An On-Line Harmonics Elimination PWM Scheme for Three-Phase Voltage Source Inverters

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Abstract— **An on-line harmonic elimination PWM (HEPWM) scheme for three-phase voltage source inverters is proposed. It is based on curve fitting method derived from the trajectories of the exact (off-line) HEPWM angles. The main advantage of the technique is its fast and efficient realization using a microprocessor. An outline to obtain the switching angles is presented. The method is proven by experimental results.**

Keywords—**PWM, harmonic elimination technique, Three-phase Invereter**

I. Introduction

The method to calculate the harmonics elimination PWM (HEPWM) switching angles was originally proposed by Patel and Hoft [1]. However, the resulting equations for the exact switching angles are transcendental and therefore could not be solved online by digital techniques. The common technique is to calculate the HEPWM switching angles off-line and then subsequently stored them into look up tables. However with a large number of possibilities of modulation index, ratio, and the required interpolation, the computing requirement can be very large. This deficiency motivates research to sought for methods to determine the switching angles on-line [2,3] This letter proposes a scheme to calculate the approximate HEPWM angles on-line based on the curve fitting of the trajectories of the exact HEPWM angles. The scheme is designed to eliminate the selected harmonics in a three-phase inverter system. Due to the simplicity of the algorithm, it is envisaged that the proposed method permits a faster and more efficient real-time computations using a microprocessor.

II. THE PROPOSED SHCEME

The generalized quarter-wave symmetry PWM pole switching waveform with unit amplitude is shown in Fig.1.The odd switching angles α_k (k=odd) define the negative going transitions and the even switching angles α_k (k=even) define the positive going transitions. Due to quarter-wave symmetry $B_n=0$; therefore only odd harmonics exist as described in (1). Equation (1) has m variables and a set of HEPWM angles (α_1, α_2 α_k through α_m) is obtained by equating any $m-1$ harmonics to zero and assigning a value to the fundamental component. These equations are nonlinear as well as transcendental in nature and has been demonstrated to be accurately solved using numerical iteration [1].

$$A_n = \frac{4}{n\pi}\left[1 + 2\sum_{k=1}^{m}(-1)^k \cos n\alpha_k\right] \quad (1)$$

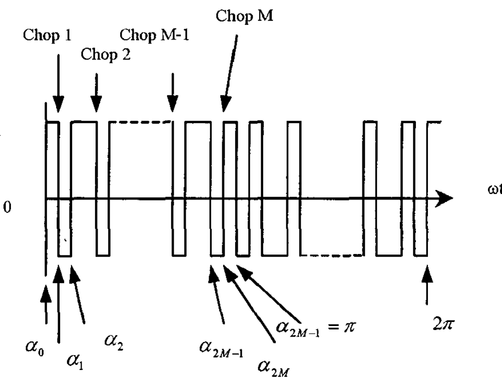


Fig.1: Generalized quarter-wave symmetric pole switching

From the solutions, trajectories for the switching angles versus the amplitude of the fundamental component of the pole switching waveform (*NP1*) can be plotted for various values of m. An example of the trajectory for m=5 is shown in Fig 1. The trajectories for other values of m will have similar pattern. From Fig. 2, for 0<*NP1*<0.8, the trajectories of the angles approximate a straight line. Hence a straight-line approximation could be used. However, for *NP1*> 0.8, the trajectories are no longer straight lines. Nevertheless, the straight-line approximation can be considered by incorporating a suitable an error correction scheme. The relationship between the normalized slopes (Δ_k) of the trajectories for the different values of m can be written as

$$\Delta_k = \frac{\dfrac{60^\circ(k+1)}{(m+1)} - \alpha_k}{\dfrac{2\times 60^\circ}{m+1}} \quad , k \text{ odd} \quad (2)$$

$$\Delta_k = \frac{\alpha_k - \dfrac{60^\circ(k)}{(m+1)}}{\dfrac{2\times 60^\circ}{m+1}} \quad , k \text{ even} \quad (3)$$

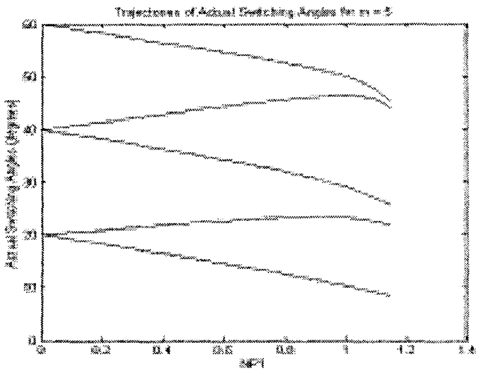


Fig.2: Switching angles trajectories for m=5

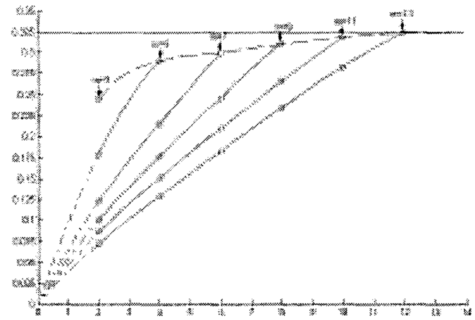


Fig. 4: Variation for even switching angles

Fig.3 shows the variation of Δ_k, for odd switching angles for various values of m. The graphs suggest that the function Δ_k resembles a set of quadratic curves with nearly constant amplitude

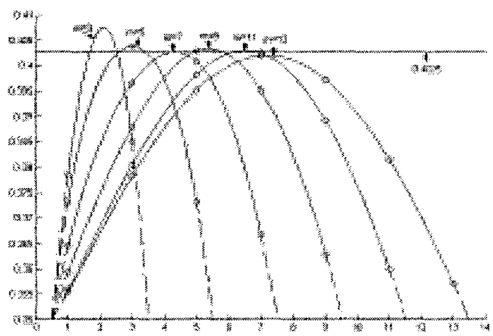


Fig. 3: Variation with odd k

Applying a quadratic fit to the curves, Δ_k can be expressed as:

$$\Delta_k = -\frac{0.21}{m^2}\left(k - \frac{m+1}{2}\right)^2 + 0.4025 \quad \text{, k odd} \quad (4)$$

The generalized equation for odd switching angles, for any value of m and $NP1$, can be formulated as:

$$\alpha_k = \frac{60^o(k+1)}{m+1} - \left[\frac{2\times 60^o}{m+1} \times \frac{\Delta_k \times NP1}{0.8}\right] \quad \text{, k odd} \quad (5)$$

For even switching angles, the variation of Δ_k with k for various values of m is shown in Fig. 4.

Applying curve fitting technique yields:

$$\Delta_k = -\frac{0.082}{(m-1)^2}\left[k - 2.482(m-1)\right]^2 + 0.505 - \frac{k}{m^3} \quad \text{, k even} \quad (6)$$

The even switching angles for any value of m and $NP1$, is then given by:

$$\alpha_k = \frac{60^o \times k}{m+1} + \left[\frac{2\times 60^o}{m+1} \times \frac{\Delta_k \times NP1}{0.8}\right] \quad \text{,k even} \quad (7)$$

Equations (4), (5), (6) and (7) can be used to calculate the approximate HEPWM switching angles for any value of m and $NP1$.

To account for non-straight line curve for the trajectories for the case for $0.8 < NP1 \leq 1.15$, an error correction scheme is incorporated. For $NP1 > 0.8$, the corrected switching angles can be formulated as:

$$\alpha_{k(corrected)} = \alpha_k - \Delta D_k \quad (8)$$

with

$$\Delta D_k = \frac{(NP1 - 0.8)^2}{0.09} \times \left[-\frac{52}{m}\left[\frac{k}{m+5} - 0.5\right]^2 + \frac{13}{m}\right] \quad (9)$$

for odd k

and

$$\Delta D_k = \frac{(NP1 - 0.8)^2}{0.09} \times \left[-\frac{52}{m}\left[\frac{k}{m+3} - 0.5\right]^2 + \frac{13}{m}\right] \quad (10)$$

for even k

III. RESULTS

To verify the validity of the algorithm, a low-power (200W) prototype inverter has been built. It is a based on a single phase inverter. The HEPWM waveform generation was implemented using a low-cost 16-bit Siemens 80C167 microcontroller. Since the algorithm is designed for three phase systems, the triplen harmonics will still exist in the output waveform of the single phase inverter. However, these harmonics will be cancelled when the line to line voltage is considered.

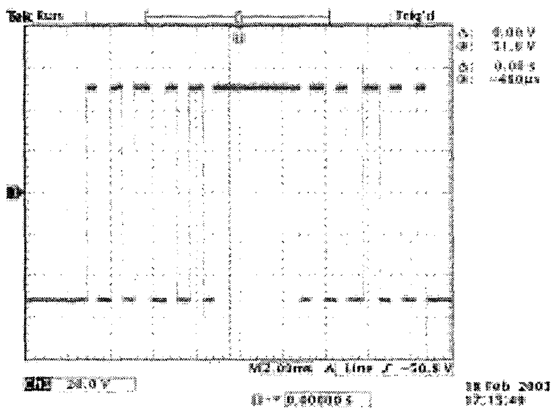


Fig. 5: Waveform of inverter output for m=5, NP1=0.7, freq = 50 Hz.

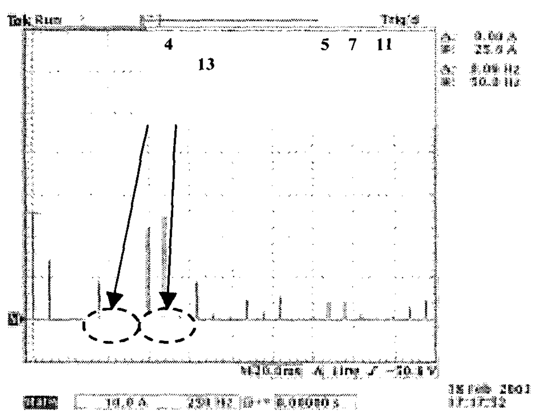
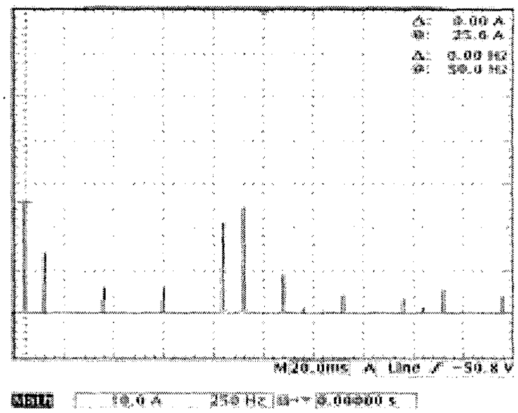
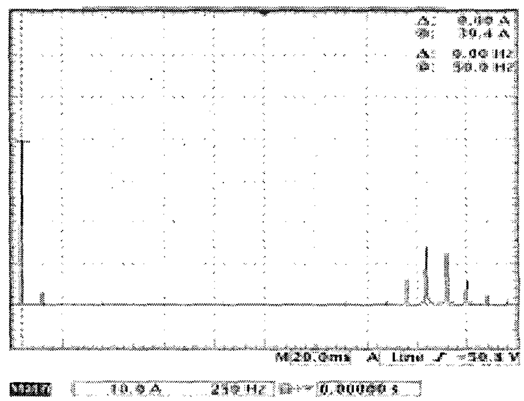


Fig. 6: Spectra of inverter output form =5, NP1 =0.7, freq= 50 Hz.

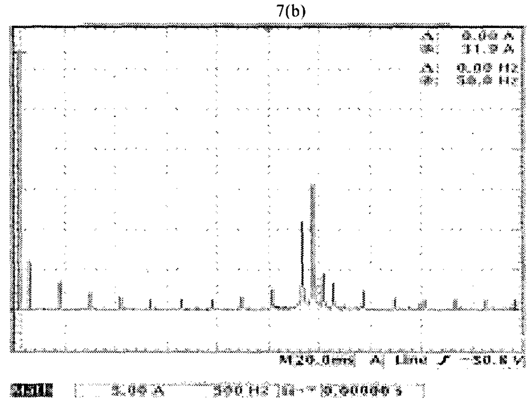
Fig.5 shows the output voltage waveform of the inverter for m=5 and NP1=0.7. For this setting the expected eliminated harmonics will be the 5th, 7th, 11th and 13th. As mentioned earlier, the triplen harmonics will remain. Fig. 6 shows the spectra of this voltage. As can be clearly seen, the expected harmonics are successfully eliminated. The triplens, of course will be automatically cancelled in a balanced three-phase system.



7(a)



7(b)



7(c)

Fig. 7: Spectra of inverter output

Figs.7 (a) through (c) show the generated spectra for m = 7, 13, and 19 respectively. For each case, a different set of NP1 is used. As can be observed, the eliminated harmonics are consistent with the predicted results presented in Table 1.

m	Harmonic eliminated
7	5,7,11,13,17,19
9	5,7,11,13,17,19,23,25
19	5,7,11,13,17,19,23,25,29,31,35,37, 41,43,47,49,53,55

Table I : Relationship between m and harmonic eliminated

V. CONCLUSION

The report proposes a scheme to calculate the on-line switching angles using HEPWM method for a three-phase system. The algorithm results in quadratic equations, which require only the multiplication process. An outline to obtain the required HEPWM switching angles is presented. The equations are programmed using a low-cost microprocessor and implemented on a prototype inverter. It was found that the scheme is able to eliminate the intended harmonics successfully.

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