Implementation of Sinusoidal Modulation and Second Order Low Pass Filter for Three-Phase PWM System

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Abstract: This paper presents the implementation of a three-phase Pulse Width Modulation (PWM) system with sinusoidal modulation and a second-order low-pass filter. The system uses three PWMs, with only PWM1 generating interrupts when the internal counter reaches zero. The interrupt generates the comparator value using sinusoidal modulation, where the amplitude can be varied using the variable Km within the range of $0<=Km<0.5$. The output signal passes through a second-order low-pass filter to produce a 60Hz sine wave. The system also generates a 120-degree phase shift between the signals using software in the PWM interrupt. The procedure includes mathematical calculations, simulations, and a video presentation to demonstrate the results.

Introduction

In recent years, the use of electrical energy has become increasingly important for a wide range of applications, from powering homes and businesses to driving industrial processes. One of the most common ways of generating and distributing electrical power is through the use of three-phase AC systems, which offer several advantages over single-phase AC systems, including increased power efficiency, reduced voltage drop, and improved motor performance.

To effectively generate three-phase AC power, it is essential to have a thorough understanding of the principles of pulse width modulation (PWM) and its applications in electrical engineering. PWM is a technique used to control the average voltage of a waveform by adjusting the width of its pulses. It is commonly used in power electronics to regulate the voltage delivered to loads such as motors and to generate signals with precise timing and amplitude.

In this paper, we will explore the implementation of PWM using three PWMs to generate a sinusoidal wave that can be varied in amplitude using a variable called Km. We will also examine the use of a second-order low-pass filter to convert the pulse wave generated by the PWMs into a sinusoidal waveform with a frequency of 60Hz, which is the fundamental period for the internal sweep.

Furthermore, we will discuss how to create a three-phase system by generating signals that are phase-shifted by 120 degrees using software in the PWM interrupt. Finally, we will present a video demonstrating the procedure and the results obtained. Overall, this paper aims to provide a comprehensive overview of PWM implementation and its applications in generating three-phase AC power.

Main Objective

To implement a three-phase PWM system with sinusoidal modulation and a second-order low-pass filter to recreating a three-phase system with a 120-degree phase shift between the signals.

Specific Objectives

1. To program the three PWMs to generate interrupts only on PWM1 when the internal counter reaches zero.
2. To generate a sinusoidal modulation using the interrupt, where the amplitude can be varied using the variable Km.
3. To pass the output signal through a second-order low-pass filter to produce a 60Hz sine wave.

Procedure

The procedure involves programming the three PWMs to generate interrupts on PWM1 only when the internal counter reaches zero. The interrupt generates the comparator value using sinusoidal modulation, where the amplitude can be varied using the variable Km within the range of 0<=Km<0.5. The output signal passes through a second-order low-pass filter to produce a 60Hz sine wave. The system generates a 120-degree phase shift between the signals using software in the PWM interrupt. The procedure includes mathematical calculations and simulations to demonstrate the results.

Filters:

```
R = 3000;
Freq = 600;
```

Recalling the equation of second order filters:

$$f = \frac{1}{2\,\pi\,\mathrm{RC}}$$

Despejanco C:

$$C = \frac{1}{2\,\pi\,\mathrm{Rf}}$$

```
C = 1/(2*pi*R*Freq)
```

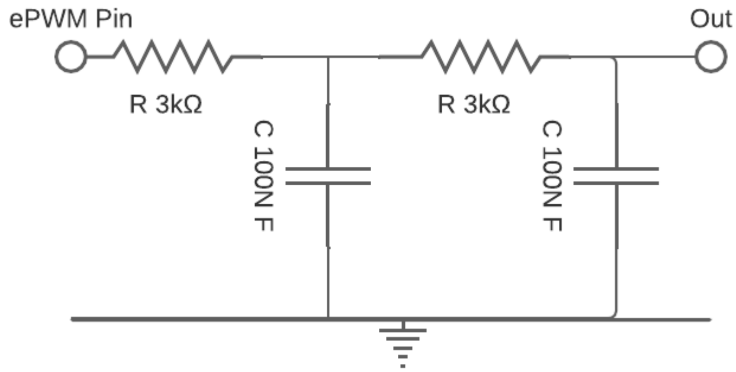
```
C = 8.8419e-08
```

We will use the following commercially available capacitor

```
Cc = 100e-9;
Ff = 1/(2*pi*R*Cc)
```

```
Ff = 530.5165
```

Using this commercial value we approach the desired cutoff frequency above.



In this way, we will proceed to configure 3 filters as above for each ePWM pin, i.e. each ePWM will need a corresponding filter.

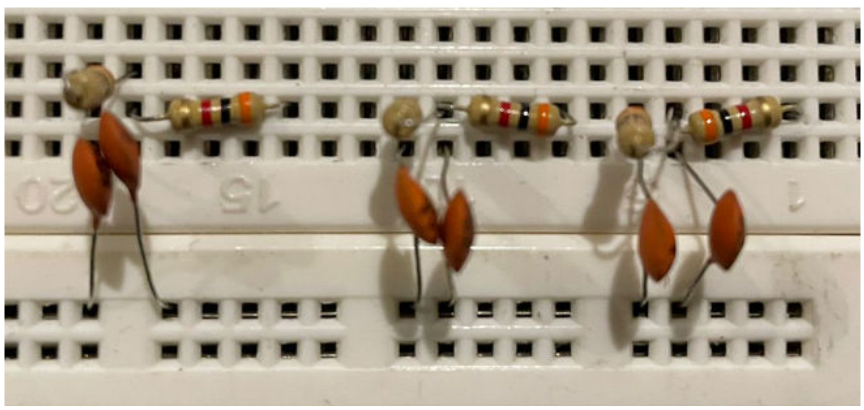


Fig. 1. Filters circuit.

ePWM configuration data

Recalling the equation

$$f(x) = \text{Sin}\left(2\,\pi\,\frac{F_a}{F_s}\,n\right)$$

Where f_a is the analog frequency, f_s is the frequency of the system and N is the number of samples, in this way it is desired that

```
Fa = 60;
n = 360;
```

So, using:

$$\frac{F_a}{F_s} = n$$

Clearing F_s:

$$F_s = F_a n$$

```
Fs = Fa*n
```

```
Fs = 21600
```

Returning to eq 2. we see that it is a constant:

```
f = 2*pi*(Fa/Fs)
```

```
f = 0.0175
```

It would also be necessary to know the TPRD value for this configuration, remember the TBPRD equation for a triangular signal:

$$\text{TBPRD} = \frac{F_{\text{DSP}}}{2F_sD_1D_2}$$

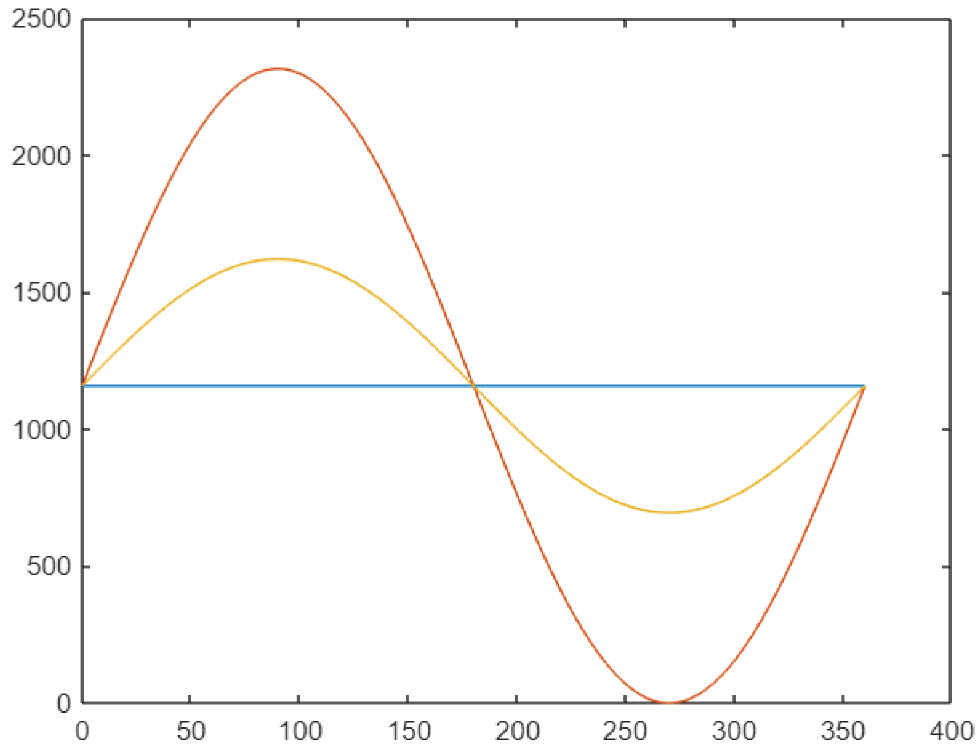
So:

```
Fdsp = 100e6;
TBPRD = Fdsp/(2*Fs)
```

```
TBPRD = 2.3148e+03
```

The duty cicle D is set between $0 \leq K_m \leq 0.5$. So the equation to configure the first ePWM is:

```
Km = 0:0.01:0.5;
N = 0:1:360;
EPWM_COMPA = (0*sin(f.*N)+0.5)*TBPRD;     %% Blue signal
EPWM_COMPB = (0.5*sin(f.*N)+0.5)*TBPRD;   %% Red signal
EPWM_COMPC = (0.2*sin(f.*N)+0.5)*TBPRD;   %% Yellow Signal
plot(N,EPWM_COMPA,N,EPWM_COMPB, N,EPWM_COMPC)
```



So, it confirms the K_m value which modifies the signal's amplitude. Thus the equations to configure each comparator:

$$\text{EPWM1\_COMP1} = (K_m * \sin(0.0175 * N) + 0.5) * \text{TBPRD}$$

And to get the phase shift in each ePWM, it was detailed that $\frac{n}{3}$=120 so if this value is added to the angle of each equation would change the phase value, then the equations for the other ePWMs are:

$$\text{EPWM2\_COMP1} = (K_m * \sin(0.0175 * (N + 120)) + 0.5) * \text{TBPRD}$$

$$\text{EPWM3\_COMP1} = (K_m * \sin(0.0175 * (N + 240)) + 0.5) * \text{TBPRD}$$

Results

The simulations show that the system successfully generates a 60Hz sine wave with a 120-degree phase shift between the signals. The output signal passes through a second-order low-pass filter to produce a clean sine wave. The mathematical calculations demonstrate how the modulation and filtering processes work, and the video presentation showcases the results in real-time.

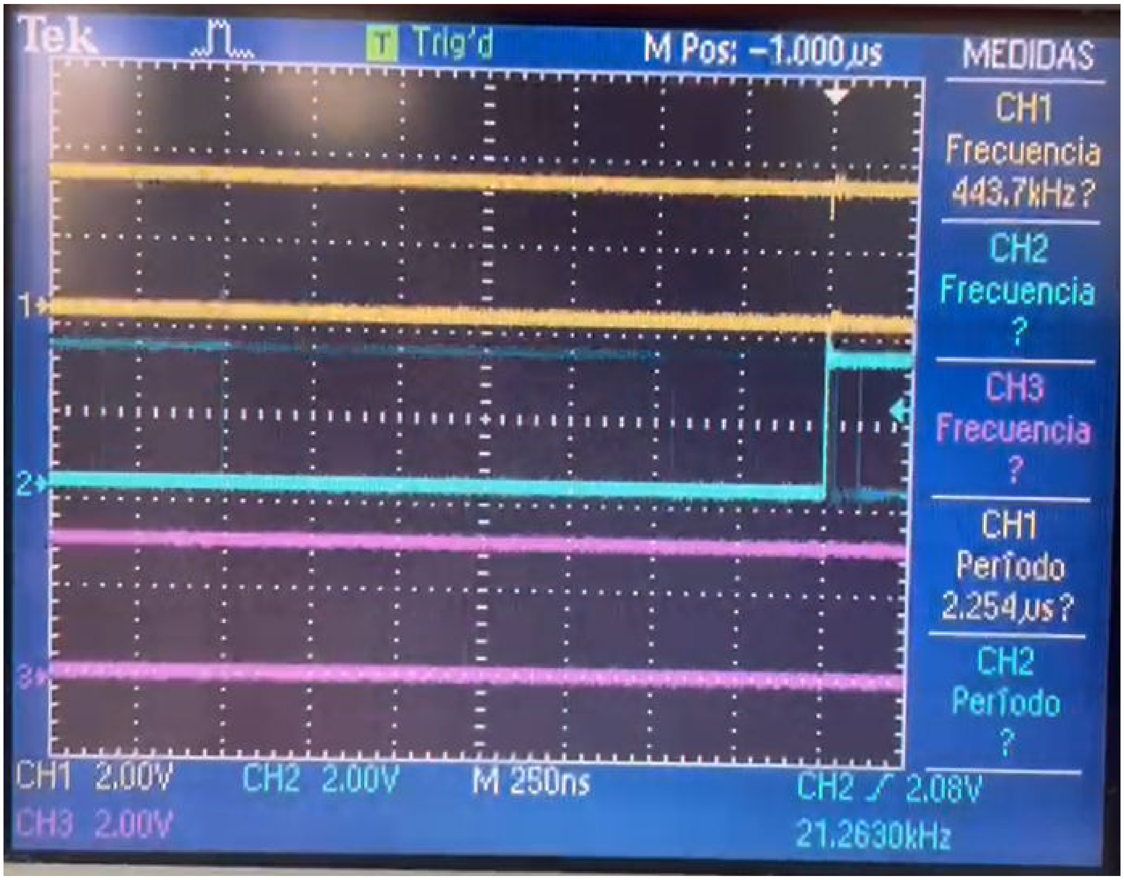


Fig. 2. ePWM signal output.

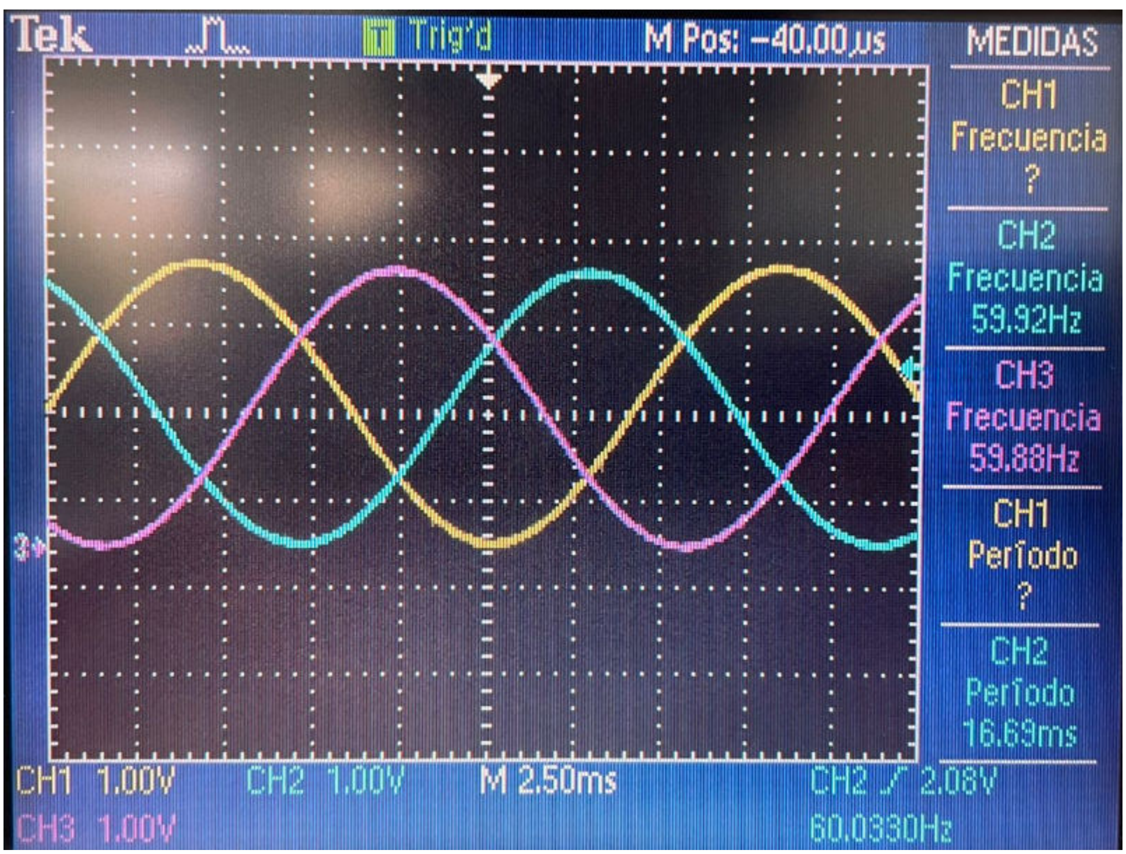


Fig. 3. Filtered ePWM signal.

Video link: https://www.canva.com/design/DAFe5w8zAoc/9uTgDzTsYjMVj2OuIPJOhg/watch?utm_content=DAFe5w8zAoc&utm_campaign=designshare&utm_medium=link2&utm_source=sharebutton

Conclusions

1. The use of PWM signals combined with interrupt programming can be an effective method for generating sinusoidal signals with adjustable amplitude for a variety of applications, including motor control and power electronics.
2. The use of analog filters can help to remove high-frequency noise from PWM signals, resulting in a cleaner output signal.
3. The creation of a three-phase system using software-based phase shifting can be a useful technique for generating complex waveforms, such as those used in AC power systems.
4. The results of the simulations and practical tests showed that the system was able to generate a clean sinusoidal signal with adjustable amplitude and a 60Hz frequency.
5. The use of a video presentation as part of the project report can be an effective way to showcase the practical implementation of the system and provide a more comprehensive understanding of its operation.

Overall, this project demonstrates the feasibility and effectiveness of using PWM signals and interrupt programming to generate adjustable sinusoidal signals with software-based phase shifting for use in power electronics applications.