Caliphate Journal of Science & Technology (CaJoST)

ISSN: 2705-313X (**PRINT**); 2705-3121 (**ONLINE**)

Research Article

Article Info

Received: 17th December 2018

Revised: 7th February 2019

Accepted: 18th February 2019

Design and Construction of a 300-Watts Modify Sine Wave Inverter

Yahaya Yusuf

Department of Physics, Zamfara College of Arts and Science, Gusau.

Corresponding author's email:

Bazata70@gmail.com

Cite this: *CaJoST* 2019, 1, 19-25

An inverter is a device that converts power from a direct current (DC) battery into conventional alternating current (AC) that can be used to operate all kinds of electrical devices. The design and construction of a power inverter for low power requirements of an electronics workshop is described. The inverter is expected to power soldering iron, laptop and a standing fan from a car battery. The integrated circuits (ICs) and other design materials were chosen based on their simplicity and availability in most of the electronics shops. From the nature of the load, a modify sine wave inverter was chosen. To minimize cost and size, the circuit was designed to operate on a high frequency transformer and hybrid circuitry. Modules associated to the design were first conducted on MULTISIM software to ascertain their working conditions before the construction procedure. The performance analysis of the functional units was carried out and found working as anticipated with a power rating of 250 watts against the targeted 300 watts.

Keywords: Direct current, Alternating current, Integrated circuit, Frequency

1. Introduction

An inverter is an electrical device that converts direct current (DC) to alternating current (AC). The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources. The inverter performs the opposite function of a rectifier. Power inverters range from the less expensive to the very expensive, with varying degrees of efficiency, quality, and output power capability. The high quality combined with high efficiency tends to be expensive. The modified sine wave inverter most often is very efficient, though there is not much processing being done on the output waveform. This results in a waveform with harmonics that may affect some sensitive equipment such as microwave ovens, laser printers, clocks, cordless tool chargers and medical monitors. The very cheap ones are the square wave inverters that have a high number of harmonics and perhaps lower efficiency.

[1] designed a circuit shown in Figure 1 using 4047 IC to generate a square wave of 50 Hz and using a step-up transformer to amplify the current and voltage.

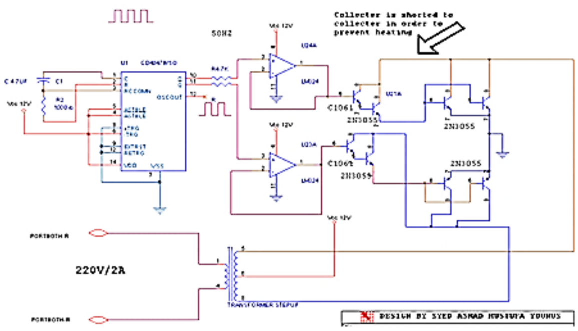

Figure 1. Designed circuit using 4047 [1].

Figure 2 is a schematic design of a DC to AC inverter circuit. Though, it is a very simple circuit since it produces square wave, the voltage is enough to power many devices [12].

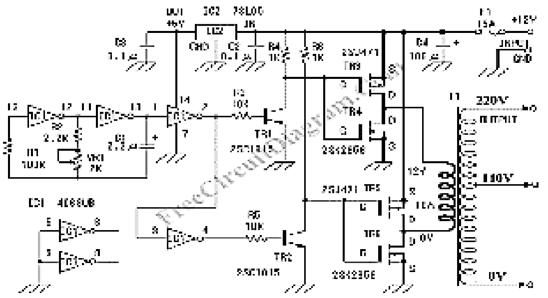

Figure 2. Schematic of Square Wave Inverter [12].

The MOSFET is configured as bridge, so the current will flow alternatively in through the primary windings of the transformer. The most expensive part of this DC-AC inverter circuit is the transformer, since it must handle high current up to 10 Amps and it has to be bulky. It can power any device up to 120 Watts using this 12 V inverter circuit.

Modified sine waves inverter is the most common type in use since it can adequately power most household appliances and power tools. Most often to have AC power supply for some basic equipment in an electronics workshop like soldering iron, laptop or a fan is challenging due to power failure from the national grid. Thus, in this paper, the design and construction of a power inverter for low power requirements of an electronics workshop is described. A modify sine wave design was chosen as it can function properly with the load intended to be use.

2. Theory

2.1 Pulse Width Modulation Technology

[2] showed that Pulse Width Modulation (PWM) is used to keep the output voltage of the inverter at the rated voltage (110V AC / 220V AC) (depending on the country) irrespective of the output load. In a conventional inverter the output voltage changes according to the changes in the load. To nullify the effect caused by the changing loads, the PWM inverter correct the output voltage according to the value of the load connected at the output. This is accomplished by changing the width of the switching frequency generated by the oscillator section. The AC voltage at the output depends on the width of the switching pulse. The process is achieved by feed backing a part of the inverter output to the PWM controller section (PWM controller IC). Based on this feedback voltage the PWM controller will make necessary corrections in the pulse width of the switching pulse generated at oscillator section. This change in the pulse width of the switching pulse will cancel the changes in the output voltage and the inverter output will stay constant irrespective of the load variations. The basic block diagram of the setup is as shown in Figure 3.

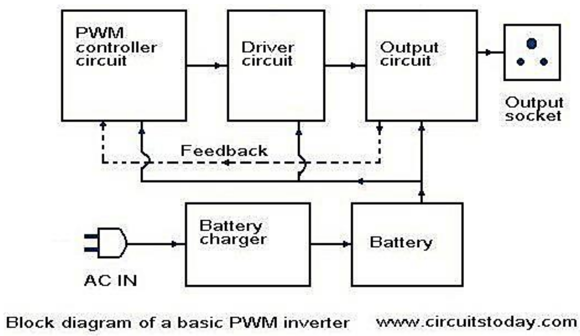

Figure 3. Basic PWM inverter block diagram [2].

The duty cycle of PWM is a percentage measurement of how long the signal stays ON and is determined by:

$$Duty\ cycle = \frac{ON\ time}{Period}\ x\ 100\% \qquad (1)$$

The H-bridge circuit converts battery DC voltage into AC using high frequency PWM (6 kHz to 20 KHz) thus feeding the 50-Hz transformer which boost it to 120V/220V AC [10]. The output of transformer contains a capacitor which filters it to make clean 50-Hz AC (Figure 4).

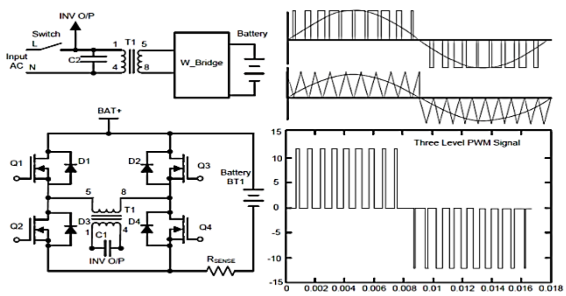

Figure 4. Inverter Mode Gate Drives [10].

3. Materials and Method

3.1 Circuit Design

The design has various functional circuits designed as a separate entity. The construction intended to be stand-alone system with the various functional circuits assembled. The general block diagram of the system is as shown in Figure 5. The stages include storage battery, PWM oscillator, driver, and high bridge output circuit.

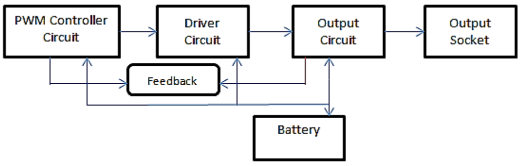

Figure 5. Block diagram of the setup.

3.2 DC/DC Converter Oscillator Design

The integrated circuit (IC) chosen for this operation is the SG3525. The SG3525 pulse width modulator control is chosen because of its simplicity in its use and also its availability in most of the electronics shops. The oscillator is responsible for converting the DC source from the battery to AC at high frequency. The pin out connections is shown in Figure 6.

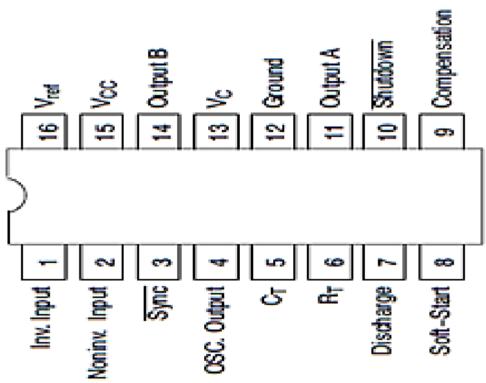

Figure 6. SG3525 pin connections [9].

The inverting input (pin1) and non-inverting input (pin 2) were inputs to the on-board error amplifier. Their main function is in feedback operation associated with Pulse Width Modulation (PWM). This enables it to increase or decrease the duty cycle depending on the voltage levels on the inverting and non-inverting inputs pins 1 and 2 respectively. The PWM frequency dependent is on the two parameters mainly the timing capacitance (C_T) and the timing resistance (R_T). The timing capacitor is connected between pin 5 and ground, while the timing resistor is connected between pin 6 and ground respectively. The resistance between pins 5 and 7 (R_D) determines the dead time of the oscillator and also slightly affects the frequency as shown in equation 2. The frequency is related to R_T, C_T and R_D by the relationship:

$$f_{osc} = \frac{1}{C_T(0.7R_T+3R_D)} \qquad (2)$$

Where R_T and R_D are timing and dead - time resistance in Ω respectively and C_T is the timing capacitance in F, while f is the frequency of the oscillator in Hz.

The range of R_D values as specified by the manufacturer's datasheet is 0 Ω to 500 Ω. For a push-pull configuration, if 50 kHz frequency is required then the oscillator frequency must be 100 kHz. The MOSFETs drives a ferrite core transformer that steps up the high frequency AC voltage. This voltage is then rectified and filtered, later being used in high bridge (H-Bridge) circuit.

The oscillator aims to drive a high frequency ferric transformer in push/pull topology. The R_T was found to be closer to a standard value of 15 KΩ and therefore chosen. The 10 µF capacitor was connected across pin 8 and the ground for the soft start as contained in the datasheet. The high frequency oscillator designed is as shown in Figure 7.

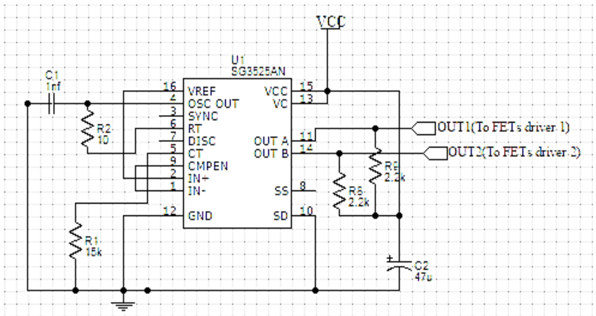

Figure 7. Designed circuit of the DC-DC Oscillator

The FET bank design was based on the half bridge configuration with two FETs to take care of the power requirement.

3.3 The High Frequency Ferric Transformer Design

Since the selected topology chosen is the push-pull, the ferric transformer should be a Centre tap. The input power source is from a 12 V battery. The output voltage of the DC-DC converter stage is 310 VDC and the transformer switching frequency chosen is 50 kHz. The ultrafast recovery diodes are configured to form a bridge rectifier. The transformer will require twice the number of primary turns as the full-bridge transformer. In operation the battery voltage does not stay fixed at 12 V. When the inverter is highly loaded, the voltage will be less than 12 V. With low loads and fully charged battery, the voltage may reach 13.5 to 14 V. Faraday's Law continues to have the final word in magnetic design, that is:

$$V = 4.44 N A_e f B 10^{-8} \quad (3)$$

Where:

V is the applied potential (volts RMS)
4.44 is the form factor for a sine wave
N is the number of turns
A is the core cross-sectional area (cm^2)
f is the frequency (hertz), and
B is the peak flux density (gauss)

Since no practical materials have been discovered which allow extremely high current density without loss, or extremely high flux density without saturation, the only variable in Faraday's equation that can be adjusted to significantly shrink the size of a magnetic flux is frequency. The great benefit of ferrites, of course, is that they permit operation at frequencies into the hundreds of kilohertz, even to several megahertz. With the frequency very high, A and N may be set to small values, and the resulting magnetic flux is miniature in comparison with a low frequency device [11]. The number of required primary turns is calculated from equation 4, that is

$$N_{pri} = \frac{V_{in(nom)} \, X \, 10^8}{4 \, X \, f \, X \, B_{max} * A_c} \quad (4)$$

Where; N_{pri} is the number of required primary turns, $V_{in\ (nom)}$ is Nominal Input Voltage, and A_c = A_e is effective cross-sectional area in cm^2.

For the push-pull, this is one-half the required number of turns. The nominal input voltage $V_{in(nom)}$ is taken to be 12 V, while the Maximum flux density (B_{max}) is taken to be in the range 1300G to 2000G. This will be acceptable for most transformer cores [6]. B_{max} was assumed to be 1500G. For ETD44, the effective cross-sectional area (A_c) given in the datasheet/specification sheet = 175 mm^2 or 1.75 cm^2 [4]

Substituting $V_{in(nom)}$ = 12 V, f = 5x10^4 Hz, B_{max} = 1500, and A_c = 1.75 cm^2 in equation 3. N_{pri} = 2.29 turns = 2 turns approximately, the transformer will require 2 turns + 2 turns on the primary side. Moving on to the secondary output, the DC-DC converter output should be 310 V. So, the transformer output should be 310 V at all input voltages. The feedback will implement to keep the output voltage fixed even with load variations – changes due to battery voltage drop and due to load change. Some headroom is left for feedback to work. The headroom also compensates for some of the losses in the converter such as in the transformer itself, rectifier, MOSFETs etc. Therefore, the transformer is designed to deliver 330 V at the secondary output if the input voltage is 10.5 V. To allow gap for the dead time, the PWM controller maximum duty cycle is taken to be 98%. At minimum input voltage (V_{in} = $V_{in(min)}$), duty cycle will be maximum. The transformer input voltage is 98% x 10.5V = 10.29V. The voltage ratio secondary to primary is 330 V: 10.29V is 32.1 turns (N). The ratio of primary to secondary turns is 1:32. Therefore, N_{sec} = N x N_{pri} = 32.1 x 2 = 64.2 approximately 64 turns are required for the secondary. The large headroom is provided for feedback to kick in and maintain the output voltage even at high loads.

3.4 The DC to AC Converter Design

In this design, the PWM oscillator chosen is the TL494 IC. The TL494 device incorporates all the functions required in the construction of a pulse-width-modulation (PWM) control circuit on a single chip. It contains two error amplifiers, and an on-chip adjustable oscillator, a dead-time control (DTC) comparator, a pulse-steering control flip-flop, a 5 V, 5% precision regulator, and output-control circuits. The device provides for push-pull or single-ended output operation, which can be selected through the output-control function [14]

The frequency of the oscillator is programmed by selecting timing components R_T and C_T. The oscillator charges the external timing capacitor, C_T, with a constant current, the value of which is determined by the external timing resistor, R_T. This produces a linear-ramp voltage waveform.

When the voltage across C_T reaches 3.0 V, the oscillator circuit discharges it, and the charging cycle is reinitiated. The charging current is determined by;

$$I_{charge} = \frac{3v}{R_T} \quad (5)$$

The period of the saw tooth waveform is;

$$T = \frac{3v \ X \ C_T}{I_{charge}} \quad (6)$$

The frequency of the oscillator is given by;

$$F_{osc} = \frac{1}{R_T X C_T} \quad (7)$$

Where v is the PD across the timing capacitor (C_T). R_T C_T is timing resistance and I_{charge} is the charge current [8]. Conversely, the oscillator frequency is equal to the output frequency only for single-ended applications. For push-pull applications, the output frequency is one-half the oscillator frequency. The output frequency needed in design is 50 Hz. C_T value was chosen to be 100 nF and R_T was evaluated and found to be 200 KΩ. A series connection of 2 x 100 kΩ is used in the construction. R_7 is to be used for negative feed-back control. TL494 low frequency oscillator designed on MULTISIM is as shown in Figure 8.

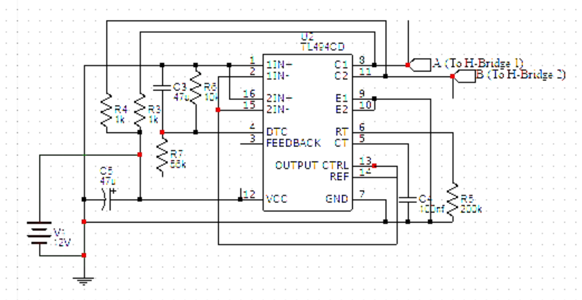

Figure 8. Designed Circuit of the DC-AC Oscillator

3.5 The High Bridge Circuit Design

MOSFETs were configured as high side and low-side switches, such as in bridge circuits. The MOSFEs driver employed in this case is a high voltage transistor KSP44. It is chosen because it has Collector-Emitter Voltage (VCEO) is 400 V [3]. Higher on time required higher capacitance. In another words, the lower the frequency, the higher the required capacitance (C) needed. The higher the duty cycles the higher the required C. For the lower frequency 50 - 60 Hz, C is estimated to be between 4.7 to 10 µF, D_5 and D_6 discharge the gate capacitances of the MOSFET quickly, bypassing the gate resistors and therefore reducing the turn off time [15]. R_5 and R_8 are the gate current-limiting resistors. The MOSFETs chosen in this design is a high voltage and current power MOSFET, UTC 10N40. The designed circuit is shown in Figure 9.

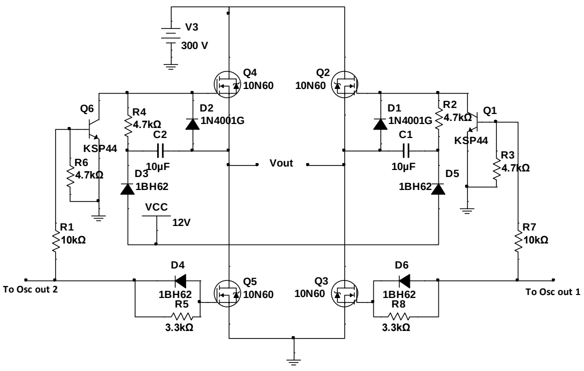

Figure 9. The Designed High Bridge Driver Circuit.

Materials used in the inverter construction are shown in Table 1, while the circuit diagrams prepared with MULTISIM.

Table 1. Material Used for Construction

S/N	Components	Description	Quantity
1	Capacitor	100 µF	4
2	Capacitor	1 nF	1
3	Integrated circuit	SG3525	1
4	IC Socket	16 Pins	2
5	Resistor	1 KΩ	4
6	Resistor	15 KΩ	1
7	Resistor	10 Ω	2
8	LED	White	1
9	MOSFET	IFR1404	2
10	Resistor	10 Ω	2
11	Resistor	10 kΩ	4
12	Transformer core	E E shape	2
13	Primary coil	AWG 27	¼ kg
14	Secondary coil	AWG 25	¼ kg
15	Insulating material	Masking tape	1 roll
16	Transformer	Ferric	1
17	Diode	HER306	4
18	Capacitor	200 µF	1
19	Capacitor	47 µF	2
20	Integrated	TL494	1

	circuit		
21	Resistor	150+47 KΩ	1
22	Resistor	47 KΩ	1
23	Resistor	100 KΩ	3
24	Resistor	3.3 kΩ	1
25	Zener diode	BZV90-C30	1
26	Potentiometer	10 kΩ	1
27	Capacitor	1 µF	1

3.6 System Construction

After the circuit design, construction was done on single Vero-board. The assembly was carried out module by module. At the end of each stage, a test was conducted to see if the constructed circuit meets the design expectations. They were first tested individually to ascertain their working conditions. A multimeter was used to conduct a continuity test for the diodes and transistors. The conducting surfaces were sand papered to ensure clean surface and prevent dry joints during soldering. Apart from the electronic components used, other miscellaneous materials such as Vero board, soldering lead, cooling fan, fuses, connecting wires (jumpers), masking tape and heat sink for the power drive, etc. were also among the construction materials. Continuity tests were also conducted to ensure that the joints were properly done. To minimize the chance of damage due to overheating on ICs, IC sockets were soldered on their positions. The ICs were plugged in after soldering. This was done in case the ICs needed replacing after a malfunction. The photograph of the constructed inverter is shown in plate 1.

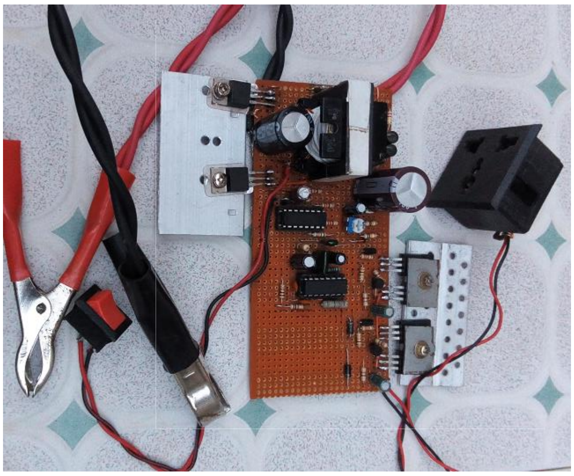

Plate 1. Photograph of the constructed circuit.

4. Results and Discussion

4.1 Simulations Test Results

Simulations of the circuit were captured as shown in Figures 10 and 11.

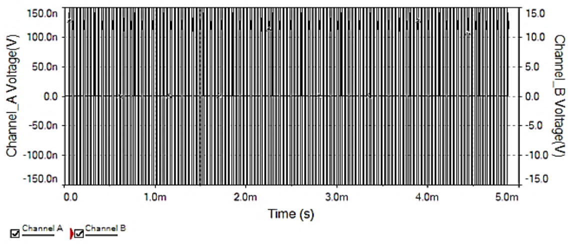

Figure 10. Simulation result of the DC-DC oscillator circuit.

The simulation result obtained from the DC-DC converter (high frequency oscillator) circuit shows a high frequency output.

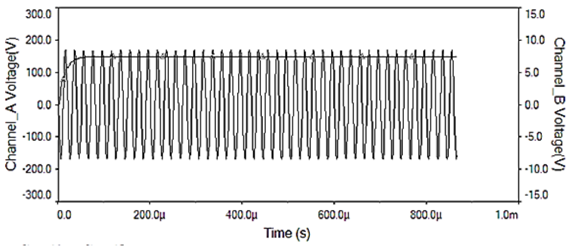

Figure 11. Simulation result on the bridge rectifier circuit

The simulation result shows the AC and DC output waveform. AC resulted from transformer directly while the DC output was obtained after rectification and filtration. The inverter outlet simulation is also shown in Figure 12.

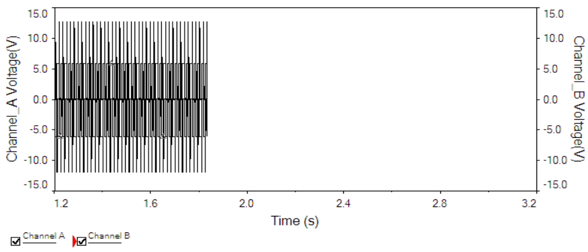

Figure 12. Result of DC-AC converter oscillator circuit

The result shows that the output waveform of the high frequency oscillator appeared to be a square wave, with potential difference (PD) between each output of about 18.0 VAC. Keeping C_t constant (1nF), when R_t was adjusted to 15 kΩ the frequency at each test point was found to be 47 kHz with a very small variation of plus or minus 0.2 kHz. Hence, the observations almost tally with the calculated value. The simulation result of the bridge rectifier based on the software shows a high DC supply of about 333 volts. This DC voltage is being converted back to AC but at a lower frequency of 50 ± 0.2 Hz. Feed-back circuit control the output to 220 volts for the safety of load(s) to be connected.

4.2 Inverter tests

After construction, each sub circuit was tested as a module to ascertain its working condition. Test conducted across a transformer using a digital multimeter shows an AC output of 18 volt on the primary winding. On the secondary terminals the AC output is infinity. This should be due to high frequency, but after the rectifier it appears to be 333 ± 2 volts DC. The final output was initially around 280 volts AC, with help of feed-back control it was adjusted to 220 volts and was found steady irrespective of the load applied. Soldering iron and laptop were connected and found working well and lastly the standing fan worked fine too with negligible harmonics being noticed. The inverter was found to be working properly with load not exceeding 250 watts.

5. Conclusion

The construction when tested was found to be working properly with some few variations resulted from the component tolerance. The inverter is capable of converting an input voltage of 12 V (DC) to 220 Volt AC. Loads such as soldering iron; laptop and standing fan were used during testing. An output power of 250 watts was obtained against the 300 watts. This should be due to losses from the transformers winding and the battery cables

Conflict of Interest

The author declares no conflict of interest.

References

[1] Ashad, M. Electronics Lab.Com 2002-2012, The Conversion of 12V DC into the 220V AC, Retrieved May 08, 2014 from mailto:mustufa66@hotmail.com

[2] Cochin, K. Design Cochin 2017-2011, (2008), Circuits today.com Designed, Retrieved Sep 16, 2012 from http://www.wavenester .com/design Cochin.

[3] Fairchild Semiconductor Corporation, “High Voltage Transistor,” KSP44 datasheet, Retrieved Dec 17, 2015 from http:// www.fairchild.com.

[4] Ferrite Core for Switching Power Supplies, Ferric Core application guide, Retrieved Feb 17, 2015 from http://www..electronics-tutorials.ws/transistor/tran_1.html.

[5] Gary, J. Jaycar Electronics 2000, Electronics Engineering Catalogue, Australia retrieved 18 Sep 2012 from www.jaycar.com.au

[6] Majid, D. From Powder to Transformer, Fairchild Semiconductor Power Seminar (2008 – 2009) pp 2

[7] ON Semiconductor 2005, Semiconductor Components Industries, LLC, Publication Order Number AND8039. Retrieved Jan 3, 2016, from http://onsemi.com

[8] ON Semiconductor, “Pulse Width Modulations Control,” TL494 Datasheet, Retrieved March 15, 1996 from http://onsemi.com

[9] ON Semiconductor, “Pulse Width Modulator Control Circuit,” SG3525 Datasheet, Retrieved Jan 17, 2015 from http://onsemi.com

[10] Sanjay, D., Ambreesh. T., Vikas. C., and Ankur. V, Application Report SLAA602A–June 2013–Revised August 2017, 800 VA Pure Sine Wave Inverter’s Reference Design, Retrieved 15 Oct 2017 from http://www.ti.com

[11] Spang and Company Butler, Technical bulletin 2012, PA 16003, Retrieved Mar 04 2013 from http://www.mag-inc.com

[12] Super, J. M, Privacy Policy design by super j man, Convert 12V DC Voltage to 110/220V AC Voltage Ported by GFXedit.com, Retrieved Jan 23, 2013 from http://www.jdavidmacor.com

[13] Swagatam, I. Swagatam Innovations, How to Make a 200 Watt Transformerless Inverter Circuit, 2013 Retrieved May 27, 2013 from http://www.brighthub.com/members/swagatam.aspx

[14] Texas Instruments, “The Pulse Width Modulations Control,” TL494 Datasheet, Retrieved Jul 28, 2014 from http://www.ti.com

[15] Unisonic Technologies Co., Ltd, “N-channel Power MOSFET,” UTC 10N40 Datasheet, Retrieved Feb 17, 2016 from http://www.unisonic.com.tw.

