The Common Use of Pulse Width Modulation "PWM" Technique in Power Electronics

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Abstract: *This paper presents general study of Pulse Width Modulation technique, and Summarizes common PWM Inverters for its large practical importance in power electronic systems (PWM is the basic control technique in power electronics).*

Keywords: Width Modulation technique (PWM)

1. Introduction

Pulse Width Modulation technique used in wide variety of applications: power electronics, sound production, telecommunication, lighting systems, etc.

In electronics and telecommunications, modulation is the process of varying one or more properties of a periodic waveform, called carrier signal (high frequency signal), with a modulating signal that typically contains information to be transmitted. [1]

Modulator in power control systems (in which PWM was used): It's a device that breaks up a DC voltage into pulses which can be changed to our needs. When we change the width of the pulses, we are modulating them.[2]

2. Pulse Width Modulation Principles

Pulse Width Modulation (PWM) is a powerful method for generating an analog signal using a digital source. A PWM signal consists of two main components that define its behavior: a duty cycle and a frequency. The duty cycle describes the amount of time the signal is in a high (on) state as a percentage of the total time of it takes to complete one cycle. The frequency determines how fast the PWM completes a cycle (i.e. 1000 Hz would be 1000 cycles per second), and therefore how fast it switches between high and low states. By cycling a digital signal off and on at a fast enough rate, and with a certain duty cycle, the output will appear to behave like a constant voltage analog signal when providing power to devices.[3]

Output signal alternates between on and off within specified period, yields Controls power received by a device. The voltage seen by the load is directly proportional to the source voltage.[4] The on-off behavior changes the average power of signal .A PWM signal is not constant, the main parameter is a duty cycle D that is a part of PWM period and describes the proportion of on time to regular interval. Equation (1), Figure (1) describes the duty cycle as the following:[5]

$$Duty\ Cycle = \frac{On\ Time}{Period} \times 100\%$$

Equation (1):

$$V_{AVG} = DV_H + (1-D)V_L$$

Equation (2),

Describes the average signal:

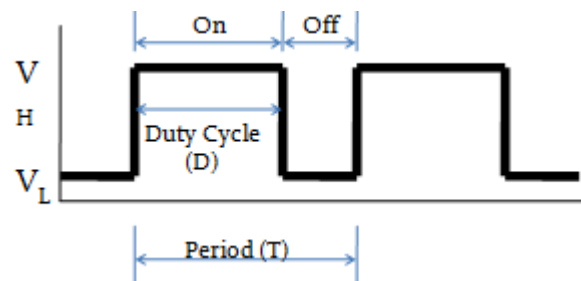(Usually, V_L is taken as zero volts for simplicity)

Figure 1: PWM signal

2.1 PWM Generation

Several methods were used to Generate PWM signals. one of them Analogue method. Analogue PWM signals (comparator output) can be made by combining a saw- tooth waveform and a sinusoid, the higher the DC level is, the wider the PWM pulses are. The DC level is the demand signal [6].as shown in figure (2):
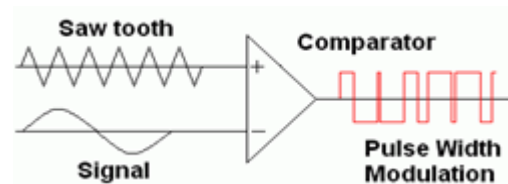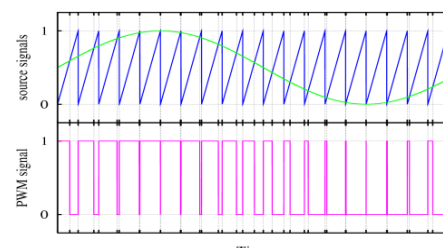

Figure 2: Principles of PWM generation

Figure 3: Wave form of PWM [5]

2.2 PWM Matlab Code Generation

Matlab enables codes for PWM generation written as the following: [7]

```
Fs=1000; % Frequency of samples

fc = 50; % Frequency of error or message signal

t=0:1/fs: 10;

temp=sawtooth((fc/2)*2*pi*t);

fc =temp/2+range(temp)/4;
plot(t,temp/2+range(temp)/4);
position_signal=sind(t*360);%position signal in degrees
desired_vel_signal=zeros(size(desired_pos_signal));
PWM = zeros(size(desired_pos_signal));
for k = 1:length(desired_pos_signal)
if     carrying_signal(k)>abs(desired_pos_signal(k))    &&
desired_vel_signal(k) >0
PWM(k) = 1;
elseif  carrying_signal(k)>abs(desired_pos_signal(k))   &&
desired_vel_signal(k) <0
PWM(k) = -1;
end
end
subplot(3,1,1);
h=plot(t,carrying_signal)
subplot(3,1,2)
plot(t,desired_pos_signal)
hold on
plot(t,PWM)
```
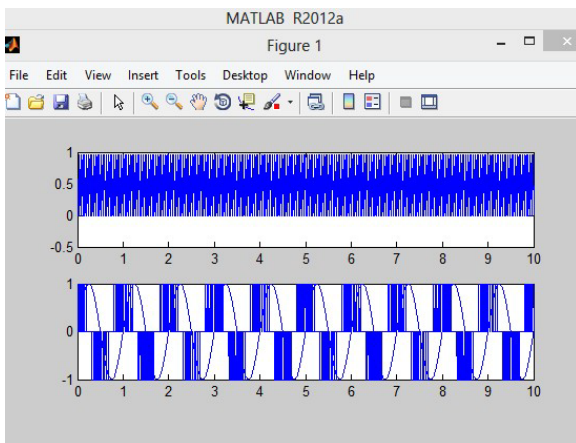

Figure 4: PWM Matlab code generation

3. PWM Inverters

By using PWM technique, the output voltage of the inverter can be directly controlled. The rapid rising and falling edges ensure that the semiconductor power devices are turned on or turned off as fast as practically possible to minimize the switching transition time and the associated switching losses.[8]

3.1 PWM Voltage Source Inverters

Inverters in power electronics refers to a class of power conversion circuit that operate from a dc voltage sources voltage or a dc current sources and convert it into a symmetric ac voltage or current.[9] voltage sources inverters(VSI) are required by many industrial applications, such as adjustable speed drives (ASDs), Similarly, as current source inverters (CSIs), where the independently controlled ac output is a current waveform. These structures are still widely used in medium-voltage industrial applications, where high-quality voltage waveforms are required.
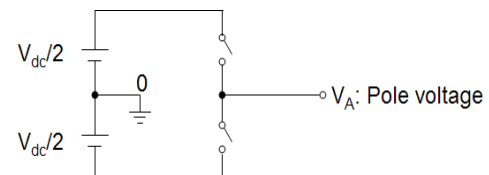

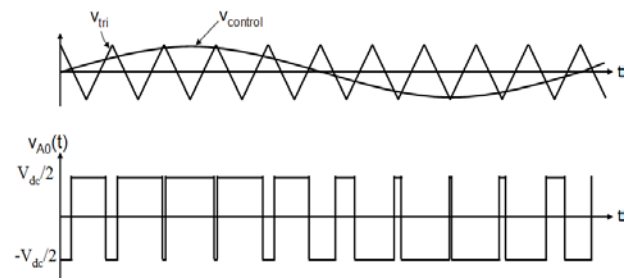**Figure 5:** PWM voltage source inverter

Figure 6: Pulse-width modulation VSI

Inverter output voltage (Figure above) :

When $v_{control}> v_{tri}$, $V_{A0} = V_{dc}/2$
When $v_{control}< v_{tri}$, $V_{A0} = -V_{dc}/2$

Control of inverter output voltage:
-PWM frequency is the same as the frequency of v_{tri}
-Amplitude is controlled by the peak value of $v_{control}$
-Fundamental frequency is controlled by the frequency of $v_{control}$
Modulation Index (m)

$$\therefore m = \frac{v_{control}}{v_{tri}} = \frac{peak \quad of \quad (V_{A0})_1}{V_{dc}/2},$$

$$Equation(2)$$

[10]

where, $(V_{A0})_1$: fundamental

frequecny   component   of V_{A0}

4. Sinusoidal PWM Inverters

For PWM control, two inputs are required: a sinusoidal reference signal, also called a control signal or a modulating signal, and a carrier signal. The triangle wave controls the switching frequency of the inverter.

Bipolar and unipolar switching are the two available methods of switching. Both methods compare the reference

signal and the carrier signal and cause switching conditions that correspond to the two signals.[11,12].

4.1 Sinusoidal PWM bipolar switching:

The magnitude of a triangle carrier signal is compared to a sinusoidal reference.
If : **V**reference(Vsine) >**V**carrier (vtri)PWM = high.
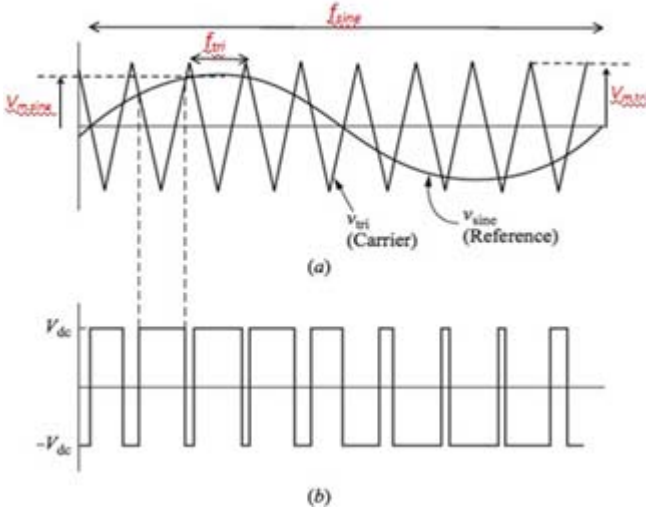If **V**reference(Vsine) < Vcarrier(vtri) PWM = low

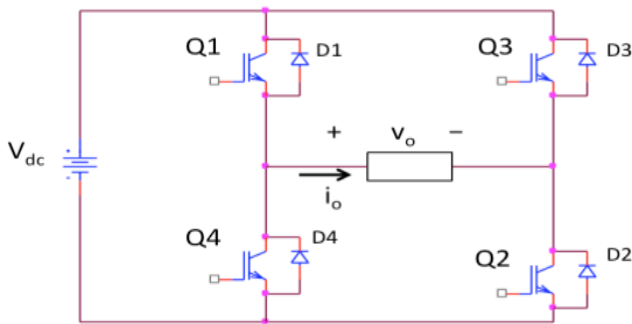**Figure 7:** Triangular wave and output voltage

Figure 8: Bipolar full-bridge inverter

$(v_{sine} > v_{tri})$: Q1 and Q2 ON; $v_o = V_{dc}$
$(v_{sine} < v_{tri})$: Q3 and Q4 ON; $v_o = -V_{dc}$ [13], [14]

4.2 Sinusoidal PWM Unipolar Switching

In unipolar switching: Two sinusoids compared to a triangle reference. Switching frequency is doubled with better frequency response and better output voltage. Unipolar is more complex switch control.
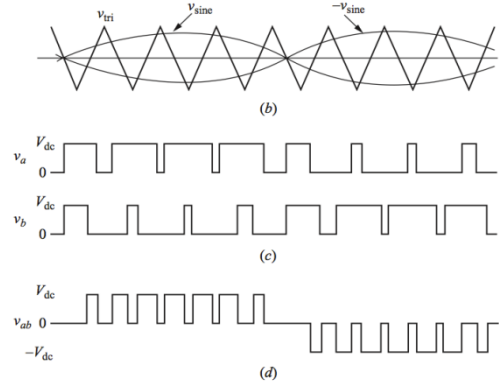

Figure 9: two sinusoidal with triangular wave and the doubled output voltage
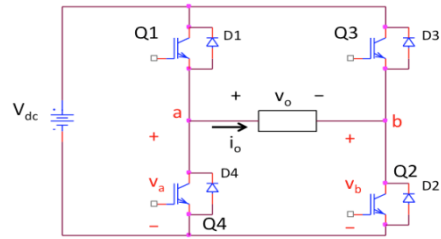

Figure 10: uniBipolar full-bridge inverter

$(v_{sine} > v_{tri})$: Q1 ON, Q4 OFF; $v_a = V_{dc}$

$(-v_{sine} > v_{tri})$: Q3 ON, Q2 OFF; $v_b = V_{dc}$

$(-v_{sine} > v_{tri})$: Q3 ON, Q2 OFF; $v_b = V_{dc}$

$(v_{sine} < v_{tri})$: Q1 OFF, Q4 ON; $v_a = 0$

Equation (3) Frequency Modulation ratio,m_f
For Bipolar PWM, m_f = odd integer

$$m_f = \frac{f_{triangle}}{f_{carrier}}$$

For Unipolar PWM, m_f = even integer.[14].

5. Conclusion

In this article, PWM technique general features are being discussed, common PWM inverters are being summarized, Matlab codes are being used for signal generation.

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