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ANGULAR PWM MODULATION (PWMA)

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Abstract: *PWMA allows the reduction of the commutation losses in the power elements of the inverters and represents a supplementary element in optimizing the power circuits, contributing as well to an increased efficiency. Due to the PWMA modulation, we are no longer confronted with the well-known problem regarding the instability of the commutations between 20 and 30Hz.*
***KEYWORDS**: PWMA MODULATION, POWER CIRCUTS, COMPUTER SIMULATIONS*

1. Introduction

Most of single-phase and three phase inverters use the sinusoidal PWM modulation, that generates the command impulses for the commutation elements by comparing a sinusoidal wave with a triangular modulator wave [1]-[3]. The result is the well-known pulsatory waveform of the engine voltage, which, after the integration, follows the sinusoidal waveform with a precision determined by the frequency of the triangular modulator waveform. The disadvantage of this approach is obvious, as the higher switching frequency determines more commutation losses in the power elements. The increased power dissipation leads to the reduction of the efficiency of the power elements, even if the heat sinks have greater dimension, because the thermic capacity of the transistors' siliceous structure is reduced. In some cases, the 3rd harmonic overlaps the sinusoidal oscillation this leads to a better commutation behavior when the inverter is maximally loaded. The implementation of the PWMA modulation allows the extension of this behavior to any kind of loads.

2. PWMA modulation

2.1. The generation of the modulating signal v_{PWMA}

The generation principle of the command signal for the proposed modulation, is similar to the sinusoidal PWM modulation, except that, in this case, the modulating signal v_{PWMA} has a special structure, as its wave-form can be easily modified by a periodical signal $s_t(\omega t)$, as in the following modulation.

Figure 1 shows how the v_{PWMA} signal is obtained. Starting from the sinusoidal signal and adding the component of the 3rd harmonic, we obtain the v_{3rA} signal; this is a sinusoidal signal with a battered peak, which presents maximum points at the moments $\frac{\pi}{3}$, and $\frac{2\pi}{3}$. This signal is added to the s_t signal, which has the period 2π and the amplitude $\pm$ A, as we can see in Figure 1. The resulting signal is the modulating signal v_{PWMA}.

The relation (1) gives the equation that characterize the v_{PWMA} signal.

$$v_{PWMA} = v_{3rA} + s_t = \\ = m^*{}_a(\sin\omega t + k_1 \sin 3\omega t) + s_t \tag{1}$$

The constant k_1 is determined from the condition starting that the reference wave must contain a maximum at the moment $\frac{\pi}{3}$.

$$\frac{dv_{3rA}}{dt} = 0 \Rightarrow m^*{}_a(\cos\omega t + 3k_1 \cos 3\omega t) = 0 \\ \Rightarrow k_1 = \frac{1}{6} \tag{2}$$

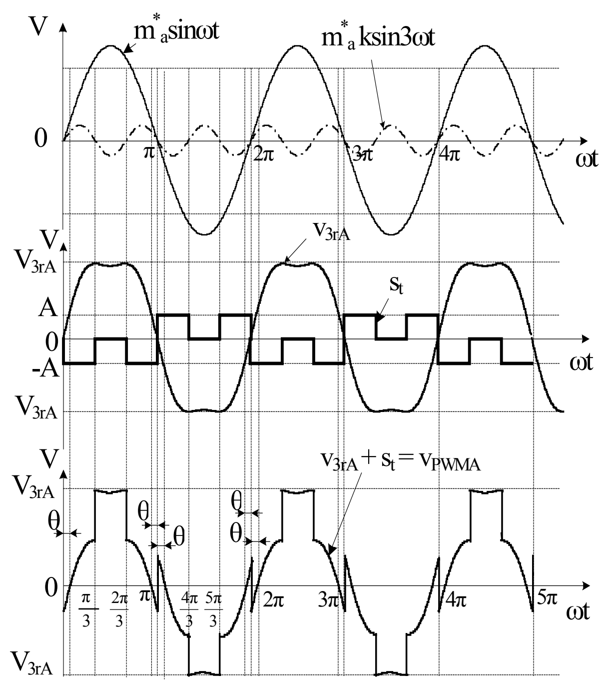

Fig. 1 Generating of the modulating signal v_{PWMA}

The maximum value of modulation degree is obtained by imposing the following condition: the maximum value of the reference wave must not exceed the amplitude of carrier at the moment $\frac{\pi}{3}$.

$$m^*{}_a \sin\frac{\pi}{3} = 1 \Rightarrow m^*{}_a = \frac{2}{\sqrt{3}} \tag{3}$$

The signal v_{3rA} is expressed by:

$$v_{3rA} = \frac{2}{\sqrt{3}}(\sin \omega t + \frac{1}{6}\sin 3\omega t) \tag{4}$$

The signal s_t, is expressed by (5);

$$s_t(\omega t) = \begin{cases} -A, \ \omega t \in \left(0, \frac{\pi}{3}\right) \cup \left(\frac{2\pi}{3}, \pi\right) \\ 0, \quad \omega t \in \left(\frac{\pi}{3}, \frac{2\pi}{3}\right) \cup \left(\frac{4\pi}{3}, \frac{5\pi}{3}\right) \\ +A, \ \ \omega t \in \left(\pi, \frac{4\pi}{3}\right) \cup \left(\frac{5\pi}{3}, 2\pi\right) \end{cases} \tag{5}$$

modulating signal v_{PWMA} is expressed by (6)

$$v_{PWMA} = \frac{2}{\sqrt{3}}(\sin \omega t + \frac{1}{6}\sin 3\omega t) + s_t(\omega t) \tag{6}$$

Analyzing the waveform of modulating signal in Figure 1, we notice that it has different phase from the origin, forming an angle θ, which can be modified by increasing or decreasing the amplitude ± A of the signal s_t the value of the angle θ is between o and $\frac{\pi}{3}$ radians. The name o this type of modulation is given by the modification of the modulating signal according to the angle θ.

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In this case the output voltage of the inverter is established by keeping the modulation degree constant and the unitary value, and by modifying the value of the angle θ.

In Figure 2 presents power circuit of the three phase inverte

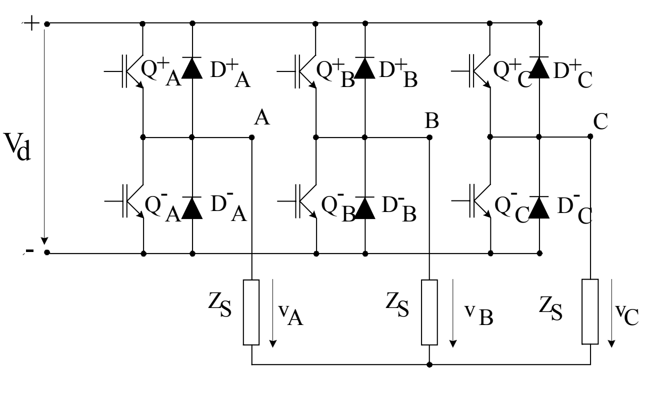


Fig. 2 Power circuit of the three phase inverter

Figure 3 presents the waveforms of the modulating signal for three different value of the angle θ. These values are determined by modification of the amplitude of the signal s_t.

Using this modulation strategy and the inverter circuit in Figure 2, in Figure 4 presents the waveform of the modulating signal, of the triangular signal, as well as, the conduction time, for each transistor of the power circuit.

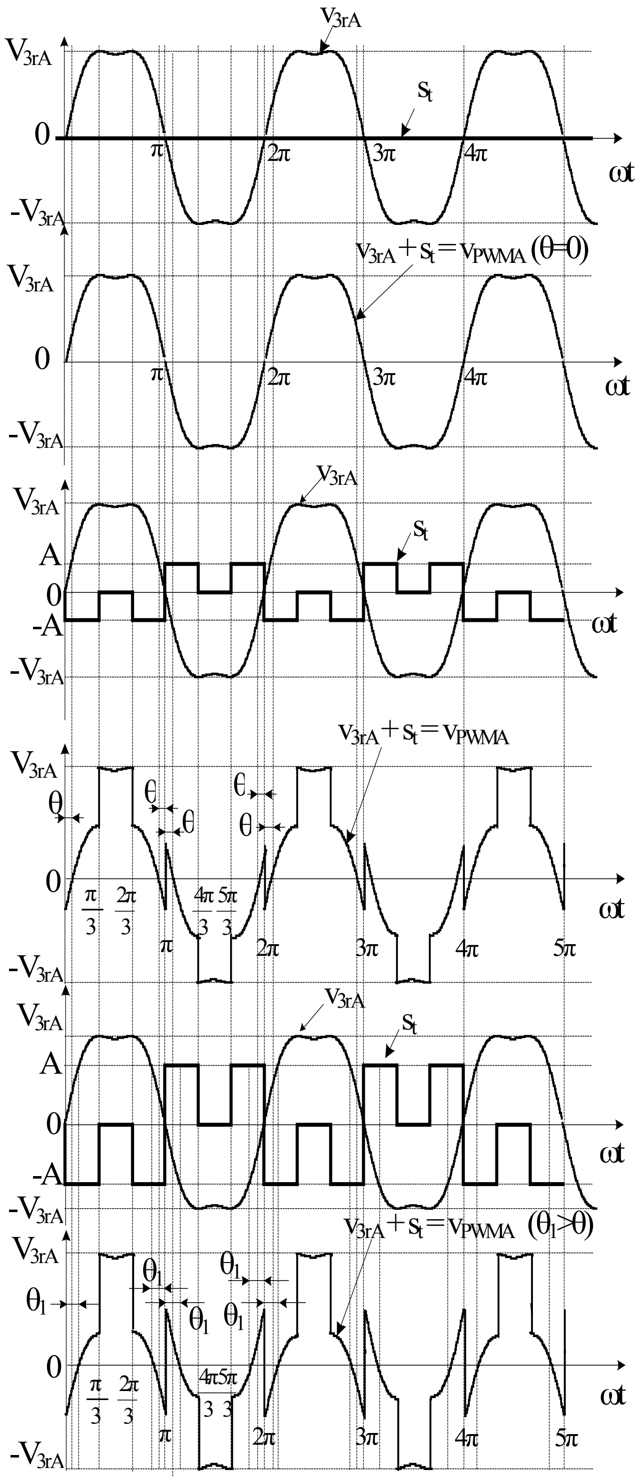


Fig. 3 Wave-forms of the modulating signal v_{PWMA} for three different values of the angle θ.

When the signal s_t has zero magnitude on fixed time intervals $\left(\frac{\pi}{3}, \frac{2\pi}{3}\right) \cup \left(\frac{4\pi}{3}, \frac{5\pi}{3}\right)$, only two of three commutation pairs modify continuously their commutation states; this can happen in any moment, but especially when it functions under nominal frequency. In these conditions, the commutation losses in the power elements are reduced by up to 30%.

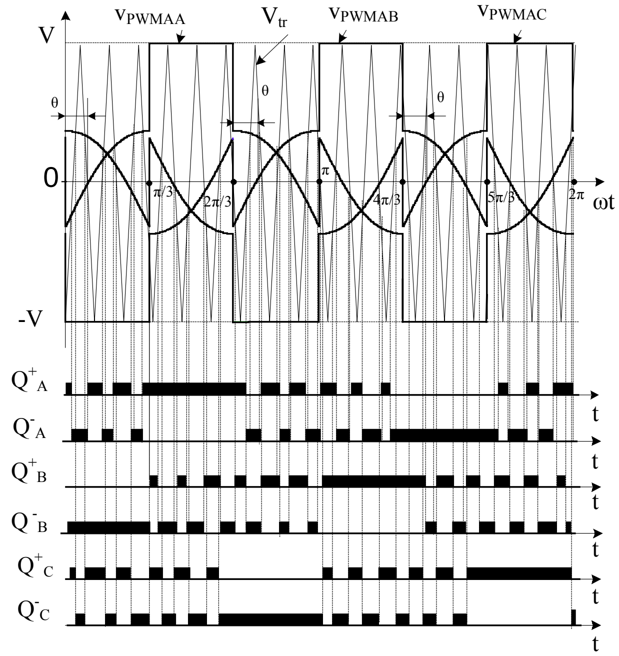
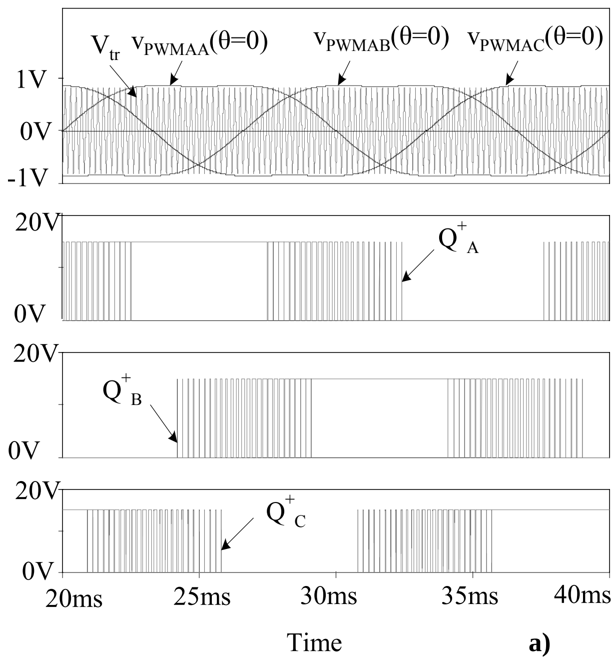


Fig. 4 Wave-forms of the triangular signal v_{tr}, of the modulating signals , and the command signals

2.2. Simulation results

The good functioning of the proposed circuits was checked by simulation Figure 5 presents the wave-forms of the triangular signal, of the modulating signal, as well as the wave forms of the command signals of the transistors Q^+_A , Q^+_B and Q^+_C (for θ=0 and θ=π/9), for a commutation frequency f_c =5kHz, and an amplitude modulation factor m_a =0,98, using the modulation strategy PWMA.



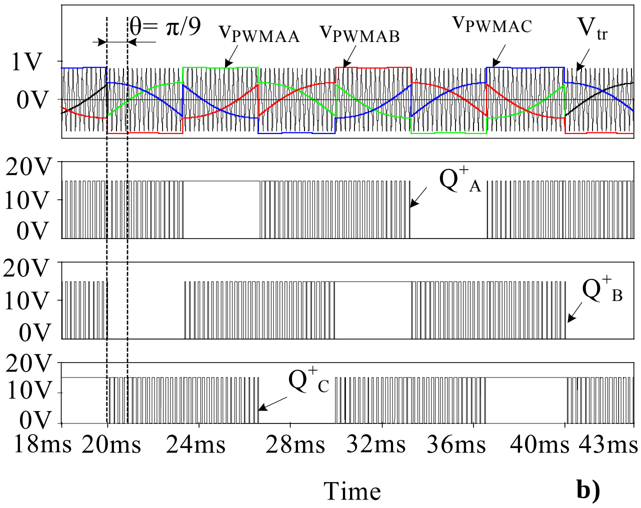


Fig.5 Wave – forms for a) θ=0, b) θ=π/9.

Figure 6 presents wave-form of the phase voltage and line voltage for f_c = 5kHz using PWMA modulation.
Figure 7 presents the spectrum of the phase voltage and the line voltage for f_c = 5kHz, using PWMA modulation.

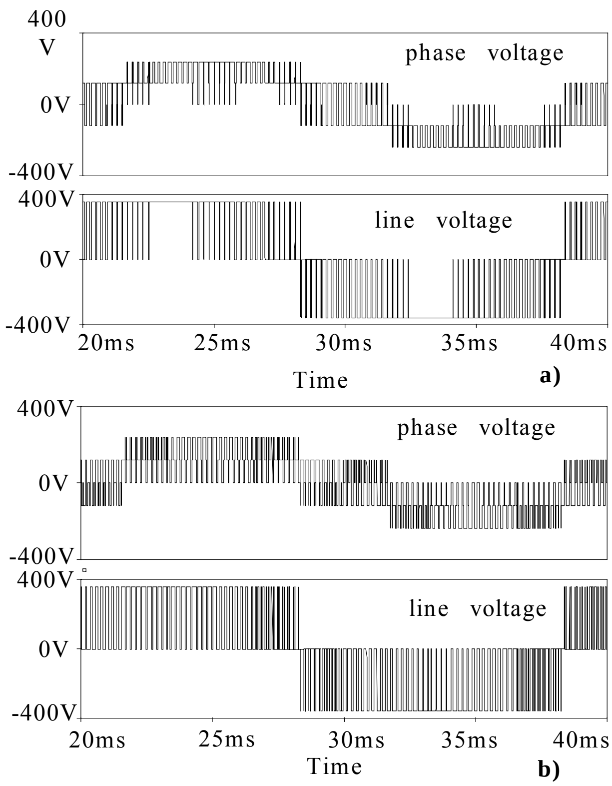


Fig.6. Wave-form of the phase voltage and line voltage for a) θ=0, b) θ=π/9

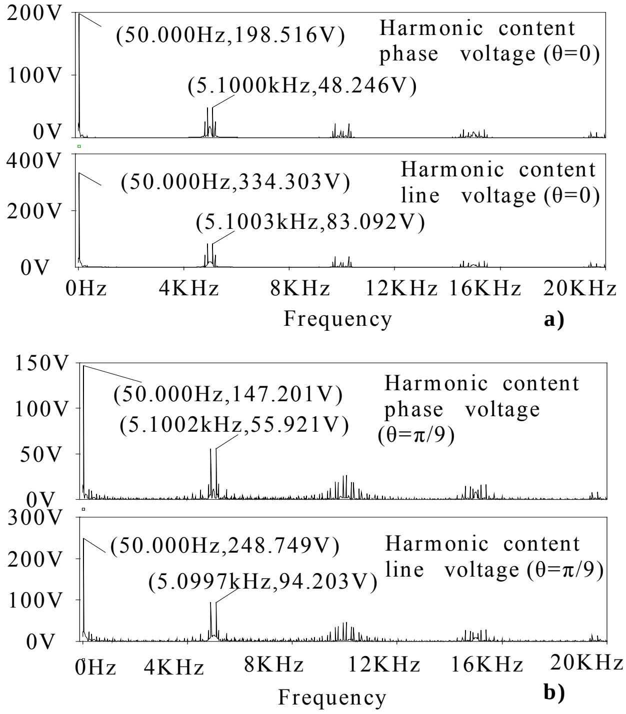


Fig.7. Spectrum of the phase voltage and the line voltage
a) θ=0, b) θ=π/9

3. Conclusion

The silent functioning of the electrical engines driven by inverters can be reached by increasing the switching frequency of the inverter, but the increase of frequency leads to greater losses during switching in the power elements. The PWMA modulation represents a relatively simple solution, which determines the reduction of the losses during commutation at high frequencies.
The command diagram of the transistors in the power circuit shows that, for the PWMA modulation, there commutation losses are reduced by approximately 30%, compared to the sinusoidal PWM modulation; moreover by adding the 3rd harmonic, the output voltage and the output power are increased.

4. References

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