IMPROVED UPQC WITH STATCOM FOR GRID VOLTAGE REGULATION BY USING FUZZY LOGIC CONTROLLER

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Abstract:

This paper presents an improved 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. 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. 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 by using this controller. Simulation results are provided to verify the new functionality of the equipment.

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

1. Introduction

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. 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 powerquality problems. Some of the solutions involve a flexible compensator, known as the unified power quality conditioner (UPQC) and the static synchronous compensator (STATCOM)

Power circuit of a UPQC consistsof the 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 fuzzy logic and dual topology of the UPQC, i.e., the iUPQC (improved unified power quality conditioner), 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 LCL filter of the power converters, which allows improving significantly the overall performance of the compensator.

2. Improved UPQC Configuration

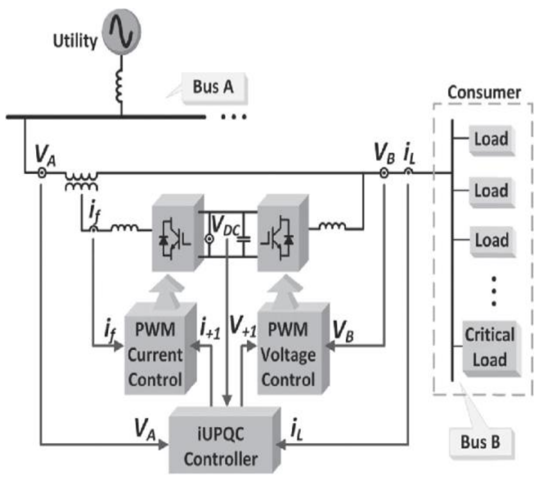

Figure (1): Improved UPQC configuration.

Figure (1) depicts in details about the connections and measurements of the iUPQC between bus A and bus B. Using fuzzy 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. 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. According to the conventional iUPQC controller, the shunt converter imposes a controlled sinusoidal voltage at bus B, which corresponds to the mentioned functionality.

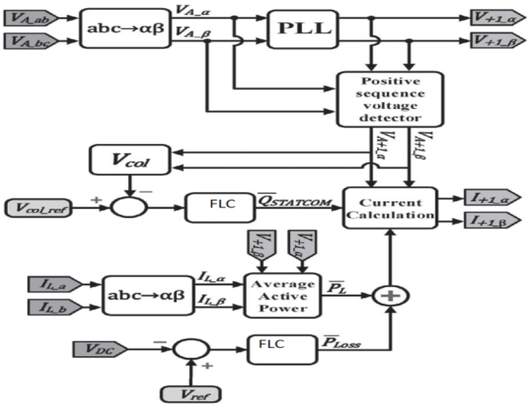

Figure (2): Novel iUPQC controller.

Figure (2) depicts in details about the novel 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. The voltage and current PWM controllers can be as simple as those employed, or be improved further to better deal with voltage and current imbalance and harmonics.

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

$$\begin{bmatrix} V_{A\_\alpha} \\ V_{A\_\beta} \end{bmatrix} = \begin{bmatrix} 1 & 1/2 \\ 0 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{A\_ab} \\ V_{A\_bc} \end{bmatrix}. \qquad (1)$$

Consequently, the signals sent to the PWM controller are the Phase-Locked Loop (PLL) outputs with amplitude equal to 1 p.u. The shunt converter imposes the voltage at bus B. Thus, it is necessary to synthesize sinusoidal voltages with nominalamplitude and frequency. There are many possible PLL algorithms, which could be used in this case, as verified. In the original approach of iUPQC, this current is calculated through the average active power required by the loads PL plus the power PLoss. The series converter synthesizes the current drawn from the grid bus (bus A). The load active power can be estimated by

$$P_L = V_{+1\_\alpha} . i_{L\_\alpha} + V_{+1\_\beta} . i_{L\_\beta} \qquad (2)$$

Where iL_α, iL_β are the load currents, and V+1_α, V+1_β are the voltage references for the shunt converter. A low-pass filter is used to obtain the average active power (PL).The losses in the power converters and the circulating power to provide energy balance inside the iUPQC are calculated indirectly from the measurement of the dc-link voltage. In other words, the power signal PLoss is determined by a fuzzy logic controller, by comparing the measured dc voltage VDC with its reference value. The Figure (2) shows additional control loop to provide voltage regulation like a STATCOM at the grid bus is represented by the control signal QSTATCOM. This control signal is obtained through a fuzzy logic controller, in which the input variable is the error between the reference value and the actual aggregate voltage of the grid bus, given by

$$V_{col} = \sqrt{V_{A+1\_\alpha}^2 + V_{A+1\_\beta}^2}. \qquad (3)$$

The sum of the power signals PL and PLoss composes the active-power control variable for the series converter of the iUPQC described. Likewise, QSTATCOM is the reactive-power control variable q. Thus, the current references i+1α and i+1β of the series converter are determined by

$$\begin{bmatrix} i_{+1\_\alpha} \\ i_{+1\_\beta} \end{bmatrix} = \frac{1}{V_{A+1\_\alpha}^2 + V_{A+1\_\beta}^2} \begin{bmatrix} V_{A+1\_\alpha} & V_{A+1\_\beta} \\ V_{A+1\_\beta} & V_{A+1\_\alpha} \end{bmatrix} \times \begin{bmatrix} \bar{P}_L + \bar{P}_{LOSS} \\ \text{獲}_{STATCOM} \end{bmatrix}. \quad (4)$$

3. Fuzzification

Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The partition of fuzzy subsets and the shape of membership CE(k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Table (I) : Fuzzy Rules

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular
E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (5)$$

$$CE(k) = E(k) - E(k-1) \quad (6)$$

4. Experimental setup

The iUPQC was connected to a grid with a voltage sag system, as depicted in Figure (3)

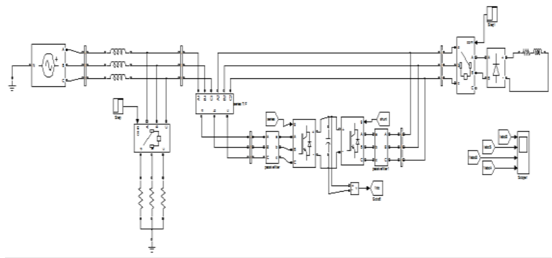

Figure (3) : Block diagram of simulation.

In this simulation case, LS = 10 mH, and RSag = 7.5 Ω To verify the grid-voltage regulation (see Fig. 7), the control of the QSTATCOM variable is enabled to compose (4) at instant t = 0 s. As shown in Figure (3) before the QSTATCOM variable is enabled, only the dc link and the voltage at bus B are regulated, and there is voltage sag at bus A. 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.

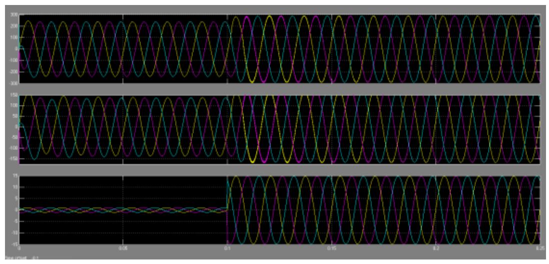

Figure (4): iUPQC with fuzzy response at no load condition: (a) grid voltages VA, (b) load voltages VB, and (c) grid currents.

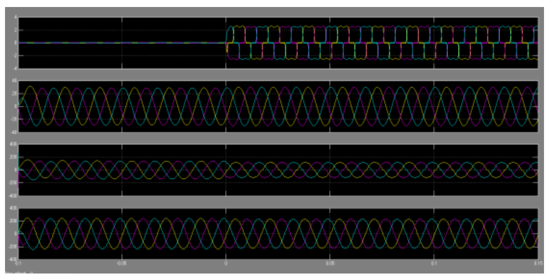

Figure (5) : iUPQC with fuzzy response during the connection of a three phase diode rectifier: (a) load currents, (b) grid currents, (c) load voltages and (d) grid voltages.

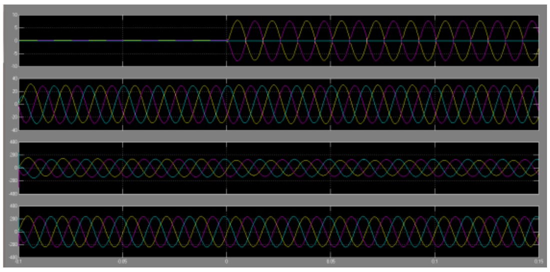

Figure (6) : iUPQC with fuzzy response during the connection of a two phase diode rectifier: (a) load currents, (b) source currents, (c) load voltages, and (d) source voltages.

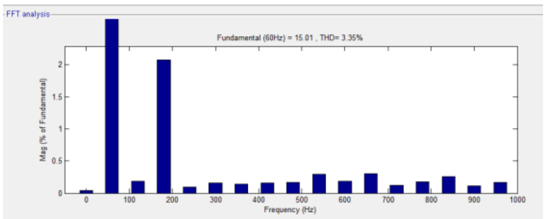

Figure (7) : THD value of grid current with fuzzy controller at no load.

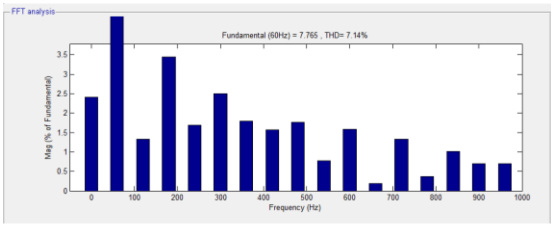

Figure (8): THD value of grid current without fuzzy controller at no load.

5. Conclusion

In this paper, 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. 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. 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. Moreover, the improved iUPQC controller may justify the costs and promotes the iUPQ Capability in power quality issues of critical systems, where it is necessary not only an iUPQC or a STATCOM, but both, simultaneously. These results have demonstrated a suitable performance of voltage regulation at both sides of the iUPQC, even while compensating harmonic current and voltage imbalances. The simulation 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.

6. References

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