International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-3, Issue- 4, April 2017
ISSN: 2395-3470
www.ijseas.com

IMPLEMENTATION OF A MICROCONTROLLER BASED PURE SINE WAVE INVERTER

Godswill Ofualagba[1] and Charles Kevwe Igbinoba[2]
[1,2]Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources, Nigeria.
[1]ofualagba.godswill@fupre.edu.ng, [2]igbinoba.charles@fupre.edu.ng

Corresponding Author: Email: igbinoba.charles@fupre.edu.ng, Tel: +2347065468402

Abstract

This paper presents the use of microcontroller (PIC18f2550) in the design of a pure sine wave inverter. The inverter is designed to deliver a maximum power of 3 KVA including losses by converting the 24 VDC input from the battery bank to 230 VAC. The microcontroller is programmed to carry out different controls and to also produce a multilevel pulse width modulation (MPWM). The controls include the fully-charged control, overload control and low battery control. The fully charged control switches OFF the charging process when the battery voltage charges up to 28 VDC. The overload control switches OFF the inverter outputs when a load connected is higher than 2.8 KVA. The low battery control switches OFF the inverter when the battery voltage drops below 20 VDC when on inverter mode. The system is designed to charge with a constant current of 10 Amp irrespective of fluctuations in the mains input voltage. The system was tested by connecting a 400 watts bulb to the output. The output went OFF when the battery voltage dropped below 20 VDC. The output wave form when tested with an oscilloscope produced a pure sine wave.

Keywords: *overload, fully charged, low battery, microcontroller, pulse width modulation*

1. Introduction

Nigeria is a middle income, mixed economy and emerging market, with expanding manufacturing, financial, communications, technology and entertainment sectors. It is ranked as the 21st largest economy in the world in terms of nominal Gross Domestic Product GDP), and the 20th largest in terms of Purchasing Power Parity. It is the largest economy in Africa; its re-emergent manufacturing sector became the largest on the continent in 2013, and produces a large proportion of goods and services for the West African subcontinent [1].

However, its power sector is performing below the level of its peer countries. Over half of the population (~55%) has no access to grid-connected electricity and those who are connected to the grid suffer extensive power outages [2].

The availability and stability of electrical energy is necessary for domestic and industrial use. However, due to its insufficiency, hence, the need for alternative sources of electricity supplies. In the event of power failure from public utility, motor generating sets and inverters could be used to power appliances and machines in homes, offices, and industries. Inverters are preferred to motor generating sets because it is noiseless, relatively small size, and pollution-free [3].

The solar power inverter with controlled output presented in this paper was designed with focus to produce a system that will meet the increasing power need of our society by looking into other mains of power generation that is naturally available, cheap, harmless to the environment and maintenance free.

2. Literature Review

The earliest inverters developed produces square wave outputs because square waves are easily generated in hardware. A simple relaxation oscillator, a step-up transformer and a number of transistors are all that are required to build a simple inverter system [4,5,6]. Though easily generated, square waves have a high level of odd order harmonics that interfere with the operation of loads such as electric motors [7, 8]. Also, to maintain an equivalent r.m.s voltage with a sine wave, square wave forms must have a peak value that is equal to the r.m.s value of the sine wave. This means that a square wave inverter will have an output voltage whose magnitude is reduced by a factor of 1.4142 in comparison to the output voltage produced by a pure sine wave inverter delivering the same amount of power. This can potentially affect the operation of loads such as microwave ovens that are sensitive to the peak value of the inverter output voltage [9].

A variant of square waves that is also easily generated is the modified square waveform. This waveform has the same peak value as an equivalent sine wave with the same r.m.s voltage, but with reduced duty cycle. Modified square waves potentially have a reduced harmonic content compared to square wave inverters, but their THD is still high for low distortion applications [8,10]. Pure sine wave inverters produce waveforms that have low distortion figures using pulse width modulation techniques. To achieve low waveform distortion and small-sized output filter components, the sampling frequency must be high compared to the frequency of the output waveform. However, high sampling frequency causes substantial switching losses in the output stage switching devices, reducing efficiency. Pure sine wave inverters are much more complex to design and manufacture, as a result, they are more expensive than square wave or modified square wave inverters [11,12].

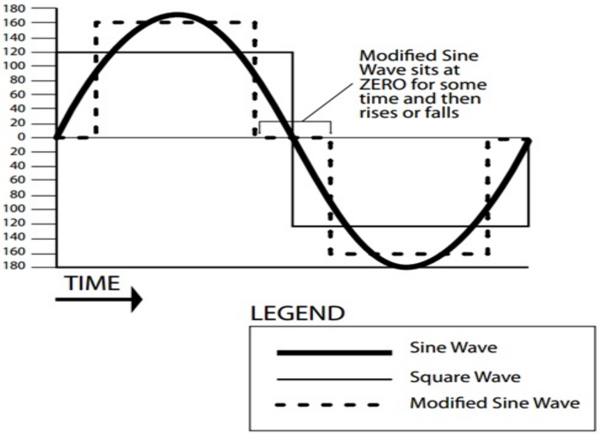

Fig 1: Square, Modified and Pure Square Wave

3. Methodology

The developed microcontroller-based pure sine wave inverter with controlled output consists of a PIC18*f*2550 microcontroller programmed to carry-out all the control functions and the production of a multilevel pulse width modulation, a MOSFET driver (IR2112) which increases the current and voltage level of the pulse width so that it can drive the MOSFET, a H-Bridge MOSFET Network for the production of the sine waveform, a Filter to remove the high harmonics components from the sine wave generated, a transformer with three taps on the high voltage winding and relay network for changeover purpose.

3.1 Signal Generator

The PWM signal to be used in the circuit is produced by a microcontroller PIC18*f*2550. For the production of the PWM, 32 samples were picked. For calculating the value of the duty cycle for the samples we use the formula

Duty cycle = the sine of the corresponding angle x maximum duty circle (1)

The corresponding angles are gotten by dividing the angle for one half cycle by total number of samples. Assuming our maximum duty cycle is given as 250 then for the first 16 samples, we have the following results for duty circle as shown in Table 1. The 16 samples are then repeated to give a total of 32 samples, to form a half wave at 50 Hz.

Table 1: Duty cycle for 16 samples

Angle	Formula	Duty cycle
0°	$\sin 0^{o} \times 250$	0
5.625°	$\sin 5.625^{o} \times 250$	25
11.25°	$\sin 11.25^{o} \times 250$	50
16.875°	$\sin 16.875^{o} \times 250$	75
22.5°	$\sin 22.5^{o} \times 250$	96
28.125°	$\sin 28.125^{o} \times 250$	118
33.75°	$\sin 33.75^{o} \times 250$	139
39.375°	$\sin 39.375^{o} \times 250$	159
45°	$\sin 45^{o} \times 250$	177
50.625°	$\sin 50.625^{o} \times 250$	193
56.25°	$\sin 56.25^{o} \times 250$	208
61.875°	$\sin 61.875^{o} \times 250$	220
67.5°	$\sin 67.5^{o} \times 250$	231
73.125°	$\sin 73.125^{o} \times 250$	239
78.75°	$\sin 78.75^{o} \times 250$	245
84.375°	$\sin 84.375^{o} \times 250$	249
90°	$\sin 90^{o} \times 250$	249
95.625°	$\sin 95.625^{o} \times 250$	250

3.2 PWM Generation Technique and Regulation

The software PWM created uses the delay function in the microC compiler, to get a frequency of 50 Hz each duty cycle has to last for 625 µs.

T (period of sine wave) = $\frac{1}{frequency\ of\ sine\ wave}$ (2)
T (period of sine wave) = $\frac{1}{50}$ = **0.02 seconds**

For a half cycle = $\frac{0.02}{2}$ = **0.01 seconds**

T_p (period of PWM) = $\frac{period\ of\ sine\ wave}{total\ number\ of\ sasmples}$ (3)

T_p (period of PWM) = $\frac{0.01}{32}$ = **312 µs**

A duty cycle in simple terms is the ratio of the time ON to period of the PWM; so each of the duty cycles previously calculated show how long the pins should stay high relative to how long they should stay low. Hence any pin of the microcontroller could be made to stay high for that period of time as calculated for each duty cycle value, and stay off for the rest of the period.

Time Period ON = Calculated by Tp × Percentage Time ON (4)

Table 2: Duty Cycle in terms of Time Period ON

Duty cycle	Percentage time on	Time period on
0°	0	0
25	0.10	30
49	0.196	60
73	0.292	90
96	0.384	119

118	0.472	147
139	0.556	173
159	0.636	198
177	0.708	220
193	0.772	240
208	0.832	259
220	0.88	274
231	0.924	288
239	0.956	298
245	0.98	305
249	0.996	310
250	0.98	312

3.3 MOSFET Selection

In the H-bridge design four MOSFETs are used on each side of the bridge therefore bringing it all to a total of sixteen MOSFETs. The Maximum input current is given by:

$$I = \frac{power\ rating}{input\ voltage} \qquad (5)$$

$$I = \frac{3000}{24} = \underline{\mathbf{125\ Amps.}}$$

So each side of the bridge should be able to carry a maximum current of 125 Amps. For this design, the MOSFET IRFP260n was chosen, having a maximum rating of 40 Amps. Four of the MOSFETs where paralleled together on each side, so that the input capacity is now 160 Amps. This is enough to handle the current sufficiently 3.4 DC-Link Capacitor Selection

The maximum ripple voltage is when the duty cycle is at 50%, so that maximum peak to peak ripple voltage is given as:

$$\Delta V_{0.5t} = V_{bus} / (32 \times L \times C \times f^2) \qquad (6)$$

Choosing an allowable 1% for the ripple voltage we can calculate the DC link capacitor value. 1% of the bus voltage is 0.2.

Re-arranging

$$C = \frac{Vbus}{32 \times l \times \Delta V_{0.5t} \times f^2} \qquad (7)$$

The primary inductance I_s calculated as
Transformer core area a = 0.00063 m^2
From the core used B = 1.3T

$$\text{So that flux linkage } \phi = B \times a \qquad (8)$$

$$\phi = 1.3 \times 0.00063 = \underline{\mathbf{0.00819\ \ weber}}$$

The secondary winding inductance $L = N\frac{\phi}{I}$ (9)

Where I is the input current calculated earlier as 138.89A

$$L = 24 \times \frac{0.00819}{138.89} = \underline{\mathbf{943\ \mu H}}$$

Then $C = \frac{24}{32 \times 0.00000943 \times 0.24 \times 3000^2} =$ **441 μF**

The maximum ripple current is given as

$$\Delta I_{0.5t} = 0.25 \times \frac{V_{bus}}{(f \times L)} \qquad (10)$$

Hence the maximum ripple current is calculated as

$\Delta I_{0.5t} = 0.25 \times \frac{24}{(3000 \times 0.00000943)} =$ **2.12 Amps**

For this project, four 470 μF, 50 V capacitors were used in parallel to efficiently handle the ripple current and the ripple voltage.

3.5 Transformer Secondary Voltage Winding Calculations

The following calculations were followed in designing the transformer, for a 3 KVA design:
The calculations were based on the following formulas:
$\text{Core area} = 1.152 \times \sqrt{}(Secondary\ voltage \times Secondary\ current)$ (11)

$$\text{Secondary winding current} = \frac{(KVA)}{(primary\ voltage \times power\ factor)} \qquad (12)$$

Secondary winding current $= \frac{(3000)}{(24 \times 0.9)} =$**138.89 Amps**

Core area = 1.152 × √(24 x 138.89) = 1.152 × 57.74 = **66.52 cm²**

$$\text{Turns per Volt (TPV)} = {}^{1}/_{(4.44 \times 10^{-4} \times CA \times flux\ density \times Ac\ frequency)}$$
(13)

Turns per volts $= {}^{1}/_{(4.44 \times 10^{-4} \times 66.52 \times 1.3 \times 50)} = {}^{1}/_{1.92} =$ **0.5 T/V**

Number of turns for Secondary winding= (Secondary Voltage/$Volts\ per\ Turns$) (14)

Number of turns for Secondary winding= 24 / 0.5 = **48 Turns**

Secondary copper wire thickness = **8 SWG**

3.6 Transformer Primary Voltage Winding Calculations

$$\text{Primary winding current} = \frac{(KVA)}{(\,Primary\ voltage \times power\ factor)} \qquad (15)$$

Primary winding current $= \frac{3000}{230 \times 0.9} =$ **14.49 Amps**

$\text{Core area} = 1.152 \times \sqrt{}(Primary\ voltage \times Primary\ current)$ (16)
Core area = 1.152 × √(230 x 14.49) = 1.152 × 57.74 = **66.52 cm²**

Turns per volts $= {}^{1}/_{(4.44 \times 10^{-4} \times 66.52 \times 1.3 \times 50)} = {}^{1}/_{1.92} =$ **0.5 T/V**

Number of turns for Primary winding= (Primary Voltage/$Volts\ per\ Turns$) (17)

Number of turns for primary winding= 230 / 0.5 = **460 Turns**

Primary copper wire thickness = **17 SWG**

3.7 Output Filter

The final component necessary to output a pure sine wave signal is an output filter. For this work we used an L-C low pass filter. This will filter out all the excess noise above the critical frequency. The goal for this is to bring the critical frequency as close as possible to the desired frequency of 50 Hz, removing other harmonics that crop up within the system.

$$F_c = \frac{1}{2\pi\sqrt{lc}} \qquad (18)$$

Since the secondary side of the transformer has an inductance, we calculated for only the shunt capacitor.
From the earlier calculations
Transformer core area a = **0.00063 m^2**
From the core used B = 1.3T
So that flux linkage $\phi = B \times a$
$\phi = 1.3 \times 0.00063 =$ **0.00819 weber**
From equation 9, L = $460 \times \frac{0.00819}{14.49} =$ **0.26 H**
Hence the capacitor value needed from the formula above is calculated from the formula:

$$C = \frac{1}{4\,\pi^2 f^2 l} \qquad (19) \qquad C = \frac{1}{4\,\pi^2 \times 50^2 \times 0.26} = 3.9 \times 10^{-5} F = \mathbf{39\ \mu F}$$

For the design the available 47µF capacitor was used.

4. Mode of Operation

In free running mode (when the inverter is not Switched ON or when there is no mains), the battery voltage is used to power the circuit. It is connected through a 10 Ω choke resistor which acts as a fuse for circuit protection. Voltage is supplied to the circuit through the 5 V and 12 V voltage regulators. The 5 VDC is fed to the microcontroller and to the MOSFET driver and to the LCD. The 12V regulator is used to power the relays and also act as a bias voltage for the MOSFET driver. In inverter mode, the microcontroller senses the battery voltage through the voltage divider circuit made up of 100 KΩ and 1 KΩ resistor. If the battery voltage is above the low battery value of 20 V, the microcontroller sends the oscillations to the H-bridge which in turn uses the oscillations to convert the battery DC voltage to an AC voltage, the AC voltage is then stepped-up by the transformer TR2 to a nominal voltage of 230 V. The output of the transformer TR2 is then passed through a filter capacitor to reduce the high harmonic component of the AC waveform. The output from the filter is then stepped-down through another transformer TR1 to provide feedback to the microcontroller. The output of the step down transformer is rectified and then passed through a voltage divider circuit made up of 100 KΩ and 10 KΩ resistors. The function of the feedback is to ensure that the output voltage is relatively fixed at 230 VAC with ±6 VAC variation. Under the condition where with the battery falls below 20 VDC which is the stated low battery, the output is switched OFF. The maximum current drawn is calculated as the total power divide by the input voltage, which is 3 KVA divided by 24 VDC, which gives a total of 125 AMPS. Therefore the overload current is set at 110 AMPS to allow for inaccuracy. Under the condition that the input current rises above 110 AMPS, the oscillation is cut off and the condition could either be read as an overload or a short circuit. In mains mode, the microcontroller senses the presence of a mains input through the help of an optocoupler U1. The 230 VAC rectified passes through a voltage divider so that a proper voltage could be used to bias the optocoupler U1. When there's Mains, 5 VDC is sent to the designated mains pin of a microcontroller through the optocoupler. This way the microcontroller is aware of the presence of mains and switches the outputs to be powered directly from mains while also switching mains into the transformer TR2, hence the transformer acts as a step down transformer in this case and steps down the 230 VAC to the appropriate 24 VAC needed to charge the battery. In this mode the H-bridge is configured as a buck converter using the lower side MOSFET as a switch, the higher side MOSFET as a diode then using the transformer as both a source and an inductor while using the DC link capacitor as ripple capacitors. The low side MOSFET is switched at the same time with a frequency of above 7 KHz. The microcontroller monitors the input current through the current transformer TR3 to ensure that the charging current is always within 9 AMPS to 10 AMPS during normal charge. When the battery voltage rises up to 27 VDC, the microcontroller switches the low side MOSFET in the buck converter configuration to ensure that the charging current is within 0.7 AMPS to 1 AMP. Charging continues as long as the battery voltage is less than the fully charge threshold and stops once the battery voltage is equal to the fully charge value of 28 VDC.

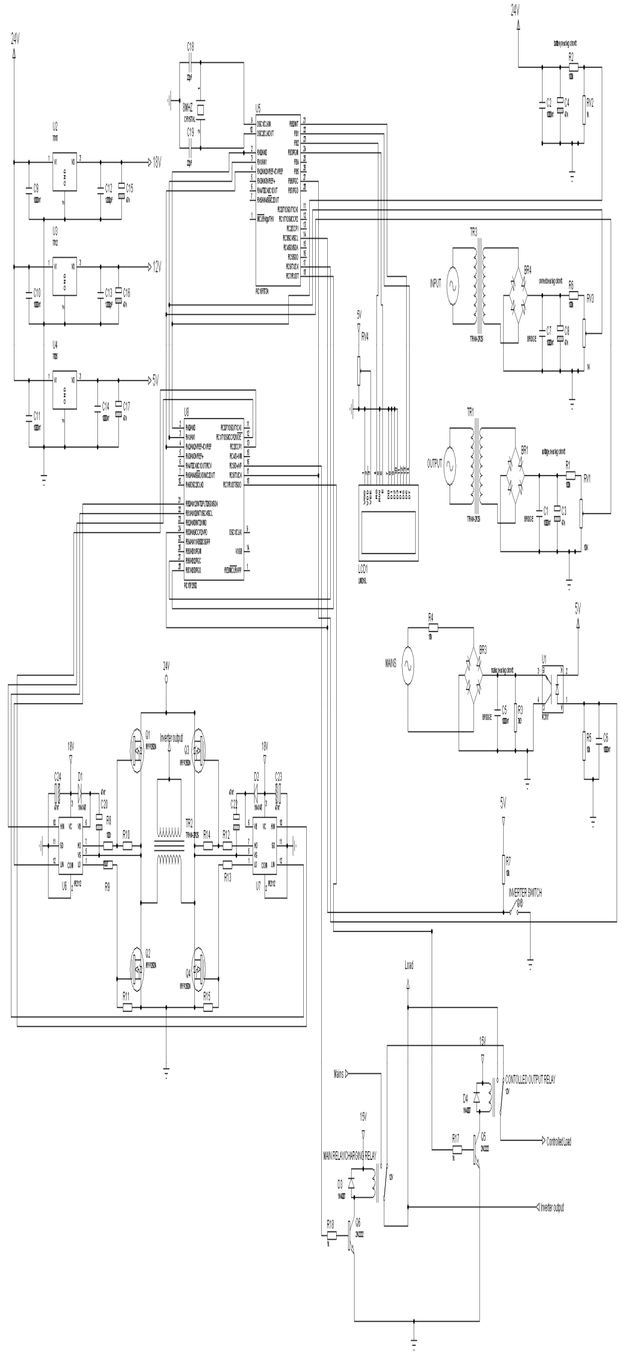

Fig 2: Complete circuit diagram of the microcontroller based pure sine wave solar power inverter with controlled output.

5. Test and Results

The inverter when tested with an oscilloscope produced a 50 Hz sine wave signal at the output as shown in figure 2. Also, a 400 watts bulb was connected to the output. After hours of running the system, the 400 watts bulb went OFF when the battery voltage dropped below 20 VDC which is the low battery set point. The drop in battery voltage and state of the output is shown in table 3.

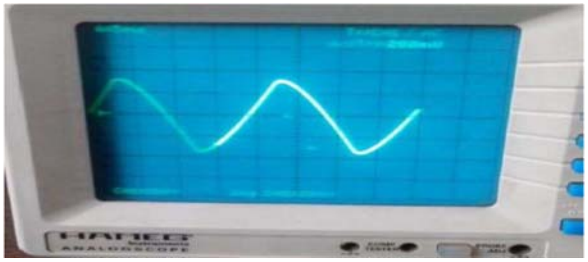
Fig 3: Inverter output waveform

Fig 4: Inverter under test

Table 3: Battery voltage and states of output

S/N	Battery Voltage (Volts)	AC Output (Volts)	Output State
1	25.0	230	ON
2	24.5	230	ON
3	24.0	220	ON
4	23.5	220	ON
5	22.0	210	ON
6	21.5	210	ON

7	21.0	210	ON
8	20.5	205	ON
9	20.0	200	ON
10	19.5	200	OFF

6. Conclusion

A microcontroller based inverter circuit that generates a pure sine waveform was developed and tested. The circuit, built around a PIC18*f*2550 microcontroller, was designed and simulated with Proteus Software, programmed with MicroC Software and then constructed on a printed circuit board. The circuit when tested produced a 230 V r.m.s 50 Hz sine wave with very low harmonics distortion which makes it suitable for powering inductive loads like microwaves and motors making then run faster, quieter and cooler. It also reduces audible and electrical noise in fans, fluorescent lights, audio amplifiers, TV, fax and answering machines. It prevents crashes in computers, weird print outs and glitches in monitors.

From the test carried out and results obtained the system performed according to the design specification. Hence, the objective was realized. The proposed system is economic, efficient and reliable and can be used for medium as well as high power applications.

References

[1] Economy of Nigeria, November 2016 [Online]. Available: https://en.wikipedia.org/wiki/Economy_of_Nigeria. [Accessed on March 04, 2017]

[2] Nigeria Power Baseline Report, September 16,2015 [Online]. Available: http://www.nesistats.org/uploads/3/6/3/6/3636925/20150916_nigeria_energy_power_report_final.pdf. [Accessed on March 04, 2017]

[3] J. Abolarinwa and P. Gana, "Design and Development of Inverter with AVR using Switch Mode Square Wave Switching Scheme," *Assumption University Journal,* vol. 13, no. 4, pp. 249-257, April 2010.

[4] G. Irving, *"Power Supplies: Switching Regulators Inverters and Converters"* first. New Delhi: BPB Publications, 1985.

[5] Funso, A. O. Micheal and A. Stephen, “On Various Oscillators and Power Amplifier Design Methods Employed for the Development of Power Inverters.” *International Journal of Research and Reviews in Applied Sciences*, Vol. 5, no. 3, (2010).

[6] Gana, J. Aboluwarin and Paul. "Design and Development of Inverter with AVR Using Switch mode Square Wave Switching Scheme" *Assumption University Journal*, pp. 249-257, 2010.

[7] M. Abdelati, and G. Frey, “A Method for Building a Simple

and Applicable Power Inverter." *In 2nd International Congress on Energy Efficiency and Energy Related Materials. Springer International Publishing*, 2015 pp. 357-367.

[8] Hann, James H. "*Modified Sine-Wave Inverter Enhanced.*" Power Electronics Technology, 2006.

[9] Ample Power Company. "Microwave Ovens and Quasi-Sine Wave A.C. [Online]. Available: https://amplepower.com/pwrnews/ micro2/index.htmlJ. [Accessed on March 05, 2017].

[10] O. A. Komolafe and I. Olufemi, "Gapped Alternate Phased Opposite Disposition Pulse Width Modulation Control for Multilevel Inverters,"*Journal of Engineering and Applied Sciences,* vol. 9, no. 4, pp. 560-567, 2014

[11] M. Hassan, J. Maqsood, M. Q. Baig, S. M. Bukhari and S. Ahmed, "Design and Implementation of Single Phase Pure Sine Wave Inverter Using Multivibrator IC." *17th UKSIMM-AMSS International Conference on Modelling and Simulation*, 2015, pp. 451-455.

[12] M. A. Ghalib, Y. S. Abdallah and R. M. Mostafa. "Design and Implementation of a Pure Sine Wave Single Phase Inverter for Photovoltaic Applications," pp. 1-8.

[13] A. A. Ogunseye and O.O Olusanya, "Design of a Microcontroller-Based Push-Pull Inverter with Automatic Voltage Regulator," *International Journal of Innovative Research and Development*, vol. 4, no. 4, pp. 27-32, April 2015.

[14] A. A. Ogunseye, O.O Olusanya and A. T. Olusesi, "Development of a Microcontroller Based Enhanced Modified Sinewave inverter," *International Journal of Engineering Research & Technology,* vol. 5, no. 3, pp. 61-65, March 2016.

[15] N. Kashappa and R. K. Ramesh, "Implementation of a Low cost PWM Voltage Source Multilevel Inverter," *International Journal of Engineering Research & Technology*, vol. 2, no. 2, pp. 317-321, February 2012.