Vol. IX No. 4 October 2016

The IUP Journal of
ELECTRICAL & ELECTRONICS ENGINEERING

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www.iupindia.in

The IUP Journal of
ELECTRICAL & ELECTRONICS ENGINEERING

Vol. IX No. 4 October 2016

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Vol. IX No. 4 October 2016

ISSN 0974-1704

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IUP Publications
(A Division of The ICFAI Society)
52, Nagarjuna Hills
Panjagutta, Hyderabad 500082
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The IUP Journal of Electrical & Electronics Engineering is a 'peer-reviewed' journal published four times a year in January, April, July and October.

Subscriptions

For subscriptions and related enquiries write to:
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IUP Publications (A Division of The ICFAI Society)
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Published by E N Murthy on behalf of IUP Publications (A Division of The ICFAI Society), # 52, Nagarjuna Hills, Panjagutta, Hyderabad 500082, Telangana, India, and printed at M/s. Mahathi Print Creations, 2-3-720/A/11, Ganganagar, Amberpet, Hyderabad 500013.

Focus

Energy harvesting is the process of capturing small energy from naturally-occurring energy sources and storing them for later use. Energy harvesting electronic modules are used in power sensing and control circuitry. The paper, "Designing an Ultra-Low Voltage Energy Harvesting Circuit Using Piezoelectric Materials", by Parveen Kumari and Sunita Malik, deals with the designing of an ultra-low voltage energy harvesting circuit. The circuit consists of a bridge rectifier, supercapacitor as energy storage device, battery, switch-mode DC-DC converter and a vibrating piezoelectric element. The proposed circuit consumes very little power and is especially suitable for the environments where ambient harvested power is too low.

Semiconductor materials that have ferromagnetism and semiconductor properties are called magnetic semiconductors. By doping the semiconducting material with low concentration of Transition Metals (TMs), Diluted Magnetic Semiconductors (DMS) are obtained. Nanoscale devices can be built using diluted magnetic semiconductors. In the paper, "A Review of Transition Metal-Doped In_2O_3-Based Diluted Magnetic Semiconductors", the authors, Rana Mukherji, Vishal Mathur, Arvind Samariya and Manishita Mukherji, present a review of the performance of various TMs doped in Indium Oxide (In_2O_3).

The paper, "Design and Implementation of a 5 k VA Inverter", by Johnson Adegbenga Ajiboye, Chukwuka Anene, Mary Adebola Ajiboye and Abraham U Usman, deals with the design and construction of a 5 kVA Pulse Width Modulated (PWM) Metal Oxide Semiconductor Field Effect Transistor (MOSFET)-based inverter, which works on the principle of PWM. The inverter converts DC supply of the battery into AC power supply and can be used for domestic purpose.

Model Predictive Control (MPC) is an advanced control, in which process dynamic models are obtained by system identification technique. MPC can predict the future events and take control actions accordingly based on a large amount of calculations. Various alternatives have been introduced in order to reduce complex calculations like Generalized Predictive Control (GPC), explicit MPC and Finite Control Set MPC (FCS-MPC). The paper, "Model Predictive Control of 3Φ, 15-Level Inverter", by R Vijayakumar and Alamelu Nachiappan, describes the implementation of FCS-MPC in power inverter loads. The simulation results show that the proposed control method is very effective for control of power inverters.

Mesosphere Stratosphere Troposphere (MST) radar is used to explore the atmospheric dynamics up to a height of about 100 km by means of a high power VHF backscatter. The MST radar system is set up in National Atmospheric Research Laboratory (NARL) at Gadanki near Tirupathi in India and is used to study winds, waves and turbulence in the troposphere, stratosphere and mesosphere. In the paper, "Calibration of the Beam Pointing Accuracy of an Antenna Array Using the Celestial Radio Source", by Madhu G C and Jhansi J, a method to calibrate the beam pointing accuracy of the MST Radar-phased antenna array is presented. The antenna beam pointing error, which is the difference between actual beam pointing direction and the desired direction, occurs due to variations in temperature and ageing of the RF hardware. The celestial radio sources can be successfully used to calibrate the beam pointing accuracy of the phased antenna array.

MSR Murty
Consulting Editor

Design and Implementation of a 5 kVA Inverter

Johnson Adegbenga Ajiboye[1], Chukwuka Anene[2],
Mary Adebola Ajiboye[3] and Abraham U Usman[4]

The paper describes the design and construction of a 5 kVA Pulse Width Modulated (PWM) Metal Oxide Semiconductor Field Effect Transistor (MOSFET)-based inverter, which works on the principle of PWM. The inverter uses IC SG3524 and a pair of Twelve MOSFETs to drive the load. The design and implementation starts with the power supply. Component selection was made with the aid of electronics data book, which made the design and calculations very easy. One main feature of this inverter is the monitoring section, and the battery-charging section connected to the inverter circuit. The inverter converts DC supply of the battery into AC power supply required by most electrical appliances/equipment when the AC main is not available; and when the AC main is available, the supply goes to the AC main sensor, the relays and battery charging section of the inverter. This inverter can be used for domestic purpose, and it is not recommended for industrial purpose where high current is required for application, such as starting a heavy-duty motor.

Keywords: MOSFET, PWM, AC, DC, Control Unit, Oscillator, Transformer, Rectifier, Inverter

Introduction

The erratic nature of power supply is a thing of major concern to all Nigerians. The cost of acquiring a generator set and the need to supplement the irregular voltage supply by the Electricity Distribution Companies of Nigeria make it essential for the construction of DC/AC power inverter.

An inverter is a device which converts the DC supply of the battery into AC power supply required by most of the electrical/electronic equipment. The process through which the inverter converts DC power supply to AC power supply is called inversion. This inversion process is the reverse of the rectifier process, where the AC is converted into DC power supply.

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In the past, Pulse Width Modulation (PWM) techniques were employed in voltage and current source inverter only. Availability of self-commuted devices, such as power transistor, Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor (IGBT) and Gate Turn-off Thyristor (GTO), have made pulse width modulated AC to DC converter popular in many applications. The steady state and dynamic performance of inverters, AC to DC converters and DC and AC drives are significantly dependent on the PWM techniques (Dubey and Kasarabada, 1993).

PWM of a signal or power source involves the modulation of its duty cycle to either convey information over a communication channel or control the amount of power sent to load (Rizzoni, 2000).

Generally, in every home, office and industry, electrical/electronic devices are installed for use. These devices require electrical power for their operation and most of these devices when not supplied with the required quality power supply are at risk of being damaged.

In Nigeria, the standard electrical/electronic equipments work on 220V/50HZ AC power supply. This power supply should not contain spikes, noise, etc. which could lead to damage of the equipment.

With this DC to AC power inverter, people now have an alternative to power supply when there is an outage, thereby reducing the effect of irregularities in power supply by the National Power body—Electricity Distribution Company of Nigeria.

This device (Inverter) will be of immense importance to rural dwellers and serve as a substitute to power supply and big generating plants. In terms of cost, size and reliability, the device stands the test of time and is relatively portable and cheap compared to other means of power generation.

Primarily, the inverter converts DC power to AC power at a desirable output voltage, current and frequency. The conversion may be achieved with such devices like the ICs, MOSFETs, capacitors, resistors, diodes and bipolar or unipolar transistors when properly arranged and combined (Nwokoye and Ezeonu, 2005).

Based on this definition and the availability of AC power, the importance of an inverter and the need for a constant source of AC power in Africa and many other developing nations cannot be overemphasized. In most of these countries, AC power is very erratic. In Nigeria, for example, there is always an incessant supply of electricity.

The DC voltage can be obtained from solar power and DC batteries. Thus, on the basis of inversion, this work shall reveal how DC power to AC power (that is converted) may be used to power fluorescent tube, television set, radio, printer, computer and also for general purpose.

System Overview

This paper presents the theory, design, analysis and construction of an inverter that converts a 12 V DC to 220 V AC at a frequency of 50 Hz. Design is the application of science and technology to the realization of a physical object to perform specific functions with optimum economy and efficiency.

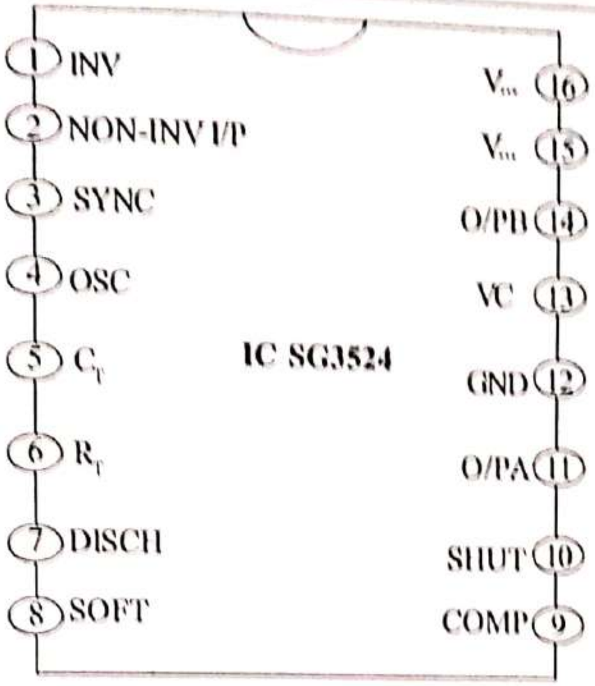
In this paper, many components were used to achieve the design objective. Each component has a function different from the other, and highly dependent on the others for the desired results. Some of the components used in this design for its proper operation include:

- The integrated circuit – SG3524
- The Seven Segment Display
- The Transformer
- The Rectifier
- The Capacitor
- The Relay
- The Resistor
- The Diode
- The Transistor
- The MOSFET

The Integrated Circuit – SG3524

The SG3524 is a series of PWM circuits used to offer improved performance when used in designing all types of switching power supplies. The on-chip + 5.1 V reference is adjusted to ±1% and the input common-mode range of the error amplifier includes the reference voltage eliminating external resistors. A sync input to the oscillator allows multiple units to be synchronized to an external system clock. These devices also feature built-in circuitry with only an external timing capacitor required. A shutdown terminal controls both the soft-start circuitry and the output stages, providing instantaneous turn off through the PWM latch with pulsed shutdown, and soft-start recycle with longer shutdown commands. These functions are also controlled by an under voltage lockout which keeps the outputs off and the soft-start capacitor discharged for subnormal input voltages. This lockout circuitry includes approximately 500 mV of hysteresis for free operation. Another feature of this PWM circuits is a latch following the comparator (Paice, 1996). Once a PWM pulse has been terminated for any reason, the outputs will remain off for the duration of the period. The latch is reset with each clock pulse. The output stages are designs capable of sourcing or sinking in excess of 200 mA (Sedra and Kenneth, 1991). The SG3524 output stage features NOR logic, giving a LOW output for an OFF state. Figure 1 shows the pin out of the Integrated Circuit SG3524.

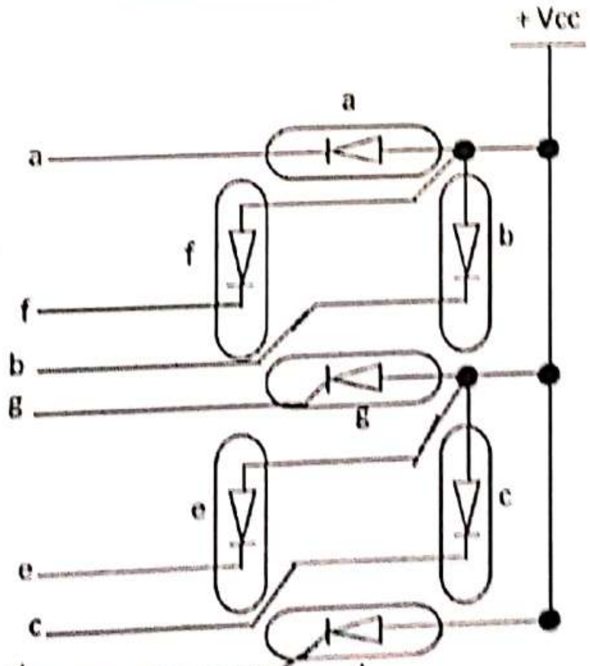
Figure 1: IC SG3524



The Seven-Segment Display

Figure 2 shows a common display format composed of seven elements or segments. Energizing certain combinations of these segments can cause each of the 10 decimal digits to be displayed. To produce a 1-segment, bands b and c are energized; to produce a 2-segment, bands a, b, g, e and d are energized.

Figure 2: Seven-Segment Display Format Showing Arrangement of Segments



One common type of seven-segment display consists of Light-Emitting Diodes (LED) arranged, as shown in Figure 2. Each segment is an LED that emits light when there is current through it. In Figure 2, the common anode arrangement requires the driving circuit to provide a low-level voltage in order to activate a given segment. When a LOW is applied to a segment input, the LED is turned ON; and there is current through it. There is also a common cathode arrangement, which requires a HIGH at each segment input to ON it. The seven segments can still be in Liquid Crystal Display (LCD) form (Sedra and Kenneth, 1991; and Theraja and Theraja, 2003).

The Transformer

A transformer works on AC signals. It cannot work on DC signals, as a DC signal does not generate mutual inductance. A transformer consists of two coils, which are wound each on laminated core. It is made up of primary and secondary sides respectively. There are two types of coils:

- Primary coil; and
- Secondary coil.

The coil to which the AC supply is applied is called the primary coil/winding. The coil in which EMF is induced and the output is taken is called secondary coil/winding. The secondary coil can have one or more windings.

In the transformer, electric energy is transferred from one circuit to another circuit. During this transfer, the current and the voltage can be changed, that is, they can be increased or reduced (Theraja and Theraja, 2003).

There is no direct electrical connection between the primary and the secondary coil in a transformer (Gupta, 2008). When AC current flows in the primary coil, there is change in the magnetic flux generated in the primary coil with induced EMF which is transferred to the secondary coil. The voltage generated in the secondary coil depends on the ratio between the number of turns in the primary coil and number of turns in the secondary coil.

In a transformer, the relationship between voltage, current and number of turns in the coils is given by:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_1}{I_2} \qquad ...(1)$$

where

V_1 is the input voltage to the primary;

V_2 is the output voltage from the secondary;

N_1 is the number of turns in the primary coil;

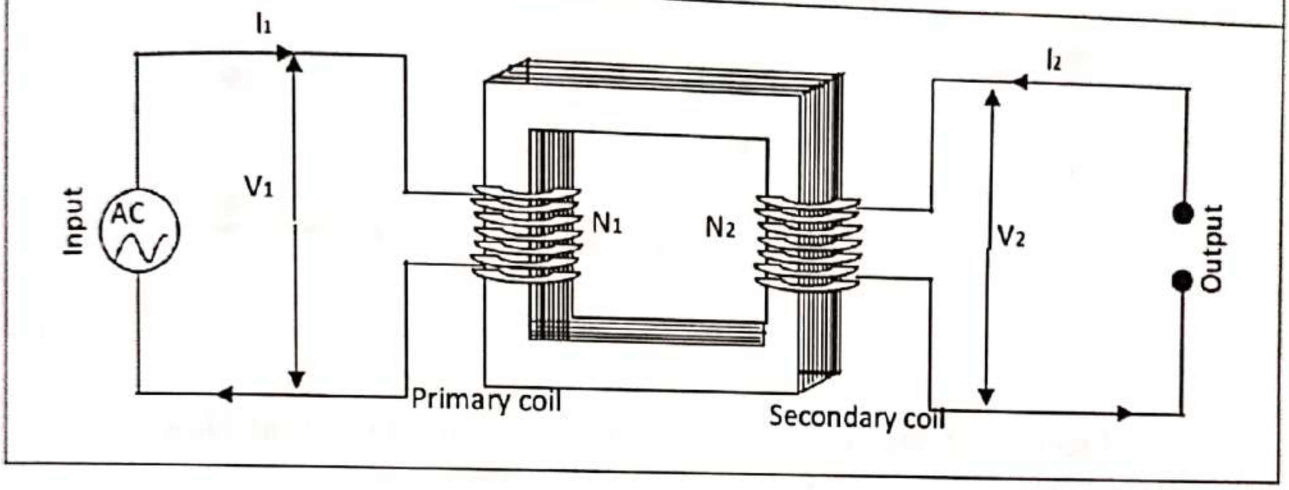
N_2 is the number of turns in the secondary coil;

I_1 is the current in the primary coil; and

I_2 is the current in the secondary coil

In an ideal transformer, there is no loss and the efficiency is 100%; but in reality, this is not easy to obtain. Figure 3 shows an ideal transformer circuit.

Figure 3: Ideal Transformer Circuit



The Rectifier

After stepping down the AC mains supply using a step-down transformer, the stepped-down AC supply is converted into DC by the rectifier circuit.

Three most common types of rectifier circuits are:

- Half wave rectifier;
- Full wave rectifier; and
- Full wave bridge rectifier

The one used in the design of this work is full wave bridge rectifier.

In this rectifier, four diodes are connected across the secondary winding in a special arrangement of diodes, called 'bridge arrangement', as shown in Figures 4 and 5.

During the positive half cycle of input AC signal in the secondary winding, point A is positive and B is negative. This makes diodes D_4 and D_3 forward biased and the current flows from point A to point D through D_4, D to C through load and from point C to B through D_3. During this time, D_1 and D_2 remain reverse biased.

During the negative half cycle of input AC signal in the secondary winding, point B is positive and A is negative. This makes diode D_1 and D_2 forward biased and the current flows from point B to point D through D_2, D to C through load and from point C to A through D_1. During this time, D_3 and D_4 remain reverse biased (Theraja and Theraja, 2003; and Nwokoye and Ezeonu, 2005).

Figure 4: Bridge Rectifier Showing Direction of Current Flow in First Half Circle

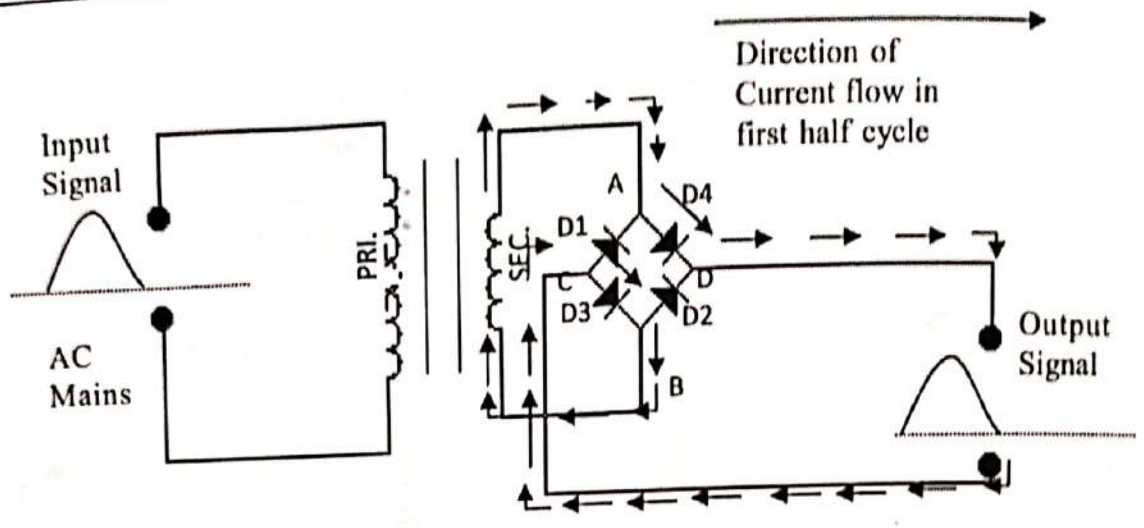
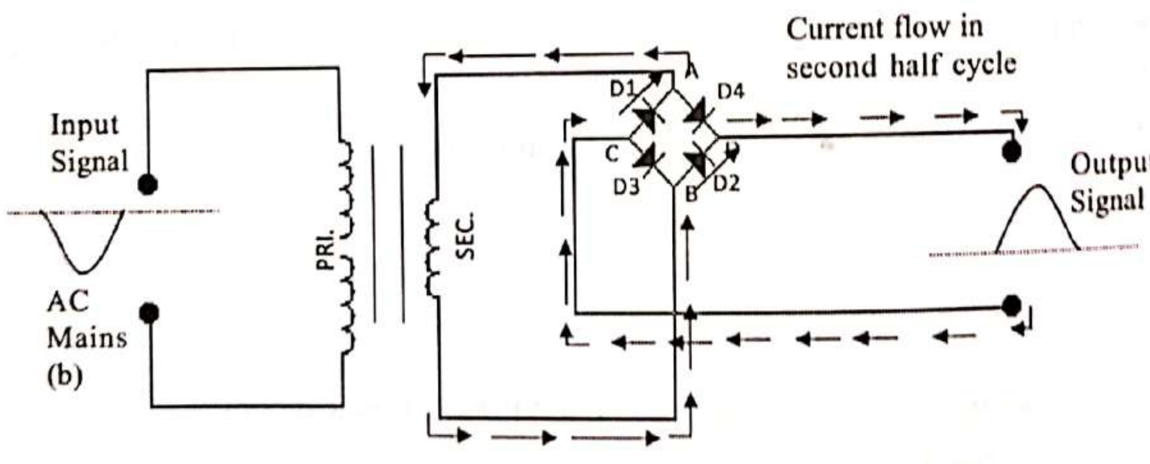


Figure 5: Bridge Rectifier Showing Direction of Current Flow in Second Half Circle



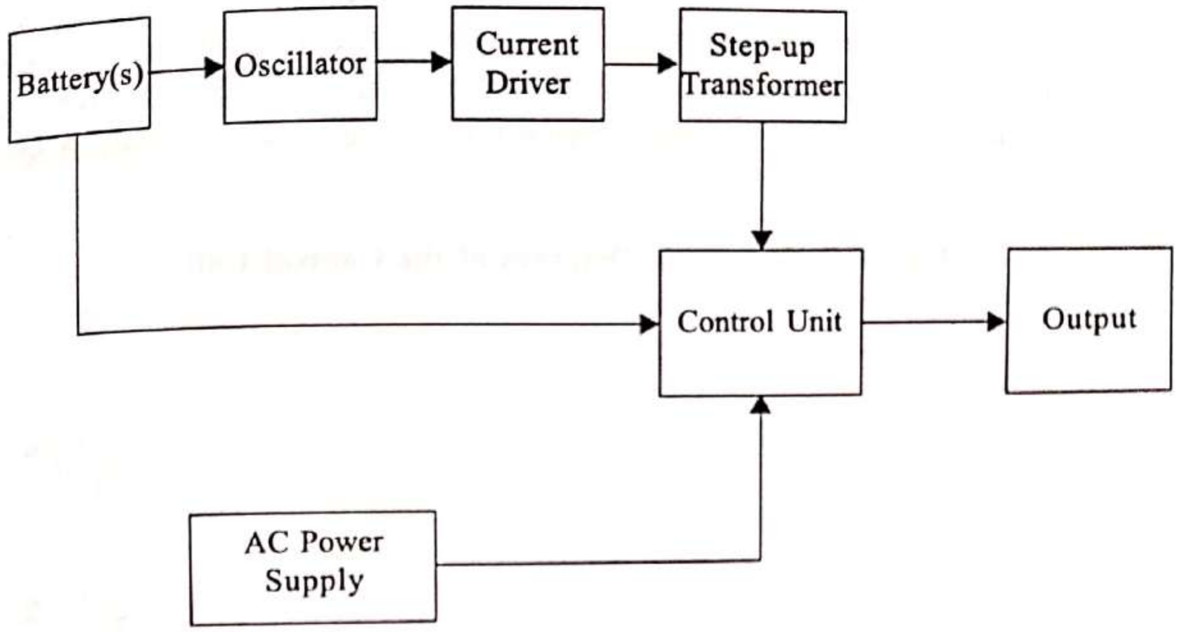
It is noted that for both half cycles of AC, direction of current through the load is same from point D to C. So the bridge rectifier rectifies full AC wave and produces DC output from the AC input using the full secondary winding.

Other components are explained in methodology.

Methodology

The block diagram of the 5kVA power inverter is shown in Figure 6. This is followed by explanation of individual blocks, design consideration and design calculation for the different components used.

Figure 6: Functional Block Diagram of the 5 kVA Power Inverter



Design Specifications

The design specifications of the inverter are summarized as:

- Output power 5 kVA;
- Output waveform = Modified sine wave;
- Output frequency = 50 Hz;
- Output voltage = 220 V AC; and
- Charging type = Constant voltage.

The capacity of an inverter is a function of:

- The type and number of power MOSFETs used; and
- The size and capacity of the power transformer used.

Therefore, in this paper, a 5 kVA transformer was designed and matched with the appropriate number of MOSFETs.

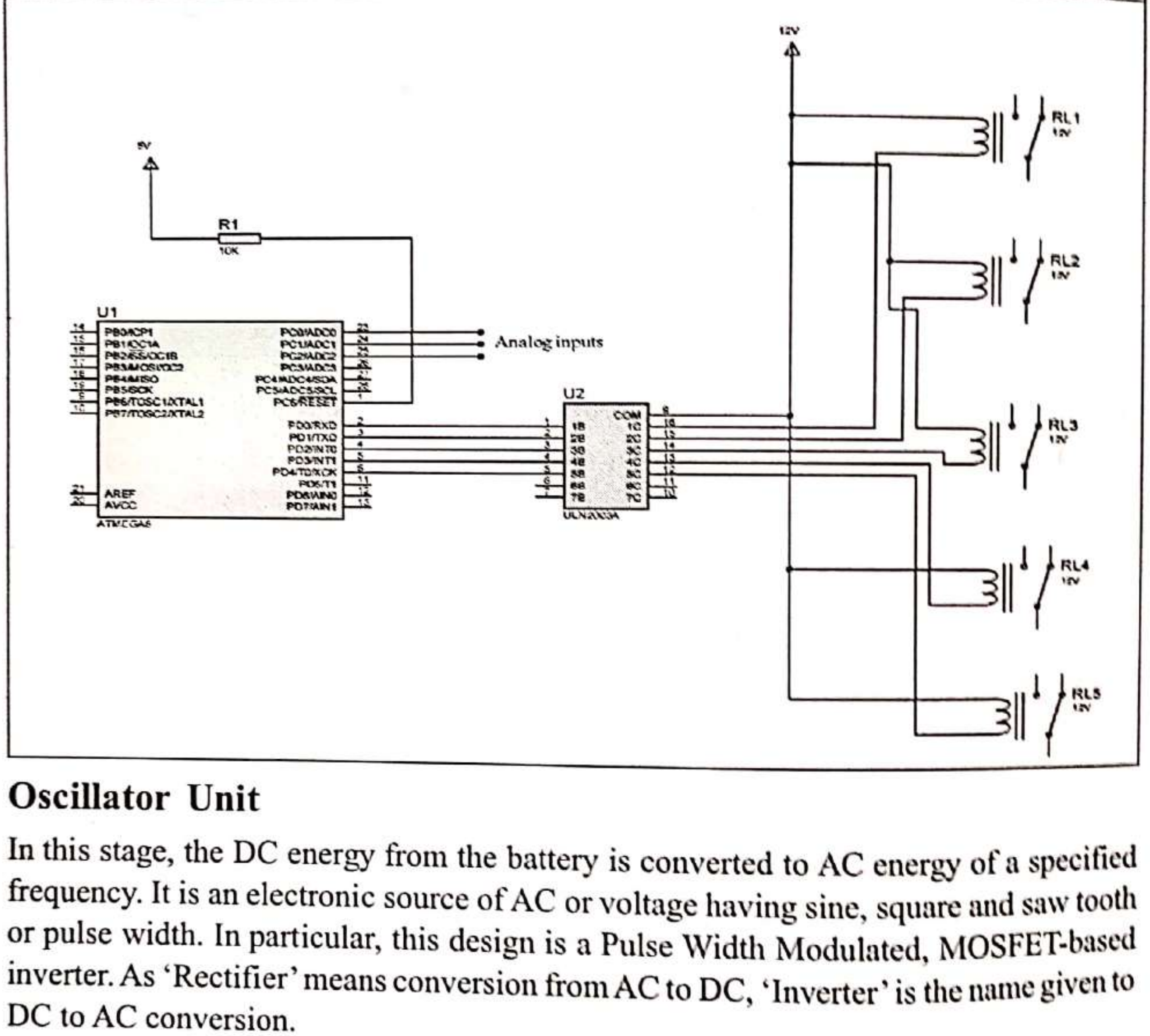
Power Supply Unit

The control unit takes power from a 5 V regulator (7805), while the oscillator stage is powered directly from the battery. To monitor the power from the Power Distribution Company, a step-down transformer 220/12 V was used and rectified using bridge rectifier. A filtering capacitor was applied and the output was connected to one of the analog inputs of the microcontroller.

Control Unit

For the control unit, the ATMega8 microcontroller serves as the central processing device, which monitors inputs such as voltage level of battery and Power Distribution Company input current/voltage level. This unit has five (5) relays connected to it via a current driver IC, ULN2003 which can drive up to 500 mA current. The ULN2003 drives the relays according to the decision taken by the microcontroller. Figure 7 is a schematic diagram of the control unit.

Figure 7: Schematic Diagram of the Control Unit



Oscillator Unit

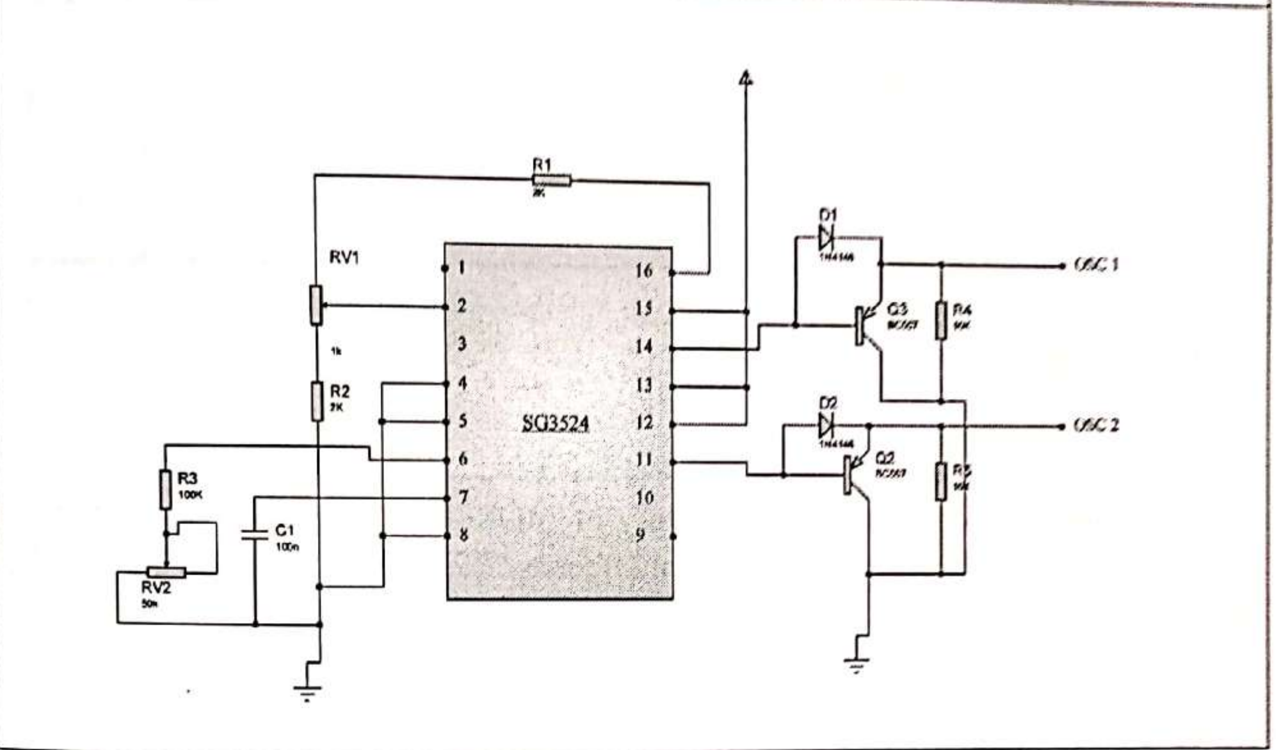
In this stage, the DC energy from the battery is converted to AC energy of a specified frequency. It is an electronic source of AC or voltage having sine, square and saw tooth or pulse width. In particular, this design is a Pulse Width Modulated, MOSFET-based inverter. As 'Rectifier' means conversion from AC to DC, 'Inverter' is the name given to DC to AC conversion.

The oscillator used in this design was PWM regulator control (SG3524) which was modified to sine wave using BC557 transistors.

The major functional unit of the IC (SG3524) is the oscillator circuitry. The oscillating frequency is varied through the resistor and capacitor connected to pin 6 and pin 7 respectively. The output of oscillator is pin 3 which is a single-ended pulse-fed directly into a flip-flop.

The flip-flop divides the single-ended output into two and fed to NOR gate, then to transistors each attached to a NOR gate at pins 12, 11, 13 and 14. Pin 14 and 11 of each transistor is used as the two outputs of the oscillator used for push pull application and fed to the BC557 transistor. The output of the BC557 transistor is fed to the preamplifier circuit using the TIP42 transistors. Pin 12 and 13 are connected to pin 15 and tied to the supply voltage of the battery. Figure 8 shows the circuit diagram of the oscillator.

Figure 8: Circuit Diagram of the Oscillator



Frequency Configuration of the Oscillator

The oscillator, SG3524 requires external synchronization for the designer to vary the pulse duration derived and consequently the frequency. The formula to calculate the oscillator frequency is given as:

$$F = \frac{1}{R_t C_t} \quad \text{...(2)}$$

$$T = R_t C_t \quad \text{...(3)}$$

where F is Frequency in Hertz; T = Time constant; R_t = Resistance; C_t = Capacitance; R_t is chosen to be 100 kΩ; and C_t also chosen to be 200 nF.

Therefore, $T = 100 \times 10^3 \times 200 \times 10^{-9}$

$T = 0.02$ s.

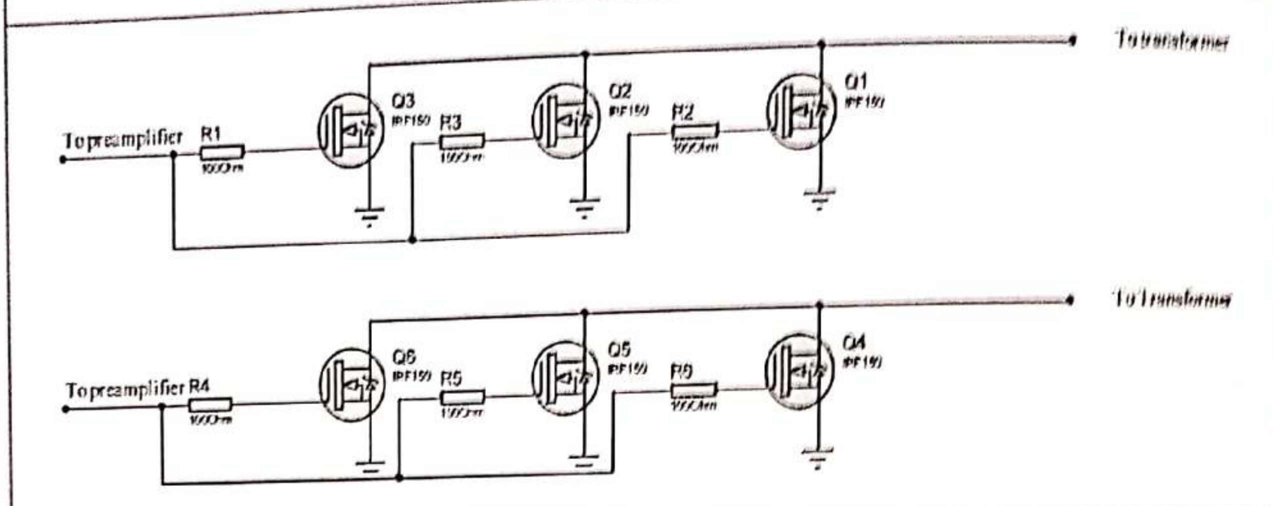
However, frequency $F = 1/T$

$F = 1/0.02 = 50$ Hz

Current Driver Unit

MOSFETs are metallic oxide semiconductors, in which the gate is completely insulated from the channel by a thin layer of silicon oxide. This permits operation with gate source or gate channel voltage above and below zero. Figure 9 shows the circuit configuration of the MOSFET.

Figure 9: Circuit Configuration of the MOSFET



This configuration consists of an array of MOSFETs connected in parallel. The MOSFET used in this design has its path number as IRF150 and the following data sheet parameters:

- Current rating = 39 A;
- Voltage rating = 100 V;
- Power factor (pF) = 0.88; and
- Power rating = 190 W

The required number of MOSFETs per channel for a 5 k VA inverter is thus obtained:

$$P = VA\ cos\theta \qquad ...(4)$$

where $cos\theta = pF$; and P = actual or real power of the inverter.

Therefore,

$P = 5000 \times 0.88 = 4400$ W

The total number of MOSFET is given by:

Number of MOSFETs = Actual power of the design/Power rating of the MOSFET:

That is, 4400/190 = 23.16.

Hence, 24 MOSFETs were used, with 12 on each parallel channel boosting the current to drive the transformer.

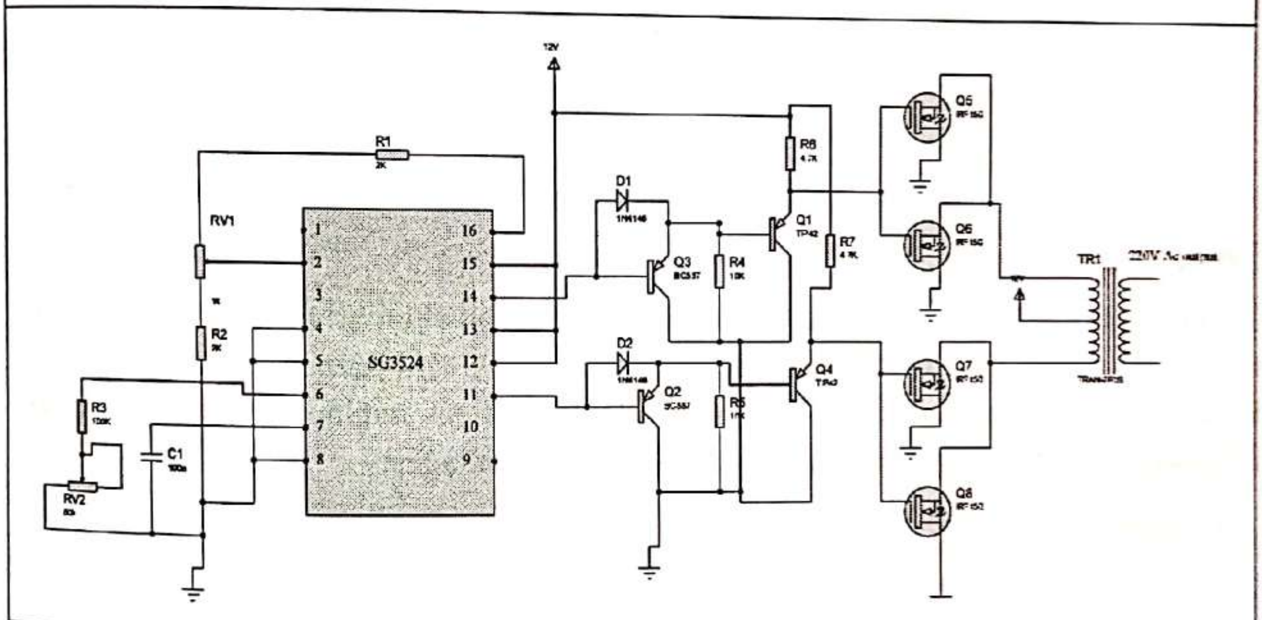
The Step-up Transformer

A transformer is a static (stationary) device by which electric power in one circuit is transformed into electric power of the same frequency in another circuit. It can step up or step down the voltage in a circuit in response to ratio of the coil at the primary and secondary winding, but with a corresponding decrease or increase in current.

The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux generated, corresponding to the input power to the transformer. The transformer used at the output stage was designed to be able to realize 220 V from the input of 12 V AC signal at the MOSFET end.

This step-up center tapped transformer, steps up 12 V AC from the output of the inverter unit to the desired 220 V AC. Figure 10 shows the complete circuit diagram of the 5 k VA inverter (inverting unit).

Figure 10: Complete Circuit Diagram of the 5 k VA Inverter (Inverting Unit)



Packaging

Packaging of the constructed project was done to achieve a good-looking and presentable device. During the packaging, the following factors were considered.

The durability of the material to be used in the packaging, materials like wood, plastic or metal could be used but for this work, metal sheet was used to ensure easy dissipation of heat to the environment.

Again, caution was taken to avoid short-circuiting of any part of the design. The portability of the package was taken into consideration to limit the space it will occupy and to ease the burden associated with the movement of the device.

The ventilation of the package was also considered to help in temperature control of the device since most of the components in the construction are heat-generating components. Figure 11 shows a picture of the neatly packaged 5 k VA inverter design.

Figure 11: Picture of Packaged 5 k VA Inverter

Conclusion

The instability of power supply in the country calls for an alternative power supply to be used as an emergency. This work has met the objective and purpose for which it was designed and constructed. It could be used in homes, offices and industries to serve as an alternative power supply because of the following advantages:

- Low maintenance cost;
- No moving parts;
- No noise pollution;
- Easy installation; and
- No environmental pollution

This work could also be used by many other electrical/electronic appliances, provided it is within the limit of operation.

Recommendation: One of the limitations of this project is that the 12 V DC battery backup cannot withstand a large load applied on it for a long period. The overload cut-off is triggered when the load on the inverter is larger than the designed capacity. Hence, for a more reliable and stable power supply, it is recommended that a larger battery backup should be provided to enable this work withstand larger loads for a long period.

The department should develop a cottage workshop where young interested students will be engaged in mass-production, customization and commercialization of this equipment (inverter), thereby encouraging entrepreneurship and product localization.

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Reference # 59J-2016-10-03-01