THE DESIGN AND CONSTRUCTION OF A 1KVA INVERTER

BY

NWANJI NWACHUKWU CHUKWUDEBE

&

OKWELUM EKENE SAMUEL
DEPARTMENT OF ELECTRICAL/ELECTRONIC ENGINEERING
FACULTY OF ENGINEERING
UNIVERSITY OF BENIN
BENIN CITY
EDO STATE

ABSTRACT

This work presents a design and prototype of 1KVA inverter with battery protection, overcharge protection and a USB port terminal for charging of mobile phones. The design is achieved by the use of discreet components such as thyristors, capacitors, zener diodes, mosfet, transformers, voltage regulators, 555 timers, operational amplifier, opt-couplers, a deep cycle battery, IC (SG3524), resistor and relays. Six mosfetswere used to increase the power carrying capacity of the circuit. Operationally, the inverter circuit gets power supply from the grid at 230 volts and converts same to 12 volts which is usable for charging battery via a charging circuit. Simultaneously, the circuit supplies power to appliances connected to the inverter circuit directly from the power grid. In the event of power failure, a relay switches the source of power to the battery, and with the help of the mosfets and the IC(SG3524), the dc power from the battery is converted to ac power which is then used to power the appliances connected to the inverter circuit. The design was tested and found to be satisfactory. The circuit was constructed and equally tested on a 50watts AC stand fan. The 50 watts' bulb was adequately. The result also shows that the current draining rate is inversely proportional to voltage supply.

KEYWORDS: Inverter, Circuit, Direct Current, Alternating Current, Electricity, Wave form

Introduction

Apparently, the country still experiences poor power supply (Somefun, 2015). The situation is made worst by the adverse effect of noise and air pollution resulting from the use of generators in the pursuit to cub the problem. For these reasons and others not mentioned, it is important to envisage an alternative source of power. This alternative should be able to power loads while also addressing the associated issue of environmental pollution. A device which could meet these requirements is what this work entails and it is called an inverter. An inverter is an electronic circuitry which converts direct current (DC) into alternating current (AC).

DC is that which is capable of flowing in just one direction, whereas, AC is one in which the direction of current changes with respect to time (Sandra & Smith, 2005) and (Forrest, 1986).

The waveform of Acing is sine wave, square wave, and triangular wave. DC can be gotten from an alternating current by a process called rectification (Brindley, 2005). On the other hand an alternating current can be realized from a direct current by switching the direct current with a generated frequency pulse.

General Layout of an Inverter

An inverter by itself cannot supply power (Civic Solar, 2015). It works with a DC battery source which can be recharged. The battery source serves as an input to the inverter while an AC voltage is the output. This setup is valid basically due to the fact that most loads utilize AC voltage to function. Hence the inverter receives a DC from a battery bank and converts the DC to an appropriate value of AC needed to power load.

In a typical inverter unit, an oscillator circuit generates a pulse which is sent to a switching circuit (Amos & James, 1981), this utilizes the pulse generated to switch the dc voltage (from the battery bank) at the centre tap of the transformer, hence converting this DC voltage to AC. The transformer then steps up this AC voltage generated and power a load. The block diagram below shows the switching direction.

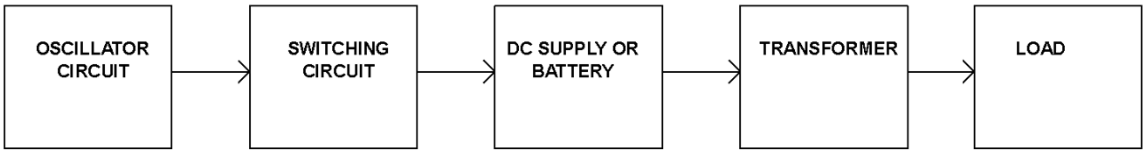


Figure 1: Block diagram showing basic working Principle of an Inverter

Application of Inverters

Inverters are used in the following areas of electrical and electronic engineering;

1. Solar power supply

2. Electric motor speed control

3. Power grid in high voltage direct current (HVDC) power transmission

4. Uninterruptible power supply (UPS)

5. Induction heating

Importance of Inverters

The importance of Inverter is felt globally beyond the engineering sector.

1. Inverters encourage storage of energy which is used in electroshock weapons and uninterruptible power supply (UPS).

2. DC power source like solar power and batteries can be used for ac appliances with the aid of inverters.

3. Induction heating which requires high frequency is made possible using inverters.

4. Due to the DC/AC conversion process of inverters, skin effect, number and size of conduction are reduced which invariably reduces cost in HVDC transmission.

Aims and Objectives of Project

The aim of this project is to design and construct a 1KVA, 50Hz modified sine wave inverter with an undercharge and overcharge protection.
To achieve stated aim, the objectives will be adhered to;

1. Design an inverter
2. Construct an inverter
3. Test the inverter

Background

According to the GE Review, an American engineer called David Prince probably coined the word Inverter for the first time in the world history (Owen, 1996). In the article, Prince highlighted virtually all key modern elements required to build a typical inverter. The article explained the functionality of an inverter and described the rectification process. Subsequently, the development and discussion of the inverter took a different dimension and was referred to as the rectifier device. In reality, it is difficult to ascertain whether Prince or anyone else originated the inverter technology. Today, inverter technology is on a very high trend across the globe. It will be in place to infer that the inverter technology ushered in renewable energy science and engineering.

Output Waveform of Inverter

Basically an inverter AC output waveform could be a pure sine wave, modified sine wave (modified square wave) or a square wave. The best and most expensive inverters are those that produce pure sine wave as output due to the technology involved in their construction (Doucet, Eggleston, & Shaw, 2007). Pure sine wave inverters are compatible with virtually all kinds of electrical equipments; nevertheless, most inverters available in the market are modified sine wave.
Doucet, Eggleton and Shaw (2007) also reported that modified sign wave can adequately power most electrical equipment with very little distortions; however, they are not used for sensitive and scientific equipment, as this equipment require very high accuracy in their functionality. The report also confirmed that the square wave inverter is rarely used as they are incapable of powering most electrical equipment.

System Components

A typical inverter contains the Battery, Transformers, Resistors, Capacitors, Diodes, Relays, MOSFETS, Comparator ICs, Oscillator IC, Voltage Regulator IC, Thyristor and a 555 timer IC (Doucet, Eggleston, & Shaw, 2007). The battery stores and produces DC for rectification, the transformer steps up or steps down the voltage, the resistor inhibits the flow of current, the capacitor stores charges, Diodes enhances flow of current in one direction, LED emits light, relays enhance switch operation, MOSFET amplifies electronic signals, and IC convert current.

Methodology

Designing and constructing a sine wave inverter can be complex. However, when broken down into smaller projects it becomes a lot easier to manage. Due to economic and load considerations, the choice of modified sine wave inverter is made. The project is broken down into specifics and detailed in the following sections. The product was subjected to a standard test and the result was in agreement with (Banerjee, 2015), (Omitola, Olatinwo, & Oyedare, 2014) and the conventional electrical electronic principles.

Pulse Width Modulator

The pulse width modulator stage is designed using a dedicated PWM IC, called SG3524.This versatile PWM controller can be used in a variety of isolated and non-isolated switching power supplies such as inverters, boost or buck converter etc. The figure below shows the pin configuration of the chip.

Battery voltage is 12V DC.

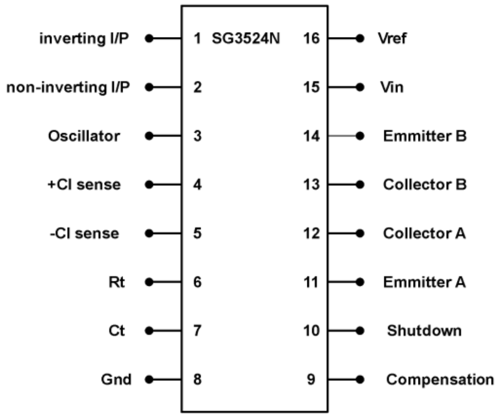


Figure 2: Diagram showing Pin configuration of SG3524 PWM IC

- V_{in} for the PWM IC (12volts) is taken from the battery source.
- Pin 16 outputs a constant +5V and used to set the voltage reference of 2.5V for the pulse-width control through voltage divider resistors to pin1.
- Pin1 and pin2 works as the feedback control input from the Opt-coupler stage connected to the load output to automatically adjust the output voltage using pin 16 voltage reference as its reference voltage to either increasing the width or reducing the width of the PWM to keep the output load voltage stable.
- Pin 11 and pin 14 is the output of the PWM
- Pin 6 and 7 is used to set the output frequency of the PWM using the formula from the datasheet.

1.15T = RC ------------------------------------ (1) Single output

1.15T = 2RC ---------------------------------- (2) Double output

$\frac{1}{T}$= F --- (3) frequency of 50Hz

There fore

$F = \frac{1.15}{2 \times R_T C_T} = 50Hz$

Where;

$C_T = 0.1\mu F$

Substituting C_T and making R_T subject

$R_T = \frac{1.15}{2FC}$-- (4)

RT =115,000 = 15KΩ

Therefore, a fixed resistor of 100 KΩ and a variable resistor of 50 KΩ are considered.

SOFT-START

The compensation pin 9 and reference pin 16 are used for the soft start circuit. This helps to prevent overshoot of the output at start. It uses a resistor and a capacitor charging circuit to introduce the delay.
The time delay can be obtained thus,
T = RC -- (5)
For time delay of $T = \frac{1}{50} = 20ms$
Assuming Capacitor value of 4.7Ωf
$R = \frac{T}{C} = 4255.3\Omega$
To get a higher time value, 4700Ω is considered. This will give 22ms delay.

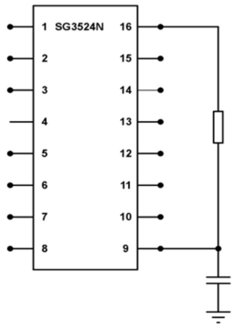


Figure 3: Soft start circuit for the PWM I

MOSFET Driver
The MOSFET stage conducts/switches the necessary load current through the step up/step-down power transformer

- The MOSFET uses in the switching step up stage are the IRFP 150N N-channel.
- A fixed resistor of 10KΩ is connected between the gates and sourced to aid fast switching by discharging any residual static charge at the gate.
- During charging, the diodes in the MOSFET transistors acts as a rectifier to the AC voltage from the step down power transformer with an external filter capacitor to charge the battery.

Datasheet of IRFP 150n
Drain to source breakdown voltage BV_{DSS} = 100V
Gate to source voltage (cut-off) = 4V
Gate to source breakdown voltage = $\pm$20V
Drain current (continuous) = 41A
Drain to source resistance r_{DSS} = 0.055Ω
Power Dissipation PD = 230Watts
A total of 6 MOSFET is considered with half of the number function for half the design period.
The maximum output of the MOSFET is given as;
Maximum Output-power = Watts x efficiency x total number of parallel mosfet.
Number of parallel mosfet =3 (three)
Worse case Efficiency of each mosfet = 80% of 250watts = 200watts.
Max. Output-power of mosfet = 200 x 3 = 600watts
Power factor of inverter = 0.6
The watts of 1KVA inverter = 1000 x 0.6 = 600watts

Therefore
Total Wattage of MOSFET = Maximum Wattage of 1KVA inverter

Battery Indicators
At low 9.5volts, the inverter is design to shut down. This arrangement involves the use of comparator IC and zener diode as the reference input terminal to the op-amp IC. The second input to the op-amp IC is connected from a voltage divider network from the positive terminal of the battery. The output from the op-amp is feed to an SCR transistor to short down the inverter when the battery goes below 9.5volts.
At full battery status of 14.5volts, the monitor circuit shuts down. In this case, the output from the op-amp is feed to a Bi-stable mode input of a 555 timer IC to stop the charging process when the battery goes above 14.5volts.
The following expressions help to define shutdown and start-up status.

$$R_L = \frac{V_{cc} - V_F}{I_F}$$

$$V_+ = \frac{V_{cc}R^2}{R^1R^2}$$

USB Port
The USB port circuit was designed with an adjustable three terminal positive voltage regulator (LM317 IC) capable of supplying more than 1.5A over an output voltage range of 1.25V to 37V.
Opt-coupler Feedback
The Opt-coupler is used in the feedback loop to control the pulse width, thereby effecting

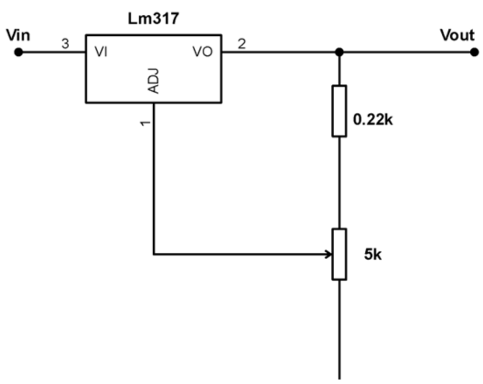


Figure 4: Voltage regulator circuit for USB port

voltage regulation. A 4N35 opt-coupler chip shown below is considered for this project.
The LED has a forward current of 5mA while the photo transistor has a maximum current of 200mA. The LED gets DC input from a bridge rectifier. For the pulse width control, the pin 2 is used for the reference voltage. Using a voltage divider of equal resistance, the V_{ref} for pin 2 is set to 2.5V when the supply is taken from pin 16 V_{ref}. Thus a variable resistor of 5KΩ was used and adjusted accordingly.

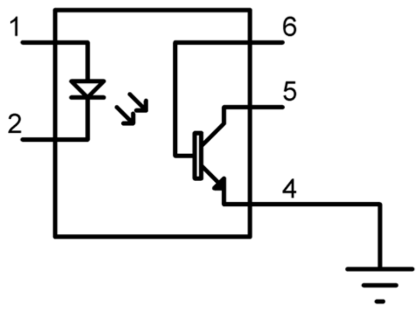


Figure 5: Opt-coupler Feedback control circuit

Operational Principle (Circuit Diagram)

The pulse-width modulator IC (IC1) generates the 50HZ alternate pulses needed to drive the MOSFETS transistors (M1-M6) through op-amp A, B and R1- R4. Diode D1, R5 and C1 are connected to aid soft start which helps to delay the output ac voltage at turn ON. At a build-up frequency of 50Hz, the AC voltage is permitted to flow through the MOSFETS transistors, while R6, VR1 and C2 set the output frequency of IC1. R7 and R8 are used to set a reference voltage of 2.5V for pulse-width modulation control through pin 2 of IC1. This reference is constantly compared with the voltage at pin 1 from the opt-coupler (IC2) to determine the trend of the pulse-width variation.

MOSFETS M1 to M6 makes up the power drivers. The alternate pulse output from IC1 is fed to MOSFETS M1 to M6 which switches the DC voltage at the primary winding of transformer T2. The primary winding transformer serves as the step-up transformer, to create the alternating voltage (AC) effect and flux change needed for transformation by the transformer. The transformer then steps-up the converted 12V AC from IC1 to 230V AC.

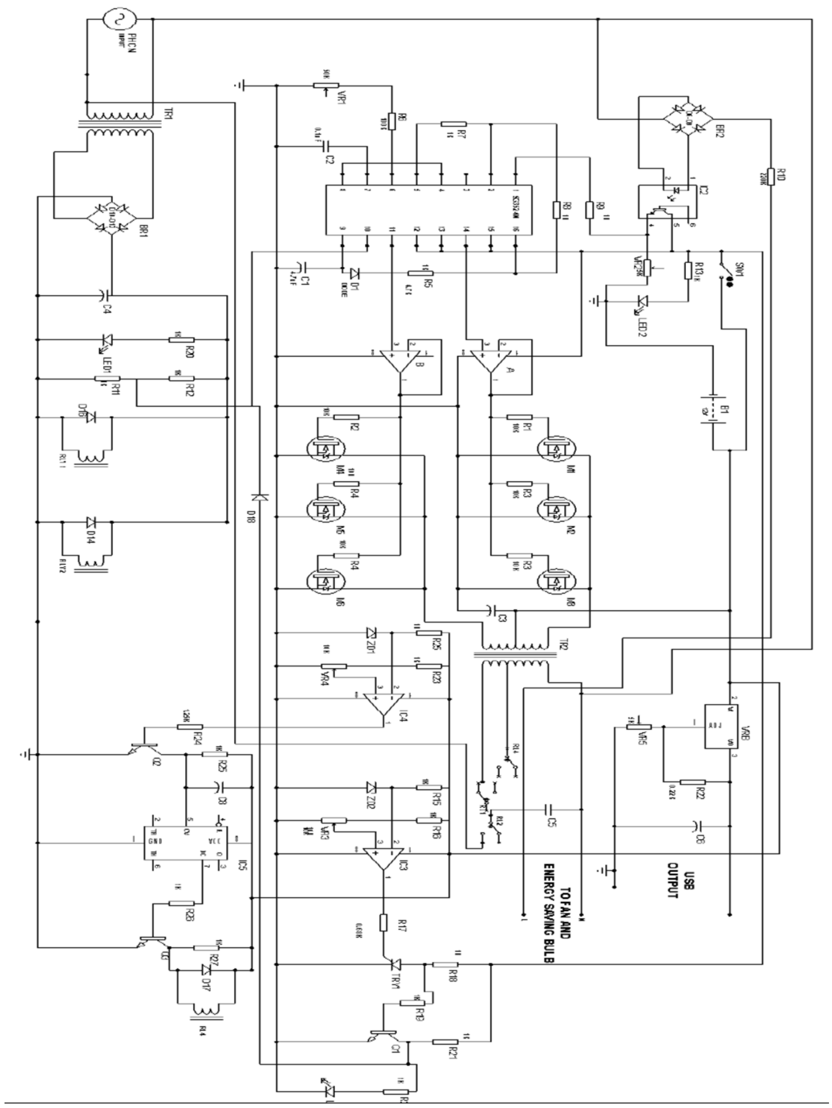
Opt-coupler IC2, bridge rectifier D6 –D9, R9 and VR2 make up the feedback network. Resistor VR2 functions as adjustment device for effective control of error voltage. The source of the feedback voltage is taken directly from the 230AC output voltage through a resistor R10. When the output voltage increases, the current in a resistor R10 increases and this causes increase in output from R9. The change is detected by IC1 through pin1 and the consequence of it is that the pulse-width of the pulses generated is gradually reduced in proportion to the change.

This is in order for the output voltage that was initially high to begin dropping to the nominal value and vice-versa. The other stages are the supervisory stage. They consist of the low battery charge detection and switch/changeover stage. The supervisory stage is design with a comparator circuit using an operational amplifier to constantly compare and check the different level of the battery voltage before changing over to shut down mode or to stops the battery from overcharging when the battery is in charging mode. IC1 is instantly shutdown by cutting off power to it by relay RLY-1 switching contact. LED1 comes on to indicate mains supply while LED2 indicate inversion.

The shutdown of IC1 stops inversion process through pin 10 of IC1 from resistors R11 and R12. The power flow from the grid is passed through a step down transformer T1 (230v–12v), rectified and filtered by diode D10-D13 and capacitor C4. R11 and R12 acts as a divider circuit which helps to stop inversion process when powered by the national grid while relay RL1and RL2 switches the circuit from inverting mode to charging mode. This inversion stoppage enables the transformer to now function as a step-down transformer (T2), stepping down 230V from mains to 12V AC which is then rectified to DC by MOSFETS M1 to M6 which will now serve as diodes and a filter capacitor C3 to charge-up the battery.

The next supervisory circuit is the low battery charge detector. IC3 is a comparator that detects the low battery charge of 10V by comparing a sampled d.c charge voltage from the battery through R15, R16, VR3, and a reference voltage set by zener diode ZD2. When the low charge limit is reached (which is at 10V), the comparator output goes positive to activate the SCR transistor (TRY1) to shut down the inversion process of the SG3524 output through transistor Q1, R18, R19, R21, R23 and LED3.
IC4 is used to stop the battery from overcharging, during charging process using R13, R14, VR3, and a reference voltage set by zener diode ZD1. It sends an output voltage to IC5 through transistor Q2, R24, R25 and C8 to trigger IC5 (bi-stable mode of 555timer IC5) to activate relay RL4 through transistor Q3, R26, R27 and D17 to stop the charging process by stopping mains (PHCN) from entering transformer T2 which acts as a step down to charge the battery. Capacitor C5 acts as a filter to reduce harmonics at the output voltage. VRB is a variable voltage regulator use to vary 12volts DC from the battery using VR5, R22 and C6 to a 5volts output USB port to charge mobile phones.

Figure 6: Circuit diagram of the inverter



CONSTRUCTION AND TESTING

The Circuit

Hard-ware simulation (Bread boarding) of the circuit was done first on a bread board as it was essential to confirm its suitability before permanent soldering on the vero-board. All ICs components were neatly soldered and continuity test carried. Condemned or unwanted copper strips along the Vero-board were neatly scrapped off to avoid short-circuits after which indicators, voltmeters and LED were connected. The circuit and MOSFETS were properly connected to the battery terminals using looped jumper cables. All the MOSFETs were screwed down to heat sinks for effective heat dissipation.

The Casing

The complete unit is housed by a metallic casing with the battery terminals for positive and negative, power switch, handle and output voltmeter neatly connected and placed in their allotted space and slots. The casing IS earthed and the components carefully laid out. The diagram of the casing is shown below:

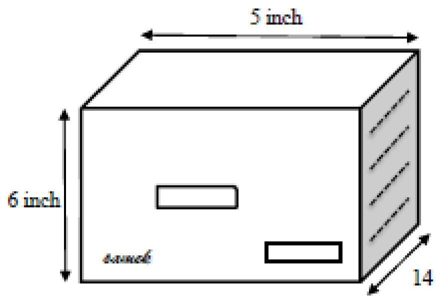


Figure 7: A diagram showing the constructed inverter casing

TESTING

The inverter unit testing was carried to ascertain its workability, and results presented as shown in the table below. Testing was achieved by connecting a voltmeter to its output for load and no load conditions. A 60W incandescent light bulb was used as the load.

Table 1: Table showing test result

NON LOAD TEST		LOAD TEST RESULT		
Output(V)	**Amps(A) Drained**	**Watts**	**Output (V)**	**Amps(A) Drained**
0.00	0.0	60	230	5.31
50	0.03	60	225	5.23
100	0.11	60	220	5.15
150	0.35	60	210	5.05
200	0.52			
220	0.71			

OBSERVATION

The key objective of designing, constructing and analyzing a 1KVA inverter outputting 230v at 50Hz was successful. However, it was observed that visible and audible effects of the odd harmonics signal including; noise, non-sinusoidal output waveform and copper loss lead to heating. The USB port outputted between 5V and 5.5V when observed with a digital meter.

RECOMMENDATIONS

On critical considerations to harness the problem of overheating, I2R losses, noise and non-sinusoidal output waveform which are caused by harmonic nuisance, the following recommendations are made;

- To reduce or eliminate noise pollution, the application of the inverter output waveform should be restricted to non-inductive loads.
- To mitigate the challenge of overheating, it should be ensured that the inbuilt fan is always operational when the unit is on load.
- A compatible filter network should be designed and constructed to act as an interface between the inverter output and the load. This will attenuate odd order harmonic components.

REFERENCES

Amos, S. W., & James, M. (1981). *Principles of transistor circuit.* Hartnolls Ltd.

Banerjee, R. (2015). Advancement of Inverter Technology for Industrial Application. *International Journal of Engineering Research & Technology*.

Brindley, K. (2005). *Starting Electronics.* Newnes 3rd Edition.

Civic Solar. (2015, August 18). Retrieved from www.civicsolar.com: www.civicsolar.com/resource/pure-sine-vs-modified-sine-wave-inverters

Doucet, J., Eggleston, D., & Shaw, J. (2007). *DC/AC Pure Sine Wave Inverter.* Worcester: Worcester Polytechnic Institute.

Forrest, M. (1986). *Engineer's Mini Notebook Volume 1, Amp and Optoelectronics Circuit and Project.* Master Publishing.

Omitola, O. O., Olatinwo, S. O., & Oyedare, T. R. (2014). Design and Construction of 1KW (1000VA) Power Inverter. *Innovative Systems Design and Engineering*.

Owen, E. L. (1996). History [origin of the inverter]. *IEEE Industry Applications Magazine*, 64-66. Retrieved fromhttp://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=476602&isnumber=10203

Sandra, S. A., & Smith, K. C. (2005). *Microelectronic Circuits.* Oxford: Oxford University Press.

Somefun, O. A. (2015). *The Erratic Electric Power Supply in Nigeria: Causes and Remedy.* Akure: Federal University of Technology.