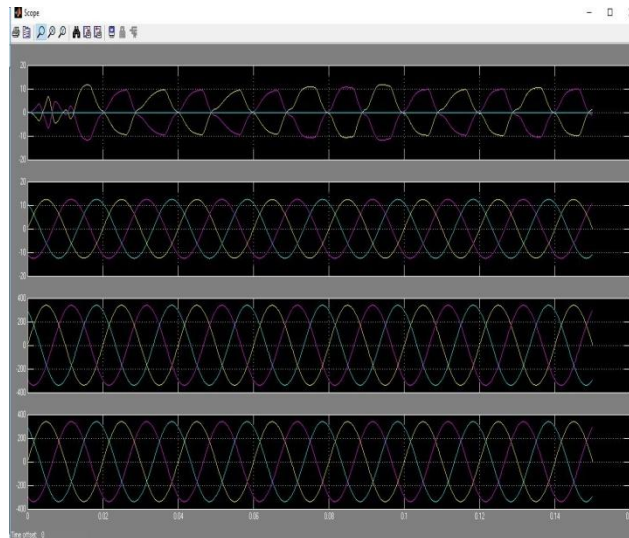


Fig5. *iUPQC* transitory response during the connection of a twophase diode rectifier: (a) load currents, (b) source currents, (c) load voltages, and (c) source voltages.

C. iUPQC with 3-Arm Rectifier

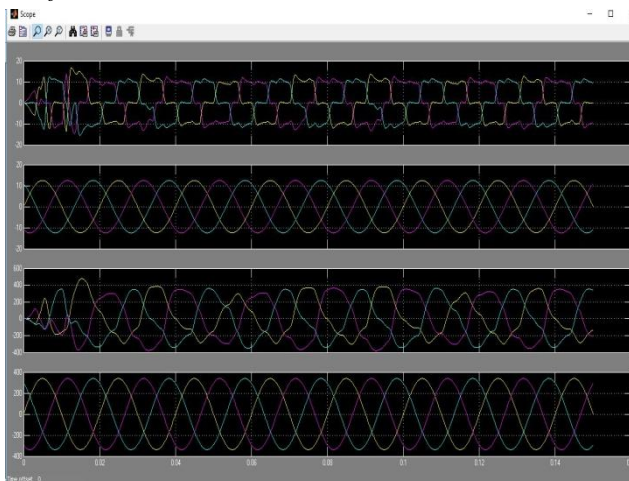


Fig6. *iUPQC* transitory response during the connection of a threephase diode rectifier: (a) load currents, (b) grid currents, (c) load voltages and (d) grid voltages.

Case: 2. PV Based iUPQC

D. iUPQC with NO-Load

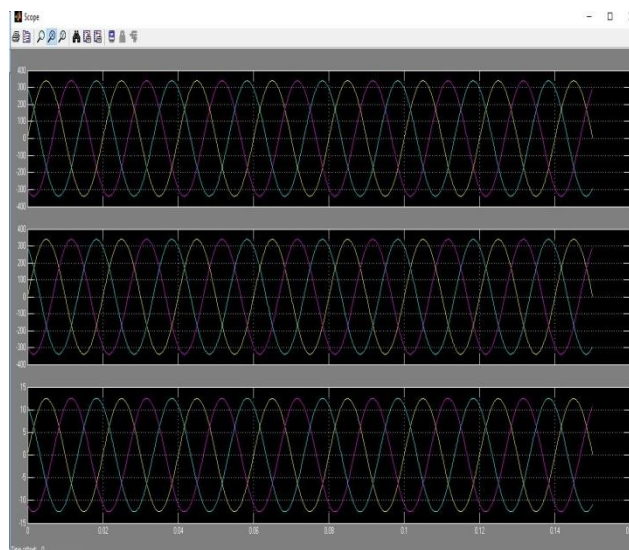


Fig7. (a) grid voltages VA, (b) load voltages VB, and (c) grid currents.

E. iUPQC with 2-Arm Rectifier

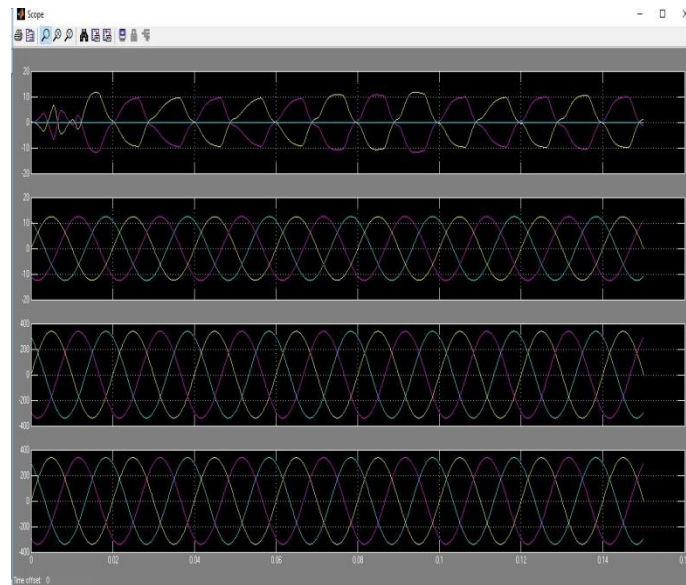


Fig8. iUPQC transitory response during the connection of a twophase diode rectifier: (a) load currents, (b) source currents, (c) load voltages, and (d) source voltages.

F. iUPQC with 3-Arm Rectifier

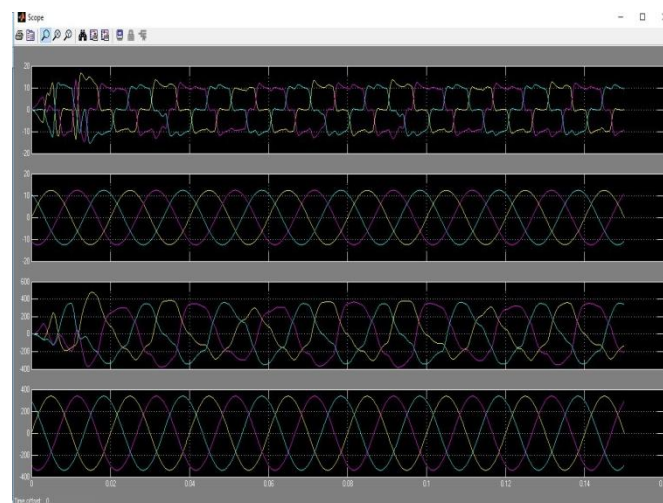


Fig9. iUPQC transitory response during the connection of a threephase diode rectifier: (a) load currents, (b) grid currents, (c) load voltages and (d) grid voltages.

5. 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 PV based 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 PV based 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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