Bipolar and unipolar schemes for confined band variable switching frequency PWM based inverter

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Article Info

ABSTRACT

The single phase inverter performance through the unipolar and bipolar strategies has been previously analyzed based on the constant switching frequency pulse width modulation (CSFPWM). However, the confined band variable switching frequency PWM (CB-VSFPWM) is currently proposed as a new variable switching frequency PWM technique through unipolar strategy to facilitate the design of high order filter, to reduce the switching losses, and to reduce the current total harmonics distortion (THD) as well. To evaluate the performance of a single phase inverter based on the CB-VSFPWM through bipolar strategy, this paper presents a comparative study of the CB-VSFPWM based inverter performance using the unipolar PWM and the bipolar PWM strategies. The study adopts MATLAB/Simulink to simulate the inverter and to analyze the simulation results in terms of harmonics spectrum, total harmonic distortion (THD), and fundamental components. The analysis of the study results gives an indication about the appropriate type of CB-VSFPWM strategy (unipolar PWM or bipolar PWM) to guarantee the desired performance of the connected inverter in terms of the electrical grid standards like THD, and harmonics spectrum of the inverter current.

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1. INTRODUCTION

Single phase inverter has been played a major role in converting stage of a direct current DC renewable energy source to an alternating current AC electricity either to be delivered to the AC loads in a standalone system or to be supplied to a utility grid through a grid connected system [1]-[3]. The power conversion systems of high performance inverters are characterized by high efficiency due to the reduction in the switching and conduction losses, and the enhancement in the total harmonic distortion (THD) level [4]-[6].

The harmonics spectrum of the inverter current is affected by the drive pulses generation scheme. Pulse width modulation (PWM) technique is a suitable one to have low harmonic levels and low THD through using constant carrier switching frequency during the fundamental frequency cycle [7]-[11]. In addition to controlling the switching losses through a simple pulses generation process in both standalone and grid connected systems. Reducing switching losses represents improving the inverter efficiency [12], [13]. In

constant switching frequency pulse width modulation (CSFPWM), the inverter switches are driving through the pulse width modulation method of pulses generation using one of the two PWM schemes; unipolar scheme and bipolar scheme. However, the disadvantage of the PWM technique is that the difficulty in guaranteeing a low THD and low switching losses simultanuosly. In other words, to have low THD, switching frequency should be increased that will reduce the filter size as well. But increasing the switching frequency increases the switching losses, this reduces the inverter efficiency. Whereas to improve the efficiency, switching losses should be reduced by reducing the switching frequency, but this will increase the current THD [14]-[16]. To manipulate the mentioned demerit of the constant switching frequency PWM technique for inverter drive pulses generation, the researchers have proposed the variable switching frequency pulse width modulation CSFPWM for enhancing the THD, switching losses, and more flexible pulses generating as well [17]-[28].

In the studies of [17]-[19], random variable switching frequency pulse width modulation (R-VSFPWM) have proposed for distributing the harmonics over a wide frequency band through adopting a random carrier frequency variation during the fundamental frequency cycle. This technique is proposed to have effectively suppressing the electromagnetic interference (EMI) noise in the power electronics conversion system. Another type of variable switching frequency PWM technique is optimal VSFPWM which have proposed to guarantee the minimum switching losses and the desired THD level in the output current of the inverter.

Recently, a new type of VSFPWM technique which is the confined band VSFPWM (CB-VSFPWM) has proposed in [24], and [25] for single phase inverters. The CB-VSFPWM technique has proposed and analyzed through unipolar scheme. This technique facilitated the low pass power filter design and avoided the restrict of the practical applications due to that the process of unconfined band of the switching frequency variation had led to the possibility of a filter resonating, and distortion possibility of the load current due to the pulse dropping by exceeding the maximum switching frequency limit [26]-[28].

Based on the above, this paper discusses and analyzes the effects of the bipolar PWM strategy on the performance of a CB-VSFPWM inverter through a comparative study between the unipolar and bipolar PWM schemes. The remaining sections of the paper are as follows: the methodology of the unipolar and bipolar PWM schemes are explained in section 2. In section 3, the principle of the CB-VSFPWM is explained. The analysis of the simulation results of the inverter voltage and current waveforms for the two schemes through the CB-VSFPWM are shown in section 4. Conclusion of the study outcomes is discussed in section 5.

2. BIPOLAR AND UNIPOLAR PULSE WIDTH MODULATION PWM SCHEMES

Pulse width modulation technique is a common technique to generate the driving pulses for the inverter system due to the simplicity in controlling the inverter voltage by controlling the duty cycle of the drive pulses. PWM based power electronics circuits and systems have many home and industrial applications, such as; motor speed controller, inverter/converter systems, and many more. The PWM inverters have many merits such as easy controlling the inverter output voltage, reducing the level of inverter current harmonics, and simple controlling function [29]-[33]. A major type of PWM is sinusoidal PWM (SPWM) which drive pulses can be obtained by one of the two strategies; unipolar and bipolar [34].

2.1. Bipolar SPWM

The process of implementing the bipolar sinusoidal PWM pulses generation for a single phase full bridge inverter is explained in Figure 1. A sinusoidal signal of reference fundamental frequency is compared with a triangular signal of carrier frequency. The value and the sign of the output voltage depend on the instantaneous values of reference and carrier waveforms. The output voltage will be $+V_{dc}$ or $-V_{dc}$ depending on the instantaneous values of the comparison levels of the reference and carrier signals as shown in (1):

$$\begin{aligned} v_o &= +V_{dc} \text{ when } v_{sine} > v_{tri} \\ v_o &= -V_{dc} \text{ when } v_{sine} < v_{tri} \end{aligned} \tag{1}$$

To have v_o is equal to $+V_{dc}$, Q_1, and Q_2 are on, whereas to have v_o is equal to $-V_{dc}$, Q_3, and Q_4 are on. It is noticeable in bipolar scheme that the switching frequency of output signal is the same as the carrier frequency signal.
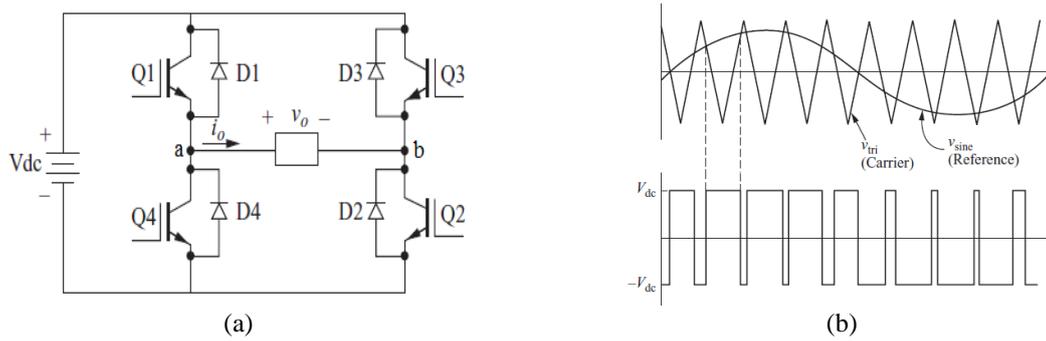
Figure 1. Single phase inverter with sinusoidal PWM scheme; (a) Full bridge inverter, (b) Bipolar PWM scheme [34]

2.2. Unipolar SPWM

Figure 2 shows the process of implementing the unipolar sinusoidal PWM scheme for a full bridge single phase inverter. To have a unipolar sinusoidal PWM scheme, the output is switched among three levels: $+V_{dc}$, zero voltage, or $-V_{dc}$. In unipolar scheme, the output voltage also depending on the instantaneous values of the the reference and carrier signals, the switch controls are as:

Q_1 is on when $v_{sine} > v_{tri}$
Q_2 is on when $-v_{sine} < v_{tri}$
Q_3 is on when $-v_{sine} > v_{tri}$
Q_4 is on when $v_{sine} < v_{tri}$

In unipolar scheme, the switch pairs (Q_1, Q_4) and (Q_2, Q_3) are complementary, and output voltage alternates between $+V_{dc}$ and zero, or between $-V_{dc}$ and zero. It is noticeable in unipolar scheme that the switching frequency of output signal is a twice of the carrier frequency signal.
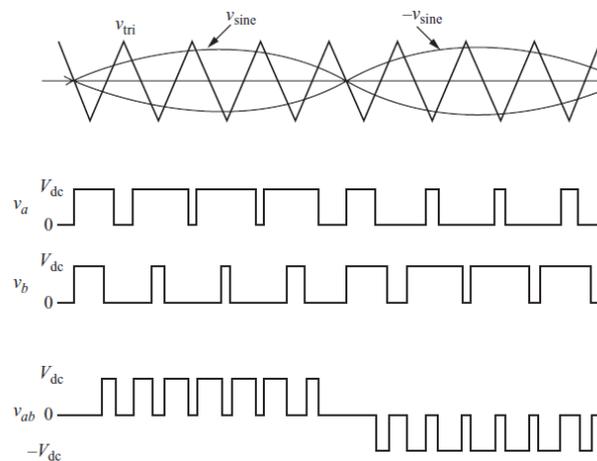

Figure 2. Single phase full bridge inverter with unipolar sinusoidal PWM scheme [34]

3.   CONFINED BAND VSFPWM WITH BIPOLAR AND UNIPOLAR SCHEMES

A new VSF PWM is proposed in [24], and [25] which is the confined band VSFPWM (CB-VSFPWM). The CB-VSFPWM is confining the frequency spectrum within a desired frequency band between a minimum switching frequency f_{min} and a maximum switching frequency f_{max} which equals to the carrier frequency f_c of CSFPWM technique as shown in (2), and (3):

$$f_{max} = f_c \tag{2}$$

$$f_{min} = B \cdot f_c \qquad B \in [0,1] \tag{3}$$

where B is a frequency control parameter, when B=1, the CB-VSFPWM scheme becomes CSFPWM. In study [24], CB-VSFPWM technique is proposed to have many merits in terms of current harmonics spectrum, total harmonic distortion THD, filter design, and inverter efficiency. The CB-VSFPWM technique is varying the switching frequency with respect to the reference frequency cycle as explained in (4):

$$f_{CB-VSF} = fc \cdot \{1 - [(1-B) \cdot abs(\sin(\omega t))]\} \tag{4}$$

The behavior of (4) is shown in Figure 3, the variable switching frequency f_{CB-VSF} is starting with maximum frequency level at the minimum voltage amplitude and reaching the minimum level at the maximum voltage amplitude. The confined switching frequency range can be selected within a variable frequency band which is $B \cdot f_C < f_{CB-VSF} < f_C$, and this indicates the importance of the parameter B of the proposed CB-VSFPWM. Figure 4 shows the behavior of the CB-VSFPWM in bipolar and unipolar schemes.

Comparing with the CSFPWM technique, the CB-VFSPWM technique is working on reducing the number PWM pulses within one fundamental cycle at minimizing B. This definitely reduces the switching losses and low order harmonic. According to (4), when B =1.0, $f_{CB-VSF} = f_C$, and the switching scheme will be similar to the constant switching frequency.
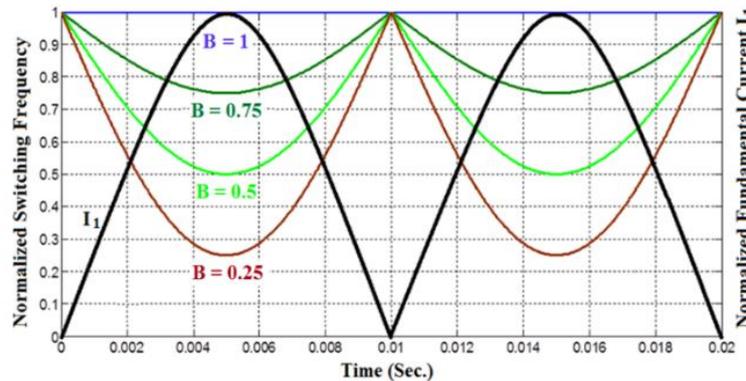

Figure 3. Behavior of the CB-VSFPWM technique for different values of B parameter [24]
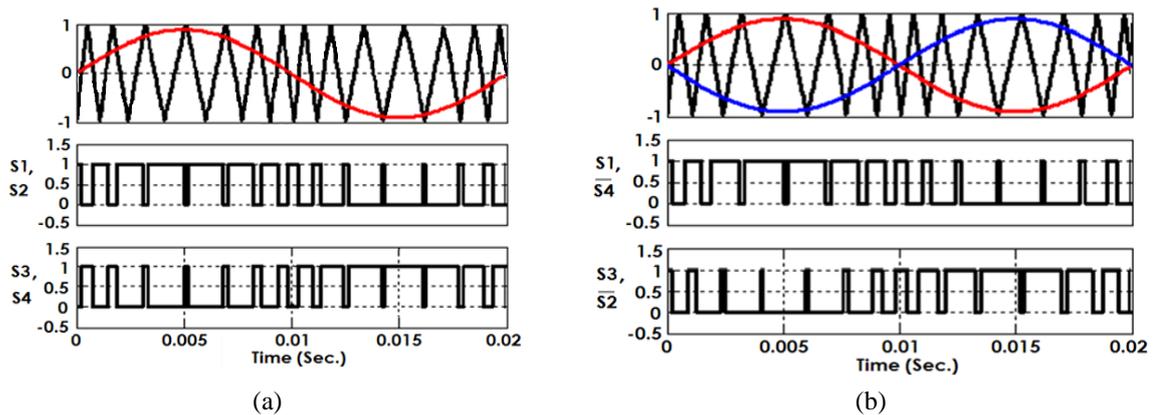

(a)   (b)

Figure 4. Drive pulses generation for a CB-VSFPWM based single phase full bridge inverter;
(a) Bipolar CB-VSFPWM scheme, (b) Unipolar CB-VSFPWM scheme

4. SIMULATION RESULTS ANALYSIS

MATLAB/Simulink is adopted to implement the single phase full bridge inverter with the two PWM schemes bipolar and unipolar based on the CB-VFSPWM technique. The inverter parameters are shown in Table 1 for the two PWM schemes. A constant series inductor of 10 mH is connected between the implemented inverter and a resistive load of 100 Ω. Figure 5 shows the Simulink simulation of the inverter

system based on the CB-VSFPWM for the two schemes unipolar and bipolar. Based on the fact of that the effective switching frequency is the same as carrier frequency in the bipolar scheme inverter and double of the carrier frequency in the unipolar PWM scheme inverter.

Table 1. Inverter parameters

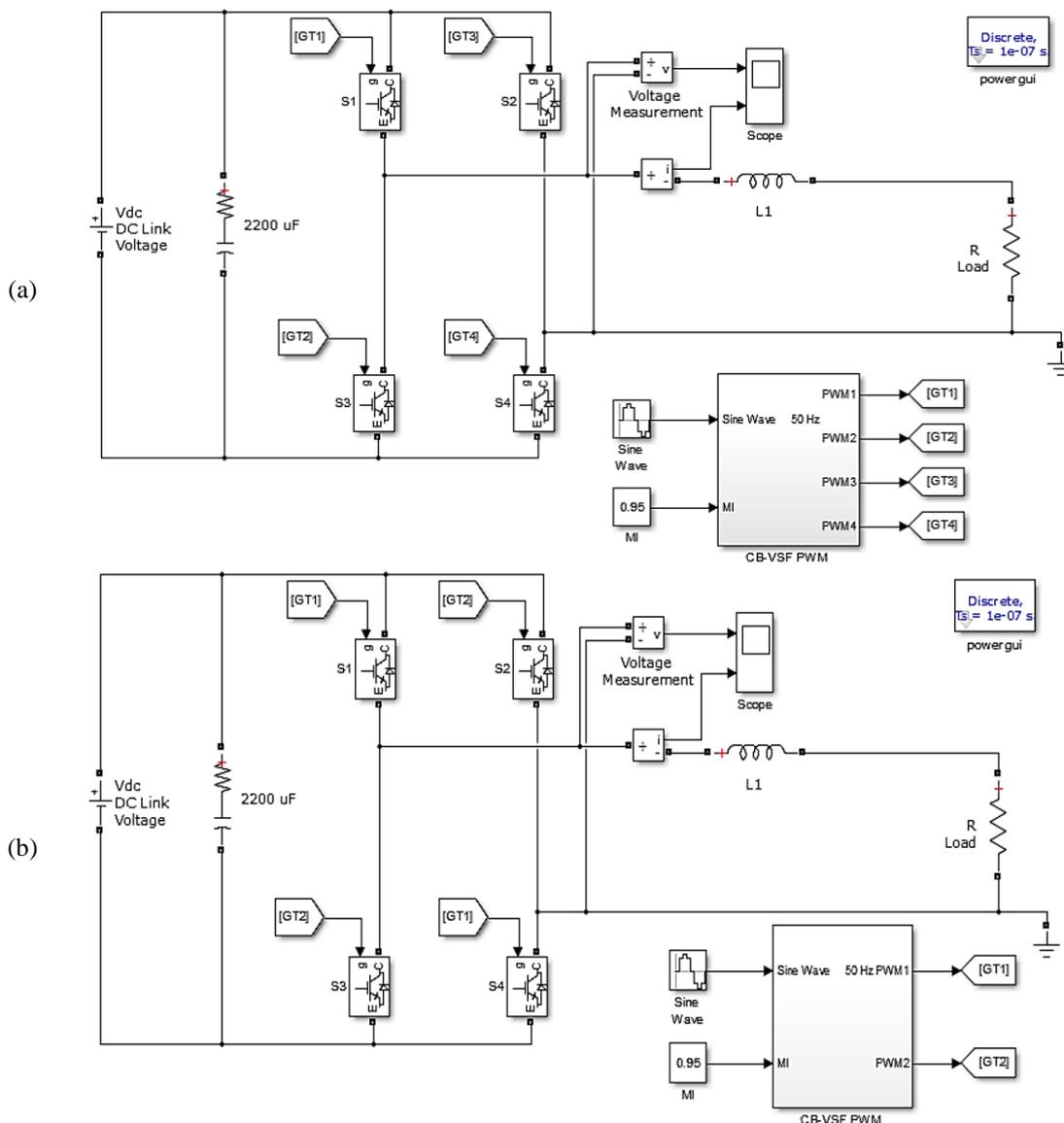| Parameter Name	Parameter Value
Input dc link voltage, V_{dc}	400 V
Rated Power	0.75 kW
Constant carrier frequency, f_C	10 kHz
CB-VSF carrier frequency range, $f_{CB\text{-}VSF}$	5 kHz to 10 kHz ($B = 0.5$)
DC-link capacitor	2200 μF, 400 V
Load resistor	100 Ω
Modulation Index, m	0.95
L-filter	10 mH

Figure 5. The simulated single phase full bridge inverter; (a) Unipolar CB-VSFPWM scheme, (b) Bipolar CB-VSFPWM scheme

Figure 6 shows the inverter output voltage and current with the harmonics spectrum and THD level as well. Figure 6 shows the two levels (400 V, and -400 V) of the inverter output voltage, and the harmonics

spectrum variation during the carrier frequency variation of (5 kHz to 10 kHz, and above) with high level of THD (103.37%). Figure 6 also shows the inverter current waveform after the effect of the series L-filter, the harmonics spectrum is shown in a frequency band starting from 5 kHz to the 10 kHz and above. THD level is (21.84%) which represents an unaccepted level by considering the grid standards [35].
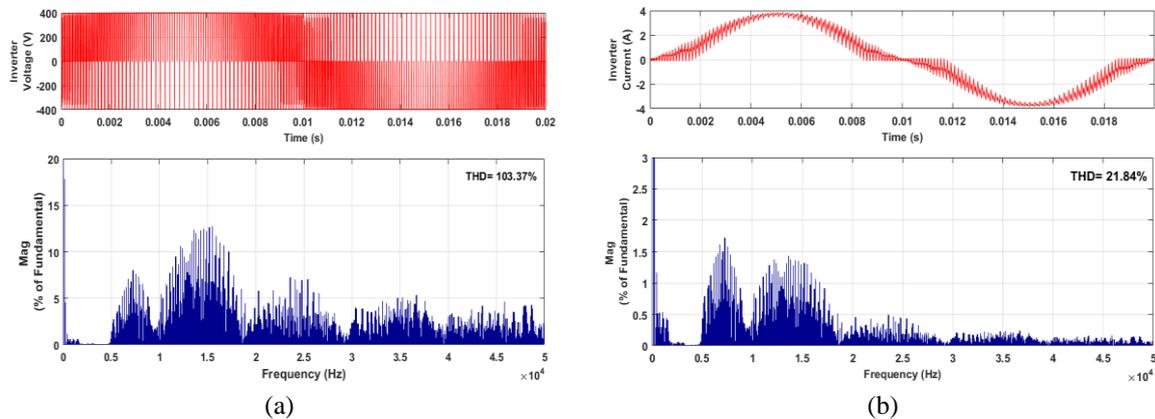

Figure 6. Bipolar CB-VSFPWM based inverter, (a) Output voltage with the harmonics spectrum and THD level, (b) Output current with the harmonics spectrum and THD level

Figure 7 shows the inverter performance based on the unipolar CB-VSFPWM, the three levels (400 V, 0 V, and -400V) of the inverter voltage, and the harmonics spectrum variation are noted at the effective switching frequency (10 kHz to 20 kHz), which is the double of the carrier frequency variation (5 kHz to 10 kHz, and above). Lower level of THD (52.36%) of inverter current is recorded. Figure 7 shows also the inverter current waveform through using the series L-filter based on unipolar CB-VSFPWM. The harmonics spectrum is appeared within a frequency band starting from 10 kHz to the 20 kHz and above. THD level (5.24%) is monitored which is very close to the accepted limit of the grid standard. In other words, it will be definitely accepted if a high order power filter [25] is inserted instead of the L-filter.
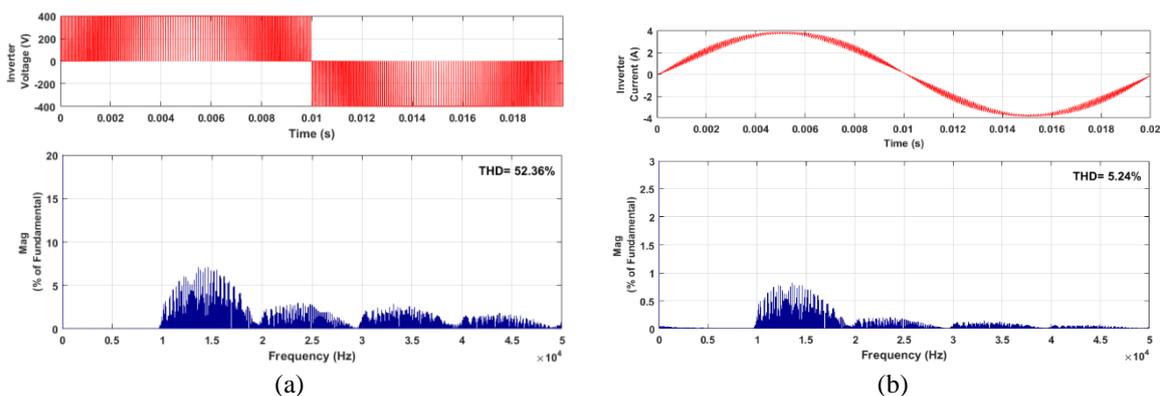

Figure 7. Unipolar CB-VSFPWM based inverter; (a) Output voltage with the harmonics spectrum and THD level, (b) Output current with the harmonics spectrum and THD level

Figure 8 proves the priority of the unipolar CB-VSFPWM on the bipolar CB-VSFPWM after investigating the harmonics spectrum with the THD level of inverter output voltage (THD=98.03%) and current (THD=21.79%) show the effect of adopting higher carrier frequency variation using the bipolar scheme. Figure 8 shows higher harmonics and THD levels using a higher range of carrier frequency using the bipolar scheme, comparing with the counterparts of the unipolar scheme at the same frequency band. Figure 9 summarizes the THD levels comparisons, and clearly demonstrates the priority of Unipolar CB VSF PWM scheme.
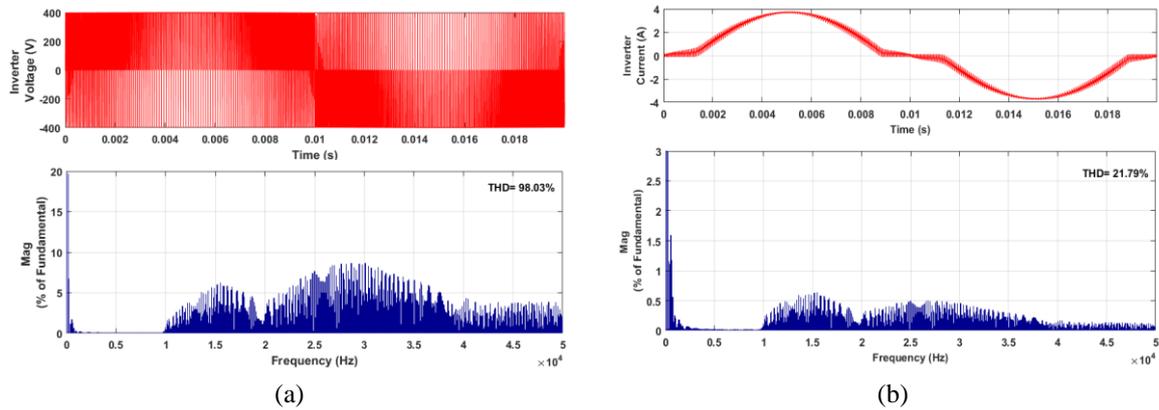
(a)   (b)

Figure 8. Bipolar CB-VSFPWM based inverter of 10 kHz to 20 kHz carrier frequency variation;
(a) Output voltage with the harmonics spectrum and THD level, (b) Output current with the harmonics
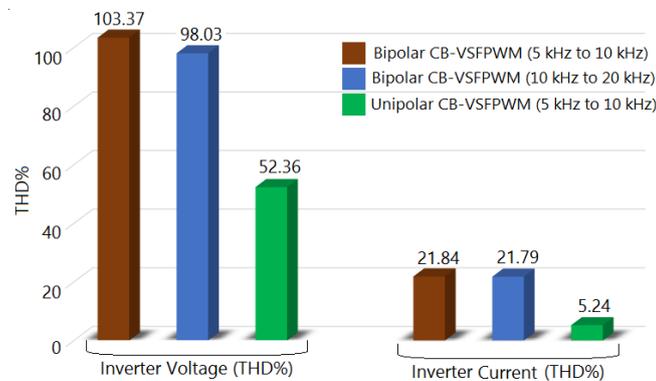spectrum and THD level

Figure 9. THD% comparison between unipolar and bipolar schemes using the CB-VSFPWM technique

5. CONCLUSION

This paper presented a comparative study about the performance of a single phase full bridge inverter based on CB-VSFPWM technique, to evaluate the inverter performance based on the CB-VSFPWM using the bipolar drive pulses generation scheme. The study simulated and analyzed the inverter performance in terms of the voltage and current harmonics and THD levels for the two schemes; bipolar PWM and unipolar PWM. The study adopted the MATLAB/Simulink to simulate the 0.75 kW inverter system with a certain parameters settings. The study concluded that the levels of harmonics and total harmonic distortion THD are low using the unipolar scheme than the bipolar scheme, and this reflected positively on satisfying the grid standards. Even through considering the same switching frequency variation range, the unipolar CB-VSFPWM scheme offered lower harmonics and lower THD level compared to the bipolar CB-VSFPWM scheme.

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