Active Power Filter for Power Quality improvement of Power Converters Functional Testing Lines

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Abstract – Testing inverters at the end of production lines is a common practice to minimize the cases of early failure. This is also the case of the company Prima Electro, which implemented a regenerative system called FFT (Final Functional Testing) line in one of its plants. However, this FFT line absorbs a very distorted grid current, whose RMS value large enough to trigger line protections. This limits the full power test of the inverters. Therefore, the goal of this thesis is the design of an Active Power Filter to improve the power quality on the grid side, reducing the grid current harmonic content and consequently its RMS value. This work has been carried out at the company Prima Electro.

I. INTRODUCTION

To be compliant with the customer specifications, each inverter manufactured by Prima Electro company must pass a 20-minute thermal test at its nominal current in the regenerative final functional testing (FFT) line represented in Figure 1. The regenerative system recirculates the fundamental component of the current thus limiting the absorbed power from the grid. However, since the Drive Under Test (DUT) is equipped with a three-phase diode rectifier, several low frequency harmonics are absorbed from the grid together with the current covering the system losses. Therefore, the grid current is distorted as shown in Figure 1. Moreover, this distortion leads to a grid current root mean square (RMS) higher than the limit of the protection fuses, causing the impossibility to complete the drives testing at full power.

To solve this issue, the identified solution is an Active Power Filter (APF) that acts as a harmonic generator, by compensating the grid harmonic content to reduce its RMS value and to improve the system power quality. The already existing APF is controlled with a sensorless grid angle identification and a rough current reference algorithm that makes the compensation not effective enough.

The thesis **goals**, which can also be considered my main contributions are:

- Implementation of an effective control code for the APF converter. The code is developed and validated in the PLECS simulation environment.
- Design and testing of a PCB board called Master Sensor Board (MSB) to sense the grid voltage and measure the currents to be compensated. The MSB will also be able to communicate with the APF, to perform grid monitoring and power quality evaluations.
- Implementation of the APF control code in Prima Electro system and testing on FFT line.

The proposed system is illustrated in Figure 2.

II. MASTER SENSOR BOARD DESIGN

The Master Sensor Board has been designed to mate with the Control Board 2.0 used to control the Prima Electro inverters on which a microcontroller is integrated. The microcontroller on the MSB is synchronized and communicates with the one installed on the APF converter using a 5 V differential digital SPI communication via HDMI cable. The designed MSB parts are depicted in Figure 3.

III. CONTROL ALGORITHM AND PLECS VALIDATION

The designed control is based on the use of multiple Proportional Resonant regulators (P-Res) that allow a zero steady state error in the regulation of a sinusoidal input at a specific resonance frequency. In detail, the three-phase diode rectifier absorbs not multiple of three odd harmonics. The harmonic sequence theory is exploited to optimize the control code and minimize the computational burden. In (d,q) 50 Hz rotating reference frame, couples of odd harmonics not multiple of three collapse on a single frequency, leading to the possibility to use a single regulator to compensate two harmonic components. The APF control has been implemented to perform a current compensation up to the 25th harmonic, using P-Res regulators at the frequencies of 300, 600, 900, 1200 Hz.

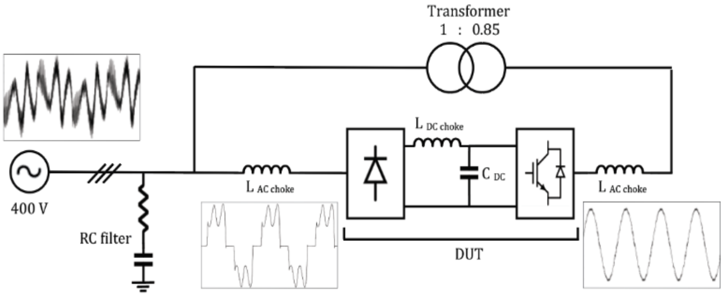

Figure 1: FFT regenerative system.

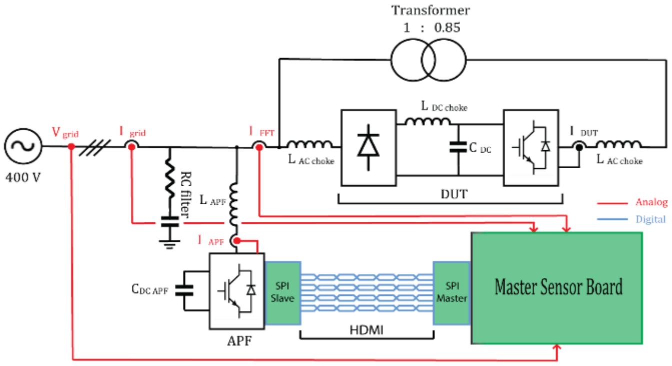

Figure 2: Proposed system single line diagram.

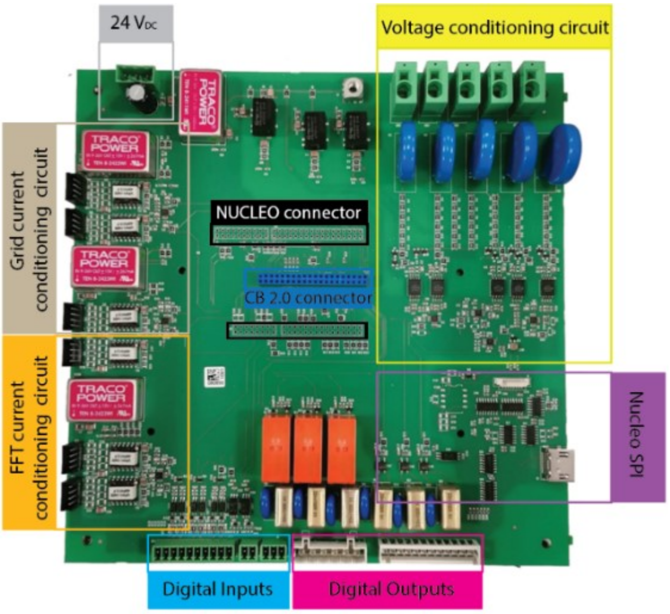

Figure3: Master Sensor Board.

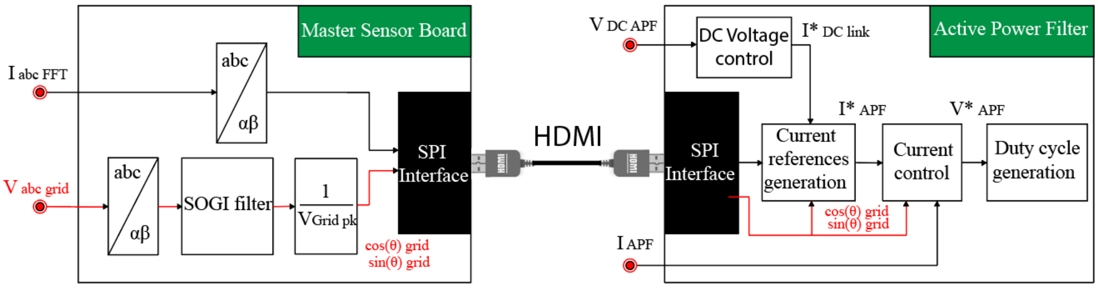

Figure 4 Proposed control block scheme.

A 50 Hz P-Res regulator operating in (α,β) is also necessary to perform the DC bus voltage regulation and the reactive power compensation of the RC ripple filter. The proposed control, shown in Figure 4, has been coded in C language on the PLECS simulation environment to test the effectiveness of the APF compensation on this kind of electrical system. The compensation results on PLECS simulation are shown in Figure 5 and prove the effectiveness of the proposed control.

IV. EXPERIMENTAL RESULTS

Once the control algorithm was validated, the code was ported on the Prima Electro control board and the system was tested in the industrial facility. A first test was performed at the maximum grid current under protection limit, to compare the current waveforms with and without compensation. The results are shown in Figure 6 and it is clear the beneficial effect of RMS current reduction thanks to the APF. Once the APF compensation appeared effective in grid current RMS reduction, a second test was performed at DUT nominal current (425 A_{RMS}) Thanks to the APF compensation, the grid current RMS was equal to 30 A and with a harmonic spectrum mainly composed by the fundamental as represented in Figure 7 and Figure 8. Finally, the APF compensation effectiveness can be evaluated by Figure 9 in which the harmonic contents of the reference currents (absorbed by the FFT) and the actual APF one are compared. All regulators worked properly except for the 1200 Hz regulator, which resulted to be unstable in the real system, probably due to the low switching frequency, set to 6 kHz, that limited the current control bandwidth.

V. CONCLUSIONS

The designed APF control gave great results in reducing the grid current RMS value and its harmonic content as reported in Table 1. The APF allows Prima Electro to complete the end of production line testing up to full power without tripping the protections.

My main contributions can be summarized as follows:

- Design of the MSB: sensing, analog conditioning and elaboration of the electrical quantities. SPI communication system which proved to be reliable and insensitive to disturbances.
- APF control code design and implementation: Effective in harmonics compensation until the 19th harmonic both in PLECS simulations and in real FFT system.

Better compensation results and control stability is possible with further APF hardware improvements in terms of microcontroller computing power and power electronic hardware, allowing a higher switching and control frequency.

DUT output current RMS value	Grid Current RMS value	
	APF OFF	APF ON
73 A	57.9 A	16.8 A
180 A	74.5 A *	22.5 A
300 A	104.2 A *	27.3 A
450 A	143.4 A *	30.9 A

Table 1: Grid current comparison APF OFF vs ON

* This value is estimated by PLECS simulation. The grid current RMS value is above the protection threshold, thus, real tests were not possible.

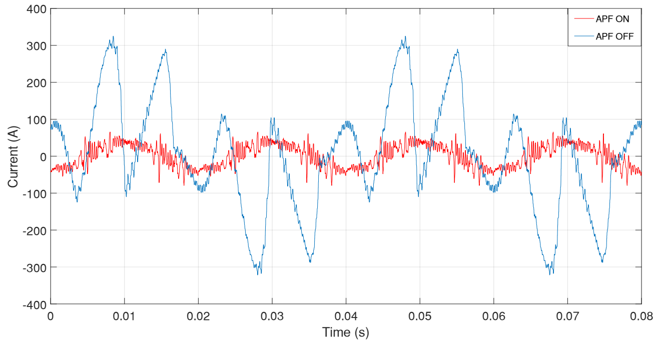

Figure 5: Grid current comparison from PLECS simulation.

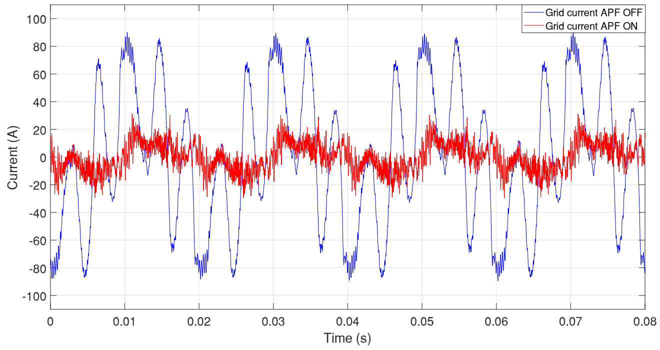

Figure 6: Grid current APF OFF vs ON comparison

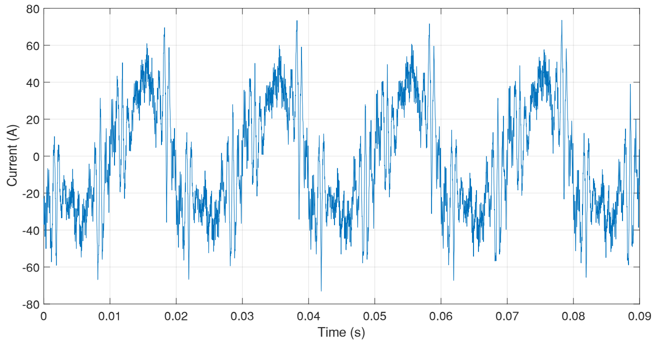

Figure 7: Grid current waveform at nominal current test

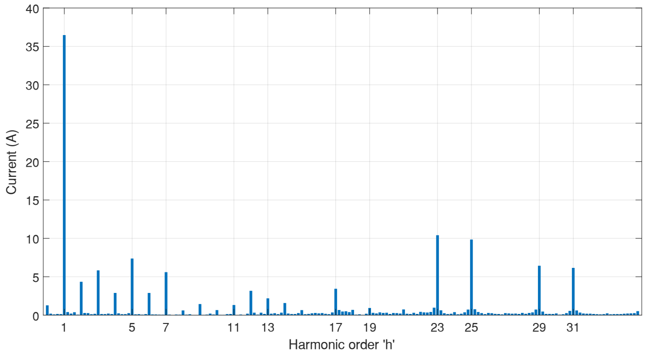

Figure 8: DFT of the grid current at nominal current test.

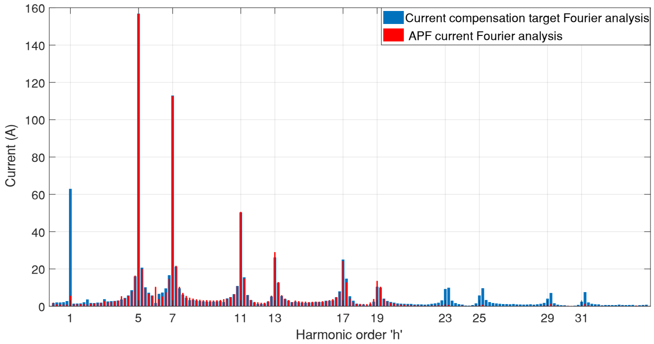

Figure 9: DFT of the APF reference current vs APF current.