DESIGN AND CONSTRUCTION OF A VARIABLE OUTPUT LEAD-ACID BATTERY CHARGER

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OCTOBER, 2006

DEDICATION

This work is dedicated to my two parents. O Allah! Have mercy on them has they brought me up while I was a Child.

ACKNOWLEDGEMENT

DECLARATION

I Umar Al-Hassan H.,declare that this work was done by me and has never been presented elsewhere for the award of a degree. I hereby relinquish the copyright to the Federal University of Technology, Minna.

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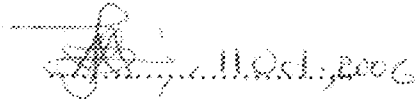..............................

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ABSTRACT

The aim of this project is to design and construct a variable output lead-acid battery charger/dc power supply. The device is designed based on six modules: The input module, ac/dc conversion module, over voltage protection module, charging-circuit and output voltage adjustment module, current-selection module and output voltage monitoring module. The device can accept both AC (240V) and DC sources that can provide enough charging voltage to give an output ranging between 1.96V – 18.6V. The input source and charging current can be selected using the appropriate switch. And also, the desired output voltage can be preset by using output voltage adjustment.

The device does not damage battery by over-charging and does not drain battery when not in use due to reverse polarity protection. It can be used as a dc power supply. At full charge of the battery, the end-of-charge indicator (green-led) will be fully brightened.

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Chapter One

Introduction

1.1   Overview

This report will look at the design and construction of a variable output lead-acid battery charger /DC power supply. It will discuss parts of research product design requirements and further into product specifications which were used to determine the way in which the project will be designed. This document will also show a system level functional block diagrams, and explain each block's function.

Implementation of each block could have been done in a number of ways but, the decision was based on a tool called value matrix analysis, which weights important criteria for each implementation option. Further, this project discusses inputs in great detail, process that went into decision, why what was chosen was chosen and for what reasons.

Each implementation is also laid out in this report, with discussion of inputs, outputs, functions and any relative information. Unsuccessful designs are also mentioned to make sure that mistakes are not repeated again.

Finally, this document includes critique of what worked and what didn't work and any further recommendations that will be taking on the function of continuing the development of a variable output lead-acid battery charger/dc power-supply.

1.2   Aim and Objectives

The aim of this project is to design and construct a variable output lead-acid battery charger/dc power-supply. The project is expected to meet the following requirements.

i.   Charge a typical lead-acid (rechargeable) battery.

ii.   Accept d.c. power sources (e.g. solar, pedal generator) and standard ac power sources (240V).

iii.   Indicate the state of charge

iv.   Prevent overcharging of battery

v.   Must not drain the battery when not in use.

vi.   Serve as a DC supply

vii.   The output voltage must be variable (1.96-18.6V)

1.3   Project Specification

The following list is the list of specifications derived for the charger/dc supply from the project requirements.

- LED indicators to indicate the state of charge

- Two output alligator clips.

- Input cord for the ac power source.

- Two input alligator-clips for D.C sources e.g. solar or pedal generator e.t.c

- Maximum weight of 1.8Kg

- Maximum volume of $(20 \times 13 \times 7.5)$ cm^3

- All labelling are to be done in English

- Product requirements should be implemented using the least complicated circuitry which reasonably meets the design criteria.

- An input switch for selecting either ac sources or dc source

- White casing.

- A digital meter to monitor output voltage.

- Output voltage adjustment

See Artist Rendition shown in Figure 1.1
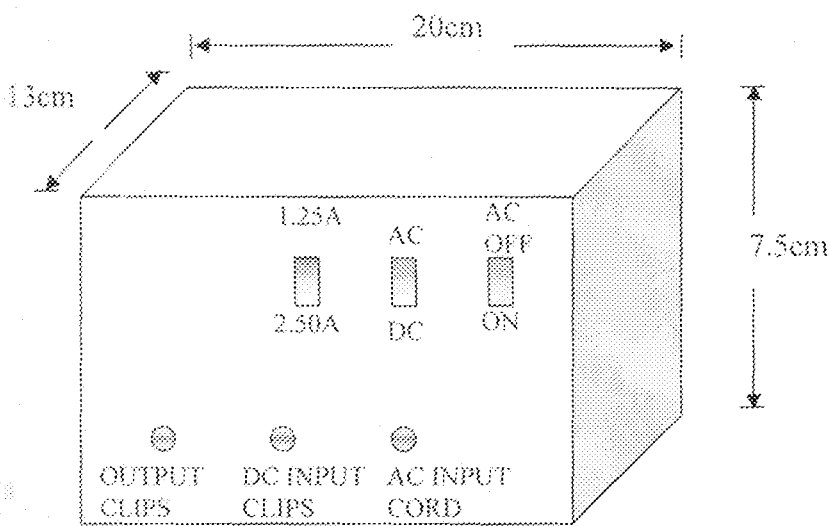
INPUT:
- DC SOURCE
- 240V AC
- CURRENT SELECTOR
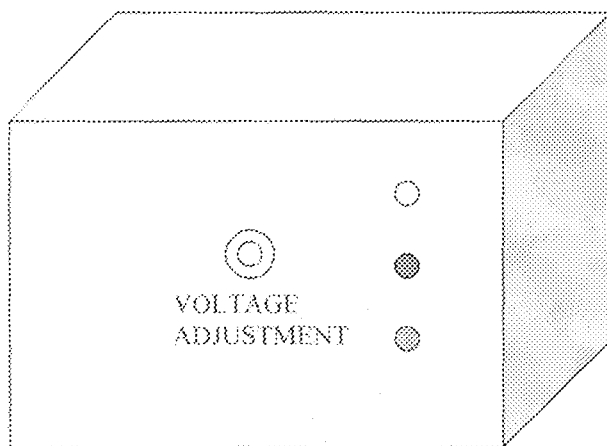
LED INDICATORS:
- WHITE (CHARGE-ON)
- GREEN (END OF CHARGE)
- RED (OVER-VOLTAGE)

Fig. 1.1: Artist Rendition

1.4   Limitations

For proper performance of the device, the following limitations must be considered.

- The circuit has to be enclosed in a case.

- The appropriate input voltages must be used, especially for the dc sources.

- The charging current of the lead-acid battery to be charged must be known.

1.5   Methodology

The purpose of this section is to analyse the different design options and to determine which ones are the most appropriate to meet the goal of designing variable output lead-acid battery charger/dc power supply. This was done by first comparing the different design approaches for each functional component of the battery charger/dc supply in order to determine feasible and still affordable designs. This was done to ensure that efforts of pursuing to design this device have merit.

Also, other lead-acid battery chargers that have been designed serve as a guide so that the project requirement will be fulfilled. Also, Technicians that use battery chargers were consulted.

After strenuous research, it was realized that, the major shortfall these battery chargers have is their inflexibility to accept different inputs such as AC and DC source use as a dc supply, variable output,. Since, variability is an absolute must for a variable output lead-acid battery charger.

There were several modules in the initial design that could be implemented in various forms, each have their own specific advantages and disadvantages. The modules were

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evaluated in terms of availability of components especially the integrated circuits, cost, ease of repair and portability.

Unfortunately, it was not possible to construct input terminal for the 110AC source due to unavailability of a dual primary dipole transformer which can be used for both 220 and 110V power source. There was problem of dc to dc converter (LM2577). But stepping down to modular level, the design was successful. All required was constructed and verified through testing.

1.6   Project Outline

The approach is to first introduce the project, after which chapter 2 reviews some previous work done on related topic. The design and implementation work were clearly indicated in chapter 3; tests, results and discussion in chapter 4. Chapter 5 is the conclusion which comprises the result obtained, problems encountered and recommendations.

Chapter Two

Literature Review

2.1   History of Batteries and Battery Chargers

In 1791, Luigi Galvani, an Italian professor of anatomy at the University of Bologna, accidentally discovered that it was possible to cause a direct or continuous flow of current along an electrical conductor by bringing two dissimilar metals into contact with moist substance.

About 1800, acting upon Galvani's discovery, Alessandro Volta, professor of natural philosophy at the University of Pavia, created the first battery "the voltaic pile". Volta assembled a series of silver and zinc disks in pairs, separating each pair with a sheet of paste board soaked in conducting liquid (salt water). When the top disk of silver was connected by an external wire to the bottom disk of zinc, current was generated by the contact of silver and zinc, whereas, it was actually developed across the salt soaked paste, which was an electrolyte.

Volta constructed pile with as many as 60 pairs of disks, but in use, the pile always dried-out and ceased to operate, forcing him finally to make a modification that he called "crown of cups". This device, consisted of a series of cups filled with salt solution, each cup containing a piece of zinc and silver. The zinc in each cup was connected electrically to the silver of an adjacent cup (cell) and the cups arranged in circles, thus making it possible to draw current from a system at a controlled rate .[4]

This achievement enabled Michael Faraday to derive the quantitative laws of electrochemistry, which established the fundamental connection, between chemical energy

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and electricity, thus opening the way for development of massive primary and secondary industries.

There are various types of storage batteries, among which are: lead-acid battery, nickel cadmium battery, silver zinc battery e.t.c. this report is based on lead acid batteries, specifically rechargeable lead acid batteries.

The lead-acid batteries are perhaps the most widely used type of rechargeable batteries. This is because it cost effectiveness and its capacity to deliver very high current as it has an extremely low internal resistance.

Other radical thinkers, however, believe that lead-acid battery technology has been around since the early days of the Egyptian pharaohs! Whether or if the "space aliens" using pyramids as their own intergalactic spaceport taught them still requires a bit more clarification [10].

As batteries are been used, their stored electrical energy also decreases until a time when it can no longer effectively discharge energy. the battery (secondary) would need to be recharged in order to restore it back to its original working state.

With the invention of secondary batteries (rechargeable), it was important to also get a suitable charger, which re-energises the flat batteries. Thus, the emergence of battery chargers came into being soon after the discoveries made by professor Luigi Galvanis's and Alessandro Volta in the late 18th century. [4].

A battery charger can thus be defined as an electronic device that can restore the life (chemical energy) of any partially or totally run down battery to its original working state.[5] Though, there are various types of battery chargers depending on the type of batteries to be recharged. This document will focus on lead-acid battery chargers (rechargeable).

The lead-acid battery charger//dc power supply has been designed as a dependable workhorse to charge and hold lead-acid batteries at their peak level, insuring a long life and maximum use.

2.2 Project Research.

The project being designed is a variable output lead-acid battery charger, which accepts a number of different inputs i.e. various forms of electrical energy. The charger/dc supply will be able to accept ac input and almost any dc input that can provide enough voltage and current needed by the charger to charge a lead-acid battery.

In order to achieve the aims and objectives of this project, various lead-acid battery chargers that have been designed were taken into consideration, which serve as a guide to make this project successful.

The first battery charger that was looked at was "a 12 volt lead-acid battery charger with automatic cut-off", designed by Adam Vasta, a final year student of the department of Electrical and computer engineering ,FUT,Minna,in year 2004. [8]

The second battery charger that was looked at was a 12 volt lead-acid battery charger with indicators that was designed by Anokwu Christopher Nkem, also a final year student of the department of Electrical and Computer Engineering, FUT., Minna, in year 2004 .[9]

Though, the first project is automatic but based on the requirements of a variable output lead-acid battery charger, it has a shortfall of accepting one input power source, output not variable and also it circuitry looks complex which will make it difficult for any technician that uses the charger to find it easy to repair incase there is fault.

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The second battery charger that was designed by Anokwu C.N. has more inflexibility than the first one, though it has indicators. But comparing it to a variable output battery charger, a number of features needed to make a battery charger variable were not met e.g. it only has one input power terminal, no voltage control and no reverse polarity to prevent charger from draining the battery.

Also, efforts were made to find out some other battery chargers that have been designed by some engineers outside the department. For example, battery minder 12 volt 5watt solar charger-voc electronics was another typical battery charger that beats the above two that was made as reference. [11]

Another battery charger that was at looked Dip light 12 volt 10 amp charger fully automatic it also has some of the features needed to design a variable output battery charger. But, the major setback of these chargers is their inflexibility to accept more than one input power source complexity and cost. [12]

In summary, what make a variable output battery charger different from the other battery chargers is its unique features like acceptance of different input power source i.e. both ac and dc, a heat sink due to excessive heat dissipated in since components, charge indicators, over voltage protection the for the dc source, surge protection, reverse polarity protection.

Chapter Three

Design and Implementation

3.1   Design Descriptions

The charger completes its task by utilizing six modules. Each module performs part of the overall function of the charger. These modules include input/output terminals, AC to DC conversion, over-voltage protection, charging circuit charging, current selector, output voltage adjustment, charging current selector, and voltage monitoring system.

3.2   Module Definition

Each of the modules in the system has a unique set of input/output specification along with operation details. These discrete specification allows each module to perform independently while working together to accomplish the overall task of charging the battery. Each module shown as part of the entire system in the schematic figure 3.2

Fig. 3.1 Functional Block Diagram

AC INPUT
(240V)

OVER
VOLTAGE
PROTECTOR

DC INPUT
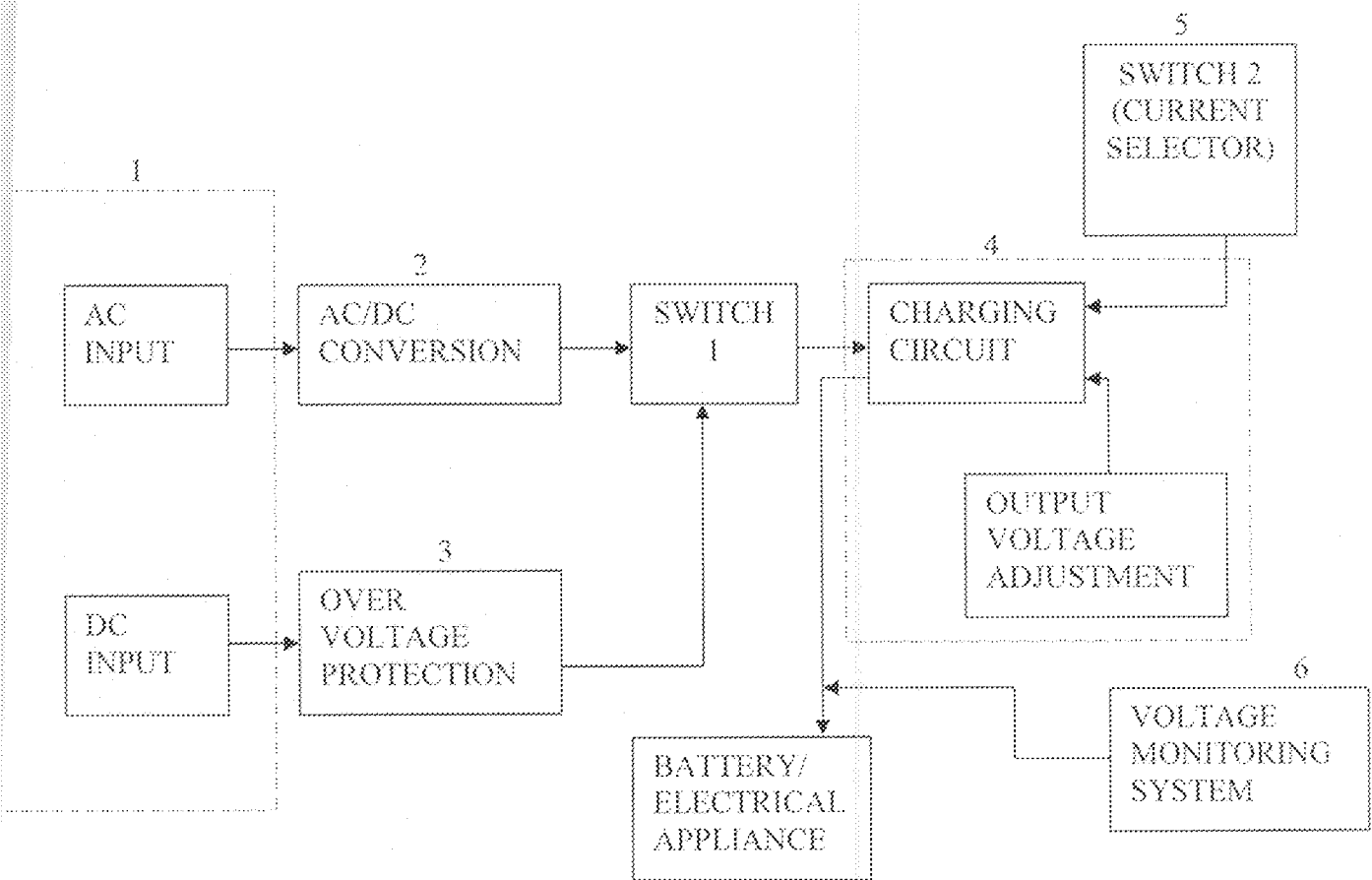
OUTPUT
VOLTAGE
MONITORING
SYSTEM
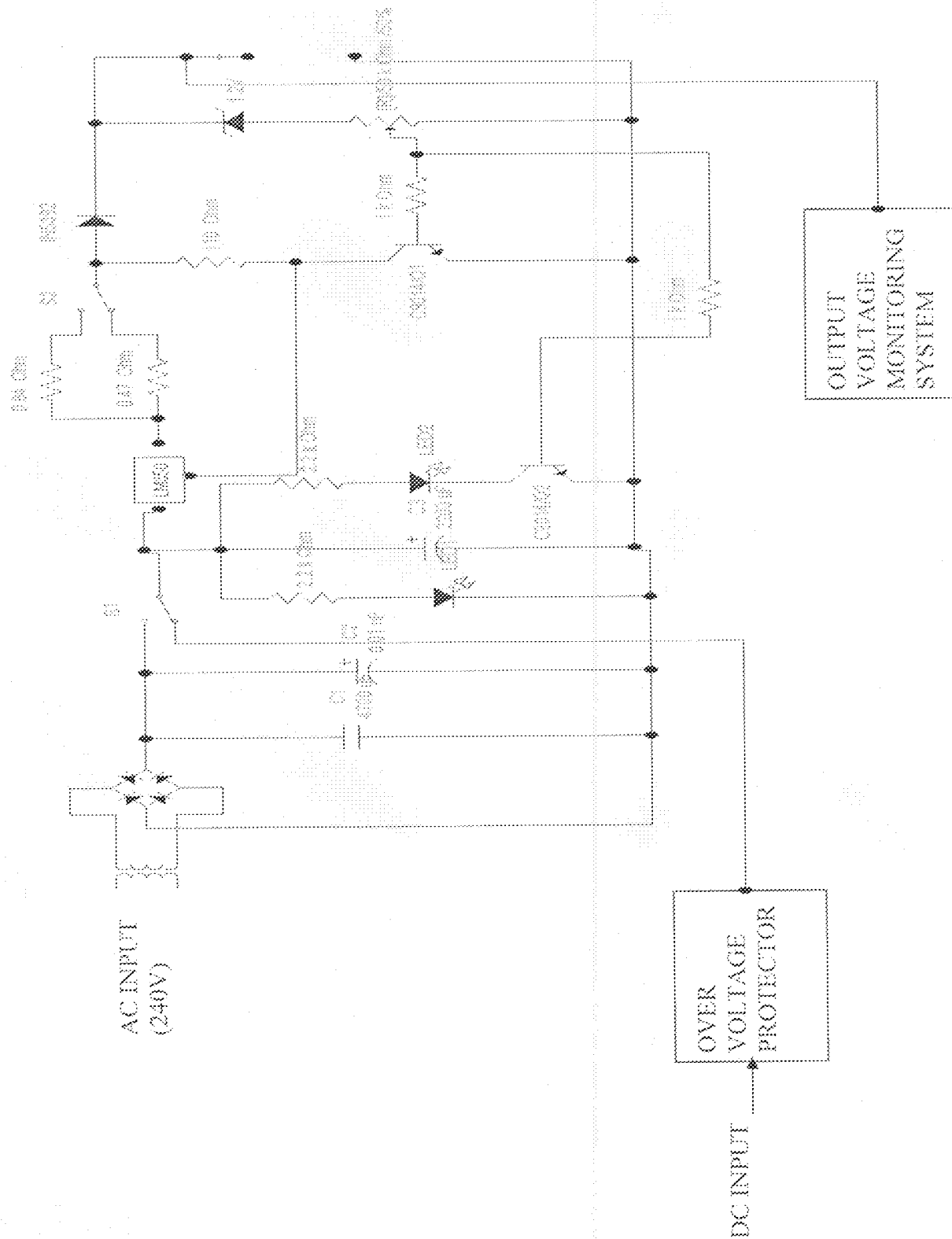
Fig. 3.2   Complete Circuit Diagram

3.3 Individual Module Analyses

3.3.1 Input and Output Terminals.

The device features input and output terminals. These allow the user to choose the type of input to be connected to the charger. And this is base on the product requirements.

- Provide input for 240V AC wall inputs

- Provide input for DC sources (e.g. solar panel and pedal generator)

- Provide output to a lead-acid battery.

Options available and advantages/disadvantages

Sockets:

This method will involve having a socket for a detachable cord for the ac input and inputs posts for the dc. It will also include posts for output to the lead-acid battery; the included cord will have banana clips to hook into the posts of the charger output and alligator clips to attach to the terminals of the battery. This method is moderately more expensive but it is very portable and easy to repair.

Cords:

This method will involve having a permanent cord for ac input as well as permanent alligator clip output to the battery. There will still be posts for the input from the dc sources. This method is less expensive but is not as portable and is not difficult to repair if the attached cords break.

Cords with posts:

This method will involve the permanent ac input cord as the only permanent cord. This design will include post for the dc input as well as posts for the output to the battery.

This method is more expensive than the cords method, but less than the sockets method. This method is also less portable than the sockets but more portable than the cords method.

The one that was used for this device is the cords due to the above analysis. Given the mechanical nature of this module, any and all input voltages will simply be passed through to the next module. This can be seen in figure 1.1

3.4 AC to DC Conversion

This module will consist of a transformer that will step down the ac voltage from 240V to 15V AC by means of a 16: 1 primary – secondary turn's ratio transformer. Then, this will pass through a full wave bridge rectifier and then filtering capacitors to achieve close to dc voltage of 19.8 volts. Without this unit, the ac input source can not be use and the charger would be next to useless.

3.4.1 Transformer's Action

Using a 15volt transformer places an upper limitation to the maximum voltage that can be drawn from the charger system. The maximum voltage at 100% efficiency and a full 240v input is:

$$15\sqrt{2} - (2 \times 0.7) - 1.25 = 18.56V$$

Where $15\sqrt{2}$ gives the maximum (peak)secondary voltage: $(2 \times 0.7) = 1.4$ volts, forward voltage drops of two forward biased diodes in the bridge rectifier; 1.25 volts an internal reference voltage in the LM350.[7]
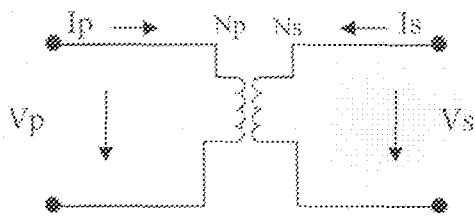
Fig. 3.3 schematic of a step down transformer

Let Np and Ns be the number of turns of coil in the primary and secondary respectively. Assuming that the magnetic coupling between the primary and secondary windings is 100%; that is all the primary flux links the secondary coils. In such cases, the turn-ratio and voltage ratio are related by the formula $\frac{Np}{Ns} = \frac{Vp}{Vs}$ = constant = turns per volt per ratio

Vp = primary voltage

Vs = secondary voltage [3].

In search for the proper transformer, many factors such as input-voltage, output voltage, output current and price. Since the primary function of a transformer is to step down large A.C signals to small ones. There is or need to make sure that the transformer would handle 240V AC standard.

One of the biggest problems encountered was the difficulty involved in getting this dual primary transformer. Instead, a single AC source transformer was then used (240 AC). And this lead to some changes in the initial circuit design. For the output needed, it was made sure that the transformer would be able to produce 15V AC with a current of 3A. The output requirement of the transformer comes directly from the input requirements of charging circuit.

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Table 3.1   Transformer Specification

Terminals	Quick Connect, solder
Input voltage	240V AC
Output voltage	15V AC
Output current	3A

3.4.2 Rectification

Following the transformer output, the next stage is in the AC/DC conversion process involved inverting the negative cycles of the AC input. The process requires the use of a full wave bridge rectifier. The required specification for the bridge rectifier was determined based in the input voltage and current. It was determined that the rectifier would have to be able to handle the peak voltage of $2/.2V(5\sqrt{2})$ along with voltage spikes from the dirty line, as well as the 3a that the charging circuit would be pulling.

The 15V AC source is rectified using a 5A encapsulated silicon diode bridge rectifier to yield $19.8v$ $(15\sqrt{2} - 2 \times 0.7)$. The bridge rectifier, is one device inside a four terminal casing (encapsulation)

Table 3.2   Bridge Rectifier Specifications

Diode/bridge type(encapsulated)	Bridge
Voltage ratings	50V
Current rating	5A
Packaging	bulk

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3.4.3 Filtering

A filter refers to that circuit which is capable of converting a pulsating output from a rectifier into a very steady DC level i.e. it minimizes the ripple content in the rectifier output. The rapidly pulsating DC voltage is smoothened by a 4700nF capacitor and by passed by a 0.01nF capacitor for improved noise performance. This output is taken to a selector switch that select between AC source and external DC source.
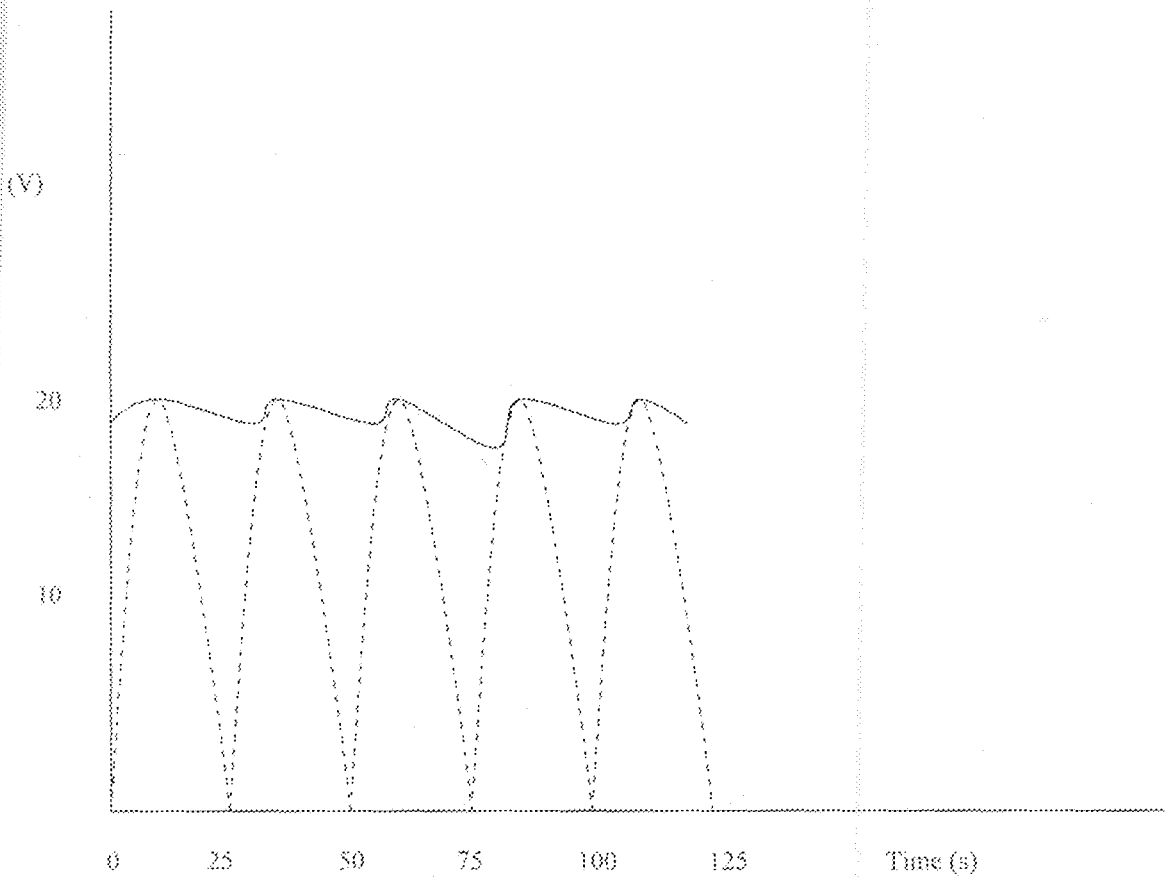
Fig 3.4 transient analysis with 4700µF capacitor

AC/DC converter schematic with 4700nf and 0.01nf capacitors is shown below
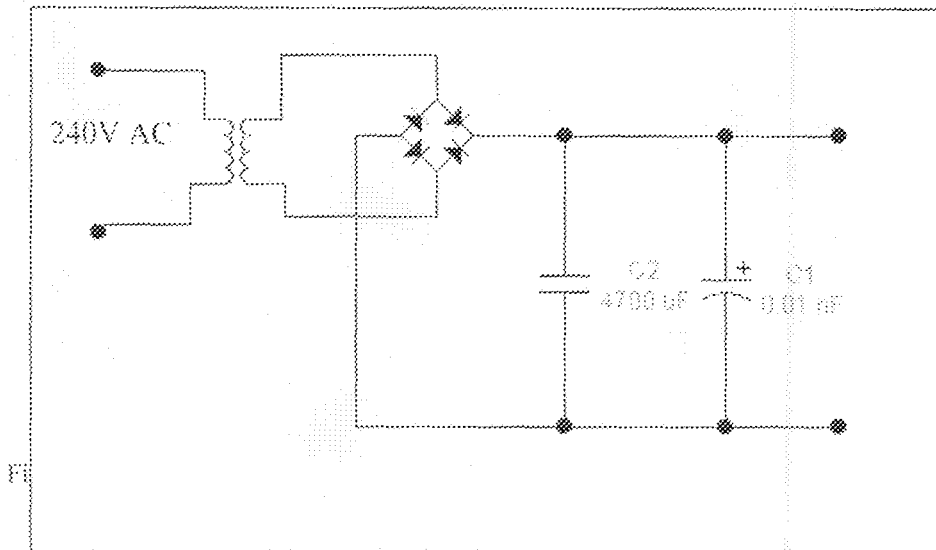
Fig. 3.5 AC/DC conversion circuit

3.5   Over-Voltage Protection

3.5.1   Solar Panel:

One of the DC inputs to the charger comes from solar pane. Solar cells are one of the main portable power sources. Inherently, they provide a constant current which is dependent on light intensity and other uncontrollable variability in the environment.

Unlike all the cell types, the solar cell is constructed from silicon-based pn- junction. Electric current is obtained through the photovoltaic conversion process instead of electro chemical process. A single solar cell can generate emf up to 0.5V. Higher output voltage or current can be obtained by connecting as many cells as possible together in series or parallel.

Many cells are usually stung together to form a larger panel, which may supply as much as several hundred watts of power under ideal lighting conditions. Typical panels are

able to drive loads in the 10 – 30 volt range, making them suitable for 12 and 24 volt applications at several amps.[3]

3.5.2 Pedal Generator

Human powered generators are another possible source of power to charge batteries. A typical bike monted generator can be expected to provide as much as 200watts at voltages in the 10-30 volt range. This makes interfacing a bike generator very similar to interfacing a solar panel. However, the charger can accept any DC source that can provide the charging voltage, apart from these two DC sources mentioned above.

Charging batteries with solar power involves connecting the solar pane directly to the battery in a "take what you can get" method of charging. This will quickly charge the battery up to approximately 80%. Although, charging the battery by hooking up to the battery directly to the solar pane could overcharge and damaged the battery. In order to prevent this: brought about the use of over-voltage protection.[11]

3.5.3 Over Voltage Protector.

This module is incorporated for two principal reasons:

i.   To protect the LM350 against excessive input-output differential voltage violation:

ii.   To protect circuit components from voltages exceeding their maximum ratings
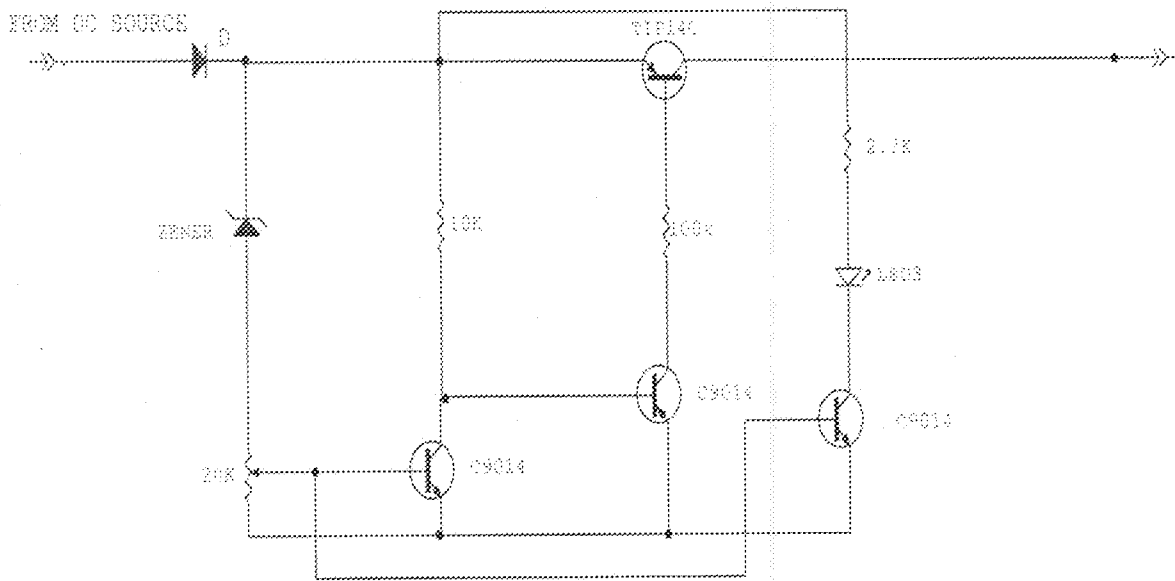
OVER VOLTAGE PROTECTION CIRCUIT

Fig. 3.6 Over Voltage Protection Circuit

The over voltage monitoring circuit shown above, makes use of three 9014 transistors and a 4A pnp TIP42 transistor which is used as a power switch. The module works on the basis of detecting an out of range voltage level at the input. This out of range voltage is sensed by a 16V zener diode shown below;
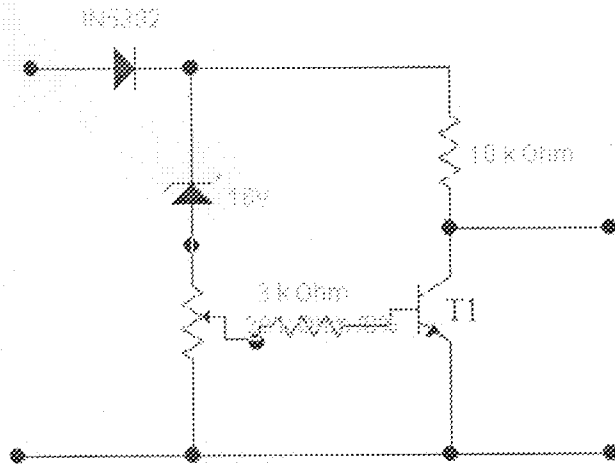
Fig. 3.7 Switching of Over Voltage Protector

To switch on at any input level is determined by the relative ratio of Ra and Rb. When T_1 turns on, it collector-emitter voltage gives low enough to switch off T_2. This is effect forces T_3 off, cutting of the input supply sources from the output.

At the same instant that T_1 switches on, T_4 also switches on, causing LED 1 to glow.

Calculation:

For T_1: $V_c = V_{cc} - I.R_c$

$I_c = h_{fe}I_b = \beta I_b$

For the transistor used, $\beta = 347$

$I_b = \dfrac{V_{in} - V_{be}}{R_b}$
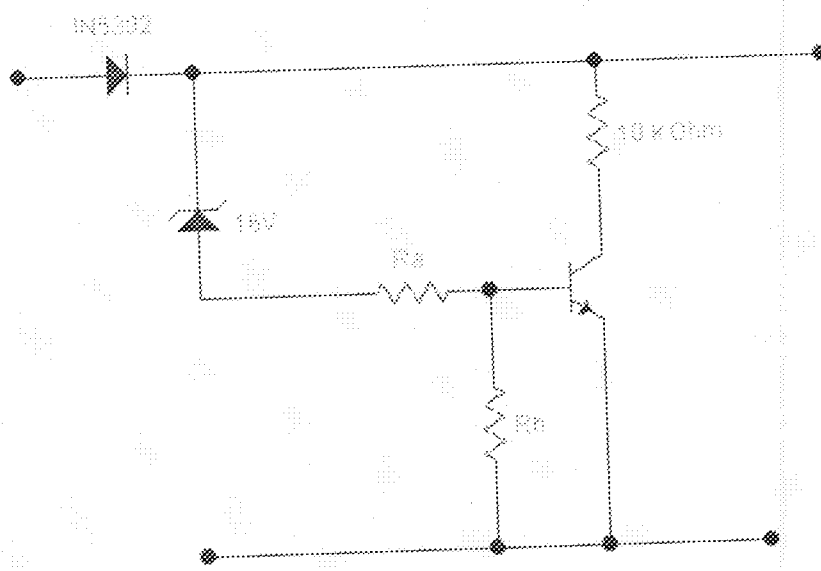
Fig. 3.8 part of voltage protection

A cut-off voltage of 30v on the auxiliary DC input was chosen. Using this value of

Vcut-off, other circuit parameters can be calculated.

$$\frac{(30 - 16) \times R_b}{R_a + R_b} = 0.7V$$

$R_a + R_b$ has a total resistance of 50kΩ. Therefore:

$$0.7 = \frac{(30 - 16) R_b}{50k\Omega}$$

$$0.7 = \frac{14 R_b}{50 \times 10^3}$$

$$14 R_b = 0.7 \times 50 \times 10^3$$

$$R_b = \frac{35000}{14} = 2500\Omega = 2.5k\Omega$$

Since $R_a + R_b = 50k\Omega$

$R_a = 50000 - 2500 = 47500 = 47.5k\Omega$

Thus, the circuit can be redrawn as shown below:
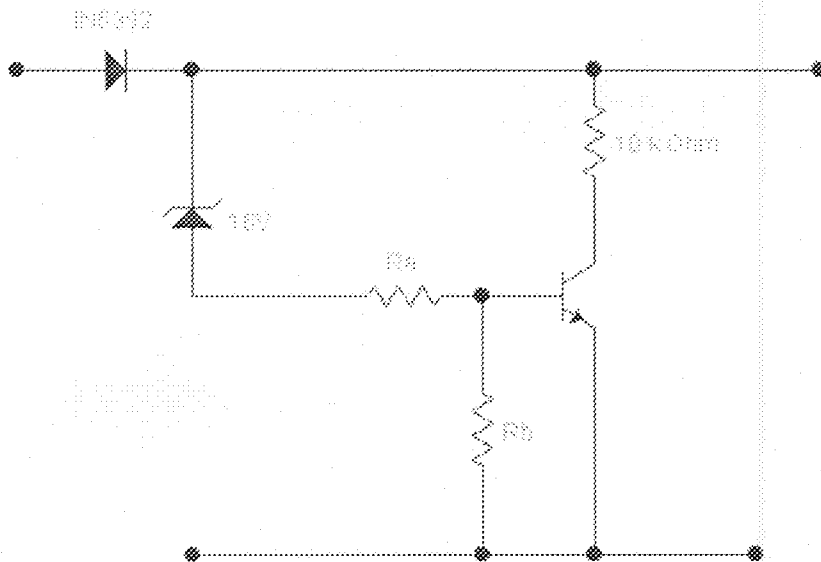
Fig 3.9 part of over voltage protector

$I_b = V_{be} = 0.7 = 2.8 \times 10^{-4} A$

Using $I_c = \beta I_b$; $I_c = 347 \times 2.8 \times 10^{-4} A$

$= 0.09716A$

$V_{cb} = V_{cc} + I_c R_c$

$= 30 - (0.09716 \times 1000)$

The above equations yields a negative value. thus, can be explained, though not feasible in the circuit above. If the transistor is hard on, i.e. fully saturated, $V_{cb} \approx 0V$. The equation ideally holds when the transistor is not 100% on.

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At saturation T_1 pulls its collector to zero, shunting of the base drive to T_2. Correspondingly, T_2's collector, connected to the base of T_3 is pulled high. The circuit can again be represented as:
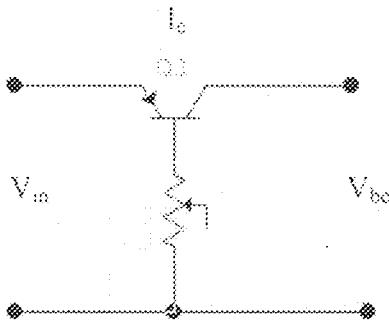
Fig. 3.10

T_2 can be considered as a variable resistor with a value that is either very low (saturated), or very high (cut off). At saturation, the resistance is approximately on zero ohms. In practiced, the base of T_3 is connected to ground through, the 100Ω resistor.

I_b is thus $\dfrac{V_B}{R_B} \cong \dfrac{V_{be}}{R_B}$

for the TIP42, V_{be} = 24V. Using the above expression I_c collector current needed to be sourced by T_3 is 3A maximum with an h_{fe} of typically 40:

$I_c = \beta I_b$, $I_b = I_c/\beta = 3/40 = 0.0075A$

TIP42 has a V_{be} of 2.1V

thus $I_b = V_{be}/R_b$

$0.0715 = 2.1/R_b$; $R_b = 2.1/0.0715 = 28\ \Omega$

A 100 Ω resistor was substituted, which give a better beta-spread and changes of the transistor parameters with operating conditions. In summary; if T_2 is off, T_2 and T_3 are on, then, V_c or $T_3 \approx V_{in} - V_{sat} \approx V_{in}$

if T_1 is on , T_2 and T_3 are off, then,

V_c for $T_3 \approx 0V$.

LED1 provides a visual over-voltage cut-out indication, turning on when the input voltage exceeds a predetermined level.

3.6 Charging Circuit and Output Voltage Adjustment Module

This module consists of a three-terminal variable out-put regulator. This module is designed around an LM350 adjustable positive voltage regulator. The regulator is capable of supplying in excess of 3A over a 1.2 to 33v out-put range.

3.6.1 Charging Method

The type of battery to be charged determines the charging system/method to be employed because there is a wide range of charging system available. Each of which has its advantage over the other in terms of efficiency, cost, and reliability.

Charging a lead acid battery is a matter of replenishing the depleted supply of energy that the battery had lost during use. This replenishing process can be accomplished with several different charger implementations: constant voltage charger, constant current charger or a "Multistage" constant voltage/ current charger. Each of these approaches has its advantages and disadvantages that need to be compared and weighed to see which one would be the most practical and realistic to fit the requirements.

3.6.2 Constant Voltage Charger:

Constant voltage charging is one of the most common charging methods for lead acid batteries. The idea behind this approach is to keep a constant voltage across the terminals drawn from the voltage source, but as the battery charges and increases internal voltage, the current will slowly fold and decay exponentially. When the battery is brought up to a

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potential full charger which is usually considered around 13.8V, the charging voltage is dropped down to a lower value that will provide a trickle charger to maintain the battery as long as it is plugged into the charger. The best characteristic of this method is that it provides a way to return a large bulk of the charge into the battery very fast. The draw back, of course, is that a complete full charge would take a much longer time since the current is exponentially decreased as the battery charges.

3.6.3 Constant Current Source

Constant current charging is another simple yet effective method for charging lead-acid batteries. A current source is used to drive a uniform current through the battery in a direction opposite of discharge.

This can be analogous to poring water into a bucket with a constant water flow, no matter how full the bucket is; constant current sources are not very hard to implement; therefore, the final solution would require a simple design. There is a major drawback to this approach. Since the battery always is being pushed at a constant rate, when it is close to being fully charged the charger would force extra current into the battery, causing over-charge. The ability to harness this current is the key to a successful charger. By monitoring the voltage on the battery, the charge level can be determined, and at a certain point, the current source would need to be folded back to only maintain a trickle charge and prevent overcharging.

3.6.4 "Multi-Stage" Constant Voltage/Constant Charging Solutions

Both constant voltage and constant current approaches have their advantages; that is the reason multistage chargers have been developed which combine the two methods to achieve maximum charge time, with minimum damage to the charging cell.[12]

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It is exceptionally easy to use and requires only two external resistors to set the output voltage. The lm 350 offers full overload protection, current and thermal limiting, and safe are protection.

This regulator is "floating" and sees only the input-output differential voltage. Therefore, supplies of several hundred volts can be regulated as long as the maximum input to output differential is exceeded. By connecting a fixed resistor between the adjustment pin and output, the LM350 can operate as a precision current regulator.[2]

Table 3.3 LM350 specification

Package	Metal can package
Terminals	3
Current output	3A
Output voltage range	1.2V – 33V
Output voltage tolerance	1% of output voltage
Temperature range	$0°C < T_j < +125°C$
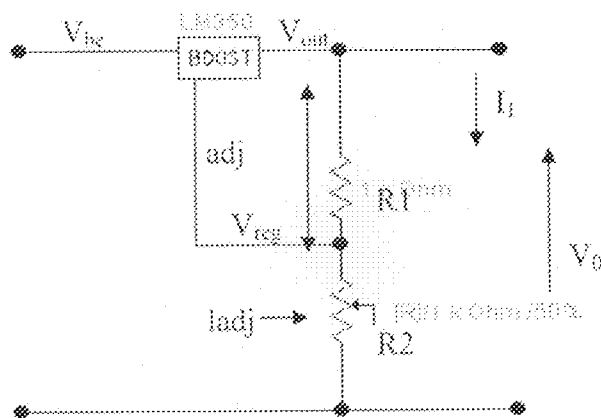
Fig. 3.11 LM350 (Regulator)

In operation, the LM 350 develops a nominal 1.25V reference voltage. V_{reg} between the output and adjustment terminal. The reference voltage is impressed across the program resistor r, and since the voltage is constant, a constant current I, flows through the output set resistor r2, giving an output voltage of $V_{out} = V_{Reg}\left(1 + \frac{R2}{R1}\right) + I_{adj} R2$

Iadj represents an error term and the regulation is designed to minimized this and make it constant with the line and load charges. For this to output establishing a returned to the output minimum load current require, if there is insufficient load on the output, the output voltage rises.

The LM350 is capable of providing extremely good regulation. Ordinarily, the lm350 regulator is configured for voltage regulation as indicated earlier on. In the current regulation mode, a constant 1.25V reference is developed across R, shown below. Hence, the LM350 is wired as below, with an output load current that is a function of R, in conjunction with the reference 1.25V. [2]
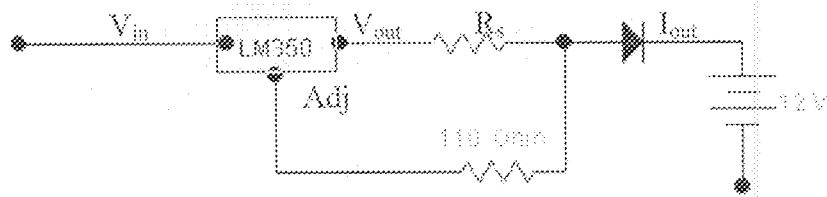
Fig. 3.12

$$I_{out} = \frac{V_{ref}}{R_s} = \frac{1.25}{R_s} \qquad 0.400 \le R_s \le 12000$$

The two basic configurations of the LM317 are embodied in the constant-current/constant voltage regulator as depicted below.
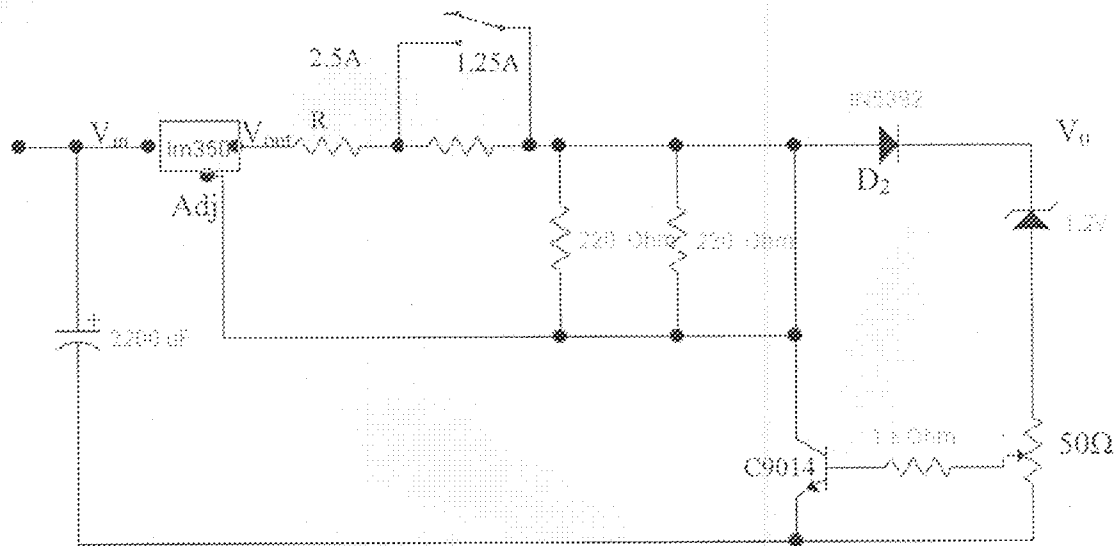
Fig. 3.13 Charging and Voltage Adjustment Circuit

3.7 Charging Current Selector

The charging current selector module enables the user of the charger to select an appropriate charging current for a particular lead-acid battery (rechargeable). The magnitude of the charging current employed is given by $I_{charge} = 1.25/R_s$,
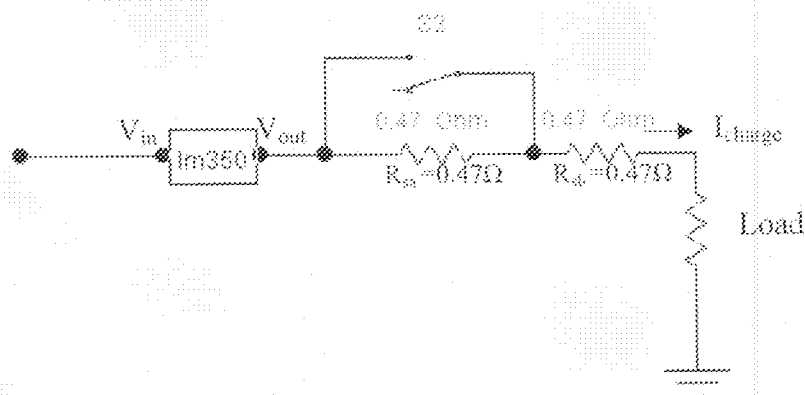
Fig. 3.14 Charging Current Selector

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Rs comprises two 0.47Ω resistors in series connection. The actual initial charging current is directly determined by how much resistance is Rs. From Figure (3.14), with the switch at position 1, R_{sa} is shunted out of the current programming loop, leaving only R_{sb} wired into the circuit, at switch position 1.

I_{charge} (initial) = 1.25/0.47 = 2.66A.

With the switch at position 2, the total serves resistances of R_{sa} and R_{sb} now determine the maximum initial charging current.

I_{out} = 1.25/0.47 + 0.47 = 1.33A.

Thus, by the setting of the charging current switch, two different initial currents can be selected to give the best performance for a given battery specification.

3.7.1 Charging Action

When a rundown battery is connected across the output terminals of the LM350 regulator, the C9014 transistor T_1 is cut, so also T_2 and the circuit reduces to
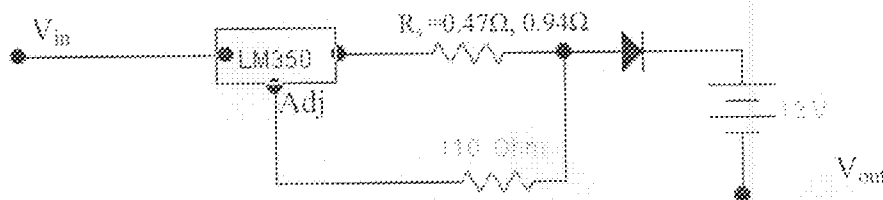
Fig. 3.15.

The regulator force a constant charging current of (1.25/Rs) A into the battery. The IN5407 diode prevents back discharge in the events of loss of input charging voltage. Thus the regulator operates in the constant-current mode.

As battery voltage terminal rises, $V_d = V_{out} - V_2$ rises. At an output voltage, the charger switches over to the constant voltage mode, holding the battery terminal voltage at a level by V_{out}.

The variable output voltage adjustment makes it versatile since a wide range of lead-acid secondary cells can be charged.

An end of charge indicator is provided to generated a visual end of charge notification. The base voltage of T_1 controlled by the voltage adjustment control. With the system connected to a rundown battery, T_1 and T_2 are both cut-off, the charger is in constant current mode, and the ε_{oc} indicator LED is off.

As the battery charges, its terminal potential rises, and the base voltages of T_1 and T_2 rise. Higher the battery terminal potential sources greater the base currents into T_1 and T_2. It is pertinent to note that the EOC (end of charge) indicator is not an on-off switched indicator, but rather a gradually switched indicator whose brightness increases as the battery charges up. At full charge the EOC indicator is fully lights.

3.8   Voltage Monitoring System.

This module is made up of a digital multimeter. This module enables the user to choose the appropriate charging voltage for a particular lead-acid battery.

This can simply be achieved by connecting the output cords of the digital meter (taken not of the polarity) to the output cords of the charger. To choose any charging voltage, the output voltage adjustment is turned clock-wise until the desired output voltage needed is displayed in the digital meter.

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It would have been better to design an in-built digital meter for this charger, but due to the fact that it will make the circuitry of charger more complex, therefore a separate digital meter was used instead. This module has some added advantages to the charger like;

- Enable user to monitor (choose) the appropriate charging voltage for any lead-acid battery (rechargeable).

- It increases the flexibility of the charger.

- It avoids unusual damage to battery, since the desired output is always displayed

Chapter Four

Test, Results and Discussion

4.1 Testing

AC/DC converter was tested in three stages. The first stage was the transformer connected to a load. The output was measured and confirmed that it would meet the charger's voltage requirement. The second stage was the transformer hooked up to the rectifier and to a load. The inversion of the negative cycle of the ac input was verified. The third stage, the ripple voltage to make sure it met the voltage requirements was measured. Though, only the transient response of the transformer with rectifier filter capacitor was shown. See figure.

4.1.1 Charging Circuit

Several methods were used to test the charging circuit, using different kinds of loads to stimulate the battery, the first method is that several high power resistors and variable resistors were used to verify the operation of the charger. The circuit was tested on an actual battery to verify the charging algorithm.

4.1.2 Output voltage adjustment, battery indicators and digital-meter.

The power supply was used to test the turning on and off of the leads. The output voltage adjustment was tested by connecting the charger to actual battery, while turning it to verify the output voltage through use of the digital meter. This was done to ensure that the charger output voltage, does not exceed the required input voltage for the lead-acid battery.

4.1.3 Charging Current Selector

This was simply tested by using various type of lead-acid batteries with different charging currents that falls within the range of 1.25 – 2.5A (standard). The operation of this current selector was verified by testing the charger on actual batteries.

4.1.4 Over Voltage Protector

The dc source over voltage protector was not tested due to the difficulty involve in getting a dc source to supply the required voltage.

4.1.5 Prototype Results/ Final Design

Consisting of only a transformer, 4700µF and 0.01nF capacitors, bridge rectifier (encapsulated), constant voltage/current regulator (LM 350), variable-resistors, resistors, prop tip42C transistor, npn C9014 transistors, LEDs, input alligator clips and cord, output alligator clips, the final implementation came out to be very simple and functional.

Module status.

4.1.6 Module Status

AC/DC conversion

Table 4.1: AC/DC Module Status

Functionality	Converts ac input into dc
Implementation	Rectified primary transformer (240V AC) signal
Input	240V AC
Output	15v rms DC @ 3A
Status	Built and implemented

The AC/DC conversion module worked as expected. It output the correct voltage.

Over Voltage Protection.

Table 4.2 Over Voltage Protection Module Status.

Functionality	Provide protection from high dc voltage for the dc input time
Implementation	Protective circuit
Input	DC from outlet of solar/pedal generator.
Output	DC signal without excessive voltage
Status	Built and implemented

This module was built and implemented but was not tested. There is confident that, if tested it would work as expected.

Charging Circuit and Output Voltage Adjustment.

Table 4.3 Charging Circuit Output Voltage Adjustment Module Table

Functionality	Provides control of the charger and output voltage
Implementation	Voltage regulation
Input	1.2V – 35V
Output	19.8V (adjustment dependent)
Status	Built and implemented

The charging circuit and the output voltage adjustment both worked completely as expected but there is an inherent design problem since the charger is built around a linear regulator, heat description from some of the components create problem, but this was addressed properly by using an heat sink for the LM350.

Indicators.

Table 4.4 Output Voltage Monitoring Systems and Charger Indicators Module Status.

Functionality	Displays output voltage and indicate ON/OFF of the charger, over-voltage, end of charge	
Implementation	3 LED array	
Input	Input voltages (AC and DC)	
Output	Each LED turns ON, depending on the chargers condition.	
Status	Built and implemented	

Also, the device was tested base on its use as a

i.   battery charger

ii. dc power supply

This was done in order to confirm whether the aims and objectives of this project have been fulfilled.

4.2   Results

The following results were obtained when the device was used as a battery charger. It was used to charge two different types lead-acid batteries with different charging currents while using the ac sources.

- For six volts lead-acid battery with maximum charging current of 1.35A

Table 4.5 result of 6V battery

Time (Mins)	Measured battery voltage (Volts)	
0.0	0.19	
15.0	1.9	
30.0	3.85	
45.0	4.8	
60.0	6.56	

- For a 12volt lead-acid battery with maximum charging current of 2.5A

Table 4.6 Result of 12V battery

Time (mins)	Measured battery voltage (volts)	
0.0	0.72	
30.0	2.10	
60.0	4.38	
120.0	6.48	
180.0	8.65	
240.0	10.90	
300.0	12.96	

The device was not tested using any dc source, due to unavailability of the dc source that would provide enough charging voltage, but there is certainty that if tested, it would work as expected.

ii.   As a power dc supply

The device worked as expected as a dc power supply it was tested using some electrical appliances that have to input terminals for dc supply e.g. a 12 volts dc audio amplifier, a 6volts rechargeable lamp.

4.3   Discussion of results

From the results obtained, for operating the device as a battery charger, the following analysis can be made. It is well known that the capacity of lead-acid batteries is rated in ampere-hour (Ah). This capacity depends, in the discharge rate of the battery.

In the table below, is a comparison between the variable output battery charger and ordinary battery charger. The time it will take each charger to charge 6v and 12v lead-acid battery using ac sources.

Table 4.7 Final Result

Lead-acid battery rating (volts)	Full charge time of variable output lead-acid battery charger (min)
6.0	60.0
12.0	300.0

From the above results, there is a full charge time difference for each battery tested using the charger.

Factors that might affect the full charge time of the new device are:

a) Unstable power supply

b) Operating the device in environment with temperature above 45oc

c) Wrong selection of charging current.

d) Wrong setting of desired output voltage.

4.4 Guides on How to Use the Device as a Charger

- For ac input, connect the input cord to nearby socket

- Likewise for dc source connect the dc input alligator clips to dc source. If it is the desired source.

- Select the appropriate source by using switch 1 (ac or dc)

- The first led should be on to indicate that the charger is functioning.

- Select the appropriate charging current for the battery to be charged. This can be known by looking at the charging current written on the battery. Use switch 2 for this.

- Connect the meter to the output terminals of the charger.

- Adjust the output voltage, adjust until the desired voltage is displayed on the meter. NB: this must be done before connecting the charger to the battery

- Now connect the battery to be charged, to the output terminal of the charger taken note of the polarity.

- Incase there is an over voltage from the DC source the third LED will be ON to indicate over voltage.

- At full charge of a battery, the second LED (green) will on to indicate end-of-charge. NB: there is no problem if the green LED ON's when charger is not connected to a battery.

4.5 Guides on How to Use the Device as a Power Supply

— The guide lines are the same as that of charging operation. The only difference is that the device should be connected to the dc input terminal of the appliance to be used for.

Chapter Five

Conclusion, Problem Statement, and Recommendations

5.1   Conclusions

The main goal of this project was accomplished, and that is the design and construction of a working prototype for lead-acid batteries. In this project, a lot was learned more than just to make a simple variable output lead-acid battery charger/ power supply, and drawing upon the knowledge from previous departmental classes. Indeed, many things about being an engineer was learned, things that could not be taught in normal text book/lecture type of course.

In summary, a lead-acid battery charger will be able to accept the standard 240VAC input and almost DC input that can provide enough voltage and current to charge lead-acid batteries. The charger output can be varied by tuning, the output adjustment.

The operation of the charger can be monitored through the LEDs and the digital meter. Inputs cards and output clips were also provided to make charging easy. Labelling was also done in English to make it easy for any user to operate the charger.

5.2   Problems Encountered

During the course of carrying-out the design of this project, various problems were encountered which led to some changes in the actual design. Some of these problems are as follows:

- Unavailability of some components in the market

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- Difficulty involved in testing modular circuit.

5.3 Recommendations

In an ideal situation, design process would never end. Continued improvements, evaluation of options, and rethinking can always be done. In the real world, however, there are dead lines and limits to resources. With that in mind, here are some recommendations to any who might take on the project and continue from where it was left.

The most important aspect of the design to be improved upon is the DC sources i.e. constructing a dc to dc converter for the device to enable have a wider range of dc voltage sources.

In other areas of continued work involve extensive improvement and testing of the over-voltage protector and other modules which will yield more important information about how well the choice of components will endure the rigor of the real world.

Initially, the actual design-concept is designing of a universal 12 volts lead-acid battery charger, but this idea was not implemented due to unavailability of some components which would have made the idea a reality i.e. these components are;

- dual prime-transformer (110V/220V AC)

- DC to DC converter (LM2577) or its equivalent.

- Charger level indicator.

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