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Simulation of Single Phase Five-Level Inverter Based Modified Pulse-Width Modulation Approach

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ABSTRACT

The solar cells can generate electrical energy in form of Direct Current (DC). Generally, electrical appliances have used an Alternating Current (AC). Sequence, an inverter circuit is needed to convert electrical energy form DC to AC. This paper aim is to simulate an inverter performance of single-phase five-level using the method of modified Pulse Width Modulation (PWM). A scheme of the circuit model of single-phase five-level inverter was constructed to investigate their performance. The model was simulated by using of PSIM Software. The simulation parameters were set as a triangular wave frequency used 2 KHz. Then, the same phase was set as the carrier waves and a sinusoidal signal with a frequency of 50 Hz as a reference signal. The circuit scheme model used a switching frequency MOSFET gate as a power switch on the single-phase five-level inverter. The result indicated the simulation as an expectation to generate a constant of five level voltage and sinusoidal current output, which the harmonics values were small. Therefore, the inverter circuit scheme is safe to use for the AC electrical appliances.

KEY WORDS: *Five-Level Inverter, Single-Phase, Pulse Width Modulation (PWM).*

1.0 INTRODUCTION

The electrical energy produced by the solar cells is still a DC voltage. While, most electrical appliances or electronic equipments used on the electrical grid is the AC voltage. It is necessary to have the inverter to convert power from DC to AC. The AC is required constant voltage that cannot damage electronic equipments. Therefore, the setting of inverter output is required in constant term such as voltage or current.

Most of the inverter circuit technology to convert power from DC into AC has a square wave output waveform. An inverter circuit, which produces a square waves have some weaknesses, so potentially damaging electronic instruments due to unstable voltage. According Phogat (2014) [1], the square wave's performance is not efficient for the electrical equipments. Therefore, it is a challenge to study inverter technology that has an efficient performance and safe for the electrical appliances or electronic equipments [2].

The PWM inverter can control the output voltage and frequency with simultaneous. The use of inverter conventional had a good contribution in the application of solar cells, but the development of multilevel inverter can reduce the harmonic components in the output current [3]. In recent years this has been a lot of research that discussed the multilevel inverter [4]. Venugopal & Mathew, (2015) [5] examined the five-level inverter with a dual reference single carrier PWM control scheme for generating an output voltage in five levels. More, Camur *et al* (2006) [6] examined the new topology for five-level inverter used the principle of switching functions to every situation in order to maintain the load current becomes sinusoidal and has a higher dynamic appearance. Elserougi *et al* (2013) [7] examined the five-level PWM inverter by using two carrier signals that are identical to each other and it offset by the amplitude of the triangular carrier signal to generate the PWM switching.

According Hahn (2006) [8], many studies inverter used Pulse Width Modulation (PWM). However, the PWM has a pulse width that should be made varies according to the amplitude of the sine wave and thus require control circuits and high-speed switching [9]. So, inverter that generates the PWM output is complicated and has a switching loss [8]. To reduce these drawbacks, this paper proposed a simulation to investigate the performance of single-phase five-level inverter. The simulation is conducted by using of PSIM software. The modified pulse width modulation approach is applied in this paper.

2.0 LITERATURE REVIEW

2.1 Inverter

The inverter is used to convert an input DC voltage into AC voltage. The inverter output voltage can be adjustable and fixed voltage. A source of inverter input voltage can use battery, solar power, or a DC voltage source to another. According to [1,10] that is divided the inverter on 3 types, namely: bridge inverter, parallel inverter and series inverter. The bridge inverter is grouped into half bridge inverter and full bridge inverter.

Based on [10], the single phase half bridge inverter can be described in Figure 1. The switches of K1 and K2 can be ON-OFF alternately. If K1 is ON and the current flowing from E/2 (+) to K1 to load B-A to E/2 (-), while K2 is opened. At the time of K2 ON, while K1 is open, the flow of E/2 (+) to load A-B to K2 to E/2 (-). Then, in this period, the load is flowed current in both directions (alternating current).

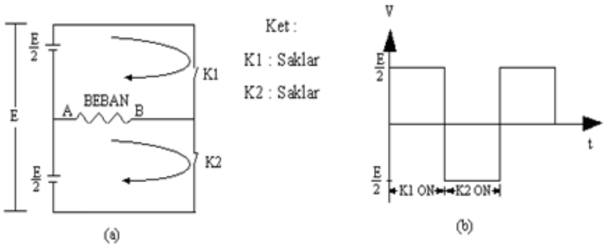


Figure 1: (a) Single-phase half-bridge Inverter, (b) Signal wave output [10].

The circuit of single-phase full-bridge inverter can be illustrated in Figure 2 [10]. The principle works the switch of K1 and K4 can be ON- OFF together and likewise the switch of K2 and K3. If K1 and K4 are ON, K2 and K3 of OFF then the current is flowed from the voltage source E (+) to K1 and then to load A-B to K4 to E (-). When the switch K2, K3: ON and K1, K4: OFF, then the current is flowed from the voltage source E (+) to K2 to load A-B to K3 to E (-). Therefore, in this period, the load is flowed current in two directions (alternating current). If the switch K1, K2, K3 and K4 are replaced to an electronic switch that meet the above criteria, for example using a MOSFET, then the rectangular full-bridge inverter can be seen in Figure 3 [6].

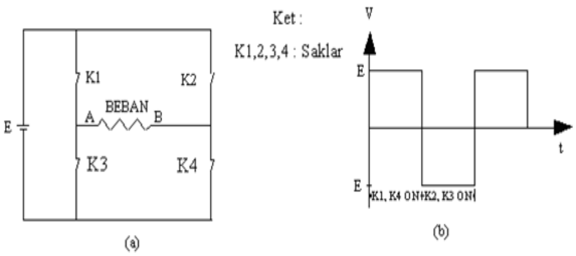


Figure 2: (a) The circuit of full-bridge inverter, (b) Signal wave output [10].

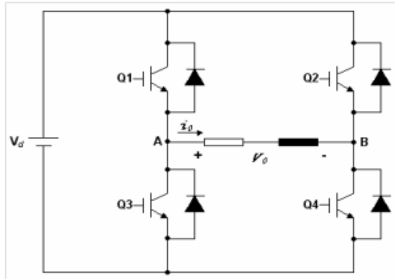


Figure 4: The circuit of conventional rectangular full-bridge inverter [6].

2.2 Modulation Method

Phase angle depending on the modulation index Ma. The modulation index inverter in this paper was adopted from Park (2003) [4]. That is defined as the modulation index of the five-level PWM inverter:

$$Ma = \frac{A_M}{2A_C} \tag{1}$$

Where: Ac = peak to peak value of the carrier, AM = peak value of reference voltage (Vref). If the modulation index is less than 0.5, changing of phase angle is obtained from equation:

$$\theta_1 = \theta_2 = \frac{\pi}{2}, \ \theta_3 = \theta_4 = \frac{3\pi}{2} \tag{2}$$

If the modulation index is greater than 0.5, then changing of the phase angle can be written by the equation:

$$\theta_1 = Sin^{-1}\left(\frac{A_c}{A_M}\right) \tag{3}$$

$$\theta_2 = \pi - \theta_1 \tag{4}$$

$$\theta_3 = \pi + \theta_1 \tag{5}$$

$$\theta_4 = 2\pi - \theta_1 \tag{6}$$

Value harmonic component of the output voltage is generated by the comparison of the reference signal and the carrier wave can be expressed as [4]:

$$Vo(\theta) = Ao + \sum_{n=1}^{\infty}(An\cos n\theta) + BnSinn\theta) \tag{7}$$

Fourier series of conventional single-phase inverter with sinusoidal PWM full-bridge is obtained from the equation:

$$An = \frac{4V_{dc}}{n\pi}\sum_{m=1}^{P}\left[(-1)^m \sin(n\alpha_m)\right] \tag{8}$$

Where m is the number of pulse, and α is the phase angle changes.

3.0 METHODOLOGY

3.1 Scheme of Single-Phase Five-Level Inverter

The single-phase five-level inverter has been assumed the DC voltage that was set at V_{DC}=2E. More, that circuit applied two capacitors, which each of them given a half of the DC voltage. Then, the output voltage at the load generated a voltage E, 0 and -E. The circuit scheme of single-phase five-level inverter consists of a source of DC that was connected by a two capacitors. Then, it was connected to four diodes, which assembled a switching element among them. Next, the circuit was connected to four switching system, which used a MOSFET as a switch in the form of conventional single-phase full-bridge inverter. The inverter circuit scheme can be seen in Figure 5.

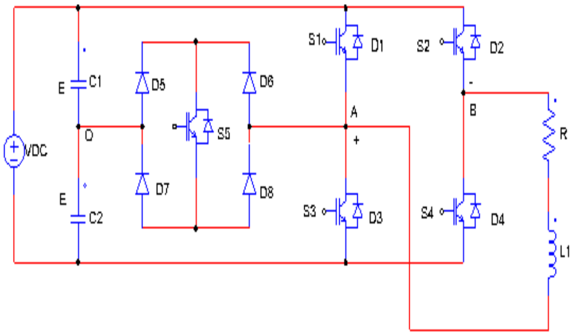


Figure 5: The circuit of single-phase five-level inverter.

The process operation of single-phase five-level inverter can be demonstrated by a ten-step switching as shown in Table 1.

Table 1: Mode switching five-level inverter.

Operation state	Output Voltage V_{AB}	Direction of the current	On switches
1	2E	+	S1,S4
2	2E	-	D1,D4
3	E	+	D5,S5,D8,S4
4	E	-	D4,D6,S5,D7
5	0	+	D3,S4
6	0	-	S3,D4
7	-E	+	D5,S5,D5,D2
8	-E	-	S2,D6,S5,D7
9	-2E	+	D2,D3
10	-2E	-	S2,S3

4.0 RESULT AND DISCUSSION

4.1 The Scheme of Modulation

To obtain an output voltage that was better than the conventional inverter, therefore the switching single-phase five-level PWM inverter implemented two triangular waves, which a frequency of 2 kHz and the same phase was useful as the carrier waves and a sinusoidal signal with a frequency of 50 Hz as a reference signal. The carrier signal and the reference signal were set above zero. Relationship between reference and carrier waves can be seen in Figure 6. The setting of pulse input was designed to use digital system with high frequency. To check the performance of switching process of the modulation PWM and control circuit at Gate of the single-phase five-level inverter, which generated the pulse shape waveform Switching ON-OFF on S1, S2, S3, S4, and S5 as can be seen in Figure 7.

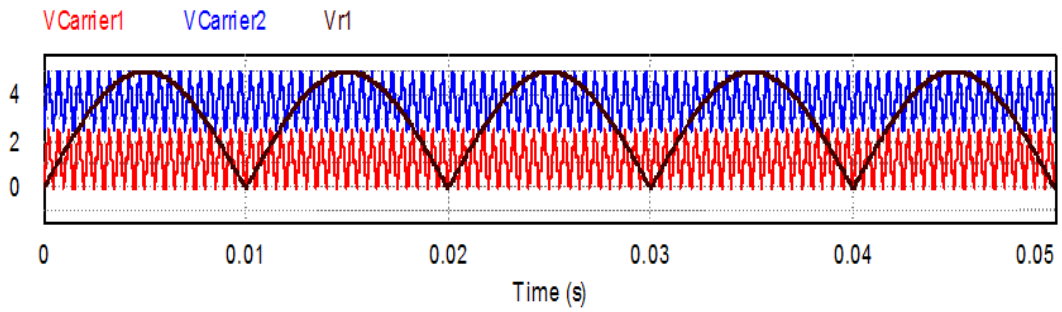
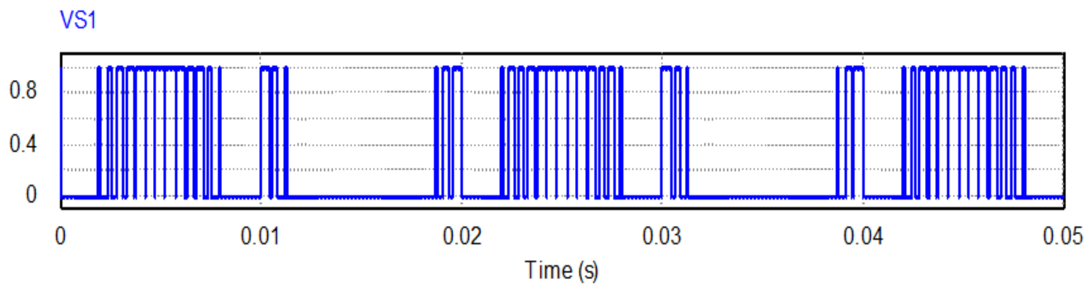
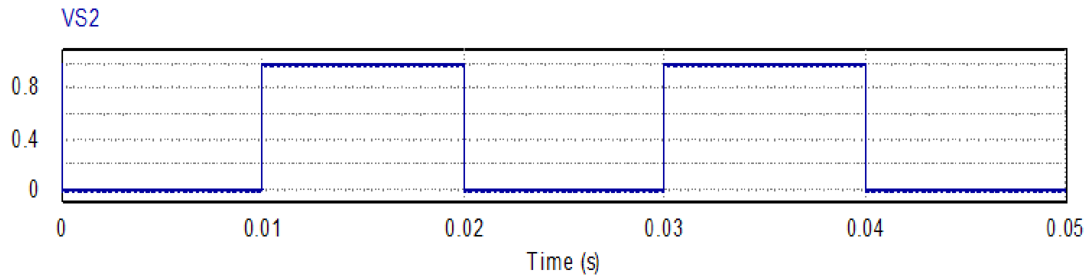


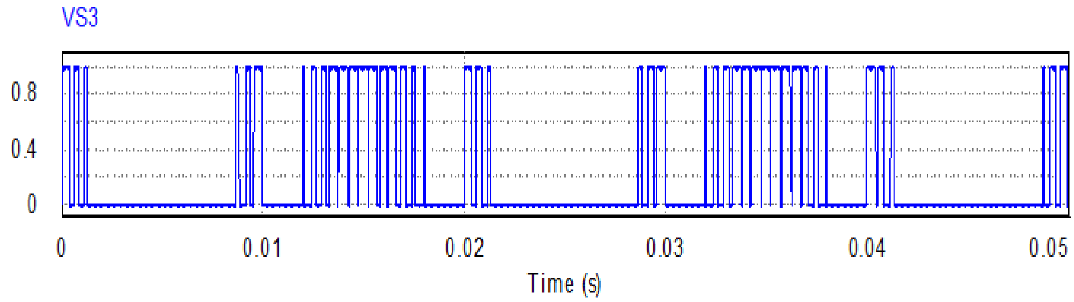
Figure 6: The signal carrier and reference of single-phase five-level inverter.



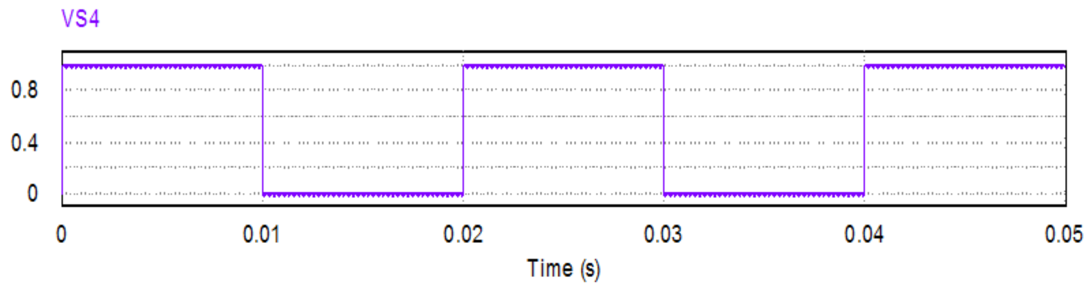
(a) PWM Switching Signal for S1



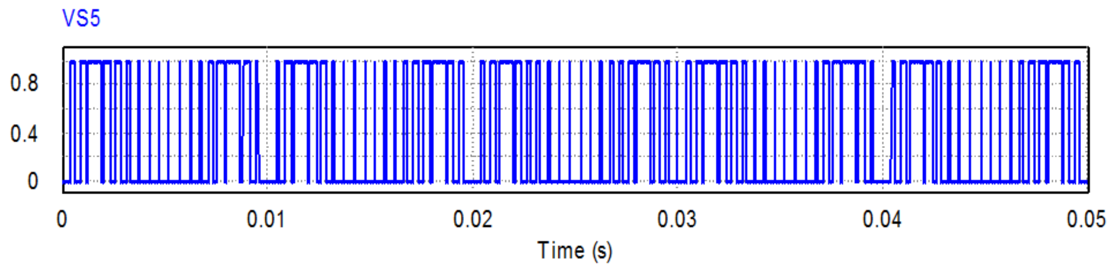
(b) PWM Switching Signal for S2



(c) PWM Switching Signal for S3



(d) PWM Switching Signal for S4



(e) PWM Switching Signal for S5

Figure 7: The switching system on Gate single-phase five-level inverter.

4.2 Discussion and Analysis

The system used a configuration circuit of single-phase five-level inverter that was made in the form of simulation using PSIM software version 9. The simulation parameters were shown in Table 2, using a 110 V DC voltage source that was connected to two capacitors on the DC side. In the single-phase five-level inverter implemented a five switching system using a MOSFET as was depicted in Figure 5. The single-phase five-level inverter was connected to load of 30 Ω resistor and 20 mH inductor. The triangular wave frequency used 2 KHz and sinusoidal frequency of 50 Hz, which served as a switching frequency MOSFET gate as a power switch on the single-phase five-level inverter.

Table 2: The simulation parameters.

DC power source of voltage	:	110 V
Load	:	R = 30 Ω, L= 20 mH
Capacitor DC side	:	C = 470 μF
Fundamental frequency	:	50 Hz
Triangular wave of voltage source	:	2 kHz

Based on the simulation result indicated that was as the expectations. The output voltage of circuit of single-phase five-level inverter entered into the load in the form of waves of the five-level as is shown in Figure 8. Next, in Figure 9 is shown the current flow on the load that performed the sinusoidal current waveform. The value of harmonic spectra of the voltage wave form is shown in Figure 10.

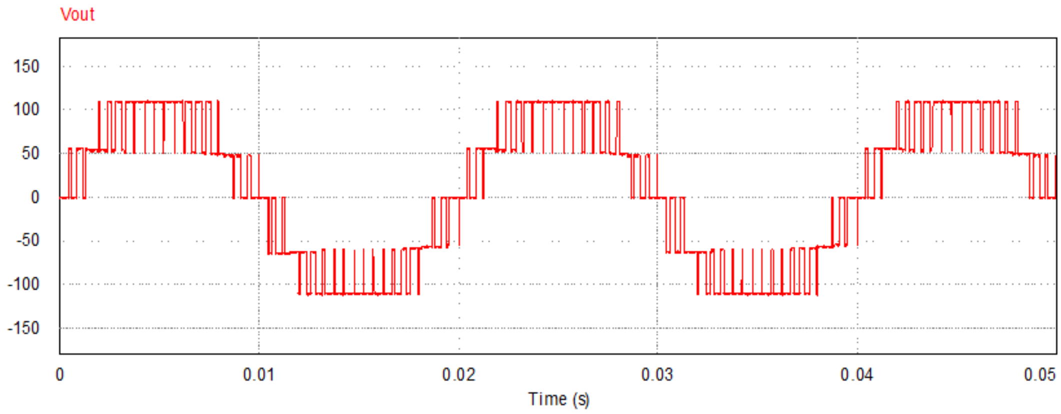


Figure 8: The output voltage of single-phase five-level inverter.

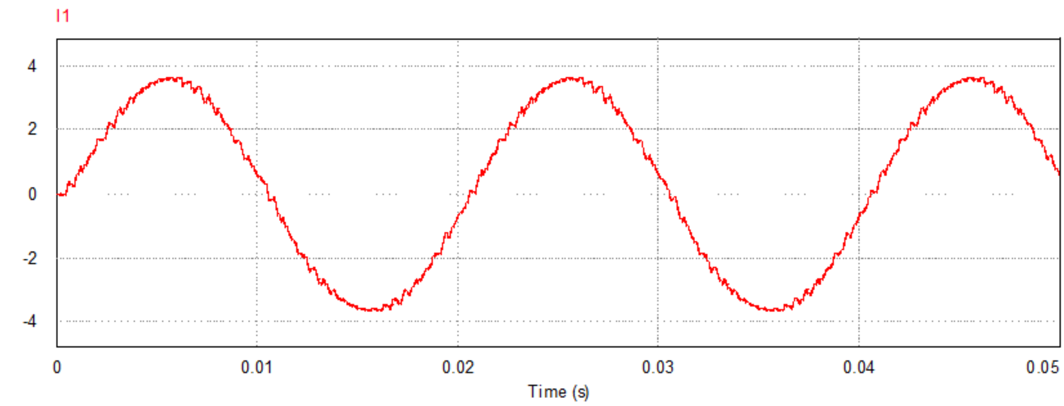


Figure 9: The output current of single-phase five-level inverter.

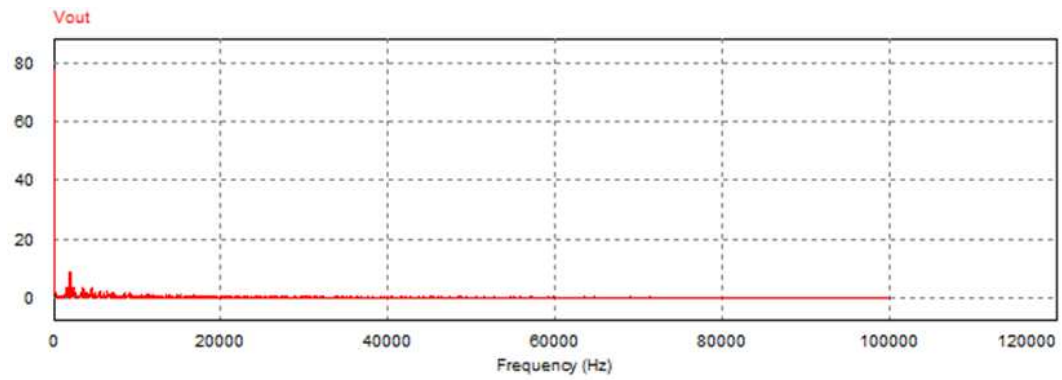


Figure 10: The harmonic spectra of single-phase five-level inverter voltage wave form.

5.0 CONCLUSION

This paper proposed the performance simulation of single-phase five-level inverter using PSIM software. The modified pulse width modulation (PWM) approach was applied to investigate the inverter performance. A source of DC was assembled with two capacitors, which produced two of the same voltage on each capacitor. The single-phase five-level inverter scheme implemented a five switching system using a MOSFET. The triangular wave frequency used 2 KHz and sinusoidal frequency of 50 Hz. The output showed the shape of five levels as expected and the output current in the form of sinusoidal, and generated harmonic spectra which small value.

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