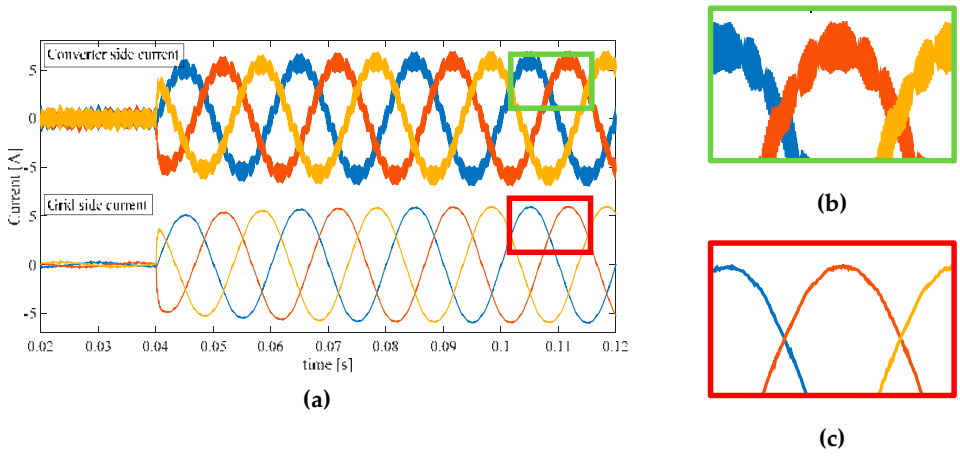

Figure 13. Converter side and grid side three-phase current with SFOPD. (**a**) Transient behavior in multiple cycles; (**b**) Ripple magnification for converter side current; (**c**) Ripple magnification for grid side current.

Figure 14 shows the low order harmonics (from third to fortieth harmonic) in grid side current I_{ga} obtained with SPD, THIPD, and SFOPD, respectively.

In the first all, it is interesting to note that the amplitude of the lower order harmonics are below of the standard harmonic current limits defined by IEEE 1574 and IEC 61727 at the PCC. However, is visible only a predominant fifth harmonic in low order spectra obtained with SPD while there are also the eleventh and thirteenth harmonics in the low order spectra obtained with THIPD and SFOPD.

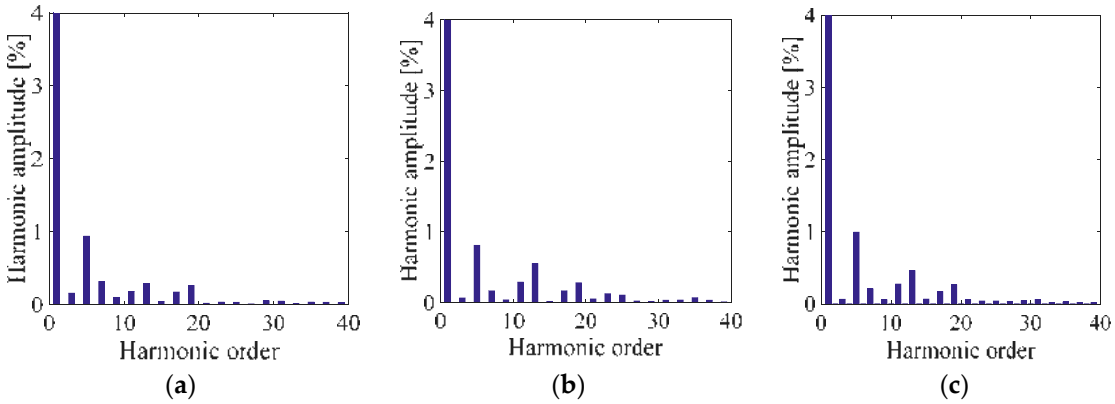

Figure 14. Low order harmonics on the grid side current I_{ga} for (**a**) SPD, (**b**) THIPD, and (**c**) SFOPD.

Figure 15 shows a comparison among harmonic spectra centered around the switching frequency of 10 kHz among line voltage V_{ab} (blue bars), converter side current I_a (red bars) and grid side current I_{ga} (yellow bars) obtained with SPD, THIPD, and SFOPD, respectively. The lower values of the grid side current harmonics, less of 0.3% referred to the fundamental amplitude, demonstrate the LCL filter effectiveness. It should be noted that in the spectra of the line voltage and currents appear only side band harmonics thanks to the three-wired connection.

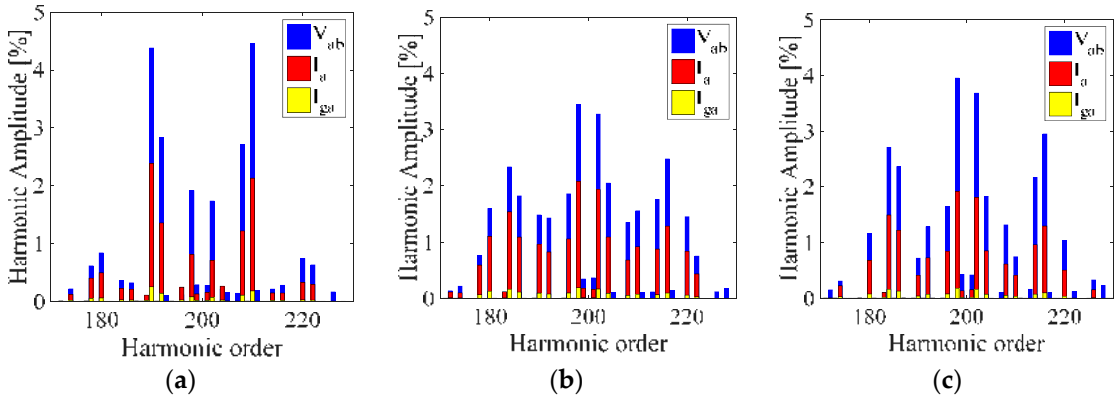

Figure 15. Comparison of line voltage harmonic spectra V_{ab}, converter side current I_a and grid side current I_{ga} centered around the switching frequency (10 kHz) in percent respect to the fundamental amplitude for (**a**) SPD, (**b**) THIPD, and (**c**) SFOPD.

In particular, harmonic spectra obtained with SPD modulation technique presents three-pair predominant of the side band harmonics while the harmonic spectra obtained with THIPD and SFOPD are different. The tool used to compare the harmonic content around the switching frequency among the SPD, THIPD, and SFOPD is the "Partial Total Harmonic Distortion" (*PTHD*%) defined as:

$$PTHD\% = \frac{\sqrt{\sum_{f_{SW}-n/2}^{f_{SW}+n/2} V_h^2}}{V_1} \cdot 100 \tag{25}$$

where f_{SW} is the switching frequency, n is the bandwidth centered around the switching frequency, h is the harmonic order and V_1 is the fundamental amplitude.

In Table 8 are summarized the *PTHD*% calculated for line voltage V_{ab}, converter side current I_a and grid side current I_{ga}.

Table 8. Partial Total Harmonic Distortion" (*PTHD*%) values obtained with SPD, THIPD, and SFOPD.

	V_{ab}	I_a	I_{ga}
SPD	7.94%	3.92%	0.38%
THIPD	7.86%	4.61%	0.43%
SFOPD	8.29%	4.08%	0.38%

It is interesting to note that the SPD and SFOPD present the lower values of the *PTHD*% as regard to the currents. While, the lower values of the *PTHD*% of the line voltage has been obtained with THIPD modulation technique. Obviously, both the modulation technique and the LCL filter concur to define the harmonic content.

2.4.2. Phase Opposition Disposition and Alternative Phase Opposition Disposition

In harmonic spectra obtained with modulation techniques based POD or APOD as carrier signals, the harmonic component at switching frequency does not appear but there are only side band.

Figure 16 shows the harmonic spectra of the phase voltage centered around the switching frequency obtained with SPOD, THIPOD, SFOPOD, SAPOD, THIAPOD, and SFOAPOD, respectively.

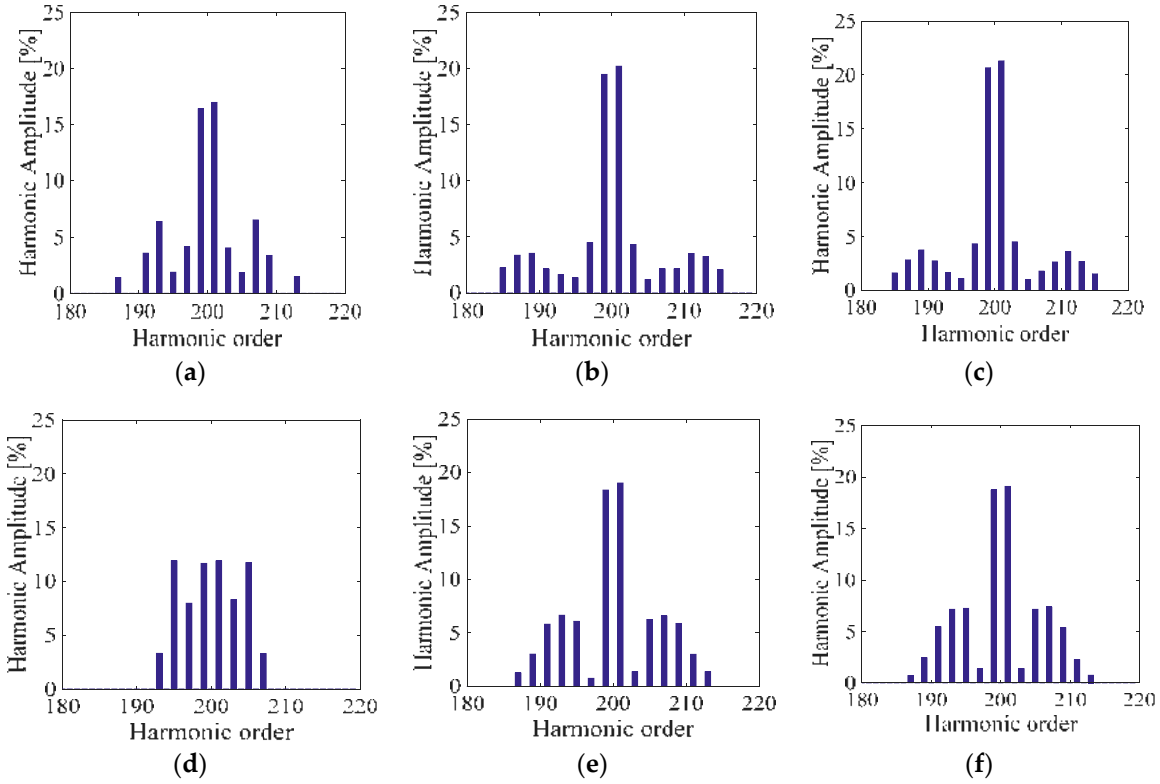

Figure 16. Phase voltage harmonic spectra centered around the switching frequency (10kHz) in percent respect to the fundamental amplitude of (**a**) SPOD, (**b**) THIPOD, (**c**) SFOPOD, (**d**) SAPOD, (**e**) THIAPOD, and (**f**) SFOAPOD.

As shown in Figure 16, the harmonic spectra are similar with a pair component predominant respect to the others while only the SAPOD (Figure 16d) presents little differences. Respect the modulation techniques PD or PS based, in the sub-section 2.4. LCL Filter Design the higher values of the filter requirements were obtained with POD and APOD.

Figures 17–22 show the transitory of the converter side currents and grid side currents from zero to the rated current obtained with SPOD, THIPOD, SFOPOD, SAPOD, THIAPOD, and SFOAPOD respectively.

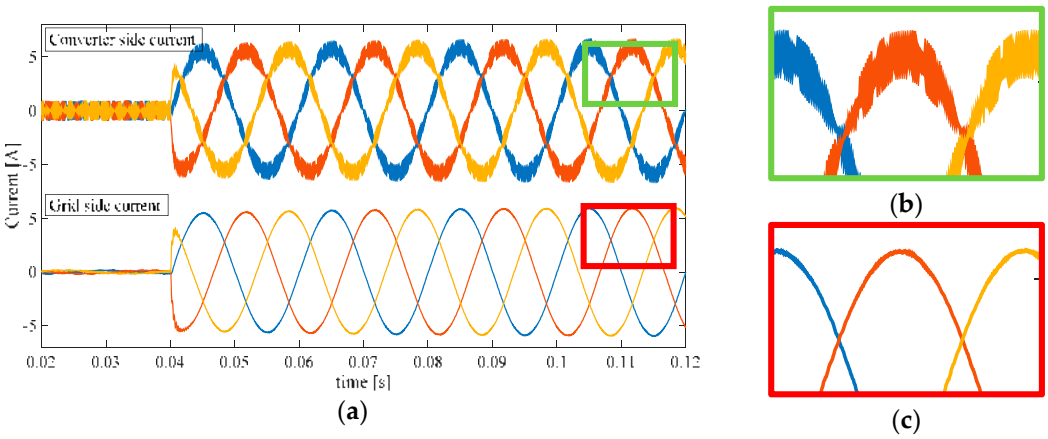

Figure 17. Converter side and grid side three-phase current with SPOD. (**a**) Transient behavior in multiple cycles; (**b**) Ripple magnification for converter side current; (**c**) Ripple magnification for grid side current.

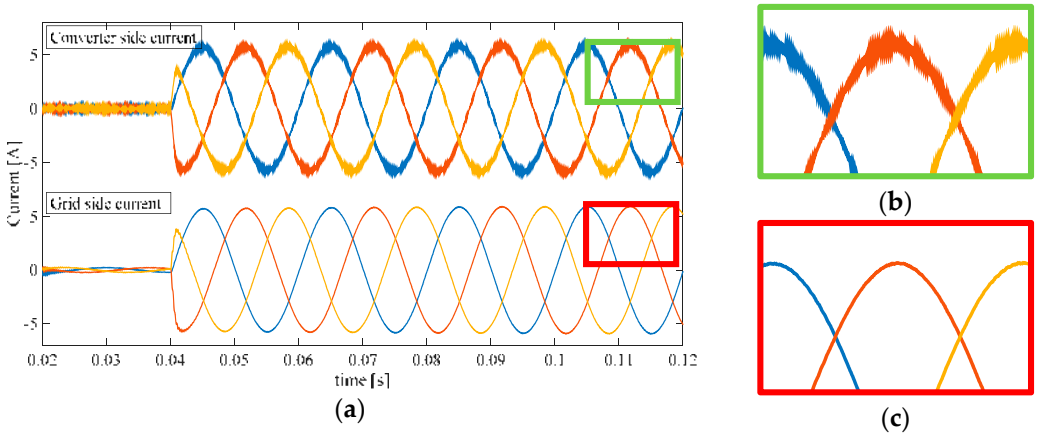

Figure 18. Converter side and grid side three-phase current with THIPOD. (**a**) Transient behavior in multiple cycles; (**b**) Ripple magnification for converter side current; (**c**) Ripple magnification for grid side current.

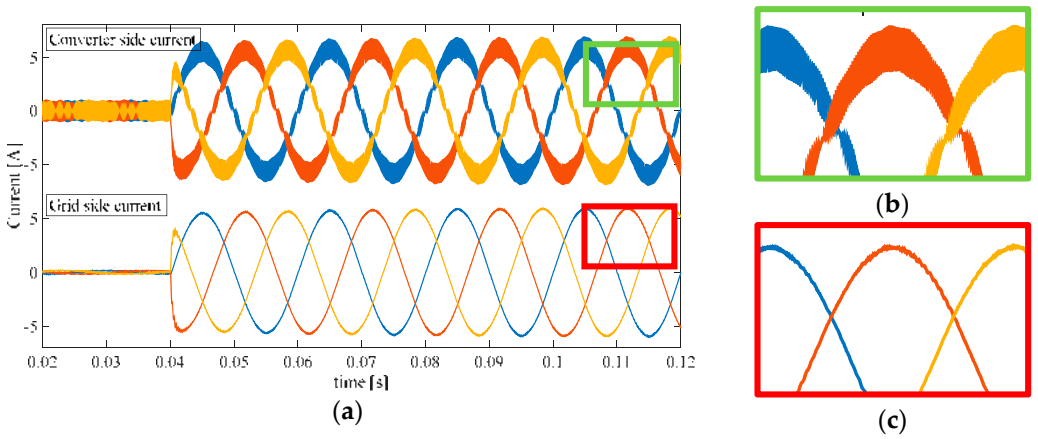

Figure 19. Converter side and grid side three-phase current with SFOPOD. (**a**) Transient behavior in multiple cycles; (**b**) Ripple magnification for converter side current; (**c**) Ripple magnification for grid side current.

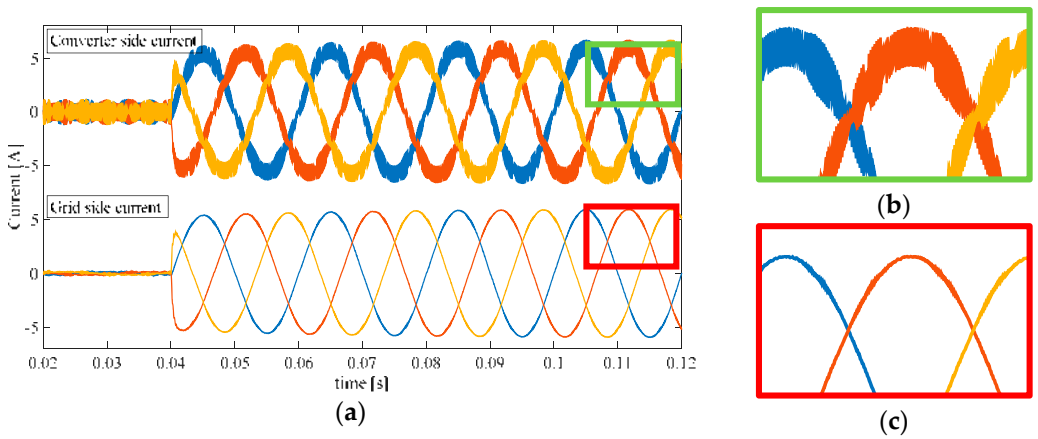

Figure 20. Converter side and grid side three-phase current with SAPOD. (**a**) Transient behavior in multiple cycles; (**b**) Ripple magnification for converter side current; (**c**) Ripple magnification for grid side current.