Vol. 1, Iss. 2 (2024) 71-84, DOI: 10.61552/JMES.2024.03.001

JMES

Journal of Management and Engineering Sciences

www.jmes.aspur.rs

Design and Construction of a 1.7 kVA Pure Sine Wave Inverter using Pulse width Modulation Technique

Nnamdi Ahuchaogu[a], Ezekiel Nnamere Aneke[a,*]

[a] *Abia State University, Uturu, Nigeria.*

Keywords:

Inverter
MOSFET
Solar
Clean Energy

* Corresponding author:

Ezekiel Nnamere Aneke
E-mail:
eng.ezekiel.aneke@ieee.org

Received: 17.03.2024.
Revised: 28.05.2024.
Accepted: 18.06.2024.

A B S T R A C T

This project is targeted on the design and construction of 1.7 kVA pure sine wave following the high demand of constant and pure electricity sources for consumer homes or small commercial. The inverter ensures clean pure solar energy is converted from DC sources to AC voltages that can be used in consumer devices. The methodology that was adopted to achieve this project construction is the pulse-width modulation technique, which ensures that DC signals is fed to a MOSFET driver circuit which then produces AC signals. This current is then stepped up by a transformer to produce the desired 220 volts AC output voltage. The transformer we used also ensures that the inverter system can take up a load of 1.7 kVA. We found out that most inverters in the market produce a modified sine wave signal, therefore we used capacitor filters to ensure we obtain a clean pure sine wave as our output. We recommend that consideration should be made to the load being used for the inverter to ensure it doesn't exceed its capacity. Also, an improved IC and MOSFET system can be used to obtain smother AC results. The aims and objectives of this project were all achieved at the conclusion of the project.

1. INTRODUCTION

1.1 Background of Study

It is required of generating and transmitting stations to supply continuous, uninterruptible power to appliances and sundry usage. But many a times even in developed countries where this is achievable the need of basic inverter still finds its usage. An inverter allows the use of 220v electrical appliances from a car battery or a solar battery. It must therefore supply a voltage that corresponds to an RMS of 230 V sine wave like the household supply or similar. Sine -wave voltages are not easy to generate. The advantage of sine-wave voltages is to soft temporal rise in voltage and the absence of higher-frequency oscillation portions, which cause unwanted counter forces on engines, interferences on radio equipment and surge currents on condensers. On the other hand, very simply switches e.g. electronic valves like MOSFET transistors can generate square-wave voltage. The efficiency of a square wave inverter is higher than that of appropriate sine-wave inverter due to its simplicity. With the help of a transformer the generated square wave voltage can be transformed to a value of 230 V or even higher as in the case of radio transmitter.

One of the fundamental challenges to face in generating square wave voltage is the ability to obtain a perfect upper and lower threshold value of the duty cycle. This must be adequately looked into in order to obtain square wave signal that is free of chatter effect. Of course, chatter effect will lead to lose of useful voltage and this may be of great influence after amplification stages. Also, the higher Percentage of the duty cycle obtained the better, this is of great important because the output transistor is either on or off, not partially on as with normal regulation, so less power is wasted as heat and smaller heat-sinks can be used. The present-day electronic circuit uses appropriate pulse width modulation (PWM) circuitry to generate the pulse-wave voltage.

This project emphasis on DC to AC power inverters aimed at inexpensively transforming a DC power source into a high voltage AC output comparable to a power that would be accessible at an electrical wall outlet. Inverters are used for many applications as in circumstances where low voltage DC sources such as batteries, solar panels or fuel cells must be converted, so that devices can run off of AC power. A perfect example is the converting of electrical power in a battery to run a laptop, TV set or a cell phone.

Low voltage DC conversion is completed in two stages. The first being the conversion of the low voltage DC power to a high voltage DC source and consequently converting the high voltage DC source to an AC wave form using pulse-width modulation (PWM). Another method of completing the desired outcome would be to first convert a low voltage DC power to AC and then using a transformer to boost the voltage to 240V. This project concentrated on the second method described and specifically transforming a low DC source into an AC output.

They are different DC to AC inverters in the market today, but basically, we have two different forms of DC output generated; modified and pure sine wave. A modified sine wave can be seen as more of square wave than a sine wave; it passes the high voltage DC for specified amount of time so that the average output power and Root Mean Square (RMS) voltage are the same as if it were a sine wave. These types of inverters are much cheaper than pure sine wave inverters and therefore are attractive alternatives. Pure sine wave inverters on the other hand produce a sine wave output identical to the power coming out of an electrical outlet. These devices are able to run more sensitive devices such as laser printers, laptop, computers, digital clocks and medical equipment. The AC power of pure sine wave inverters also reduces audible noise in fluorescent lights and can be used to run inductive loads such as motors, faster and quieter due to their low content of harmonic distortion. Electrical machines or gadgets are made with some certain specifications or standards.

In addition, power inverter is an electrical appliance that can be used with DC source as an alternative source of energy supply in the event of power failures and energy crisis. It is cheap, clean, very contusive and silent when in operation and a very reliable source of power supply as to generator. Modern research and technologies have shown that inverter is one of the cheapest forms of energy generation. Throughout the world, it is readily available and can be partner to solar energy particularly using photo-voltaic cells (PVC) with a battery bank as a reservoir to collect and store solar energy in large scale power generation/production for rural and very remote areas' electrification project in the Nation. Sine wave, modified sine wave and square wave.

Most domestic appliances such as personal computers, television sets and lighting systems among others, operation has largely been controlled by hydro-electric power supply (National Grid). This is not much a reliable source of energy due to the persistent power failure from our only reliable Nation Grid in the country, which has been the result of low water level in the dam(s) during harmattan seasons, faulty underground cables and transformer failures. Especially, the 2012, 2015 and the current energy crisis and such experiences are seriously estimated worldwide in the near forthcoming as a result of unfavorable climatic change. This development therefore seeks to use inverter with DC source as an alternative source of energy supply in the wake up of these challenges to power household appliances.

Moreover, the standards are safety precaution governing the using of the appliances, for constant operation and safety of electronics and electrical appliances, inverters are introduced into or attached to appliances to store power to supply the appliances, since power supply can cause appliances like computer, TV set, refrigerators and many other electrical appliances to burn out or spoil beyond repairs. The DC/AC power inverter which is an electronic appliance that store power is designed to power some selected domestic appliances at the output even if its input power is not stable makes it possible for electrical and electronics appliances to be protected in areas where there is power crisis. Also, inverters uninterruptible power supplies, one of the examples of DC/AC power inverters are also used to protect and store power for appliances and thus are dependable in appliances protection by not losing files or programs.

1.2 Statement of Problem

In the market and application of power inverters, there are many choices. These range from the very expensive to the least expensive with varying degrees of quality, efficiency and power output capabilities. High quality combined with high efficiency exists thought is often at a high monetary cost. Our goal is to fill a place which seems to be lacking in the power inverter market and applications one for a fairly efficient, inexpensive inverter with a pure sine wave output aimed at powering domestic appliances in the event of power outages and energy crisis. Utilizing analogue components to achieve a clean sinusoid output with very little switching noise shared with the low-priced manufacturing that comes with an analogue method.

1.3 Aim and Objectives of the Project

The aim of the project is to design and construct a low-cost inverter with high efficiency and quality output capabilities to power some selected domestic appliances such as computers, television sets and lighting systems.

The objectives of the project include the following:

- To design a 1.7 kVA transformer using the maximum flux density, window dimension, coil disposition and winding calculation parameters.
- To construct a 1.7 kVA pure sine wave inverter, using the pulse width modulation technique.
- To test the constructed inverter for validation by running the inverter on load for a given period of time and observing its performance.

1.4 Significance of the Project

The key importance of this study is to use low DC source to give out a high output AC power. Also, the inverter is cheap, reliable and portable. In addition, it used low power electronic switching devices to give out a desirable high AC power.

1.5 Scope of the Project

This project work covers the design and simulation of a 1.7 kVA pure sine-wave power inverter that can power the loads that are within its capacity. It is designed to serve majorly as a supplement to the mains power supply and is therefore not meant to serve as a permanent independent stand-alone power supply. The design is capable of automatically switching to mains or inverter mode when appropriate and features all forms of protection techniques/schemes to guard the system and the connected appliances against any form of danger that may arise during operation. The design does not accommodate a high-power surge beyond its stated capacity and hence cannot be used to power high inductive loads like industrial electric motors and high-power air conditioners. It can be used to power very sensitive and life dependent devices/equipment like medical equipment and servers because of the near absence of harmonic content in the final power output of the design.

1.6 Limitations of the Project

- Cost of the components especially the transformer and the micro-controller.
- Time duration of the project.
- Unreliability of power supply.
- The scarcity of some of the components.

2. LITERATURE REVIEW

2.1 Theory of the Literature

In the world today, there are currently two types of current, namely direct current (DC) and alternating current (AC), each with its own advantages and disadvantages. DC power is simply the application of a steady constant voltage across a circuit resulting in a constant current. A battery is the most common source of DC transmission as current flows from one end of a circuit to the other. Most digital circuitry today is run off DC power as it carries the ability to provide either a constant high or constant low voltage, enabling digital logic to process code executions. Historically, electricity was first commercially transmitted by Thomas Edison, and was a DC power line. However, this electricity was low voltage, due to the inability to step up DC voltage at the time, and thus it was not capable of transmitting power over long distances.

$$V=IR \tag{1}$$

$$P=IV \tag{2}$$

$$P=I^2R \tag{3}$$

As can be seen in the equations above, power loss can be derived from the electrical current squared and the resistance of a transmission line. When the voltage is increased, the current decreases and concurrently the power loss decreases exponentially; therefore, high voltage transmission reduces power loss. For this reasoning electricity was generated at power stations and delivered to homes and businesses through AC power. Alternating current, unlike DC, oscillates between two voltage values at a specified frequency, and it‘s ever changing current and voltage makes it easy to step up or down the voltage.

For high voltage and long-distance transmission situations all that is needed to step-up or step-down the voltage is a transformer. Developed in 1886 by William Stanley Jr, the transformer made long distance electrical transmission using AC power. Electrical transmission has therefore been mainly based upon AC power, supplying most homes with a 240 volt AC source. It should be noted that since 1954 there have been many high voltage DC transmission systems implemented around the globe with the advent of DC/AC enviers, allowing the easy stepping up and down of DC voltage. Like DC power, there exist many devices such as power tools, radios and TV's that run off of AC power. It is therefore crucial that both forms of electricity transmission exist; the world cannot be powered with one simple form. It then becomes a vital matter for there to exist easy ways to transform DA to AC power and vice versa in an efficient manner. Without this ability people will be restricted to what electronic devices they use depending on the electricity source available. Inversion is the conversion of de power to AC power at a desired output voltage or current and frequency.

A static semiconductor inverter circuit performs this electrical energy inverting transformation. The terms voltage-fed and current-fed are used in connection with the output from inverter circuits. A voltage-source inverter (VSI) is one in which the DC input voltage is essentially constant and independent of the load current drawn. The inverter specifies the load voltage while the drawn current shape is dictated by the load. A current-source inverter (CSI) is one in which the source, hence the load current is predetermined and load impedance determines the output voltage. The supply current cannot change quickly. This current is controlled by series de supply inductance which prevents sudden changes in current. The load current magnitude is controlled by varying the input DC voltage to the large inductance; hence inverter response to load changes is slow. Being a current source, the inverter can survive an output short circuit thereby offering fault ride-through properties. Voltage control may be required to maintain a fixed output voltage when the DC input voltage regulation is poor, or to control power to a load.

The inverter and its output can be single-phase, three-phase or multi-phase. Variable output frequency may be required for AC motor speed control where, in conjunction with voltage or current control, constant motor flux can be maintained. Inverter output waveforms (either voltage or current) are usually rectilinear in nature and as such contain harmonics which may lead to reduced load efficiency and performance. Load harmonic reduction can be achieved by either filtering, selected harmonic-reduction chopping or pulse-width modulation.

2.2 Review of related work

Omotosho et al [1] published a research at the journal of informatics and mathematical sciences on the design and implementation of a sine wave inverter circuit developed to run AC appliances at a low cost with high efficiency. The design consisted of two stages i.e. the DC-DC step up stage and a DC-AC inverter stage. The DC-DC step up converter is based on a push-pull design to step 24 VDC to 300 VDC. Pulse width modulation was used i.e. the sg3525 pulse width modulator. The DC-AC inverter stage comprised of four power mosfets (metal oxide semiconductor field emitter transistor) in an h-bridge configuration, driven by a 40 kHz square wave encoded/modulated by a 50 Hz sine wave that was derived from a tl084 quad op amp sine wave oscillator. An output voltage range of about 240-260 VAC from 300 VDC input was obtained. A low pass filter was used to filter out the high frequencies and thus isolate the harmonics so a 50 Hz fundamental frequency was retained

Davidson et al. [2] conducted a research on a smart inverter with the ability to automatically regulate incoming voltage. This was developed using microcontroller with the oscillating circuit that generates a sinusoidal pulse width modulation (SPWM) signal which is safe for home appliances. Combination of electromechanical relays with voltage sensing circuit produces automatic voltage regulation that enables the system switch to appropriate output voltage. Avr circuit is integrated into the inverter circuit to regulate supply and conserve energy in the power bank for efficient usage. The system also incorporates arduino based switching system comprising of the circuit and control applications. The smart switching module utilizes the arduino uno microcontroller for remote switching of over the internet with capability to select a power source for an outlet (whether battery or mains), and also keep an outlet switched on for a user set length of time per day.

Ahmed and Khan [3] conducted a research on the design of a microcontroller based pure sine wave single phase inverter. The system has an output of 220 V and 50 Hz. The sinusoidal pulse width modulation technique has been used for the design. The circuit is simulated in proteus to ensure the output results are verified practically. The experimental result shows a good argument with the simulation data. The inverter has fewer harmonics, is simpler to design compared to the traditional inverter technology. The designed inverter is tested on various AC loads and is essentially focused upon low power applications

Also, Ghalib et al. [4] published a research they conducted aimed at developing the control circuit for a single phase inverter which produces a pure sine wave with an output voltage that has the same magnitude and frequency as a grid voltage. A microcontroller, based on an advanced technology to generate a sine wave with fewer harmonics, less cost and a simpler design. The technique used is the sinusoidal pulse width modulation signal (SPWM) which is generated by microcontroller. The designed inverter is tested on various AC loads and is essentially focused upon low power electronic applications such as a lamp, a fan and chargers etc. The proposed model of the inverter can improve the output wave forms of the inverter and the dead time control reduced to 63µs. The finished design is simulated in proteus and psim software to ensure output results which is verified practically.

Furthermore, Ronilaya et al [5] conducted a research on the implementation of arduino nano microcontroller for a single-phase pure sine wave inverter. This paper presents the implementation of arduino nano microcontroller for a single-phase pure sine wave inverter, which can convert DC voltage to AC voltage at high efficiency and low cost. Solar-powered electricity generation is being favored nowadays as the world increasingly focuses on environmental concerns. The designed inverter converted DC voltage into AC voltage for a small-scale off-grid solar pv system suitable for electrification in remote areas, pollution-free, and inexpensive. Its inverter uses a sinusoidal pulse width modulation technique and a simple circuit, consisting of only 2 mosfet switches and 1 mosfet driver. The h-bridge inverter's output is applied to a step-up transformer with a dual coil input and a single-coil output, and hence, we can create positive and negative sides of the wave. Mitigate a voltage noise; a capacitor is installed in parallel at the secondary side of the transformer. Several simulations are performed to verify the effectiveness of the designed inverter using proteus software, and continued hardware implementation. Based on some experiments we have done; the designed inverter produces a 230 vrms, 50 Hz sine wave with very low harmonics distortion. The highest efficiency was obtained using 2200 nf / 400 V of the filter capacitor, and the smallest voltage regulation gained using 2200 nf / 400 V of the filter capacitor when compared with other capacitors. The proposed system is economical, efficient, and reliable and can be used for small scale power applications.

Alhamrouni et al [6] conducted a research on design of single phase inverter for photovoltaic application controlled with sinusoidal pulse width modulation. They stated that the application of fossil fuels likes coal, oil and gas gives the enormous environmental impact and hazardous effects to the earth. Hence, renewable energy has become the most tremendously friendly methods to generate the electricity without pollution and emissions. Inverter is a power electronics device which is used to convert direct current (DC) into alternating current (AC). The conventional inverter no longer fulfills the requirement of reducing harmonic distortions plus it causes global warming and greenhouse effect. For increasing the efficiency and reliability of the system, the pv inverter becomes a vital part in the conversion of DC to AC output. This research thus presents a single-phase photovoltaic inverter controlled with sinusoidal pulse-width modulation (SPWM) and low pass filter connection between the inverter and the utility grid to reduce the harmonics due to intermittent nature of the renewable energy sources. Unipolar and bipolar switching scheme are applied to control the magnitude and frequency of output voltage and result of both unipolar and bipolar are compared

2.3 Summary of the review

Having reviewed the previous works done by others in this field, the design and construction of a pure sine wave inverter can be achieved following the implementation of the simulation of the inverter circuit done in Matlab Simulink. The implementation to obtain a pure sine wave was obtained using the pulse width modulation technique (PWM). However, we noticed a few problems common in their constructions, and they were discussed and corrected in the study gap.

2.3 Study gap

In spite of previous research done on this pure sine wave inverter, found that most of the results of their research and construction still produced a humming sound when the inverter was put to use. This was because the form of alternating current produced by the inverter wasn't very pure. This also caused heat to be generated by the inverter, thus making it less efficient to be used especially for very sensitive devices. These problems were solved in this project work using the pulse width modulation technique (PWM technique).

3. MATERIALS AND METHOD

3.1 Materials

These are the materials used in the design and construction of a single phase 1.7 kVA pure sine wave inverter. The following materials were used in the design and construction of the inverter.

- Micro controller: The microcontroller is the main and integral part of an inverter. The main working of microcontroller is to control the switching of signals according to the requirements.
- Bipolar junction transistors (BJTs): BJT or a bipolar junction transistor is a three layered device which is capable of controlling the current flow. In a BJT, a small current at the input of the device can control larger currents at the output.
- H-Bridge: H –bridge is a topology in which four switching devices BJTs, MOSFETs or IGBTs are integrated together in a single circuit. The name H-Bridge is given to it because of the typical arrangement of this circuit.
- MOSFETs: The Metal-Oxide-Semiconductor-Field-Effect-Transistor (MOSFET) is a voltage controlled device and requires a very small input current. It is mainly used for switching of electronic signals as its switching speed is very high. It is the most commonly used FET in low-power high-frequency circuits. The MOSFET is composed of a channel of n-type or p-type semiconductor material, and is accordingly called an N-MOSFET or a P-MOSFET.
- Low-Pass Filters: A low-pass filter is a circuit offering easy passage to low-frequency signals and difficult passage to high-

frequency signals. There are two (2) kinds of filters; LC Filters and LC Filter over RC Filter.

- Auto-Transformer: The auto transformer is used to step up or step down alternating current in the inverter as load demands, or as required by the inverting circuit.
- Connecting Cables: The connecting cable interconnects the solar power inverter to the protection equipment and the electricity grid.

3.2 Method

The technique used in the design and construction of a 1.7 kVA pure sine wave inverter is the Pulse-Width Modulation (PWM) Technique.

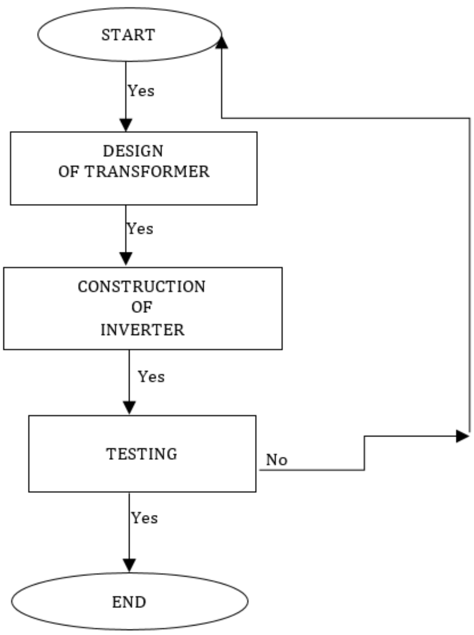

Fig. 1 Work Flow Chart.

3.2.1. Pulse-width modulation (PWM) technique

Pulse width modulation (PWM) is a modulation technique that generates variable-width pulses to represent the amplitude of an analog input signal. The output switching transistor is on more of the time for a high-amplitude signal and off more of the time for a low-amplitude signal. The digital nature (fully on or off) of the PWM circuit is less costly to fabricate than an analog circuit that does not drift over time. PWM is widely used in ROV applications to control the speed of a DC motor and/or the brightness of a lightbulb. For example, if the line were closed for 1 µs, opened for 1 µs, and continuously repeated, the target would receive an average of 50% of the voltage and run at half speed or the bulb at half brightness. If the line were closed for 1 µs and open for 3 µs, the target would receive an average of 25%.

There are other methods by which analog signals are modulated for motor control, but OCROV and MSROV systems predominate with the PWM mode due to cost and simplicity of design.

3.2.2. Pulse-width modulation (PWM) oscillator

To generate the required frequency 50Hz, an oscillator is used (a stable multivibrator IC SG3524, a dedicated pulse width modulator). The oscillator circuit is shown in Fig. 2. It is also known as “free-running relaxation oscillator” and it has no stable state, but two half-stable states between which it keeps oscillating continuously on its own without any external excitation [7]. This versatile PWM controller can be used in a variety of isolated and non-isolated switching power supplies such as inverters. By supplying a constant 12 Volt DC through a voltage regulator to the IC SG3524 PWM, the frequency of the oscillating signal was determined using R_3, comprising a 20 kΩ variable resistor, connected in series with a 56 kΩ resistor and both connected in parallel with a capacitor C_2 (0.22 µF) to form the RC time constant network.

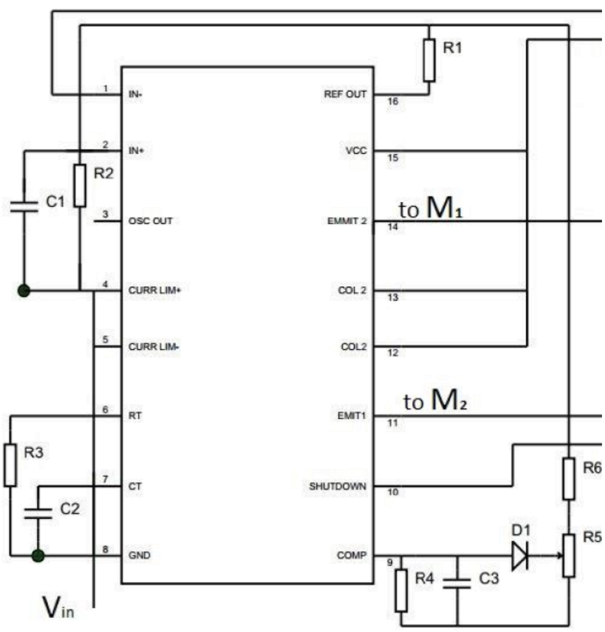

Fig 2. SG3524 PWM IC pin configuration.

Calculation of Component Values

Choosing: Frequency of Oscillation = 50Hz, and Timer Capacitor (C_2) = 0.22μF. Timer resistor R_3 can be estimated using the relationship:

$$R_3 = \frac{1.15}{2 \cdot FC_2} = 57.5 \text{ k}\Omega$$

Input voltage Vin for the pulse width modulator is taken from the battery source (24 V DC). The chip is powered with 9V through a 7809 voltage regulator. Pin 16 is connected to an internal +5V regulator and it was used to set the voltage reference of 2.5 V for the pulse-width control through voltage divider resistors to pin 1. R_1 (5kΩ and R_2 (4.7kΩ were used as the closest available value and connected to form a voltage divider, C_1 (47μF) was connected for stability. Pin 1 was used as the feedback control input from the opto-coupler stage. C_2 and R_3 were used for compensation to cancel a pole at frequency f = 200Hz, as recommended by the data sheet for stability. C_2 is chosen as 100 nF and R_3 is calculated. Hence R_3 = 50000Ω. A value of 47kΩ was used as the closest available standard. A voltage divider comprising resistors R_4 (fixed resistor) and R_5 (variable resistor) forms a voltage divider to aid manual pulse width variation through compensation pin 9. Given reference voltage: V_{in} = 5 V and taking R_4 = 4.7kΩ, V_0 = 3.4V.

$$V_0 = \left(\frac{R_5}{R_4 + R_5}\right) V_{in}$$

$$R_5 = \left(\frac{V_0}{V_{in} + V_0}\right) R_4, R_5 \approx 10\text{k}\Omega$$

Diode D_2 is a diode type is as diode type IN4004 was and a voltage reference set by a Zener diode connected to prevent R_4 and R_5 from affecting and a passive delay circuit. LM358 op-amp was compensation by R_3 and C_2.

3.3 Design of 1.7 KVA Transformer

Design Specification

The circuit design incorporates several circuits and their collective specifications are:

- Power rating: 1.7 kVA,
- Frequency: 50 Hz,
- Number of Phases: Single,
- Input Voltage: 24 V DC (Inverter), 220 V AC (Mains),
- Output Voltage: 220 V AC,
- Circuit Supervisory Indicators: Low battery Charge, Inversion, Mains supply,
- Energy sources: Deep cycle rechargeable batteries.

3.3.1. Design of Transformer

The transformer design involves the core, and coil design. The transformer is a single-phase step-up transformer of 1.7 kVA, 24 V 0-24 V, at the primary winding and 220V at the secondary winding, air cooled, Frequency f = 50Hz, Maximum flux density Bm = 1.5 T, Constant of proportionality K = 0.35 (to ensure turn per voltage is not too high and give room for allowable tolerance) and, Current density J = 3.0 A/mm^2.

Design of Core

Voltage per turn:

$$E_t = K \cdot \sqrt{S} \text{ kVA} = 0.35 \cdot \sqrt{1.7} = 0.4563$$

Net Core Area:

$$A_i = \frac{E_t}{4.44 \cdot f \cdot B_m} = \frac{0.4563}{4.44 \cdot 50 \cdot 1.5} = 152 \text{ mm}^2$$

Magnetic Flux:

$$(\emptyset) = B_m \cdot A_i \cdot b = 1.5 \cdot 152 \cdot 10^{-6} = 0.28 \cdot 10^{-3} \text{ Wb}$$

Window space factor:

$$K_w = 0.1 + 0.07 \cdot \log_{10} \frac{kVA}{0.1} - 0.2 \; kVA = 0.31763$$

Window Area:

$$A_w = \frac{S}{2.22 \cdot f \cdot B_m \cdot A_i \cdot K_w \cdot J \cdot 10^{-3}} = 241.2 \text{ mm}^2$$

Window dimension is given by: L·W, where L= 3·W window length, and W = window width.

$$W = \sqrt{\frac{A_w}{3}} = \sqrt{80.4} = 8.967 \text{ mm}$$

Gross core cross sectional area:

$$A_g = \frac{A_i}{\text{Stacking factor}} = \frac{152}{0.9} = 168.9 \text{ mm}^2$$

Stack height:

$$\text{Stack height} = \frac{A_g}{\text{Width of sentral limb}} = \frac{168.9}{8.967} = 18.83 \text{ mm}^2$$

Lamination pieces:

$$\text{Lamination pieces} = \frac{\text{Stack height}}{\text{Lamination thickness}} = \frac{18.83}{0.5} = 38$$

Design of Coil

Number of turns:

Primary turns N = V_1/ E_t = 24 / 0.4563 = 53 turns.

Secondary turns N = V_2/ E_t = 220 / 0.4563 = 483 turns.

where primary voltage V_1 =24 V, and secondary voltage V_2)= 220 V.

Since the winding is wound twice on the primary side for both halves of the switching period, the total primary winding will be N_1= 2·53 = 106 turns. Total number of turns = 106 + 483 = 589 turns.

Winding calculations:

Primary Current = kVA rating / input voltage = 1700 / 24=70.83A

Secondary Current = kVA rating / input voltage 1700 / 220= 7.73A

Conductor size:
Conductor cross sectional area for the primary winding:

A_1 = I / J = 70.83 / 3 = 23.61 mm^2

d_1= = 5.5317 mm^2 (gauge 18)

Conductor cross sectional area for the secondary winding:

A_2 = I / J = 7.73 / 3 = 2.577 mm^2

d_2 = 1.8114 mm^2 (gauge 10)

Winding height:
The height occupied by the winding coils is approximately 5% less than Window length = 0.95,·L = 0.95·91.14= 86.587 mm, Approx. = 87 mm
Turns/layer = Winding height / Diameter of conductor. For secondary = 87 / 1.8114= 48 turns/layer.
Total number of layers = Number of turns / Turns per layer. Number of layers in primary = 170 / 48 = 4 layers. Number of layers in secondary = 38 / 15= 3 layers.
Mean Length of Turn = 2·(width of central limb + stack height + window width) = 2·(54 + 86 + 30.38) = 340.76 mm, Approx. = 341 mm.

Total Length of Winding T_L = mean Length of turns·total number of turns. For primary L_1 = 340.76·38 = 12948.88 mm. For secondary turns L_2 = 340.76·170= 57929.2 mm. Total length = L_1 + L_2 = 57929.2 + 12948.88 = 70878.08 mm

Winding parameter calculation

The pulse generator block (sampling frequency) with negative bias voltage gives the bidirectional 50 % duty cycled square waveform. It is converted into triangular signal by an integrator. The amplitude of this triangular waveform is amplified by a gain block. The sine wave with 50 Hz frequency is derived from signal generator block. This sine wave is subtracted from triangular wave and result is compared with zero. If result is less than or equal to zero then output of comparator block is set to one otherwise zero. Thus SPWM is generated. This SPWM is splitted into two separate 180 degree out of phase waveforms with a NOT and AND gates phase splitter circuit. This drives the MOSFETs (ideal switches) connected to the primary terminals of center tapped transformer (12V to 230V step up mode 600VA) alternately biased by Battery voltage (Vb). The secondary of transformer is coupled to an LC filter and load. The voltage feedback is derived from the rectifier and attenuator circuit. The error is generated by comparing this fed back DC voltage with set point. The result is added with sinusoidal wave. This varies the duty cycle so as to keep the output voltage constant.

3.4 Construction of 1.7 kVA pure sine wave inverter

Fig. 3 shows the complete circuit diagram of the PWM inverter circuit. IC_3 (SG3524) is the pulse-width modulator IC and its function is to generate the 50 Hz alternating pulses from pin 14 and 11, needed to drive the MOSFET banks (M_1 and M_2).

R_4 and C_3 are for compensation while R_3 and C_2 determine the frequency of oscillation. Resistors R_1 and R_2 set the reference voltage of 2.5V for pulse width modulation control, through pin 2 of the IC. This reference is constantly compared with the voltage at pin 1 from the opto-coupler to determine the trend of the pulse-width variation but it works in inverse relation, so as to balance the change in output voltage. When the output voltage tends to increase, the pulse width reduces and vice versa to keep the output voltage constant within a tolerance range.

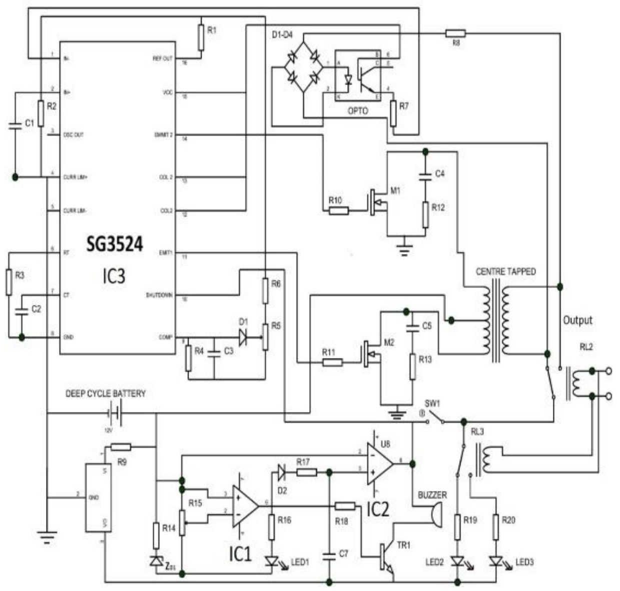

Fig. 3. Complete Circuit Diagram of the 12V, 1.5 kVA Inverter Circuit.

The MOSFET banks M_1 and M_2 make up the power drivers. The alternating pulse output from IC3 is fed to MOSFETS banks M_1 and M_2. M_1 and M_2 switch the DC voltage at the primary of center-tapped transformer T_1, which is serving as the step-up transformer to create the alternating voltage effect and flux change needed for transformation by the transformer. The transformer then would step up the now converted 12 V DC to 220 V AC. Opto-coupler, bridge rectifier D_1-D_4, R_7 and R_8 make up the feedback network. The output voltage is rectified to DC. Resistor R_8 helps to appropriately adjust the error voltage for effective control. The source of the feedback voltage is taken from the output of the auxiliary winding. When the output voltage increases, the auxiliary winding output voltage increases and this causes increase in output from R_8. This change is detected by IC_3 through pin 1 and the consequence is that the pulse-width of the pulses generated is gradually reduced in proportion to the change. This is so that the output voltage that was initially high would begin to drop to the nominal value and Vice-versa.

The supervisory stage comprises: low battery detection and switch/change over. The changeover switch is the relay. The coil of the relay serves as the mains voltage detector, as it energizes when there is mains supply. The relay controls the load (output) to mains supply whenever mains supply is restored. IC_3 is instantly shutdown by cutting off power to it by relay RLY_2 switching contact. LED_3 comes on to indicate mains supply while LED_2 indicates inversion. The shutdown of IC_3 stops inversion process. This inversion stoppage enables the transformer to now function as a step-down transformer T_2, stepping down 220 V from mains to 12 V AC which is then rectified to DC by MOSFETs M_1 and M_2 which will now serve as diodes to charge up the battery.

The next supervisory circuit is the low battery charge detector. IC_1 is a comparator (LM358) that detects the low battery charge by comparing a sampled DC charge voltage set by zener diode ZD_1. When the low voltage limit is reached, the comparator output goes positive and LED_1 comes on, to indicate low battery charge.

IC_2 (LM358), R_{17}, C_7 and D_2 form a passive delay circuit. The function is to create delay before shutdown, from the time low battery charge is detected, to when inverter shuts down. Diode D_2 prevents C_7 from discharging into IC_1. R_9 is a limiting resistor discharging into IC_1. R_9 is a limiting resistor to 7809 (a 9V IC voltage regulator) R_{14} limiting resistance to zener diode ZD_1. R_{16}, R_{19}, R_{20} are limiting resistances to LEDs. M_1 and M_2 represent separate bank of 5 MOSFETs connected in parallel to handle the load current for each side.

3.4.1. Construction of Driver Section

The MOSFET stage is shown in Fig. 4.

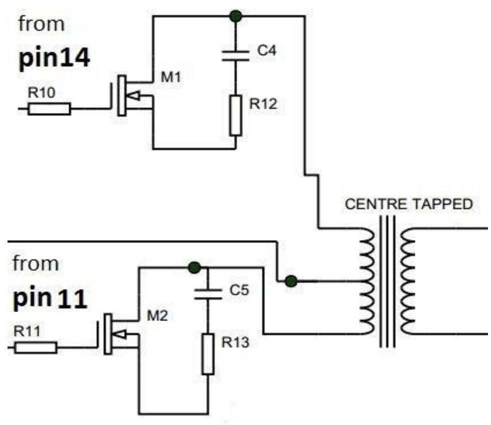

Fig. 4. MOSFET Drivers.

It conducts the load current through the center-tapped, step up transformer.

- MOSFET used in the design is IRF 150 N-Channel
- Fixed resistors of 10 kΩ were connected between the gate and source to aid fast switching by discharging any residual charge at the gate.
- A total of 12 MOSFETs were used for the design of the MOSFET driver. 6 for each half of the full period.

3.4.2. Construction of Low Battery Indicator/Shutdown

The battery status monitor circuit is designed to give a visual indication using a LED and a buzzer for audio indication of low battery condition during operation. The circuit in Fig. 5 will delay shutdown of the system after 60 seconds. The circuit consists of a comparator used for the comparator IC.

The reference voltage is determined by the zener diode Z_{D1}. Zener diode rating is:

Power rating = 300mW,

Breakdown voltage = 6.2V,

Thus $I = P / V = 300 \cdot 10^{-3} / 6.2 = 48.3$mA,

$R_{14} = V / I = 6.2 / 48.3 \cdot 10^{-3} = 128\ \Omega$.

A value of 120 Ω is chosen as the closest standard value. IC_2 and R_{17}, C_7 and D_2 form a passive delay circuit which creates a delay or time lag from the time of low battery detection, to final shutdown. Diode D_2 prevents C_7 from discharging into IC_1.
Time delay $T = 0.7\ R_{17}\ C_7$.
$T = 60$ s and $C_7 = 100$ μF, hence:

$R_{17} = 60 / 0.7 \cdot 100^{-3} = 857142\ \Omega \approx 1\ M\Omega$

The limiting value for the LED can be determined thus:

$$R_{16} = \frac{V_{cc} - V_f}{I_f}$$

Where $R_L = R_{16}$ = Limiting resistance, I_f = Forward conducting current, V_f = Forward voltage drop, Vcc = comparator output. For the LED, $V_f = 2.2$ V, $I_f = 8$ mA, $R_{17} = 850\ \Omega$ (a value of 850 was used as the closest standard) TR_1 is the buzzer driver and it is enabled whenever there is an output from IC_1 indicative of low battery condition R_8 is a base resistor R.
For a base current of 1 mA, the resisto,r where I = base current, V_{cc} = Supply Voltage. $R_{18} = 11.4$ kΩ (10 kΩ was chosen as the standard value).

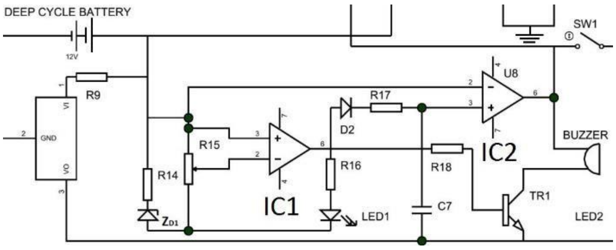

Fig. 5. Low Battery Indication and Shutdown.

3.4.3. Construction of Voltage Detection/Changeover Unit

An automatic changeover switch was designed for this work. This is shown in Fig. 6. A 220V operating relay was connected to serve as mains voltage detector and switchover.

When mains power is interrupted, this activates the relay switch contact to changeover the supply from mains to inverter mode supply. The action reverses chosen frequency since the ripple voltage will be greatest at this frequency. Since

When mains power is restored, thus providing automatic changeover action.

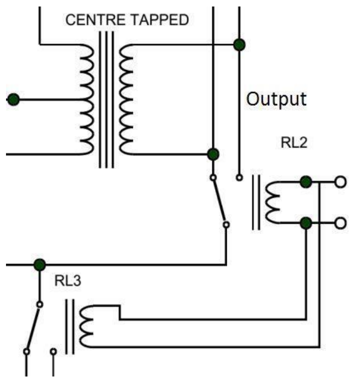

Fig. 6. Voltage Detection and Changeover Switch.

The circuit uses a half wave rectifier circuit. The MOSFET bank drain-to-source diode was used for the rectification, and has the same specification as the MOSFET. Since this is a PWM system, calculations for the value of the output filter capacitor will be done at the capacitor. Capacitor values are determined by the output current. A capacitor of 35V, 4700μF rating was used in the design, as a higher value is preferable for better ripple rejection.

3.4.4. Construction of Optocoupler Feedback Section

The voltage feedback section is made up of the optocoupler, R_{11} and R_{13}. R_{11} and R_{13} form a voltage divider and they serve to sample the output DC of the battery to IC_1 PWM that will in turn affect the pulse width modulation of drive pulses. The circuit is shown in Fig. 7. Their chosen values are 10 kΩ each. R_{13} was made variable for tuning purpose. The Optocoupler used in the design is 4N35.

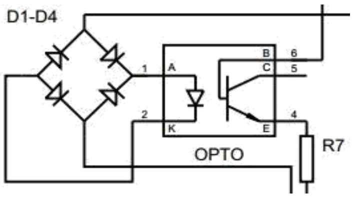

Fig. 7. Pin configuration of 4N35 Optocoupler.

The Led has a forward current of 5 mA and the photo-transistor has a maximum.

A bridge rectifier provides DC input to the LED of the optocoupler. For a conducting current of 1 mA, the limiting resistor would be:

$$R_7 = \frac{V_s - V_f}{I_f} = \frac{220\ \text{V} - 2\ \text{V}}{1\ \text{mA}} \approx 220\ \text{k}\Omega$$

For the pulse width control, pin 2 is used for the reference voltage (2 V).

3.4.4. Construction of casing

The complete unit was housed in a metallic red casing. Battery terminals for positive and negative, power switch, handle and output meter were fixed in their allotted slots and connected to their respective points on the circuit. The casing was earthed and each stages carefully arranged inside and connected together.

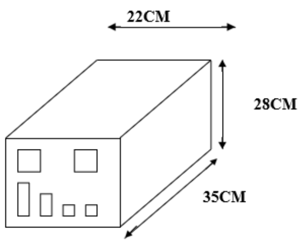

Fig. 8. Inverter Casing.

Fig. 9. Front view of the Inverter.

Fig. 10. Back view of an Inverter.

3.5 Validation of Results

While constructing, all components used were tested to ascertain their conformity with the required standard of the objective of this project. The output voltage of the inverter was a pure sine wave, filtered by a 2 µF / 400 V capacitor connected across the output terminals to remove the unwanted harmonics and leaving smooth pure sine waveform output voltage.

During the testing, two 18 A, 12 V DC cells were connected in series to the terminals of the inverter. We connected a socket extension line to the output of the inverter. A light bulb, a small fan, as well as some devices to charge were also connected to the extension line, and they all functioned properly. Without any humming sound. A multimeter tester was used to ascertain results from testing.

We plugged in the AC input of the inverter to a wall socket, to test for charging. The inverter charged the batteries properly. We ensured that the inverter while plugged in was properly earthed, all sockets or switches used were properly fused, to avoid damage due to stray currents.

$$Duration = \frac{Battery\ Voltage\ Output \times Current\ capacity}{Load\ Power\ Rating}$$

When total load = 100 W:

$$Duration = \frac{12 \times 75}{100} = 9\ hours$$

When total load = 1000 W:

$$Duration = \frac{12 \times 75}{1000} = 0.9\ hours = 54\ min.$$

Discharge Duration

Battery power rating = 24 V × 100 As= 2400 VA.

Duration when load is 500 W =2400/500= 4.8 hrs.

Duration when load is 1000 W = 2400/1000= 2.4 hrs.

4. RESULTS AND DISCUSSIONS

4.1 Inverter Testing Results

Tests were carried out to confirm that the design performed as expected. The two tests were carried out are: (1) Open circuit test/No Load Test (2) On Load test

Open Circuit Test Result

The 12 V sealed and rechargeable battery was connected to the inverter circuit. The positive terminal of the battery was connected to the centre-tapped transformer, while the negative terminal was connected to the overall ground of the inverter circuit. The inverter was switched on, and the variable resistor R5 in the control circuit was adjusted until the output voltage of 220 V was recorded

Battery power rating = 24 V, 75 Ah

Efficiency = measured power (KVA) value/desired power (KVA) value * 100%

Table 4.1 Test Results.

S/N	Type of test	Desired value			Measured value			System efficiency (%)
		V (V)	I (A)	P (kVA)	V (V)	I (A)	P (kVA)	
1	No Load Test	220	0.35	1.7	220	0.41	1.675	98.5
2	Load Test	220	4.5	1.7	220	4.8	1.641	96.5

4.2 Inverter Testing Results

The desired values are the standard values which should be obtained from an ideal 1.7 kVA inverter system. The measured values are the actual values we obtained from the 1.7 kVA inverter which we have constructed upon testing.

The inverter produced a pure sine wave voltage, rated 220 V. This was tested with a multimeter tester. The pure sine wave inverter was then plugged into an alternating current power source through a wall socket, and a 24 V DC voltage was produced across the battery terminals to charge them. This was also tested with multimeter tester.

The duration at which the inverter discharges under load condition depends on the total power of load connected to its output terminal and the power rating of the battery connected to its input terminal. Bearing in mind that total load must not exceed 1700watts.

The circuit worked satisfactorily as expected and demonstrated voltage stability on load, providing an alternative source of power.

The results of the tests that were carried out throughout the whole design were all gotten through systematic checks and observations, and using the appropriate test tools and equipment where necessary. The major tests that were carried out all met the expected specifications with negligible deviation or tolerance. One thing was peculiar about the results; each of the tests that were carried out in each of the subsystems that make up the inverter system was done in relation to the next subsystem that was connected to it. The outputs from the inverter system were all as expected as shown by the final results. When the final installation was made, the system was tested by gradually loading it to see that it responds to the load increase as expected; and after the load test we observed that batteries voltage dropped slightly due to the loading effect and that was normal. Before final assembling, the different sections that make the whole system were tested individually. This pattern was adopted to make troubleshooting, analysis and testing easy and reliable. It is expected that all the results of the tests that were carried out continuously conform to the specified standards as long as the system is used within its capacity and under the standard test conditions. Based on the pattern of tests and observations used in this project, it is expected that the system performs its intended duty throughout its useful life as long as it is used as prescribed, and this is because of the fact that the system was designed under standard operating conditions of the immediate environment.

5. CONCLUSIONS

The basic goal of this project, which is designing and construction of a working DC-AC pure sinewave inverter that could efficiently provide 1700 W of power has been achieved. Different signals were generated to control MOSFET switches arranged in an H- bridge. The aim was to modulate the bridge with a PWM and obtain a PWM and filter the bridge output to get a pure sine wave. Although the final output waveform was not the desired waveform, the design went along in trying to design an affordable sine wave inverter. This project provides a good building block that can be added in to many general-use high-power applications, as well as a base to work off for a self-regulating power supply. We successfully improved on previous works by some good percentage, especially due to the improvement of the charging system of the inverter and the low battery alarm system.

REFERENCES

[1] T.V. Omotosho, D.T. Abiodun, S.A. Akinwumi, C. Ozonva, G. Adeyinka, and L.N. Obafemim "Design and Construction of a Pure Sine Wave Inverter," J. Inform. Math. Sci., vol. 9, no. 1, pp. 397–404, 2017.

[2] Davidson, O., Osunde, U., and Godswill, N. (2019). On a smart inverter with the ability to automatically regulate incoming voltage. Journal of Electrical and Electronics Engineering (IOSRJEEE) Volume 3, Issue 3 (Sep. - Nov. 2019), pp. 12-25

[3] N. Ahmed and Z. R. Khan, "Microcontroller Based Pure Sine Wave Inverter," 2021 IEEE International Conference in Power Engineering Application (ICPEA), Malaysia, 2021, pp. 173-177, doi: 10.1109/ICPEA51500.2021.9417841.

[4] M. A. Ghalib, Y. S. Abdalla, R. M., and Mostafa, "Design and Implementation of a Pure Sine Wave Single Phase Inverter for Photovoltaic Applications." https://monolith.asee.org/documents/zones/zone1/2014/Student/PDFs/136.pdf (accessed Feb. 1, 2023).

[5] F. Ronilaya, S. Ilmawati, M. Huda, W. Anistia, I. N. Syamsiana, and M. N. Hidayat, "A development of an Arduino pure sine wave inverter for a small scale off-grid solar PV system," IOP Conference Series: Materials Science and Engineering, vol. 1073, no. 1, p. 012043, Feb. 2021, doi: 10.1088/1757-899x/1073/1/012043.

[6] I. Alhamrouni, N. Zainuddin, M. Salem, N. H. A. Rahman, and L. Awalin, "Design of single phase inverter for photovoltaic application controlled with sinusoidal pulse width modulation," Indones. J. Electr. Eng. Comput. Sci., vol. 15, no. 2, p. 620, 2019, doi: 10.11591/ijeecs.v15.i2.pp620-630.

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