Investigation of PWM using Sinusoidal Waveform as a Career Signal for Reduction of Magnitude of Specified Harmonics

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ABSTRACT: Many researchers have been done on PWM switching methods for finding better ways to supply the loads, which have lower harmonics in outputs. Applying of triangular career signal in SPWM is a common way. In this paper, the novel technique of using of sinusoidal career signal has been presented. To validate the proposed techniques, simulation studies have been carried out with SABER software. Results have been compared with conventional SPWM. The results show that in some harmonics this new technique is better than SPWM method. Therefore this new technique can be used for decrease some specified harmonics. Moreover, simplifying of solving the related mathematical equations is another advantage of this new method, because only sinusoidal equations are appeared and triangular signal is not used.

Keywords: Pulse Width Modulation, SPWM, Harmonics, SABER, Triangular Career Signal.

INTRODUCTION

The multilevel inverters have become an important technology in a high-power conversion system (Selvaraj and Rahim, 2009; Lakshminarayanan et al., 2007; Rodriguez et al., 2007; Meynard et al., 2002; Bernet et al., 2005; Gopinath et al., 2009; Leon et al., 2009). The crucial advantage of multilevel inverters is the increasing of the number of levels and, consequently, the improvement of harmonic contents in the output voltage and using devices of low voltage rating with lesser switching frequency. The topologies, such as single and three-phase neutral-point-clamped inverters (Leon et al., 2009; Barros and Silva, 2008; McGrath and Holmes, 2002; Khan et al., 2009), cascaded H-bridge inverter (Das et al., 2009; Lezana et al., 2009; Lezana et al., 2007; Leon et al., 2009), and flying capacitor inverter (Meynard et al., 2002), are well established in medium voltage drives and power system applications.

In PWM, various methods are used (Joachim, 1992) and SPWM is one of the popular methods (Bowes, 1975). In conventional SPWM the reference signal with nominal frequency is compared with a triangular career signal with switching frequency and the output leads to the gate of switches such as IGBT's. Therefore the pulses are created in inverter’s output which supplies the load. In this paper the new technique of using a sinusoidal career signal has been represented. The outputs of these novel methods have been simulated and analyzed using of SABER software, and the results have been compared with conventional SPWM. For accurate comparison, all conditions of two systems has set the same, except the career signal. The frequency of reference signal is 50 Hz and the frequency of career signal is 10 kHz.

CONVENTIONALSPWM

In SPWM technique a triangular career signal and sinusoidal reference signal intersect each other. In using of triangular career non linear equations are appeared. Reference signal equation:

\[ y = A_r \cdot \sin(2 \cdot \pi \cdot f_r \cdot t) \]  \hspace{1cm} (1)

Where \( A_r \) is the amplitude of reference signal, and \( f_r \) is the frequency of the reference signal.
First part of career signal equation:
\[ y = \frac{Ac}{4fc} t = 4Ac * fc * t \quad 0 \leq t \leq \frac{1}{4fc} \]  
(2)

Where \( Ac \) is the amplitude of career signal, and \( fc \) is the frequency of the career signal. The answer is obtained by solving below non linear equation:
\[ Ar\sin (2 \pi * (t - \frac{1}{4fc}) = 4Ac * fc * t \quad 0 \leq t \leq \frac{1}{4fc} \]  
(3)

Second part of career signal equation:
\[ y = \frac{-Ac}{4fc} \left( t - \frac{1}{2fc} \right) = -4Ac * fc * t + 2Ac \quad \frac{1}{4fc} \leq t \leq \frac{3}{4fc} \]  
(4)

The answer is obtained by solving below equation:
\[ Ar\sin (2 \pi * (t - \frac{1}{2fc}) = -4Ac * fc * t + 2Ac \]  
\[ \quad \frac{1}{4fc} \leq t \leq \frac{3}{4fc} \]  
(5)

The first part of \( k \)th cycle of career signal equation:
\[ y = \frac{Ac}{4fc} \left( t - \frac{k-1}{fc} \right) = 4Ac * fc * t - 4Ac * (k-1), \quad K \in \mathbb{Z}, \quad \frac{4k-5}{4fc} \leq t \leq \frac{4k-3}{4fc} \]  
(6)

And the answer is obtained by solving below equation:
\[ Ar\sin (2 \pi * (t - \frac{k-1}{fc}) = 4Ac * fc * t - 4Ac * (k-1), \quad K \in \mathbb{Z}, \quad \frac{4k-5}{4fc} \leq t \leq \frac{4k-3}{4fc} \]  
(7)

The second part of \( k \)th cycle of career signal equation:
\[ y = \frac{-Ac}{4fc} \left( t - \frac{2k-1}{2fc} \right) = -4Ac * fc * t + 2Ac * (2k-1), \quad K \in \mathbb{Z}, \quad \frac{4k-3}{4fc} \leq t \leq \frac{4k-1}{4fc} \]  
(8)

And the answer is obtained by solving below non linear equation:
\[ Ar\sin (2 \pi * (t - \frac{2k-1}{2fc}) = -4Ac * fc * t + 2Ac * (2k-1), \quad K \in \mathbb{Z}, \quad \frac{4k-3}{4fc} \leq t \leq \frac{4k-1}{4fc} \]  
(9)

Below figure shows the circuit that has been used for triggering of inverter switches.
In novel technique, PWM using sinusoidal career, the sinusoidal signal is used instead of triangular career signal. By changing the career signal, different outputs are appeared. The width of pulses changes and becomes smaller in comparison of using of triangular career signal.

In PWM with sinusoidal career signal, there is only one equation. Reference signal equation:

\[ y = A_r \sin (2 \pi f_r t) \]  \hspace{1cm} (10)

Where \( A_r \) is the amplitude of reference signal, and \( f_r \) is the frequency of the reference signal. Career signal equation:

\[ y = A_c \sin (2 \pi f_c t) \]  \hspace{1cm} (11)

Where \( A_c \) is the amplitude of career signal, and \( f_c \) is the frequency of the career signal. The answer is obtained by solving below trigonometric equation:
\[ A_c \sin (2 \pi f_c t) = A_c \sin (2 \pi f_c t) \] (12)

Below figure shows the circuit that sinusoidal carrier signal have been used for triggering inverter switches.

By using Fourier transform for output waveform, the magnitude of frequency components are obtained as indicated in figure 11. Other setting of the circuit doesn't change. The frequency of carrier signal is 10 KHz and the amplitude of carrier is 1 and the amplitude modulation ratio is 0.8.

DC supply of inverter has been considered as an ideal power supply. While in practice, a rectifier is used to produce DC voltage, and rectifier's output is not ideal and has problems such as voltage ripple. But this simplifying is useful to analyze the PWM techniques and its affect on harmonics. In above figure the frequency of carrier signal is 10 KHz and the amplitude of carrier is 1 and the amplitude modulation ratio is 0.8.

By using Fourier transform for output phase voltage waveform, the magnitude of frequency components are obtained as indicated in below figure. In this paper 9 harmonics has been investigated for calculating frequency components.

These harmonics are result of pulse width modulation, and high frequency effects of circuit such as parasitic elements of circuit are not considered.

**SIMULATION RESULTS**

To verify the proposed novel methods, simulation studies have been carried out and the results have been compared with conventional SPWM. The results of conventional SPWM and PWM using sinusoidal career signal have been shown in below table. This table shows that in some harmonics the new technique with sinusoidal career signal has better performance in comparison of SPWM with triangular career signal.
Figure 9. Three phases PWM using sinusoidal carrier signal

Figure 10. Phase voltage waveform using sinusoidal carrier signal

Figure 11. The magnitude of frequency components of PWM using sinusoidal carrier signal
The above table shows that the magnitudes of harmonics 2,3,4 and 7 has been decreased, and the magnitude of harmonics 5 and 6 has been increased.

**CONCLUSION**

In this paper the novel technique, PWM using of sinusoidal career signal has been represented. From the simulation results, it is observed that in some harmonics PWM using of sinusoidal career signal has better performance compared to conventional SPWM. Therefore, this new technique can be used for reduction of magnitude of some specified harmonics. Moreover, simplifying of solving the related mathematical equations is another advantage of this new technique.

**REFERENCES**


