Design of a solar charge controller set point and lead acid battery capacity tester

Thesis submitted for partial fulfillment of the requirements for Masters of Science (MS) in Renewable Energy Technology, Institute of Energy, University of Dhaka.

Submitted By:
Tanvir Rayhan
Roll: 08, 3rd batch
&
Shahriar Hossain
Roll: 26, 3rd batch
Session: 2013-2014

MS in Renewable Energy Technology (RET)
Institute of Energy, University of Dhaka
Dhaka, Bangladesh

DECLARATION

It is hereby, declared that the work presented in this thesis is the outcomes of the investigation performed by us under the supervision of Md. Habibur Rahman, PhD (Professor, Department of EEE, University of Dhaka, Bangladesh). We also declare that no part of this project has been submitted elsewhere for the award of any degree.

Supervised By	Signature
………………………………………………	______________________
Md. Habibur Rahman, PhD	Tanvir Rayhan
Professor	Roll: 08, 3rd batch
Department of EEE	
University of Dhaka	
	______________________
	Shahriar Hossain
	Roll: 26, 3rd batch

ACKNOWLEDGEMENT

We take this opportunity to express our deep sense of gratitude and profound respect to all those who have guided and inspired us for this work.

First and foremost, we extend our deep gratitude to our project supervisor Md. Habibur Rahman, PhD (Professor, Department of EEE, University of Dhaka) for his guidance, timely advice and support render during all stages of the research work. We express our whole hearted gratitude to him.

We have also got help from Institute of Energy during the course of this work.

We convey our thanks to our parents and friends who have directly or indirectly helped us in the successful completion of the project.

Finally we thank ALLAH for his blessings.

Abstract

This aim of this thesis is the designing of testing instrument for SHS. SHS is a growing sector in our country. In every SHS batteries and a DC charge controller are used. But capacities of those batteries or the performance of the DC charge controllers are not always verified before use. Due to that the system performance may become a problem for the consumers. These instruments can measure the capacity of a battery and sense the different set-points of a DC charge controller. From the measured data the capacity of the battery can be measured and can be decided whether it's good enough to use in a SHS or a battery which is already being used should to be replaced according to standard specification. By sensing the set-points of a DC Charge Controller we can compare with the standard set points and decide if the Charge Controller is good enough to use in a SHS. The purpose of this project is to determine the quality of the batteries and the DC charge controllers can be measured before using it on a SHS, so the consumer can be secured from a faulty system. We have used "Arduino IDE", open source software is used for the programming and communication interface between the computer and the data acquiring circuits. The developed systems have been in the laboratory of IE. It is found that the developed instrument works properly.

Table of Contents

Chapter- 1

Introduction

1.1 Introduction

Photovoltaic (PV) power systems convert sunlight directly into electricity. A residential PV power system enables a homeowner to generate some or all of their daily electrical energy demand on their own roof, exchanging daytime excess power for future energy needs (i.e. nighttime usage). The house remains connected to the electric utility at all times, so any power needed above what the solar system can produce is simply drawn from the utility.

For a developing country like ours where 38% of the people are not connected to any kind of grid electricity, Photovoltaic is the only way to meet their daily power demand.

IDCOL started the SHS program in 2003 to ensure access to clean electricity for the energy starved off-grid rural areas of Bangladesh. The program supplements the Government’s vision of ensuring ‘Access to Electricity for All’ by 2021.

About 3 million SHSs have already been installed under the program in the off-grid rural areas of Bangladesh till April 2014. As a result, 13 million beneficiaries are getting solar electricity which is around 9% of the total population of Bangladesh. IDCOL has a target to finance 6 million SHS by 2017, with an estimated generation capacity of 220 MW of electricity.

IDCOL initially received credit and grant support from the World Bank and GEF to start the program. Later, GIZ, KfW, ADB, IDB, GPOBA, JICA, USAID and DFID came forward with additional financial support for expansion of the SHS Program.

At present 47 Partner Organizations (PO) are implementing the program. IDCOL provides refinancing and grant support as well as necessary technical assistance to the POs. POs install the SHSs, extend credit to the end users and provide after sale services.

More than 65,000 SHSs are now being installed every month under the program with average year to year installation growth of 58%. The program replaces 180,000 tons of kerosene having an estimated value of USD 225 million per year. Moreover, around 70,000 people are directly or indirectly involved with the program.

The program has been acclaimed as one of the largest and the fastest growing off-grid renewable energy program in the world[1].

1.2 Performance of the storage battery

Storage efficiency of a battery is a very important factor for the overall power output to the load terminals. It is a well-known phenomenon that battery voltage keeps on increasing as the battery is charged. The usual upper cutoff voltage for 12V storage batteries, while charging is taking place, is around 14.5V. However, this voltage drops down to around 13V within a time of about 30 minutes once the charging is switched off and no effective discharging taking. At the same time, the battery voltage comes down below 12.5V very rapidly as the load starts drawing current from the battery. This fact actually means that while charging at 14.5V, the battery consumes 14.5watt/amp of the charging current but delivers a power of 12.5watt/ampere to the load. Considering the average charging voltage to be 13.5V and the average voltage during discharging is 12V, the effective charging efficiency of the battery is

h_b= 12V/13.5V= 0.89

This factor may get even worse as the batterybecomes old. On top of this, all the batteries have self-discharge(internal discharging) throughout itsworking life and can be significant particularly whenthe battery becomes old. However, battery self-dischargeeffect is much smaller compared to otherlosses and is ignored here [2].

1.3 Performance of the Charge Controller

The charge controller is a very important device used to ensure long life of the storage battery of a SHS. Charge controllers are usually high efficiency circuits controlling the charging and discharging of the battery as per requirement set by the battery manufacturer. The protective diode used in the charge controller, prevents the battery from trickle discharge through the reverse saturation current of the panel during night hours. This diode causes a voltage drop of about 0.6V, where the usual nominal voltage of the battery is 12V. This voltage drop right away incurs a loss reducing the overall efficiency by a factor of about 0.95. The Charge controllers usually run at efficiency around 95% considering the losses both during charging and discharging. Other than the loss incurred in the BJT or MOSFET switches, the control circuit continuously consumes an average of 15mA. Summed up over the period of 24 hours a day, this comes out to be 4.5WH/day. However, the most important factor that reduces the output of the solar panel is the charging of the battery at a voltage, which is significantly lower than the panel voltage for maximum power output. For most of the panels having peak power less than 100W, the voltage for peak power is about 17V as mentioned by different solar panel manufacturers. Higher capacity panels have a lower peak power voltage. For panels having peak power less than 100W, it delivers 12W per ampere to a 12V battery where as it has a capacity to provide 17W per ampere. Assuming the average charging voltage of the battery to be 13.5V, efficiency of charging is 13.5/17@0.8. For a charge controller without maximum power point tracking facility, the overall performance factor for the charge controller is

hcc= 0.95x.95x.8=0.722

1.4 Thesis Organization:

The thesis is organized in an order such as to provide the readers with a general understanding ofthe different components present in SHS, before moving on to the details specific to the project. The followingchapter discusses about lead acid battery, theconcept of solar charge controller such as PWM and MPPT charge controller. This chapter also explains how maximum power transfer can berealized with a maximum power point tracker. These generaldiscussions are followed by the chapter which details the software and how it. Chapter 5 provides a detailed design and block diagram of the overall. Chapter 6 gives a detailed explanation of how the system works. It includes the operation principle and experimental procedure. On chapter 7 we presented our test result which we acquired from this device. The thesisends with the concluding chapter that discusses future aspects of this project.

Chapter- 2

Battery

2.1 Battery history

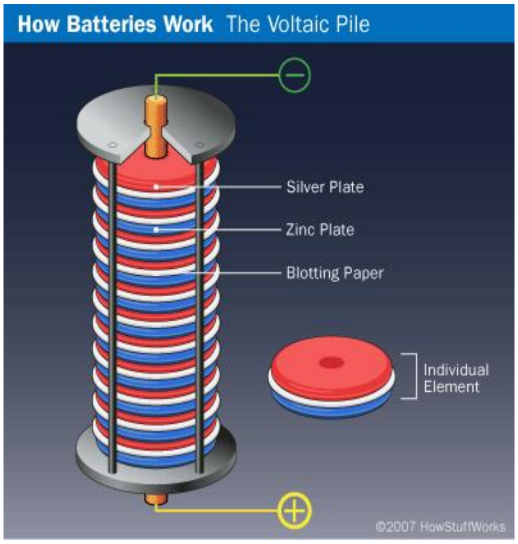


Figure 1simple single cell battery

Batteries have been around longer than you may think. In 1938, archaeologist Wilhelm Konig discovered some peculiar clay pots while digging at Khujut Rabu, just outside of present-day Baghdad, Iraq. The jars, which measure approximately 5 inches (12.7 centimeters) long, contained an iron rod encased in copper and dated from about 200 B.C. Tests suggested that the vessels had once been filled with an acidic substance like vinegar or wine, leading Konig to believe that these vessels were ancient batteries. Since this discovery, scholars have produced replicas of the pots that are in fact capable of producing an electric charge. These "Baghdad batteries" may have been used for religious rituals, medicinal purposes, or even electroplating.

In 1799, Italian physicist Alessandro Volta created the first battery by stacking alternating layers of zinc, brine-soaked pasteboard or cloth, and silver. This arrangement, called a voltaic pile, was not the first device to create electricity, but it was the first to emit a steady, lasting current. However, there were some drawbacks to Volta's invention. The height at which the layers could be stacked was limited because the weight of the pile would squeeze the brine out of the pasteboard or cloth. The metal discs also tended to corrode quickly, shortening the life of the battery. Despite these shortcomings, the SI unit of electromotive force is now called a volt in honor of Volta's achievement.

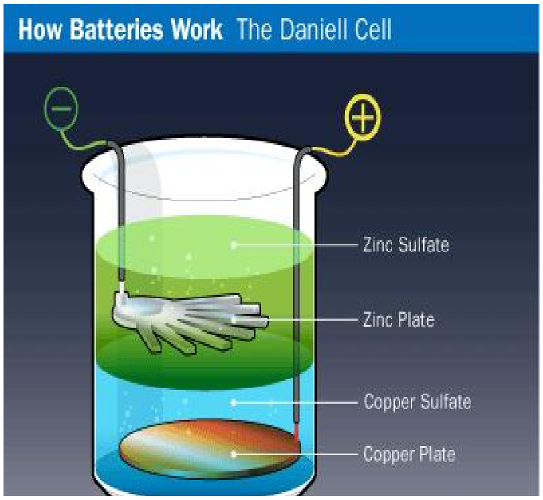


Figure 2 Daniell cell

The next breakthrough in battery technology came in 1836 when English chemist John Frederick Daniell invented the Daniell cell. In this early battery, a copper plate was placed at the bottom of a glass jar and a copper sulfate solution was poured over the plate to half-fill the jar. Then the zinc plate was hung in the jar, and a zinc sulfate solution was added. Because copper sulfate is denser than zinc sulfate, the zinc solution floated to the top of thecopper solution and surrounded the zinc plate. The wire connected to the zinc plate represented the negative terminal, while the one leading from the copper plate was the positive terminal. Obviously, this arrangement would not have functioned well in a flashlight, but for stationary applications it worked just fine. In fact, the Daniell cell was a common way to power doorbells and telephones before electrical generation was perfected.

By 1898, the Colombia Dry Cell became the first commercially available battery sold in the United States. The manufacturer, National Carbon Company, later became the Eveready Battery Company, which produces the Energizer brand [3].

2.2 Why test battery systems

There are three main reasons to test battery systems:

1. To insure the supported equipment is adequately backedup
2. To prevent unexpected failures by tracking the battery's health
3. To forewarn/predict death

And, there are three basic questions that battery users ask:

1. What are the capacity and the condition of the battery now?
2. When will it need to be replaced?
3. What can be done to improve / not reduce its life?

Batteries are complex chemical mechanisms. They have numerous components from grids, active material, posts, jar and cover, etc. – any one of which can fail. As with all manufacturing processes, no matter how well they are made, there is still some amount of black art to batteries (and all chemical processes). A battery is two dissimilar metallic materials in an electrolyte. In fact, you can put a penny and a nickel in half of a grapefruit and you now have a battery. Obviously, an industrial battery is more sophisticated than a grapefruit battery. Nonetheless, a battery, to work the way it is supposed to work must be maintained properly. A good battery maintenance program may prevent, or at least, reduce the costs and damage to critical equipment due to an AC mains outage. Even though there are many applications for batteries, they are installed for only two reasons:

- To protect and support critical equipment during an AC outage
- To protect revenue streams due to the loss of service

There are two main battery chemistries used today – lead-acid and nickel-cadmium. Other chemistries are coming, like lithium, which is prevalent in portable battery systems, but not stationary, yet. Volta invented the primary (non-rechargeable) battery in 1800. Planté invented the lead-acid battery in 1859 and in 1881 Faure first pasted lead-acid plates. With refinements over the decades, it has become a critically important back-up power source. The refinements include improved alloys, grid designs, jar and cover materials and improved jar-to-cover and post seals. Arguably, the most revolutionary development was the valve-regulated development. Many similar improvements in nickel-cadmium chemistry have been developed over the years[4].

2.3 Battery types

There are several main types of battery technologies with Subtypes:

The next table compares the characteristics of the six most commonly used rechargeable battery systems in terms of energy density, cycle life, exercise requirements and cost. The figures are based on average ratings of commercially available batteries at the time of publication. Exotic batterieswith above average ratings are not included.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer	**Reusable Alkaline**
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-300	80(initial)
Internal Resistance (includes peripheral circuits) in mW	100 to 200 6V	200 to 300 6V	<100 12V	150 to 250 7.2V	200 to 300 7.2V	200 to 2000 6V
Cycle Life (to 80% of initial capacity)	1500	300-500	200-300	500-1000	300-500	50(to 50%)
Fast Charge	1h	2-4h	8-16h	2-4h	2-4h	2-3h

Time						
Overcharge Tolerance	Moderate	Low	High	Very low	Low	Moderate
Self-discharge / Month (room temperature)	20%	30%	5%	10%	10%	0.3%
Cell Voltage (nominal)	1.25V	1.25V	2V	3.6V	3.6V	1.5V
Load Current - peak - best result	20C 1C	5C 0.5C or lower	5C 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 60°C
Maintenance Requirement	30 days to 60 days	60 days to 90 days	3 to 6 months	Not req.	Not req.	Not req.
Typical Battery Cost (US$, reference	$50 7.2V	$60v 7.2v	$25 6V	$100 7.2V	$100 7.2V	$5 9V

only)						
Cost per Cycle (US$)	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970	1991	1999	1992

Table 1 characteristics of the six rechargeable batteries

2.4 The Lead Acid Battery

Invented by the French physician Gaston Planté in 1859, lead acid was the first rechargeable battery for commercial use. Today, the flooded lead acid battery is used in automobiles, forklifts and large uninterruptible power supply (UPS) systems. During the mid-1970s, researchers developed a maintenance-free lead acid battery, which could operate in any position. The liquid electrolyte was transformed into moistened separators and the enclosure was sealed. Safety valves were added to allow venting of gas during charge and discharge. Driven by diverse applications, two designations of batteries emerged. They are the sealed lead acid (SLA), also known under the brand name of Gelcell, and the valve regulated lead acid (VRLA). Technically, both batteries are the same. No scientific definition exists as to when an SLA becomes a VRLA. (Engineers may argue that the word 'sealed lead acid' is a misnomer because no lead acid battery can be totally sealed. In essence, all are valve regulated.) The SLA has a typical capacity range of 0.2Ah to 30Ah and powers portable and wheeled applications. Typical uses are personal UPS units for PC backup, small emergency lighting units, ventilators for health care patients and wheelchairs. Because of low cost, dependable service and minimal maintenance requirements, the SLA battery is the preferred choice for biomedical and health care instruments in hospitals and retirement homes. The VRLA battery is generally used for stationary applications. Their capacities range from 30Ah to several thousand Ah and are found in larger UPS systems for power backup. Typical uses are mobile phone repeaters, cable distribution centers, Internet hubs and utilities, as well as power backup for banks, hospitals, airports and military installations. Unlikethe flooded lead acid battery, both the SLA and VRLA are designed with a low over-voltage potential to prohibit the battery from reaching its gas-generating potential during charge. Excess charging would cause gassing and water depletion. Consequently, the SLA and VRLA can never be charged to their full potential. Among modern rechargeable batteries, the lead acid battery family has the lowest energy density. For the purpose of analysis, we use the term 'sealed lead acid' to describe the lead acid batteries for portable use and 'valve regulated lead acid' for stationary applications. Because of our focus on portable batteries, we focus mainly on the SLA.

2.5 Advantages and Limitations of Lead Acid Batteries

Advantages

- Inexpensive and simple to manufacture — in terms of cost per watt hours, the SLA is the least expensive.
- Mature, reliable and well-understood technology — when used correctly, the SLA is durable and provides dependable service.
- Low self-discharge —the self-discharge rate is among the lowest in rechargeable battery systems.
- Low maintenance requirements — no memory; no electrolyte to fill.
- Capable of high discharge rates.

Limitations

- Cannot be stored in a discharged condition.
- Low energy density — poor weight-to-energy density limits use to stationary and wheeled applications.
- Allows only a limited number of full discharge cycles — well suited for standby applications that require only occasional deep discharges.
- Environmentally unfriendly — the electrolyte and the lead content can cause environmental damage.
- Transportation restrictions on flooded lead acid — there are environmental concerns regarding pillage in case of an accident.
- Thermal runaway can occur with improper charging.

2.6 Why Lead Acid

Most economical for larger power applications where weight is of little concern. The lead acid battery is the preferred choice for hospital equipment, wheelchairs, emergency lighting and UPS systems.

The figures are based on average ratings of batteries available commercially at the time of publication; experimental batteries with above average ratings are not included.

1. Internal resistance of a battery pack varies with cell rating, type of protection circuit and number of cells. Protection circuit of Li-ion and Li-polymer adds about 100mW.
2. Cycle life is based on battery receiving regular maintenance. Failing to apply periodic full discharge cycles may reduce the cycle life by a factor of three.
3. Cycle life is based on the depth of discharge. Shallow discharges provide more cycles than deep discharges.
4. The discharge is highest immediately after charge, then tapers off. The NiCd capacity decreases 10% in the first 24h, then declines to about 10% every 30 days thereafter.Self-discharge increases with higher temperature.
5. Internal protection circuits typically consume 3% of the stored energy per month.
6. 1.25V is the open cell voltage. 1.2V is the commonly used value. There is no difference between the cells; it is simply a method of rating.
7. Capable of high current pulses.
8. Applies to discharge only; charge temperature range is more confined.
9. Maintenance may be in the form of ‘equalizing’ or ‘topping’ charge.
10. Cost of battery for commercially available portable devices.
11. Derived from the battery price divided by cycle life. Does not include the cost of electricity and chargers.

2.7 The Battery Pack

In the 1700 and 1800s, cells were encased in glass jars. Later, larger batteries1 were developed that used wooden containers. The inside was treated with a sealant to prevent electrolyte leakage. With the need for portability, the cylindrical cell appeared. After World War II, these cells became the standard format for smaller, rechargeable batteries. Downsizing required smaller and more compact cell design. The button cell, which gained popularity in the 1980s, was a first attempt to achieve a reasonably flat geometry, or obtain higher voltages in a compact profile by stacking. The early 1990s brought the prismatic cell, which was followed by the modern pouch cell.

2.8 Charging the Lead Acid Battery:

The charge algorithm for lead acid batteries differs from nickel-based chemistry in that voltage limiting rather than current limiting is used. Charge time of a sealed lead acid (SLA) is 12 to 16 hours. With higher charge currents and multi-stage charge methods, charge time can be reduced to 10 hours or less. SLAs cannot be fully charged as quickly as nickel-based systems.

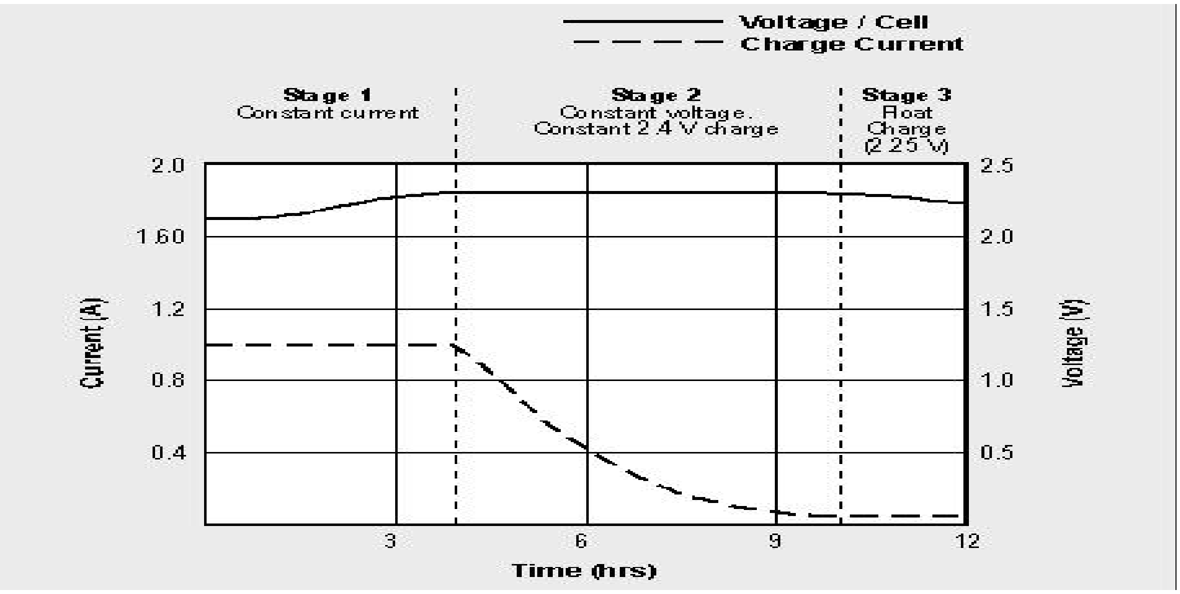


Figure 3Charge stages of a lead acid battery

A multi-stage charger applies constant-current charge, topping charge and float charge. During the constant current charge, the battery charges to 70 percent in about five hours; the remaining 30 percent is completed by the slow topping charge. The topping charge lasts another five hours and is essential for the well-being of the battery. This can be compared to a little rest after a good meal before resuming work. If the battery is not completely saturated, the SLA will eventually lose its ability to accept a full charge and the performance of the battery is reduced. The third stage is the float charge, which compensates for the self-discharge after the battery has been fully charged.

The optimal float charge voltage shifts with temperature. A higher temperature demands slightly lower voltages and a lower temperature demands higher voltages. Chargers that are exposed to largetemperature fluctuations are equipped with temperature sensors to optimize the float voltage. Regardless of how well the float voltage may be compensated, there is always a compromise. The author of a paper in a battery seminar explained that charging a sealed lead acid battery using the traditional float charge techniques is like 'dancing on the head of a pin'. The battery wants to be fully charged to avoid sulfation on the negative plate, but does not want to be over-saturated which causes grid corrosion on the positive plate. In addition to grid corrosion, too high a float charge contributes to loss of electrolyte. Differences in the aging of the cells create another challenge in finding the optimum float charge voltage. With the development of air pockets within the cells over time, some batteries exhibit hydrogen evolution from overcharging. Others undergo oxygen recombination in an almost starved state. Since the cells are connected in series, controlling the individual cell voltages during charge is virtually impossible. If the applied cell voltage is too high or too low for a given cell, the weaker cell deteriorates further and its condition becomes more pronounced with time. Companies have developed cell-balancing devices that correct some of these problems but these devices can only be applied if access to individual cells is possible.

A ripple voltage imposed on the charge voltage also causes problems for lead acid batteries, especially the larger VRLA. The peak of the ripple voltage constitutes an overcharge, causing hydrogen evolution; the valleys induce a brief discharge causing a starved state. Electrolyte depletion may be the result. Much has been said about pulse charging lead acid batteries. Although there are obvious benefits of reduced cell corrosion, manufacturers and service technicians are not in agreement regarding the benefit of such a charge method. Some advantages are apparent if pulse charging is applied correctly, but the results are non-conclusive.

An SLA must be stored in a charged state. A topping charge should be applied every six months to avoid the voltage from dropping below 2.10V/cell. The topping charge requirements may differ with cell manufacturers. Always follow the time intervals recommended by the manufacturer. By measuring the open cell voltage while in storage, an approximate charge-level indication can be obtained. A voltage of 2.11V, if measured at room temperature, reveals that the cell has a charge of 50 percent and higher. If the voltage is at or above this threshold, the battery is in good condition and only needs a full charge cycle prior to use. If the voltage drops below 2.10V, several discharge/charge cycles may be required to bring the battery to full performance. When measuring the terminal voltage of any cell, the storage temperature should be observed. A cool battery raises the voltage slightly and a warm one lowers it[4].

Caution: When charging a lead acid battery with over-voltage, current limiting must be applied once the battery starts to draw full current. Always set the current limit to the lowest practical setting andobserve the battery voltage and temperature during the procedure. If the battery does not accept a normal charge after 24 hours under elevated voltage, a return to normal condition is unlikely.

2.9 Discharge Methods:

The purpose of a battery is to store energy and release it at the appropriate time in a controlled manner. Being capable of storing a large amount of energy is one thing; the ability to satisfy the load demands is another. The third criterion is being able to deliver all available energy without leaving precious energy behind when the equipment cuts off.

2.10 C-rate:

The charge and discharge current of a battery is measured in C-rate. Most portable batteries, with the exception of the lead acid, are rated at 1C.

The capacity of a battery is commonly measured with a battery analyzer. If the analyzer's capacity readout is displayed in percentage of the nominal rating, 100 percent is shown if 1000mA can be drawn for one hour from a battery that is rated at 1000mAh. If the battery only lasts for 30 minutes before cut-off, 50 percent is indicated. A new battery sometimes provides more than 100 percent capacity. In such a case, the battery is conservatively rated and can endure a longer discharge time than specified by the manufacturer.

One battery that does not perform well at a 1C discharge rate is the SLA. To obtain a practical capacity reading, manufacturers commonly rate these batteries at 0.05C or 20 hour discharge. Even at this slow discharge rate, it is often difficult to attain 100 percent capacity. By discharging the SLA at a more practical 5h discharge (0.2C), the capacity readings are correspondingly lower. To compensate for the different readings at various discharge currents, manufacturers offer a capacity offset. Applying the capacity offset does not improve battery performance; it merely adjusts the capacity calculation if discharged at a higher or lower C-rate than specified. The battery manufacturer determines the amount of capacity offset recommended for a given battery type.

2.11 Depth of Discharge:

The typical end-of-discharge voltage for nickel-based batteries is 1V/cell. At that voltage level, about 99 percent of the energy is spent and the voltage starts to drop rapidly if the discharge continues. Discharging beyond the cut-off voltage must be avoided, especially under heavy load.

Since the cells in a battery pack cannot be perfectly matched, a negative voltage potential (cell reversal) across a weaker cell occurs if the discharge is allowed to continue beyond the cut-off point. The larger the number of cells connected in series, the greater the likelihood of this occurring.

If the battery is discharged at a rate higher than 1C, the more common end-of-discharge point of a Nickel-based battery is 0.9V/cell. This is done to compensate for the voltage drop induced by the internal resistance of the cell, the wiring, protection devices and contacts of the pack. A lower cut-off point also delivers better battery performance at cold temperatures.

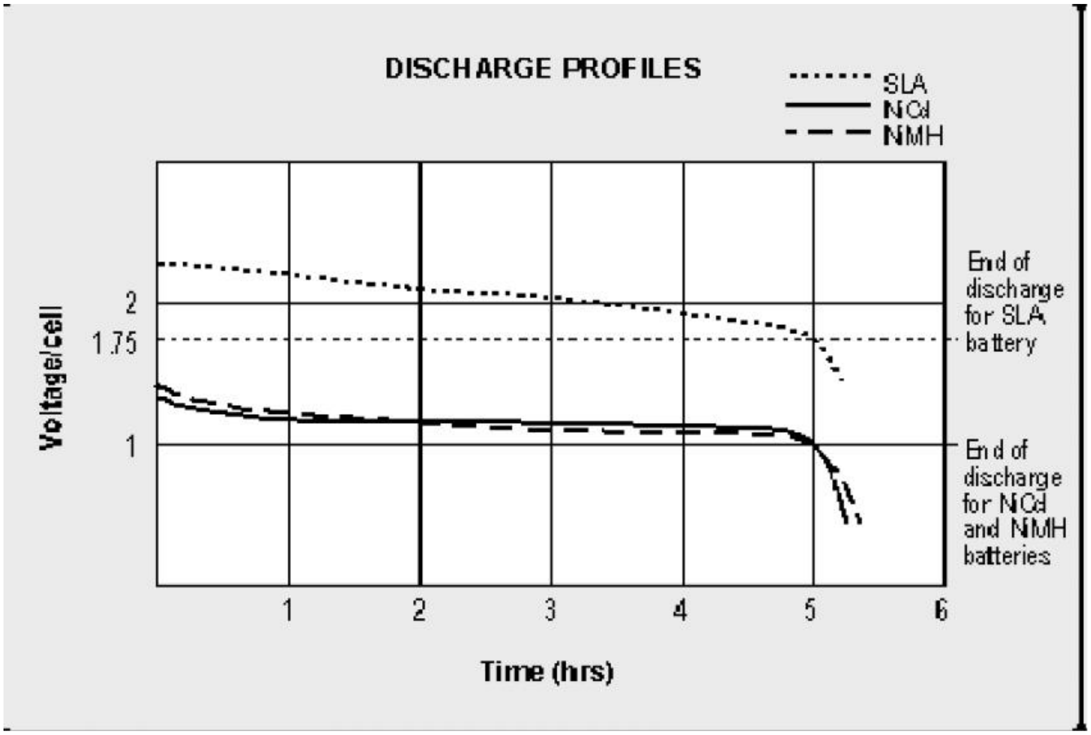


Figure 4Discharge characteristics of NiCd, NiMH and SLA batteries

The recommended end-of-discharge voltage for the SLA is 1.75V/cell. Unlike the preferred flat discharge curve of the NiCd, the SLA has a gradual voltage drop with a rapid drop towards the end of discharge. Although this steady decrease in voltage is a disadvantage, it has a benefit because the voltage level can be utilized to display the state-of-charge (SoC) of a battery. However, the voltage readings fluctuate with load and the SoC readings are inaccurate.

The SLA should not be discharged beyond 1.75V per cell, nor can it be stored in a discharged state. The cells of a discharged SLA sulfate, a condition that renders the battery useless if left in that state for a few days[4].

Chapter -3

Charge Controller

3.1 Charge controller

A charge controller or charge regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. In simple words, Solar Charge controller is a device, which controls the battery charging from solar cell and also controls the battery drain by load. The simple Solar Charge controller checks the battery whether it requires charging and if yes it checks the availability of solar power and starts charging the battery. Whenever controller found that the battery has reached the full charging voltage levels, it then stops the charging from solar cell. On the other hand, when it found no solar power available then it assumes that it is night time and switch on the load. It keeps on the load until the battery reached to its minimum voltage levels to prevent the battery dip-discharge. Simultaneously Charge controller also gives the indications like battery discharge, load on, charging on etc. In this thesis we are using microcontroller based charge controller. Microcontroller is a kind of miniature computer containing a processor core, memory, and programmable input/output peripherals. The Functions of a microcontroller in charge controller are:

- Measures Solar Cell Voltage.
- Measures Battery Voltage.
- Voltage Regulation (VR) set point
- Array Reconnect Voltage (ARV) set point
- Low voltage Load Disconnect (LVD) set point
- Load Reconnect Voltage (LRV) set point

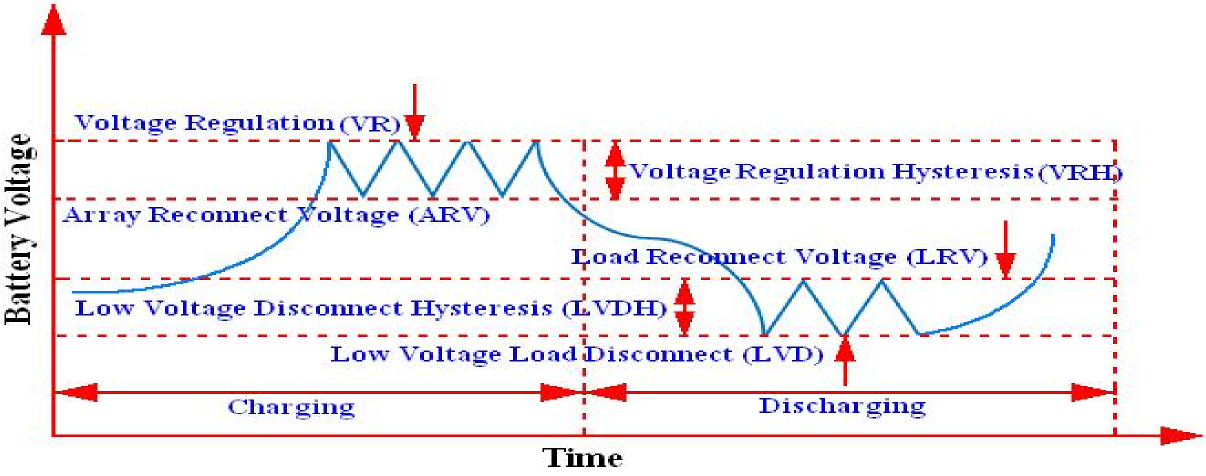


Figure 5Charge Controller set points

- **Array Reconnect Voltage (ARV) set point**

When the battery voltage decreases to a predefined voltage, the array is again reconnected to the battery to resume charging. This voltage at which the array is reconnected is defined as the array reconnect voltage (ARV) set point.

- **Voltage Regulation Hysteresis (VRH)**

The voltage difference between the **voltage regulation set point** and the **array reconnect voltage** is often called the voltage regulation hysteresis (VRH).

If the hysteresis is too great, the array current remains disconnected for long periods, effectively lowering the array energy utilization and making it very difficult to fully recharge the battery.

If the regulation hysteresis is too small, the array will cycle on and off rapidly, perhaps damaging controllers which use electro-mechanical switching elements.

- **Low Voltage Load Disconnect (LVD) Set Point**

If battery voltage drops too low, due to prolonged bad weather for example, certain non-essential loads can be disconnected from the battery to prevent further discharge. This can be done using a low voltage load disconnect (LVD) device connected between the battery and non-essential loads.

The LVD is either a relay or a solid-state switch that interrupts the current from the battery to the load, and is included as part of most controller designs. In some cases, the low voltage load disconnect unit may be a separate unit from the main charge controller.

- **Load Reconnect Voltage (LRV) Set Point**

The battery voltage at which a charge controller allows the load to be reconnected to the battery is called the load reconnect voltage (LRV). After the charge controller disconnects the load from the battery at the LVD set point, the battery voltage rises to its open-circuit voltage.

When additional charge is provided by the array, the battery voltage rises even more. At some point, the controller senses that the battery voltage and state of charge are high enough to reconnect the load, called the load reconnect voltage set point[5].

3.2 Why do we need a Charge controller?

- **Longer battery life:**
  - reducing the costs of the solar system
  - reducing battery disposal problems

- **More battery reserve capacity:**
  - increasing the reliability of the solar system
  - reducing load disconnects
  - Opportunity to reduce battery size to lower the system cost
  - Ability to recover lost battery capacity
  - Increase battery charge acceptance
  - Maintain high average battery capacities
  - Reduce battery heating and gassing

- **Greater use of the solar array energy:**
  - get 20% to 30% more energy from your solar panels for charging
  - stop wasting the solar energy when the battery is only 50% charged
  - opportunity to reduce the size of the solar array to save costs

- **Greater user satisfaction:**
  - get more power when you need it for less money[6]

3.3 How to Size a Solar Charge Controllers

Choosing a well-made charge controller is integral to the long life and efficiency of your entire solar power system. By optimizing the power coming in from your solar panels, you will get that much closer to offsetting your use of traditional on grid power sources and by protecting your battery supply you protect yourself from any unwanted and unneeded replacement costs. Your solar charge controller is an item well worth investing in and researching as your customize your solar panel electric system. Make sure you choose an option that is scalable and appropriate for your power load and make sure that you have sufficient battery storage space for the solar panels you have chosen to install. We will advise you on everything from optimizing your current power load to how best to install your solar panels and on choosing the right solar charge controller! Solar charge controllers are rated and sized by the solar panel array current and system voltage. Most common are 12, 24, and 48-volt controllers. Amperage ratings normally run from 1 amp to 60 amps, voltages from 6-60 volts.

For example, if one module in your 12-volt system produces 7.45 amps and two modules are utilized, your system will produce 14.9 amps of current at 12 volts. Because of light reflection and the edge of cloud effect, sporadically increased current levels are not uncommon. For this reason we increase the controller amperage by a minimum of 25% bringing our minimum controller amperage to 18.6. Looking through the products we find a 20-amp controller, as close a match as possible. There is no problem going with a 30-amp or larger controller, other than the additional cost. If you think the system may increase in size, additional amperage capacity at this time should be considered[7].

3.4 Different types of Solar Charge Controller:

PWM and MPPT charge controllers are both widely used to charge batteries with solar power. The PWM controller is in essence a switch that connects a solar array to the battery. The result is that the voltage of the array will be pulled down to near that of the battery. The MPPT controller is more sophisticated (and more expensive): it will adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply the varying voltage requirement of the battery plus load. Thus, it essentially decouples the array and battery voltages so that there can be, for example, a 12 volt battery on one side of the MPPT charge controller and panels wired in series to produce 36 volts on the other. It is generally accepted that MPPT will outperform PWM in a cold to temperate climate, while both controllers will show approximately the same performance in a subtropical to tropical climate.

3.5 Maximum Power Point Tracker

I-V characteristic of a PV panel simulated by MATLAB is shown below in Figure: 6. For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. The power P is given by P=VI. A plot of panel output power vs. panel voltage is shown in figure: 2.5 which have a peak point indicated by MPP which falls off on both sides. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve, at which the module operates with the maximum efficiency and produces the maximum output power.

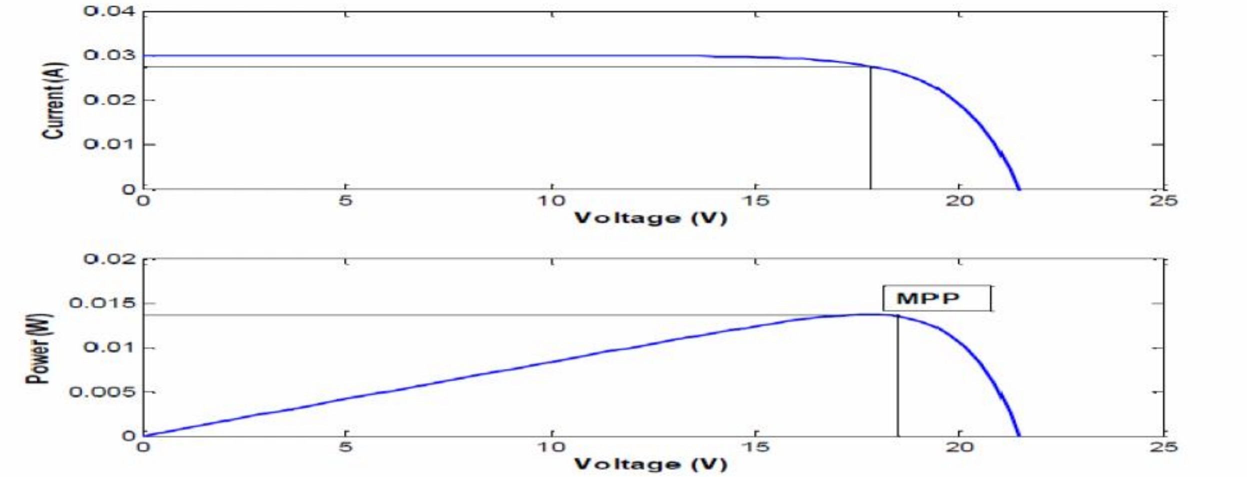


Figure 6 I-V characteristic of a PV panel

In a (Power-Voltage or current-voltage) curve of a solar panel, there is an optimum operating point such that the PV delivers the maximum possible power to the load. This unique point is the maximum power point (MPP) of solar panel. Because of the photovoltaic nature of solar panels, their current-voltage, or IV, curves depend on temperature and irradiance levels. Therefore, the operating current and voltage which maximize power output will change with environmental conditions. As the optimum point changes with the natural conditions so it is very important to track the maximum power point (MPP) for a successful PV system. So in PV systems a maximum power point tracker (MPPT) is very much needed. In most PV systems a control algorithm, namely maximum power point tracking algorithm is utilized to have the full advantage of the PV systems[8].

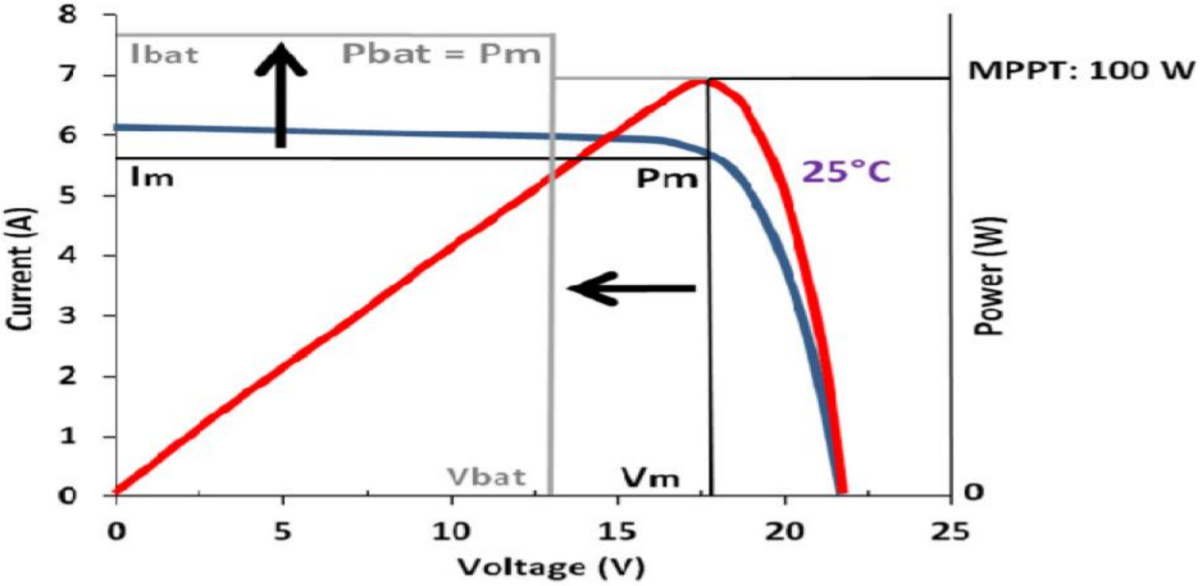


Figure 7MPPT controller, graphical representation of the DC to DC transformation

3.6 The PWM charge controller:

Pulse Width Modulation (PWM) is the most effective means to achieve constant voltage battery charging by switching the solar system controller's power devices. When in PWM regulation, the current from the solar array tapers according to the battery's condition and recharging needs.

PWM solar chargers use technology similar to other modern high quality battery chargers. When a battery voltage reaches the regulation set point, the PWM algorithm slowly reduces the charging current to avoid heating and gassing of the battery, yet the charging continues to return the maximum amount of energy to the battery in the shortest time. The result is a higher charging efficiency, rapid recharging, and a healthy battery at full capacity. In addition, this new method of solar battery charging promises some very interesting and unique benefits from the PWM pulsing. These include:

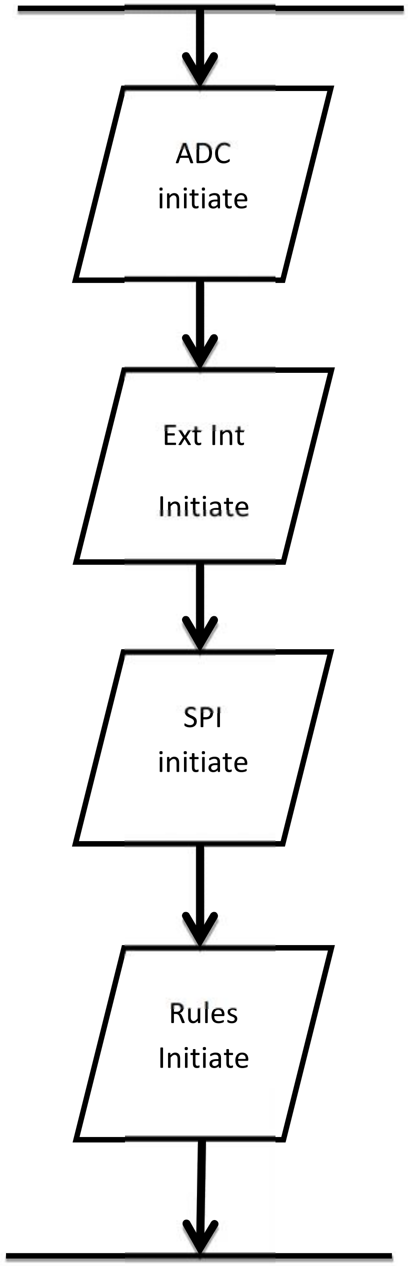
- Ability to recover lost battery capacity and desulfate a battery.
- Dramatically increase the charge acceptance of the battery.
- Maintain high average battery capacities (90% to 95%) compared to on-off regulated state-of charge levels that are typically 55% to 60%.
- Equalize drifting battery cells.
- Reduce battery heating and gassing.
- Automatically adjust for battery aging.
- Self-regulate for voltage drops and temperature effects in solar systems[6].

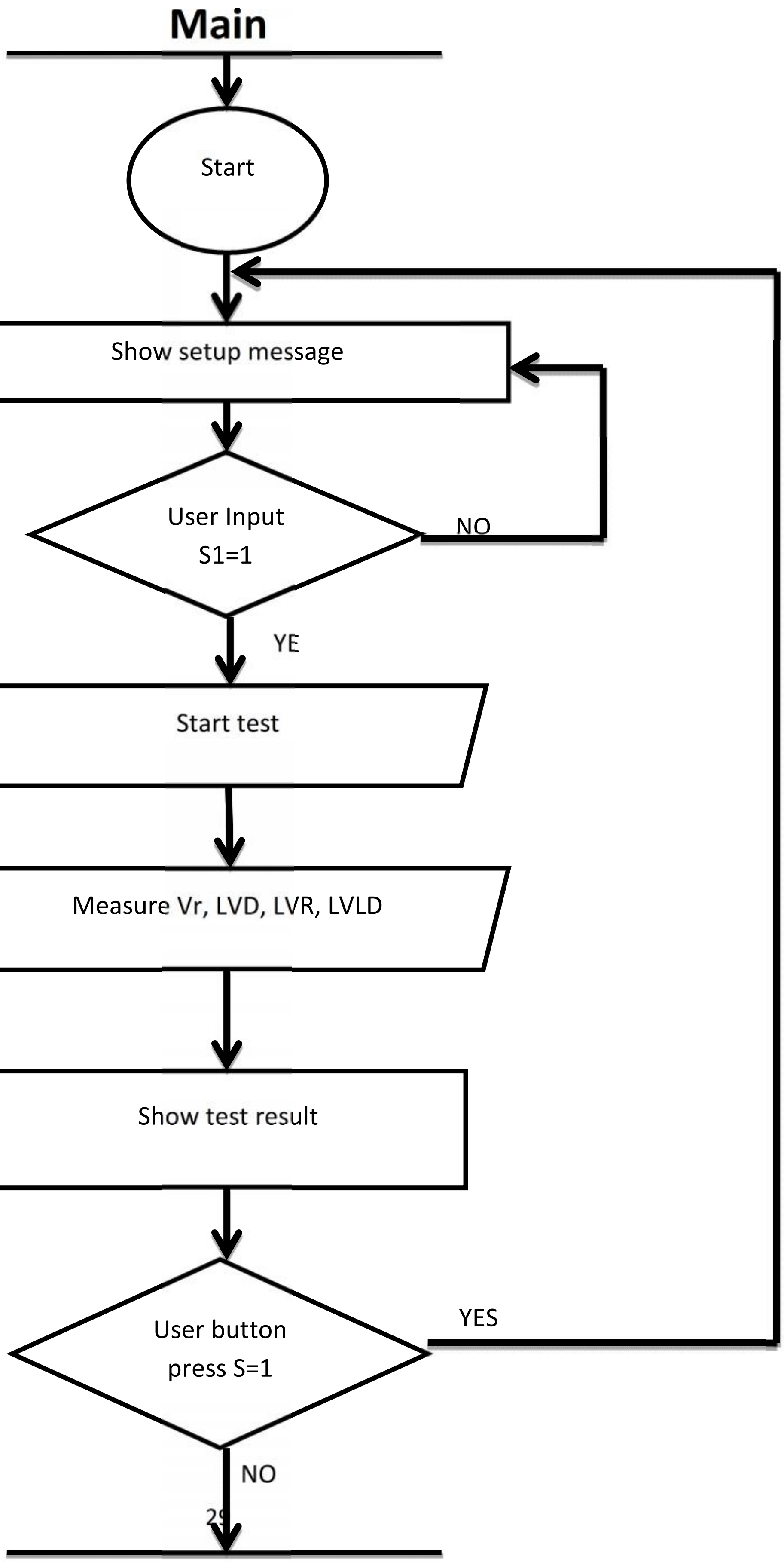
Chapter- 4

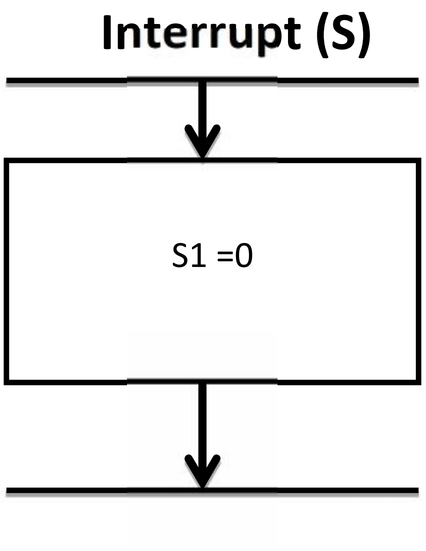
Software

4.1 Charge controller Operational Flow charts

Initialization

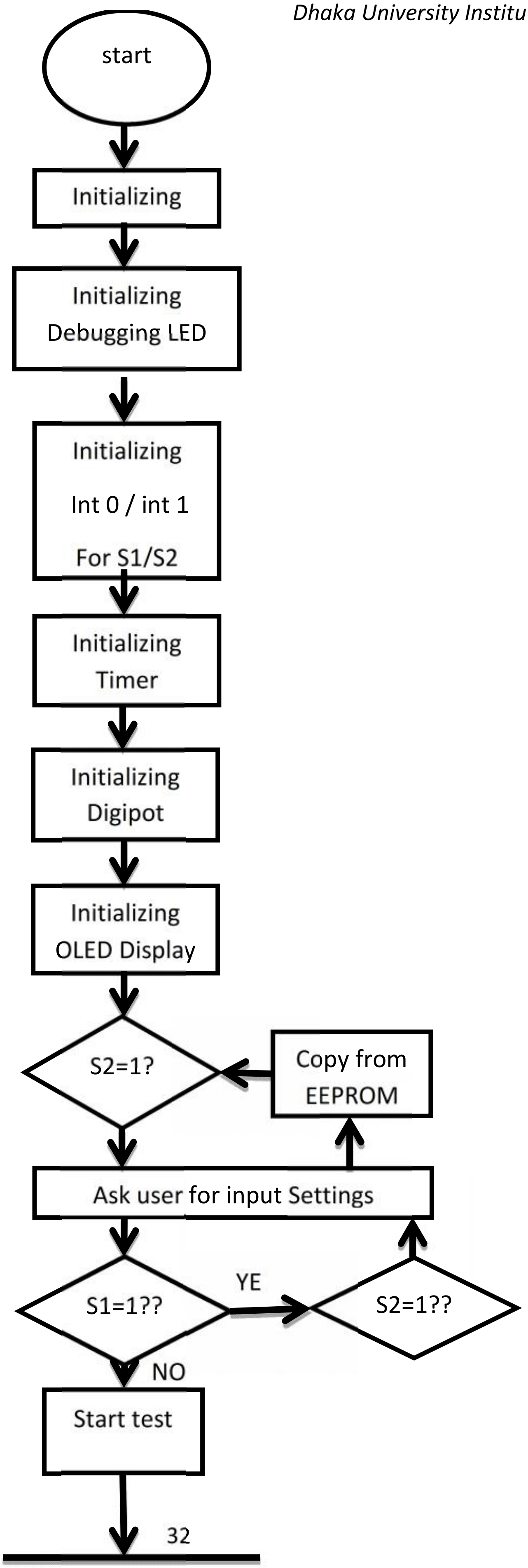



Main
Start
Show setup message
User Input
S1=1
NO
YE
Start test
Measure Vr, LVD, LVR, LVLD
Show test result
User button
press S=1
YES
NO

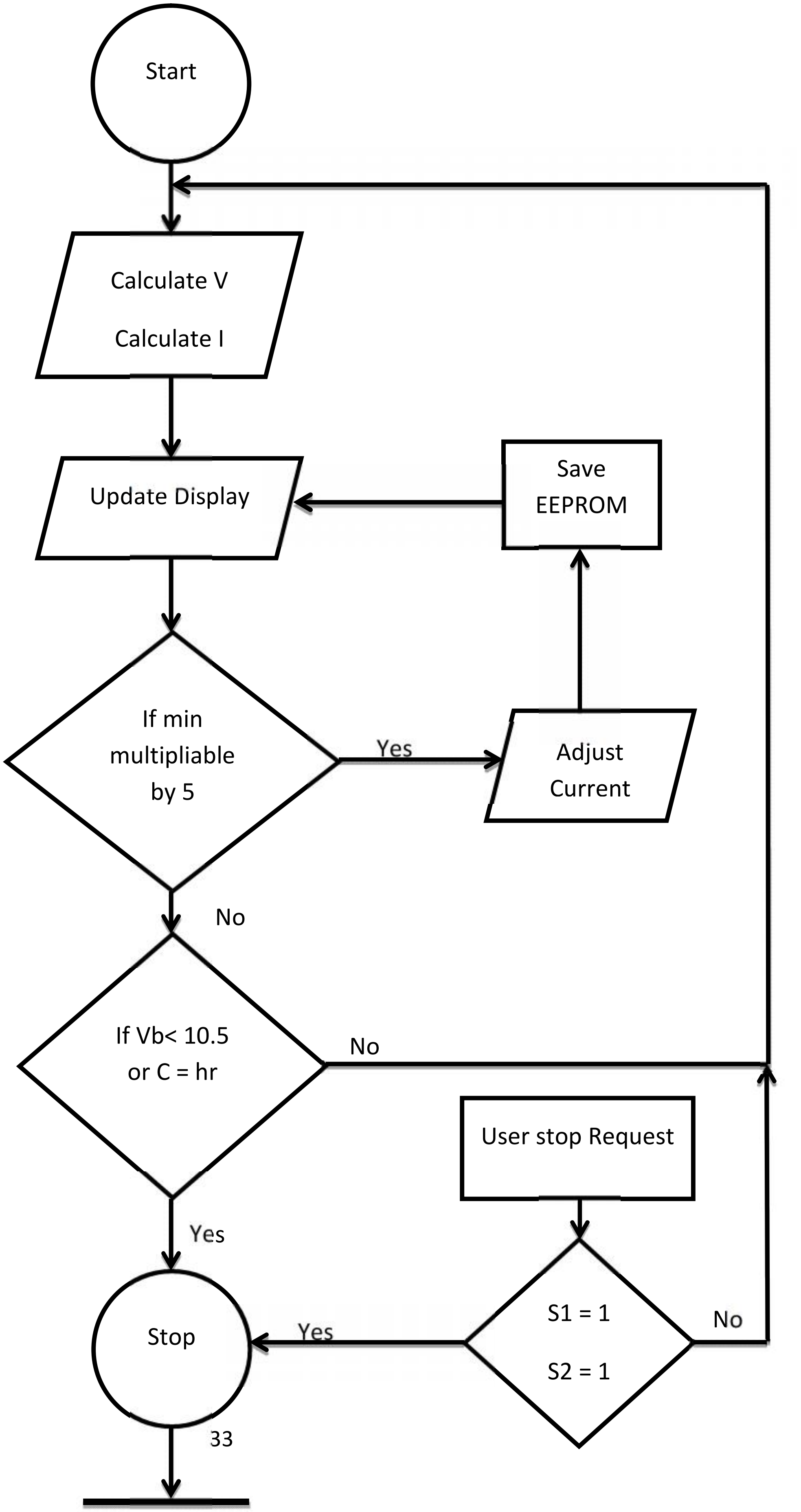

Interrupt (S)
S1 =0

4.2 Battery Tester Operational Flow charts

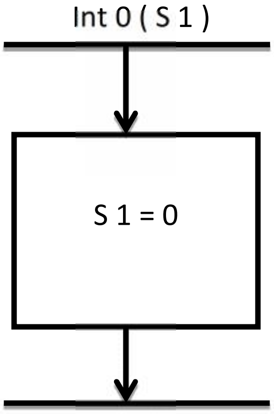
Initializing

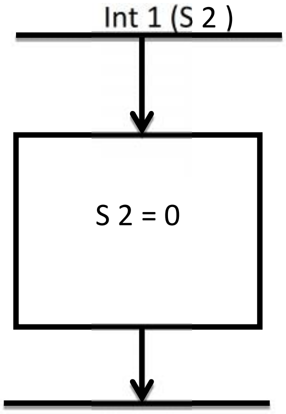


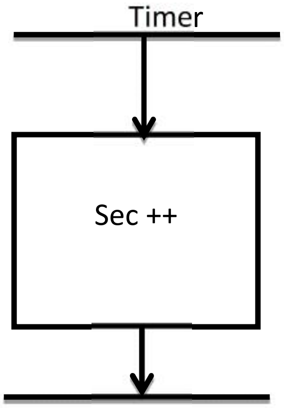
Main


Start
Calculate V
Calculate I
Update Display
Save
EEPROM
If min
multipliable
by 5
Yes
Adjust
Current
No
If Vb< 10.5
or C = hr
No
User stop Request
Yes
S1 = 1
S2 = 1
No
Stop
Yes

Interrupt







Chapter- 5

Hardware

5.1 Battery Capacity tester Block Diagram:

The main working units of the battery capacity tester are shown in the following block diagram. The function of each unit is described in the following headings.

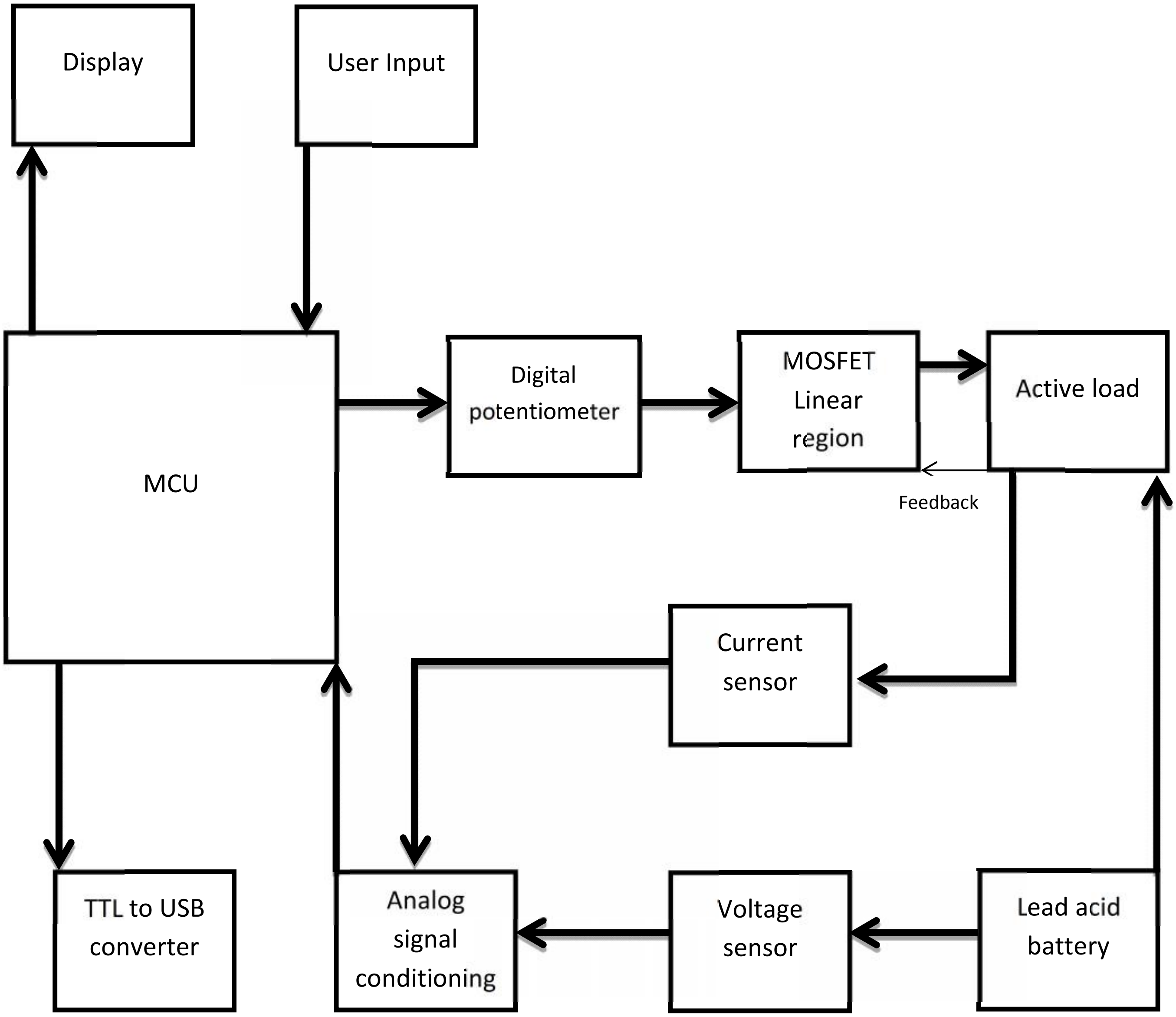


Figure 8Battery Capacity tester Block Diagram

MCU:For this project Atmel 8-bit AVR ATMEGA328 RISC-based microcontroller is used(fig-13). Which has 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.

The code was written in the flash memory to operate the device, the EEPROM is used to save the battery terminal voltage during the test periodically. The I/O pins are used in display, user input and communication. The 16-bit timer is used to keep record the test duration. Interrupts INT0 and INT1 are used to take user input during anytime of the test. The Universal Synchronous and Asynchronous serial Receiver and Transmitter (USART) is used for serial communication with the host PC to transfer data at 9600 baud rate and upload code to the device. SPI is used to program the resistance of the digital potentiometer. A/D converter is used to calculate current and voltage signal coming from analog signal conditioning unit, 1.1V internal reference is used for A/D conversion.

By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed.

Digital potentiometer: The MCP4131 device offer a wide range of product offerings using an SPI interface. This family of devices supports 7-bit and 8-bit resistor networks, and Potentiometer.

- Single Resistor Network options
- Potentiometer or Rheostat configuration options
- Resistor Network Resolution 7-bit: 128 Resistors (129 Steps)
- RAB Resistances options of10kΩ
- Zero Scale to Full-Scale Wiper operation
- Low Wiper Resistance: 75Ω (typical)
- SPI Serial Interface (10 MHz, modes 0,0 & 1,1)
  - High-Speed Read/Writes to wiper registers
  - SDI/SDO multiplexing (MCP41X1 only)

- High-Voltage Tolerant Digital Inputs: Up to 12.5V

- Supports Split Rail Applications

- Wide Operating Voltage:

- 2.7V to 5.5V - Device Characteristics Specified

- 1.8V to 5.5V - Device Operation

- Wide Bandwidth (-3 dB) Operation:

- 2 MHz (typical) for 5.0 kΩ device

- Extended temperature range (-40°C to +125°C)

5V is applied across the potentiometer $R_{ab,}$ Because of this when resistance is increased the voltage will increase by small steps of 40 mV.

User Input: As user input 2 momentary contact switches are used. User inputs are used to set the test parameters, copy data from EEPROM, and manually stop the test anytime.

TTL to USB converter: PL-2303HX is used to connect the MCU with the host PC. PL-2303HX provides a convenient solution for connecting an RS232-like full-duplex asynchronous serial device to any Universal Serial Bus (USB) capable host. PL-2303HX highly compatible drivers could simulate the traditional COM port on most operating systems allowing the existing applications based on COM port to easily migrate and be made USB ready.

Display:A 64x128 pixel OLED display was used to show the operating instruction and test data during the test.

Analog signal conditioning: This unit consists of LM-358 duel Opamp, LM-324 quad Opamp, TL-431 three terminal precision voltage references (fig-15). By using tl-431, two precision voltages of 1.8V and 9.35V are generated. Since the A/D converter reference voltage is 1.1V, both voltage and current signals are buffered, then precision reference voltages are subtracted from voltage and current signal and farther scaled down to meet the A/D conversion range.

Current sensor: ACS-712 is a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. When the current is zero the output voltage signal is 2.5V . For each amp of current change sensed, the output voltage signal changes by

66mV.because of analog signal conditioning maximum current sensing range in this configuration is from 0 amp to 13.9 amp.

Voltage sensor: Since the battery nominal voltage is 12V, to feed the A/D conversion range precision 9.35V is subtracted, then buffered and scaled down. Then the signal in supplied to the A/D converter. Because of this configuration, battery voltage below 10.1V can't be measured.

MOSFET linear region driver: This unit consist of 1 Digipot and 2 Op-amp. The resistance of the Digipot is variable with the programming of micro-controller. By varying this resistance the voltage is also varied. This variable voltage is gained 2.5 by an Opamp at first Opamp then it is used as an input in the non-inverting channel of the 2nd Opamp. The inverting channel of the 2nd Opamp is connected with the source of the MOSFET; the output of the 2nd Opamp is connected with the gate of the MOSFET.

Opamp will try to do anything with in their capability to keep their both (+) Input and (-) Input at same voltage level.

No Current Flows In or Out of the Opamp Input pins.

So, Opamp U2 will try to keep its both (+) Input and (-) Input at 2.5 Volt. The (-) Input of U2 is directly wired to 1 Ohms Resistance R1. According to Ohms Law V=IR, 2.5 Amp current must flow through the Resistor R1. There is now way the Opamp's Input will deliver this current.

This is where the Opamp U2 will Output a Suitable Gate Driving Voltage Such-A-Way that the MOSFET Q1 turns on partially operates like a voltage controlled current source.

Active load: These units consist of MOSFET IRFP-260 and a networked resistive load(fig-12). The MOSFET can dissipate maximum 280W and maximum drain current is 29amp at 100°C or 46 amps at 25°C. The network resistive load consists of thirty 5W, 1Ω ceramic resistor which makes up for 150W maximum power dissipation possible.

Lead acid battery: The battery which needs to be tested should be a 12V lead acid battery.

5.2 Charge Controller Tester Block Diagram:

The main units of the Charge Controller Tester are shown in the following block diagram and the function of each unit is described in the following headings.

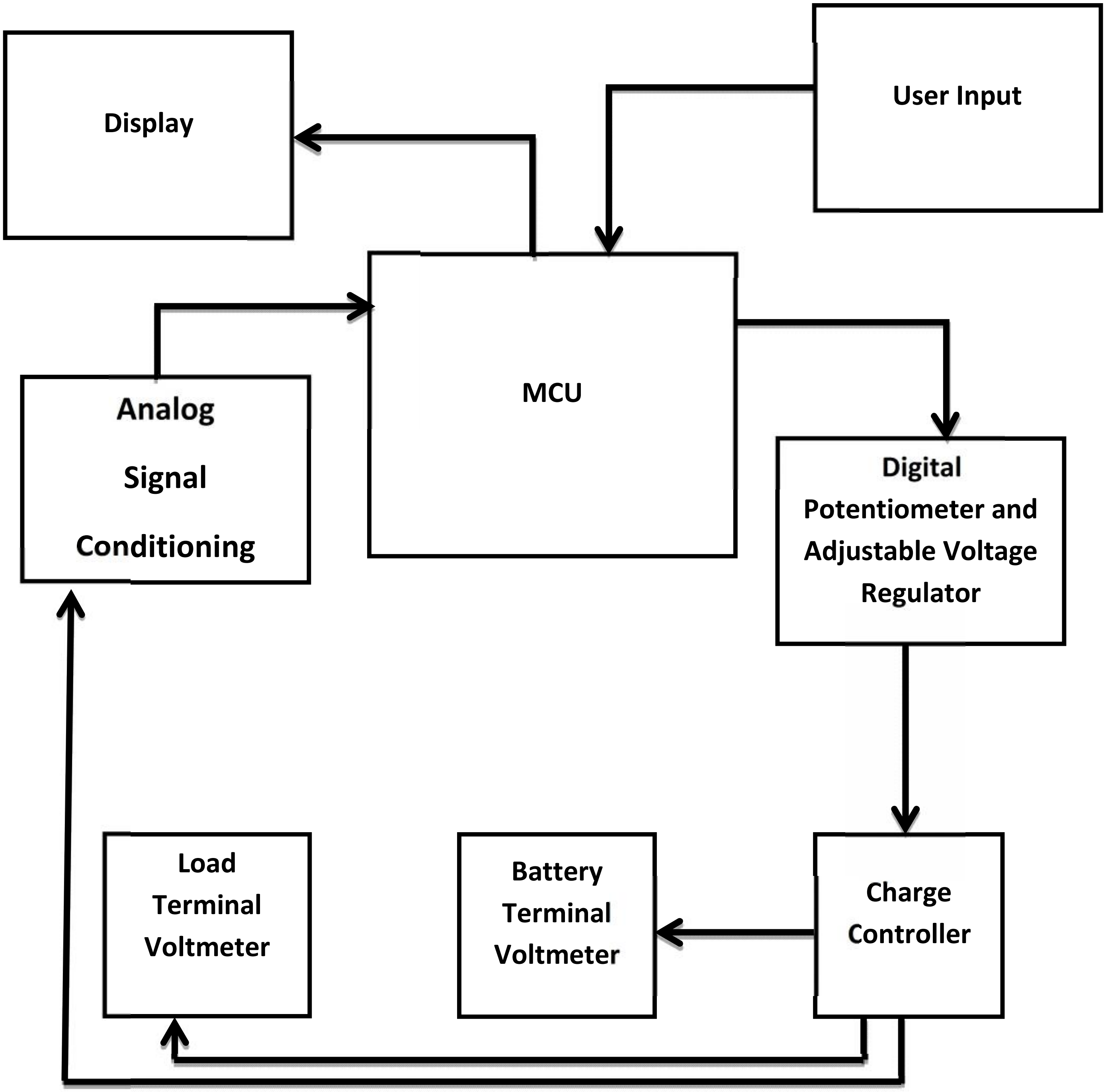


Figure 9Charge Controller Tester Block Diagram:

MCU: For this project Atmel 8-bit AVR ATMEGA8 RISC-based microcontroller is used(fig-13). Which has 8KB ISP flash memory with read-while-write capabilities, 512B EEPROM, 1KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.

The code was written in the flash memory to operate the device; The I/O pins are used in display, user input and communication. Interrupts INT0 is used to take user input during anytime of the test. The Universal Synchronous and Asynchronous serial Receiver and Transmitter (USART) is used to upload code to the device. SPI is used to program the resistance of the digital potentiometer. A/D converter is used to calculate voltage signal coming from analog signal conditioning unit, 2.56V internal reference is used for A/D conversion.

By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed.

Digital potentiometer and adjustable voltage regulator: The MCP4131 device offer a wide range of product offerings using an SPI interface. This device used here is a 7-bit,10KΩ resistor network, and Potentiometer.

- Single Resistor Network options

- Potentiometer or Rheostat configuration options

- Resistor Network Resolution 7-bit: 128 Resistors (129 Steps)

- RAB Resistances options of10kΩ

- Zero Scale to Full-Scale Wiper operation

- Low Wiper Resistance: 75Ω (typical)

- SPI Serial Interface (10 MHz, modes 0,0 & 1,1)

- High-Speed Read/Writes to wiper registers

- SDI/SDO multiplexing (MCP41X1 only)

- High-Voltage Tolerant Digital Inputs: Up to 12.5V

- Supports Split Rail Applications

The LM317 device is an adjustable three-terminal positive-voltage regulator capable of supplying more than 1.5A over an output-voltage range of 1.25 V to 37 V. It requires only two external resistors to set the output voltage.

Variable test voltage is generated through LM-317 by using digital potentiometer as one of the external resistor to set the output voltage. Voltages from 10.1V to 15.5V are being supplied from this unit.

User Input: As user input 1 momentary contact switch is used. A user inputs is used to start the test.

Display: A 16x2 character LCD display was used to show the operating instruction and test data during the test.

Analog signal conditioning: This unit consists of LM-324 quad Opamp(fig-15). Since the A/D converter reference voltage is 2.56V, voltage signal is buffered and scaled down to meet the A/D conversion range.

Load terminal voltmeter and battery terminal voltmeter: Because of the charge controllers internal design, it is possible that the battery, panel and loads negative (-ve) terminals are not common. Due to that to separate LED DC voltmeters are used to measure the load terminal and battery terminals voltage. These voltmeters can measure voltage from 2.5V to 30V.

Connection of Charge Controller with the System: The charge controller that needs to be tested should be connected in all three terminals at these ports.

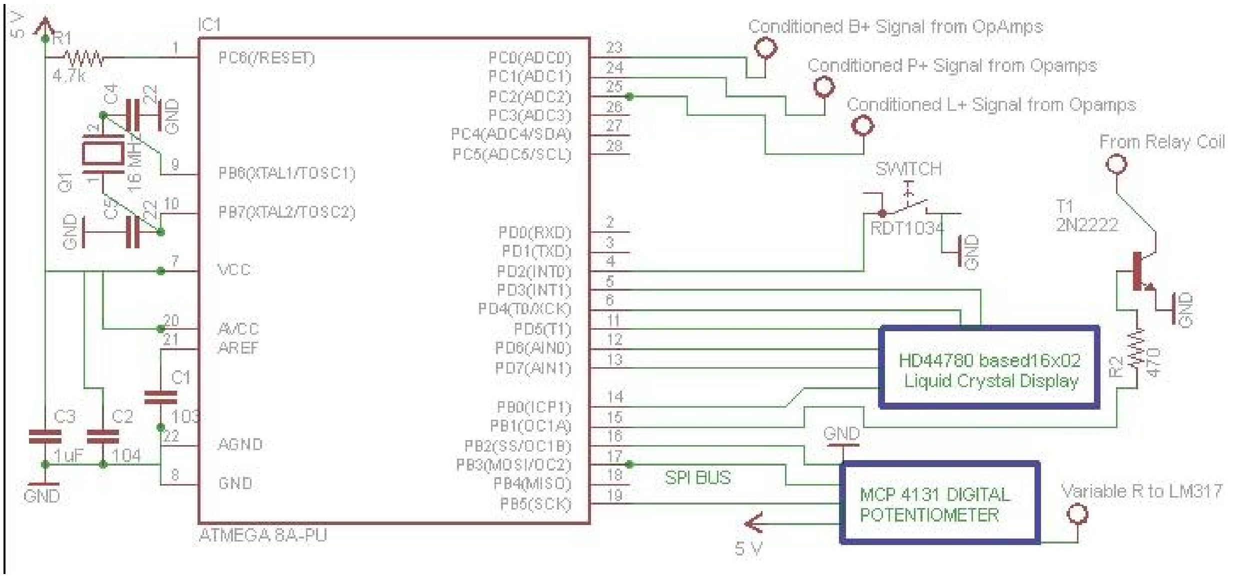


Figure 10Circuit Diagram part I

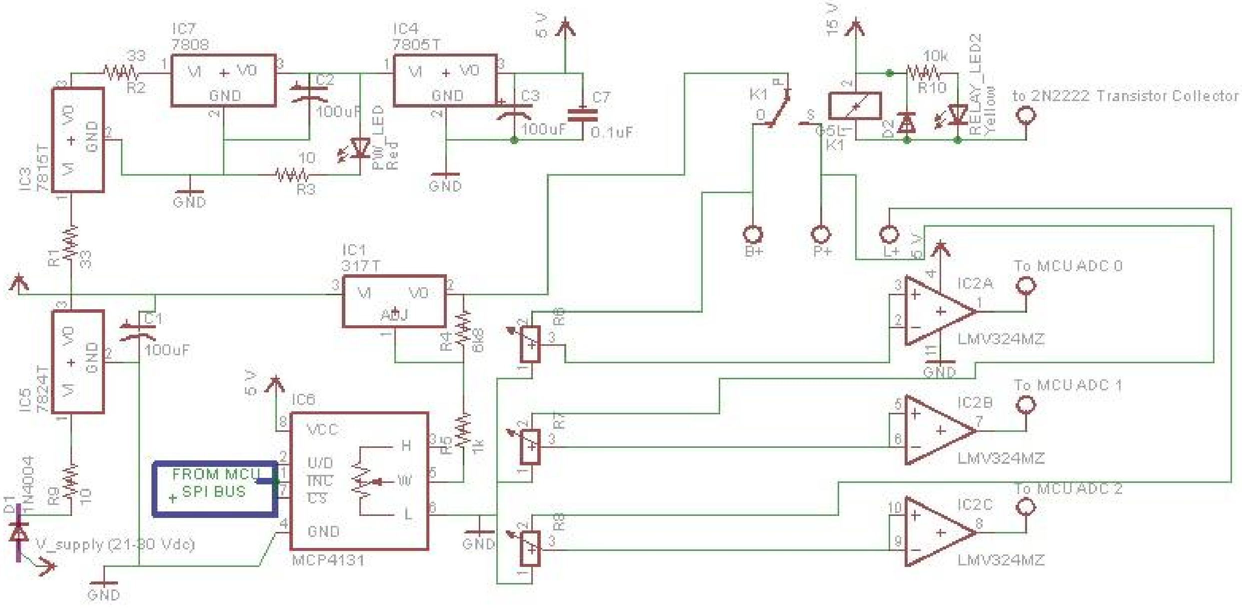


Figure 11Circuit diagram part II

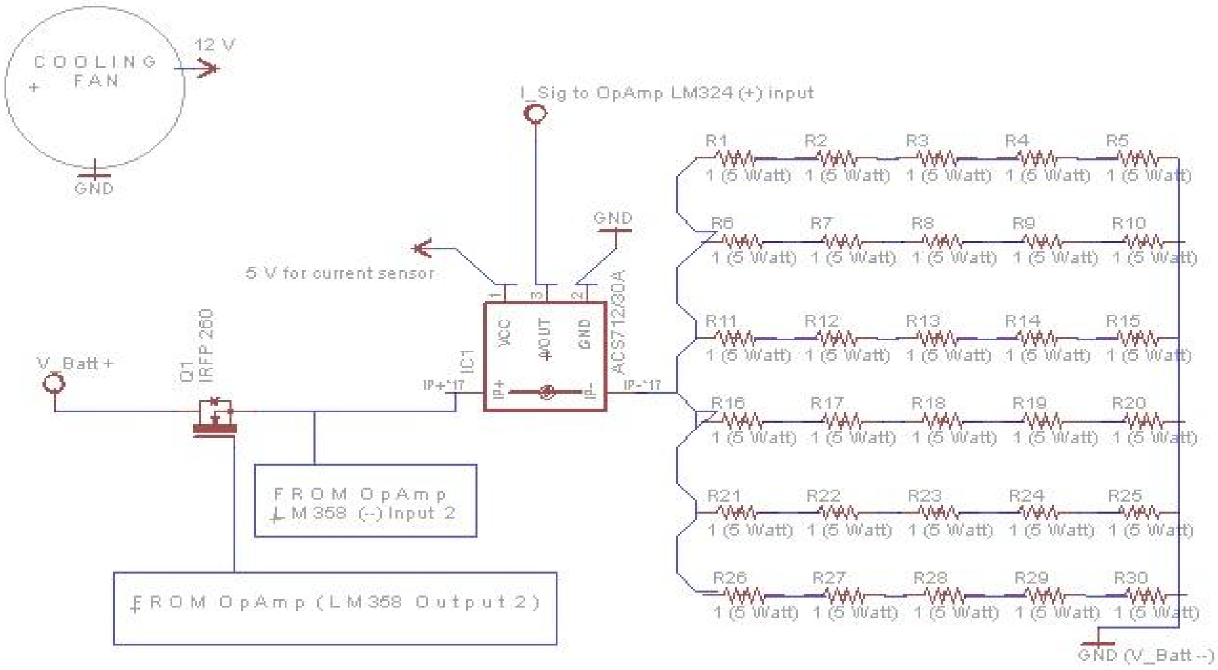


Figure 12Load circuit diagram

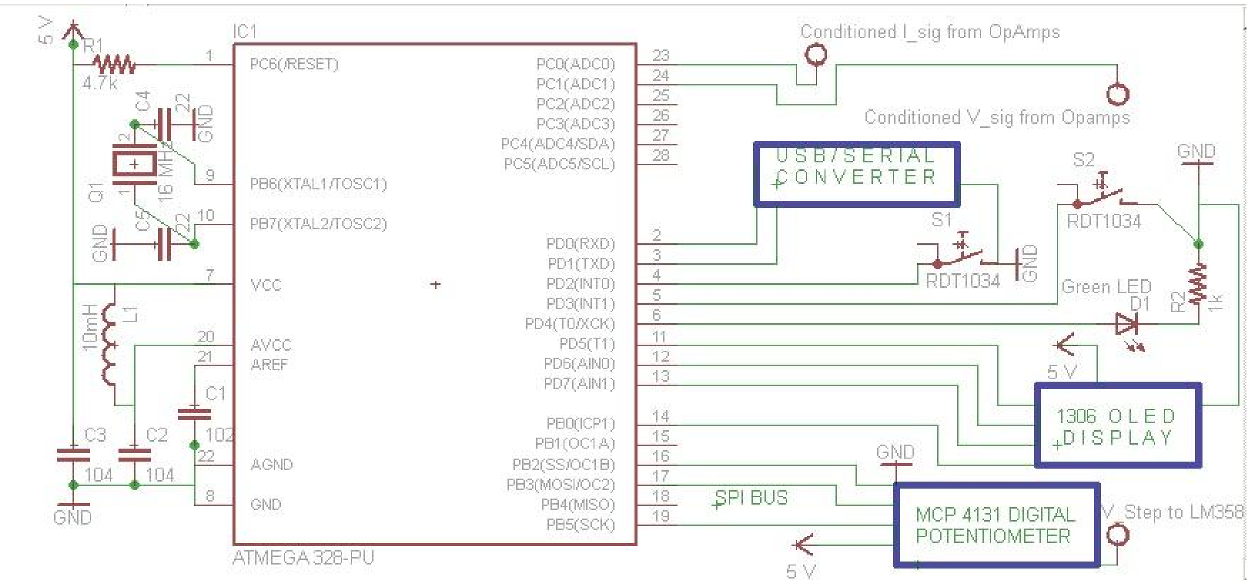


Figure 13MCU digital circuit

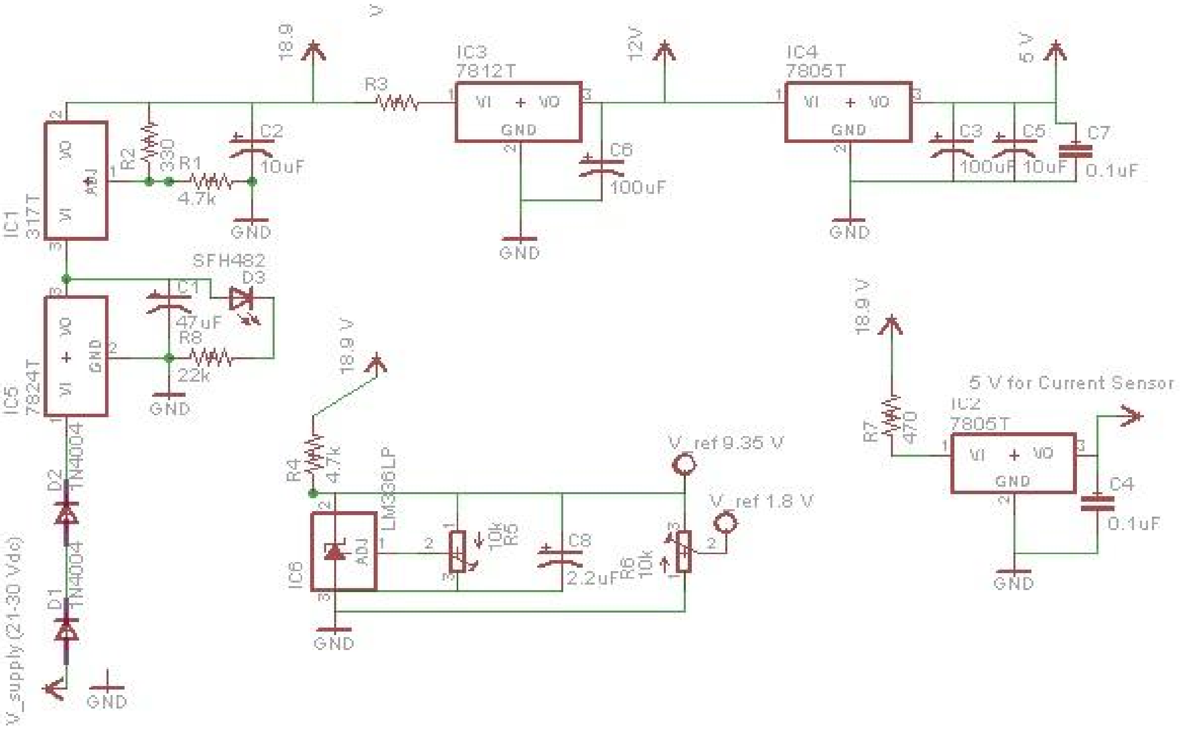


Figure 14Power Circuit

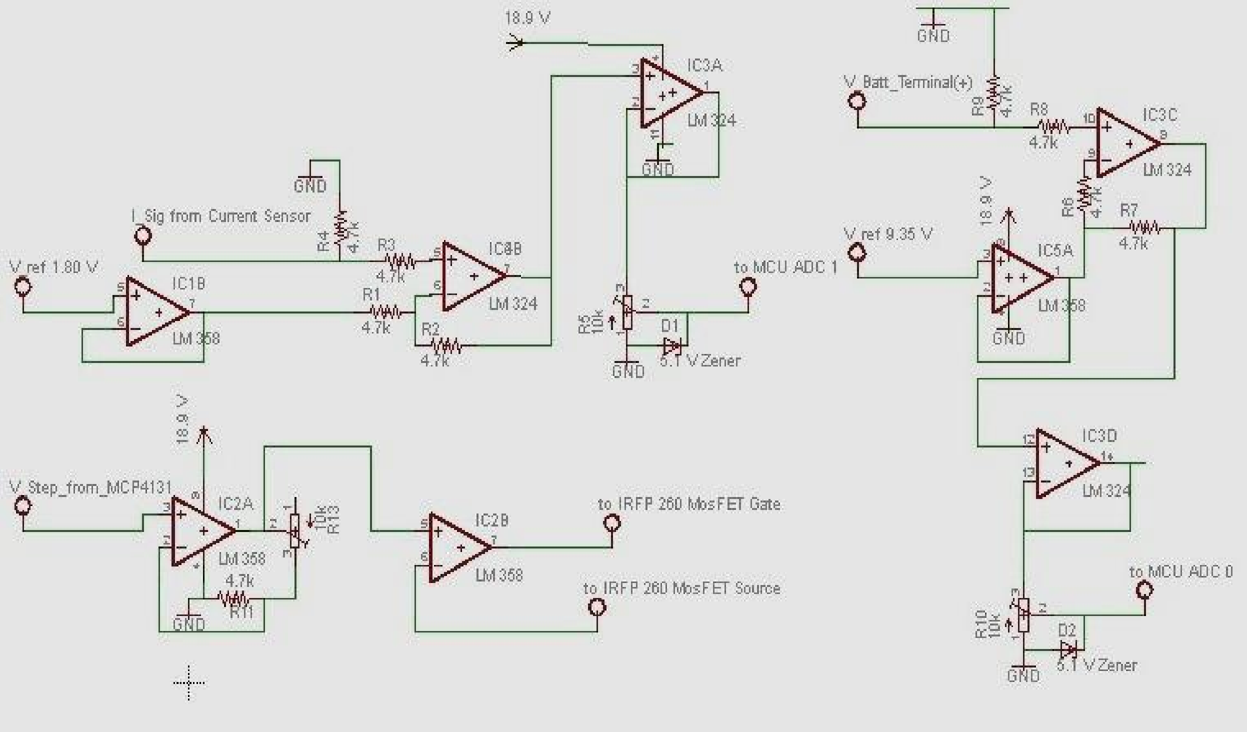


Figure 15Signal circuit

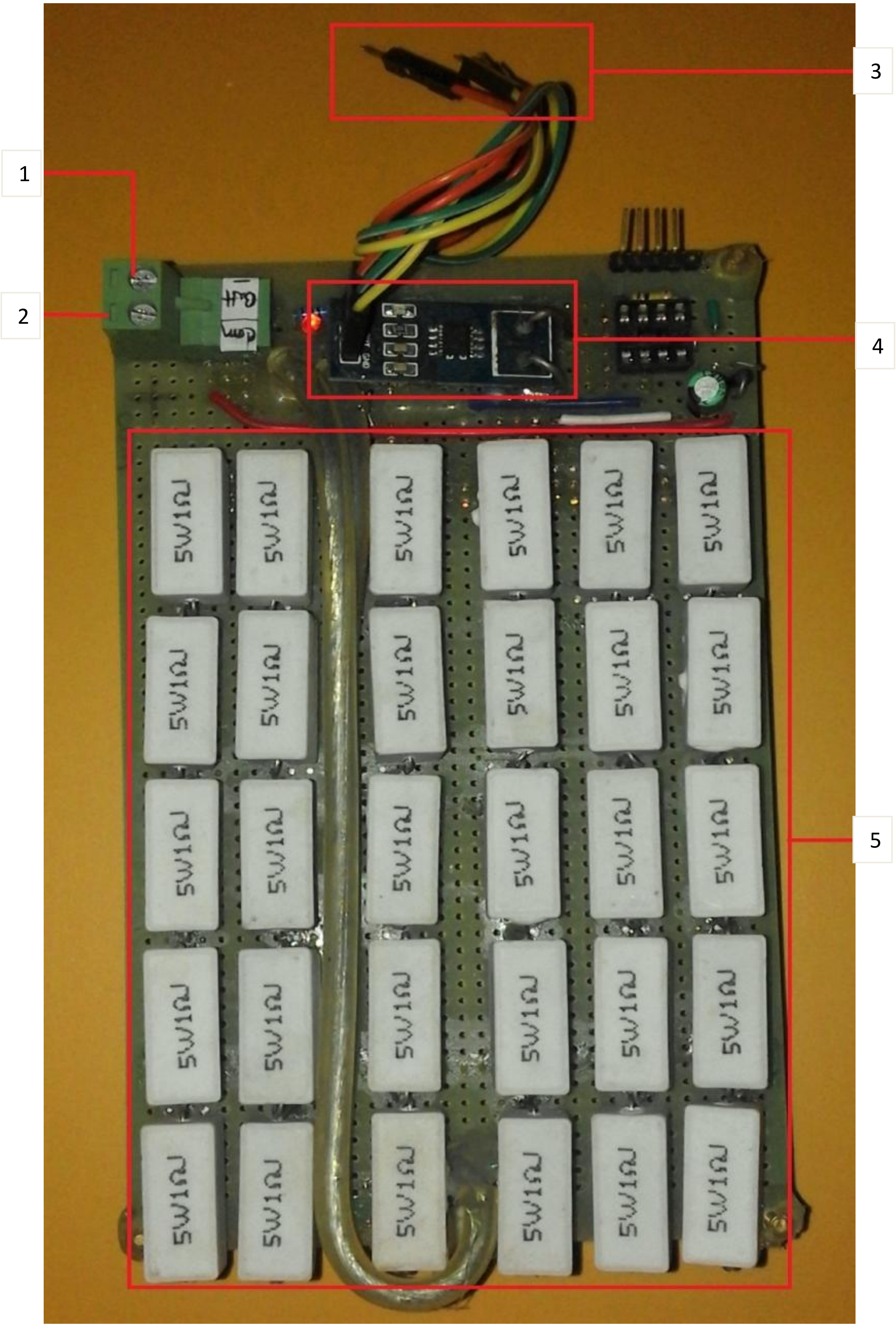


Figure 16 Load resistor network Unit

5.3 Load resistor network Unit

1. Load resistor network Unit From MOSFET source: the battery tester MOSFET is connected here
2. To common ground.
3. Power to current sensor: red wire – 5V
   Yellow wire – Ground
   Green wire – transmit the measured current signal to Analog signal conditioning unit
4. 30A (up to) hall effect current: : ACS712. 30A is used to sense current. It's a Hall Effect current sensor.
5. Load resistor network: per resistor is of 5W, 1 ohm. There are 30 resistors in total. Per line 5 resistor is in series connection, and 6 such lines are in parallel with each other. Equivalent resistance is .870 ohm and total load is of 150W. Current sensor is connected in series with this network.

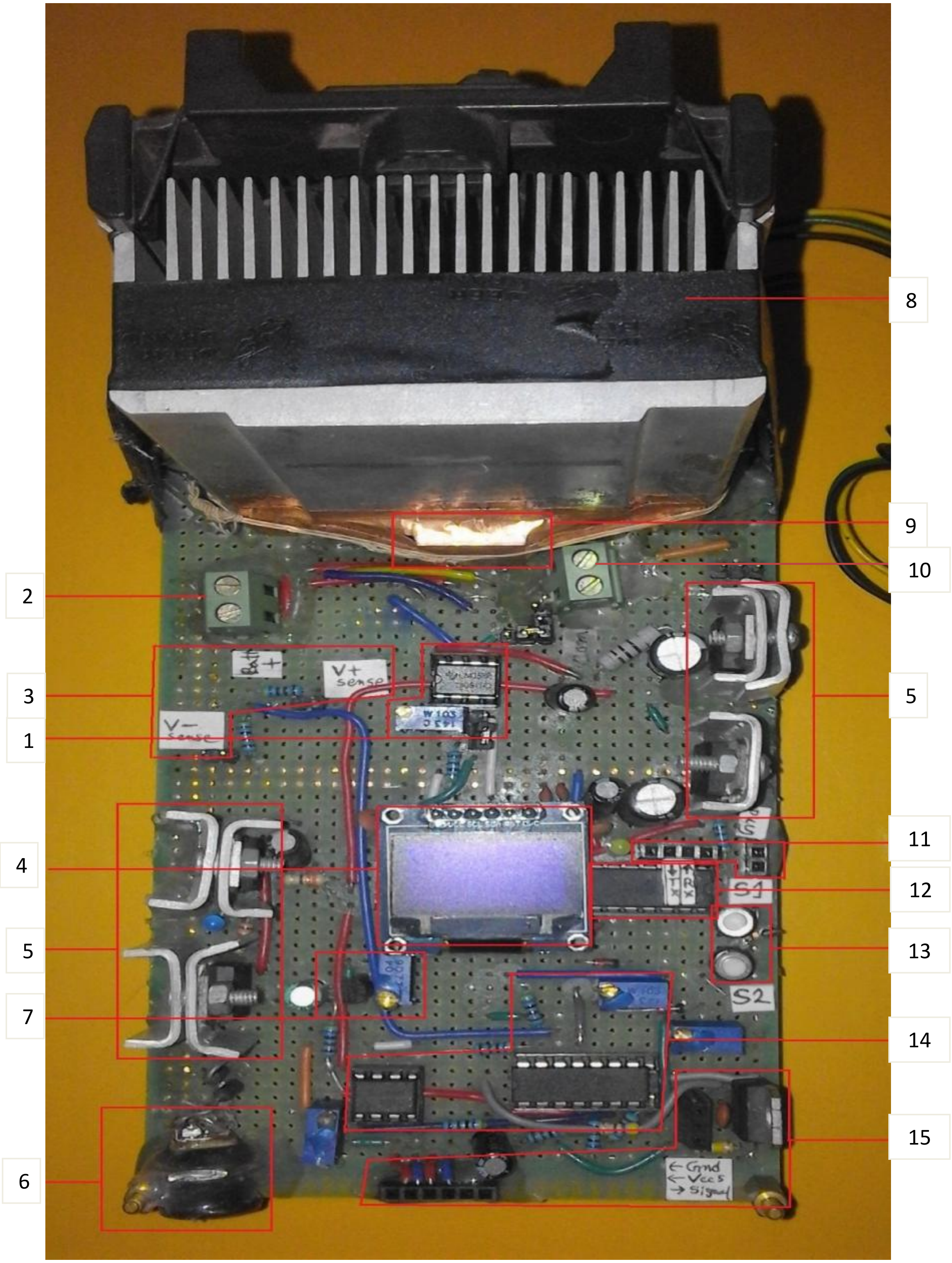


Figure 17battery testing Unit

5.4 battery testing Unit

1. MOSFET linear region driver: this unit consist of 1 Digipot and 2 Op-amp. The resistance of the Digipot is variable with the programming of micro-controller. By varying this resistance the voltage is also varied. This variable voltage is gained 2.5 by an Opamp at first Opamp then it is used as an input in the non-inverting channel of the 2nd Opamp. The inverting channel of the 2nd Opamp is connected with the source of the MOSFET, the output of the 2nd Opamp is connected with the gate of the MOSFET.

   Opamp will try to do anything with in their capability to keep their both (+) Input and (-) Input at same voltage level.

   No Current Flows In or Out of the Opamp Input pins.

   So, Opamp U2 will try to keep its both (+) Input and (-) Input at 2.5 Volt. The (-)Input of U2 is directly wired to 1 Ohms Resistance R1. According to Ohms Law V=IR, 2.5 Amp current must flow through the Resistor R1. There is now way the Opamp's Input will deliver this current.

   This is where the Opamp U2 will Output a Suitable Gate Driving Voltage Such-A-Way that the MOSFET Q1 turns on partially operates like a voltage controlled current source.

2. From battery: the positive of battery is connected here with a thick wire. The battery discharging current pass through here. It is also connected with the Drain of the MOSFET.
3. Battery voltage sensor: through this the battery voltage is provided to the Analog Signal conditioning. Both battery terminals are connected here with 2 different wire to measure the voltage.
4. User display: this Display is used as a output for the user. User can configure setting or obtain data from this display.
5. Regulated power rails: there are 4 voltage rails of 18.9V, 12V, 5V, 24V.
   a. 18.9V – is supplied to Op-amp
   b. 12V - Supplied to fan
   c. 5V – supplied to Micro-controller, Display, Current sensor, Digipot.
   d. 24V - voltage is reduced from 32V
6. Power input to device: input voltage is 21V-32V Vdc, it is reverse voltage protected.
7. Precision voltage reference: 9.35V and 1.8V are generated here in the purpose of Analog signal conditioning.
8. Heat sink cooling fan: It is used to cool the MOSFET down. There is a 12 V fan in the heat sink.
9. Active load (MOSFET): the MOSFET is operated in linear region as a variable resistor. Here the Drain to Source voltage depends on the Gate to Source voltage.(shown in figure below)

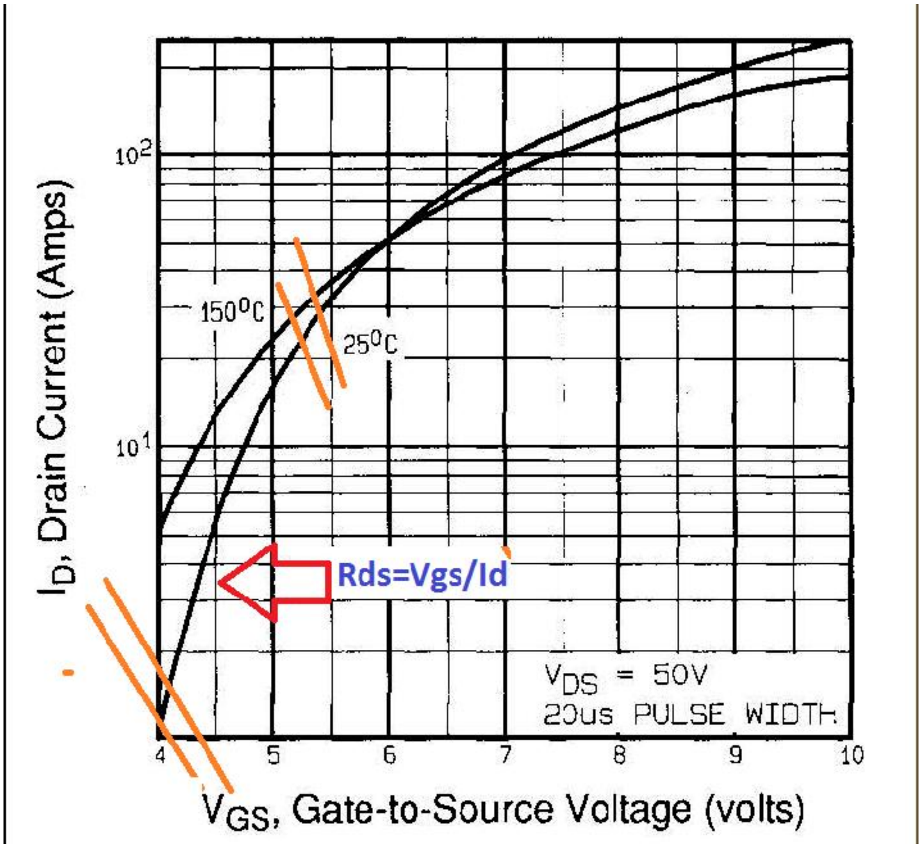


Figure 18MOSFET characteristics

10. To resistor network: the source of MOSFET is connected to the load resistor network through here.
11. Serial data port: there are 5 ports in here. The ports are used as
    a. 2 ports are used as ground
    b. Reset
    c. Receive
    d. Transmit

    After the test the result can be transferred to PC through this serial port by using USB 2.0 from the EEProm.

12. Micro controller: this microcontroller controls this whole unit. It also control the display. It take the input from the user. Also controls the active load. The voltage and current signal is saved in EEProm by converting through ADC.
13. User input switch: by this user can configure the parameters of the test. User can stop the test and collect data from EEProm.

14. Analog signal conditioning block: voltage and current signal is buffered here. Then it is differentiated by Opamp and scaled down by using voltage divider rule. Then it is sent to the ADC of microcontroller.
15. 5v supply for current sensor and data from current sensor: it is a dedicated 5V supply for current sensor for better power rejection ratio.

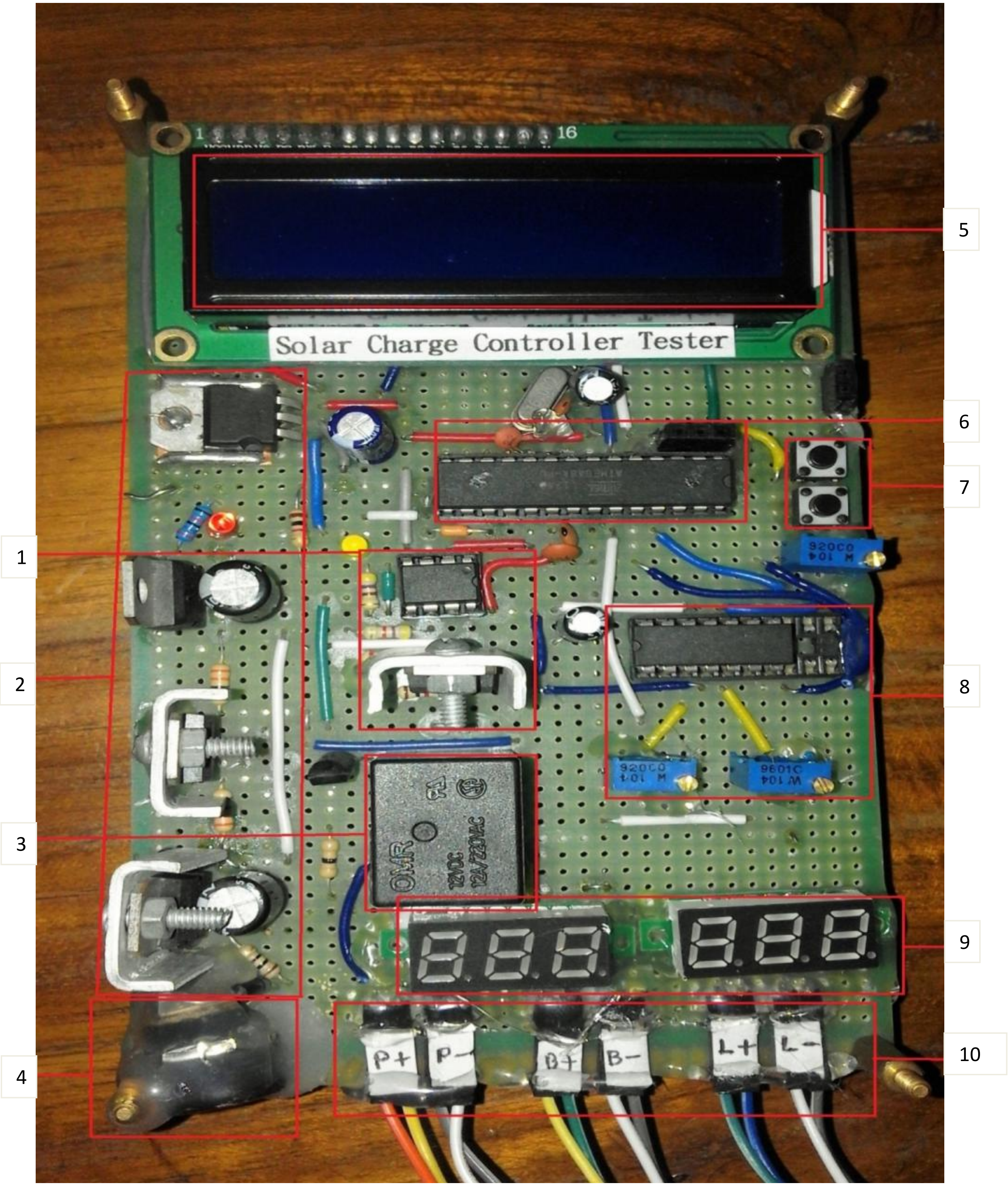


Figure 19Charge Controller testing Unit

5.5 Charge Controller testing Unit

1. Variable test voltage generator: It is consisting of Digipot and adjustable voltage regulator. By varying the resistance of the Digipot variable voltage is generated. Voltage can be varied from 10V to 15.5V with per step of being 0.1V.
2. Regulated power supply: there are 4 voltage rails of 24V, 15V, 8V, 5V.
   a. 24V – power to variable voltage generation unit.
   b. 15V – to power relay.
   c. 8V – to power Op-amp
   d. 5V– to power micro-controller, Display, Digipot.
3. Test voltage switching relay: the job of this relayis to switch the connectionof the 'variable test voltage generator' to the positive of battery or panel.
4. Device power input (21-32 Vdc): input voltage is 21V-32V Vdc, it is reverse voltage protected.
5. User input display: after turning on the tester, user operating instruction s Displayed here and after the test is competed the result is shown here also.
6. Microcontroller: this micro-controller suns this whole system. It senses the voltage of ADC. Generates variable voltage by varying the resistance. Takes input the from user and shows the test on the display as output.
7. User input switch: by these 2 switches user can start the test and after the rest user can redo the test again.
8. Analog signal conditioning/buffering block: to measure 3 voltages of the 3 terminals of charge controller those voltages are scaled down and sent to the ADC of the micro-controller after being buffered by the Opamp.
9. Voltmeter: to show the panel and load reconnect and disconnect voltages.
10. Test probes to 'charge controller under test': these test probes are connected to the charge controller's battery, load and panels terminals.

Chapter -6

Operation

6.1 Operating Principle of the Battery Capacity Tester

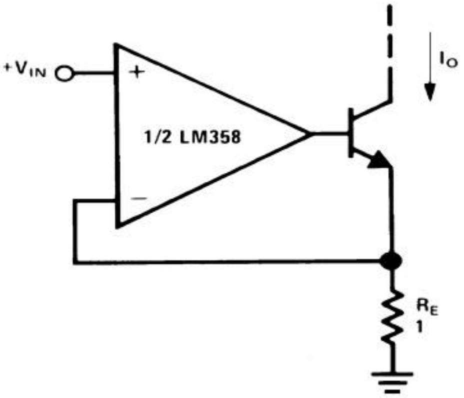


Figure 20Current Sink

The high compliance Current Sink (picture above) is the part that of the device consists of a MOSFET (attached with the big Heat sink), a high wattage Resistors Network, an Opamp which can maintain a constant current through the MOSFET by adjusting its output such a way that the MOSFET is operated in the linear region.

The amount of current through the active load is directly proportional to the V_{in} applied to the non-inverting terminal of this Opamp.

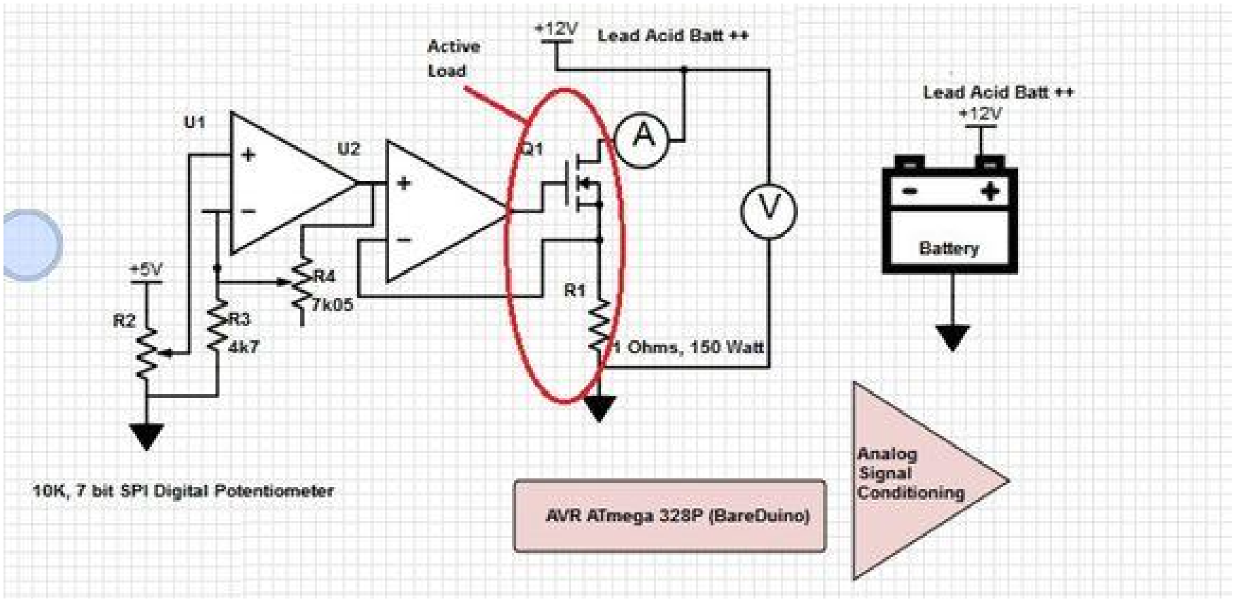


Figure 21Battery Capacity Tester Core Block

This Vin is generated based on the User Input Setting to the Microcontroller during initialization. A 7 bit 10k Ohms Digital Potentiometer is connected to the Microcontroller through SPI Bus and 5 volt is applied across it's 10k resistor, so voltages in step of about 40mV (e.g. 0mV, 40mV, 80mV, ….. up to 5V) can be made from the sweep output of the Digital Potentiometer by controlling from the Microcontroller. Then this voltage is fed to another Opamp to Gain 2.5 times, so steps of 100mV, 200mV, 300mV …… up to 12.5 Volts can be produced. This Step Voltages are applied to the Vin of the MOSFET Driving Opamp, this Opamp will produce a Gate Voltage to operate the MOSFET such a way the current steps of 100 mA, 200 mA, 300 mA …. Up to 12500 mA can be sinking through the active load.

6.2 Experimental Procedure with the Battery Capacity Tester

The Battery Capacity Tester Device has two parts: the "Resistor Network & Current Sensor" is part(A) and the "Active Load, Control & I/O" is part(B). Before starting test and even before powering up the device, two parts must be interconnected.

Here is how it should be connected:

"Com" terminal (Green Connector) of part(A) should be connected to "Com" terminal of part (B) with a thick wire (22/7). Com terminal does not represent system common ground but it is the common point of MOSFET Source and Resistor Network. Alternatively, a Ammeter can be

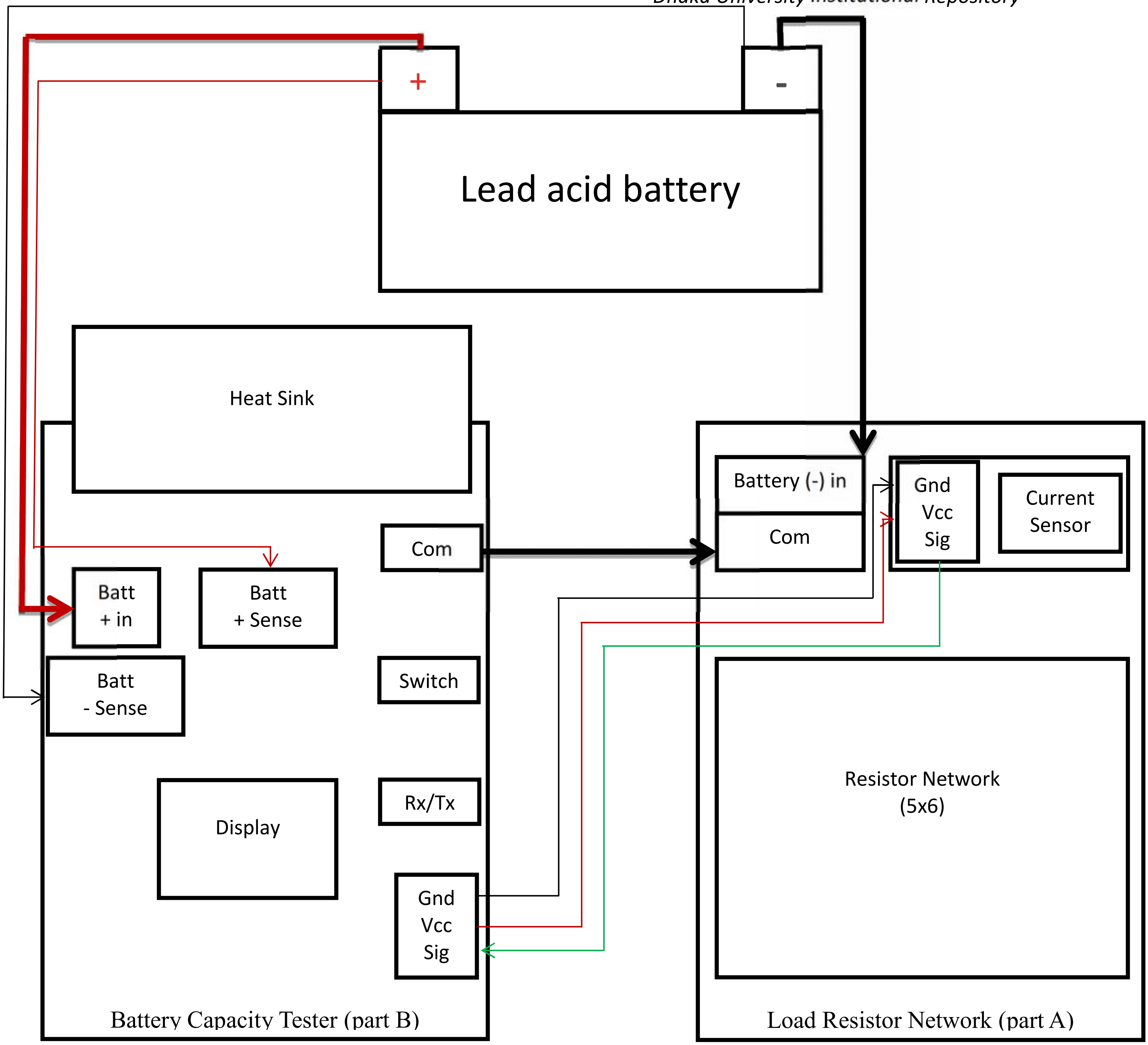


Figure 22 Device interconnection for Battery Capacity Tester

connected between "Com"s of part(A) and part(B) to manually measure the discharge current instead of connecting a wire, which should be connected for the whole period of the test.

Next, three wires coming form part(A) current sensor needs to be connected to the female header on part(B) marked as (Gnd, Vcc, Signal) on the bottom right corner of part(B). The Red wire goes to Vcc, the Yellow wire goes to Gnd and the Green wire is the current signal goes to signal.

Then, another separate cable pair (Red-Blue) needs to be connected to “V+ Sense” and “V-Sense” male header pins on part(B). The alligator clips on the other end will be connected later to the Battery Positive (+) and Negative (-) terminals.

Next, one Red thick wire is connected to Batt+ (Green Terminal) on part(B) and one Black thick wire is connected to Batt- (Green Terminal) on part(A) firmly so they don’t get detached during test.

Now the device is powered up with a 24-32 VDC power supply. Using the instructions on display and S1/S2 input buttons, New Test, Discharge Current, C –Rates are configured. When the display will show “Now Connect Batt+ & Batt - …..” message, then the other end of the thick Black wire is connected to the Battery Negative terminal, also the black alligator clip attached to V-Sense wire is connected to the Battery Negative terminal.

Similarly the thick Red wire is connected to the Battery Positive terminal, also the red alligator clip attached to V+Sense wire is connected to the Battery Positive terminal.

Finally, pressing S1/S2 switch the test begins to discharge the battery.

The test will end if one of the 3 conditions are met :

If user aborts test using S1/S2 switches

If battery voltage reaches 10.5 volts

If C hours of time elapsed during test

The test should never be aborted by pulling out the wires, sudden change of current may damage MOSFET. Instead using S1/S2 switches along with instructions displayed to abort the test, the software will slowly Ramp Down the current to zero avoiding any possibilities of damage.

The device should never be connected to battery without powering it up first and before initialization. Otherwise high currents will flow for a short duration of time and may damage the system.

Battery should never be connected to the device in Reverse Polarity to avoid serious damage.

At the end of each test all the voltage data points are saves on the EEPROM of the microcontroller, which can be copied to a PC using a USB-Serial converter. There is a serial port available on part(B) marked as (RX/TX/Gnd). By connecting a Serial-USB converter here and following the instructions on the display along with pressing S1/S2 switching and opening a Serial Terminal (like Putty, Serial Monitor) data can be copied to PC. Each time new test data is Overwritten on the Old Test data. Serial baud rate is 9600 for this system.

6.3 Operating Principle of the Charge Controller Tester

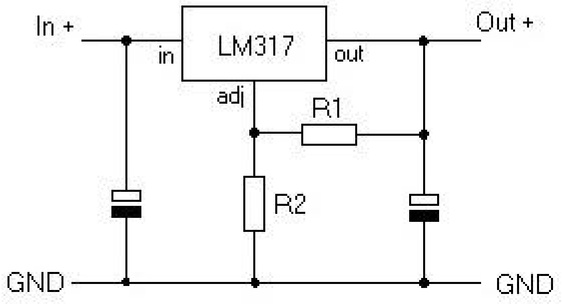


Figure 23Adjustable Voltage Regulator

The Adjustable Voltage Regulator is the part of this device which will simulate a variable voltage from 10 volts to 15.5 volts on the charge controller's Panel and Battery terminals to get the set points. Similar like the battery capacity tester, here a 10k digital potentiometer and a fixed value resistor is used as R2 (see picture above). So, the resistance of R2 is varied from the microcontroller. This is how voltage steps of 10.1V, 10.2V, 10.3V ….. up to 15.5 volts can be generated to test the charge controller.

Because different manufacturers make charge controllers differently, many charge controller's Battery (--), Panel (--), Load (--) terminals are not system common ground. So measuring voltages on these terminals with single ended ADC is difficult.

To avoid this issue, two separate LED Voltmeters are used to measure voltages on Battery and Load Terminals, while the Panel terminal voltage is measured using ADC and shown on the LCD display.

6.4 Experimental Procedure with the Charge Controller Tester

The Charge Controller Tester Device needs to be connected to a Charge Controller under test. The Connection are relatively simple as following :

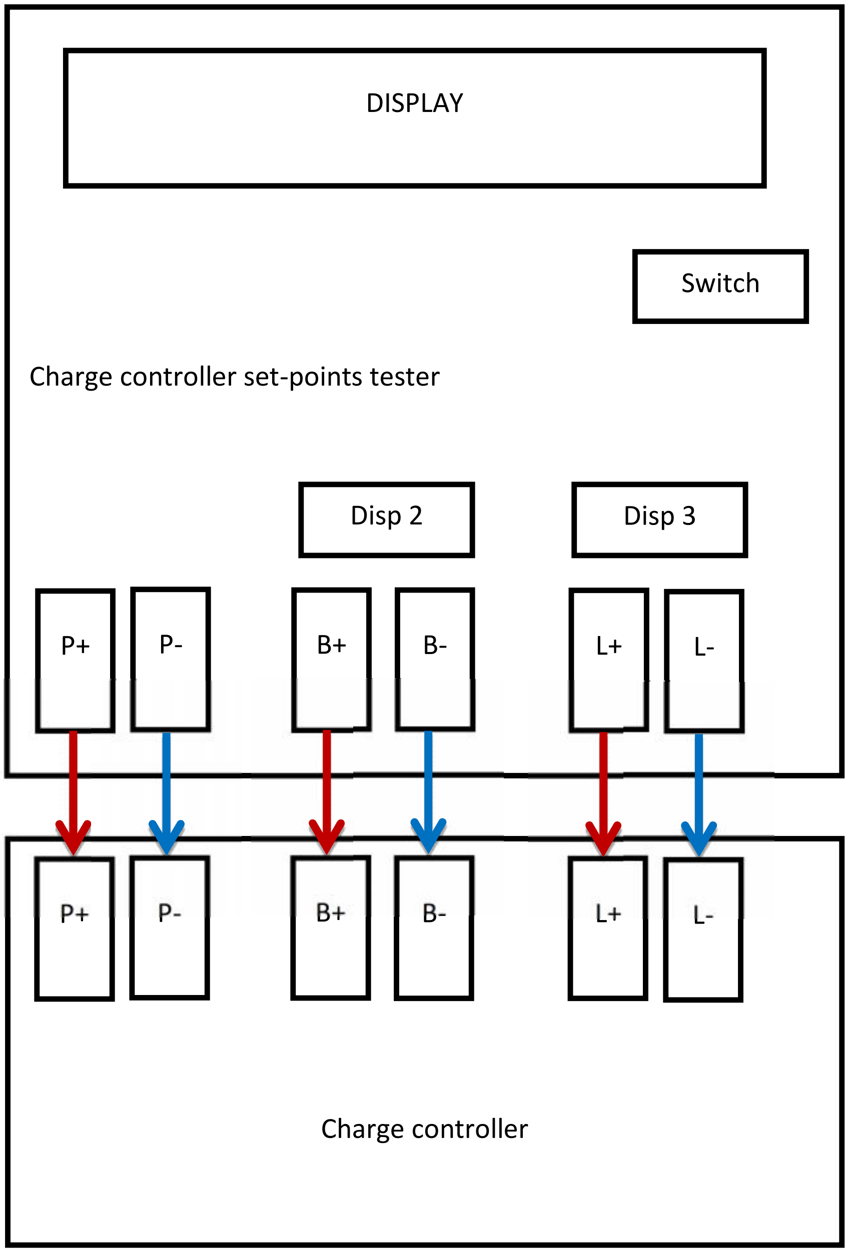


Figure 24Device interconnection for Charge Controller Set-points tester

The P+ and P- marked cables are connected to the Panel+ and Panel – terminals of the charge controller, the B+ and B- marked cables are connected to the Battery+ and Battery – terminals of the charge controller, similarly L+ and L- marked cables are connected to the Load+ and Load– terminals of the charge controller.

The tester is powered up from a 24-32 VDC power supply. The LCD display will show a message how to connect the tester to a charge controller, then ask user to press switch to start test.

The test will begin once the user presses any of the switches, panel terminal voltage will rise with a step of 0.1 volts starting from 10 volts, the battery terminal voltage will rise along with panel voltage, which will be shown on the Greee LED Voltmeter Display. At the beginning of test run, the load terminal voltage will be absent for a while, because the load is disconnected due to low battery terminal voltage. As the voltage rises, around 12+ some voltage the load will connect and the load terminal voltage will appear on the Red LED Voltmeter Display. The first value on Red LED Voltmeter Display is the Load Reconnect voltage.

Now as the Panel terminal voltage rises, so does the Battery terminal. But around some 14+ voltage, with the rise of Panel terminal voltage, the Battery terminal voltage won't rise. The maximum voltage on the Green LED Voltmeter is the Panel Disconnect voltage. During this time the Green Voltmeter voltage will fluctuate between 13 something to 14 volts. The minimum voltage during this on Green Voltmeter is the Panel Reconnect Voltage.

Once the Panel terminal voltage (on LCD display) reaches 15.5 volts, it will start to fall. Now the Battery/Load voltages will follow it. At some voltage between 10 something to 11 something volts the voltage on Red LED voltmeter will disappear. The last value on Red LED volt is the Low Voltage Load Disconnect voltage.

The whole test will run again, just in case user failed to capture the set points.

Chapter- 7

Calculation

7.1 Battery capacity and Charge Controller set points test data

Test Parameters and Battery Information Table	
Battery Type	Sealed Maintenance Free Lead Acid Battery Brand : SUNCA
Battery Rated Capacity	4.5 Ah, two 6V Battery in series = 12 V nominal
Battery History	Purchased about 6 months back (September, 2015) , about 10 partial discharges were done during this period, Battery was charged few times with a 40 Wp Solar Panel and a Charge Controller which has Panel Disconnect voltage 14.4 volts and Battery Reconnect voltage of 13.3 volts. Battery has been Equalized up to 15.5 volts few times
Amb. Temp (before Test)	21 degree C
Battery Terminal Voltage (before Test)	12.97 volts (6.48 V + 6.49 V)
Discharge C –rate	C/5 (5 hrs test)
Discharged Current Set Value : Measured Value (a) Measured Value (b)	 900 mA (by user before starting test) 880 mA = 0.88 A (from Multimeter) 920 mA = 0.92 A (from Current Sensor)
Specific Gravity	Not measured due to Sealed Battery Type
Battery Test End Condition	Reached 10.5 volts (1.75 per cell) before 5 hrs
Battery Terminal Voltage a. Just after Test (when load is released) b. After 30 minutes c. After 1 Hrs.	 11.26 Volts (5.54 V + 5.72 V) 11.71 Volts (5.84 V + 5.87 V) 11.78 Volts (5.87 V + 5.91 V)
Amb. Temp (After Test)	21.0 degree C

Table 2 Test Parameters and Battery Information Table

<u>Test Data and Charge Controller Information Table</u>	
Charge Controller Type	Non MPPT
Rating	12 V, 10 A
Test Voltage Applied	To Charge Controller’s Panel Terminal
Voltage Measured	From Charge Controller’s Battery and Load Terminal
Test Voltage Range	10.0 volts to 15.5 volts
Voltage Step	0.1 volt
Measurement Error	+/- 0.1 volts
Regulation Points obtained from Test	
LVD (Load Disc.)	11.2 volts
LR (Load Conn.)	12.5 volts
VR (Panel Disc.)	14.1 volts
PR (Panel Rec.)	13.6 volts (approx.)***
LED Indications	Battery Voltage Level
G1 (Full)	12.6 volts
G2 (Full)	12.5 volts
G3 (Full)	12.4 volts
G4 (Mid)	12.3 volts
Y1 (Mid)	12.2 volts
Y2 (Low)	12.1 volts
R1 (Low)	11.9 volts
R2 (Very Low)	11.7 volts
R3 (Deep Disc)	11.5 volts
*** Panel Reconnect Voltage can’t be measured accurately due to frequent reconnect/disconnect – because there is no real battery connected to battery terminal It is also dependent on the internal design of the Charge Controller.	

Table 3 Test Data and Charge Controller Information Table

7.2 Data collected from EEPROM

Manual Data Records During Test		TEST Data Copied from EEPROM			
Time Hrs	Terminal Voltage	Time Hrs	Terminal Voltage	Time Hrs	Terminal Voltage
00:01	12.54	00:00	12.75	02:00	11.89
00:05	12.49	00:05	12.49	02:05	11.86
00:10	12.46	00:10	12.46	02:10	11.84
00:15	12.42	00:15	12.42	02:15	11.82
00:20	12.37	00:20	12.37	02:20	11.79
00:25	12.31	00:25	12.30	02:25	11.76
00:30	12.25	00:30	12.25	02:30	11.73
00:35	12.22	00:35	12.22	02:35	11.71
00:40	12.20	00:40	12.21	02:40	11.68
00:45	12.19	00:45	12.19	02:45	11.65
00:50	12.17	00:50	12.17	02:50	11.62
00:55	12.15	00:55	12.15	02:55	11.59
01:22	12.05	01:00	12.14	03:00	11.56
01:30	12.02	01:05	12.12	03:05	11.52
01:36	11.99	01:10	12.10	03:10	11.49
01:45	11.95	01:15	12.07	03:15	11.45
02:07	11.85	01:20	12.05	03:20	11.40
02:23	11.77	01:25	12.03	03:25	11.36
02:48	11.63	01:30	12.02	03:30	11.31
02:51	11.61	01:35	12.00	03:35	11.25
03:15	11.44	01:40	11.97	03:40	11.19
03:30	11.31	01:45	11.95	03:45	11.11
03:45	11.11	01:50	11.93	03:50	11.00
03:59	10.50	01:55	11.91	03:55	10.81
	STOPPED			03:59	10.50

Table 4 TEST Data Copied Obtained EEPROM

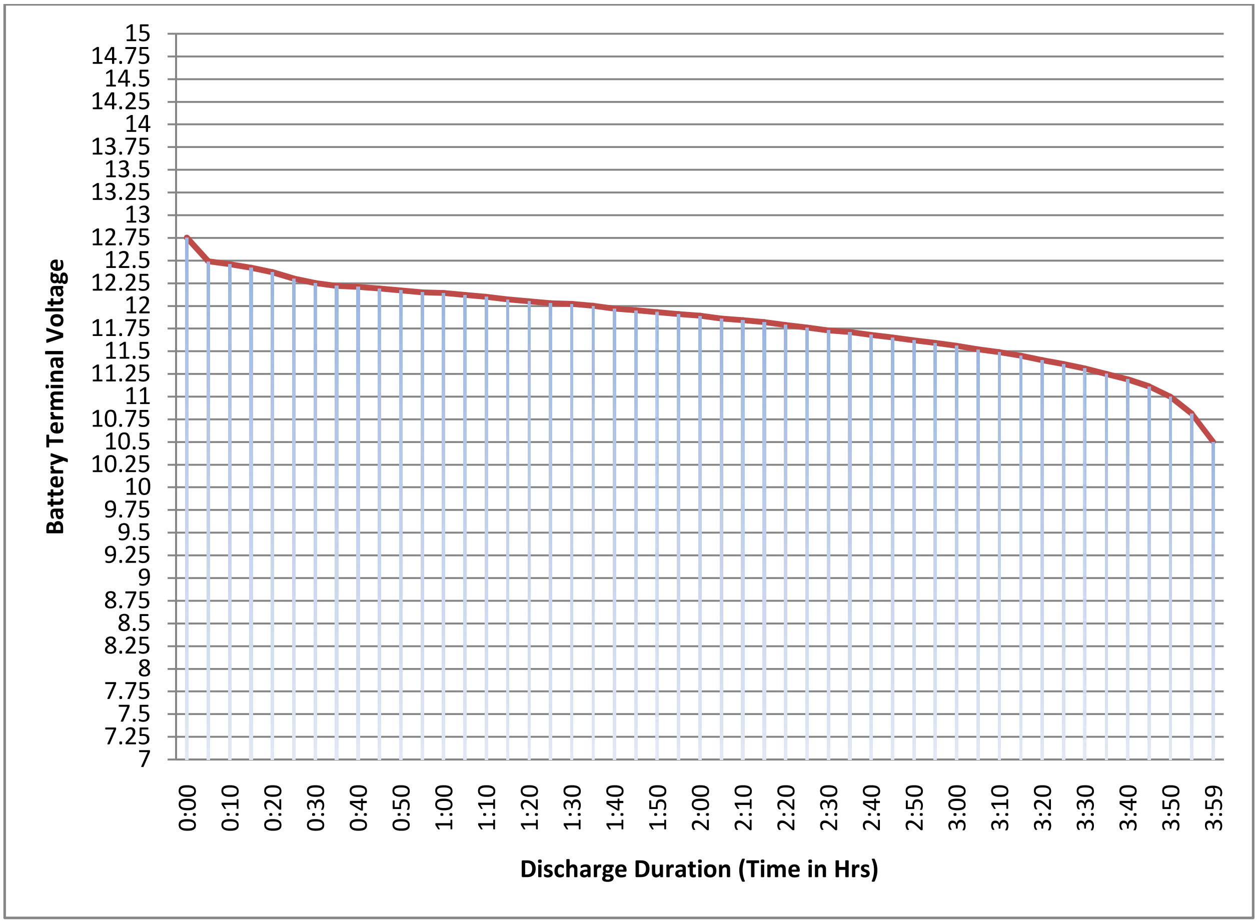


Figure 25Battery Discharge curve

7.3 Calculation:

Battery Capacity (minimum) = 3.98hrs x 0.9 A = 3.585 Ah

7.4 Observation:

Same Lead Acid battery may provide different capacity under different circumstances.

Here, we conducted the test on ambient temperature of 21 degree Celsius, if the test was performed on warmer temperature, a little more capacity increase would have been observed.

Standard test temperature is 25. At higher temperature capacity increase due to more chemical activity.

Battery capacity also depends on Discharge Rate. The test was conducted at C/5 discharge rate. If the battery was discharge at C/10 or C/20, more capacity will be available from the battery.

Battery capacity also depends on individual cells capacity. One weak cell will reduce the whole battery's capacity. After the test, we observed that one of the 6 Volt battery showed 5.54 volts but the other showed 5.72 volts. Because of the first battery has at least one weak cell, the overall capacity somewhat reduced.

Battery's may provide over capacity than their rated capacity if the temperature is right, all the cells are healthy, charging/discharging rate is low (less than C/20) or the battery is relatively new (less Sulfation), electrolyte level/specific gravity is good.

From the discharge curve, 4 slopes are observer:

During the start of discharge there is a sharp terminal voltage drop from 12.9 to 12.5 volts

Then there is a relatively slow terminal voltage drop from 12.5 to 12.25 volts

Next, the terminal voltage steadily falls from 12.25 to 11.25 volts, most of the battery's capacity lies within this range.

Finally the terminal voltage of the battery stiffly drops from 11.25 to 10.5 volts range, not much energy is extracted from the battery here, but discharging with in this region should be avoided for longer battery life.

Chapter 8

Conclusion

Bangladesh is a developing country and 38% of the population is still not connected to any grid for electricity. People are very much interested in using SHS for their needs. 65,000 SHSs are now being installed every month under the program with average year to year installation growth of 58%. The battery and the charge controller have big impact on the overall efficiency of a SHS. Our aim was to a design a device that can be used to easily evaluate the condition of battery capacity and the performance of a DC charge controller.

While testing battery capacity it needs to be considered that the capacity of a battery depends on the temperature. Also slower discharge rate are better to measure the battery capacity.

The ideal set points for charge control vary with a battery's temperature. Some controllers have a feature called "temperature compensation." When the controller senses a low battery temperature, it will raise the set points. Otherwise when the battery is cold, it will reduce the charge too soon.

The control of battery charging is so important that most manufacturers of high quality batteries (with warranties of five years or longer) specify the requirements for voltage regulation, low voltage disconnect and temperature compensation. When these limits are not respected, it is common for batteries to fail after less than one quarter of their normal life expectancy, regardless of their quality or their cost.

From the test data we acquired from the battery capacity tester, we can see the condition is good. The voltage drop across the terminals is very steady and as it should be for a good battery.

However, the test data we acquired from the DC charge controller tester, we can see not all four set points of the Dc charge controller meet the IDCOL standard. The low voltage disconnect (LVD) is 11.2V. According to IDCOL which should be 11.6 Vdc +/- 0.1 Vdc.

From the test data we acquired from the charge controller set-points tester, LVD of 11.2Vdc will provide a longer backup initially but with the cost of shorter battery life cycles. This is why manufacturers usually set lower LVD despite the IDCOL specification.

Future works:

According to IDCOL specifications for solar charge controller, few more tests should be added to improve the device's testing capability, those are as follows:

- To able to check whether the charge controller's input current rating is greater than 120% of the module's rated short circuit current and capable of handling at least 120 percent of the rated current at PV, battery and load terminals for at least for 1 hour without being damaged
- Measuring charge controller's self-consumption, when no LED's are lit it should not exceed 20 mA and 50 mA with LED
- Checking the charge controller weather it has reverse current protection or not
- Testing if the charge controller has the short circuit protection on load and panel terminal
- Whether the Charge Controller can withstanding 25Vdc at PV terminal when battery and load is disconnected
- To check if the Efficiency of the charge controller is at least 90%

For the battery testing device few for testing capabilities can be added. As follows:

- Capable of testing battery Impedance
- To be able the measure the inter-cell connection resistance
- Testing individual cell-voltage
- Measuring Specific Gravity of the electrolyte
- Testing the internal temperature of battery under various load

Appendix

---

1. The data sheet of atmel82718-bitavrmicrocontroller-
2. The data sheet of MCP4131 Digital Potentiometer
3. The data sheet of LM-358 duel Opamp
4. The data sheet of LM-324 quad Opamp
5. The data sheet of ACS712 30ACurrent sensor
6. The data sheet of Arduino Uno
7. The data sheet of IRFP-260 MOSFET
8. Program of the Instrument

Charge Controller Coding

main

```
#include <LiquidCrystal.h>
#include <SPI.h>
#include <avr/interrupt.h>

float VB=0.0;
float VP=0.0;
float VL=0.0;

float LD=0.0;
float LR=0.0;
float PR=0.0;
float PD=0.0;

uint8_t S1=1;
const uint8_t slaveSelectPin=10; // SPI bus chip select for mcp4131
uint8_t pot_pos =0; //potentiometer position

LiquidCrystal lcd(4, 3, 8, 7, 6, 5);

void setup()
{
  analogReference(INTERNAL);
  pinMode(2, INPUT_PULLUP);
  attachInterrupt(0, SW1, FALLING);// Interrupt for Swithc 1
  init_LCD();
  init_SPI_digipot();
  init_relay();

}
```

```
void loop()

{
  Wait_for_Start_Test();

  Load_Reconnect();
  Load_Disconnect();
  Panel_Reconnect();
  Panel_Disconnect();

  Show_Result();


}
```

Digipot

```
void init_SPI_digipot(void)
{

  pinMode (slaveSelectPin, OUTPUT);
  // initialize SPI:
  SPI.begin();
  for(int i=0;i<=65;i++)
  {
    digitalPot_dec(); // wrt PB <> PW
    delay(10);

  }
  pot_pos=0;
}



void digitalPot_inc(void)
{
 digitalWrite(slaveSelectPin,LOW);
  SPI.transfer(0x08);// the increment command
  digitalWrite(slaveSelectPin,HIGH);
  pot_pos++;
}


void digitalPot_dec(void)
{
 digitalWrite(slaveSelectPin,LOW);
  SPI.transfer(0x04);// the decrement command
  digitalWrite(slaveSelectPin,HIGH);
  pot_pos--;
}
```

Inturrupt

```
void SW1()
{
    S1=0;
}
```

ControlFn

```
void Wait_for_Start_Test (void)
{
 LD=0.0;
 LR=0.0;
 PR=0.0;
 PD=0.0;
  while(S1)
  {
  Before_Test();
  }
 S1=1;
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Test is Starting");
 lcd.setCursor(0, 1);
  lcd.print("Now [Method #01]");
delay(1500);
}

void Load_Reconnect(void)
{
  lcd.clear();
  while(VL<9.9)
  {
    if (pot_pos<65)
    {
     digitalPot_inc();
    }
    Calc_VBatt();
    Calc_VLoad();
    Print_VBatt();
    Print_VLoad();
    delay(300);
  }
      LR=VB;
```

```
}




void Load_Disconnect(void)
{
  lcd.clear();
  while(VL>9.9)
  {
    if (pot_pos>0)
    {
    digitalPot_dec();
    }
    Calc_VBatt();
    Calc_VLoad();
    Print_VBatt();
    Print_VLoad();
    delay(300);
  }
      LD=VB;
      delay(200);
      while(pot_pos>0)
      {
       digitalPot_dec();
      delay(15);
      }

}

void Panel_Reconnect(void)
{
 lcd.clear();
      while(pot_pos<60)
      {
       digitalPot_inc();
      delay(15);
      }

// uint8_t loopcounter=0;
  while(VP<9.9)//||(loopcounter<100))
  {
    if (pot_pos>0)
    {
    digitalPot_dec();
    }
    Calc_VBatt();
    Calc_VPanel();
    Print_VBatt();
    Print_VPanel();
    delay(300);
//    loopcounter++;
  }
```

```
      PR=VP;
      delay(200);


}

void Panel_Disconnect(void)
{
  float Old_VP=0.0;
 // uint8_t loopcounter=0;
  while(VP>9.9)//||(loopcounter<100))
  {
    if (pot_pos<65)
    {
    digitalPot_inc();
    }
    Old_VP=VP;
    Calc_VBatt();
    Calc_VPanel();
    Print_VBatt();
    Print_VPanel();
    delay(300);

  //  loopcounter++;
  }
      PD=Old_VP;
      delay(200);
      while(pot_pos>0)
      {
       digitalPot_dec();
      delay(15);
      }

}


void Show_Result(void)
{
 while(pot_pos)
 {
     digitalPot_dec();
     delay(10);
 }


  while(S1)
{
 lcd.clear();
 After_Test();
}
S1=1;
}
```

Calculation

```
/*
A0 >> Battery +
A1 >> Panel +
A2 >> Load +

*/

void Calc_VBatt (void)
{

  int Vb_adc[10];
  for(int x=0;x<10;x++)
  {
  Vb_adc[x]=analogRead(A0);
  }
  int Vb_sum=0;
  for(int x=0;x<10;x++)
  {
  Vb_sum=Vb_sum+Vb_adc[x];
  }
  float Vb_avg= Vb_sum/10.0;

  VB= (Vb_avg*20.00)/1023.0;

}


void Calc_VPanel (void)
{

  int Vp_adc[10];
  for(int x=0;x<10;x++)
  {
  Vp_adc[x]=analogRead(A1);
  }
  int Vp_sum=0;
  for(int x=0;x<10;x++)
  {
  Vp_sum=Vp_sum+Vp_adc[x];
  }
  float Vp_avg= Vp_sum/10.0;

  VP= (Vp_avg*20.00)/1023.0;

}


void Calc_VLoad (void)
{

  int Vl_adc[10];
  for(int x=0;x<10;x++)
```

```
  {
  Vl_adc[x]=analogRead(A2);
  }
  int Vl_sum=0;
  for(int x=0;x<10;x++)
  {
  Vl_sum=Vl_sum+Vl_adc[x];
  }
  float Vl_avg= Vl_sum/10.0;

  VL= (Vl_avg*20.00)/1023.0;

}
```

Display

```
void init_LCD(void)
{
  lcd.begin(16, 2);
  lcd.print("  Solar Charge ");
  lcd.setCursor(0, 1);
  lcd.print("Controller Tester");

}

void Before_Test(void)
{
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" Connect Charge ");
  lcd.setCursor(0, 1);
  lcd.print(" Controller's ");
  delay(1500);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" P,B,L ");
  lcd.setCursor(0, 1);
  lcd.print(" To The Tester, ");
  delay(1500);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" Then Press the ");
  lcd.setCursor(0, 1);
  lcd.print(" Switch to Start");
  delay(2000);


}


void Print_VBatt(void)
{
  lcd.setCursor(0, 0);
  lcd.print(" Batt Volt:");
  lcd.setCursor(12, 0);
```

```
  lcd.print(VB);
}

void Print_VPanel(void)
{
  lcd.setCursor(0, 1);
  lcd.print("Panel Volt:");
  lcd.setCursor(12, 1);
  lcd.print(VP);
}

void Print_VLoad(void)
{
  lcd.setCursor(0, 1);
  lcd.print(" Load Volt:");
  lcd.setCursor(12, 1);
  lcd.print(VL);
}

void After_Test(void)
{
  lcd.setCursor(0, 0);
  lcd.print("ChargeController");
  lcd.setCursor(0, 1);
  lcd.print(" Test Results ");
  delay(2000);

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" Load Conn:");
  lcd.setCursor(12,0);
  lcd.print(LR);

  lcd.setCursor(0,1);
  lcd.print(" Load Disc:");
  lcd.setCursor(12,1);
  lcd.print(LD);

  delay(2500);

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Panel Conn:");
  lcd.setCursor(12, 0);
  lcd.print(PR);

  lcd.setCursor(0, 1);
  lcd.print("Panel Disc:");
  lcd.setCursor(12,1);
  lcd.print(PD);
  delay(2000);

  lcd.clear();
  lcd.setCursor(0, 0);
```

```
  lcd.print("Press Switch to");

  lcd.setCursor(0, 1);
  lcd.print(" Test Again !!");

  delay(1500);




}
```

Relay

```
void init_relay(void)
{
pinMode(9,OUTPUT);
digitalWrite(9,0);
}


void relay_on(void)
{
 digitalWrite(9,1);
}
void relay_off(void)
{
 digitalWrite(9,0);
}
```

Battery tester coding

Main

```
/* Open Source Design
* Code written by Shahariar Hossain, IE DU, Batch 3
** This firmware is for Lead Acid Battery Capacity Tester
*** Development & Testing Device Hardware & Farmware Date : 2015,Sep-Dec
-------------------------------------------------------*/

#include "U8glib.h"
#include <SPI.h>
#include <avr/eeprom.h>
#include <avr/interrupt.h>

#define LED 4
// cheap chinese OLED(scl,sda,nothing,d/c,rst)
//real H/W connection
U8GLIB_SSD1306_128X64 u8g(8, 7, 9, 5,6);
//U8GLIB_SSD1306_128X64 u8g(5, 6, 9, 8,7);
```

```
// Float to hold Voltage and Current readings
float Vb=0.0;
//int Vb=0;
float Ic=0.0;
float Im=0.0;

int I_base=462; // ADC value @ 0A current
int V_base=229;// @ 10.5 Volt

const uint8_t slaveSelectPin=10; // SPI bus chip select for mcp4131
uint8_t pot_pos =0; //digital potentiometer trimmer position

// Interrupt variables for Time keeping and User Input from press switch
volatile uint8_t sec=0;
volatile uint8_t S1=1;
volatile uint8_t S2=1;

// Timer variables
uint8_t oldsec=0;
uint8_t mint=0;
uint8_t hr=0;
uint8_t j=0;

int disc_I=0;// initial discharge current value (upto 10000 mA or 10.0A in
step of 100 mA or 0.1 A)
int C=05;// initial C rate

int eeprom_nth_data=0; // data index for EEPROM

// stopflag 1 means any stop condition occured : Vb<10.5 or Test runtime =
C hrs or User Stopped
uint8_t stopflag =0;


void setup(void) {
// u8g.setRot180();// flip display
// 1.114 volt Internal Analog Ref on Atmega328p
// provides 10 bit ADC Resolution of 1.075 mV
  analogReference(INTERNAL);
  pinMode(LED,OUTPUT); // Green LED for debugging Interrupts and EEPROM

  pinMode(2, INPUT_PULLUP);
  attachInterrupt(0, SW1, FALLING);// Interrupt for Swithc 1

  pinMode(3, INPUT_PULLUP);
  attachInterrupt(1, SW2, FALLING);// Interrupt for Swithc 2
// Avr internal timer for timebase
  init_timer1();
// Sets Potentiometer to 0 ohms
  init_SPI_digipot();
  delay(100);
  init_screen();delay(5000); // Shows Initializarion screen for 5 sec
  eeprom_or_test();
```

```
  user_input(); // take test configuration form user
  set_current();
}


void loop(void)
{

// Calculates Current in Amps and Voltage in Volts

Calc_I();
Calc_V();

// updates the screen with time,measured V & I
update_ui();

// adjusts current if changed on every 5 th minute
  if ((mint%5==0)&&(sec>56))
  {
    adjust_current(); // enable this function when everything is OK
    update_ui();
  }



//Stops test in one of the following 3 situations
// Abort by user / Battery Voltage below 10.50 Volt / Test Runtime exceeds
C hrs

if((Vb<=10.5)||(hr==C))
{
  // make Vb 10.5 later
 stop_test();
}

// User Stop Request
if (S1==0)
{
 stop_check();
}


// save eeprom every 5 min
if((mint%5==0)&&(sec==0))
{
 // save_eeprom();
 update_ui();
}


}
```

DigiPot

```
// Follwoing Function are for Controlling MCP4131 10K Diigital
Potentiometer
// over SPI bus

void init_SPI_digipot(void)
{

  pinMode (slaveSelectPin, OUTPUT);
  // initialize SPI:
  SPI.begin();
  for(int i=0;i<=65;i++)
  {
    pinMode(4,1);
    digitalPot_dec(); // wrt PB <> PW
    pinMode(4,0);
    delay(10);

  }
  pot_pos=0;
}

// Resistence Increase Function (1 Step = about 75 Ohms)

void digitalPot_inc(void)
{
 digitalWrite(slaveSelectPin,LOW);
  SPI.transfer(0x08);// the increment command
  digitalWrite(slaveSelectPin,HIGH);
  pot_pos++;
}


// Resistence Decrease Function (1 Step = about 75 Ohms)

void digitalPot_dec(void)
{
 digitalWrite(slaveSelectPin,LOW);
  SPI.transfer(0x04);// the decrement command
  digitalWrite(slaveSelectPin,HIGH);
  pot_pos--;
}
```

Control

```
/*
Note :
Im is the measured current
disc_I is the expected discharge current set by user


*/
```

```
// Adjust Current function Adjusts the Discharge current equals to Set
Value

void adjust_current(void)
{
  Calc_I();

// set the current with in  50 mA of expected
  if (Im<((disc_I.0)/1000.00))
  {
  digitalPot_inc();
  delay(50);
  }
  else if ((Im.05)>(disc_I/1000))
  {
  digitalPot_dec();
  delay(50);
  }

}


// Sets current for the first time
void set_current(void)
{
  for(int k=0;k<=(disc_I/100);k)
  {
    adjust_current();
    delay(5);

  }
}
// This Function takes necessary actions for stopping the test
// by Ramping Down the discharge current to 0A, stopping the Timer,


void stop_test(void)
{
    while(pot_pos>0)
    {
    digitalPot_dec();// slowly reduce the discharge currnet
    digitalWrite(LED,1);
    delay(100);
    digitalWrite(LED,0);
    }

   stopflag=1;
   update_time();

    while(1)
    {

    test_stopped();
```

```
    delay(50);
    }
}

// Confirms user request for manual stop test

void stop_check(void)
{
  S2=1;
  S1=1;
  while(S1)
  {
  digitalWrite(LED,1);
  manual_stop();
  if(S2==0)
  {
    stop_test();

  }
  }
  digitalWrite(LED,0);
   S1=1;
}

// Updates Display during test with Battery Voltage,
// Discharge Current, Test Run Time Info periodically

void update_ui(void)
{

   if(sec!=oldsec)
 {
   update_time();
   update_disp();
 }
}
```

Calculation

```
// Measures ADC & Calculates Discharge Current : Range: 0-13.9 A in
resolution of 25 mA

void Calc_I(void)
{int I_temp=0;
 for (int i=5;i>0;i--)
 { I_temp=I_temp+analogRead(A1);}

int I_avg= I_temp/5;
```

```
  Im=(I_avg-I_base)*13.91/(1023-I_base);

  delay(1);
 if (Im<0.03){Im=0.0;}
}


// Measures ADC and Calculates Battery Voltage

// NOTE : Battery Voltage Measureing Range :10.10 V to 14.3 V

// Below or Above this range result is not accurate
!

void Calc_V(void)
{

 int V_temp=0;
 for (int i=5;i>0;i--)
 { V_temp=V_temp+analogRead(A0);}
 int V_avg=V_temp/5;

 Vb=(V_avg-V_base)*0.004767+10.50;

  delay(1);
}
```

Interrupt

```
// timer compare interrupt service routine, Periodic Interrupt, Time
keeping

ISR(TIMER1_COMPA_vect)
{
  sec++;
}

// IRS for S1 and S2 buttons for user controll
// use pinMode(x, INPUT_PULLUP) for standby
// and pull down (falling edge interrupt)

void SW1()
{

  S1=0;
//  digitalWrite(LED,HIGH);
}
void SW2()
{
  S2=0;
```

```
 // digitalWrite(LED,LOW);
}
```

Display

```
// Loops the Display Screen after Test Stopped
void test_stopped(void)
{
   u8g.firstPage();
  do {
    draw12();
  } while( u8g.nextPage() );


}

// Loops the Display Screen for manual stop input form user
void manual_stop(void)
{
   u8g.firstPage();
  do {
    draw11();
  } while( u8g.nextPage() );

}

// Loops the Display Screen wheather to enter EEPROM for
// Old test Data or Run a New Test
void fetch_or_test(void)
{
    u8g.firstPage();
  do {
    draw0();
  } while( u8g.nextPage() );

}

// Loops the Display Screen during Start Up

void init_screen(void)
{
    u8g.firstPage();
  do {
    draw1();
  } while( u8g.nextPage() );

}

// Loops the Display Screen with Update V,I,Time value
```

```
void update_disp(void)
{
    u8g.firstPage();
  do {
    draw2();
  } while( u8g.nextPage() );

}

// Loops the Display Screen for User (input) Setup for current value
void set_batt_current(void)
{
    u8g.firstPage();
  do {
    draw3();
  } while( u8g.nextPage() );

}

// Loops the Display Screen for User (input) Setup for c-rate value
void set_c_rate(void)
{
   u8g.firstPage();
  do {
    draw4();
  } while( u8g.nextPage() );


}

// Loops the Display Screen with instructions before starting test
void begin_test(void)
{
   u8g.firstPage();
  do {
    draw5();
  } while( u8g.nextPage() );


}

// Loops the Display Screen druing data Copying from EEPROM-Serial-USB(PC)
connection
void eeprom_to_serial(void)
{
   u8g.firstPage();
  do {
    draw7();
  } while( u8g.nextPage() );


}
```

```
void fetch_screen(void)
{
   u8g.firstPage();
  do {
    draw10();
  } while( u8g.nextPage() );


}


// The follwing Draw functions are U8GLIB functions for displaying
// Text/Data on the 1306 OLED Display, which are Sub-Function of the above
Functions
// Details can be found : https://code.google.com/p/u8glib/wiki/u8glib

void draw0(void)
{
  u8g.setFont(u8g_font_5x8);
  u8g.drawStr( 0, 10, "MENU: NEW TEST / OLD DATA");
  u8g.drawStr( 0, 24, "PRESS S1 to ACCESS");
  u8g.drawStr( 0, 36, "LAST TEST'S DATA (EEPROM)");
  u8g.drawStr( 0, 48, "PRESS S2 for SETTING");
  u8g.drawStr( 0, 60, "NEW TEST PARAMETERS");


}


void draw1(void)
{
  u8g.setFont(u8g_font_6x12);
  u8g.drawStr( 0, 10, "DON'T CONNECT BATTERY");
  u8g.setFont(u8g_font_7x14B);
  u8g.drawStr( 0, 28, "LEAD ACID BATTERY");
  u8g.drawStr( 0, 46, "  CAPACITY TESTER ");
  u8g.drawStr( 0, 64, " Initializing....");

}

void draw2(void) {
  // graphic commands to redraw the complete screen should be placed here
  u8g.setFont(u8g_font_6x10);
 //u8g.drawStr( x upto 128, y upto 64, "String")
 // u8g.drawStr( 0, 44, "Current (est):"); u8g.setPrintPos(90,
44);u8g.print(Ic);
  u8g.drawStr( 0, 24, "Current(Load):"); u8g.setPrintPos(90,
24);u8g.print(Im);u8g.drawStr( 120, 24, "A");
  u8g.drawStr( 0, 12, "Volt (V_Batt):");
u8g.setPrintPos(90,12);u8g.print(Vb);u8g.drawStr( 120, 12, "V");
 u8g.drawFrame(0,28,128,28);
  u8g.drawStr(3,39,"To STOP this TEST");
  u8g.drawStr(3, 51,"Manually, PRESS: S1");
  u8g.drawStr( 0, 64, "Runtime");
```

```
  u8g.setPrintPos(48,64);u8g.print(hr);
  u8g.drawStr( 60, 64, "h: ");
  u8g.setPrintPos(78,64);u8g.print(mint);
  u8g.drawStr( 90, 64, "m: ");
  u8g.setPrintPos(108,64);u8g.print(sec);
  u8g.drawStr( 120, 64, "s");

}


void draw3(void)
{
  u8g.setFont(u8g_font_6x10);
  u8g.drawStr( 0, 10, "Set Current: PRESS S1" );
  u8g.drawStr( 0, 24, "Discharge");
  u8g.drawStr( 0, 34, "Current = ");

  u8g.setPrintPos(60,34);u8g.print(disc_I);
  u8g.drawStr( 84, 34, "mA");
  u8g.drawStr( 0, 40, "_____________________");
  u8g.drawStr( 0, 50, "After Setting Current");
  u8g.drawStr( 0, 60, "PRESS S2 to Proceed");

}


void draw4(void)
{
  u8g.setFont(u8g_font_6x10);
  u8g.drawStr( 0, 10, "Set C-Rate: PRESS S1" );
  u8g.drawStr( 0, 28, "C-Rate: C/");
  u8g.setPrintPos(60,28);u8g.print(C);
  u8g.drawStr( 0, 60, "PRESS S2 to Proceed");

}


void draw5(void)
{
  u8g.setFont(u8g_font_6x10);
  u8g.drawFrame(0,0,128,14);
  u8g.drawStr( 1, 11, "!NOW CONNECT BATTERY!" );
//  u8g.drawStr( 0, 16, "....................." );
  u8g.drawStr( 0, 26, "V_Batt(+) & V_Batt(-)");
  u8g.drawStr( 0, 38, "After Connecting Batt");
  u8g.drawStr( 0, 50, "PRESS S2 to Start");
  u8g.drawStr( 0, 62, "Discharging Test");


}

void draw7(void)
{
{
```

```
  u8g.setFont(u8g_font_6x10);
  u8g.drawFrame(0,0,128,14);
  u8g.drawStr( 1, 11, " CONNECT RX/TX/Gnd to" );
//  u8g.drawStr( 0, 16, "...................." );
  u8g.drawStr( 0, 24, "Computer using a USB");
  u8g.drawStr( 0, 34, "to Serial Converter.");
  u8g.drawStr( 0, 44, "Start a Terminal");
  u8g.drawStr( 0, 54, "Programm,then PRESS");
  u8g.drawStr( 0, 64, "S2 to Copy EEPROM.");


}

}

void draw10(void)
{
  u8g.setFont(u8g_font_6x10);
  u8g.drawFrame(0,0,128,14);
  u8g.drawStr( 1, 12, "Hopefully Previous" );
//
  u8g.drawStr( 1, 24, "TEST DATA COPYING" );
//  u8g.drawStr( 0, 16, "...................." );
  u8g.drawStr( 0, 36, "From EEPROM to Serial");
  u8g.drawStr( 0, 48, "In Progress.....");


}


void draw11(void)
{
  u8g.setFont(u8g_font_6x10);
  u8g.drawStr( 0, 10, "STOP TEST/CONTINUE");
  u8g.drawStr( 0, 24, "PRESS S2 to STOP TEST");
 // u8g.drawStr( 0, 36, "LAST TEST'S DATA (EEPROM)");
  u8g.drawStr( 0, 44, "PRESS S1 to CONTINUE");
  u8g.drawStr( 0, 56, "RUNNING this TEST");



}



void draw12(void)
{
  u8g.setFont(u8g_font_6x10);
  u8g.drawFrame(0,0,128,14);
  u8g.drawStr( 18, 11, "! TEST STOPPED !" );
//
  u8g.drawStr( 18, 24, "( OR COMPLETED )" );
//  u8g.drawStr( 0, 16, "...................." );
  u8g.drawStr( 0, 36, "Disconnect Battery,");
  u8g.drawStr( 0, 48, "Then Restart Tester");
```

```
  u8g.drawStr( 0, 64, "Duration:");
  u8g.setPrintPos(60,64);u8g.print(hr);
  u8g.drawStr( 72, 64, "h: ");
  u8g.setPrintPos(90,64);u8g.print(mint);
  u8g.drawStr( 102, 64, "m ");

}
```

Timer

```
// This portion of the code is written in AVR style
void init_timer1(void)
{
  noInterrupts();            // disable all interrupts
  TCCR1A = 0;                // disabling PWM functionality form timer
  TCCR1B = 0;                // reseting before configuration
  TCNT1  = 0;                //

  OCR1A = 62500;             // compare match register 16MHz/256/1Hz
  TCCR1B |= (1 << WGM12);    // CTC mode
  TCCR1B |= (1 << CS12);     // 256 prescaler
  TIMSK1 |= (1 << OCIE1A);   // enable timer compare interrupt
  interrupts();              // enable all interrupts
}

void update_time(void)
{

   noInterrupts();
   oldsec=sec;

    if (sec>=60)
    {
      mint=mint+1; // after every 60 sec, minute is incremented by 1
      sec=0;
    }
    if (mint>=60)
    {
      hr=hr+1;// after every 60 min, hour is incremented by 1
      mint=0;
      if((hr==C)||(stopflag==1))
      { TIMSK1 &= ~(1 << OCIE1A); } // freeze runtime by disabling
interrupt when test ends
    }
    interrupts();

}
```

User Input

```
// User Inputs and Settings (choices) are taken here

void eeprom_or_test(void)
{
  S2=1;
  S1=1;
while(S2)
 {

  fetch_or_test();
  while (S1==0)
  {

    eeprom_to_serial();
    while(S2==0)
    {
      //eeprom_to_serial();
      fetch_screen();
      fetch_eeprom();

    }
  }


 }
}

void user_input(void)
{
  // this part will take discharge current setting from user interface
  // using Switchs as input and display as output to user
  S2=1;
  S1=1;
  while(S2)
  {
  set_batt_current();
    if (S1==0)
    {
    disc_I=disc_I+100;
    if(disc_I>10001)
    {disc_I=0;}
    S1=1;
    }
  }

  // This part will set the C Rate or how long the test will run
  S2=1;
  while(S2)
  {
    if (S1==0)
    {
     j++;
```

```
      if(j>=3)
      j=0;
     }
     if (j==0)
     {C=05;}
     if (j==1)
     {C=10;}
     if (j==2)
     {C=20;}
     S1=1;
     set_c_rate();

   }


   // this part will take user command for starting the test

   S2=1;
   while(S2)
   {
   begin_test();
   digitalWrite(LED,1);
   }
   digitalWrite(LED,0);
   sec=0;mint=0;
}
```

EEProm

```
// timer compare interrupt service routine, Periodic Interrupt, Time
keeping
ISR(TIMER1_COMPA_vect)
{
  sec++;
}

// IRS for S1 and S2 buttons for user controll
// use pinMode(x, INPUT_PULLUP) for standby
// and pull down (falling edge interrupt)

void SW1()
{

  S1=0;
//  digitalWrite(LED,HIGH);
}
void SW2()
{
  S2=0;
 // digitalWrite(LED,LOW);
}
```

Reference

1. http://idcol.org/home/solar
2. Design Considerations for Solar PV Home Systems in Bangladesh, M. Rezwan Khan and M. Fayyaz Khan, Department of EEE, BUET, Dhaka 1000, Bangladesh
3. http://www.sciencebuddies.org/science-fair-Projects/project_ideas/Energy_p015.shtml#background
4. Batteries In A Portable World, Isidor Buchmann.
5. Charge Controllers for PV Systems, Professor Dr. Rezaul Karim Mazumder,University of Liberal Arts Bangladesh
6. http://www.morningstarcorp.com/wp-content/uploads/2014/02/8.-Why-PWM1.pdf
7. http://www.edama.jo/Content/Documents/b33c0381-6a3f-42f4-94b5-f78da38d8510/52178b70-fec0-4903-aa92-70f4a586cabb.pdf
8. https://www.victronenergy.com/upload/documents/White-paper-Which-solar-charge-controller-PWM-or-MPPT.pdf
9. http://batteryuniversity.com/learn/article/how_to_calculate_battery_capacity