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Design and Construction of an Inverter for University ICT Loads

Mbunwe Muncho Josephine, Madueme Theophilus Chukwudolue

Abstract: ***In trying to restore a stable power generation in this part of the world for effective research studies and to improve administrative duties in the University of Nigeria Nsukka, this paper discusses the design and construction of a single phase inverter for information communication and technology equipment's (ICT) which includes printers, computers, and network switches etc. The inverter system converts the DC voltage from a battery to AC voltage. The output is a pure sine wave, with the voltage and frequency of the standard grid (50Hz, 230V). A pulse width modulated (PWM) switching scheme together with a full bridge converter and filter is use to realize this design. The sinusoidal pulse width modulation (SPWM) switching scheme is the main logic control circuit of this inverter and provides a PWM output using operational amplifiers and microcontroller. This logic circuit is connected to a driver circuit to ensure sufficient gate driving current and voltage for the full bridge converter (H-bridge) switches (power MOSFET). The pulse signals are used to drive MOSFET in a H-bridge configuration to produce an output that is bipolar The output of this inverter switches from positive to negative (bipolar). This output from the MOSFET when filtered produces a sine wave output. This project is implemented and simulated using MATLAB simulation software.***

Keywords: ICT, H-Bridge, SPWM, Bipolar, Microcontroller.

I. INTRODUCTION

Electricity supply is one of the most important economic infrastructural facilities that are responsible for a nation's economic and technological development. The efficiency of the electricity will not only influence returns on investments of several enterprises, it will influence the decision on potential investment. Electricity which is the main source of power for our domestic consumption, industrial development, education and health facilities should be rehabilitated to enhance growth and productivity. Photovoltaic inverters are inverters either used for day system only or for day and night periods. The later describe the ones that have battery backup for use when the sun is down or cloudy. The simplest and least expensive photovoltaic system is the day use and consists of module wired directly to an appliance with no storage device. When sun shines on the modules, the appliance consumes the electricity generated. Higher isolation (sunshine) levels results in increased power output and greater load capacity [1]. The method employed by [2], was first programing a microcontroller to generate four control signal (two sinusoidal pulse width modulating SPWM signal and two other complimentary square wave signal) and then MOSFET driver was used to amplify the power of the signals.

The cost of good quality inverters is high in the Nigerian market thus people tend to use cheap inverters sure as square wave and modified sine wave to power devices which requires sine wave because the topologies are less expensive and easy to implement. Using the square wave or modified sine wave to power devices that require sine wave goes against the manufacturer's specification for powering sensitive equipment such as Desktop computers, Laptops, Printers, Network switches, Oscilloscopes etc. This cost gradual damage to electronic components, data transmission errors and delays in time dependent devices, which results in additional maintenances expenses, data pollution and loss of life in time dependent medical equipment's. Sine wave inverters give a pure sine wave output and operate in near perfect efficiency. The main objective is to design and develop a cost-effective inverter system to provide pure sine wave AC voltage at maximum efficiency.

Inverters are power conversion devices widely used to convert DC input voltage to AC output voltage. The ideal voltage wave output is sinusoidal. Practically, inverters are non-sinusoidal with harmonics [3, 4]. These harmonics damage the electronic devices in the inverters. The harmonic content at the output depends on the number of pulses per cycle [5-10]. Some research works show that the output wave signals are distorted. Solving the loss problem, pulse per cycle is affected. Therefore, the use of high switching technique contributes to high power losses. For a good design, the following factors are to be considered: Equipment cost, Filter size and switching element power loss. To solve these problems, dead time is controlled [11, 12].

II. DESIGN METHODOLOGY

One of the most widely used and economical methods of actualizing a sine wave inverter is using high frequency inverter topologies. High frequency inverters make use of a communication technique known as pulse width modulation (PWM) that modulates a low frequency (reference signal operating at a supply frequency of 50Hz) on to a carrier frequency that is a multiple of the fundamental frequency.

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* Correspondence Author

Mbunwe Muncho Josephine*, department of Electrical Engineering, University of Nigeria, Nsukka, Enugu, Nigeria. Email: muncho.mbunwe@unn.edu.ng or mamajoesix@gmail.com

Madueme Theophilus Chukwudolue, department of Electrical Engineering, University of Nigeria, Nsukka, Enugu, Nigeria. Email: theophilus.madueme@unn.edu.ng

This multiple is chosen to be odd so as to eliminate odd harmonics. The high frequency reduces components count, size and filter requirement. The PWM signal generated is used to drive power switches (power BJT's, power MOSFET's and/or IGBT's) which causes the dc input to change with time thus generating an ac signal. This type of PWM is known as sinusoidal PWM (SPWM).

Sinusoidal Pulse-width modulation (SPWM) decreases the total harmonic distortion of load current. A PWM inverter output, with some filtering, generally meet total harmonic distortion (THD) requirements easily than the square wave switching scheme. The unfiltered PWM output has a relatively high THD, but the harmonics is at much higher frequencies than for a square wave, making filtering easier [13]. With SPWM technique, the output voltage amplitude can be controlled with the modulating waveforms. This will give an advantage by reducing filter requirements, leading to harmonics decrease and amplitude output voltage control. Disadvantages will include more frequent switching.A sinusoidal reference signal and a triangular carrier signal using is generated using op amps. When the instantaneous value of the sine reference is larger than the triangular carrier, the output is at $+V_{dc}$, and when the reference is less than the carrier, the output is at $-V_{dc}$.

$$v_0 = +V_{dc}, \text{ for } v_{sine} > v_{tri} \quad (1)$$

$$v_0 = -V_{dc}, \text{ for } v_{sine} < v_{tri} \quad (2)$$

This version of PWM is bipolar because the output alternates between plus and minus the dc supply voltage. The switching scheme that implements bipolar switching using the full-bridge inverter of Figure 3.3b is determined by comparing the instantaneous reference and carrier signals:

$$S_1 \text{ and } S_2 \text{ are on, when } v_{sine} > v_{tri} \; (v_0 = +V_{dc}) \quad (3)$$

$$S_3 \text{ and } S_4 \text{ are on, when } v_{sine} < v_{tri} \; (v_0 = -V_{dc}) \quad (4)$$

Carrier waves can be either saw tooth or triangular signals. In this work, a triangular wave will be used at 1 kHz as determined by the circuit. This frequency is chosen as a multiple of the fundamental frequency with modulation index (mf) of 21. The PWM output then exhibits odd symmetry thus eliminating odd triple harmonics [13].

A. Inverter System Design Operation

The inverter system consist mainly of the microcontroller, full bridge converter and a low pass filter as shown in the basic block diagram of Figure 1. The output of the inverter is 50Hz and 220Vac as expected.

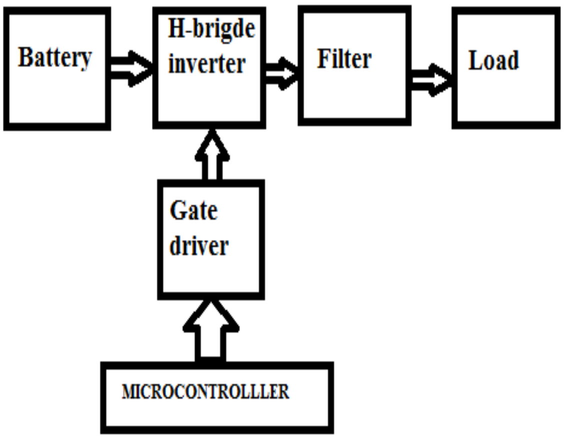

Fig. 1: Block diagram of an inverter

B. Microcontroller

The Arduino Uno microcontroller was use in this work. The gating signals for the power switches are programmed. The pulse is generated by writing a code that converts a 50Hz analog signal to a digital signal with vary duty cycle and a switching frequency of 1kHz.the duty cycle changes with respect to the reference sine wave. A lookup table is generated to map the analog sine wave to a digital value. An 8-bit resolution with a range from 0 – 255 is used for each signal. Two signals are generated which are 180 degrees out of phase. The Code algorithm is as shown in Figure 2.

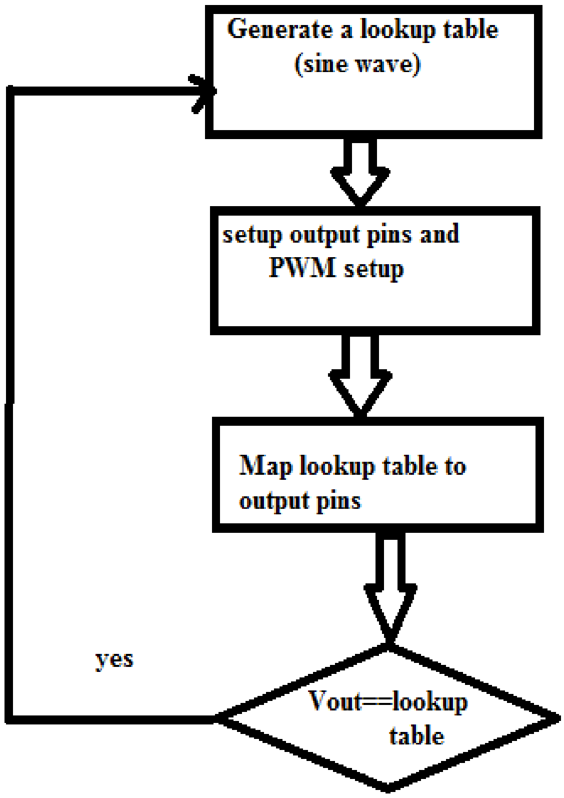

Fig. 2: The Code algorithm

C. H-Bridge

This H-Bridge controls different switches placed across a load.

If the load is a motor, the state will correspond to forward, reverse, and off states. Figure 3 and Table 1 shows H-Bridge configuration and valid H-Bridge Switch States respectively.

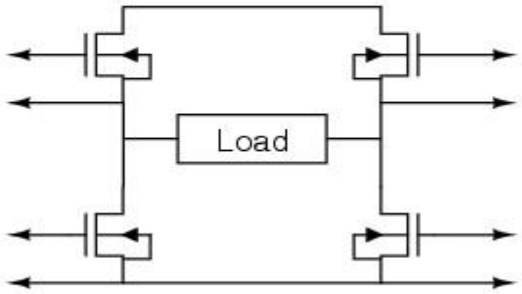

Fig. 3: H-Bridge Configuration using N-channel MOSFET.

Table 1: Valid H-Bridge Switch States

High Side Left	High Side Right	Low Side Left	Low Side Right	Voltage Across Load
On	Off	Off	On	Positive
Off	On	On	Off	Negative
On	On	Off	Off	Zero Potential
Off	Off	On	On	Zero Potential

The switches used for implementing an HBridge are mechanical or built solid state transistors. The use of P-Channel MOSFETs on the high side and N-Channel MOSFETs on the low side is easier, but to minimized power loss all N-Channel MOSFETs and a FET driver, lower "on" resistance can be obtained. The use of all N-Channel MOSFETs requires a driver, since in order to turn on a high side N-Channel MOSFET; there must be a voltage higher than the switching voltage. This difficulty is often overcome by driver circuits capable of charging an external capacitor to create additional potential.

D. Gate Driver

The driving of the MOSFET gate is dependent on two basic categories, a low-side and a high-side configured, in the full H-bridge circuit. The high-side of the MOSFETs (Q1,Q2) can float between the ground and the high voltage power, the low-side of the MOSFET (Q3,Q4) is connected between the power source and is constantly ground [14], the driver IR2110 is used for this paper.

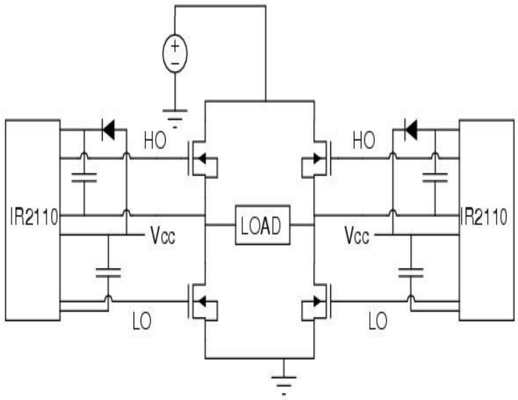

Fig. 4: H-Bridge with MOSFET Drivers

Operation of the IR2110 device is controlled through generated PWM signals. The PWM signal will be fed to the HIN and LIN pins simultaneously. The pins are driven by the effect of the logic. If the internal logic detects a logic high, the HO pin will be driven; if a logic low is detected, the LO pin will be driven. The SD pin controls shut down of the device. Additional pins that require external connections are the Vss pin which is tied to the ground, the Vcc pin which is tied to 12V, pins requiring connections to bootstrapping components and outputs to MOSFETS.

III. RESULTS AND DISCUSSIONS

Using Matlap simulation, the inverter design is simulated with a resistive load of 100Ω and nominal voltage of 220V.Amplitude of the carrier (triangular) wave is 10V with a switching frequency of 1kHz and the amplitude of the reference (sine) wave is 8V with a switching frequency of 50Hz. Figure 5 and Figure 6 shows the MATLAB system representation and results respectively, with pulse signals as shown in Figure 7.

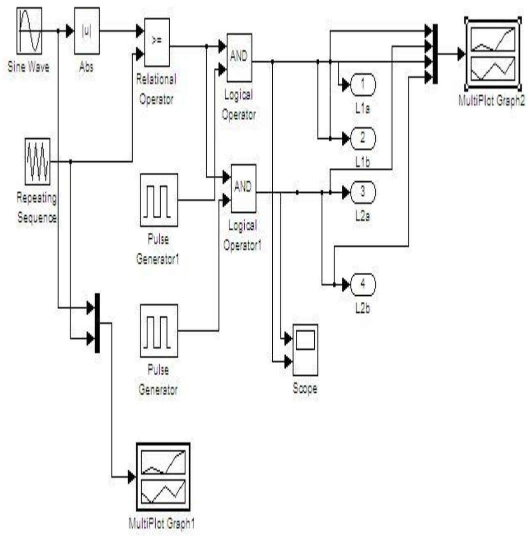

Fig. 5: Internal block parameters of PWM block

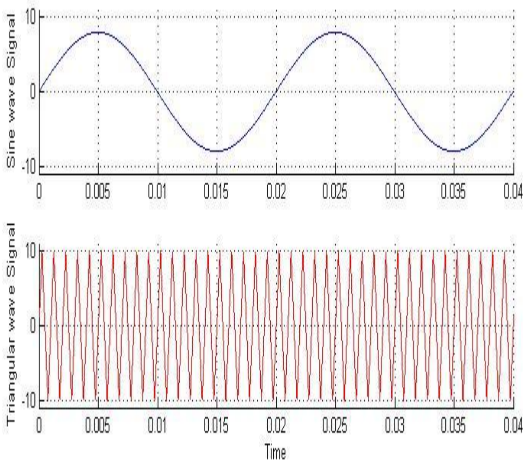

Fig. 6: Sine and triangular waves

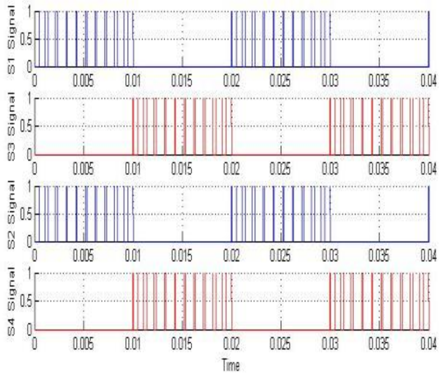

Fig. 7: Pulse signals

H-bridge configuration and a low pass filter that produces a sine wave output is as shown in Figure 8 and Figure 9 shows the simulated results. This circuit is connected to a resistive load(100Ω) hence the current wave form is identical to the voltage (sinusoidal).

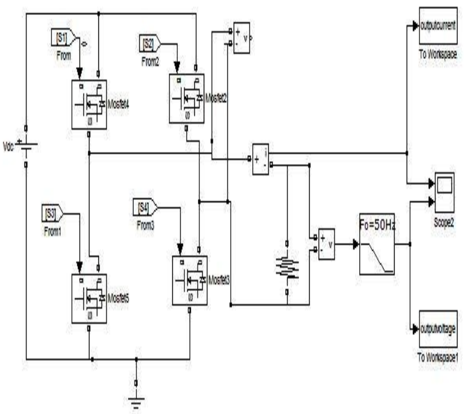

Fig. 8: Circuit block diagram

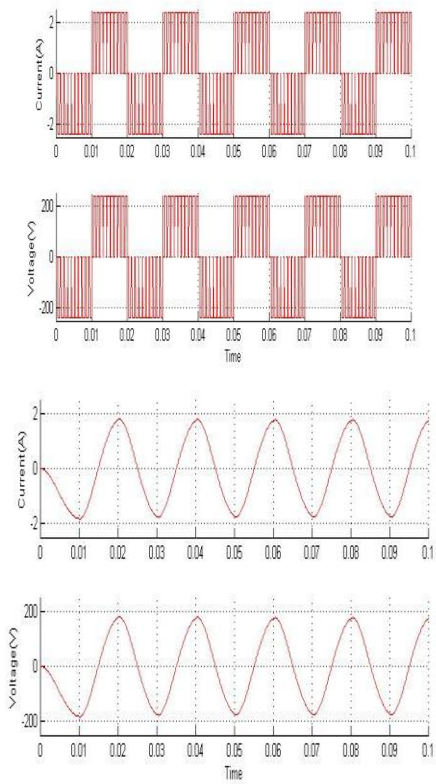

Fig. 9: Filtered output current and filtered output voltage

IV. DESIGN IMPLEMENTATION

Before In this paper, bipolar switching was used. The implementation of pure sine wave inverter in the following sections describes how the project was implemented with op amps/microcontroller and each sub circuit was coupled together. The output pulses and inverter output voltage are as seen from the oscilloscope is shown in Figures 10- 14.

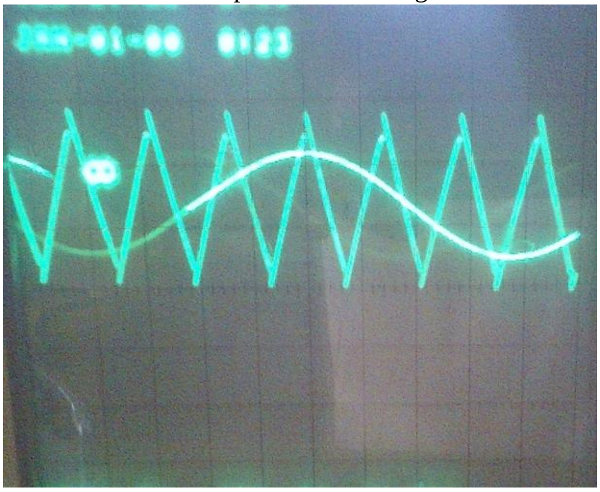

Fig. 10: Sinusoidal pulse with modulation with op amps.

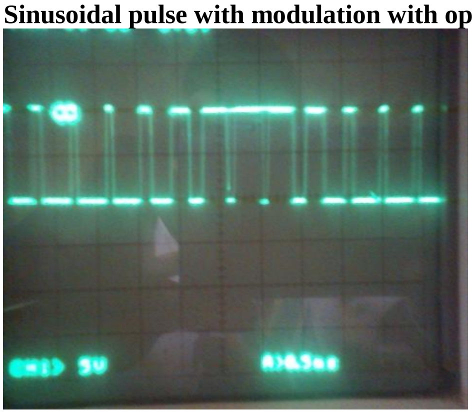

Fig. 11: Pulses of different pulse widths with op amps.

The following signals shows a logic level high when the sine wave is greater than the triangular wave and a logic level low when the sine wave is less than the triangular with a variable pulse width indicating the modulation of a sine wave signal.

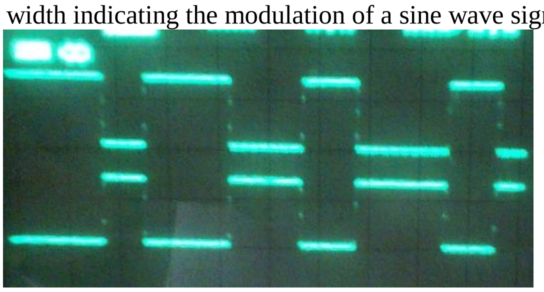

Fig. 12: Complementary pulse signals with op amps.

The Figure 13 shows a clearer behavior of the generation of pulses for a sine wave inverter. When the sine signal is compare with a triangular signal, the sine signal is modulated on to the triangular and the intermediate signal is a train of pulses which are narrow at the rising edge and falling edge but wider at the middle that follows the behavior of the sine wave. The intermediate signal is used to drive MOSFET in an H-bridge configuration to produce output that is bipolar (see Figure 13a: unfiltered voltage and Figure 13b: unfiltered current, page).

These outputs from the MOSFET when filtered reproduce a sine signal that is similar to the reference modulating signal (sine wave).

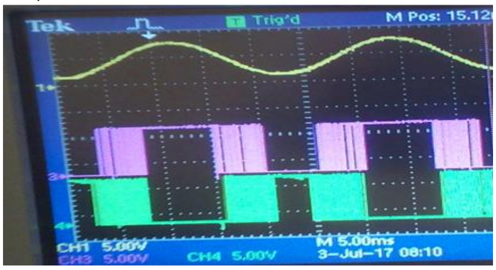

Fig. 13a: Sine and modulated signals on digital oscilloscope with op amps.

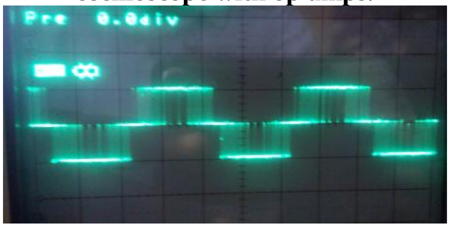

Fig. 13b: Output waveform from microcontroller.

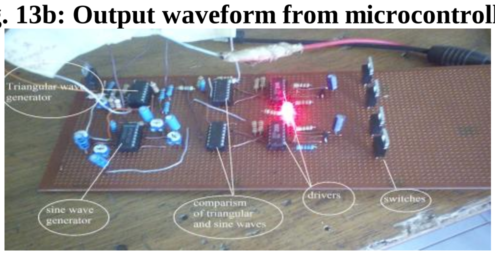

Fig. 14: The configuration on a Vero board

Low pass filter is constructed with a cut off frequency of 50Hz comprising of a transformer and a centrifuge capacitor. The transformer filter is very bulky due to the low frequency of 50Hz and more expensive than LC filter inductor but simple to design. The transformer is design to sustain a power 2kVA, with a primary current, voltage, turns 166.6A, 12V, 22 turns respectively and secondary current, voltage, turns 8.3A, 240V, 425 turns respectively. The corresponding primary and secondary wire size were checked from standard wire gauge (SWG) table that correspond to the current carrying capacity.

V. CONCLUSION

The design and construction of a University inverter system with output voltage regulated is presented with a specific constraint that does not only focus attention on availability and stability of energy supply to the load in an event of public utility failure, but it has incorporated algorithm for regulating the output voltage with varying battery voltage and load which make it better compared to other power inverter available in shops. This paper presented converter switch power supply using SPWM technique. The test results show that, the system has performed to the desired design specification. Thus, the set objectives were realized with all design procedures duly observed.

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AUTHORS PROFILE

Mbunwe Muncho Josephine, working as a lecturer in the Department of Electrical Engineering, University of Nigeria, Nsukka. Had her Bachelor of Engineering (B. Eng) in Electrical Engineering and Masters (M. Eng) in Electric Power Systems in 2000 and 2005 respectively. Am currently doing research for Ph. D degree in the same field in University of Nigeria, Nsukka.

Professor Theophilus Chukwudolue Madueme, FNSE, FNIEEE, MIAENG
The Ven. Engr. Theophilus Chukwudolue Madueme is a Professor of Electric Power Systems and High Voltage Engineering. He was born on 21st June, 1949. He graduated with Msc in Electrical Engineering from Chalmers University of Technology Gothenburg, Sweden in 1979. He obtained his PhD in Electrical Engineering from University of Nigeria, Nsukka in 1994. He became a Professor of Electric Power Systems in 2002. His area of specialization is Electric Power Systems and High Voltage Engineering. He is a COREN registered engineer. He is a Fellow of the Nigeria Society of Engineers (FNSE). He is also a Fellow of the Nigerian Institution of Electrical and Electronics Engineers (FNIEEE). He served as the Dean of the Faculty of Engineering at the University of Nigeria, Nsukka between 2012 and 2014.

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