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Research paper

Comparison of selective harmonic elimination and SPWM techniques for unipolar inverters

Ezzidin Hassan E. Aboadla [1, 2] *, Sheroz Khan [1], Mohamed H. Habaebi [1], Teddy Gunawan [1], Belal A. Hamida [1], Mashkuri Bin Yaacob [1], Ali Aboadla [2]

[1] *Department of Electrical and Computer Engineering, International Islamic University Malaysia (IIUM)*
[2] *Higher Institute of Science and Technology, Al-Zhara, Libya*
**Corresponding author E-mail: aboadlla@gmail.com*

Abstract

Several modulation schemes are used to operate power electronics devices MOSFETs and IGBTs in power converters and are also utilized to reduce the influence of Total Harmonic Distortion (THD) in the output voltage of these inverters. Selective Harmonic Elimination (SHE) and Sinusoidal Pulse Width Modulation (SPWM) are the most popular techniques used in this regard. Number of notches and modulation index (m) are the important parameters used to design both techniques. Total Harmonic Distortion is utilized as a standard to measure the signal quality for both schemes. This paper discusses a comparison study of using SHE and SPWM techniques in full bridge inverter. MATLAB and PSIM tools are used to estimate and verify the performance of both techniques and the results are obtained experimentally.

Keywords: *Modulation Index; Selective Harmonic Elimination; Sinusoidal Pulse Width Modulation; THD; Unipolar Inverter.*

1. Introduction

Recently, due to the fast development in the power electronics technology, power converters such as DC-to-DC or DC-to-AC become the most significant devices in the high and medium power application [1], [2]. DC-to-AC power inverters can be categorized into a half-bridge inverter, full-bridge inverter, and multilevel inverter. The main function of the power inverters is to invert the DC power source from the renewable sources such as solar energy or storage cells to AC voltage source [3]. Practically, the output waveform of the inverters is a discontinuous signal and contains unwanted harmonics. However, by using filter with the inverter, the output waveform becomes good quality and closer to a sinusoidal waveform. Total Harmonic Distortion (THD) is an important parameter utilize to measure the quality of the inverters signal [4]. Therefore, the inverter output signal is of high quality when it contains less harmonic distortion. To reduce the effect of harmonics on the inverter signal, there are several schemes used such as SPWM, and SHE techniques. These methods depend on the applications and the switching frequencies to produce a high-quality waveform with less THD, the first important step is selecting the suitable modulation technique. SPWM works with high switching frequency and is a popular scheme utilized in industrial applications to produce a good quality signal however it leads to switches losses [5]. However, Selective Harmonic Elimination (SHE) which works with low switching frequency is an appropriate technique in medium and high-power application among modulation schemes. PSIM and MATLAB tools are used to examine and evaluate the influence of both techniques SHE and SPWM on the THD using a unipolar inverter and the result is validated experimentally.

2. Sinusoidal pulse width modulation

Sinusoidal Pulse Width Modulation provides a control signal for power switches IGBTs and MOSFETs. SPWM can be generated by comparing two signals; a carrier signal f_c (triangular) and reference signal f_r (sinusoidal) as shown in Figure 1. The modulation index (m) consider the most significant parameter utilized to design SPWM. The magnitude of the fundamental component can be controlled by changing the value of the modulation index in the range from 0 to 1 [6], [7]. The ratio of the magnitude of the reference signal (V_r) to the magnitude of the carrier signal (V_c) is used to obtain the value of the modulation index [8].

$$m = \frac{V_r}{V_c} \quad (1)$$

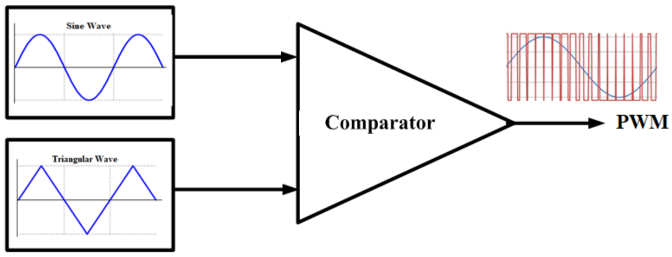

Fig. 1: PWM Signal Generating.

The frequency value of the sinusoidal signal uses to determine the output frequency of the inverter. However, the frequency of the carrier signal uses to determine the switching frequency of the PWM signal also it uses to determine the number of notch per half cycle as given below:

$$n_p = \frac{f_c}{f_r} \quad (2)$$

Where: n_p is the pulses in a half cycle.
SPWM technique can apply in two ways with a single-phase H-bridge inverter; unipolar and bipolar topology.

2.1. SPWM for bipolar inverter

For this topology, SPWM is generated by matching sinusoidal signal with a triangular signal as presented in Figure 2. The output voltage shape of this inverter between +Vdc and -Vdc as shown in Figure 3. Hence, this kind of inverter defined as two-level inverter.[9], [10].

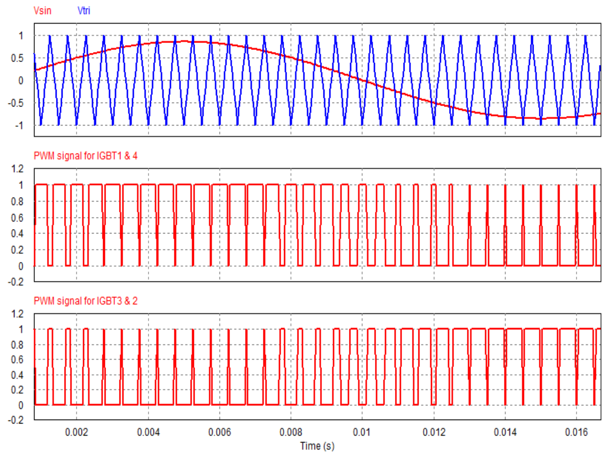

Fig. 2: Comparative between Two Signals and Switching Gate Signals of Bipolar SPWM.

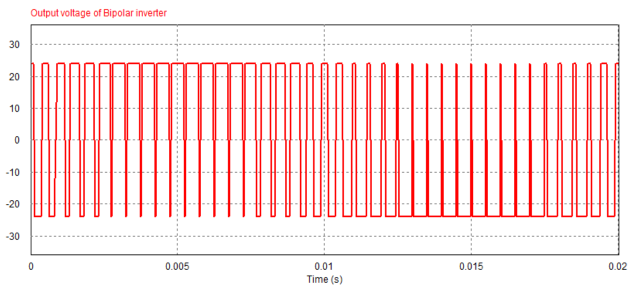

Fig. 3: Output Voltage Signal of SPWM Bipolar Inverter.

2.2. SPWM for unipolar inverter

In this topology, the SPWM is produced by comparing two sinusoidal signals as a reference have the same frequency, magnitude, but delayed 180º with a high-frequency triangular signal as shown in Figure 4. This kind of inverter called three-level inverter because the output voltage waveform changes between +Vdc, 0, -Vdc as shown in Figure 5 [11]. Because of more level is lowest THD, the output of the unipolar inverter is a higher quality than the bipolar inverter [12-14].

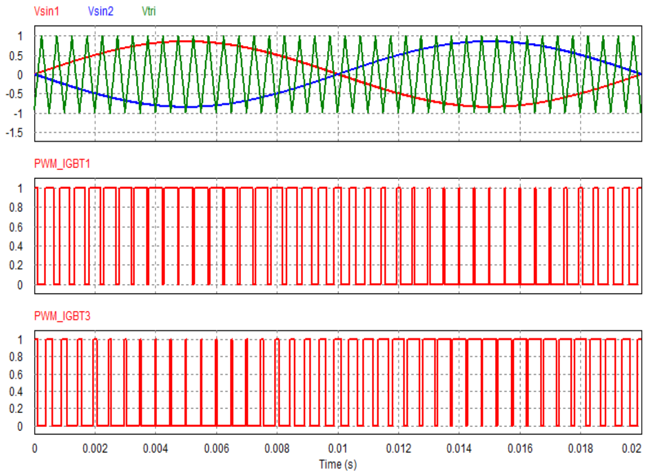

Fig. 4: Comparative Signals of Unipolar SPWM and Switching Gate Signals.

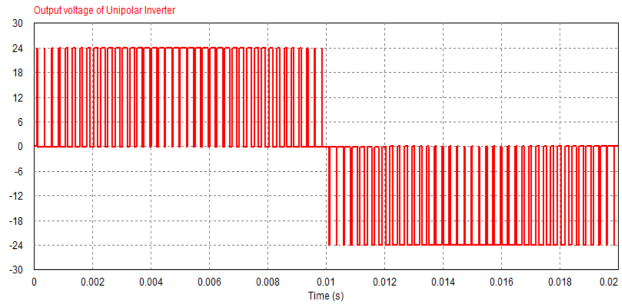

Fig. 5: Output Voltage Signal of SPWM Unipolar Inverter.

3. Selective harmonic elimination

Selective Harmonic Elimination scheme works on the low switching frequency and depends on the number of pulses in the output voltage signal to mitigate unwanted odd harmonics. By identifying the positions and durations of switching angles of these notches, undesired odd harmonics can be canceled totally from the output voltage signal of the inverter. SHE is a mathematical technique used to eliminate odd harmonics of 3rd, 5th, 7th, etc. from the output voltage signal of the inverter which is full bridge or multilevel inverter [15], [16]. SHE technique has the ability to mitigate the effect of switching losses and the current ripples [17], [18]. One of the numerical methods such as Genetic Algorithm or Newton-Raphson is used to determine a number of nonlinear equations in order to compute unknown switching angles $(\alpha_1, \alpha_2, \ldots\ldots, \alpha_N)$ as shown in Figure 6 [19–21]. Due to the symmetrical waveform, even harmonics do not appear in the inverter output signal. The output waveform of the full-bridge inverter is produced by the following Fourier series equation.

$$V_{out}(\omega t) = \sum_{n=1}^{\infty} V_n \sin(n\omega t) \quad (3)$$

Where: n is the order of odd harmonic, V_n is the magnitude of the harmonics order, which can be given by:

$$V_n = \frac{4V_{dc}}{n\pi} \sum_{k=1}^{N} (-1)^{k+1} \cos(n\alpha k) \quad (4)$$

Where: N is the number of the switching angles per quarter, V_{dc} is the amplitude of DC source, α_k is switching angles, conditioned by the following:

$$\alpha_1 < \alpha_2 < \cdots < \alpha_N < \frac{\pi}{2} \quad (5)$$

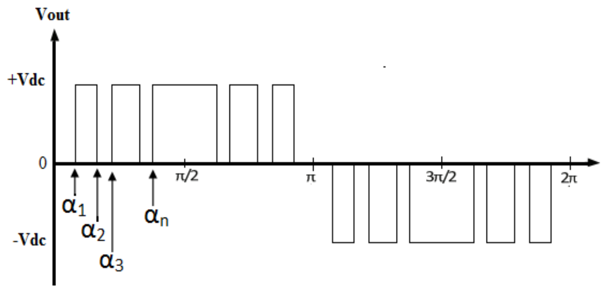

Fig. 6: The Output Signal of the Unipolar Inverter.

Because of half-wave symmetry of the inverter output signal, the number of the eliminated low order odd harmonics are dependent on the number of switching angles per quarter cycle. For example, if the number of switching angles equals N, therefore, can be eliminated N-1 of the odd harmonics. The nonlinear equations of SHE scheme can be obtained as the follows:

$$\begin{cases} V_1 = U \\ V_n = 0, n = 3,5,7,\ldots \end{cases} \tag{6}$$

Where: U is the desired of the fundamental voltage.
The undesired odd harmonics can be removed by making its amplitude equal to zero, $V_n = 0$. For instance: assuming the number of switching angles (N=3), therefore two low order odd harmonics can be eliminated such as 5^{th}, 7^{th}. Triplen harmonics such as 3rd, 9th, 15th, etc. can be canceled automatically by line to line voltage in the three phase electrical system [22]–[24]. The SHE equations which are used to compute three unknown angles (α_1, α_2, and α_3) are given as:

$$\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3) = m\frac{\pi}{4}$$

$$\cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) = 0 \tag{7}$$

$$\cos(7\alpha_1) - \cos(7\alpha_2) + \cos(7\alpha_3) = 0$$

Where: m is the modulation index, $m = \frac{V_1}{V_{dc}}$, $(0 \leq m \leq 1)$

By varying the modulation index in the range from 0 to 1, the amplitude of the fundamental component can be controlled.

4. Simulation and experimental results

Comparison of two modulation schemes; Selective Harmonic Elimination and Sinusoidal Pulse Width Modulation. PSIM and MATLAB simulation tools have been used to evaluate both methods on a unipolar full bridge inverter using the following conditions:

Vdc=24v

Fundamental frequency =50Hz
Switching frequency = 1kHz

4.1. Simulation results of SPWM scheme

Unipolar H-bridge inverter has been applied to examine the performance both techniques. In the SPWM technique, 1kHz is used as switching frequency to operate the IGBTs. The number of notches per half cycle is calculated by (2).

$$n_p = \frac{f_c}{f_r} = \frac{1000}{50} = 20 \text{ pulses}$$

Figure 7 and Figure 8 depicted the output voltage signal and the harmonic spectrum analysis respectively.

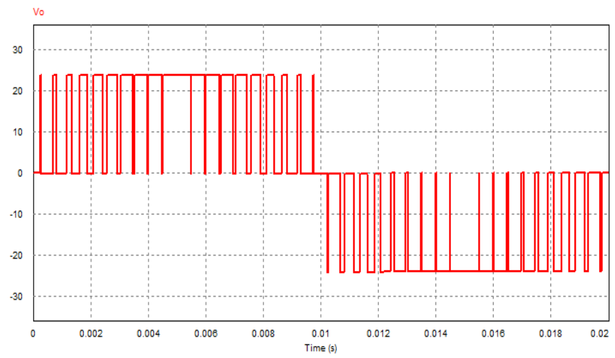

Fig. 7: Output Voltage Signal of the Unipolar Inverter.

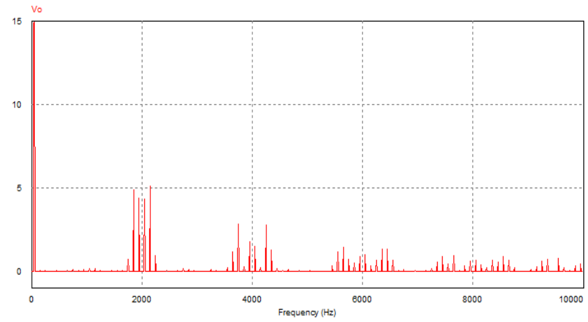

Fig. 8: FFT Analysis of SPWM Unipolar Inverter at M=1.0.

From the simulation result of SPWM method, most of undesired harmonics have appeared and the higher harmonics magnitude also have appeared around the multiples of the switching frequency with THD =53.19%.

4.2. Simulation results of SHE technique

Because of the symmetry of SHE signals, only switching angles at a quarter cycle has been used to remove low order odd harmonics. In this case, the number of pulses per quarter cycle assumed five-pulses. The switching frequency of SHE technique is given as:

$$n_p = \frac{f_r}{50} = 5 \text{ pulses}$$

The switching frequency in SHE technique,

$$f_r = 5x50 = 250\text{Hz}$$

Five SHE equations have been applied to compute five unknown angles position. The optimal solution of these angles is utilized to mitigate four odd harmonics of 3^{rd}, 5^{th}, 7^{th}, 9^{th}. Newton-Raphson scheme has been applied by the Matlab program to determine these switching angles. The best result of these angles has achieved at m=1 as is listed in Table 1. The output waveform of the unipolar inverter and the harmonic spectrum analysis is shown in Figure 9 and Figure 10 respectively. It is observed that all undesired harmonics have been canceled from the output waveform with THD =48.39%.

Table 1: The Solution of Five Unknown Switching Angles

Switching angles	α1	α2	α3	α4	α5
Degree	20.3455	31.1286	41.5084	61.5168	64.4158

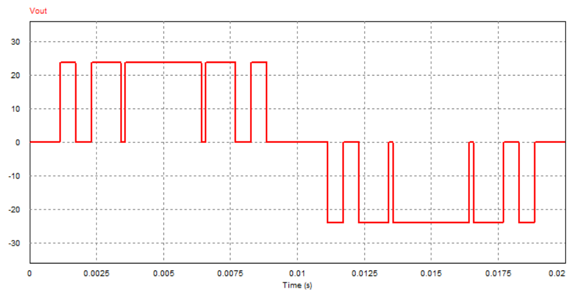

Fig. 9: Output Voltage Signal of SHE Unipolar Inverter.

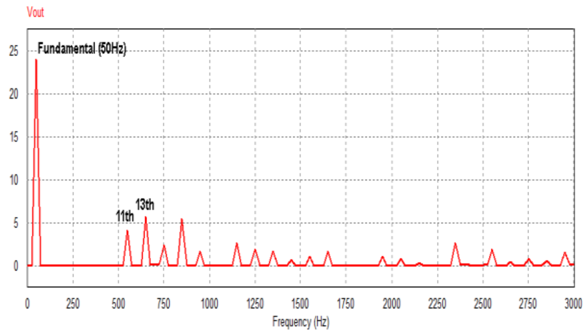

Fig. 10: FFT Analysis of SHE Unipolar Inverter at M=1.0.

From the simulation results, SHE modulation technique can work by the low switching frequency with the lowest THD and highest fundamental voltage amplitude. However, SPWM modulation technique works by highest switching frequency and the highest number of pulses per half cycle that leads to more switches losses with increasing THD.

The simulation results have validated experimentally using a full-bridge unipolar inverter. The PWM signal for both techniques has been generated by the Arduino Uno board. RIGOL DS1054 oscilloscope has been used to view the practical results for both methods. The harmonic spectrum analysis and the output voltage waveform for SHE modulation scheme is illustrated in Figure 11. While Figure 12 shows the practical results of SPWM modulation technique. It can be observed that the experimental results are in complete agreement with the simulation results almost identical in shape and values.

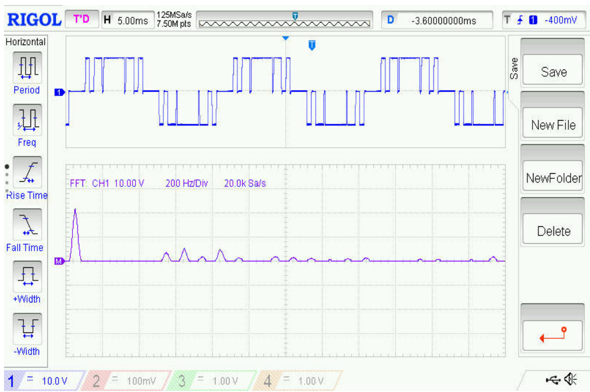

Fig. 11: Harmonic Spectrum Analysis and Output Voltage Signal for She.

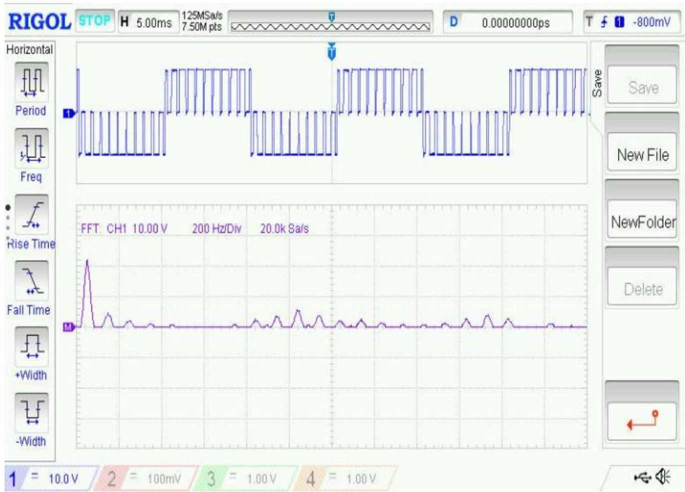

Fig. 12: Harmonic Spectrum Analysis for SPWM.

5. Conclusion

Comparison of the influence two modulation techniques, SHE and SPWM on the THD for unipolar full-bridge inverter have been validated and evaluated by simulation and experimentally. Minimum THD is the best quality output signal. The switches gate signal has been generated by the Arduino Uno board. Selective Harmonic Elimination works with low switching frequency and least switching pulses. SHE technique is the common modulation scheme used for power inverter to eliminate the odd harmonics with the lowest switches losses. In this paper, SHE method has achieved the lowest THD and the highest fundamental voltage amplitude than when compared with the similar results by SPWM method.

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