Design and Construction of a High Power Professional Solar Charge Controller

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Design and Construction of a High Power Professional Solar Charge Controller

A Project Report submitted to the
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ELECTRICAL AND ELECTRONIC ENGINEERING

By

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Session: 2011-2012

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The Project titled **"Design and Construction of a High Power Professional Solar Charge Controller"** submitted by Mohammed Afzal Hossain Bhuiyan, Student No. 062201, Session: 2011-2012, has been accepted as satisfactory in partial fulfillment of the requirement for the **Degree of Master of Engineering in Electrical and Electronic Engineering** on 04th March, 2012.

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DECLERATION

I hereby declare that this project or any part of this project has not been submitted elsewhere for the award of any degree or diploma.

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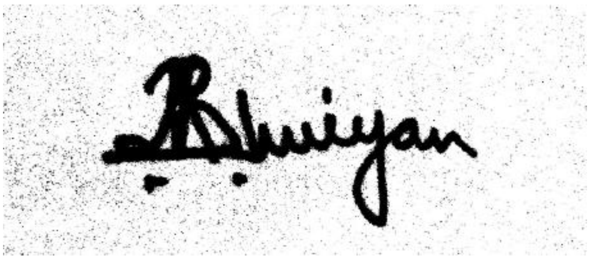


(Mohammed Afzal Hossain Bhuiyan)

ABSTRACT

The main goal of this project is to use the solar power in large scale to charge storage batteries. Recent technological developments in thin-film photovoltaic (PV) cells are leading to new generations of portable solar arrays. The professional high power solar charge controller is used in the lazar (PV) system to maximize the PV output power, irrespective of the temperature and irradiation conditions. It protects batteries from any kind of electrical disturbance, i.e. overcharging, over loading, deep discharge and all kinds of transient effects. It consists of battery charge control unit, battery voltage level indicator. Lode & charging status indication system, deep discharge alarm and indication system. The used model can be easily modified to fit data from different batteries.

In the first stage of the project, a solar charge control unit was designed and constructed accordingly. In this part, how the battery is being charged from solar panel would be seen. Protection systems, like overcharging, disconnection the PV array from the battery during night have been ensured in this part.

In the second stage, battery voltage level indication unit was designed and constructed. It will ensure whether battery is charging or not. It will display battery voltage level. Four LED will indicate different voltage levels.

In the third stage of the project, other protection units like over load protection unit, under voltage protection unit and short circuit protection units have been designed and constructed accordingly.

When there will be deep discharging in the battery or voltage in the battery terminal will be lower than the rated voltage, deep discharging protection unit will disconnect the load from the battery.

It can be modified very easily in a higher rating capacity; simply replacing some relate components by higher rating ones. These components are available in the local markets and cheaper. The solar charge controllers available in the market are of 20

Contents

Chapter 1

INTRODUCTION

1.1 Background of the Project

Energy is a basic need of human society and has rightly been termed by many as the "life-blood" which keeps human civilization progressing. Without adequate access to modern energy, poor countries can be trapped in a vicious circle of poverty, social instability and underdevelopment (World Energy Council 1999). One such energy starved country is Bangladesh. In 2003, Bangladesh's energy consumption per capita was only 157 kilograms of oil equivalent (Kgoe) which is one-tenth of the world's energy consumption per capita. Bangladesh's endowment of conventional energy resources is neither adequate nor varied, as a result of which it suffers from an acute energy crisis and crippling power shortages. However, Bangladesh is endowed with relatively abundant renewable energy resources such as solar and biogas energy.

The main objective of the study is to explore the extent to which renewable energy technologies (RETs), such as solar home systems (SHS) and biogas digesters, can provide reliable and affordable energy services in the rural regions of Bangladesh. While world powers continue to debate on climate change and who should take more responsibility for saving the world, an ambitious green energy program in Bangladesh is banking on the poor to find a sustainable solution.

In a country, like Bangladesh, of 160 million, where 80% people live in poverty and 70% have no access to grid electricity. They have to rely on highly polluting Kerosene oil and diesel generators for lighting and depend on bio-mass, wood, cow dung and crop residue for cooking, which not only create indoor pollution but, through misuse of resources, lead to deforestation, soil erosion and floods. The research & exploration of solar energy to use in Bangladesh is started in 1996.

Grameen Shakti a famous NGO in Bangladesh has targeted to have one million solar home systems, by Solar Charging installations by 2015. They planned to achieve this through promoting local entrepreneurs who will market, install, and carry-out repair and maintenance activities at the local level.

From an excellent beginning of 228 homes in 1997, Grameen Shakti now powers over 135,000 homes, currently adding 5,000 homes every month using photovoltaic technology. Three million trees have been planted under the plantation scheme.

A World Bank report stated that if a million solar home systems could be implemented in Bangladesh by 2015, it would be able to reduce an estimated 48,000

tones of CO_2 emission a year by replacing kerosene and diesel generators. Bangladesh is a country of tropical weather. It has the great potentiality to utilize solar energy 8 hours/day in average through the year except winter having two months. In winter the average is 6 hours/day.
Solar home systems generally supply electricity at night time for 4 to 5 hours only from battery backup. Hence these systems wouldn't be popular in areas where electricity is available. It is found that in rural areas where electricity is available, the consumers are deprived of smooth electricity. They can get electricity for few hours. Hence solar energy might have tremendous demand where grid electricity is not available. If 1% area of Bangladesh is covered by 10% efficient solar panels, electricity generation would be 40000MW, reported by Grameen Shakti.

The solar system involves a photovoltaic panel that converts sunlight into electricity, a battery that stores the electricity, a charge controller that regulates charging and discharging of battery, a load like, fluorescent tube lights, installation kits and connecting devices. Normally a fast rate charger is not "smart" and cannot detect when the battery is fully charged, then overcharging is likely, which also damages the battery. Similarly to over discharging condition.
Due to these drawbacks and lifespan improvement process of these types of batteries like lead-acid batteries if we use High Power Professional Solar Charge Controller (SCC) properly then lifespan of batteries can be extended. Basically here it's controlled that battery charging rate is kept normal, not fast or slow. The discharge limit will not go under the 40%. The SCC can sense according the program that when it's needed to give charge and when at nearly full charged it's needed to cut off from the solar panel. For further operation this proposed SCC can control the movement of the load according the charge and discharge of the battery.

1.2 Objectives of the Project

I. To design a 60A professional solar charge controller.

II. Construction of the proposed 60A solar charge controller.

III. Implementation of the proposed 60A solar charge controller in DUET PV system.

1.3 Project Report Organization

Project report on design and construction of a high power professional charge controller is organized as follows.

Chapter 1: Introduction of the project (background of the project) objectives, origination of the project all presented in this chapter.

Chapter 2: Focuses on Theory of Solar PV system, battery units, control unit, etc.

Chapter 3: presents detail designs of different units of a 60A professional solar charge controller.

Chapter 4: presents construction of different unit like battery units, control unit etc.

Chapter 5: Includes overall discussion on project and future recommendation.

Chapter 2

THEORY OF A SOLAR CHARGE CONTROLLER

2.1 Block Diagram of a Solar Charge Controller

The Photovoltaic Charge Controller System consists of seven subsystems or units, each of them having its own function. These seven subsystems are connected in accordance with the block diagram presented in the following Figure 2.1.

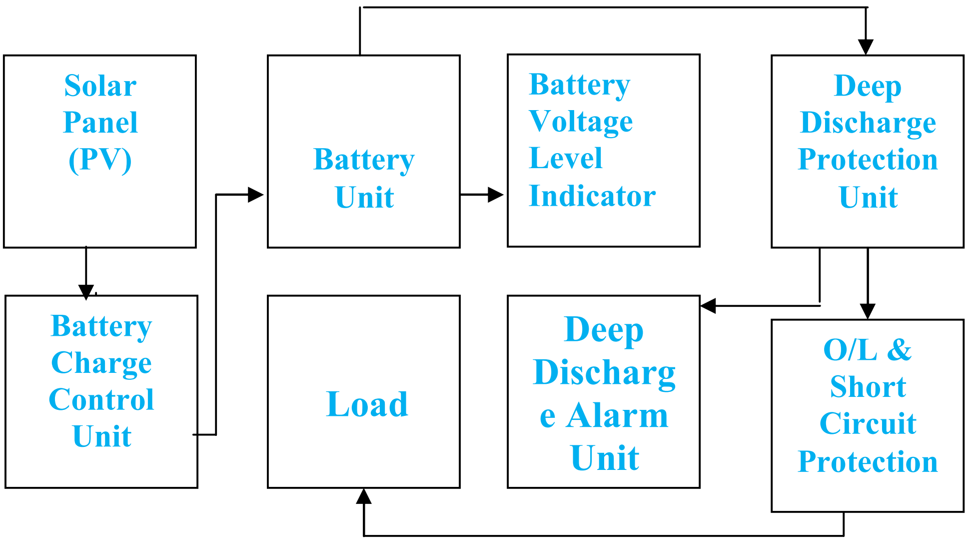


Figure 2.1:- Block Diagram of a Solar Charge Controller

The units mitigating the Solar Charge Controller are Solar Panel, Battery Charge Control Unit, Battery Unit, Battery Voltage Level, Load & Charging Status Indication Unit, Deep Discharge Protection Unit, Deep Discharge Alarm & Indication Unit and Over Load & Short Circuit Protection Unit.

2.1.1 Solar Panel (PV)

The invention of amorphous silicon and hybrid dye photovoltaic (PV) cells are the recent technological developments in thin-film photovoltaic industry. They are the main components in creation of solar array. The photovoltaic cell is a pn junction designed and developed for the enhancement of the creation of the electron-hole pairs delivered by the sunlight. It works like a normal diode.

Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, electric current is being generated which can be used as electricity.

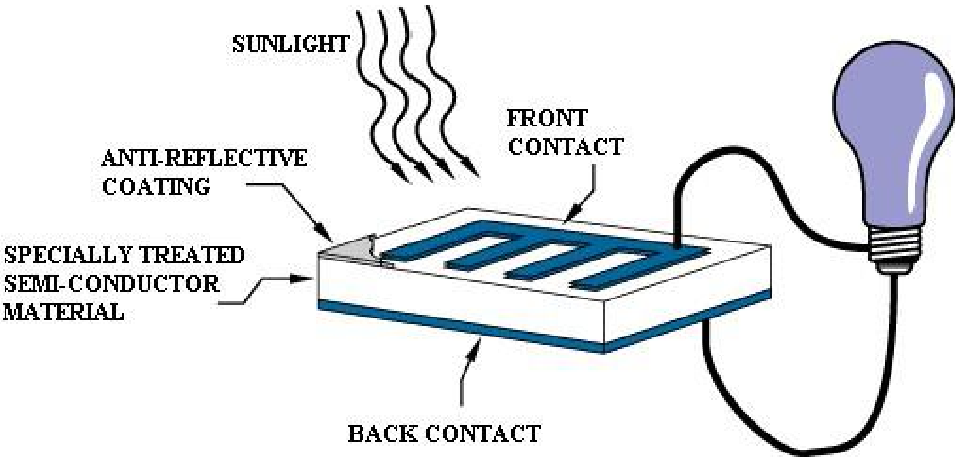


Figure 2.2:- Basic Photovoltaic Cell

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel Prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.

The diagram above illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field; one side is positive one while the other side is negative. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -- that is, electricity. This electricity can then be used to power a load, such as a light or operating a pump.

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system.

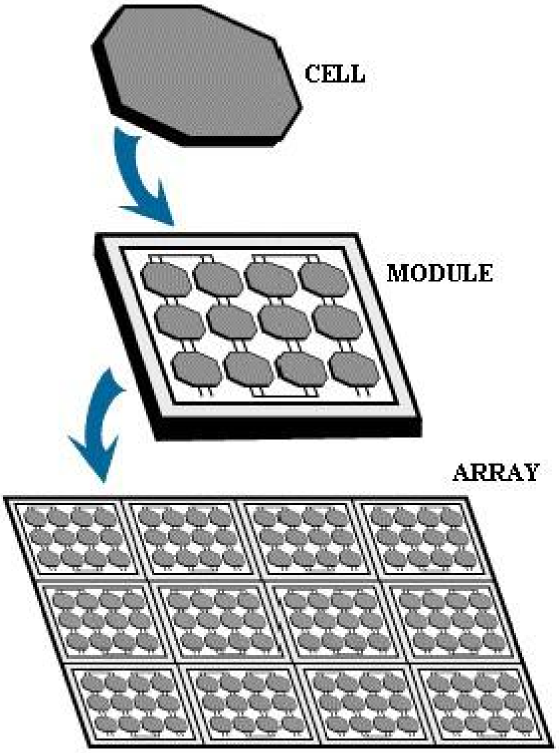


Figure 2.3:- Photovoltaic Array

The current produced is directly dependent on how much light strikes the module.

Multiple modules can be wired together to form an array. In general, the larger the area of a module or array, the more electricity will be produced. Photovoltaic modules and arrays produce direct-current (dc) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

Today's most common PV devices use a single junction, or interface, to create an electric field within a semiconductor such as a PV cell. In a single-junction PV cell, only photons whose energy is equal to or greater than the band gap of the cell material can free an electron for an electric circuit. In other words, the photovoltaic response of single-junction cells is limited to the portion of the sun’s spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used.

One way to get around this limitation is to use two (or more) different cells, with more than one band gap and more than one junction, to generate a voltage. These are referred to as "multijunction" cells (also called "cascade" or "tandem" cells). Multijunction devices can achieve higher total conversion efficiency. They can convert more of the energy spectrum of light to electricity.

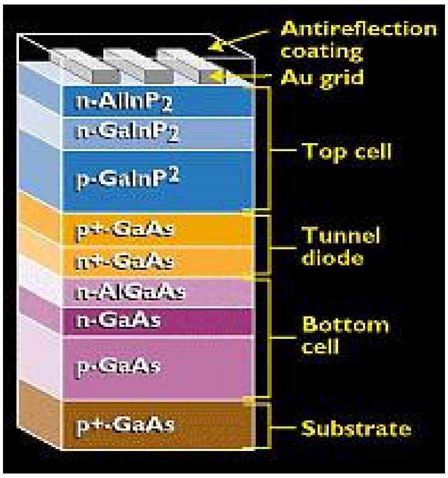


Figure 2.4:- Multijunction Device for Solar Cell

As shown above, a multijunction device is a stack of individual single-junction cells in descending order of band gap. The top cell captures the high-energy photons and passes the rest of the photons on to be absorbed by lower-band-gap cells.

Much of today's research in multijunction cells focuses on gallium arsenide as one (or all) of the component cells. Such cells have efficiencies of around 35% under concentrated sunlight. Other materials studied for multijunction devices are amorphous and copper indium diselenide.

As an example, the multijunction device above uses a top cell of gallium indium phosphide, "a tunnel junction," to aid the flow of electrons between the cells, and a bottom cell of gallium arsenide.

Now let us explain the electrical equivalent model of the Solar Charge system.

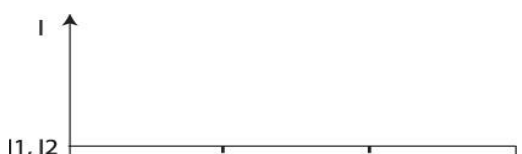


Figure 2.5:- Ideal Current – Voltage (I-V) Curve of a PV Cell

In reality the I-V characteristics curve for a PV cell does not look like Figure 2.5, but exhibits the following characteristics.

From the following Figure 2.6, we can see that the slight current drop between points M and A is a result of some of the current passing through the internal resistance of the PV cell. Between points A and S the load resistance increases forcing some of the current to flow through the diode resulting the fast drop in current to the load. This continues until point S where all the current flows through the diode and the internal resistance.
Figure-2.6 shows the lines for different load resistances. The slopes of these load lines are given by 1/R. So, lower resistances result in steeper load lines and

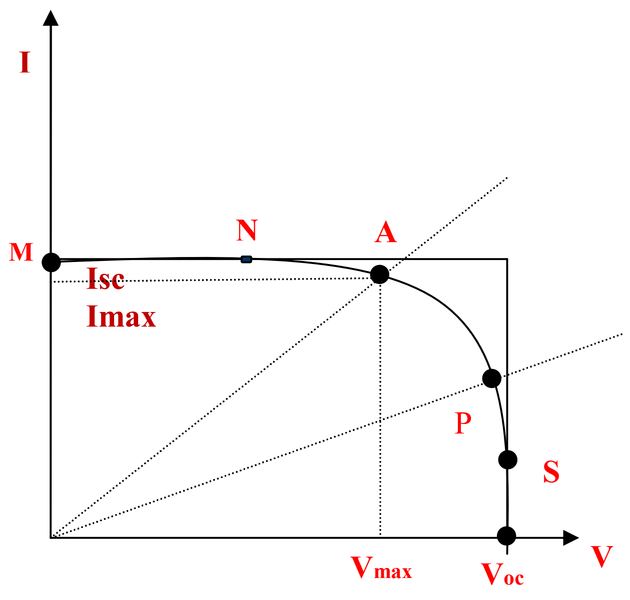


Figure 2.6:- Typical Current – Voltage (I-V) Curve of a PV Cell

higher resistances result in flatter load lines. The operating point of the PV connected to these loads is restricted to the intersection of the load line and I-V curve.
The operation point on the I-V curve is greatly determined by the insulation, array voltage, cell temperature and the load connected to the array. By altering the amount of sun light falling to the PV module, the current that the module can produce can also be altered. The current and power output of the used solar panel is approximately proportional to illumination intensity (irradiance). At a given intensity, the module voltage is determined by the characteristics of the load.

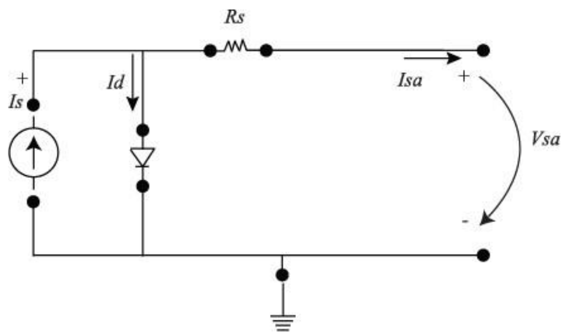


Figure 2.7:- Electrical Equivalent Model of a Solar Cell

By increasing the temperature, a slightly higher current can be produced. However this increase in temperature has a negative effect on the cell voltage. The increase in temperature forces the diode in Figure- 2.7 to conduct at a lower voltage, reducing the PV voltage where the curve collapses before desired output voltage and greatly reduces the output power.
The effect of varying the load on the PV operating point can be explained using ohms law: I =V/R (1)

The model shown in the Figure 2.7 contains a current source I_S, one diode and a resistor Rs. The net current is the difference between the photocurrent Is and the normal diode current i_D. The diode current is given by:

$$i_{D.} = I_0 \times \left(e^{(Vm + RsIsa)/mVt} - 1\right) \quad (2)$$

Where:

I_0 = Diode current (strongly dependent on temperature);
Vsa = Voltage imposed across the cell;
M = Ideal factor (ideal: m =1; real: m>1);
Vt = Thermal potential given by (3);

Rs = Series cell resistance.

$$Vt = KT/q \qquad (3)$$

Where :

K: Boltzmann constant, $K = 1.38\times10^{-23}$ J/K;

T: Cell temperature in K, $^{0}C = 273.16^{0}K$;

q: Electric charge of electron, $q = 1.6\times10^{-19}$ C.

The net current, i_{sa} is given by (4):

$$i_{sa} = I_s - I_0\left(e^{(Vsa + RsIsa)/mVt} - 1\right) \qquad (4)$$

Taking into account the model for a single solar cell, it is possible to determine the I-V characteristic of M cells in series:

$$V_{sa} = \gamma\times Vt \times\ln\left((I_s - i_{sa} / M\times I_0) + 1\right) - R_s i_{sa} \qquad (5)$$

Where $\gamma = m\times N$. For the used solar panel M = 1, N = no of series connected cells and it is assumed m = 1.

In short, a real solar cell can be characterized by the following fundamental parameters:

Short circuit current: I_{sc} is the greatest value of the current generated by a cell. It is produced under short circuit conditions: $V_{sa} = 0$;

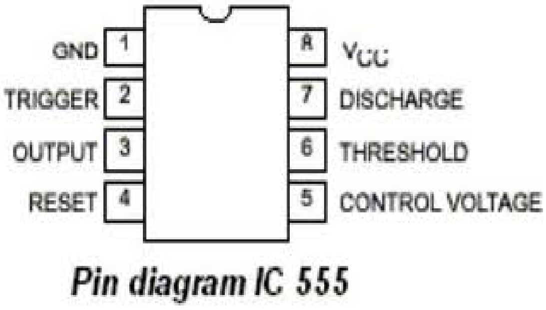
Open circuit voltage: It corresponds to the voltage drop across the diode (p-n junction) when it is traversed by the photocurrent I_s, namely when the generated current is $i_{sa} = 0$. It can be mathematically expressed as:

$$V_{oc} = \gamma\times Vt \times\ln\left((I_s / M\times I_0) + 1\right) \qquad (6)$$

The Solar Panel of my project has been installed above the roof top of the substation of the DUET campus. It consists of four polycrystalline PV modules from Solarex Co. The rated capacity of each PV module is 240W. The total installed capacity of the Solar Panel is 960W, integrated by four PV modules connected in parallel. The Solar Panel is supplying to a load of 600W pertaining to fifteen energy saver bulbs of each 40W. The load can be increased up to the rated capacity of the Solar Panel. It is an alternative street light supply to the DUET residential area.

2.1.2 The Battery Charge Control Unit

In the following figures-2.8(a), (b) &(c) the symbol and pin diagram of a Timer IC 555, a typical and generalized 60A Battery Charge Control Unit and a 60A Battery Charge Control Unit which was constructed for the project have been shown. The Battery Charge Control Unit is the main part the project. It protects the battery from over charging during day time and disconnects the PV module from battery at night. It includes a TIMER IC NE555 as a voltage comparator controlled by the input voltage applied to its Threshold (pin 6) and Trigger (pin 2).



<u>Figure 2.8(a):- Symbol & Pin Diagram of IC 555</u>

Its output is collected from pin 3. The figure and the pin diagram of the IC NE 555 and the circuit diagram of the Battery Charge Control Unit are shown in the following Figure 2.8. The output of the NE 555 timer is directly connected to the base of an npn transistor, Q2 via a series resistor, R7. Q2 transistor's collector and emitter are in parallel to the gate and source of the MOSFET Q3.

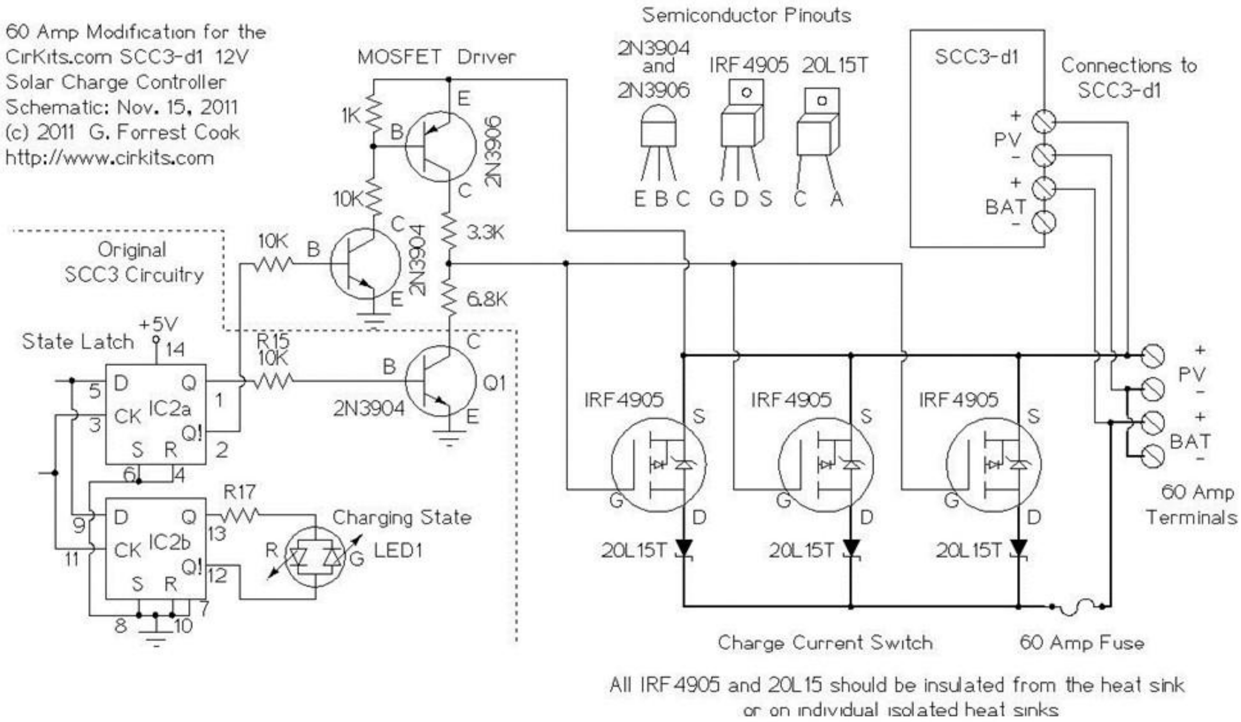


Figure 2.8(b):- Typical Battery Charge Control Unit

In the above Figure 2.8(b), the schematic diagram of the generalized form of a Solar Charge Controller has been shown.

It is collected from the internet addressed at: www.cirkits.com. In my project a modified version of this Solar Charge Controller has been adopted after a lot of studies, simulation and trial tests. Its schematic diagram of has shown in the following Figure 2.8(c).

Q3 MOSFET is in series with the relay array. Relay array's normally close (NC) contacts are in series with battery and MOSFET array. The arrays of the Q1 MOSFET are in series with relay array and PV module. They prevent the battery from supplying energy to solar panels during night. Resistance R2, R3, R4, R5 and VR1 are used in this circuit as voltage divider which is connected with the pin 2 and pin 6 of the 555 timer IC. D1 is a zener diode and its break down voltage is 21V.

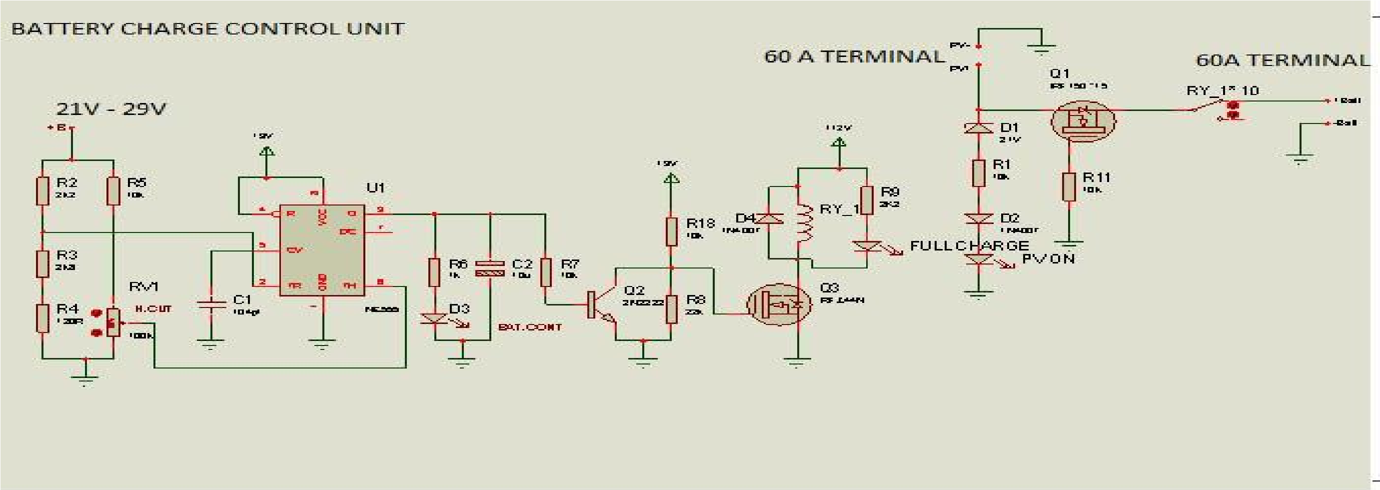


Figure 2.8(c):- Battery Charge Control Unit of the Project

During day time sun light falls in to solar panel, it converts solar energy to electric energy. The amount of converted energy depends on the intensity of the sun light. When solar panel produces sufficient voltage, the connected battery starts to charge. This charging voltage is implied as the input of the pin 2 and 6 of the IC 555. When the battery terminal voltage reaches at 28.8V, the potential difference across pin no. 6 reaches above 6V (2/3Vcc). Hence the output of the NE 555 IC becomes low and Q3 MOSFET switches to on, and the relay RY_1 triggers to disconnect the battery from solar panel. Again when the potential difference across pin no. 2 goes down to 3V (1/3Vcc), the battery voltage goes down to 26.3V. So, the output of the 555 IC is high and Q3 MOSFET becomes off (Vgs = 0), so, the inactive RY_1, relay array reconnects the battery to solar panel.

During night, when solar charging voltage goes down less than the battery terminal voltage, MOSFET Q1 becomes inactive as its source voltage is less than drain voltage. Also, if the solar charging voltage drops to less than zener break down voltage 21V, it behaves as an open circuit. Hence, it prevents the battery from supplying energy to solar panels during night.

2.1.3 Battery Unit

A battery is a device capable of storing electrical energy by means of a reversible chemical reaction. There are several different types of battery.
They are classified by size, utility and construction. The most common battery is the lead-acid battery. But nickel-cadmium, nickel-iron and nickel-hydride are also available and important. Rechargeable batteries tend to have a lower start voltage and shorter usage cycle; however, they make up the difference by being reusable. They are lighter in weight than alkaline batteries.

Figure 2.9:- Nickel-Cadmium Battery

Ni-Cd batteries are the most popular type of rechargeable battery. They are quick to charge and work well in extreme temperatures. They will last up to 500-700 charge/discharge cycles. Ni-Cd batteries can suffer from what is called the "memory effect". If a Ni-Cd battery is recharged before it is fully discharged, the recharge process can create a layer of bubbles in the battery which will eventually prevent the battery from discharging beyond that point. To avoid this problem, it is recommended that Ni-Cd batteries be fully discharged before recharging. If they are only partially discharged and then recharged, then after several such recharge cycles, the batteries may not be able to recharge to full capacity.
NiMH batteries do not suffer from this memory effect. They also last approximately 30% longer than Ni-Cd batteries on each charge, and they are environmentally safer than Ni-Cd batteries as they are made from non-toxic materials. The disadvantages in the NiMH batteries are more expensive than Ni-Cd's and only last for approximately 300-400 charge/discharge cycles.
To understand how a battery backup solar array provides power throughout the night as well as the day we need to know how batteries work to both store and

discharge that power. The chemistry of the standard lead-acid accumulator battery is not simple but it is worth the effort to understand the working of this marvel of engineering. Not only will this understanding give us insight into the workings of one of the devices we rely on in daily life, but it will also inform us as to how best to maintain these batteries to maximize their lifespans. In my project, a battery unit has been utilized which consists of rechargeable Lithium-ion (Li-ion) and Lead acid cell batteries from NAVANA supplier. Each battery has an output voltage 12V and an energy storage capacity of 100AH. The unit has been integrated by two batteries of 24V rating.

2.1.3.1 General Battery Chemistry

A lead-acid is contained of Sulfuric acid (H2SO4), Pb, water and Lead-oxide (PbO2). The electrolyte is the solution of Sulfuric acid in water. A battery consists of a series of cells, connected in series to provide the desired output voltage. The output of a lead-acid cell is a little over 2 V and also depending on the state of charge. Therefore for a 12 V lead acid battery simply it requires 6 cells connected in series. A battery stores electrical energy by dint of forcing electrons into positions in which they contain more energy by applying a voltage on the battery connectors.
The reactions that take place in a battery are complex. The process of an element *losing* electrons is called oxidation. An element that *gains* electrons is said to be undergoing reduction. Together these form a reaction pair called a redox reaction (reduction and oxidation together). We can track the movement of electrons in chemical reactions by using oxidation number rules_which gives us insight into how the chemical reactions in batteries generate electron flow. Redox reactions are fundamental to battery electrical discharge and recharging, and therefore critical to the success of battery backup solar systems.

The controlled corrosion of metals in batteries gives electron flow. The metal corrodes, or is oxidized and released electrons in the process. Unless a battery has been designed so that reversing this process, i.e. supplying electricity, will undo the oxidation of the metal the battery will eventually cease to function. This is why batteries eventually go "flat". Once the principle of metal corrosion producing electrical current was identified, battery technology advanced rapidly. The lead acid accumulator batteries we all rely on to start our cars were very early development and is still in widespread use today. As with Ni-Cad batteries, these are regular features of small electronic devices and are rechargeable. These cells are usually of the AAA or AA size. NiMH batteries are also sometimes found in larger applications such as cars where, obviously, the batteries are scaled up for the purpose.

NiMH batteries can be recharged many hundreds of times. A fully charged NiMH battery offers similar performance to a single use alkaline cell of the same size.

2.1.3.2 Lead-Acid Cell Charge Control Method

On the positive electrode:

$PbO_2 + H_2SO_4- + 3H^+ + 2e \rightarrow PbSO_4 + H_2O$

On the negative electrode:

$Pb + HSO4- \rightarrow PbSO4 + H^+ + 2\ e-$

Overall reaction:

$Pb + PbO_2 + 2HSO_4- + 2H^+ \rightarrow 2PbSO_4 + 2H_2O$

Where, e- is a negative charge of an electron.

When a load is connected to the battery, the reaction becomes reversed and the electrons release the stored energy. The capacity of a battery is measured by Ampere-Hour.

2.1.3.3 NiMH Charge Control Method

The charge transfer equation of a NiMH cell is given by the following equation.

On the positive electrode:

$Ni\ (OH)_2 + OH- \leftrightarrow NiOOH + H_2O + e-$

On the negative electrode:

$N + H_2O + e- \leftrightarrow MH + OH--$

Where, e- is a negative charge of an electron, M is an intermettalic compound usually formed with a mixture of a metal and rare earth.

2.1.3.4 Starting and Deep Cycle Type Battery

Basically there are two types of batteries; they are namely starting and deep cycle batteries. Different batteries are designed as per different demands. A starting battery which is used in most cars is designed to deliver a large current during a short time. A deep cycle batteries are those of type which can withstand at deep discharges. It has less instant energy but greater long term energy delivery. The main difference between the two batteries is the plate-thickness. The plates of the deep-cycle batteries are up to 35 times thicker than those of starting batteries. Hence, deep cycle batteries can survive a number of discharge cycles and it is suitable for use in application where power supply standby is needed.

2.1.3.5 Battery Charging

Batteries can be charged in best 3 steps, bulk charge, absorption charge and float charge. During bulk charge, the highest charge current is sent to the batteries until the battery is 80-90% charged. During absorption charge, current is limited as internal resistance of the battery increases. The applied voltage is a little higher. Absorption charge lasts until the battery is fully charged. During float charge, voltage is reduced. The purpose of float charge is to keep a charged battery from discharging, thus enhancing battery life.

2.1.3.6 Battery Life

As the storage and release of energy in batteries involves solving and dissolving the plates in the electrolyte, batteries do not last forever. Batteries are rated for a certain number of cycles to certain depth of discharge. When taken care of, batteries can last for decades, while when mistreated, they can die prematurely. Main causes for premature battery death are overcharging, charging with a too high charge current and sulfating. The first two causes can be prevented by a charge controller. Sulfating is the formation of a large lead sulfate on the battery plates and occurs when the battery is left unused, in a low or uncharged state for a longer period of time. Sulfating is sometimes reversible by controlled charging of the battery. In a well-designed system that is being used the way it was designed for, these problems will not occur and the batteries will provide reliable and y convenient energy storage for years or decades depending on the battery quality.

2.1.4 Battery Voltage Level Indicator Unit

The Battery Voltage Level, Load & Charging Status Indicator Unit of the project would be responsible to indicate the different voltage levels of the battery unit. Therefore, it will give a warning to the user about battery charging conditions to take necessary action. However, my project has a self-protection system to protect the battery from over and under charging. The Battery Voltage Level Indicator Unit consists of a Quad Operational Amplifier Integrated Circuit, model LM324N, one adjustable positive voltage regulator IC, model LM317T. The LM324N operational amplifier IC is a high performance voltage comparator, operates from $^{+}$3V to $^{+}$32V belonging to a 14 pins family.
When battery voltage goes down to a predetermined lower value of 21V, then the 'RED' LED is illuminated, when battery voltage is greater than 23V, 'YELLOW' LED is illuminated, when battery voltage is greater than 25V then 'GREEN' LED is illuminated, when battery voltage is greater than 27V then another 'GREEN' LED is illuminated.

2.1.5 Deep Discharge Protection Unit

The Deep Discharge Protection Unit is responsible to protect the battery unit from fast discharging. It consists of a voltage comparator IC, model LM324N, one Silicon Control Rectifier (SCR), model BT134, one low ampere current rating driving relay, model SONGLE SRD-12 and ten high ampere current rating relays, model OMRON MY4 connected in parallel . When the battery terminal voltage falls down to a predetermined lower value, the Deep Discharge Protection Unit disconnects the battery from load and protects it from more discharging. This protection system is sensed by the terminal voltage level of connected battery.

2.1.6 Deep Discharge Alarm Unit

The Deep Discharge Alarm Unit initiates alarms, when the voltage of the battery unit drops down to a predetermined lower value. It consists of a voltage comparator IC, model LM324N, a multivibrator circuit which is formed by NE555 timer IC and a sounder (Buzzer). It operates from $^{+}$5V to $^{+}$15V and it belongs to an 8 pins family. This alarm system is sensed by the voltage level of the connected battery.

2.1.7 Over Load & Short Circuit Protection Unit

The Over Load & Short Circuit Protection Unit protects the solar panel and the battery from over loading and short circuit condition. When the load current reaches more than 1.5 times or more than that, the protection units disconnect the load from the battery or from the solar system. This protection unit consists of one voltage comparator IC, model LM324N, one Silicon Control Rectifier (SCR), model BT134, and one adjustable positive voltage regulator IC, model LM317T.

It operates from +1.25V to +40V (max.) and it belongs to a 3 pins family. This over load & short circuit protection system is sensed by the amount of load, which are connected to battery or the value of voltage drop across the over load sensing coil.

Chapter 3

DESIGN OF A SOLAR CHARGE CONTROLLER

The design of a Solar Charge Controller is the combination of the several unit designs. These involve Battery Charge Control Unit design, design relay array for the Battery Charge Control Unit, Battery Voltage Level Indicator Unit design, Deep Discharge Protection Unit design, Over Load and Short Circuit Protection Unit design, Deep Discharge Alarm Unit design and Power Supply Unit Design.

3.1 Controls and Protections

i. The proposed Solar Charge Controller should keep the battery on full voltage condition.
ii. It should protect the battery from over-charging.
iii. It should protect the battery from over-discharging.
iv. It should prevent the battery from supplying electricity to solar panels during nights.
v. It should prevent the solar panels and batteries from short circuit and overload conditions.

3.2 Technical Specification

The Technical Specifications of a Solar Charge Controller are stated in the following details:

I.	Solar panel voltage at open circuit condition	:	38.8 V.
II.	Solar panel voltage at full load	:	30 V.
III.	Rated charging current	:	60 A.
IV.	Rated Load current	:	60 A.
V.	Working voltage	:	24 V.
VI.	No load current	:	≤ 200 mA.
VII.	Charging circuit voltage drop	:	≤ 0.5 V.
VIII.	Over voltage protection	:	30 V.
IX.	Load circuit voltage drop	:	≤0. 5 V.
X.	Work temperature	:	0 ºC to $^{+}$55 ºC.
XI.	Charge off voltage :		28.8V.
XII.	Charge returns voltage	:	26.3 V.
XIII.	Alarm on voltage	:	21.3 V.
XIV.	Shut down voltage	:	21 V.
XV.	Over load, protection	:	1.25 times of rated current, 60s.
XVI.	Short circuit protection	:	≥1.5 times of rated current.

3.2 Battery Charge Control Unit

The Battery Charge Control Unit is the main part of the project. It protects the battery from over charging during day time and disconnects the PV module from battery at night. This unit consists of timer IC NE 555, voltage divider resistors, one transistor, two MOSFET, a zener diode and LEDs.

The three resistors in the voltage divider all have the same value (5K) in the bipolar version of this IC). The comparator reference voltages are 1/3 and 2/3 of the supply voltage, $^{+}$Vcc, whatever that may be. Here, we considered $^{+}$9 V.

The internal flip-flop changes state when the trigger input at pin 2 is pulled down below $^{+}V_{CC}/3$. When this occurs, the output (pin 3) changes state to $^{+}V_{CC}$ and the discharge pin 7 is turned off. The trigger input can now return to $^{+}V_{CC}$; it will not affect the state of the IC.

However, if the threshold input (pin 6) is now raised above (2/3) of $^{+}V_{CC}$, the output will return to ground and the discharge pin 7 will be turned on again. When the

threshold input returns to ground, the IC will remain in this state, which was the original state when we started this analysis.
The figure-3.1 shows the pin diagram of the Timer IC 555 used for the Battery Charge Control Unit. The IC is available in 8-pin.

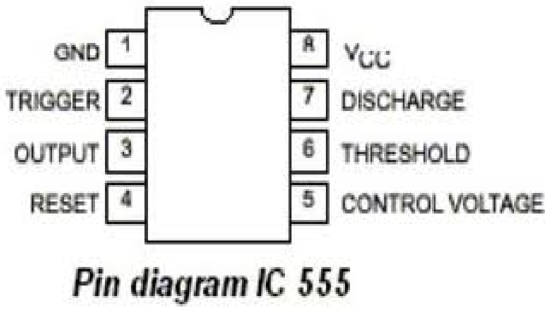


Figure-3.1: Timer IC 555 used in Battery Charge Control Unit

The pin connections of NE 555 are as follows:

1. Ground.
2. Trigger input.
3. Output.
4. Reset input.
5. Control voltage.
6. Threshold input.
7. Discharge.
8. $^{+}V_{CC}$. $^{+}5$ to $^{+}15$ volts in normal use.

The output of the IC 555 timer is directly connected to the base of Q2 (npn) transistor via a series resistor, R7. Q2 transistor's collector and emitter are parallel to the gate and source of the Q3 MOSFET. Q3 MOSFET is in series with the relay array. Relay array's normally close (NC) contacts are in series between battery and MOSFET array. The arrays of Q1 MOSFET are also in series between relay array and PV module. They prevent the battery from supplying electricity to solar panels at night. Resistors R2, R3, R4, R5 and RV1 are used in this circuit as voltage divider which are connected with the pin 2 and pin 6 of the 555 timer IC. D1 is a zener diode with a break down voltage 21V, which is in series with R1, D2 and PV on LED, and parallel to the PV module.
During day time, when sun light falls in to solar panel, it converts solar energy to electric energy. The amount of converted energy depends on the intensity of the sun light. When solar panel produces sufficient voltage, connected battery starts to be charging. Hence 555 IC's 2 & 6 no pins act as input sensing ports.

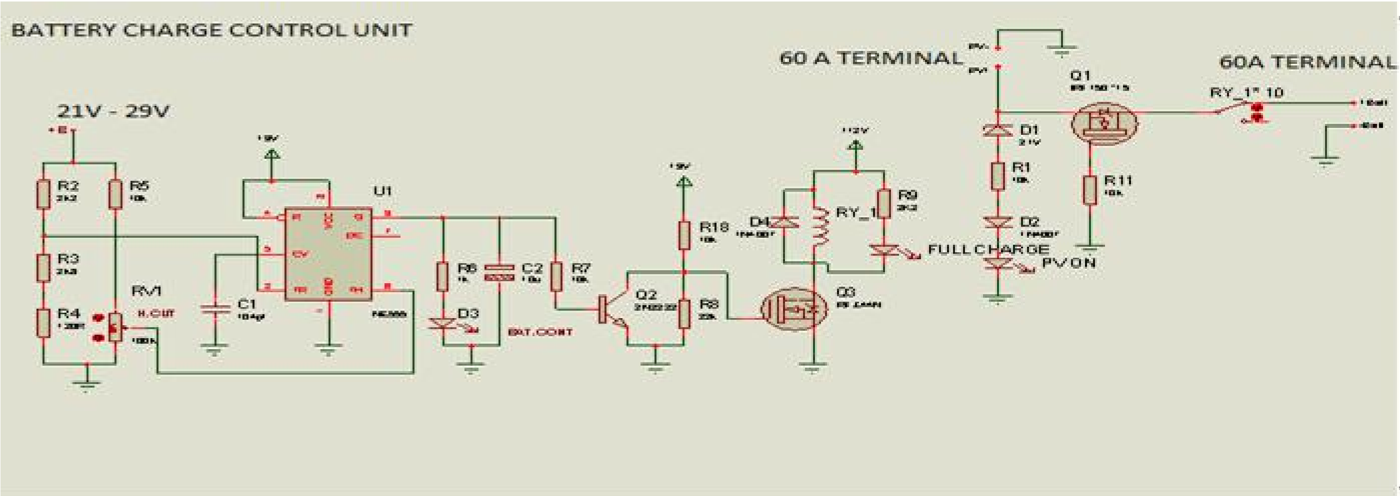


Figure-3.2: Battery Charge Control Unit

When battery voltage reaches to 28.8V, the potential difference across the pin 6 reaches above 6V, (2/3Vcc). Hence the output of the 555 IC becomes low and Q3 MOSFET switches to ON, and the switch RY_1, for this relay array disconnects the battery from solar panel. Again when the battery voltage goes down to 26.3V, potential difference across the pin 2 goes down to 3V (1/3Vcc). So, the output of the 555 IC becomes high and Q3 MOSFET becomes off (Vgs = 0). So, the inactive RY_1, relay array reconnects the battery to solar panel.

Let us consider, when 24V battery is fully charged its terminal voltage reaches to (2.4×12) V= 28.8V and when the battery terminal voltage is pulled down to below 26.3V, relay array reconnects the battery with solar module.

V_{cut} = Battery terminal voltage when it is fully charged or relay array disconnect the battery from solar module = 28.8V.

V_{rec} = Battery terminal voltage when relay array reconnects the battery with solar module = 26.3 V.

V_{cc} = Power supply voltage of IC 555 timer = $^{+}$ 9V.

We get,

$V_6 = 2/3 \times V_{CC}$.

$= 2/3 \times 9V$.

$= 6V$.

Let, $R5 = 22 \times 10^3$ ohm

$RV1 = R5 \times 2V_{CC} \ / \ (3V_{cut} - 2V_{CC})$

$= 22\times10^{3}\times2\times9 / (3\times28.8 - 2\times9)$

$= 5.79\times10^{3}$ ohm

I have used here 10Kohms variable potentiometer (POT).
Again,
$V_{2} = 1/3\times V_{cc}$ volt.
Let,
$R2 = 22\times10^{3}$ ohm

$R3 = V_{cc}\times R2 / (3\times V_{rec} - V_{cc})$ ohm
$= 9\times22\times10^{3} / (3\times26.3 - 9)$ ohm

$= 2.832\times10^{3}$ ohm

Let, $R3 = 2.2\times10^{3}$ ohm

So, $R4 = (2.832\times10^{3} - 2.8\times10^{3})$ ohm $= 32.6$ ohm

But practically, the value of R4 = 120 ohm has been considered.
The practical circuit of the project has been configured as per the above values of different components for the optimization of a Battery Charge Control Unit.

3.3 Calculation for No. of Relays Used in the Relay Array

Let,

I = Rated charging current = 60 A.
I_{SC} = Short circuit current
I_{R} = Rated current rating of each relay = 30A.
N = Number of relay.
Consider, Short circuit current = 1.5 times of rated full load current
$I_{sc} = 1.5\times I$
$= 1.5\times60$
$= 90$ A
For safe operation again consider tolerance limit = 10%

So, considerable safe operating current = $I_{sc} + (I_{sc}\times10\%)$

$= (1.5\times I_{SC}) + (1.5\times I_{SC})\times10\%$
$= 1.65\times I_{SC}$ A
$= 1.65\times90$ A
$= 148.5$ A

Number of Relays must be used in the charge control unit relay array,

$N = (1.65 \times I_{SC}) / I_R \quad = (1.65 \times 90) / 30 = 4.95$

Therefore, N = 4.95 i.e. 5 no. relays must be connected in parallel for safe operation.

3.4 Battery Voltage Level Indicator Unit

The Battery Voltage Level Indicator Unit, which has been used for the proposed project consists of four LEDs. They indicate different voltage status of the battery. The unit indicates whether the battery voltage is enough or not. The schematic diagram of the unit is shown in the following Figure 3.3.

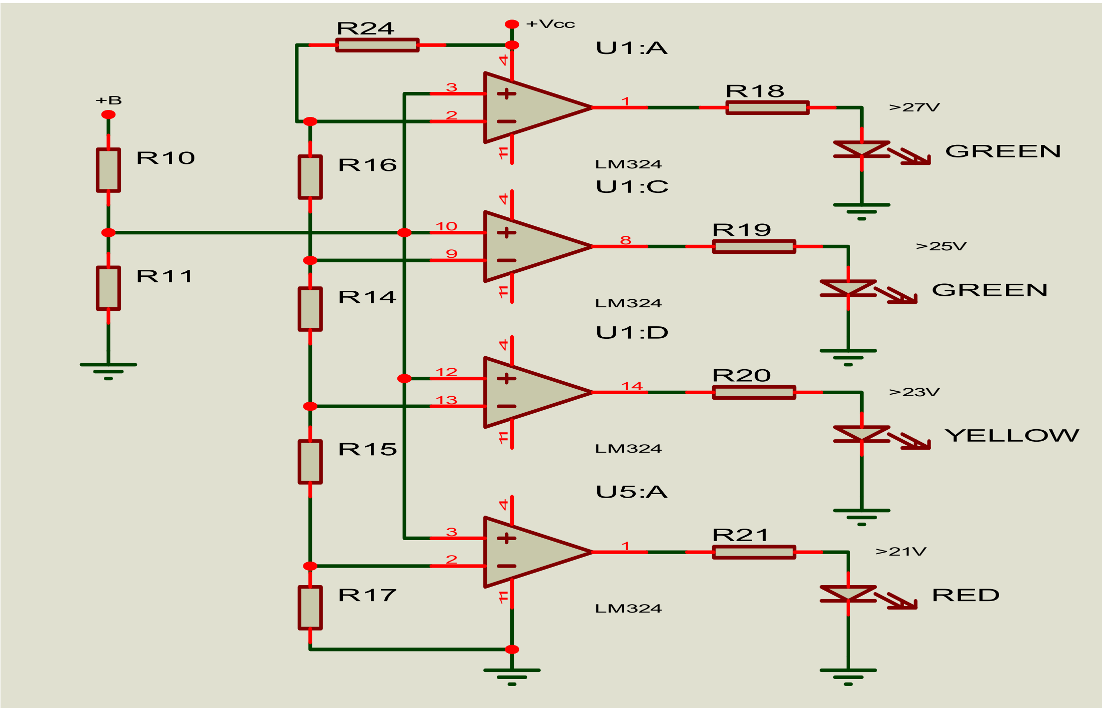


Figure-3.3: Battery Voltage Level Indicator Circuit

The LEDs illuminate one by one according to different voltage levels. When the battery voltage falls down to 21V 'RED' LED illuminates, when battery voltage is greater than 23V 'YELLOW' LED illuminates, when battery voltage is greater than 25V 'GREEN', LED illuminates, and finally when battery voltage is greater than 27V, another 'GREEN', LED illuminates.

Let,

$V_{in} = V11 =$ Input voltage (non-inverting terminals) of all comparators,
V_b = Battery terminal voltage (21V to 29V),
V_{CC} = Power supply voltage of LM324N,
$= {}^{+}9V$.
R10 = 100K,
R11 = 15K,
R24 = 4.7K, R16 = 220R, R14 = 220R,
R15 = 220R, R17 = (2.2K + 330R) = 2.233K.

From voltage division rules we get,

$V_{in} = V11 = (Vb \times R11) / (R11 + R10)$,

If, $V_b = 28V$ then,
$Vin = (28 \times 15 \times 10^3) / (100 \times 10^3 + 15 \times 10^3)$ volt,

$= 3.75V$.
If, $V_b = 21V$ then
$= (21 \times 15 \times 10^3) / (100 \times 10^3 + 15 \times 10^3)$ volt,

$= 2.74V$.

Therefore, the operating voltage range is between 3.75V and 2.74V.
The difference between them is (3.75V – 2.74V) = 1.01V
So, I designed to illuminate the LEDs within an interval of 0.25V.
To illuminate the first LED, minimum voltage input for the comparator requirement is 2.74V.
Similarly, to illuminate the second, third and fourth LED, required voltages are 2.99V, 3.24V and 3.49V respectively.
Now, $V_{17} = (Vcc \times R17) / (R14 + R16 + R15 + R17 + R24)$ volt

$= 9 \times 2530 / (220+220+220+2530+4700)$

$= 2.88V. \geq Vin$ (1^{st} stage).

Therefore, $V_{21} = {}^{+}9V$ and hence RED LED illuminates.

Again, $V_{15} = Vcc \times (R15 + R17) / (R14 + R16 + R15 + R17 + R24)$

$= 9 \times (220 + 2530) / (220+220+220+2530+4700)$

$= 3.13V. \geq Vin$ (2^{nd} stage).

Therefore, $V_{20} = {}^{+}9V$ and hence YELLOW LED illuminates.

Also, $V_{14} = Vcc \times (R14 + R15 + R17) / (R14 + R16 + R15 + R17 + R24)$ volt,

$= 9 \times (220+220+2530) / (220+220+220+2530+4700)$ volt,

$= 3.38V \geq Vin$ (3rd stage).

Therefore, $V_{19} = {}^{+}9V$ and hence GREEN LED illuminates.

Finally, $V_{16} = Vcc \times (R14+R15+R16+R17) / (R14+R15+R16+R17+R24)$ Volt,

$= 9\times (220+220+220+2530) / (220+220+220+2530+4700)$ Volt,

$= 3.63V \geq Vin$ (4th stage).

Therefore, $V_{18} = {}^{+}9V$ and hence another GREEN LED illuminates.

3.5 Deep Discharge Protection Unit

The Deep Discharge Protection Unit consists of a TRIAC, model BT134, voltage comparator IC model LM324N, one Silicon Control Rectifier (SCR), one low current rating driving relay, model SONGLE SRD-12 and five high ampere current rating relays, model OMRON MY4.

This protection system is controlled by the voltage level of the connected battery. When the battery terminal voltage is ≤ 21V the op-amp (U2B) output will be high and the SCR will operate the low ampere current rating driving relay, model SONGLE SRD-12.

The low ampere current rating relay drives the load side relay array which disconnects the load from battery. Load will remain disconnected till the reset switch is pressed. The schematic diagram of the Deep Discharge Protection Unit has been shown in the following Figure 3.4. It is designed as per the model collected from internet addressed: www.cirkits.com. It is adopted after a lot of studies, simulation and trial tests.

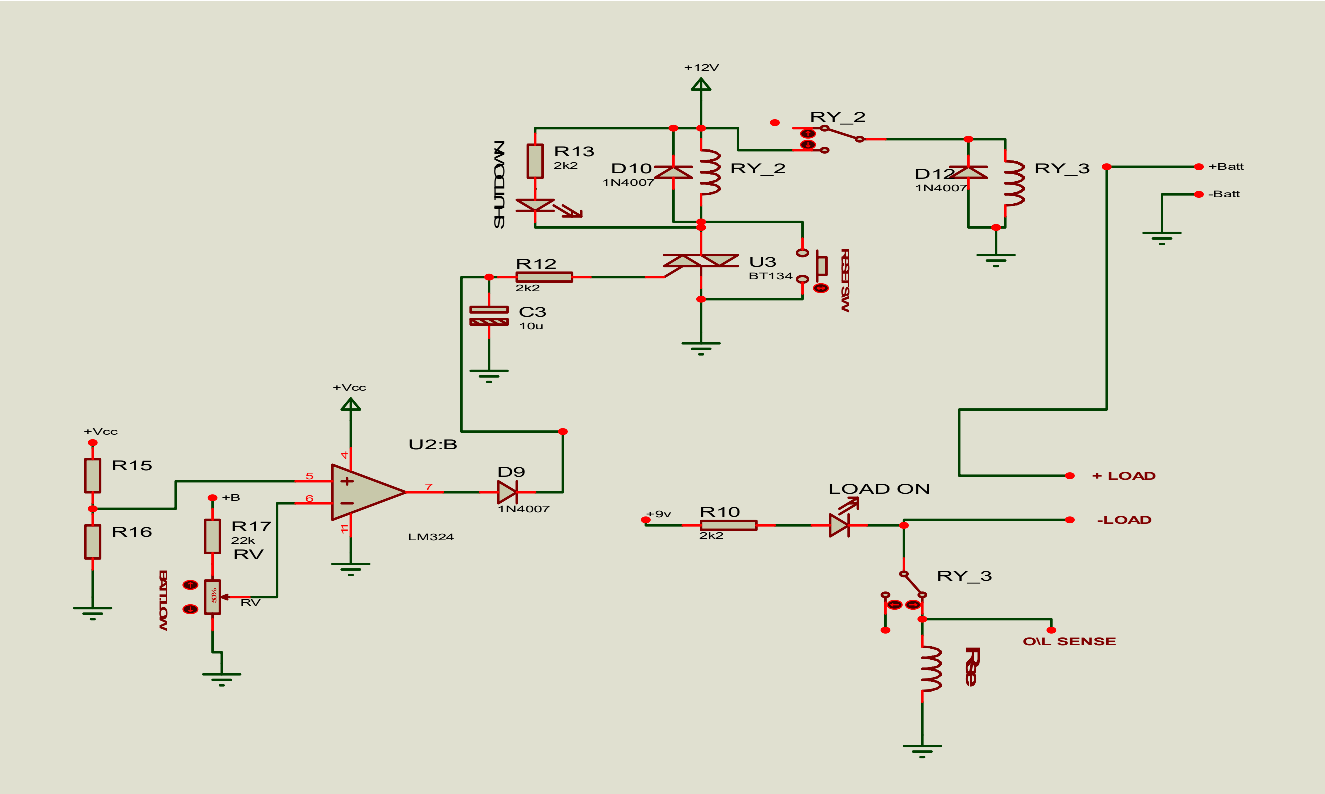


Figure-3.4: Deep Discharge Protection Circuit

Let us consider, the 24V battery is discharged its terminal voltage, V_b to (1.75×12) V = 21V.

Let,

$V_{in} = V_{RV}$ = Input voltage (inverting terminal) of U2: B comparator.

V_{16} = Input voltage (non-inverting terminal) of U2: B comparator.

V_{CC} = Power supply voltage of LM324N.

$= {}^{+}9V$.

R15, R16 = 10K.

R17 = 22K.

From voltage division rule we get,

$V_{16} = (V_{CC} \times R16) / (R15 + R16)$

$= (9\times10000) / (10000 + 10000) = 4.5$ V.

$V_{in} = V_{RV} = (V_b \times RV) / (RV + R17)$

$4.5 = (21\times RV) / (RV + 22000)$

$RV\times4.5 = 22000\times4.5 + 21\times RV$

$RV = (22000\times4.5) / (21 - 4.5)$

= 6000, ohm.

But I have used here 10 kilo ohms logarithmic variable potentiometer (POT).

For Vb = 21 V, we get $V_{RV} = (Vb \times RV) / (RV + R17) = 4.4$ Volt

So, $V_{16} \geq V_{RV}$, i.e. battery terminal voltage is less than 21V and hence $V_0 = {}^{+}Vcc$.

So, diode D9 will be forward biased and SCR BT143 becomes active and triggers the relay to disconnect the load from battery.

So, load is permanently disconnected from the battery and will remain disconnected till the reset switch is pressed. Load on LED becomes off.

Otherwise,

$V_0 = 0$ V (Load on LED bright). In this state load remains connected to the battery.

3.7 Over Load & Short Circuit Protection Unit

The Over Load & Short Circuit Protection Unit consists of one voltage comparator IC, model LM324N, one Silicon Control Rectifier (SCR), model BT134, and One adjustable positive voltage regulator IC, model LM317T. The schematic diagram of the unit is shown in the following Figure 3.5.

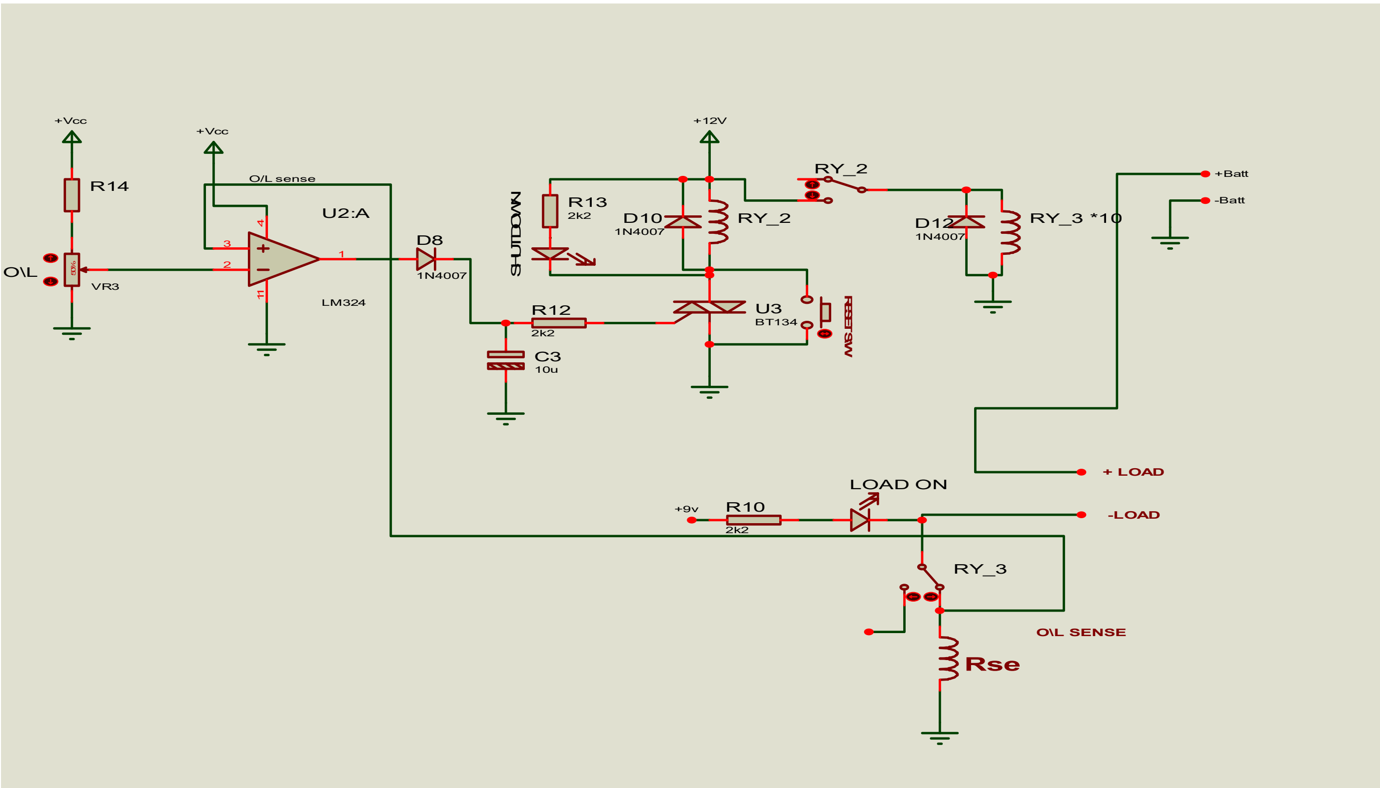


Figure-3.5: Over Load & Short Circuit Protection Circuit.

One low ampere current rating driving relay, model SONGLE SRD-12 and five high ampere current rating relays, model OMRON MY4 are connected in parallel to each other. The LM317T Operates from ^+3V to ^+40V (max.) belonging to a 3 pins family. This Over Load & Short Circuit Protection Systems are controlled by the amount of load which are connected to the battery or the value of voltage drops across the over load sensing coil. When the amount of connected load is greater than the rated rating load or if short circuit occurs at load terminal, then the op-amp (U2: A) output becomes high. It will forward bias the diode D8. Hence the SCR will be activated and operates the low ampere current rating driving relay, RY_2, model SONGLE SRD-12. Subsequently, low ampere current rating relay drives the load side relay array RY_3 which disconnects the load from the battery. Load will remain disconnected till the reset switch pressed.

Let us consider,
V_{Rse} = Input voltage of the non-inverting terminal of the U2: A comparator.
V_{VR3} = Input voltage of the inverting terminal of the U2: A comparator.
V_{CC} = Power supply voltage of LM324N.
= + 9V
I_1 = Rated load current or fault current passes through the Over Load coil.
= 100A
R14 = 10K.
Rse = Over load coil resistance (dc).
= 0.01ohm (SWG = 6, dia = 2cm, turns = 8, 100W).
SWG = Standard Wire Gauge.
We get,
$V_{Rse} = I_1 \times Rse$ volt
$= 100 \times .01$
= 1 volt

$V_{VR3} = (Vcc \times RV3) / (RV3 + R14)$

$1 = (9 \times RV3) / (RV3 + 10000)$

$VR3 = (10000) / (9-1)$

= 1250, ohm.

I used 10 kilo ohms variable potentiometer (POT) here to select 1250 ohm resistor
Now with this setting, if the load is more than 100A, that means if Over Load or Short Circuit occurs, RY_3 relay will be triggered and subsequently load will be disconnected from the battery.

3.8 Deep Discharge Alarm Unit

The Deep Discharge Alarm Unit consists of one voltage comparator IC; model LM324N, an astable multivibrator circuit which is formed by NE555 timer IC. It operates from the output of an npn transistor 2N2222. The transistor is biased from the output of the comparator LM324. The output of the comparator is linked with the base of the npn transistor (Q1). It acts as a switch. When the battery voltage goes down 21.4V then the comparator's output will be high and Q1 transistor will be active.

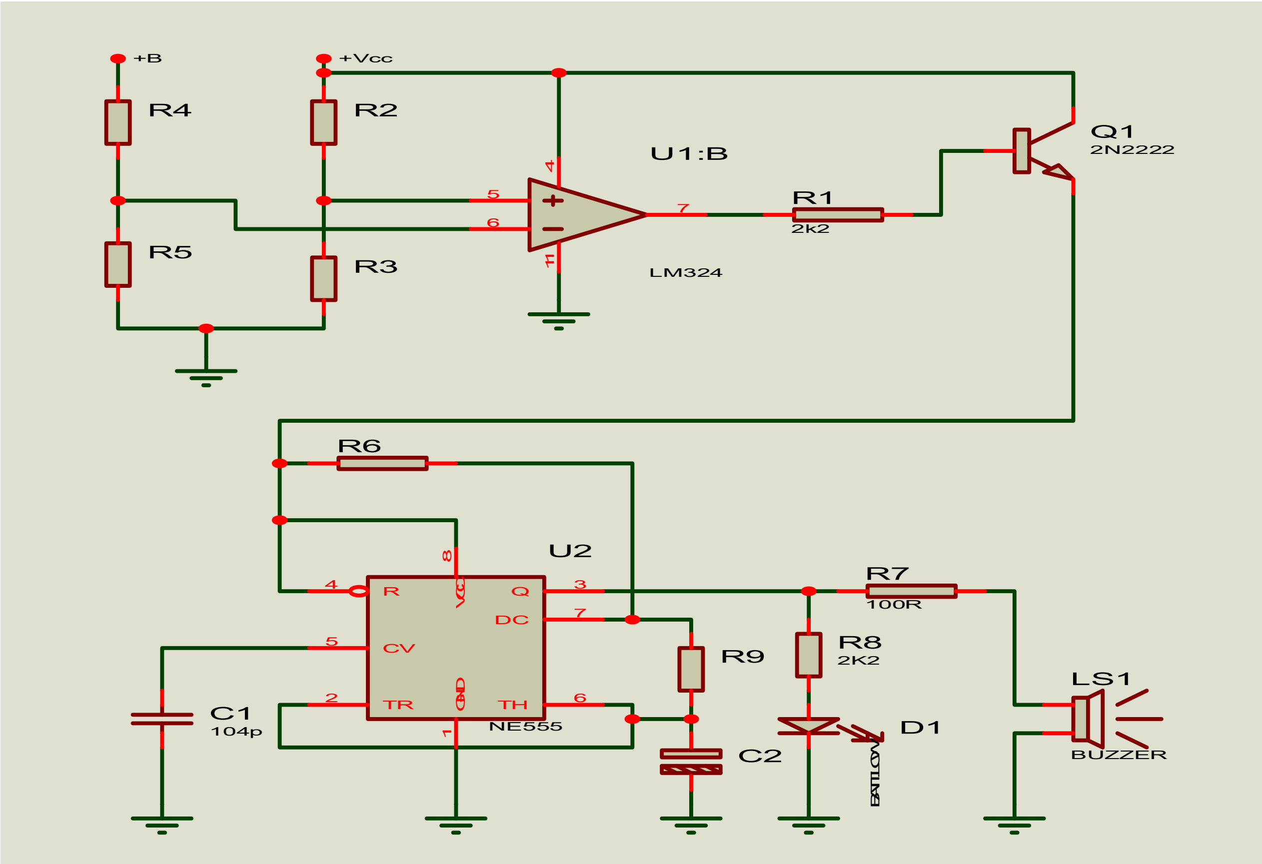


Figure-3.6: Deep Discharge Alarm Circuit.

The schematic diagram of the unit is shown in the above Figure 3.6.
The output of Q1 transistor is connected to the RESET pin 4 of the 555 Timer IC. Timer IC generates a square wave at its output (pin 3) which is connected to a buzzer and a LED D1 for alarm and indication.
When the battery terminal voltage goes down to less than 21.4V say 21.3V, the Unit must be active and the buzzer must produce beep sound. The output pulses of NE 555 are determined by the values of the resistors R6, R9 and the capacitor C2.

Let us consider,

$V_{CC} = +9$ V,

R2 = 10K, R3 = 10K, therefore, the input of the comparator LM324, $V_5 = 4.5$V.

Let R4 = 100K, $V_b = 21.3$V, now I must adjust the value of R5, so that V_6 must be less than V5. Let $V_6 = 4.45$V. By voltage division rule we get, $V_6 = (R5 \times Vb)/(R5+R4) = 4.45$V. Hence, R5 = 26409 ohms. I must consider, 26kohms = 22K+2K+2K ohms.As per the above settings, the output of the comparator was high and the npn transistor, Q1was forward biased, subsequently it activated the buzzer to beep. Also the diode D1connected via R8 resistor illuminated to give the indication. Now how long the buzzer would beep or remain silent, would depend on the output pulse of the timer IC NE555. This pulse would be determined by R6,R9 and C2.

The capacitor C2 charges via R6 and R9. When the voltage across the capacitor reaches 2/3Vcc, pin 6 of NE555 detects it and pin 7 connects to pin1 ,i.e to 0V. In this state C2 discharges via R9. Again when the voltage across the capacitor reaches 1/3Vcc, pin 2 detects it and pin 7 turns off to repeat the cycle. Capacitor, C2 charging time is given by : $t_1 = 0.69(R6+R9)C2$ second and discharging time is given by $t_2 = 0.69R9C2$ second. Hence the time for one complete cycle is given by $t = t_1+t_2 = 0.69(R6+R9)C2$ second.

Therefore, frequency $f = 1/t = 1/0.69(2.2\times10^3 + 2 \times100\times10^3)10\times10^{-6} = 0.712$ Hz. Now the High time/charging time = 0.69(R6+R9)C2 = 0.70 second. And the Low time/discharging time = $0.69 \times R9 \times C2 = 0.69$ second. Therefore, the buzzer will beep for 0.70 second and remain silent for 0.69 second and will repeat the same.

3.9 Power Supply Unit

The schematic diagram of the Power Supply Unit of the Solar Charge Controller has been presented in the following Figure-3.7. It consists of a voltage regulating IC, LM317 T, a feed-back resistor, R12 and a variable or fixed voltage controlling resistor, R13. According to output voltage requirement, it is of two types; variable or fixed. The value of the feedback resistor should not be so high. I considered its value 100 ohms.

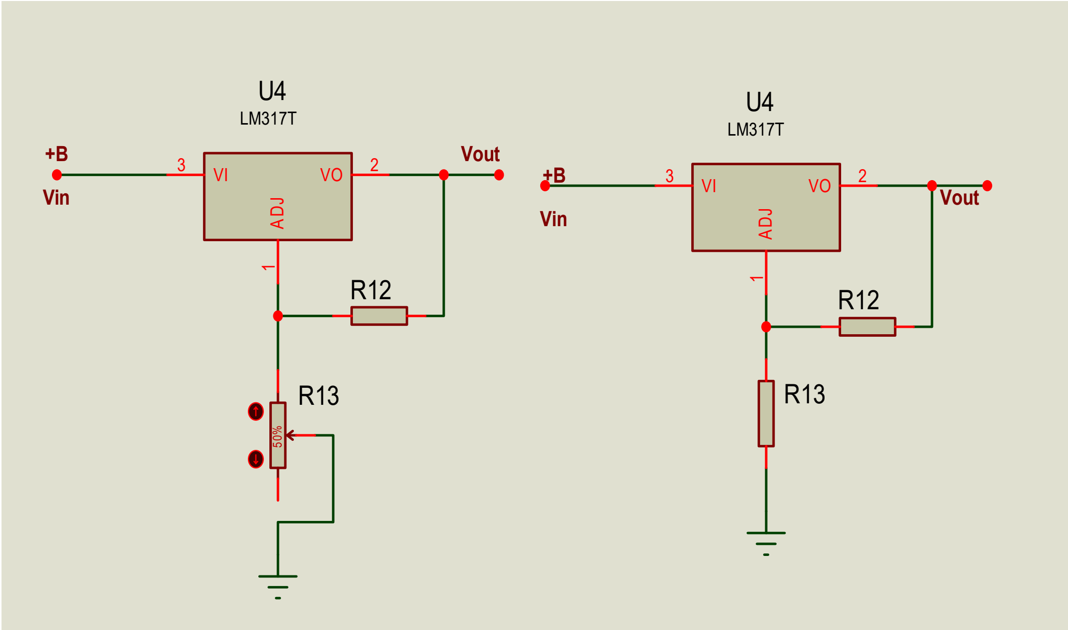


Figure-3.7: Power Supply Unit Circuit Diagram

Let us consider, a Power Supply Unit of 9V output will be constructed. The internal voltage drop is considered to be 3V. Hence the input of the Unit must be 12V or more. Whatever may be the input voltage of the comparator be, its output voltage must be 9V. I must simulate the value of fixed or variable resistor R13 to fulfill the project.

Let us consider,
V_{out} = Output voltage of regulator IC, LM317T = Vcc = +9V, while R12 = 100 ohms.
V_{in} = Input voltage of regulator IC, LM317 T = 36V,
R12 = Feedback resistor = 100 ohms,
R13 = Variable or fixed voltage control resistor which is to be determined.
We know that $V_{out} = 1.25 \times (R12 + R13) / R12$
$9 = 1.25 \times (100 + R13)/100$
$900 = 1.25 \times (100 + R13)$
$1.25 \times R13 = 900 - 125$
R13 = 620 ohms.
Therefore, we can get a desired voltage from a Power Supply Unit output as per the above design, irrespective of the input of the Unit.

Chapter 4

CONSTRUCTION OF A SOLAR CHARGE CONTROLLER

4.1 Construction of the Battery Charge Control Unit

For the construction of an IC NE 555 based Battery Charge Control Unit, the following components were used:

1. IC1 – 317T Voltage Regulator
2. IC2 - NE555 Timer Chip
3. R1, R7, R10, R11-10K, Ohm 1/8 Watt 10%
4. R2, R3R5, R8, R9-22K Ohm 1/8 Watt 10%
5. R4- 120, R6 – 1KOhm 1/8 Watt 10%
6. Q1 - 2N2222 or Similar NPN Transistor
7. Q2 - IRF540 or Similar Power MOSFET
8. C1 - 140uF 35V 10%
9. C2 - 10uF 35V 10%
10. PB1, PB2 - NO Momentary Contact Push Buttons
11. LED1 - Green LED
12. LED2 - Yellow LED
13. RLY1 - 40 Amps SPDT Automotive Relay
14. D1 - 1N4001 or Similar, Zener Diode
15. RV - Variable Resistor, 10K.
16. Prototype Circuit Bread-board.
17. Some Wires.

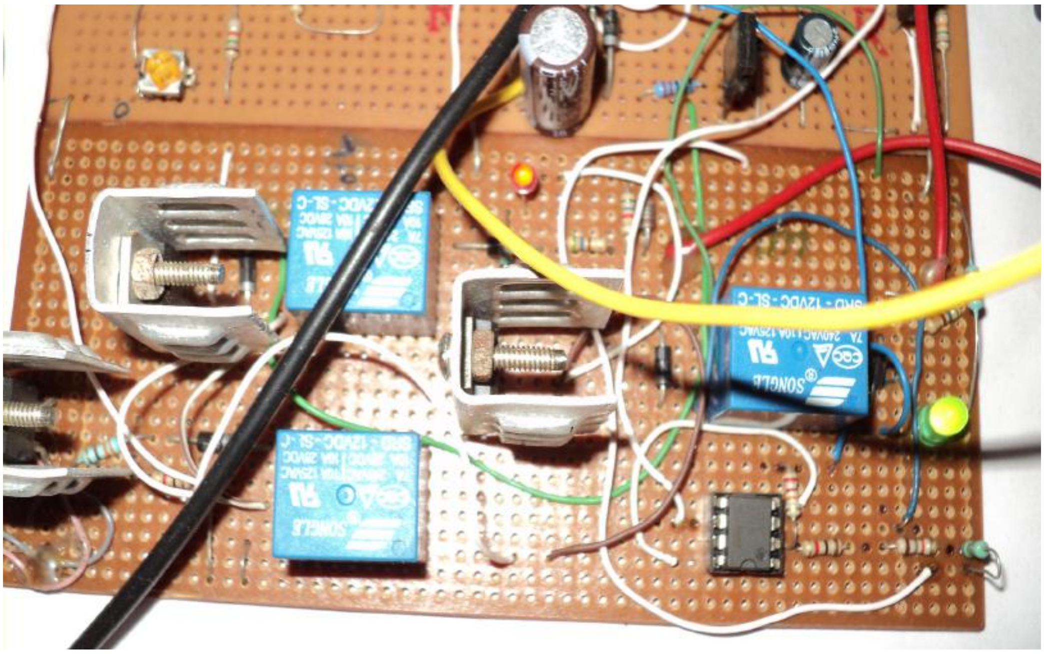


Figure 4.1: IC NE555 Based Battery Charge Control Unit

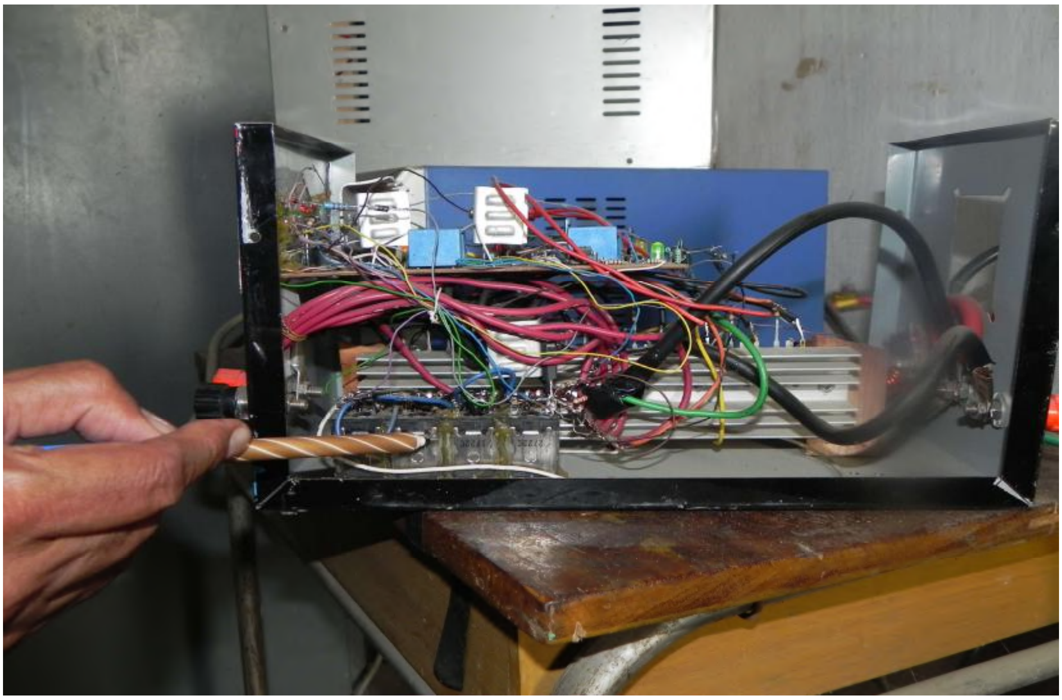


Figure 4.2: Battery Charge Control Unit With Relay Array

The above Figures 4.1 and 4.2 are the real pictures of the Battery Charge Control unit of my project. These were taken from DUET Campus.

For the construction of the circuit I did rely on the data sheet of the components.

I have fixed the timer IC NE555 and the npn transistor on the prototype circuit-breaded board as per the above as per design and as per the above configuration. I connected the output (Pin3) of the 555 timer IC directly to the base of Q2 (npn) transistor via series resistor R7. I connected the threshold Pin6 of IC555 to the variable potentiometer RV1, and the trigger pin2 to battery terminal resistor R2. Its pin4 and pin8 are connected to $^{+}$ 12 Vcc. Its pin5 is connected to the capacitor C1. The collector and emitter of the transistor Q2 are connected in parallel via resistor R8 and then connected to the gate of the MOSFET Q3, the gate is connected to the +12Vcc via resistor R18. As shown in the Figure 4.1, the Q3 MOSFET is connected with relay array, in series. Relay array's normally close (NC) contacts are connected in series between battery and the drain of the Q1 MOSFET. The source of Q1 is connected in series with the +ve terminal of the PV module. The cathode of the Zener diode D1 is also connected to the source the Q1 MOSFET. This arrangement prevents the battery from supplying electricity to the solar panels at night. In this way I have completed the construction of the circuit of Battery Charge Control Unit.

In my personal lab, I have applied 29V as Vb battery charging voltage I observed that the relay triggered that means battery became disconnected from the PV panel and while applied voltage Vb was less than 28V, relay did not trigger.

Also, when I applied battery terminal charging voltage less than 21V, I observed that PV module became disconnected from the battery.

Experimentally, I found that when battery voltage reached to 28.8V then the potential differences across the pin 6 of NE555 reached to 6.4V with respect to ground. Then the output of the 555 timer was zero corresponding to pin 3 negative terminals. Q3 MOSFET was activated and its gate to source voltage was 6.2V. Hence, the relay array disconnected the battery from solar panel. Again when battery voltage goes down to 26.3V then the potential difference across the pin 2 of NE555 was 3V with respect to ground. Then the output of the 555 timer was high, it was 8.2V corresponding to pin 3 and negative terminal. Hence Q3 MOSFET became off and its gate to source voltage was zero. As a result the relay array reconnected the battery to solar panel. I measured this voltage by using a digital voltmeter.

These tests were carried out for the Solar Charge Controller in real in DUET campus and revealed that the results were perfect in all cases.

4.2 Construction of the Battery Voltage Level Indicator Unit

The construction of the Battery Voltage Level Indicator Unit is mainly based on the quad op-amp IC LM324. I have used four Nos. LM 324 ICs. The unit indicates different voltage levels of the connected battery unit. The practical diagram of the unit is shown in the following Figures 4.3 and 4.4.

The components used for the construction of the unit are listed below:

1. Quad Op-amp IC LM324 - four nos,
2. R18, R19, R20, R21- all 330 ohms current limiting resistors,
3. R14, R15, R16 - all 220 ohms voltage dividing resistors,
4. R17, R24 – 2533 and 2.7 K ohms voltage dividing resistors respectively,
5. R10, R11- 100K, 15K voltage dividing resistors respectively,
6. LED of Green, Yellow and Red colors – four nos,
7. Connecting wire,
8. + 9V supply source.

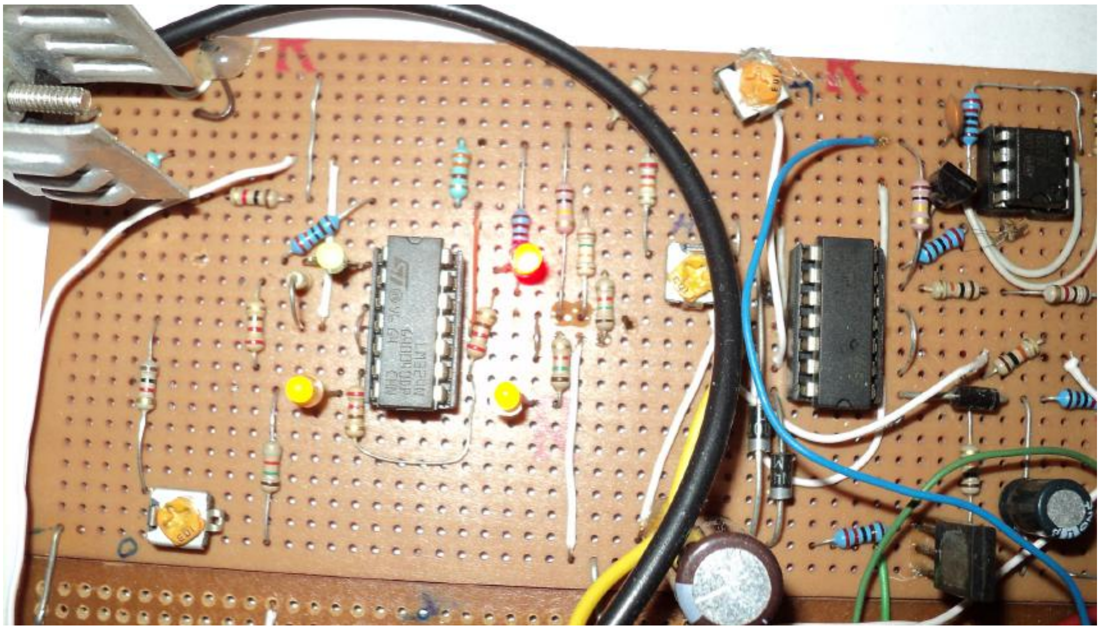


Figure 4.3 : Battery Voltage Level Indicator Circuit.

Figure 4.4: Battery Voltage Level Indicator Setup Inside Casing

I have connected all the non-inverting terminals (pins 3, 5, 10, 12) of all four comparators IC LM324N to the battery terminals via voltage dividing resistors R10 and R11. Also, I have connected the inverting terminals pins (1, 6, 9, and 13) of the comparator to + 9 Vcc via voltage dividing resistors R14, R15, R16, R17 and R24. However, all non-inverting terminals are directly connected to each other. I have connected all the pins (1, 8, 14, and 1) utilized as the output of the comparators to the LEDs connected via series resistors R18, R19, R20 and R21 respectively. They illuminate in different voltages to indicate different voltage levels of the battery. Thus as per the design, I succeeded to construct the circuit diagram of a Battery Voltage Level Indicator. Experimentally, when + 9V power supply was connected to 4 no pin of LM324N I recorded different voltages at the inverting terminals. 2.88V, 3.13V, 3.38V and 3.63V were measured at the inverting pins 13, 9, 6 and 2 respectively. Now, I applied different voltages at the battery terminal.
I observed that while applied voltages at the battery terminals were 27V, 25V, 23V and 21V GREEN, GREEN, YELLOW and RED LEDs were illuminated one by one respectively. I tested it in DUET campus for the Solar Charge Controller and its performance was satisfactory.

4.3 Construction of the Deep Discharge Protection Unit

The Deep Discharge Protection Unit consists of a voltage comparator IC, model LM324N, one Silicon Control Rectifier (SCR), model BT134, one low ampere current rating driving relay, model SONGLE SRD-12 and five high ampere current rating relays, model OMRON MY4 connected in parallel .This protection system is controlled by the voltage level of connected battery. The practical diagram which I used for the project is shown below in two separate forms in the Figures 4.5 and 4.6. I have connected all the components as per the schematic diagram of a Deep Discharge Protection Unit.

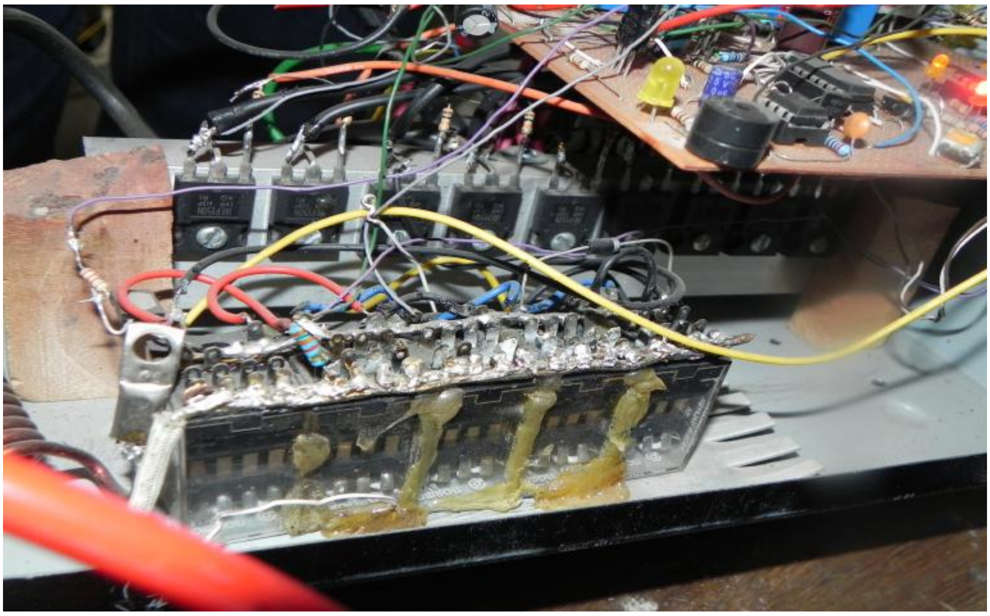


Figure 4.5: Deep Discharge Protection Unit Relay Array Setup

Experimentally, I have used a 1400VA pure sine wave inverter as a load which is connected to load terminals of the proposed solar charge controller. Output of the sine wave inverter is connected to DUET street light lines. From the Deep Discharge Protection Circuit I have measured the voltage of non-inverting terminal of comparator, LM324N, it was 4.5V corresponding to pin 5 with respect to negative terminal. I opened the solar module from solar charge controller PV terminals and switch ON the IPS with 600 watt ac load. I observed that battery terminal voltage was decreasing. After 50 minutes the battery terminal voltage went down to 21V. At the same time I noticed that the voltage of inverting terminal of comparator, LM324N was 4.45V corresponding to pin 6 and negative terminal of Vb.

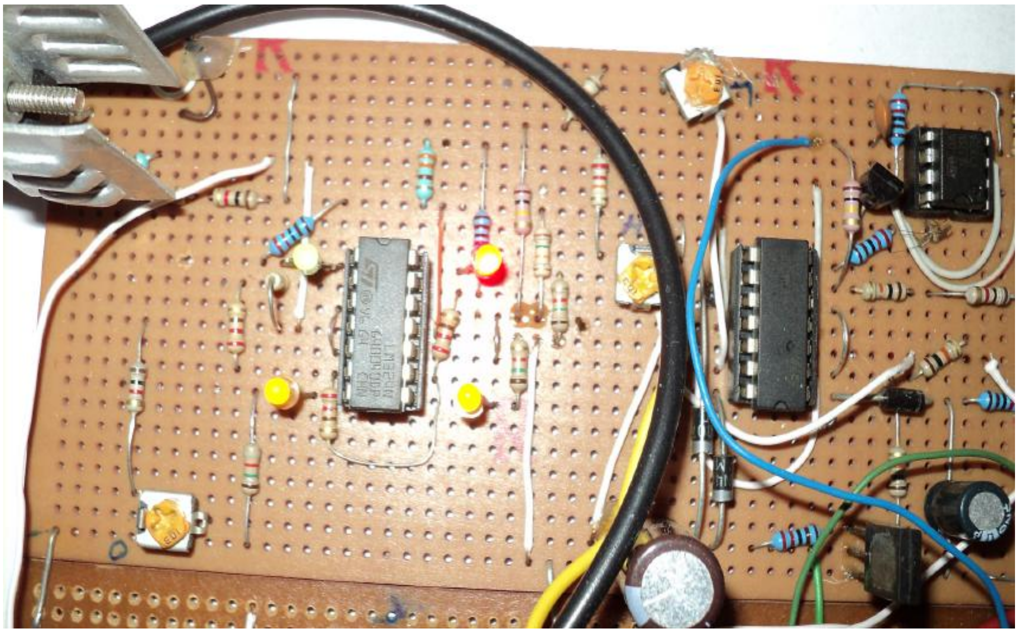


Figure 4.6: Deep Discharge Protection Circuit With LM324N

As a result, the output of the comparator was high, I measured it was7.9V in between pin 7 and the ground. So, SCR gate triggered the relay array. Finally load side relay array disconnected the load from battery. Load would remain disconnected till the reset switch pressed. I tested it in DUET Campus and the performance was nice.

4.4 Construction of Over Load & Short Circuit Protection Unit

The Over Load & Short Circuit Protection Unit consists of one voltage comparator IC, model LM324N, one Silicon Control Rectifier (SCR), model BT134, one adjustable positive voltage regulator IC, model LM317T, one low ampere current rating driving relay, model SONGLE SRD-12 and five high ampere current rating relays, model OMRON MY4 connected parallel. I configured the unit as per the schematic diagram and as per the help of the data sheet of the components. The practical figures of the unit are shown in the following figures 4.7 and 4.8.

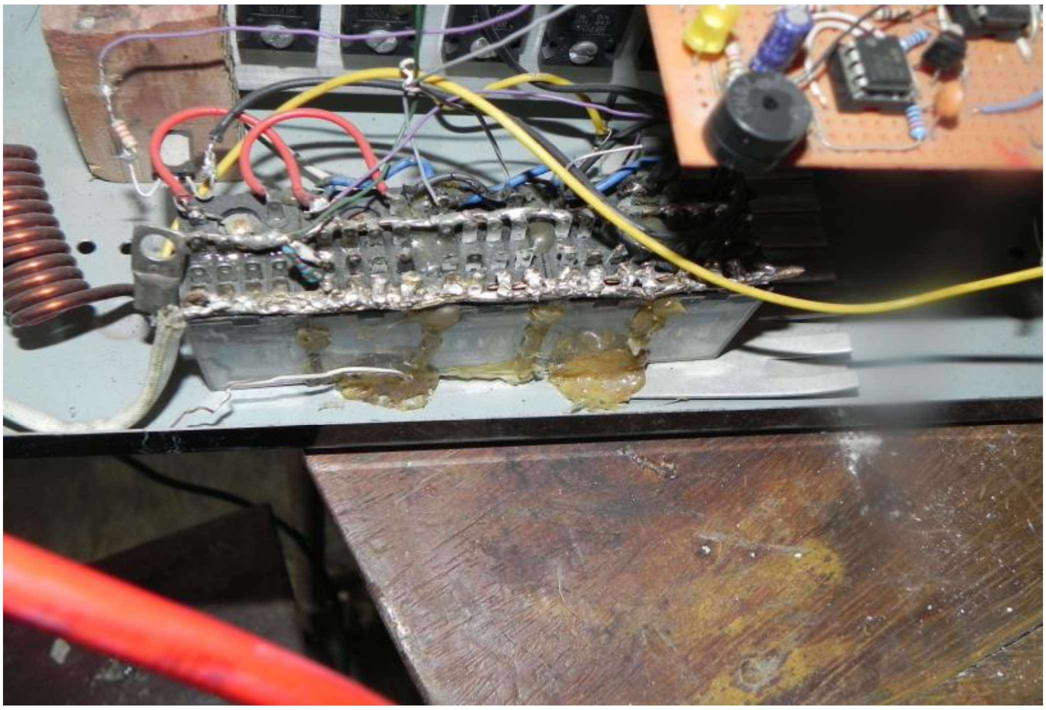


Figure 4.7: Over Load & Short Circuit Protection Unit With Relay Array And Over Load Sensing Coil

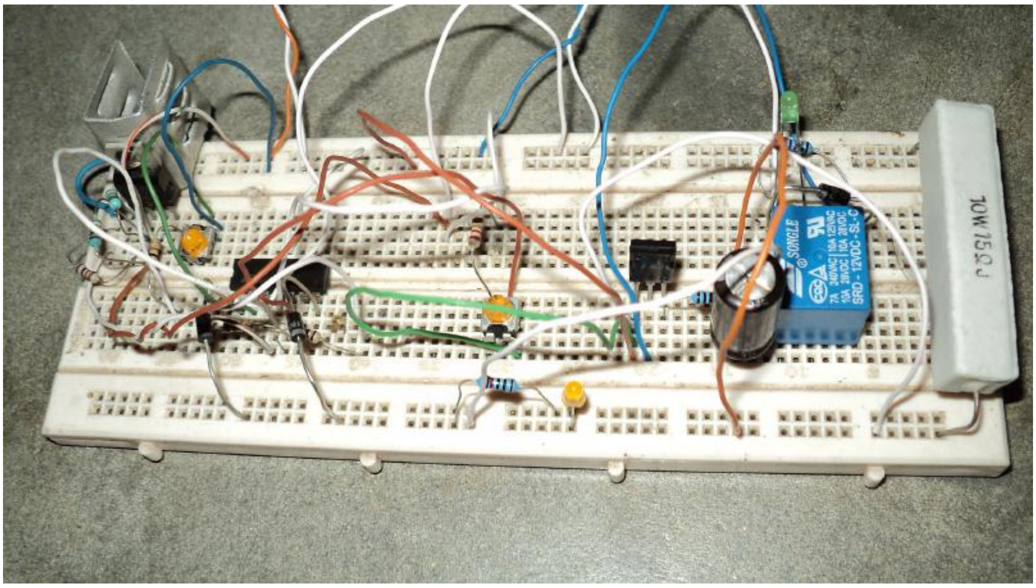


Figure 4.8: Over Load & Short Circuit Protection Unit Circuit

Practically, I have connected the non-inverting terminal/pin3 of the comparator directly to the connecting point of the operating relay RY_3 and the over load sensing coil. I have connected the inverting terminal/pin2 of the comparator to the variable

10K potentiometer VR3,which is then connected to supply source + 9V, V_{CC} via current limiting 10K resistor, R14.
The output pin1 of the comparator then I connected to the anode of the diode D1. The cathode of the diode is then connected to the gate of the SCR via a 22 K series resistor, R12. Terminal2/output of the SCR has been connected the relay arrays. 10μF Capacitor has been connected as per schematic to control transient effects. Thus the unit was configured. It was constructed for 100A current rating.
To verify the experiment, I imposed more load to the Charge Controller in DUET Campus. And also I did the short circuit operation by shortening the terminals of the pin 3 of the comparator and over load sensing coil Rse.
In both cases it revealed tripping of the relays and disconnected the load from the battery. Load remained disconnected till the reset switch pressed.
Its performance was satisfactory.

4.5 Construction of Deep Discharge Alarm & Indication Unit

The Deep Discharge Alarm & Indication Unit consists of one voltage comparator IC, model LM324N, an astable multivibrator formed by NE555 timer IC, an npn transistor, model 2N2222 and a Buzzer. I have constructed the unit as per the design schematic diagram and as per the following Figure- 4.9.

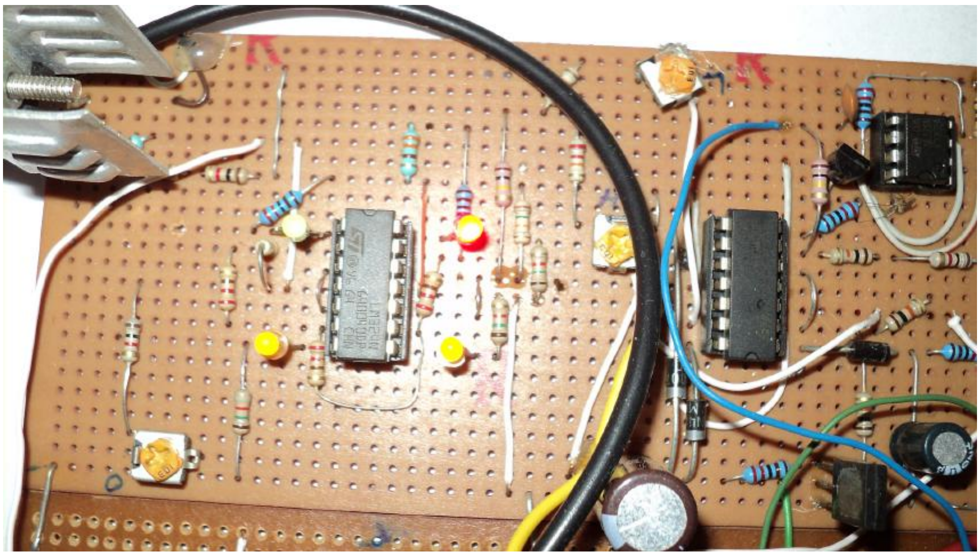


Figure 4.9: Deep Discharge Alarm and Indication Circuit

I have connected the non-inverting terminal/pin 5 of the comparator to + 9 Vcc via voltage dividing resistors R2 and R3 of 10K each. The inverting terminal/pin 6 of the comparator has been connected to battery voltage, Vb terminal, via another voltage dividing resistors R4 and R5 of 100K and 26K respectively. The output/pin 7 of the comparator has been connected to the base of the Q1 transistor via a series resistor R1 of 22K ohms. The collector of it has been biased from + 9Vcc. The output of the transistor has been connected to the buzzer via timer IC NE 555 and a series resistor, R7 of 100 ohms. I have connected the other components of the unit as per the designed schematic diagram. I have constructed the unit in such a design that when the battery terminal voltage goes down to 21.5 V, the buzzer should beep.

I observed that when the battery voltage was greater than 21.6V, then the voltage of inverting terminal of comparator, LM324N was 4.6V corresponding to pin 6 and negative terminal. As a result, the output of the comparator was low as 0V at pin7. So, alarm system did no activate. Again when the battery terminal voltage was smaller than 21.4V, then the inverting terminal voltage of comparator, LM324N was 4.45V corresponding to pin 6 and negative terminal. As a result, the output of the comparator was high as 8.1V at pin 7. As a result, Q1 transistor became active and I measured the output voltage (Emitter to negative) was 7.9V. Subsequently, IC 555 became activated and its output generated quite enough signal to beep the buzzer. in addition, the connected LED illuminated to indicated the under voltage status of the battery of the solar charge system.

The beeping and interval timing was satisfactory as per the design and its performance was quite nice.

4.6 Construction of Power Supply Unit

The main part of the Power Supply Unit is the IC LM317. It is of 3 pin family. I have connected its pin3 to supply input Vb, pin2 to output terminal and pin1 to a feedback arrangement. Feedback resistor R12 of 100 ohms is connected between pin@ and pin1. R13 is a resistor of 620 ohms connected to pin1. It can be fixed or variable. The Power Supply Unit has been shown in Figure 4.10 within the Solar Charge Controller.

4.7 Complete Circuit Diagram of a High Power Professional Solar Charge Controller

I have collected some pictures of my project of the Solar Charge Controller which is installed in the Substation of DUET Campus and those are presented in the following Figures:

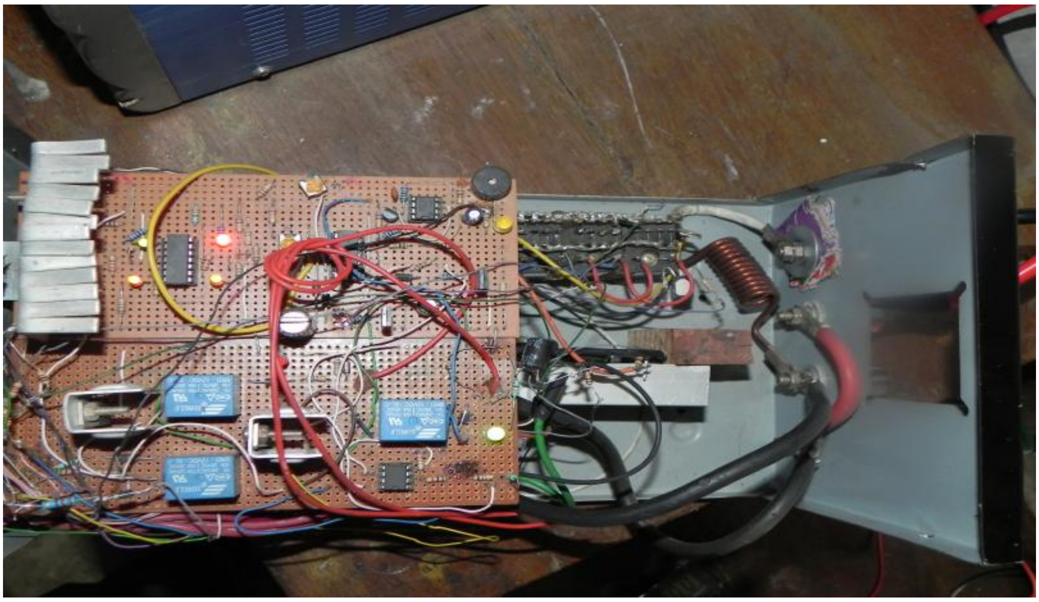


Figure 4.10: Complete Assembly Diagram of the Solar Charge Controller at DUET Campus

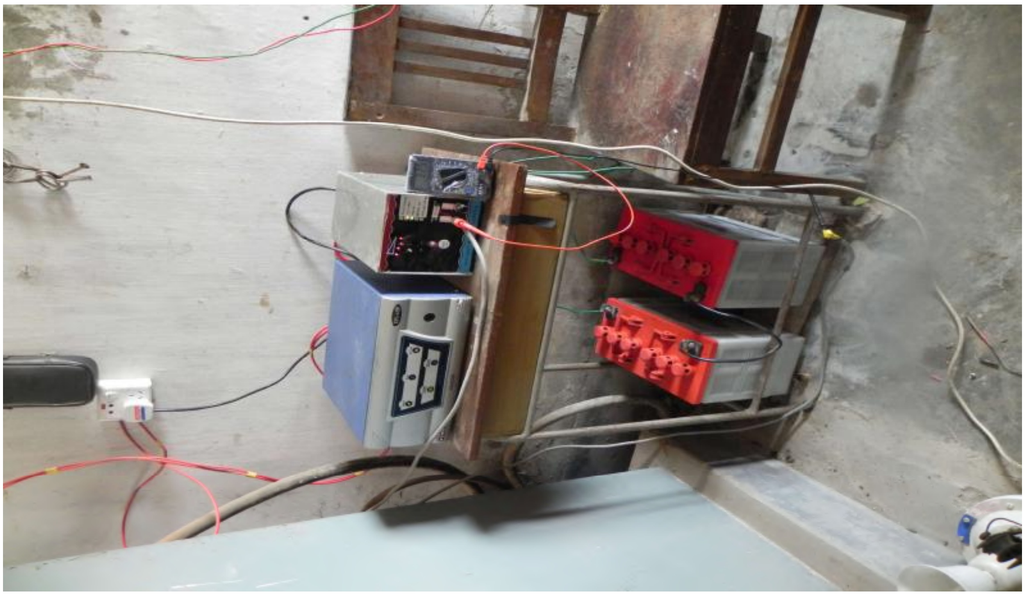


Figure 4.11: Solar Charge Controller Connected with the Battery at DUET Substation

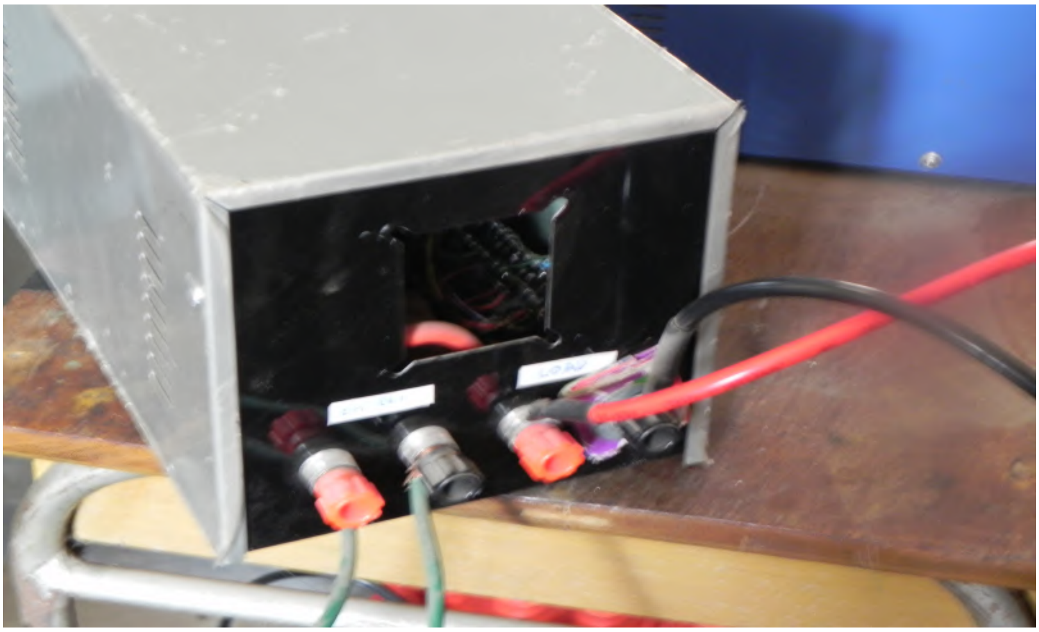


Figure 4.12: Solar Charge Controller Connected to the Load

Figure 4.13: Solar Charge Controller Connected with the Load while Disconnected From PV Module

Figure 4.14: Battery Terminal Voltage while PV Module Disconnected

Figure 4.15: PV Module Terminal Voltage while Battery Disconnected

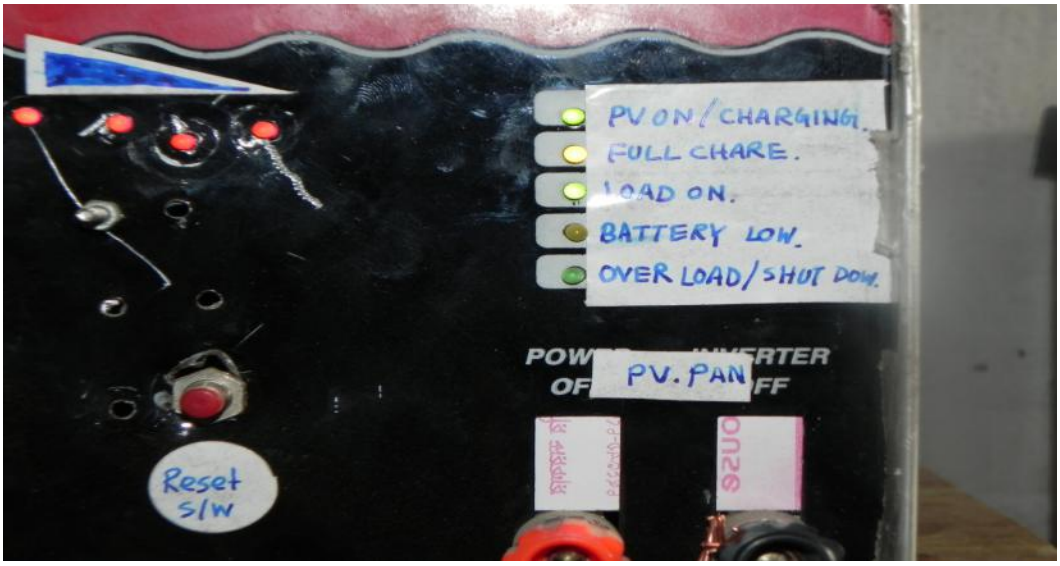


Figure 4.16: Solar Charge Controller Front View

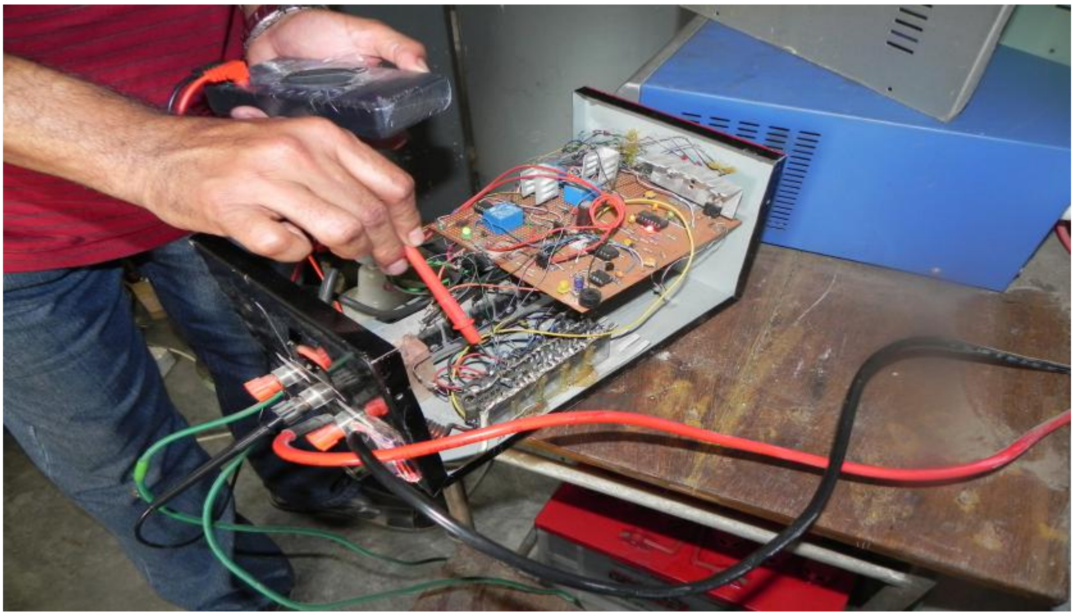


Figure 4.17: Experimental Data Collection From Solar Charge Controller

4.7 Experimental Data Collection from PV Module

Dated: 06/03/12

I have collected the terminal voltage of the Solar Panel while disconnected from battery. It was collected on hourly basis. The Solar Panel is situated in the DUET Campus Substation. The data has been represented in the following table.

Serial No	Time (hrs.)	Voltage (V)
1	07:30	32.8
2	08:30	33.3
3	09:30	33.4
4	10:00	33.0
5	10:30	32.5
6	11:00	32.3
7	11:30	32.1
8	12:30	31.9
9	13:30	31.8
10	14:30	32.8
11	15:00	32.3
12	15:30	32.0
13	16:30	31.8

Table: Hourly Voltages of the Solar Panel while Disconnected from battery

Chapter 5

DISCUSSION AND CONCLUSION

5.1 Discussion and Conclusion

The main objective of this project was to design, construct and implementation of a High Power Professional Solar Charge Controller successfully. This goal of this project has been achieved. The essential features of the project have been studied from several books, journals and websites, whose list has been incorporated in the References. At first, the schematic circuit design of a High Power Professional Solar Charge Controller was integrated. When the simulated result was satisfactory, I started the layout design. It was done in different stages, for different units of the solar charge controller, like Battery Charge Control Unit, Relay Array of the Charge Control Unit, Battery Voltage Level Indicator Unit, Deep Discharge Protection Unit and Over Load & Short Circuit Protection Unit etc. Each stage was configured together to produce a complete and unique solar charge controller. It was tested in a real life possible use. This project has presented an efficient standalone PV charge controller by incorporating an improved high power, with high performance charging system and designing a new controller scheme which incorporates both a simple solar charge controller algorithm and a battery charging algorithm. In addition, the proposed Solar Charge Controller design gives better controller efficiency. The Solar Charge Controllers which are available in the market have lower rated charging current, lower rated loading capacity, less protections, more complicated, smaller life and more expensive than that of the Solar Charge Controller, I have constructed and installed for my project. So, the construction of the Solar Charge Controller was successful. Its performance was quite satisfactory. It was tested in real use in DUET Campus and it is functioning properly. Such a PV charge controller design can provide efficient and stable power supply for various applications in Bangladesh.

5.2 Future Recommendation

While I have improved the reliability of overcharge detection for Lead-acid batteries, the algorithm we have proposed do not guarantee that the system will never be fooled and the overcharge will be properly detected at all times. For the proposed solar charge controlling method, the information about the effect of external disturbances in the battery temperature can not be totally decoupled due to physical constraints (package, position of the battery, etc…). Adding additional external temperature sensors covering all the areas of the pack could add information on the heat transfer between the solar charge controller pack and its surrounding such as the part of the pack is heated by sunlight, thereby allowing the algorithm to be balanced properly.
It was observed that a better solar charge controller could be designed with more effective algorithm by using Microcontroller based Maximum Power Point Tracking (MPPT) technology and Simulink software instead of Proteus software for simulation. At this point of the Project, it is not practical. So, I am recommending the above two outlined technologies to be incorporated and the Solar Charge Controller would be designed and constructed accordingly in future for better performance.

References

[1] S. Rahman and K. Tam, "*A feasibility study of photovoltaic fuel cell hybrid energy system", IEEE Trans.Energy Conversion*, vol. 3 pp. 50-55, Mar, 1998.

[2] E. Koutroulis and K. Kalitzakis, *"Novel battery charging regulation system for photovoltaic applications"*, IEEE proc.-Electr.Power Appl, vol.151, No 2, March 2004.

[3] Mohamad A.S. Masoum, Hooman Dehbonei and Edward F. Fuchs, *"Theoretical and Experimental Analysis of Photovoltaic System with Voltage and Current Based Maximum Power Point Tracking"*, IEEE Transaction of energy conversion, vol.17, No4, Dec.2002.

[4] Lijun Gao, Shengyi Liu and Roger A. Dougal, *"Dynamic Lithium-ion Battery Model for System Simulation*" IEEE Transaction on Component and Packing Technologies, Vol.25 No.3 Sep. 2002, pp1521-3331.

[5] S. Megahed and W. Ebner, *"Lithium-ion battery for electronic application",* J.Power Sources, vol 54, pp 155-162, 1995.

[6] Prof. Dr. Neem Chandra Bhowmik, Director Renewable Energy Research Centre, University of Dhaka, *Bangladesh Renewable Energy Report*".

[7] Faisal Ahammed, School of Business Studies & Dilder Ahmed Taufiq, "*Case Study Applications of Solar PV on Rural Development in Bangladesh",* Southeast University & Promotion of the Use of Renewable Energies (PURE) German Technical Cooperation, Gulshan-2, Dhaka-1212.

[8] Masudul Haider Imtiaz, "*design & implementation of an intelligent solar hybrid inverter in grid oriented* system for utilizing PV energy", International Journal of Engineering Science and Technology" Vol. 2(12), 2010, pp7524-7530.

[9] F. H. Fahmy, S. M. Sadek, N. M. Ahamed, M. B. Zahran, and Abd El-Shafy A. Nafeh, "*Microcontroller-Based Moving Message Display Powered by Photovoltaic Energy*", Electronics Research Institute, PV Dept., NRC Building, El-Tahrir St., Dokki, 12311-Giza, Egypt.

[10] Md. Ashiquzzaman, Nadia Afroze, Md. Jabed Hossain, Umama Zobayer, and Md. Mottaleb Hossain, *"Cost Effective Solar Charge Controller Using Microcontroller",* Canadian Journal on Electrical and Electronics Engineering Vol. 2, No. 12, December 2011.

[11] European Journal of Scientific Research, **"***A New Controller Scheme for Photovoltaic Power Generation Systems",* ISSN 1450-216X Vol.33 No.3 (2009), pp.515-524,

[12] Russell Hasan, "*A Research Report on Solar Power Investment: The Dawn of Solar Power",* Alternative Energy News Source (Altenews.com).

[13] A.A.Azooz, J M. Sulayman, "*Electronic control circuit for solar battery charging",* Department of Physics, College of Science, Mosul University, Mosul – Iraq.

[14] Maisha M Islam, **"***The Socio-economic Viability of Renewable Energy Technologies in Rural Bangladesh*", Economics Department Mount Holyoke College South Hadley, MA 01075 May 05, 2010.

[15] *www.infim.ro/rrp/2007_59_1/art07Azooz.pdf*

[16] www.umpir.ump.edu.my/.../*PHOTOVOLTAIC_CHARGE_CONTROLLER*..

[17] www.iris.lib.neu.edu/cgi/viewcontent.cgi?article=1008&context=elec...

[18] www.mendeley.com/**research**/micro**controller**-based-smart-**charge-co**.

[19] www.cirkits.com