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HARMONIC ANALYSIS OF A THREE-PHASE PWM INVERTER

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Abstract *The presence of nonsinusoidal voltage and currents in electric power systems is the consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, unbalanced power systems, lighting controls, computer and data processing equipment, as well as industrial plant rectifiers and inverters. These electronic-type loads cause harmonic pollution in the system. This paper presents the analysis of harmonics from the PWM inverter.*
Keywords*: harmonic analysis, three-phase inverter,PWM, nonsinusoidal, data acquisition*

Introduction

In modern electrical energy systems, voltages and especially currents become very irregular due to the large numbers of nonlinear loads and generators in the grid. Particularly, power electronic-based systems such as adjustable speed drives, power supplies for IT-equipment and high-efficiency lighting and inverters in systems generating electricity from distributed renewable energy sources are sources of disturbances

Distortions encountered are, for instance, harmonics, flicker, and transients, all being elements of power quality problems [1].

Power quality problems can cause system equipment malfunction; computer data loss and memory malfunction of sensitive loads such as computer, programmable logic controller controls, protection, and relaying equipment; and erratic operation of electronic controls. Therefore, it is necessary to monitor these disturbances [2].

In the last years, the development of the power electronic devices, make possible to obtain the new techniques of power conversion.

These techniques achieve the bettering of the current waveform and the power factor, an easy filtration and the minimum commutation losses.

All of these advantages are obtained with the systems that use the high switching frequencies. In these cases the distortions appear at the switching frequencies.

A source of harmonics in this category is the electrical drives that use the pulse-width modulated technique.

Pulse-width Modulated (PWM) inverters

Switch-mode dc-to-ac inverters are used in ac-motor drives and uninterruptible ac power supplies where the objective is to produce a sinusoidal ac output whose magnitude and frequency can both be controlled.

In PWM inverters, the input dc voltage is essentially constant in magnitude. Therefore, the inverter must control the magnitude and the frequency of the ac output voltages.

This is achieved by pulse-width modulation (PWM) of the inverter switches and hence such inverters are called PWM inverters. There are various schemes to pulse-width modulate the inverter switches in order to shape the output ac voltages to be as close to a sine wave as possible [3].

The load-independent commutation and the relatively high switching frequency, which permit rapid response to the controller, make the pulse-width modulated voltage source thyristor inverter an excellent choice for drives with high dynamic performance [4].

In inverter circuits, the PWM is a bit more complex; we would like the inverter output to be sinusoidal whose magnitude and frequency should both be controllable. In order to produce a sinusoidal output voltage waveform at a desired frequency, a sinusoidal control signal at the desired frequency is compared with a triangular waveform establishes the inverter switching frequency and is generally kept constant along with its amplitude U_p (figure 1).

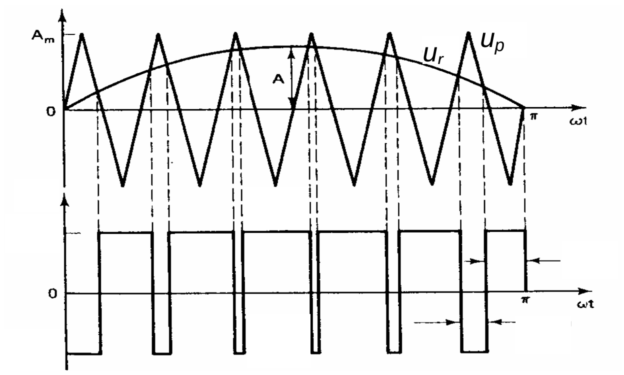


Figure 1: pulse-width modulated technique

It is necessary to define a few terms. The triangular waveform u_p in figure1 is at a switching frequency f_p, which establishes the frequency with which the inverter switches are switched (f_p is also called the carrier frequency). The control signal u_r is used to modulate the switch duty ratio and has a frequency f_r, which is the desired fundamental frequency of the inverter voltage output (f_r is also called the modulating frequency), recognizing that the inverter output voltage will not be a perfect sine wave and will contain voltage components at harmonic frequencies of f_r [3].

The amplitude modulation ratio *r* is defined as:

$$r = \frac{U_r}{U_p} \qquad (1)$$

where U_r is the peak amplitude of the control signal. The amplitude U_p of the triangular signal is generally kept constant. The frequency-modulation ratio *m* is defined as:

$$m = \frac{f_p}{f_r} \qquad (2)$$

The harmonic spectrum is shown in figure 2, where the normalized harmonic voltages $(U_{Ao})/(U_d/2)$ having significant amplitudes are plotted.

This plot show the harmonic in the inverter output voltage appear as sidebands, centered around the switching frequency and its multiples, that is, around harmonics *m*, *2m*, *3m*, and so on.

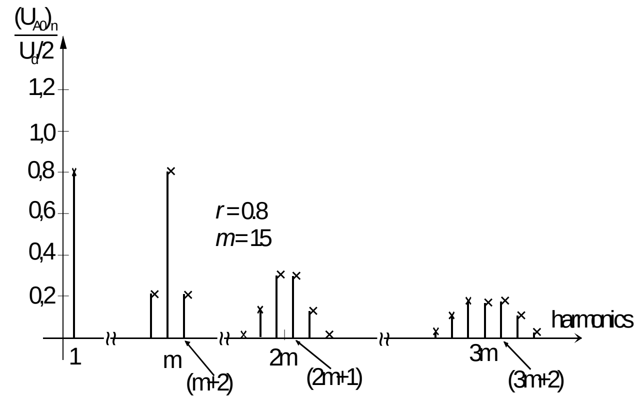


Figure 2: the harmonics spectrum for PWM inverter

This general pattern holds true for all values of *r* in a range 0 to 1. For a frequency modulation ratio $m \geq 9$ (which is always the case, except in very high power ratings), the harmonic amplitudes are almost independent of *m*, though *m* defines the frequencies at which they occur. Theoretically, the frequencies at which voltage harmonics occur can be indicated as:

$$f_n = (jm \pm k) \cdot f_r \qquad (3)$$

that is, the harmonic order *n* corresponds to the *k*th sideband of the *j* times the frequency-modulation ratio m:

$$n = jm \pm k \qquad (4)$$

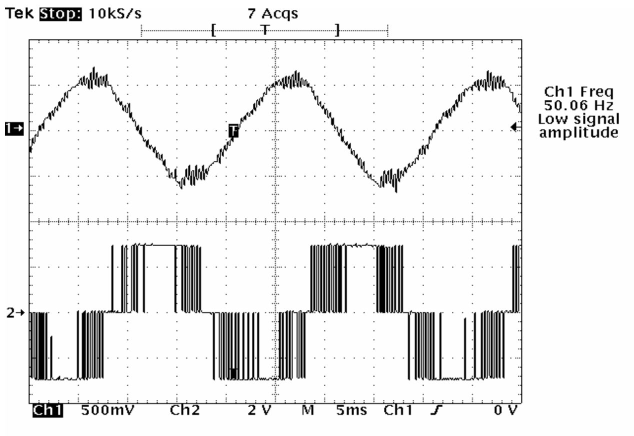
where the fundamental frequency corresponds to $n = 1$. For odd values of *j*, the harmonics exist only for even values of *k*. For even values of *j*, the harmonics exist only for odd values of *k*.

Experimental Results

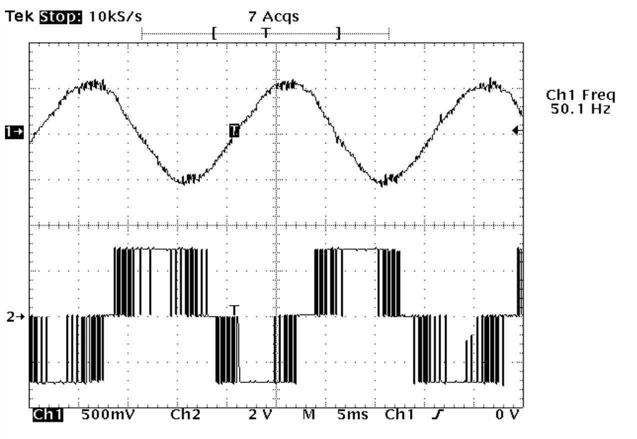
For emphasize that the PWM inverter produce harmonics families that are depend by modulation ratio, we make some experimental determinations at f_r = 50 Hz and f_p = 3 kHz, respectively f_p = 6 kHz. We use the frequency static converter – Leroy Somer. The three-phase induction motor is the consumer. Figure 3 shows the arrangement.

Figures 4 a, b displays the current (first waveform) and voltage (second waveform) waveforms distorted at the consumer, for the two values of f_p.

Figure 3: the arrangement



a (f_p = 3 kHz)



b (f_p = 6 kHz)

Figure 4: the current and voltage waveforms to the inverter output

The data acquisition for the voltage and the current we make with the digital oscilloscope – TDS 310 from Tektronix. Next we transfer the date in the PC with the help of WaveStar 23 program. It may be save these dates both text format and graph format. The dates in the text format are readied with Matlab6.

Figure 5 illustrates the harmonic spectrum of current from the case when f_p = 3 kHz and figure 6 illustrates the harmonic spectrum of voltage in the same case.

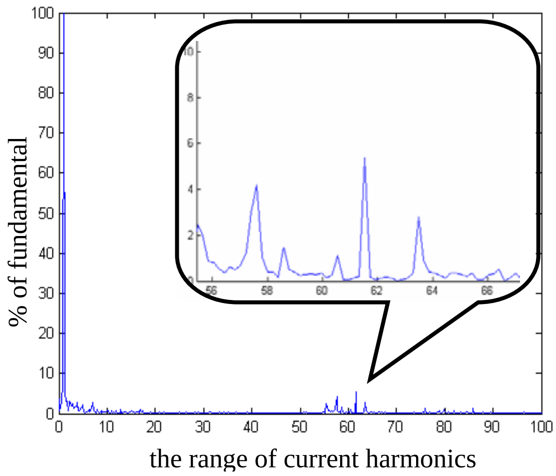


Figure 5 (f_p = 3 kHz)

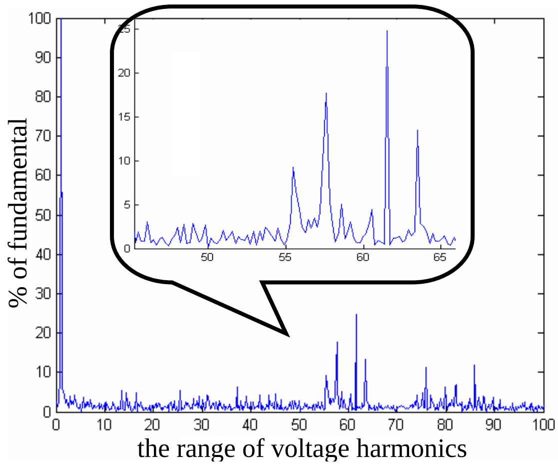


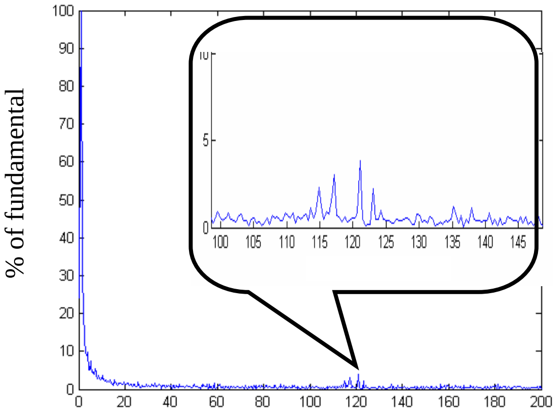
Figure 6 (f_p = 3 kHz)

Figure 7 illustrates the harmonic spectrum of current from the case when f_p = 6 kHz and figure 8 illustrates the harmonic spectrum of voltage in the same case.

For f_p = 3 kHz and f_r = 50 Hz, the modulation ratio m = 60. Therefore, the first harmonics family (which is the most important) appear at 60±2, 60±4, approximately at 3 kHz, that is clear from the figures 5 and 6.

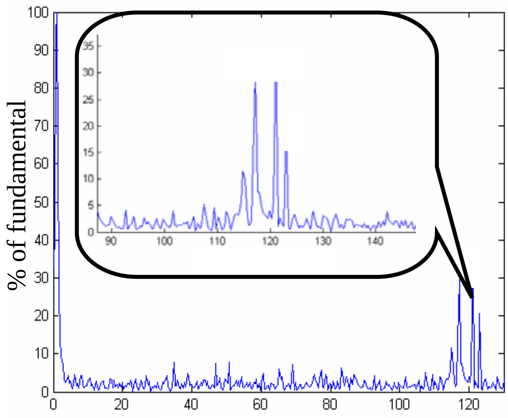
It can be observed that the voltage harmonics are higher in amplitude than the current harmonics. The amplitude of the voltage harmonics is ≈ 20% of fundamental. Because these harmonics appear at higher frequencies, they are not so dangerous for the electric power system.

For f_p = 6 kHz and f_r = 50 Hz, the modulation ratio m = 120. Therefore, the first harmonics family (which is the most important) appear at 120±2, 120±4, approximately at 6 kHz, that is clear from the figures 7 and 8.



the range of current harmonics

Figure 7 (f_p = 6 kHz)



the range of voltage harmonics

Figure 8 (f_p = 6 kHz)

Conclusions

The PWM inverters permit to obtain better waveforms, which are easy to filter. Therefore, the harmonics are translated at the high frequencies.

Because of the relative ease in filtering harmonic voltages at high frequencies, it is desirable to use as high a switching frequency as possible, but the switching losses in the inverter switches increase proportionally with the switching frequency.

Therefore, the number of commutations must be choice with attention for to obtain: a good output voltage waveform, the minimum harmonics spectrum, a good efficiency for inverter, and the sure operation.

References

[1] Driesen, L.J., Belmans, J.M., *Wavelet-Based power quantification approaches*, IEEE Transactions On Instrumentation And Measurement, Vol. 52, No.4, August 2003

[2] Dash, P.k., Panigrahi, B.K., Sahoo, D.K., Panda, G., *Power quality disturbance data compression, detection, and classification*, IEEE Transactions On Power Delivery, Vol. 18, No.2, April 2003

[3] Mohan, N., Undeland, T.M., Robins, W.P., (1989), *Power Electronics: Converter, Applications, and Design*, John Wiley & Sons, New York,

[4] Leonhard, W., (1990), *Control of electrical drives*, Springer-Verlag, New York.