Fast Fourier Transform Analysis on Harmonic Content for SPWM Design and Implementation Based on New Modulation Approach

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Abstract- This paper is focusing on optimizing harmonic content in Sinusoidal Pulse Width Modulation (SPWM) design. The results show that by varying number of bits, modulation index and switching frequency, the harmonic content to Total Harmonic Distortion (THD) can be analyzed and optimal method to reduce the harmonic content of THD can be found. This SPWM is designed using VHDL and implemented on ALTERA (DE2-70 board). The results, the SPWM signals and its Fast Fourier Transform (FFT) waveform, are measured using Digital Oscilloscope. The Total Harmonic Distortion (THD) is calculated from measured waveform. From the analysis, for 10 bit, mod index one and at frequency of 20 kHz, Total Harmonic Distortion for the SPWM design is optimized.

Key-Words— Sinusoidal Pulse Width Modulation (SPWM), Harmonic Content, Modulation Index, Field Programmable Gate Array (FPGA), Total Harmonic Distortion (THD) and Fast Fourier Transform (FFT).

1 Introduction

PULSE with modulation (PWM) is normally used as a controller in power conversion and motion control. It also widely used for converting DC power to AC power in low power wind plants [3]. A control technique for the PWM converter is based on the input current control, in which the current commands are provided from the detect power-source voltages [4]. There are various kinds of modulation modes available such as sinusoidal PWM, current tracking PWM, space vector PWM and harmonic elimination [1].

In the early days, many different PWM techniques have been presented and sinusoidal PWM (SPWM) has been commonly used today, [2].The problem in SPWM is the produced signal has larger harmonic content. In the previous study, several methods had been investigated to produce fewer harmonics. The traditional method to reduce harmonic content is by generating the pulse width with equivalent area [1]. Other approach is based on the optimization of the shape of the triangular voltage waveform. The results have shown that the total harmonic distortion of the optimized voltage waveform decreases gradually and thus helps improve on the power quality during the conversion [3].

In this project, a new modulation technique is proposed by reducing the number of harmonics through minimizing pulse width area. The modulation technique is based on optimization design of the sine waveform to generate PWM waveform containing less Total Harmonic Distortion for certain modulation index. By optimizing the sine waveform design, the full of the PWM waveform is less harmonic than previous PWM design.

2 Sinusoidal pulse width modulation

2.1 Concept of SPWM output

The sinusoidal pulse width modulation (SPWM) produced by comparing between triangular waveform, V_c and sine waveform, V_{ref} .The sine waveform is also called as reference signal and the triangular waveform is called as carrier signal. The cross over point between triangular waveform and sine waveform will generate the pulse width. The output SPWM is illustrated Fig.1.

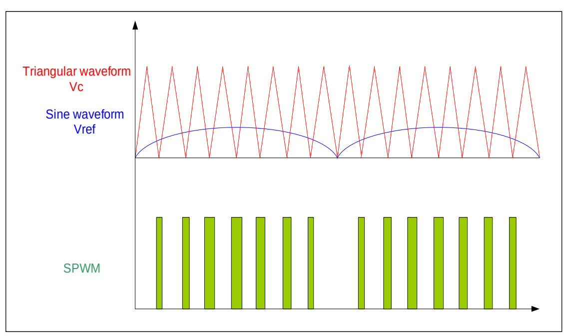

Fig. 1 Formation of SPWM

When sine waveform, V_{ref} is greater than triangular waveform, V_c the pulse width will go to level high or go to the 'On' state. When the sine waveform, V_{ref} lowers than triangular waveform, V_c the pulse width will go to the lower level or to the 'off' state. The cross over point illustrate in Fig. 2.

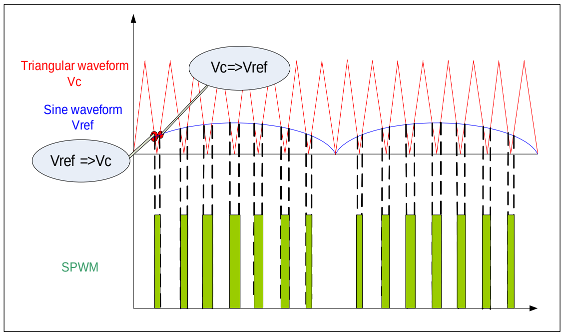

Fig. 2 Cross over point to generate SPWM

2.2 Harmonic in SPWM

Harmonic is a sinusoidal component of a periodic wave or quantity having a frequency which the frequency is an integral multiple of the fundamental frequency. Harmonic is very important to make sure the wave produced is accurate and meet the required specification. It is also can show any complex waveform, whether it is produced by a musical instrument or a power system. The harmonic in sine wave can be illustrated in Fig. 3 and Fig. 4.

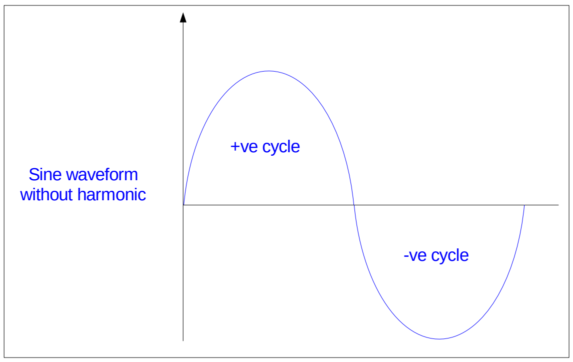

Fig. 3 Sine waveform without harmonic

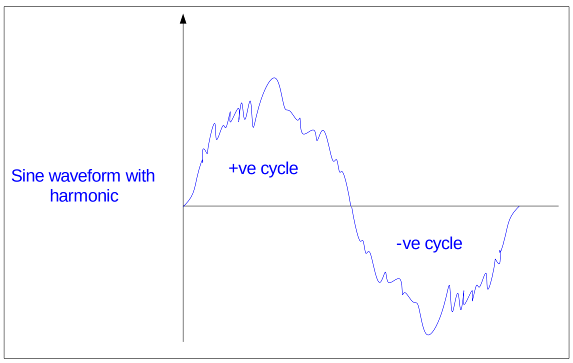

Fig. 4 Sine waveform with harmonic

3 Method to improve the resolution

In the previous method, the sine wave is produced by count up from 0 to 24 which represent the first quarter (zone A) then count down from 24 to 0 which represent for second quarter (Zone B) as illustrated in Fig. 5.

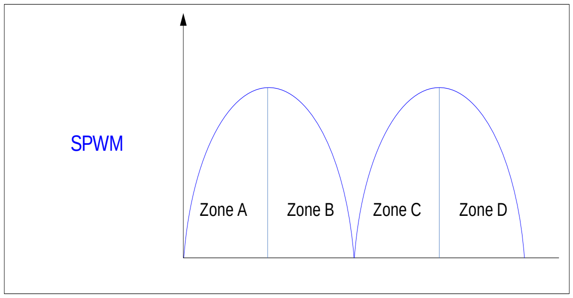

Fig. 5 Concept to formation of half cycle sine waveform

In this paper, the design is based on positive cycle sine wave in order to reduce complexity when designing using VHDL.

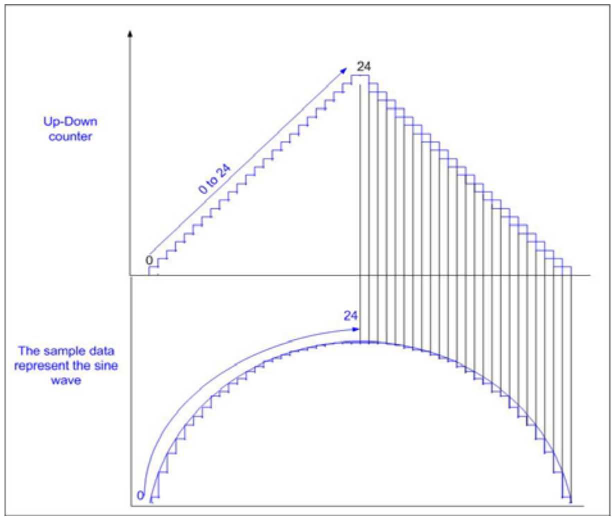

Fig. 6 Sine waves produce by quarter cycle

The counter will count up from 0 to 24, and then count down from 24 to 0. At the same time the sample data will represent the sine wave according to the counter. By using this concept; the aim of this project is to create more quarter cycle in sine wave. The generated quarter cycle in square wave for mod index 5, 8 and 10 are up to 32 quarter, 256 quarter and 1024 quarter respectively. The expected result for all the mod index are illustrated in Fig.7 to Fig.9

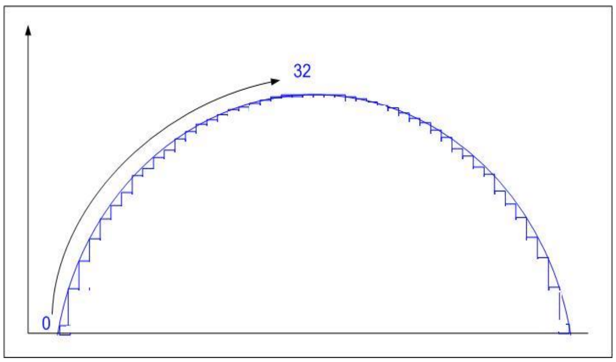

Fig.7 Sine wave with 32 quarter for number of bit 5

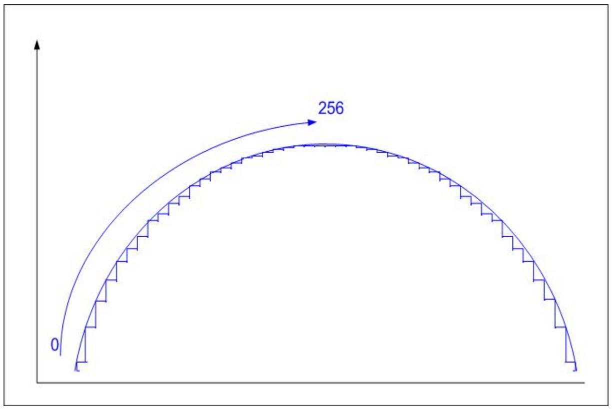

Fig. 8 Sine wave with 256 quarter for number of bit 8

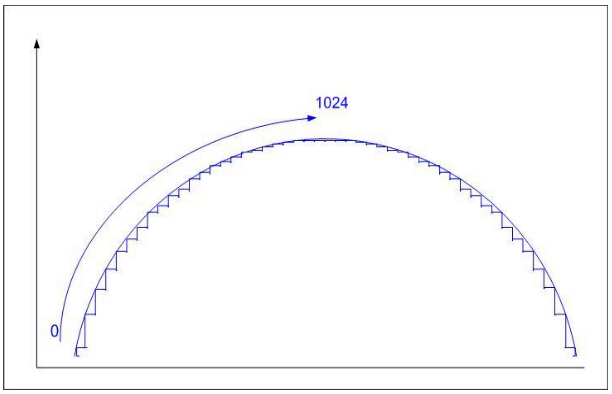

Fig. 9 Sine wave with 1024 quarter for number of bit 10

The mod index or modulation index (Ma) is a ratio between sine waveform (V_{ref}) and carrier waveform (V_c). The magnitude of output voltage is proportional to the Ma. The output voltage can be controlled by varying the Ma.

Equation 1 is used to generate sinusoidal by using sample data.

$$V_{ref} = 1024 \left[\sin\left(\frac{0.08789\, k}{180\, \pi} \right) \right] \quad (1)$$

k= magnitude

Number of pulse (p) is 100 for 50Hz sine frequency waveform, (f_{ref}), and 5 kHz triangular frequency waveform, (f_c).

$$\text{Sine frequency,} \qquad f_{ref} = \frac{1}{T_{ref}}$$

(2)

$$\text{Triangular frequency,} \qquad f_c = \frac{1}{T_c}$$

(3)

$$\text{Pulse,} \qquad p = \frac{T_{ref}}{T_c}$$

(4)

T_{ref} = reference time

T_c = carrier time

4 Result and Discussion

To determine the optimal method in reducing the harmonic content of THD, SPWM waveform needs to be converted to Fast Fourier Transform (FFT) as shown in Fig. 10. By using FFT, the SPWM signals are transformed into frequency domain and the harmonic in this system can be calculated.

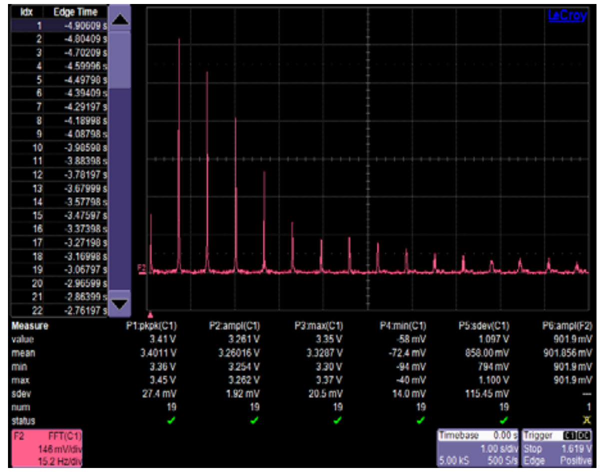

Fig. 10 Converting SPWM to Fast Fourier Transform (FFT) wave.

Table 1 concludes all the result to show harmonics content in SPWM design. The data in the table is determined from the analysis. From the FFT waveform, the analysis is done by calculating total harmonics distortion by using equation 5. The data used during the analysis is taken from FFT waveform illustrated in Fig. 17 [5].

$$THD = \sqrt{\left(\left(\frac{V_s}{V_{s1}} \right)^2 - 1 \right)} \quad (5)$$

V_{s1} = RMS of fundamental component

$$V_{s1} = \left(\frac{V1}{\sqrt{2}} \right)^2$$

V_s = Total RMS of voltage

$$V_s = \sum \left(\frac{V1}{\sqrt{2}} \right)^2 + \left(\frac{V2}{\sqrt{2}} \right)^2 + \ldots \left(\frac{Vn}{\sqrt{2}} \right)^2$$

Table 1
Total Harmonics distortion (THD)

Number of bit	Modulation Index	Frequency	Total Harmonic Distortion (THD)
5	1	5 KHz	0.526
	0.5		1.006
	0.1		1.660

	0.1	20 KHz	1.529
	0.5		0.922
	1		0.444
8	1	5 KHz	0.434
	0.5		1.021
	0.1		1.802
	0.1	20 KHz	1.670
	0.5		1.166
	1		0.413
10	1	5 KHz	0.385
	0.5		1.019
	0.1		1.759
	0.1	20 KHz	1.504
	0.5		1.013
	1		0.497

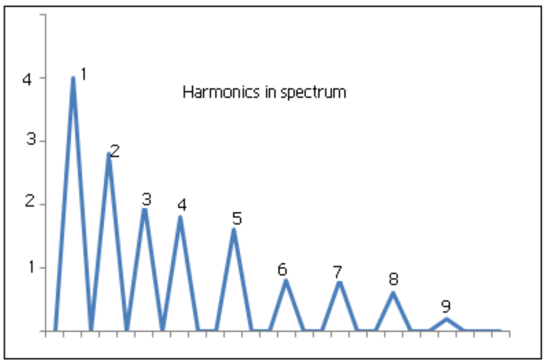

Figure 17. FFT waveform

5 Conclusion

From this project we can conclude, the harmonic contents will be more when the modulation index is low. Table1 shows the THD for this system is decreased when the modulation index is increased. By increasing number of bit used in representing the coefficients for sine wave signals, it will also reduce the harmonics for this system. This system has been tested using 5, 8 and 10 bit, and overall we can see the optimal method to reduce THD if the system use higher number of bit and in this case10 bit resolution and switching frequency is at 20 KHz.

References

[1] M. S. N. Romli, Z. Idris, A. Saparon and M. K. Hamzah "An Area-Efficient Sinusoidal Pulse Width Modulation (SPWM) Technique for Single Phase Matrix Converter (SPMC)", 3rd *IEEE Conference on Industrial Electronics and Applications,* 2008.

[2]Y.X.Gao, "*A Method of Reducing Harmonic Contents for SPWM*", in IEEE 1999 International Conference on Power Electronics and Drive Systems, PEDS'99, July 1999

[3] N. Tutkun, "A new modulation approach to decrease total harmonic distortion of the SPWM voltage waveform using genetic optimization technique", Department of Electrical & Electronic Engineering Faculty of Engineering, Zonguldak Karaelmas University, 2004

[4] Toshihiko Noguchi, Hiroaki Tomiki, Seiji Kondo "Direct Power Control of PWM converter without Power-Source Voltage" *IEEE transaction on Industry Applications*., vol. 34, pp. 473-479, Jun 1998.

[5] Ned Mohan, Tore M. Undeland and William P.Robbinson "Power Electronic: Converters, Application and Design", 2002.

[6] Z. Idris, M.K Hamzah, Dr Azilah Saparon, N.R Hamzah and N.Y Dahlan "FPGA Design of Single –phase Matrix Conveter Operating as cycloconverter" in *7th International Conference on Power Electronics and Drive Systems,* pp. 301-307, 2007.

[7] M. N. Md Isa, M.I. Ahmad, Sohiful A.Z. Murad and 1M. K. Md Arshad, "FPGA Based SPWM Bridge Inverter", American Journal of Applied Sciences 4., vol. 8, pp. 584-586, 2007.