

# Development of a Microcontroller Based Low Distortion Modified Push-Pull Power Inverter

Abiodun Alani Ogunseye<sup>1</sup>, Taofik Titus Ogunseye<sup>2</sup>

<sup>1</sup>Department of Electrical/Electronics & Computer Engineering, Bells University of Technology, Nigeria

<sup>2</sup>Department of Physics, University of Ibadan, Nigeria  
abbey\_ogunseye@yahoo.com

**Abstract**— In d.c to a.c power conversion systems, it is desirable that power inverter systems have high power conversion efficiency and low total harmonic distortion (THD) figures. Modified squarewave and squarewave inverters, the simplest inverter types, have high efficiency figures but their high THD figures limit their usefulness in powering harmonic-sensitive loads. In this work, the output waveform of the standard modified squarewave inverter was modified to form a five level waveform whose properties can be optimised for low distortion figures. With a MATLAB® program, the parameters of the five level waveform were adjusted and a THD of 1.25% was obtained. A microcontroller-based circuit was designed, constructed and tested to generate the optimised low distortion waveform from a 12 V d.c source. A sinusoidal signal was obtained from the constructed inverter circuit after filtering its five-level output waveform with a simple inductor-capacitor (LC) low pass filter.

**Keywords**— *Microcontroller, Five level Waveform, Push Pull inverter, Total Harmonic Distortion*

## I. INTRODUCTION

Inverters are important components in most renewable energy schemes whose performance indices affect the overall performance of the entire system. Such performance indices of a power inverter system include the power conversion efficiency and total harmonic distortion (THD) figures. High efficiency figures are desirable because it translates to a lower amount of energy wasted as heat, resulting in a higher reliability figure of the inverter. The presence of harmonics in the output waveform of an inverter can cause degradation in the performance of sensitive electrical loads such as audio and medical equipment that are powered from such an inverter. Thus, harmonic-sensitive devices must be powered from an inverter system that has a low output waveform distortion. Ideally, an inverter should have an output voltage that is devoid of harmonic contents, i.e 0 % THD figure. This ideal is difficult to efficiently achieve in practice; most real world inverters have non-zero distortion figures, even after efforts have been made to reduce the harmonics with low pass filtering.

Conventional modified squarewave inverters have high efficiency figures, but their THD figure is high. In this work, the possibility of reducing the THD figure of conventional modified square waveform was explored. The conventional

three-level modified square waveform was modified by adding an additional voltage level each in both the positive and negative portion of the waveform, forming a five level waveform. The parameters of this waveform were then optimised to obtain a low distortion figure. A microcontroller based circuit was developed to synthesize the resulting waveform from an external d.c source.

## II. LITERATURE REVIEW

Various inverter types with different efficiency and THD performance have been developed over the years. The squarewave inverter is easily implemented in hardware, [2,3] but it has a high level of distortion, about 45%. Also, the third harmonic component of its output waveform, the hardest to filter away, is theoretically about a third of the fundamental component. This limits the usefulness of squarewave inverters in powering harmonic-sensitive loads. The modified square wave inverter, a variant of the square wave inverter, has a lower distortion figure compared to the squarewave inverter, but its THD figure of 23.8% [4] is still too high for powering sensitive loads. The modified squarewave inverter have been used to successfully power non-critical loads such as electric motors[1]. These high distortion inverters however have low switching losses, because their output devices are switched at the output line frequency, typically 50 or 60 Hz. This translates to high efficiency figures.

The true sinewave inverter uses sinusoidal pulse width modulation schemes to generate low distortion output voltages, making it suitable for powering noise-sensitive loads. In this type of inverter, a high frequency sawtooth waveform is used to sample a reference sinewave [5, 8]. This scheme produces a waveform whose harmonics are typically widely separated in frequency, making it easy to filter away the unwanted harmonics with a very simple low pass filter. Its mode of operation, however, requires that the output devices must be switched at relatively high rates to minimise distortion, resulting in high switching losses and consequently, low efficiency figures at high output power levels [4].

The high switching losses of true pwm-based sinewave inverters prompted [4] to propose a simple modification to the modified square waveform. The proposed waveform modifies a standard modified square waveform by adding an additional voltage level in each direction, as shown in Fig. 1. In [4], the

ratio of A to B was fixed at 0.5. This waveform can be

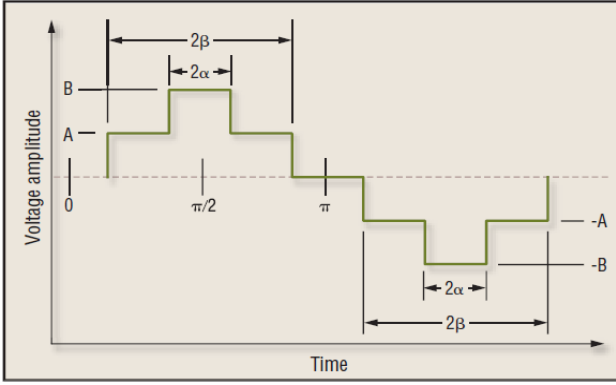


Fig. 1: A five level waveform [4].

efficiently generated and has a distortion figure of 6.5%. To synthesize this waveform, the output devices must be switched at a rate that is three times the frequency of the output waveform. In comparison, a true sinewave inverter using pwm principles switches at a rate higher than this to minimise waveform distortion. Inverters generating Hann's waveform will have a high power conversion efficiency figures as a result of reduced switching losses and a reasonably low THD value. An example of such an inverter was developed in [6].

The possibility of further reducing the distortion figure of the five level waveform proposed by Hann is explored in this work. To achieve this, the restriction on the ratio of A to B ( $\gamma$ ) of 0.5 in [4] was removed. This gave us another parameter, in addition to the duration of the pulses that were adjusted to obtain lower waveform distortion. A microcontroller-based circuit that generates the resulting low distortion waveform from a 12 volts d.c source was developed and constructed. The output waveform of the developed inverter circuit has a repetitive frequency of 50 Hz.

### III. METHODOLOGY

#### A. Development of the proposed waveform

The five level waveform in Fig. 1 has four parameters, namely the pulse magnitude values A and B and the pulse width parameters  $\alpha$  and  $\beta$ . These parameters can be optimised to reduce the THD figure of the waveform. If the harmonic content above the ninth are ignored, the ratios of A and B are set to 0.5 and  $\alpha$  and  $\beta$  are assigned values of  $0.248\pi$  and  $0.42\pi$ , the THD figure is 6.51% [4].

The waveform in Fig.1 has odd quarter wave symmetry, so it has only odd sinusoidal wave harmonics. If we express the waveform  $x(t)$  in the Fourier sense, we have

$$x(t) = \sum_{n=0}^{\infty} a_{(2n+1)} \sin 2\pi(2n+1)ft \quad (1)$$

Where  $f$  = repetitive frequency of  $x(t)$  and

$a_{(2n+1)}$  is the Fourier coefficient

The THD for this wave is

$$THD = \frac{\{\sum_{n=1}^{\infty} [y \sin(2n+1)\beta + (1-y) \sin(2n+1)\alpha] / ((1+2n))^2\}^{1/2}}{[(y \sin(\beta) + (1-y) \sin(\alpha))]} \quad (2)$$

Where  $\gamma = A/B$  and  $n = 0, 1, 2, \dots$

From (2), we see that the THD figure depends on the values of  $\alpha$ ,  $\beta$  and  $\gamma$ . To evaluate eq. (2) on a digital computer, the number of harmonics must be limited to a finite value.

A simple MATLAB programme was used to evaluate the minimum THD figure for various values of  $\gamma$ ,  $\alpha$  and  $\beta$  and a specified number of harmonics. The program is a simple modification of the program used in [6] to investigate the distortion figure of a five level waveform. The values of  $\gamma$  were made to vary between zero and one in steps of 0.05. Also, the values of  $\alpha$  and  $\beta$  were made to vary from zero to  $0.5\pi$  in steps of  $0.05\pi$ .

With the maximum harmonic content limited to the seventh harmonic, the waveform has a THD of 1.25% when  $\gamma$ ,  $\alpha$  and  $\beta$  are 0.6,  $0.2\pi$  and  $0.4\pi$  respectively. The third harmonic, the hardest to filter out, is about 1.15% of the wanted fundamental component. The fifth harmonic has zero amplitude while the seventh harmonic is about 0.49% of the fundamental component.

Harmonic contents of the waveform above the 7<sup>th</sup> harmonic have non-negligible amplitudes. This will not of much consequence to the overall THD figure if a low pass filter is used to attenuate the third and higher order harmonic contents of the wave.

#### B. Developed Inverter Circuit

A microcontroller based inverter circuit was developed to synthesize the low distortion five level waveform. The inverter circuit, shown in Fig. 2, was designed around a PIC16F628A microcontroller that is clocked at 8MHz with an external crystal oscillator. This circuit was designed along the same lines as that in [7]. The microcontroller generated precisely timed pulses at its output pins that are used to control the switching states of the output switching devices.

To synthesize the five level waveform from a single voltage source, the inverter circuit must have two voltage transformation ratios. This was achieved by using a multi-tap step-up transformer that has two voltage transformation ratios, depending on the selected transformer tap. A core reset winding was added to the transformer to reset it when the two output switches are in the OFF state. This was done to ensure output waveform purity, especially under low output loading conditions.

In Fig. 2, some of the output switches are configured as bipolarity switches using two MOSFETs connected back to back (Q1-Q2 and Q3-Q4). This was done to prevent excessive heat loss due to the conduction of the body diodes that would result if a single MOSFET switch was used. For example, if Q5 conducts, a negative voltage is induced across the bipolarity switch formed by Q3 and Q4. If a single MOSFET switch was used here, the body diodes would conduct heavily, leading to excessive heat loss and ultimately to the failure of the switch.

To obtain low distortion output waveform, an LC filter with a cut-off frequency of 112 Hz was used to filter the output waveform produced by the inverter circuit. The prototype of

the inverter circuit was constructed on a general purpose printed circuit board.

C. Inverter firmware

The microcontroller firmware is based on a simple time-triggered finite state machine. A timer unit on the microcontroller (timer1) was programmed to generate interrupt signals periodically. At each interrupt event, the finite state machine goes into the appropriate state and waits for a specified duration by monitoring the value of the timer register. Once that time elapses, the firmware changes the values of the microcontroller output pins as required to synthesize the output waveform. The software was developed with MicroC® software for PIC series of microcontrollers and its functionality verified by using it to test a Proteus® model of the inverter circuit.

IV. RESULTS AND DISCUSSION

Fig. 3 shows a MATLAB® plot of the spectrum of the five level waveform, showing the relative amplitudes of the harmonics up to the seventh harmonic. Apart from the fundamental component, higher level harmonics, up to the seventh harmonic, have very low amplitudes. If harmonics

above the seventh harmonic are ignored, this waveform has a THD of 1.25%. This is an improvement on the works done by [4] where a THD of 6.25% was achieved with the same five level waveform having a  $\gamma$  value of 0.5.

Fig. 4 shows the prototype circuit that was constructed on a general purpose printed circuit board. This circuit, powered from a 12 volts d.c source, generates a waveform whose repetitive frequency is 50Hz. The unfiltered output voltage of the inverter circuit is shown in Fig. 5.

The square edges in this waveform are due to the presence of other harmonics in addition to the fundamental sinusoidal signal. These unwanted harmonic signals are removed by filtering the output waveform of the inverter with a simple LC filter. With the output LC filter connected to the output of the inverter, the resulting filtered inverter output waveform is shown in Fig. 6. As seen in Fig.6, this waveform has an essentially sinusoidal shape.

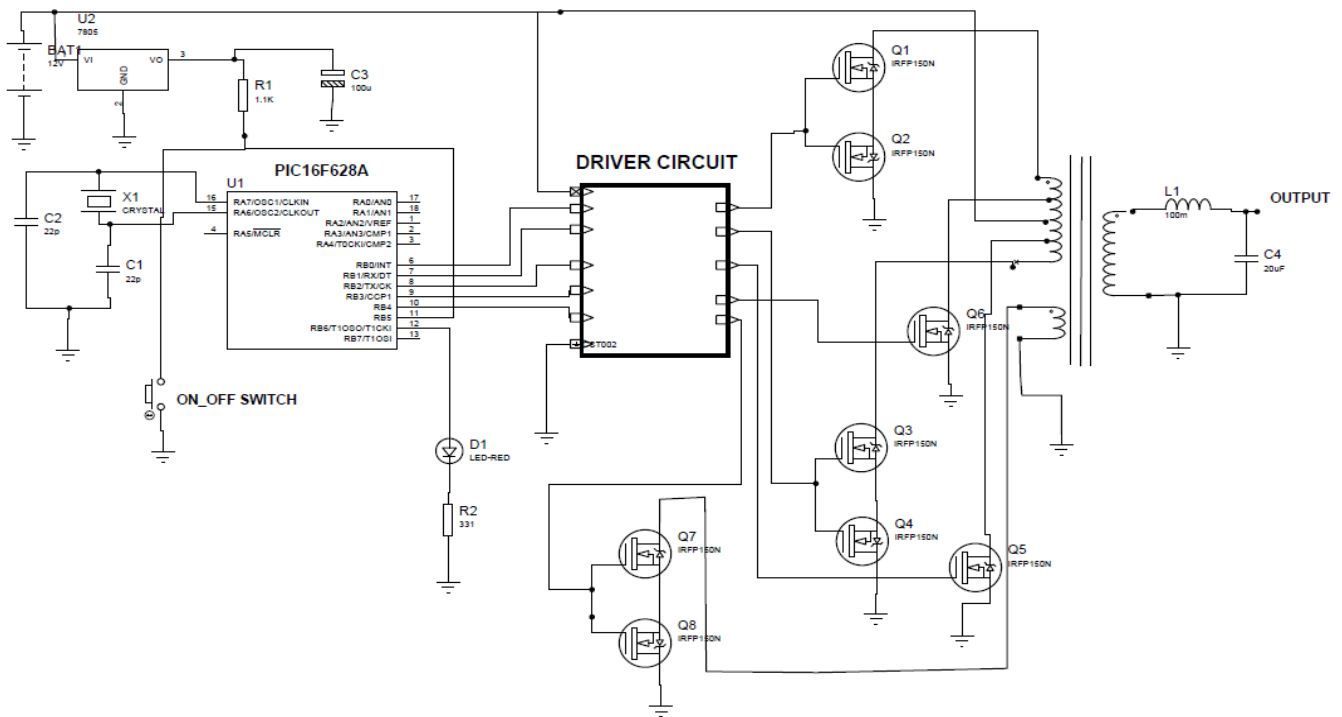


Fig. 2: A microcontroller based inverter circuit

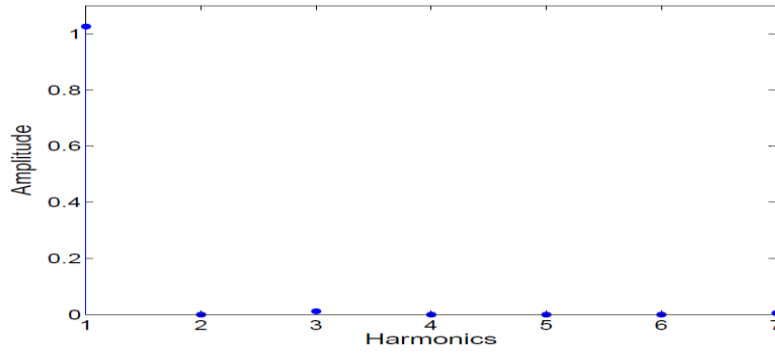


Fig. 3: Amplitude spectrum of the developed waveform

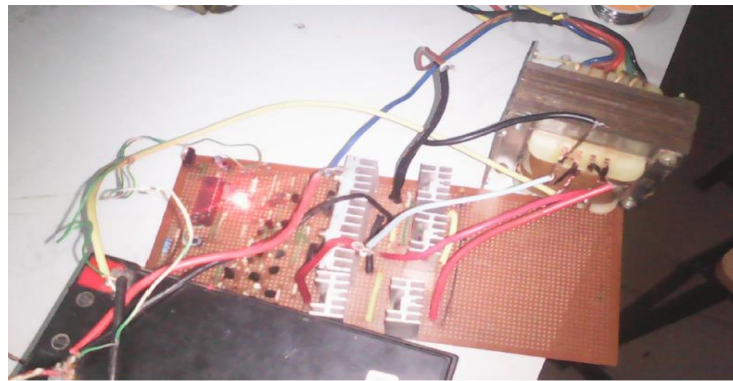


Fig. 4: The Constructed Inverter circuit

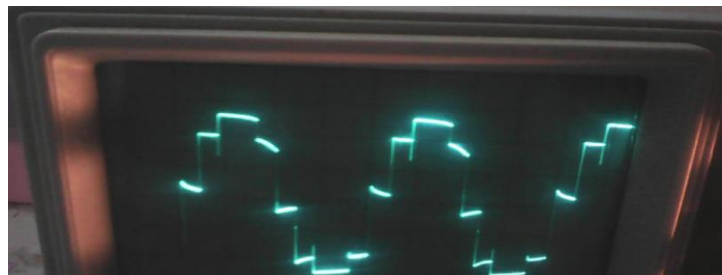


Fig. 5: The unfiltered output waveform of the Inverter circuit.

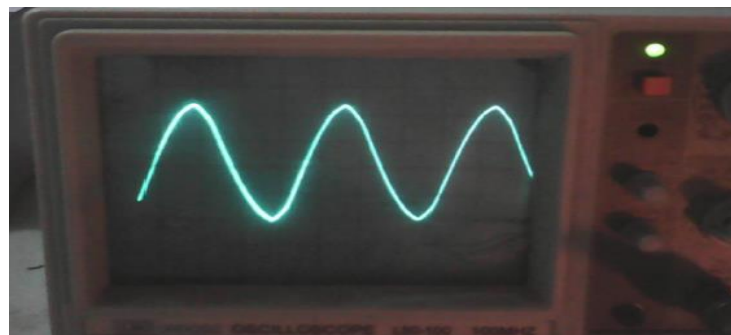


Fig. 6: The output waveform of the inverter after filtering with an LC filter.

## V. CONCLUSION

A five level waveform that can be efficiently implemented was analysed and optimised for low distortion figures. It was possible to minimise its distortion figure to an insignificant value of 1.25%. An inverter circuit, based on Microchip's PIC16F628A microcontroller, that generates this waveform having these optimised parameters was developed, constructed and tested. The filtered output waveform of the inverter has a shape that approximates a sinusoid, suggesting that its distortion figure is low.

Future works can focus on further reducing the distortion figures of the five level waveform analysed in this work.

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