Vol. 10(36), Apr. 2020, PP. 4557-4567

Contents list available at IJMEC

International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)

Journal Homepage: www.aeuso.org

PISSN: 2411-6173 - EISSN: 2305-0543

Design and Implementation of 500W Pure Sine Wave DC-to-AC Converter

Hillary C. Idoko, Candidus U. Eya and Crescent O. Omeje

Department of Electrical Engineering University of Nigeria, Nsukka Enugu, Nigeria

Phone Number: +2348034473935

****Corresponding E-mail:*** chika.idoko@unn.edu.ng

Abstract

This paper presents a DC-to-AC power converter for low power hospital equipment. The aim is to efficiently transform a DC power source to a high voltage AC output at low total harmonic distortion and pure sine wave. The modulation technique employed is bipolar switching scheme. It was realized by utilizing a sinewave and triangular generators. Those signal generators are made of capacitor, resistors and TL084 in appropriate form. The proposed system is light in weight and cheap in production. The proposed system produces a clean sinewave inverter voltage output of 220Vrms, power rating of 500W and total harmonic distortion of 2.09%.

Keywords: *dc-ac converter, harmonic distortion, pure sinewave*

1. Introduction

Generally, power inverter are used for many applications such as in AC drives, hospital equipment, tractions, home and office appliances [1]- [2]. There are different classes of inverters such as voltage source inverter, current source inverter, transformer-less inverter, transformer-based inverter, buck inverter, boost inverter, buck-boost inverter, modified sinewave inverter, qausi-inverter, multilevel inverter, square wave inverter, pure sinewave inverter etc.[3]-[8]. All these inverters have common property of converting DC power to AC power at desired voltage and frequency. The square wave inverters have a simpler circuitry and are less expensive; meanwhile, 50% performance and reliability are not guaranteed in comparison with the sine wave inverters. Besides, the application of square wave inverters put additional strains on our already crippled power sector in our global world especially Nigeria. Transformer-based inverters are considered to be rugged in structure and can withstand large loads but they have many disadvantages such as noise pollution, non-portability, large space possession and distorted output waveforms. The multilevel inverters are very good in operation with low harmonic distortion, high voltage levels and less voltage stresses across the power switches but they have difficult and complex control measures and occupy space. These inverters differ in their outputs, providing varying levels of efficiency and distortion that can affect electronic devices in different ways. A modified sine wave is similar to a square wave but instead has a “stepping” look to it that relates more in shape to a sine wave. This can be seen in Figure 1, which displays how a modified sine wave tries to emulate the sine wave itself. The waveform is easy to produce because it is just the product of switching between 3 values at set frequencies, thereby leaving out the more complicated circuitry needed for a pure sine wave. The modified sine wave inverter provides a cheap and easy solution to powering devices that need AC power. It does have some drawbacks as not all devices work properly on a modified sine wave, products such as computers and medical equipment are not resistant to the distortion of the signal and must be run off of a pure sine wave power source [3].

Article History:

Received Date: Apr. 02, 2019

Accepted Date: Aug. 09, 2019

Available Online: Apr. 01, 2020

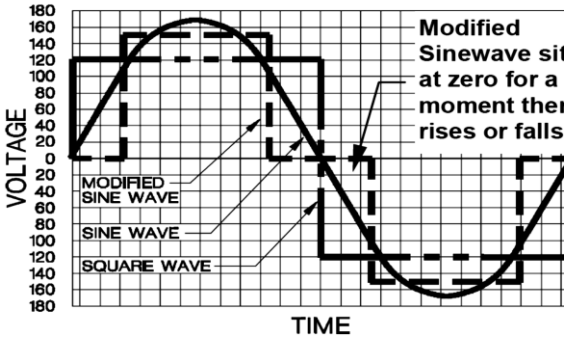


Fig:1: Different inverter wave forms[3]

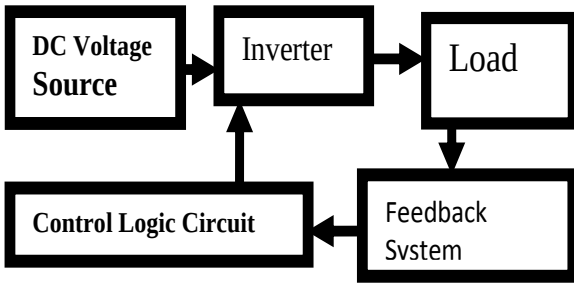


Fig.2: Block diagram of the proposed system

Pure sine wave inverters are able to simulate precisely the AC power that is delivered by a wall outlet. Usually sine wave inverters are more expensive than modified sine wave generators due to the added circuitry. This cost, however, is made to provide power to all AC electronic devices, allow inductive loads to run faster and quieter, and reduce the audible and electric noise in audio equipment, TV's and fluorescent lights

2. Materials and Methodology

The materials used in this project are the signal generators (consisting of capacitors, operational amplifiers and resistors) IGBTs, jumper wires, copper wires and bread boards. The design and implementation schemes were used in this research work. The blocked diagram of the proposed system is shown in Fig.2

Fig.2 illustrates the block topology of the proposed system and how they are connected. The dc voltage source can be from battery, solar panel, fuel cells or rectified AC source. The inverter converts the DC power to AC power after the appropriate triggering signals have been supplied to the inverter. When the voltage across the load is below or above 220Vrms, the voltage sensor acts and sends the signal difference to the power circuit through the feedback system and PI controller within the control unit. The reason is to ensure output voltage stabilization.

3. Control Logic Circuit Design

3.1. Sine Wave Generator

The Sine Wave Oscillator Circuit in Fig.3.1 is a circuit that provides modulating sinewave signal that determines the frequency of output voltage of the inverter. The circuit completes this task with four operational amplifiers that either buffer or amplify the signal, resistors and capacitor. This oscillator is a phase shift oscillator, but unlike other phase shift varieties as in [1] that require phase shifts of 90 degrees or more, this particular oscillator only requires a 45 degree shift in order to function. This is because of the four op amps, that when placed in series, produce a total 180° shift.
This oscillator offers a few features that other oscillators cannot; the biggest factor is that the frequency stability holds while still giving a low distortion output. The reason for this involves the four filters that the signal passes through, providing a clear and stable signal at generator output, as shown in Fig.3.1. The circuitry and values chosen are shown in Fig.3.1 and the op-amp chip chosen to complete the task was an LM348 as it is an inexpensive part and meets all the requirements of creating this sine wave. TL084 can also serves as an alternative for LM348

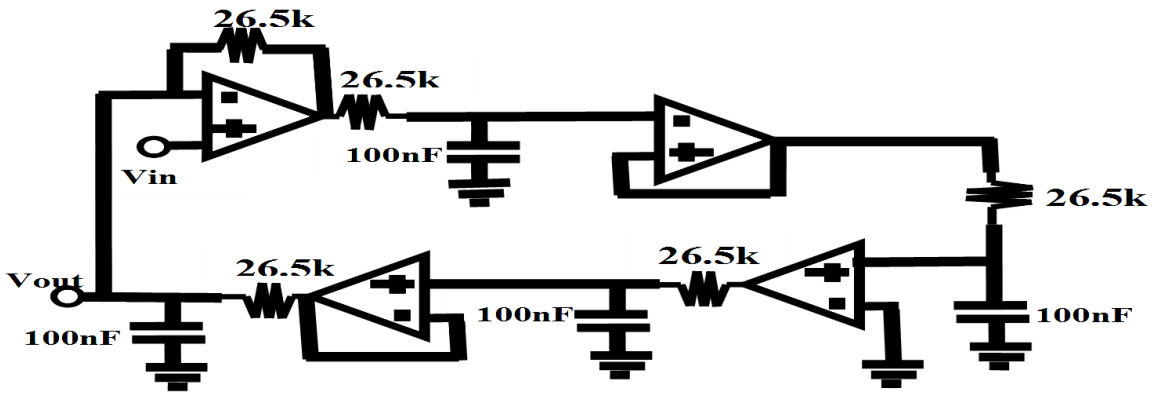


Fig.3.1 Triggering Signal Circuit

Four identical RC filters phase shift the signal 45 degrees each. This causes a 180-degree phase shift which is then returned to a zero-degree phase shift with the inverting amplifier placed across the first operational amplifier. The mathematical expression behind the phase shift of the filter in Fig.3.1 is shown in equations 1-3

$$\text{Vout} = \frac{\frac{1}{j\omega C}\times Vin}{R+\frac{1}{j\omega C}} = \frac{\text{Vin}}{jR\omega C+1} \quad (1)$$

When $\omega = \frac{1}{jC}$

$$A = \frac{Vout}{Vin} = \frac{1}{j+1} \quad (2)$$

Another side effect of the filtering, however, is that the signal becomes attenuated enough so that the signal must be amplified so that the oscillator works. It will only work if the signal being passed back into the system is the same as the one it started with.

$$|A| = \left|\frac{1}{j+1}\right| = \frac{1}{\sqrt{2}} \quad (3)$$

$$A_{\text{Total}} = \left(\frac{1}{\sqrt{2}}\right)^4 = \frac{1}{4} \quad (4)$$

As the (1) – (4) show the total attenuation of the system is ¼ of the original signal, therefore the amplification of the inverting amplifier must be of magnitude 4. When this knowledge is coupled with the 180-degree phase shift of the filters it can be determined that the amplifier have a value of -4 in order for the circuit to pass back the original signal and thereby oscillate.

Frequency of oscillation is given by

$$f = \frac{1}{2\pi fc} \quad (5)$$

3.2. Carrier Wave Generator

Where: m_f = frequency modulating index=23, fc=carrier wave frequency, fs=reference sine wave frequency= 50Hz The generation of the triangular carrier wave was done with analog components. The circuit for the construction of the triangle wave generator consists of a square wave generator and integrator, as shown in Fig.3.2

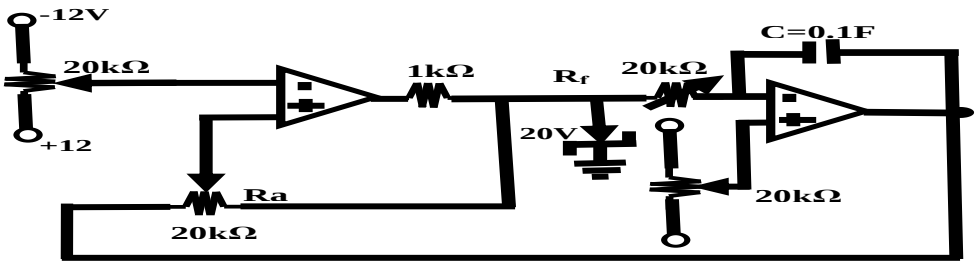


Fig.3.2 Triangular wave generator circuit

The circuit in Fig.3.2 oscillates at a frequency of $1/4R_afC$, and the amplitude is controlled by resistance of 20 KΩ, Ra. The frequencies generated by this circuit depend on the slew rate of the operational amplifiers. Using a TL084, output waves with frequencies of up to 40 kHz can be generated. Speeds at 50k Hz require an op-amp with a faster slew rate. Then, using the TL084,with C=0.1uF, and four 20kΩ variable resistors connected as shown in Fig. 3.2 this circuit generates square and triangle waves oscillating at 1150Hz.

4. Sinusoidal Pulse Width Modulation (SPWM)

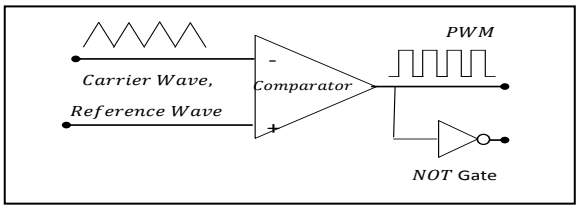


Fig.4 Sinusoidal Pulse width modulation block topology

A carrier wave of magnitude 1.0V and frequency of 1150Hz was compared with a sine wave reference signal of magnitude 0.8V and frequency of 50Hz as shown in Fig.4

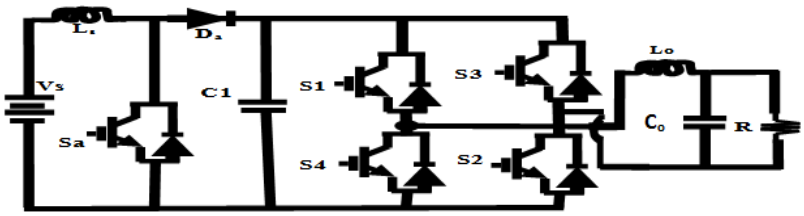


Fig.5. Inverter Circuit coupled with conventional boost converter [2]

The input inductance L_s, capacitance C_1, and boosted voltage, V_b are obtained using the expressions in (7), (8) and (9) under continuous current mode scheme [9]-[10]

$$L_s = \frac{D(1-D)^2R}{2f_c} \tag{7}$$

$$C_1 = \frac{D}{Rf_c(\Delta V_o/V_o)} \tag{8}$$

$$V_b = \frac{V_s}{1-D} \tag{9}$$

D-duty cycle, R-load resistance, f_c- switching frequency, Δv_o- voltage ripple, Vo - output voltage.

When the boost converter switch, **Sa** =1, the power diode, D_a=0, then the Ls is built up linearly while the energy stored in C1, feeds the inverter. As soon as, **Sa** = 0 and $\mathbf{D_a}$=1, the energy built up in Ls, is supplied to the H-bridged inverter. The inverter converts the DC power to AC power after receiving

the proper triggering signals from the control unit. Generating a sine wave centered on zero volts requires both a positive and negative voltage across the load, for the positive and negative parts of the wave, respectively. This is achieved from a single source through the use of four IGBT switches arranged in an H-Bridge configuration coupled with conventional boost converter shown in Fig. 5

5. Bipolar Switching

The switching scheme that implements bipolar switching using the full bridge inverter of Fig. 6.1 is determined by comparing the instantaneous reference and carrier signal:

S1 and S2 are ON when Vsine > Vtri. (Vo = +Vdc)

S3 and S4 are ON when Vsine < Vtri. (Vo = -Vdc)

6. Simulation Results

In order to validate the theoretical and practical analysis and operation of the proposed single phase DC-AC Converter, MATLAB/SIMULINK simulation was used and the results are presented in this section. The gating signals generated by comparing triangular carrier wave with reference sine wave are presented in Fig.6.1. The Complete simulink Model of the whole system is shown in appendix I

The performance of the inverter is analyzed under resistive load. Fig. 6.1 illustrates the simulated waveforms for comparing the sinewave signal and the carrier wave. It is observed that the carrier wave is 1.0V while the sinewave signal is 0.8. The modulation index of the system is 0.8.

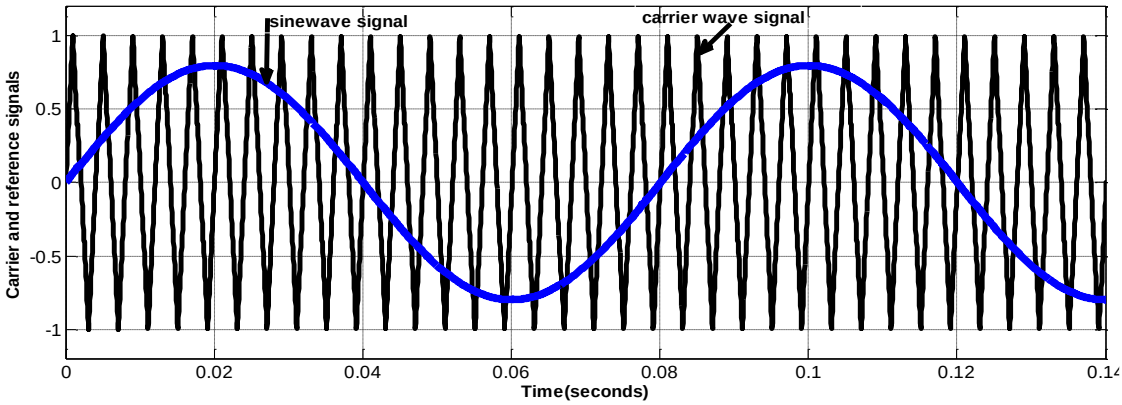


Fig.6.1: Carrier wave and reference signals

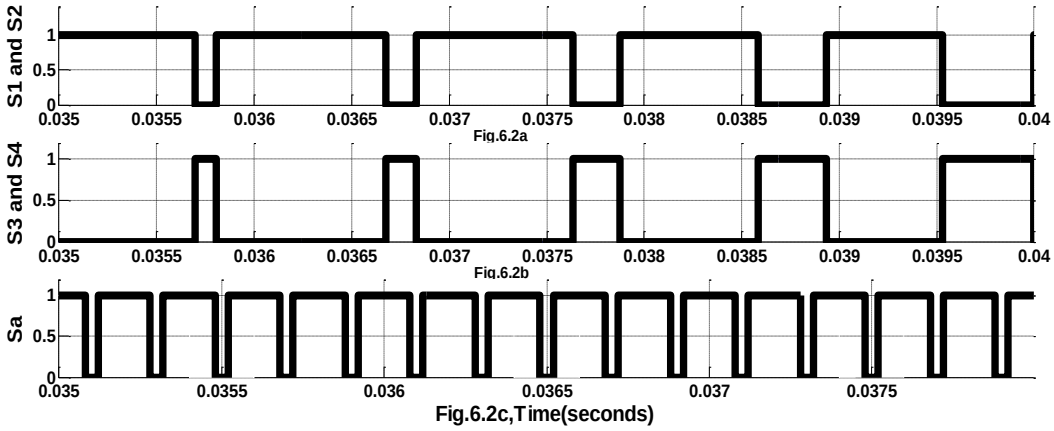


Fig.6.2a: SPWM of S1 and S2, Fig.6.2b: SPWM of S3 and S4 , Fig.6.2c SPWM of Sa

Fig.6.2a signal is used for firing power switches, S1 and S2 while its complementary signal in Fig.6.2b is utilized for turning S3 and S4 in Fig.5. They are produced with the aid of comparing of signals in Fig.6.1. In Fig.6.2c, it is observed that it has more compressed pulse widths. This signifies that it has higher switching frequency than those signals in Fig.6.2a and Fig.6.2b. Its pulse width signals are meant for triggering the boost switch, **Sa** of conventional boost converter in Fig.5

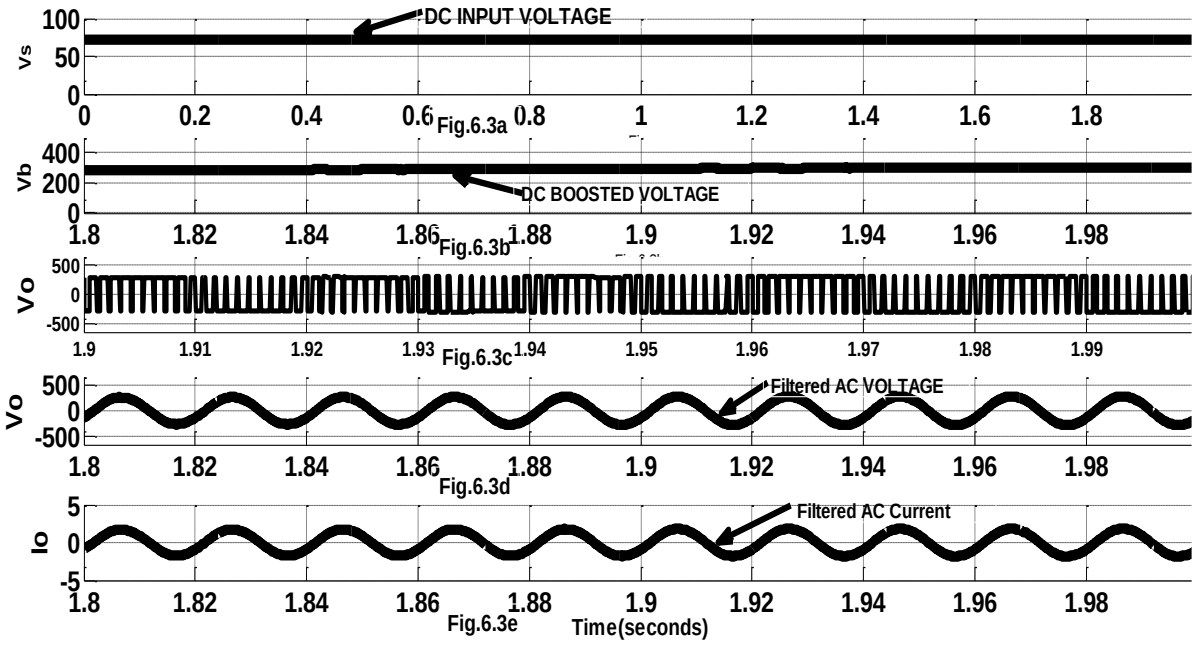


Fig.6. 3a: DC input Voltage. Fig.6.3b: DC boosted voltage. Fig.6.3c: Unfiltered AC inverter Voltage. Fig.6.3d: Filtered AC voltage. Fig.6.3e. Filtered Inverter output Current

The Fig. 6.3a indicates that the source voltage of the proposed system is 72V. In Fig.6.3b, the boosted voltage value of 360V is displayed at 1.8 seconds ≤ t ≤ 1.99 seconds. The duty ratio of the DC-DC converter is shown in Table.1. The unfiltered voltage value of the proposed system was shown in Fig.6.3c. And it is observed that it has a maximum value of 315V. The filtered inverter output voltage with pure sinewave and maximum voltage of 311V is shown Fig.6.3d at 1.8seconds ≤ t ≤ 1.99 seconds. The corresponding pure sinewave inverter output current of 3.273A is displayed in Fig.6.3e. Then, for clarity sake, Fig 6.3a – Fig. 6.3e are shown in Appendix 1I.

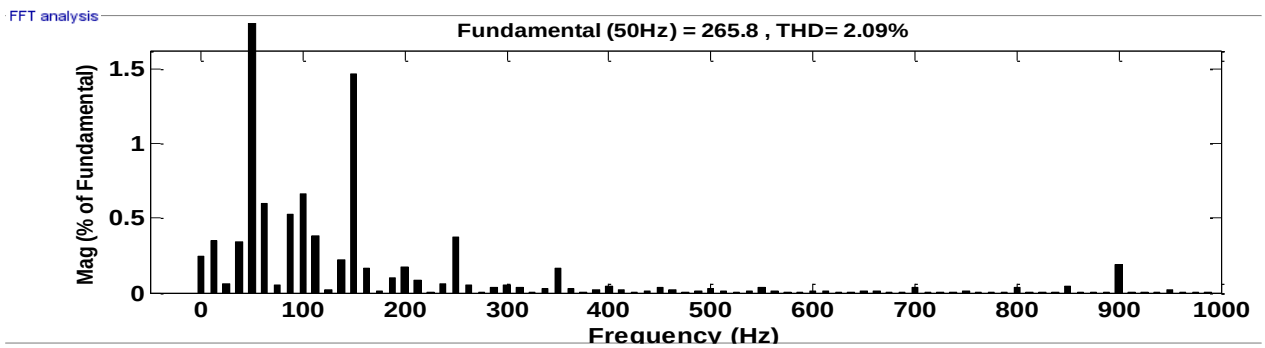


Fig.7. Spectral analysis of the simulated system

Fig.7 depicts the spectral analysis of the simulated system in this research work. It was analyzed based on taking four cycles, maximum time at 3 seconds, frequency of 50Hz and the frequency of 1000Hz in Fast Fourier Transform setting in the simulated MatLab/Simulink environment. And from Fig. 7, it is observed that the total harmonic distortion (THD) is 2.09%.

Table 1: Proposed System Parameters

Items	**Ratings**
Input voltage, Vs	72.0V
Input inductance, Ls and Capacitance,C1	153µH and 33.3µF
Duty Cycle, D	0.80
Boosted voltage, Vb	360V
Proportional and integral constant values	10 and 0.01
Voltage ripple	0.1%
Peak Inverter voltage and current	311V and 2.27A
Fundamental and Switching frequencies	50Hz and 5000Hz
Total harmonic distortion, THD	2.09%
Load resistance and power	48 Ω and 500W
Filter capacitance and inductance	50 µF and 5mH

Table.1 portrays the proposed system parameters and some values obtained from the simulation.

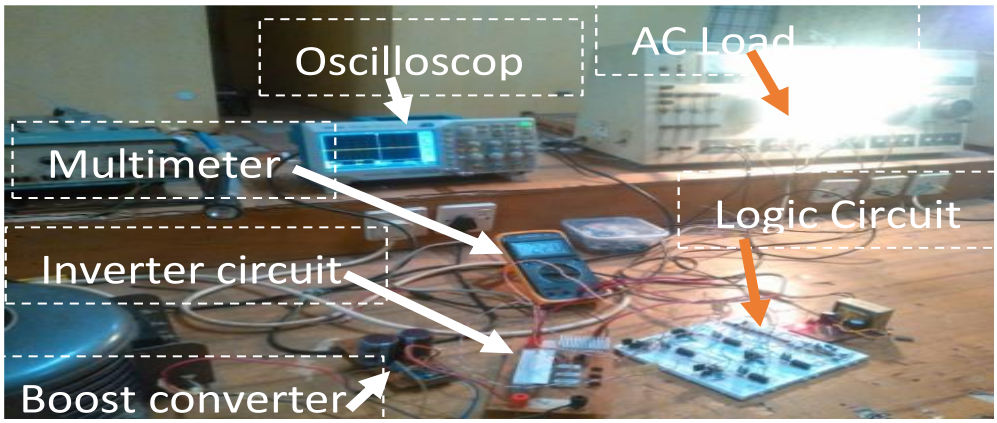


Fig.8. Prototype of the entire implemented system

7. Experimental Results and Discussion

The experimentation of this research work was carried out in the Laboratory of Industrial Electronics, Power Devices and New Energy Systems in Electrical Engineering, University of Nigeria, Nsukka. The prototype of the system is shown in Fig.8.

Fig.8 is made up of an implemented 500W DC-AC Converter and two 200W bulbs with some measuring instrument such as Oscilloscope and Multimeter. The Oscilloscope measured the inverter voltage waveform while the Multimeter measured 220Vrms value of the inverter output voltage.

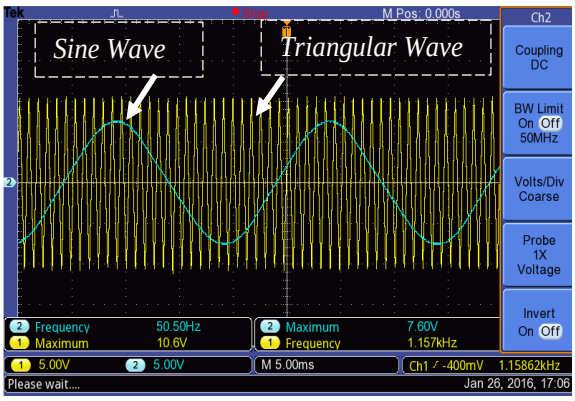


Fig.9. Signal reference sine and carrier waves

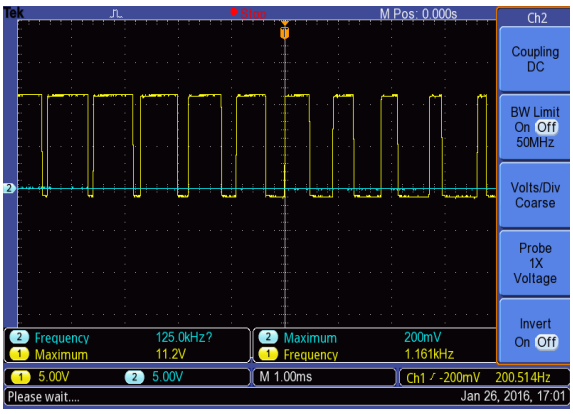


Fig.10. Gating signals of S1 and S2

The 7.60V logic sine and 10.6V carrier waves are shown in Fig.9. The logic sine and the triangular waves have operating frequencies of 50.5 Hz and 1.157 KHz respectively. They are passed through a comparator to generate pulse width signals.

The gating signals of S1 and S2 are displayed in Fig.10. They are generated from output of comparator used in Fig. 9.They have amplitudes and frequency of 11.2V and 1.16 kHz respectively. The whole triggering signals are passed through the driver circuit in order to have the capability to drive those power switches

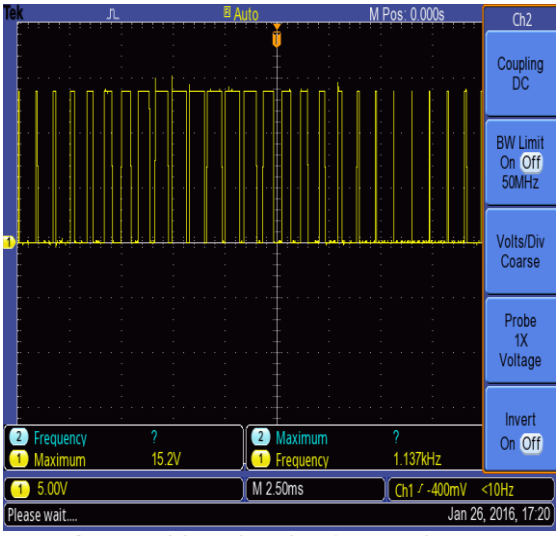


Fig.11. Firing signals of S3 and S4.

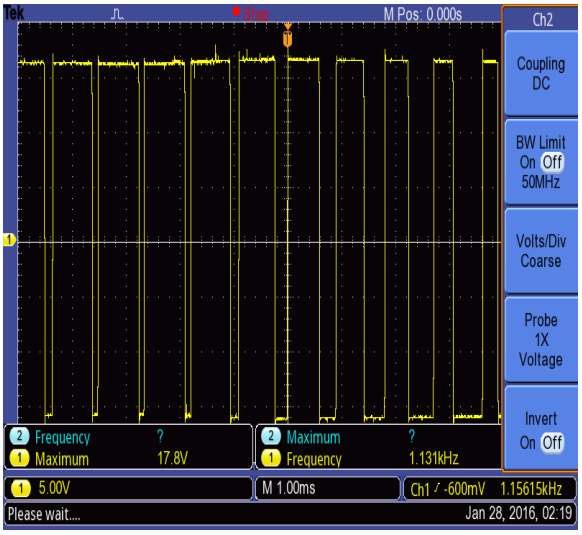


Fig.12. Inverter Output Voltage Waveform without Filter

Fig.11 indicates the firing signals for turning ON S3 and S4. They are the complementary switch signals of S3 and S4.

The inverter output voltage without filter components is shown in Fig.12. It is scaled down to the magnitude of 17.8V. It is observed from the waveform that it contains high harmonic distortions. In order to minimize the harmonic, it is passed through an inductance-capacitance (LC) filter. As it is allowed to flow through the LC filter, it generated the waveform in Fig.13

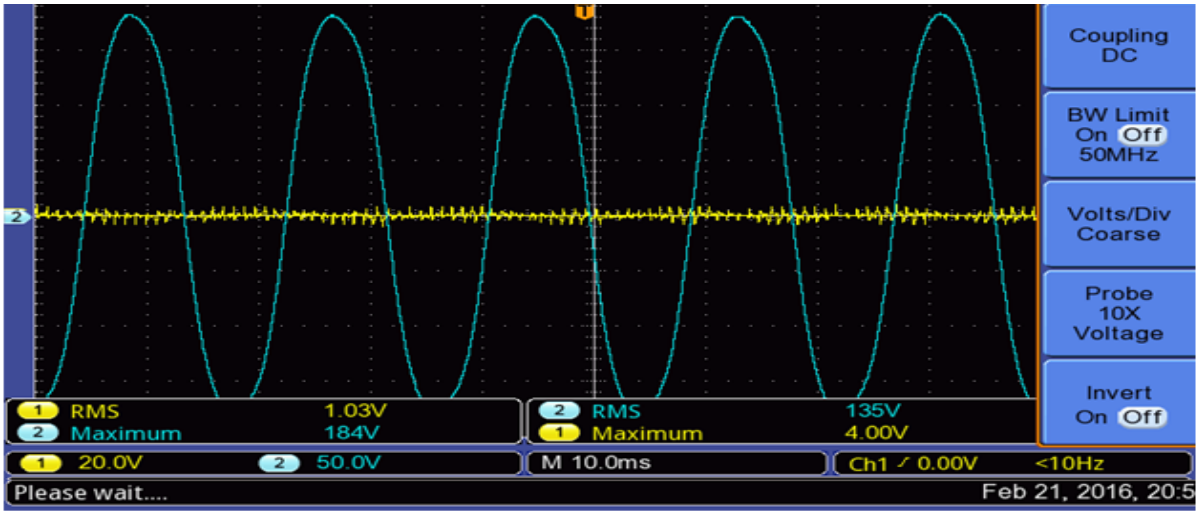


Fig.13. Inverter Output Voltage Waveform with L-C Filter

Fig.13 displayed the sinewave of inverter output voltage scaled down to 14.8V with help of probes of the oscilloscope used. The frequency of filtered output voltage waveform is 50.05Hz. The conventional two 200W bulbs were used to show that it can be mass-produced commercially.

Conclusion

This paper has presented a design and implementation of 500W pure sinewave DC-to-AC Converter. The following results were accomplished: 220Vrms (311V) voltage, 2.273Arms (3.214A), 2.09% and pure sine waveform. The system has the advantages of low total harmonic distortion, stumpy powerloss, simple design and control, low cost of components and small component count. Then, from the result obtained so far, it can be concluded that this prototype can be efficiently applied to hospital equipment with high precision

References

[1]] A.Haider, R. Alam, N. Binte Yousuf and K. M. Salim , "Design and Construction of Single Phase Pure Sine Wave Inverter for Photovoltaic Application,"International Conf. IEEE,2013

[2] B.K. Bose, "Modern Power Electronics, Evolution, Technology and Applications", NY, IEEE Press, 1992

[3] C.U Eya and Agu, " Solar powered single phase boost differential Inverter," Nigeria Journal of Technology Vol..34, 2014, pp.164-176

[4]] Daniel.W Hart, "Power Electronics," McGraw-Hill, the McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020. 2011

[5] I. Mohan, T.M. Undeland and W.P. Robbins, "Power Electronics

[6] Muhammed. H. Rashid, "Power Electronics Circuits,Devices and Application, 3rd Edition Prentice Hall India, 2004,

[7] Sanjay Dixit, Ambreesh Tripathi, Vikas Chola, and Ankur Verma, " 800VA Pure Sine Wave Inverter's Reference Design," Texas Instrument SLAA602A–June 2013–Revised August 2017.

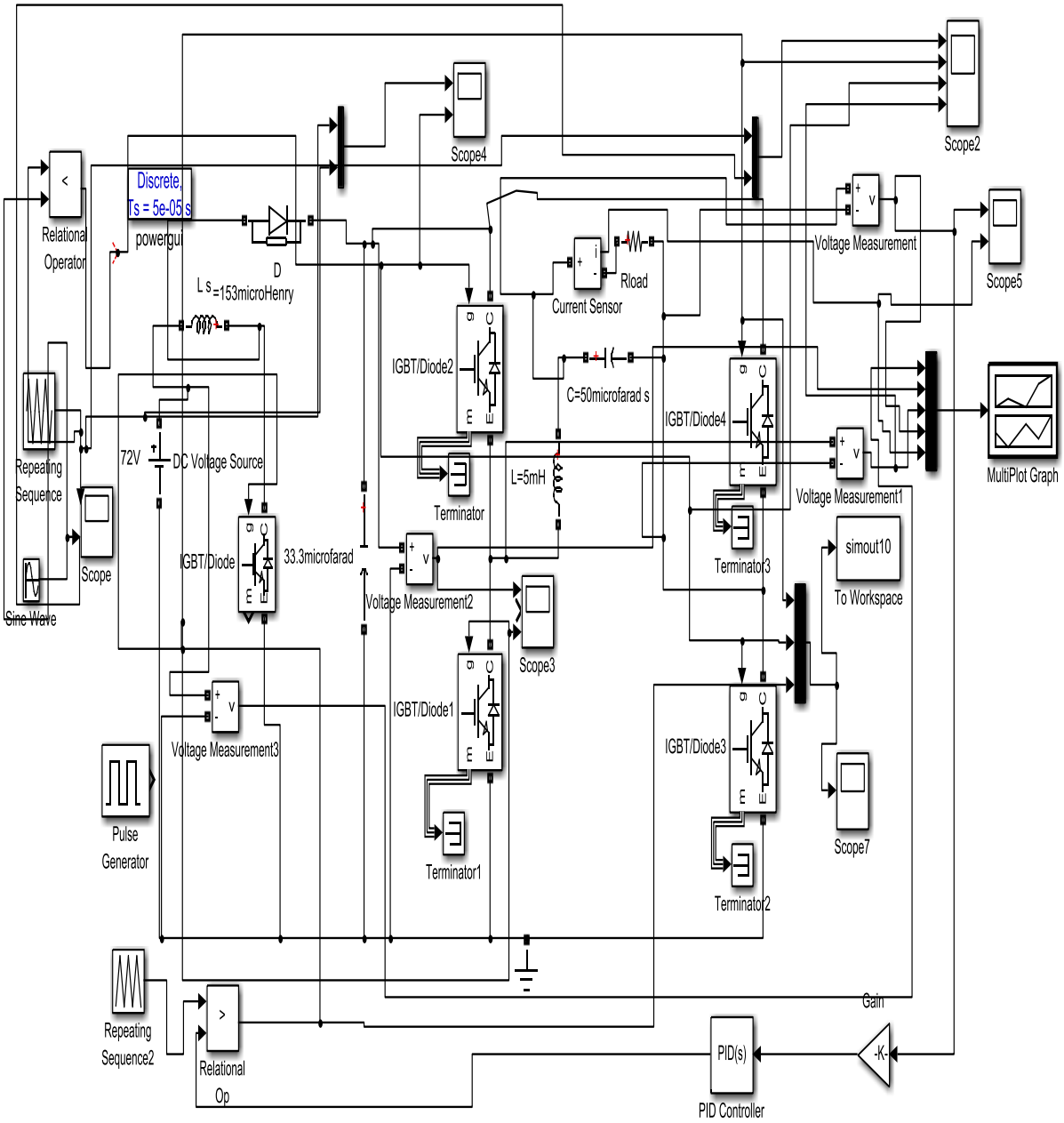
[8] Olusegun O. Omitola1*, Segun O. Olatinwo1 and Taiwo R. Oyedare "Design and Construction of 1KW Power Inverter," Innovative Systems Design and Engineering, Vol.5, No.2, , 2014, pp.1-13 .

[9] R. Haider *et al*., "Design and construction of single phase sine waveinverter for photovoltaic application ", Proc. ICIEV 2012, pp.190-194

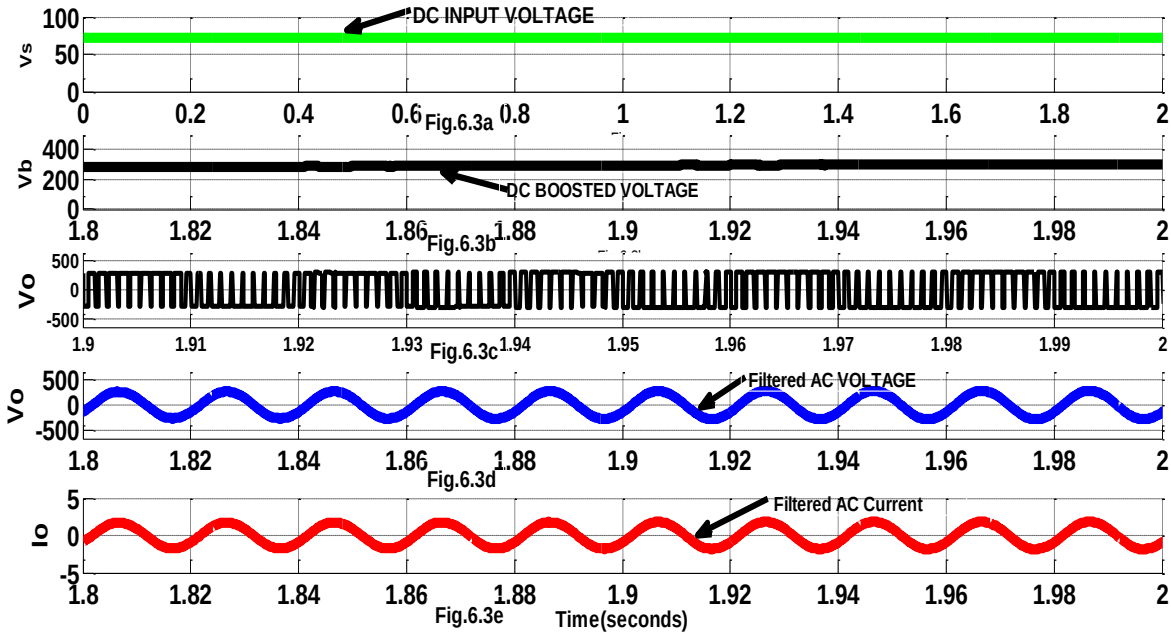
[10] Zhong, D.; Tolbert, L.M.; and Chiasson, J.N. Active harmonic elimination for multilevel converters. IEEE Trans.on Power Electronics.21(2), 2006, pp. 459-469.

.

APPENDIX I


Discrete,
Ts = 5e-05 s
powergui
Relational Operator
D
L s=153microHenry
Scope4
Scope2
Voltage Measurement
Scope5
Current Sensor
Rload
IGBT/Diode2
C=50microfarad s
IGBT/Diode4
MultiPlot Graph
Repeating Sequence
72V
DC Voltage Source
Terminator
L=5mH
Voltage Measurement1
Scope
IGBT/Diode
33.3microfarad
Voltage Measurement2
Terminator3
simout10
To Workspace
Sine Wave
Scope3
IGBT/Diode1
IGBT/Diode3
Voltage Measurement3
Pulse Generator
Terminator1
Scope7
Terminator2
Repeating Sequence2
Relational Op
Gain
PID(s)
-K-
PID Controller

Appendix II



Autor(s)

Engr. Hillary Chika Idoko obtained his B.Eng. and M.Eng. degrees in Electrical Engineering from the University of Nigeria, Nsukka in 2012 and 2016 respectively. He is currently a PhD student (Electrical Machines and Drives option) in the same university. He is a member of Nigeria Society of Engineers (MNSE) and Nigeria Institution of Electrical and Electronics Engineers (MNIEEE). His research interest is electrical machines and drives.
email: chika.idoko@unn.edu.ng

Engr. Dr. Eya Candidus received his B.Eng degree in Electronics Engineering, 2006 from University of Nigeria, Nsukka. He also obtained his M.Eng , and Ph.D. degrees in Electrical Engineering, from the same University of Nigeria, Nsukka respectively in 2011 and 2017. He is a Member of Nigeria Society of Engineers (MNSE), registered member Council of the regulation of Engineering in Nigeria(COREN), member of IAENG. Areas of his research interests include power electronics and New energy systems applications, Multilevel inverter system, smart grid intelligent systems, condition monitoring, power electrnics and Electric motor drives, control systems, parametric system applications and solar system applications.
email: Candidus.eya@unn.edu.ng

Engr. Omeje Crescent Onyebuchi received his B.Eng and M.Eng degrees in Electrical Engineering, in 2004 and 2011 from University of Nigeria, Nsukka respectively. He is currently a PhD student in the Department of Electrical Engineering, University of Nigeria Nsukka and Lecturer in the Department of Electrical /Electronic Engineering Uinversity of Port Harcourt. He is a member of Nigerian Society of Engineers (MNSE) and a registered member Council of regulation of Engineering in Nigeria. Areas of his research interests include Multi-level capacitor voltage balancing, Power Electronics applications and electric motor drives.
email: crescent.omeje@uniport.edu.ng