DESIGN AND CONSTRUCTION OF 300VA DC TO AC INVERTER

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DEDICATION

This project is dedicated to God who is able to make impossible things possible.

DECLARATION/CERTIFICATION

I, OLUKOMOGBON OLORUNFEMI ABIODUN declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

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ABSTRACT

The 300VA DC to AC inverter is an electronic device that converts a given 12Volts (direct current) from a battery source to 220V (alternating current) to provide backup and uninterrupted power supply to consumer equipments. Within its circuitry is an automatic voltage regulator and a frequency adjustment system for both voltage and frequency stabilization. Also included is a charging system that charges the battery once mains power is restored. The modular form of design was employed and construction carried out in stages, with theoretical backing from various books and websites.

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CHAPTER ONE

INTRODUCTION

Advancements in micro-electronics application technology have sparked an advanced growth in the field of power electronics. This growth has led to the application of discrete components and devices for design and construction of power electronics systems for an effective way of achieving efficient power utilization.

Due to various disturbances to power supply from mains or generating firms, it is imperative to design a system that eliminates or reduces the effects of such disturbances: these disturbances could be an overvoltages, undervoltages, spikes, surges, variation in frequency and even power outages. The alternative source of power that would have help reduce the effect of the above disturbances, to a larger extent is the diesel and petrol generators, but the fumes produced by it, the high noise level and the high cost of purchase, has made it a less likely option.

DC to AC inverter has proven to be the best alternative source of power supply that means the above demands. It produces a regulated and continuous power from a low voltage DC source (12V) such as a car battery. This makes the device suitable when you need to use AC powered tools and appliances when AC mains power is not available. Examples of AC powered tools are operating appliances in mobile homes, running audio, video and computing equipment in remote areas, lighting in homes etc.

Although most appliances and tools designed for mains power (AC) can tolerate a small variation in supply frequency; they can malfunction, overheat or even be damaged if frequency changes significantly. Examples are electro-mechanical timers, clocks with small synchronous motor. To avoid such variations in frequency, the AC to DC inverter has embedded in its circuitry components that inverters output frequency is stabilized and can be varied within a specified range. This is an advantage, when electronic equipment with frequency rating different from that of a region to which it was exported could be changed to the required frequency.

Another feature of the DC to AC inverter is an automatic voltage regulation that senses a drop or increase in output voltage and stablizes the output voltage from the device.

An automatic switchover system of the inverter employs a relay in obtaining continuous voltage supply, whether power from mains is on or off. When power from mains supply fails, the relay switches from mains supply to the DC (12V) battery supply. And it switches back to mains supply when mains power is supplied and immediately begins to charge the battery.

The charging circuitry of the DC to AC inverter, monitors battery voltage level and charges when voltage from battery is low and stops charging when battery voltage reaches maximum allowable limit.

1.1 AIMS AND OBJECTIVES

The 300 VA DC to AC inverter was designed to provide a, low noise, pollution free, low cost alternative source of electric power of 220V, when mains power fails or is not available.

To provide a regulated AC output voltage of 220V at a stable frequency from a 12V Direct Current battery.

1.2 METHODOLOGY

The 300● Watts DC to AC inverter was designed and constructed after research into the theoretical and analytical analysis of the device in textbooks, websites and consultation with individuals with expertise in the electronic field.

The modular form of design was employed in the design. Design was carried out in stages with test carried out at each stage, with relevant measuring devices to compare and contrast with expected results.

Cost of production, non-availability of efficient testing equipments, losses in transformer, manufacturer's error, were some of the constraints to achievable performance.

The block diagram of the inverter is shown below.

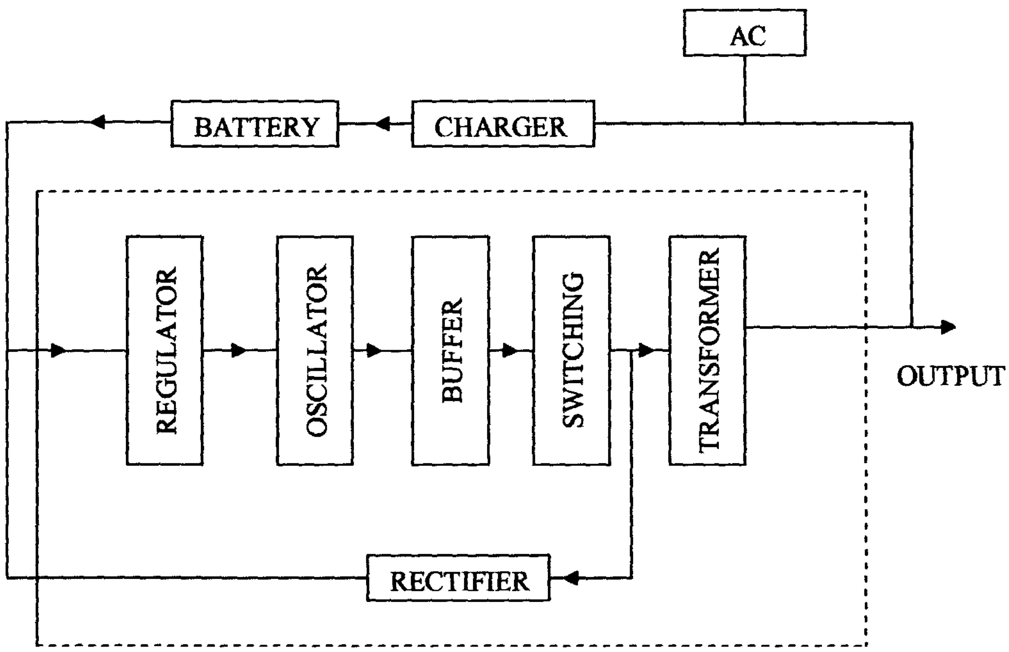


Fig. 1.0 Block diagram of 300W DC to AC inverter.

CHAPTER TWO

LITERATURE REVIEW/THEORETICAL BACKGROUND

Despite the negative effect of war, one of the benefits of World War II was the use of inverters during that period. The inverters of that period were of the motor generator variety; an AC generator whose armature was being driven by a DC motor. That was the only way to invert DC to AC during that period and a popular brand of that era was the Redi-line which are still available today. The motor generator was quite reliable with its output wave form compatible with a wide variety of applications, but it was inefficient, it required 30 amps to turn on and it had no start up surge capacity [2].

Tripplite, a Chicago based company founded in 1922 started producing inverters. The early unit used mechanical vibrators to oscillate DC power into square wave AC. In the early 1960s, after the invention of the transistor by William Shockey in 1948, solid state transistors replaced the mechanical vibratos. One of the advantages of this inverter was that the unregulated square ware design could operate resistive loads, but it had no surge power for starting motors. It was unable to operate reactive loads like compressors, ice makers or microwave ovens. It had many compatibility problems including no frequency control, which was added later. This allowed a steady draw, which could operate turntable motors and clocks. Through the years, square ware technology has been phased out. Present day modified sine wave technology is utilized [2,3].

Vanner Inc. was established in 1977. In 1979, Vanner introduced their first inverter: a 1000 Watt modified sine wave unit. For this 1000 Watt inverter, Vanner patented true RMS (root mean square) regulation and a power transistor drive technique. This achieved an unheard of 87% efficiency, a few years later; the product line expanded with 2200W and 3000W inverters. In 1986, one of the inverters included a microprocessor control circuit [3].

First generation inverters used Meteroid Darlington Technology. This special circuit metered base current to power a transistor proportional to load [3]. Second generation inverters used FETs (field effect transistors). Since FETs have almost no switching losses; efficiency was markedly improved. In 1990 integrated circuits allowed the creation of energy management systems. In 1993, the first micro processor controlled inverter/charger was introduced. The advantages of modified sine wave technology are efficiency and relative economical cost. The modified sine wave, however, still cannot run all loads because of peak voltage regulation and the fact that AC output is not a true sine wave.

Trace engineering developed and patented improvements to the modified sine wave technology in their sine wave sine's inverters, while not a true sine wave; the output is a multi-step approximation that results in fewer load incompatibilities [2].

Starpower Technologies Corporation with headquarters in British Columbia, Canada was founded in 1988. The company manufactured MSW (modified sine wave) inverters using high frequency design; and provided portable power for remote areas worldwide. In 1995, they introduced a pure sine wave inverter/charger using high frequency switching techniques; they were successful in producing a high output charger with a power factor approaching "1". There is negligible distortion at the DC part in both inverter and charger, which is viewed as a technological milestone [2,3].

Most inverters do their job by performing two main functions, first they convert incoming DC into AC, and then step up the resulting AC into mains voltage level using a transformer [9].

Earlier inverters made use of tunnel diodes, SCRs and transistors in the inversion process [7], but modern inverters use a basic circuit scheme like that shown in Fig. 2.1 below [9].

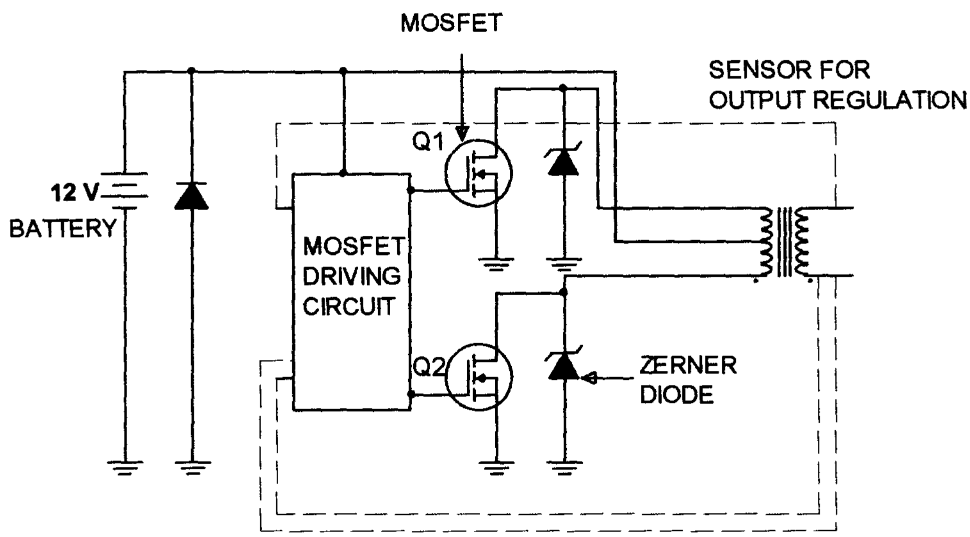


Fig 2.1 Basic Circuit Scheme of DC-AC Inverter

As can be seen the DC from battery is converted into AC very simply, by using a pair of power MOSFETs (Q1 and Q2) acting as very efficient electronic switches. The positive 12V DC from the battery is connected to the centre tapped of the transformer primary. While each MOSFET is connected between one end of the primary and earth. So by switching on Q1, the battery current can be made to flow through the top half of the primary and to earth via Q1. Conversely, by switching on Q2 instead, the current is made to flow the opposite way through the lower half of the primary to earth.

Therefore by switching the two MOSFETs on alternately, the current is made to flow first on one half of the primary and then in the other, producing an alternating magnetic flux in the transformation core. As a result a corresponding AC voltage is induced in the transformers secondary winding and as the secondary has 24 times the number of turns in the primary, the induced AC voltage is much higher [9].

CHAPTER THREE

DESIGN AND IMPLEMENTATION

The following pages contain the steps taken in the design and construction of the 300VA DC to AC inverter. The mode of operation of each module of the design is carefully explained, with diagrams of each module drawn, and specifications, reasons for the use of components stated, also appropriate values obtained at each stage in terms of voltage and current are supplied. Components were well tested before connections for each stage was made on veroboard, which test and measurement for output for each stage was carried out using appropriate instruments to verify workability.

3.1 AUTOMATIC VOLTAGE REGULATOR

3.1.1 Voltage Regulation:

In any power supply circuit like the inverter output voltage may vary or fluctuate due to the fact that as load increases, the output voltage of power supply drops, this means that load current varies with the load. Then the output voltage is said to be unregulated. The function of a voltage regulator in a power supply unit is to provide a steady value of output voltage despite possible variation in voltage and load. In this, project discrete components were employed for voltage regulation and their description is given below:

3.1.2 DESCRIPTION OF COMPONENTS

- ***The C9013 transistor:***

The C9013 transistor is a Bi-polar junction transistor (BJT) of the NPN type, and has the following parameters and current relationship:

I_C (mA)	-	500
P_d(mW)	-	625
V_{ce} (max)	-	20V

V_{be} (max) - 40V

h_{fe} - 120V

The C9013 was chosen for this circuit, because of its high gain which makes it respond to very small changes in voltage, thereby providing excellent voltage regulation.

- ***The Zerner diode:***

The simplest and commonest voltage regulator in use is the Zerner diode whose voltage current characteristic curve is shown below

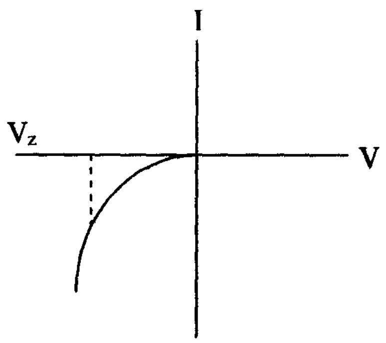


Fig. 3.1: Current characteristic curve of Zerner diode

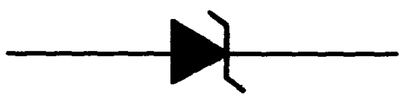


Fig. 3.2: Symbol of Zerner diode

Zerner diode operates in the reverse biased region, if the reverse voltage is increased from 0 volts only the reverse saturation current flows. At the breakdown voltage V_Z; the negative current starts to increase appreciably. Any voltage higher than V_Z applied to the diode does not increase the output voltage, despite rapid increase in reverse current. This means that Zerner diode can regulate the voltage applied to it provided breakdown voltage is exceeded [10]. The Zerner diode used in the regulator circuit is a 3.1V Zerner diode.

- ***The capacitor:***

The capacitor used in the regulator circuit is a 10μF capacitor, it is used to smoothen voltage from the rectifier circuit.

3.1.3 Mode of Operation

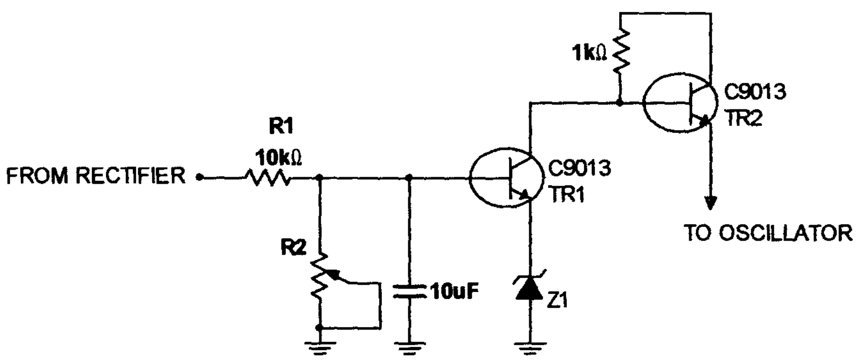


Fig. 3.3 Circuit Diagram of automatic voltage regulator

The voltage regulator shown above is known as the close loop feed back automatic voltage regulator, its main component is the C9013 general purpose transistor. The input to the Network is from a full wave rectifier connected to the drains of the power MOSFETS (IRFP150) at the primary of inverter's transformer to monitor voltage variations. Transistor TR2 is called the series pass transistor and serves as the control device while the Zerner diode produces the reference voltage. TR2 is the error amplifier. The 1KΩ resistor is the load resistor for TR2 and R1 and R2 form a voltage divider for the output voltage and provide feedback to TR1. The emitter voltage of TR1 is Zerner regulated and its base voltage is proportional to output voltage from TR2. This allows TR1 to amplify any error between reference and output.

When load at the output of the inverter demands more current, causing a decrease in output voltage. The voltage divider sends less voltage to the base of TR1. TR1 responds by conducting less current, and voltage will drop across R3 (1KΩ). The base voltage of TR2 goes up and TR2 is turned on harder, which increases output voltage to oscillator and therefore the general output. The reverse happens when there is an increase in output voltage [4].

- ***Maximum Output from AVR***

Voltage at the base of the error amplifier is found first:

$$VB\,(TR1) = V2 + 0.7 \quad = \quad 3.1V + 0.7V$$

$$= 3.8$$

V_{out} is determined by the voltage divider and VB (TR1)

$$VB(TR_1) = V_{out} x \frac{R_2}{R_1 + R_2}$$

$$3.8 = V_{out} x \frac{10}{10+10}$$

$$V_{out} = 2 \text{ x } 3.8 = 7.6V$$

with V_{out} known the base voltage of series transistor can be determined by adding 0.7

$$VB(TR_2) = V_{out} + 0.7 = 7.6 + 0.7 = 8.3V$$

To get voltage drop across R1

$$VR_1 = Vm - VB\,(TR_2)$$

$$= 12V - 8.3V = 3.7\text{Volts}$$

Ohms law gives current in R_1

$$V = IR_1 : I = \frac{V}{R_1} = \frac{3.7}{1K\Omega} = 3.7mA$$

3.2 THE OSCILLATOR

3.2.1 The CD4069UB

The oscillations from this current is obtained through the CD4069UB IC, which is a 14 dual in line plastic package, consisting of six CMOS inverter circuits (NOT gates). It has a supply voltage range of 3 volts minimum and 18V maximum at a full package temperature of -55°C to +125°C, medium speed of operation of tpLH = 30ns at 10V. Maximum input current of 1 NA at 18V.

The CD4069UB was selected for this project for the following reasons:

1. Extremely low static (non-switching) power consumption of CMOS makes it ideal for battery and battery back up systems in which current drain in the battery is a major consideration.
2. Better noise immunity than TTL devices.
3. Lower power consumption at higher frequencies.

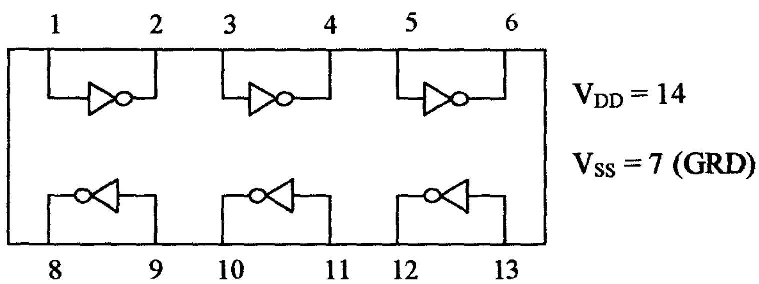


Fig. 3.4 Diagram of CD4069 showing pin configurations

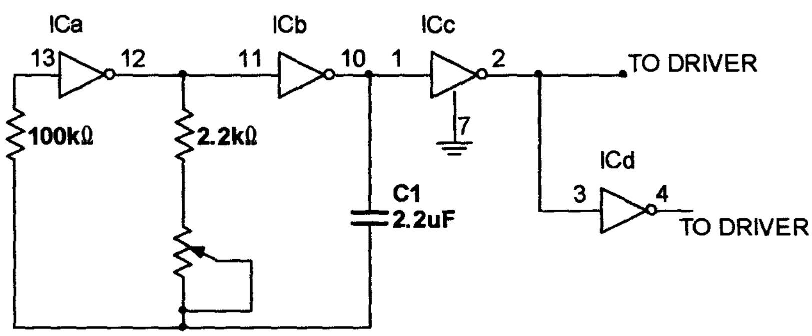


Fig 3.5 Internal structure of CD4069UB

3.2.2. Working Principle

Oscillator circuit was shown as drawn above for easier explanation. When the circuit is switched on, the 2.2μF capacitor charges up and during this period the output of ICb is higher and therefore the final output through ICc is low and ICd is high. The 2.2μF capacitor charges up to supply voltage. When capacitor is fully charged and then begins to discharge, the input to ICa is low and final output at ICc is high while output of ICd is low. The frequency at which this occurs is determined by the 2.2μF, 2KΩ variable resistor and 2.2KΩ resistor. The cycle of charging and discharging which is the frequency is determined by the formula below:

$$f = \frac{1}{2.2 \times C \times R}$$

Minimum frequency:

$$f = \frac{1}{(2.2 \times C \times R)}$$

$$f = \frac{1}{2.2 \times 2.2 \times 10^{-6} \times 4.2 \times 10^{3}}$$

$= 49.2\text{Hz}$

Maximum frequency

$$f = \frac{1}{2.2 \times 2.2 \times 10^{-6} \times 2.2 \times 10^{3}}$$

$$= \frac{1}{10.648 \times 10^{-3}}$$

$$= \quad 93.9Hz$$

3.3 BUFFER / DRIVER

The buffer or driver region is made up of two Bi-polar junction transistors which are C9013 and C9012 which are NPN and PNP transistors respectively. Their basic characteristics or voltage/current profile are given below.

Table 3.0 Specifications for C9012 and C9013 transistors

IC (mA)	Pd (mW)	Vce (max)	Vb (max)	Hfe
C9012 500	625	(20V)	40V	120
C9013 500	625	(20V)	40V	120

$h_{fe} = \beta$ – This is ratio of dc collector current to dc base current

$$B = IC/IB$$

V_{ce} – Collect emitter voltage

V_b – base voltage

The symbols of the two transistors are shown below

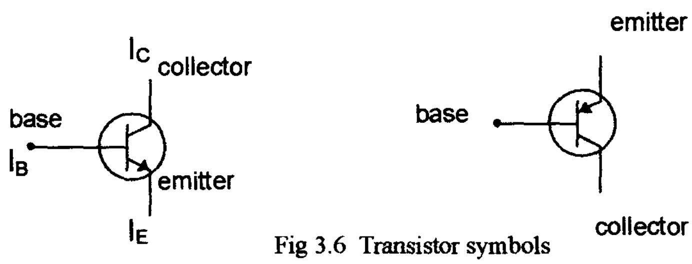


Fig 3.6 Transistor symbols

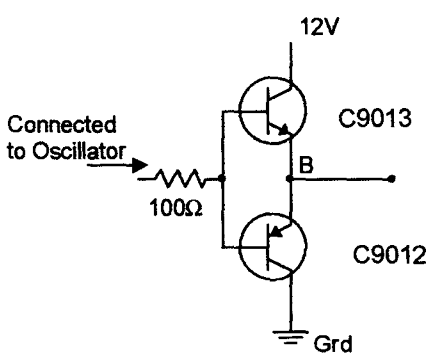


Fig. 3.7 Driver circuit

The setup of the driver above is known as class B push pull amplifier, which requires two power transistors of the same type with closely matched parameter. But the chief requirement of a complementary pair as the set up above is also known as is a pair of closely matched but oppositely doped power transistors. The term complementary arises from the fact that one transistor is PNP type (C9012) and the other is NPN type (C9013). They have symmetry and both are made with the same material and have the same maximum rating.

With no input signal, neither transistors conducts and therefore current through B is Zero. When input signal is positive going the C9013 is biased and goes into conduction and when input signal is negative going C9013 is turned off and C9012 conducts. The circuit possesses the essential characteristics of an emitter follower i.e. unity voltage gain, no phase inversion and input impedance much higher than output impedance. The buffer serves as a link between the oscillator and the Power MOSFETS, since the oscillator cannot directly turn on the Power MOSFETS for switching to take place. The drivers with small gate resistors are needed to overcome capacitive loading since the MOSFETS must be turned on fully in something less than a micro-second [6].

Since voltage drop along the transistors is 0.7, then voltage along MOSFETs IRFP150, which is the load in this case is $V = 6 - 0.7 = 5.3V$.

3.4 MOSFET SWITCHES

Field effort transistors (FET) are grouped into three major categories. The first two categories are both types of metal oxides semi-conductors field effect transistors or MOSFETs. The third category is the junction field effect transistor (JFET). The IRFP150N MOSFET used in this project belongs to the enhancement mode MOSFET. As the name indicates, this MOSFET operates only in enhancement mode and has no depletion mode. It works with large positive gate voltage only. It differs in construction from Depletion mode in that structurally there exists no channel between the drain and source. Hence it does not conduct when VGS = 0, that is why it is called a normally OFF MOSFET [7].

The IRFP150N is a power MOSFET with specifications:

V_{DS} (max) = 100V

I_D (max) = 42A

P_D (max) = 250W

V_{GSTH} = 2V to 4V

K = 2.83

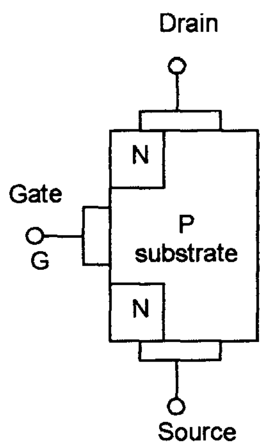


Fig.3.8 Structure of N-channel MOSFET

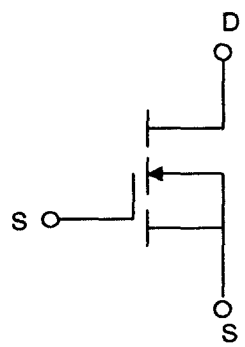


Fig. 3.9 Symbol of enhancement MOSFET

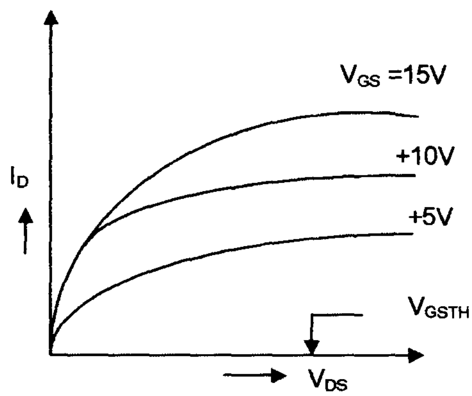


Fig. 3.10 VI Characteristics of MOSFET

When a positive voltage is applied to the gate of the N-channel MOSFET, the electrons in the N-Channel of the source and drain are attracted to the gate and go into the P-channel semi-conductor in between the source and drain. The movement of these electrons forms a bridge or thin layer of free electrons which stretches all the way from source to drain through which electrons flow. The size of this layer or bridge is determined by voltage applied to the gate. The gate is isolated electrically from the source by a layer of silicon oxide. Theoretically, no current flows into the gate when direct current voltage is applied to it. However in order to turn on a MOSFET, a gate to source voltage (V_{GS}) which should be greater than the minimum gate source voltage (V_{GSTH}) known as threshold voltage, needed to deliver sufficient current to charge the input capacitance in desired time is applied. Turn off is achieved by reducing gate voltage below threshold voltage level.

When $V_{GS} < V_{GSTH}$, $I_D = 0$

Drain current starts only when $V_{GS} > V_{GSTH}$

For a given VOS (Drain voltage) the value of ID is given by:

$$ID = K\,(V_{GS} - V_{GSTH}^{2})$$

Where K is a constant which depends on the particular MOSFET.

Therefore, in order to meet the 300 Watts requirement, 4 identical devices i.e. IRFP150N are connected as two pairs and in parallel and each pair is connected to one end of the primary of the transformer as shown in the diagrams below (Fig. 4 & 5).

Each pair of MOSFETs supplies current to the transformer at different periods of oscillation supplied by the driver circuit. When input into T7 and T8 from buffer or driver circuit is high and the input to T9 and T10 is low, T7 and T8 are in the ON condition while T9 and T10 are in OFF condition. Therefore electric current flows in the direction AB of the primary of the transformer.

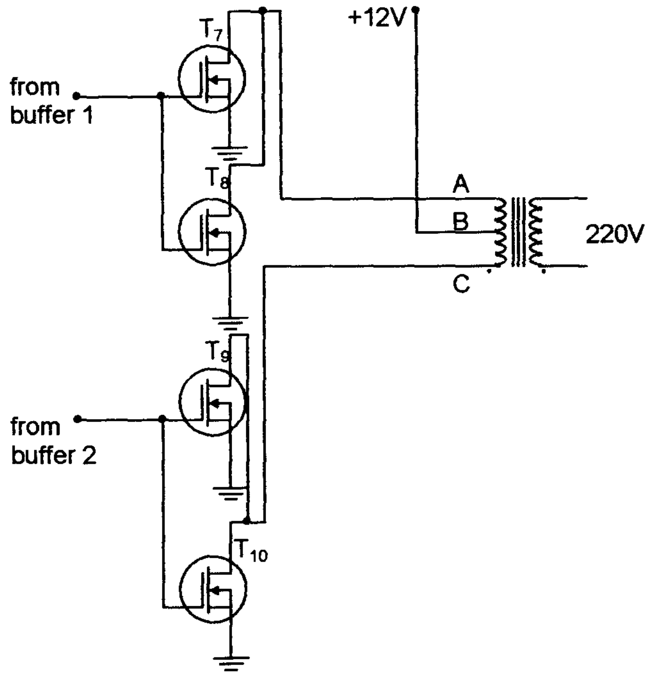


Fig. 3.11 Circuit diagram of MOSFET switches

In the second period of oscillation T9 and T10 are ON while T7 and T8 are OFF, therefore current flows in the direction CB of the primary side of the transformer. Therefore by switching the pair of MOSFETs ON alternatively current is made to flow in the first half of the primary of the transformer and then in the other, producing an alternating magnetic flux in the transformers core. As a result a corresponding AC voltage (220V) is induced in the transformers secondary winding, with switching frequency determined by the frequency of the oscillator [9].

The IRFP150N was used as power switch for the following reasons:

(a) Long life

(b) Ruggedness

(c) High Frequency response

(d) Switching time can be easily controlled

(e) Low noise

(f) High power

3.5 THE RECTIFIER

The rectifier is made up of 1N4001 diodes with the following parameters:

Maximum recurrent peak reverse voltage (V_{RRM}) = 50V

Maximum RMS voltage (V_{RMS}) = 35V

Maximum DC blocking voltage (V_{DC}) = 50V

Maximum average forward rectified current = 1.0A

The rectifier is connected to the Drains of the MOSFETs (IRFP150N) to convert alternating current voltage to direct current (DC) voltage and therefore monitor variations in output voltage.

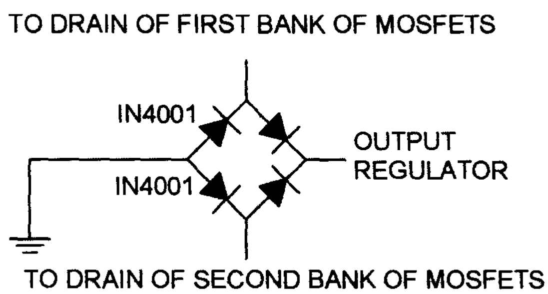


Fig. 3.12 Rectifier

3.6 THE TRANSFORMER

The transformer is used to change the voltage profile of the inverter from 12V to 220V A.C. i.e. it is a step up transformer. The output of the inverter is gotten across the transformer's secondary terminals. The transformer is a 12 volts centre tapped transformer with the transformer's primary rating, it implies that the maximum power that can be handled by the transformer is (12 x 25)W = 300 and assuming that the transformer has 100% efficiency, the maximum power that can be gotten from the secondary windings will be300watts although the practical value will be less, due to various losses in transformer, such as copper loss, eddy current losses.

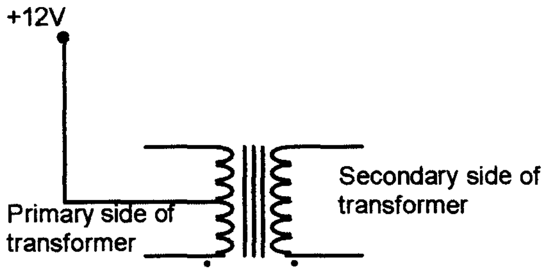


Fig. 3.13 Symbol of transformer

For the transformer windings the voltage per turn was chosen to be 2.

Therefore for the primary turns

$$\text{Volt per turn} = \frac{N_P}{V_P}$$

Where V_P = Primary voltage = 12V

N_P = Primary turns

Volt per turn = 2

$\therefore N_P = 220 \times 2$

= 440 turns

For secondary turns

$$\text{Volt per turn} = \frac{Ns}{V_S}$$

Where V_S = Secondary voltage = 12

N_s = Secondary turns = ?

Volt per turns = 2V

$\therefore N_S = 12 \times 2 = 24 \ turns$

Primary power = Secondary power

$I_P V_P = V_S I_S$

Where I_P and I_S are the primary and secondary current respectively.

$$\frac{I_P}{I_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$$

but $I_S = 1.363$

$$\frac{I_P}{1.363} = \frac{220}{12}$$

$$I_P = \frac{300}{12} = 25A$$

Power P = IV

Power = 220 x 1.363 = 299.86 $\approx$ 300W.

True power or actual power i.e. actual power dissipated in circuit

P = IV cos θ

Where cos θ = 0.8

P = 300 x 0.8 = 240 watts

- ***Output power:***

Since the transformer is centre tapped, the output power is half the maximum power of MOSFET Bank since there are two MOSFETS in each bank which each having maximum power of 250W.

The total maximum output power that will be 2 x 250W = 500W.

3.7 THE SWITCH OVER SYSTEM

To switch over from mains supply to the inverter supply, when there is no supply from mains and vice-versa, the inverter uses a relay. A relay is an electromagnetic device operated by varying the input, which in turn is used to control other devices connected to its output. It forms the simplest form of automatic switching in electrical circuits.

The relay employed in the circuit is a 220V relay. The diagram and mode of operation of the relay is given below:

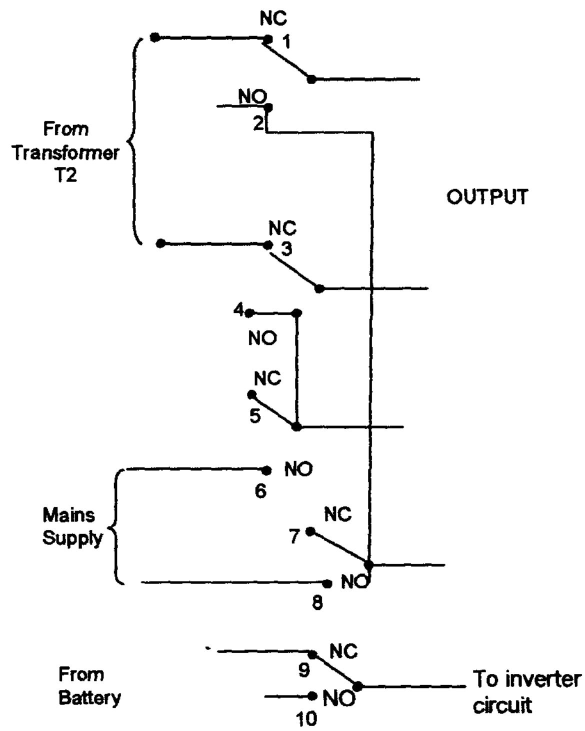


Fig. 3.14 Diagram of relay setup

When there is no voltage supply from mains Pin 9 (normally closed) supplies 12Volts DC from battery to the inverter circuitry and output (AC) is received from Pin 1 and 3 which are normally closed contacts. But as soon as mains power is restored electric current passes through the coil of the relay and this current causes the NC (normally closed) contacts to be attracted to the NO (Normally open) contacts this causes supply from battery to be isolated from the circuit while alternating voltage from mains is received at the output through pin 2 and 4 which are Normally open contacts (NO), at the same time this contacts are connected to the battery charging circuit and begin charging the battery. But when power from mains goes off the relay losses its magnetism and starts to supply voltage from the battery.

3.8 REVERSE POLARITY PROTECTION

A power diode 1N5042 is connected to the positive battery lead to protect the inverter circuit from damage, if the connectors to the battery are accidentally reversed. This means that when battery leads are connected with the correct polarity the diode is reverse biased and remains dormant. But if the battery connectors are accidentally reversed the diode is forward biased and conducts, decoupling voltage to earth.

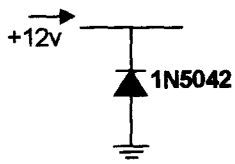


Fig. 3.15 Reverse Polarity protection unit

3.9 BATTERY

The duration for the effectiveness of a battery depends on the size of the battery and the load on the inverter. To determine how long a load can run specific calculations can be done to determine the proper battery bank size.

These are a few basic formulae and estimation rules used:

Formula 1: Power in watts (W) = Voltage in volts (V) x current (A)

Formula 2: For an inverter running from a 12V battery system the DC current required from the 12V battery system the DC current required from the 12V battery is the AC power delivered by the inverter to load in Watts (W) divided by 20.

Since as a benchmark the battery industry rates batteries at 20 hour rate i.e. how many amperes of current battery can deliver for 20 hours at 80°F till voltage drops to 10.5 for 12V battery, though this is not obtainable due to some factors.

Formula 3: Energy required from battery = Document to be delivered (A) x time in hours (H)

Applying the above formulas to the inverter circuit we have

For Formula 1: $P = IV = 200 \times 1.363 = 299.86 \approx 300$Watts

For Formula 2: DC Current to be delivered by 12V battery = 300/20 = 15 Amperes

For Formula 3: Energy required by load in Ampere Hours (AH) is determined. For example if load is to operate for 3 hours then formula 3 gives

Energy to be delivered by battery = 15 amperes x 3 hours = 45 ampere Hours (AH)

But capacity of battery is determined based on runtime and usable capacity. And usable capacity at 3 hours discharge rate is 60%. Hence actual capacity to deliver 45 AH will be: 45/0.6 = 75AH.

Finally actual desired rated capacity of batteries is determined based on the fact that 80% of capacity will be available with respect to rated capacity due to non-availability of optimum operating and charging conditions so final requirements:

75AH/0.8 = 93.75AH

3.10 THE CHARGING SYSTEM

3.10.1 Description of components:

The transformer:

The transformer used in the charging unit is a step down transformer of 220V to 15V at 3000mA. The transformer rating was chosen, though the charger can operate on 12Volts, to meet up for copper losses and eddy currents loses and voltage drops.

The transformer is a static piece of apparatus by means of which electric power in one circuit is transformed to electric power of the same frequency in another circuit. The basis of the transformer is mutual induction between two circuits linked by a common magnetic flux [7].

The Rectifier:

The rectifier used in the charge circuit is a full ware bridge rectifier, it is embedded in a four terminal case. It was chosen, because it was observed that components packaged in casings are more durable than when they are used as single components. A rectifier is just a circuit that employs one or more diodes to converts ac (alternating current) / voltage into pulsating dc (direct current)/voltage [7].

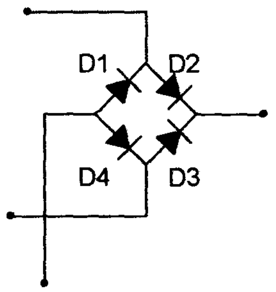


Fig. 3.16 Rectifier Circuit

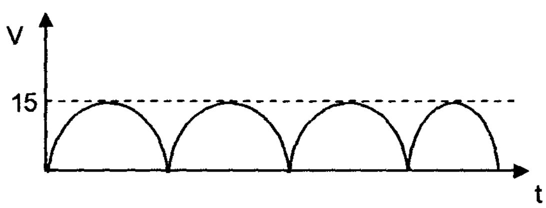


Fig. 3.17 Output Waveform of rectifier

Capacitor:

The capacitor in the charging unit helps reduce ripple magnitude. The capacitor used in the charger circuit is a 22000μF, 25V capacitor.

Light –emitting diode (LED):

Light emitting diodes are forward biased PN junction diodes that emit visible light when energized by voltage and current. The LEDs used in the charger circuit are used to indicate when charge is ON and when battery voltage is low.

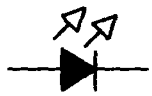


Fig. 3.18 Light-emitting diode

Zerner Diode:

The simplest and commonest voltage regulator in use is the Zerner diode. The Zerner diode used in the charging circuit are 3.38 Zerner diodes and 3.26 Zerner diode. It is used in the circuit to fix a reference voltage to the comparison purpose.

The LM339 Comparator:

The LM 339 is 14 lead dual in line plastic package, it is a quad comparator containing four independent voltage comparator circuits connected to external pins as shown in Fig 3.19 below. The LM339 has the following specifications:

Power supply voltage = +36V or ±18V

Max input offset voltage = ±5.0V

Input offset current = ±50

Input common mode voltage range = -1.5V

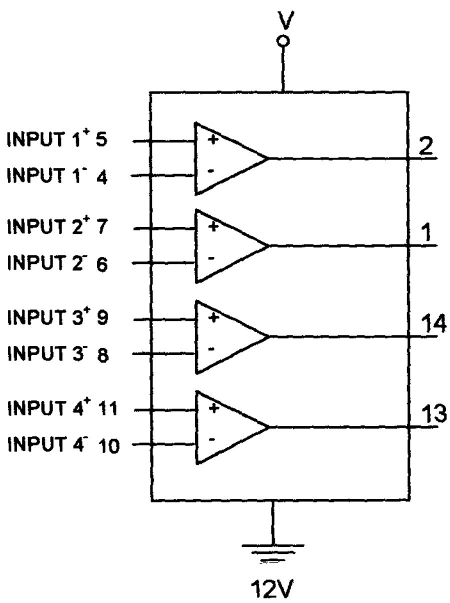


Fig. 3.19 LM 339 showing pin configurations

Each comparator has inverting and non-inverting inputs and a single output. The figure below describes how the comparator can be used. It shows one of the LM339 comparator circuits connected as a zero crossing detector. Whenever the input signals goes below 0V, the output switches to V^+ the output switches to V^-, only when the input goes below 0V. A reference level other than 0 volts can also be used, and either input terminal can be used as the reference, then the other terminal then being connected to the input signal.

If the negative input is set at reference level, V_{ref}, the positive input goes above V_{ref} and results in a positive differential input with output with output

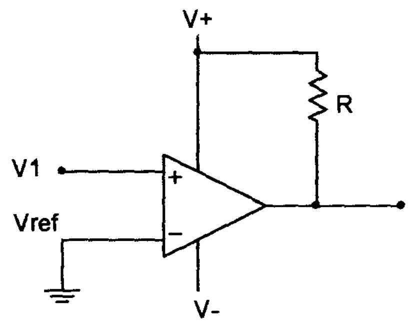


Fig. 3.20 Zero crossing detector

driven to the open circuit state. When the non inverting input goes below Vref, resulting in a negative differential input, the output will be driven to V^-.

The 2N222 Transistor:

The 2N222 transistor is used in the circuit to switch on the relay, it has the following specifications.

I_C(mA) : 800mA

P_d (mW) : 500mW

V_{ce} max: 40V

V_b max : 75V

h_{fe}: 100 – 300

2N222 is a Bipolar junction transistor.

Relay:

The relay used in the charger circuit is a 12V DC 10A relay. The relay is used to make contact for charging to proceed.

3.11 MODE OF OPERATION OF CHARGING UNIT

The mode of operation of the charging circuit is such that a battery voltage below 12 volts the inverting input of IC2 becomes lower than the non-inverting input with this condition the output of IC2 goes high and the transistor TR11 is turned on and energizes the relay and charging of the battery commences.

As soon as the battery voltage level rises to about 15V the inverting input of IC2 becomes higher than that of the non-inverting input. The output goes low and charging stops.

IC3 gives a visible signal with the aid of LED2 for battery voltage condition or level. When battery voltage level is above 10 volts the inverting input is higher than the non-inverting input of IC3, therefore the output of IC3 will be low and the LED3 will be off. But as soon as the battery voltage falls below 10 volts the inverting input becomes lower than the non-inverting input and the output this goes high and LED2 glows indicating that battery is low.

3.11.1 POWER SUPPLY UNIT

The power supply unit is made up of the 240V AC/15AC at 3000mA step down transformer, the rectifier and the 220μF capacitor. This section or unit supplies the charging circuit with necessary voltage for operation. While the rectifier converts

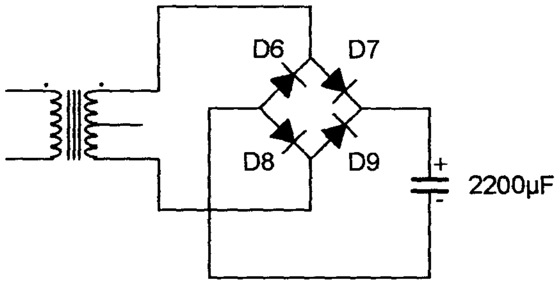


Fig. 3.21 Power Supply Unit

the output alternating current (AC) voltage from the transformer T2 secondary to a pulsating DC (Direct current) voltage the 2200µF capacitor filters the ripple voltage from the rectifier output.

The maximum expected voltage at the secondary turns of transformer T2 is given as:

$$V_{max} = V_{r.m.s.} \times \sqrt{2}$$

$$Where\ V_{r.m.s.} = 15V$$

$$\therefore V_{max} = 15\sqrt{2} = 21.21V$$

DC voltage after rectification is given as

$$V_{dc} = 2V_{max}/\Pi$$

$$= 2 X 21.2 / 3.142 = 13.5V$$

For capacitor voltage, Vc rating must be greater than $V_{r.m.s.} \times \sqrt{2}$

Where Vr.m.s. = 15V

$$\therefore \text{Vmax} = 15\sqrt{2} = 21.21V$$

DC voltage after rectification is given as

$$V_{DC} = 2V_{max}/\Pi$$

$$= \frac{2 \times 21.2}{3.142} = 13.5V$$

For capacitor voltage, V_C rating must be greater than $V_{r.m.s.} \times \sqrt{2}$ where $V_{r.m.s.} = 15V$

$\therefore V_C > 15\sqrt{2}$

$V_C > 21.2V$

$\therefore V_C$ Value of 25V was chosen

For capacitance rating of C_3 (filtering capacitor)

$$\Delta V = \frac{V_m}{2fRC}$$

Where ΔV = Peak to peak ripple voltage; and if ripple voltage of 15V is to be tolerated

f = frequency

$R = 8\Omega$

$V_m = 21.21$

$$\therefore C = \frac{V_m}{2fR\Delta V}$$

$$= \frac{21.21}{2\times50\times8\times13}$$

$= 2{,}039\mu F$

Therefore a capacitance value of 2220μF was chosen.

3.11.2 CHARGER ON INDICATOR

This unit indicates when the power is supplied to the charger. It is made up of a resistor and a LED (LED2).

Fig. 3.22 Indicator

For limiting resistor R,

$$R = \frac{V_{CC} - V_D}{I_D}$$

$V_{CC} = 15V$

V_D = diode voltage (LED) = 2V

I_D = Light emitting diode current = 13mA

$$\therefore R = \frac{15-2}{13mA} = 1000\Omega = 1K\Omega$$

3.11.3 VOLTAGE COMPARATORS

For charging to be possible, there is a need to compare voltages, so that when voltages go beyond a preset value or below the preset value a particular voltage is given out. For the charging, when voltage drops below 15V charging commences while for the battery low indicator when battery voltage drops below 10V the LED is supplied with voltage and glows. This is made possible by two Opamps embedded within the LM339IC

For charging IC2 (Opamp):

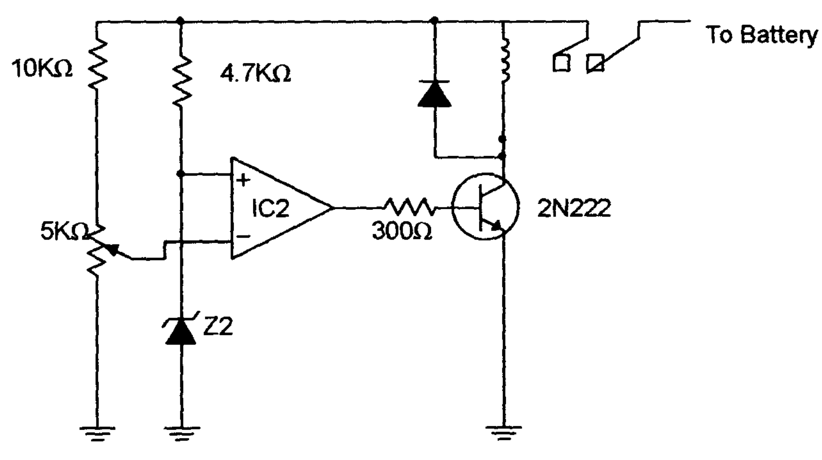


Fig. 3.23 Charging Circuit

The charging process stops when battery voltage is at 15V. A Zerner diode Z2 of 3.38V was used as the reference voltage and the voltage divider network of RT and VR3 was set to 3.38V, such that above the voltage the output of the op-amp (i.e. IC2) goes low therefore charging stops.

The variable resistor, VR3 was set thus

$$V_{ref} = \frac{15 \times R_2}{10+5K}$$

Where $V_{ref} = 3.38V$

$$3.38 = \frac{15R_2}{15K}$$

$50700 = 15R_2$

$RB = 33800\Omega$

The 5KΩ variable resistor was then set thus

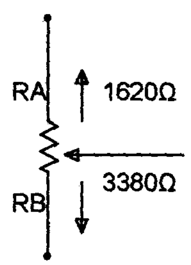


Fig. 3.24 Setting resistance value of variable resistor

Such that the voltage across RB is 3.38V at battery voltage of 15V.

Resistor R9 was chosen to properly voltage bias the 3.38V Zerner diode.

Let current through Z2 be 2.13mA

$$R9 = R = \frac{15-5}{2.13mA} = 4.6948 \approx 4.7K$$

5V reference was chosen in the above calculation because a Zerner diode requires a voltage higher than its rated value to function properly. When the output from the IC2 is high it switches transistor TR11 ON and the relay is therefore energized and 15V charging voltage is supplied to the output of the charger.

For the low battery indicator, a 3.26V Zerner diode was chosen such that at a battery level of 10V the indicator illuminates to indicate low voltage from battery. The variable resistor VR4 was set thus.

$$V_{ref} = \frac{10 \times R_2}{15K\Omega}$$

$$3.26 = \frac{10 \times R_2}{15K\Omega}$$

$$R11 = \frac{48900}{10}$$

$$R11 = 4890\Omega$$

The 5KΩ variable resistor was set thus:

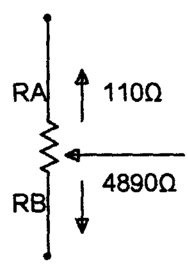


Fig. 3.25 Setting resistance of variable resistor for low battery indicator

Such that the voltage across R11 is 3.26V at a battery voltage of 10V

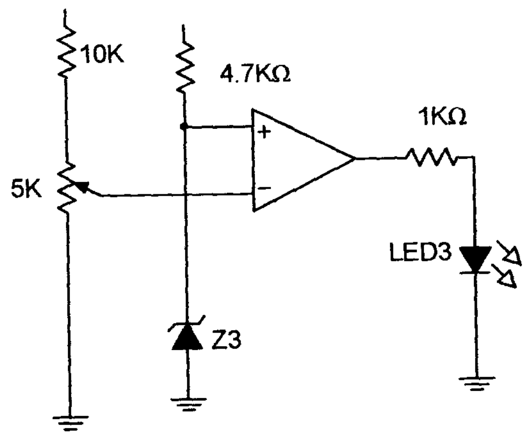


Fig. 3.26 Low battery indicator

CHAPTER FOUR

TESTS, RESULTS AND DISCUSSION OF RESULTS

4.1 TEST

Each of the constituent units of the device was simulated one after the other and then finally soldered one after the other to the vero board with a soldering iron. Short circuit and open circuit test was carried out to protect the components from damage.

The oscillator stage output and inverter output were tested with a multimeter and values obtained recorded. At construction stage, the output of oscillator was connected to a speaker and oscillations were verified from sounds heard. Effects of load on battery voltage was observed on a multimeter and recorded. Also rate of charging of charging unit was observed and recorded.

4.2 RESULTS

The following results were obtained from the test carried out on the inverter.

Output voltage from inverter = 220V

Output voltage from oscillator = 6.3V

Output voltage from charger = 15V

Output current from charger = 1.08A

Output current from inverter = 1.3A

Table 4.1: Rate of charge of battery voltage level on 20W load (bulb)

t/min	Battery Voltage	Inverter Output Voltage	ΔV
0	16.8	220V	0.52
2	11.53	220V	0.15
4	11.38	220V	0.15
6	11.16	220V	0.22
8	10.95	220V	0.52
10	10.74	220V	0.15
12	10.47	220V	0.22

Initial battery voltage = 12.20V

Battery capacity = 7.2Ah

Table 4.2: Charging rate of battery charger

t/min	V/V	ΔV
0	11.86	0.09
2	11.95	0.09
4	11.97	0.02
6	12.00	0.03
8	12.05	0.05
10	12.08	-0.03
12	12.08	-0.00
14	12.07	-0.01
16	12.05	-0.02
18	12.04	0.01
20	12.05	0.02

Initial battery voltage = 11.77V

A.C. Voltage = 218V

Charging voltage = 14.27V

Battery voltage after charging = 11.95V

Frequency of oscillation was found to vary between 42.6Hz minimum and 76.6Hz maximum.

4.3 DISCUSSION OF RESULTS

Results obtained from Table 4.1 for battery level load was connected to inverter in operation, show that for a drop in battery voltage level from 16.8V to 10.47V output remained constant, this verifies the effectiveness of the automatic voltage regulator.

Also the rate of voltage drop is high, this means that inverter consumed a lot of energy on load. Loads with higher power caused a drop in voltage e.g.220v to 200v on a 100 watt bulb, this means that voltage regulation did not cover all values of power for load and MOSFETS did not dissipate enough power.

CHAPTER FIVE

5.1 CONCLUSION

The design and construction of the 300VA DC to AC inverter was presented in the previous chapters. The device was able to convert 12 volts Direct current (DC) from a battery to 220 Volts alternating current (AC). Switchover from mains supply to inverter supply and vice-versa was possible. A charging voltage of 15V was obtained from charging unit output, though charging current was low. Also voltage regulation for some high power load within the 300VA capacity was not efficient, with subsequent drain in battery power supply. A larger capacity battery was found to give longer duration of supply from inverter.

5.2 RECOMMENDATIONS

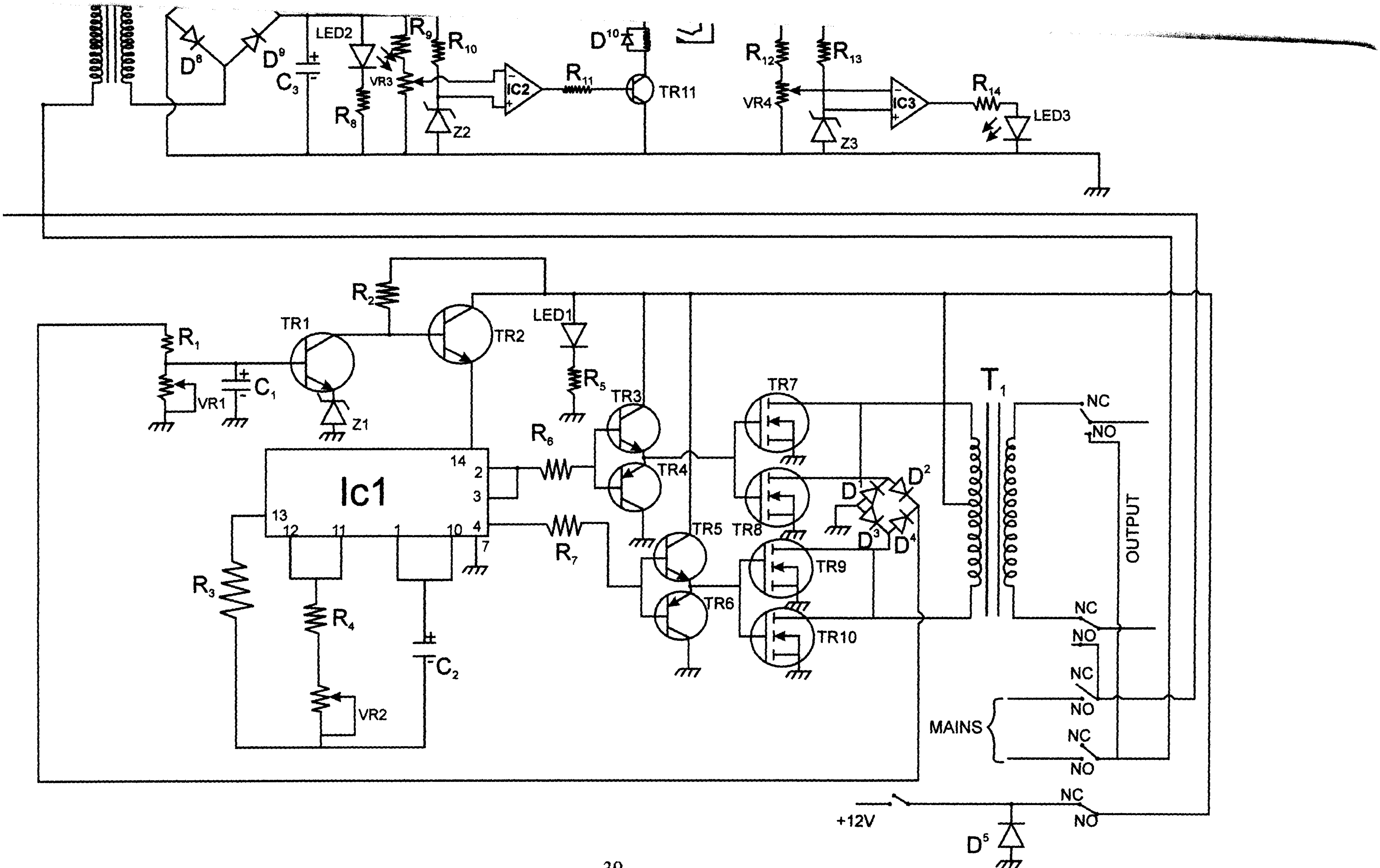
Rapid and dynamic advancements in the electronics field makes it possible for modification and improvements to be made on any electronic device and the DC to AC inverter is not an exception. It is for this reason that the following recommendations for improvement on this particular design are made:

(i) The driver/buffer circuit and the automatic voltage regulator could be simply replaced by ICs to reduce complexity and increase efficiency.

(ii) The cords for connection to battery can be replaced by a terminal for connection of battery to reduce risk of a short circuit.

(iii) The department should incorporate the design and construction of inverters as part of the practical Programme, because of its application in various fields in the future, for example the electric car.

(iv) Power MOSFET with more power dissipation can be used in order to maintain a regular power output when device carries more load.


D8
D9
C3
LED2
R9
R10
VR3
R8
Z2
IC2
R11
D10
TR11
R12
R13
VR4
Z3
IC3
R14
LED3
R2
R1
TR1
TR2
LED1
VR1
C1
Z1
R5
R6
TR3
TR4
TR7
T1
NC
NO
Ic1
14
2
3
13
12
11
1
10
4
7
R7
TR5
TR8
D1
D2
D3
D4
TR9
TR6
TR10
OUTPUT
R3
R4
C2
VR2
MAINS
+12V
D5

Values of Components

$R_1 = 10k\Omega$

$R_2 = 1k\Omega$

$R_3 = 100K\Omega$

$R_4 = 2.2K\Omega$

$R_5 = 4.7K\Omega$

$R_6 = 100\Omega$

$R_7 = 100\Omega$

$R_8 = 1K\Omega$

$R_9 = 10K\Omega$

$R_{10} = 4.7K\Omega$

$R_{11} = 300K\Omega$

$R_{12} = 10K\Omega$

$R_{13} = 4.7K\Omega$

$R_{14} = 1K\Omega$

IC_1 = CD4069UB

IC_2 = LM339

IC_3 = LM339

$VR_1 = 10K\Omega$

$VR_2 = 2K\Omega$

VR_3 = 5K

VR_4 = 5K

$C_1 = 10\mu F$

$C_2 = 2.2\mu F$

$C_3 = 2{,}200\mu F$

TR_1 = C9013

TR_2 = C9013

TR_3 = C9013

TR_4 = C9012

TR_5 = C9013

TR_6 = C9012

TR_7 = IRFP150N

TR_8 = IRFP150N

TR_9 = IRFP150N

TR_{10} = IRFP150N

TR_{11} = 2N222

D_5 = 1N5402

$D_1 = D_2 = D_3 = D_4 = D_6 = D_7 = D_8 = D_9$ =1N4001

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