## Project on

# DESIGN AND DEVELOPMENT OF AN AUTOMATIC SOLAR CHARGE CONTROLLER

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**East West University, Dhaka**

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# Declaration

We, the student of B.Sc. of the Department of Electronics and communication Engineering at East West University bearing ID:2012-2-55-018 and ID:2012-2-55-028, would like to declare that this project on "**Design and development of an automatic solar charge controller**" has been authentically prepared by us.

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# Certificate

This is to certify that the Project report on "**Design and development of an automatic solar charge controller**" submitted for the partial fulfillment of the B.Sc. degree in Electronic and communications Engineering from the East West University, has been carried out by the student bearing ID:2012-2-55-018 & ID:2012-2-55-028, under my supervision. To the best of my knowledge and as per their declaration, the whole work and the complete project report has been prepared by the students and has not been submitted to anywhere else.

The project report can be considered for evaluation.

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Md.Latifur Rahman Rana

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# ABSTRACT

As the sources of conventional energy deplete day by day, resorting to alternative sources of energy like solar and wind energy has become essential of the hour. Solar-powered lighting systems are readily available in rural as well as urban areas. These include solar lanterns, solar home lighting systems, solar street lights, solar garden lights and solar power packs. All of them consist of four components: solar photovoltaic module, rechargeable battery, charge controller and load. In the solar-powered lighting system, the solar charge controller plays an important role as the battery's overall life depends mainly on it. In this point of view, this project presents designing a Solar Charge Controller for the Solar Battery Charging Station with the function to disconnect and reconnect battery and load during battery over charging or discharging. Instead of using readily available microcontroller board (Eg. Arduino), here Arduino microcontroller (Atmega328) has been used to make the system cost-effective. The source code for the Arduino microcontroller is written in Arduino software. Furthermore, to ensure the full charge and to avoid over discharge the SOC of the battery has been properly determined by sensing the terminal voltage of the battery and the charging or discharging current. Normal charge controller has four set-points which are fixed, but here the set-points will be automatically adjusted depending on the level of charging and discharging current. As a current sensor ACS712 hall current sensor has been used. The system has been simulated and practically implemented. Performance study of the system shows that it works properly within the range 10A maximum.

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# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Bangladesh Government has set up the goal of providing electricity to all by 2020 and to ensure reliable and quality supply of electricity at a reasonable and affordable price. Sustainable social and economic development depends on adequate power generation capacity of a country. There is no other way for accelerating development except to increase the power generation by fuel diversification. Development of Renewable Energy is one of the important strategies adopted as part of Fuel Diversification Program. In line with the Renewable Energy policy 2009, the Government is committed to facilitate both public and private sector investment in Renewable Energy projects to substitute indigenous non- renewable energy supplies and scale up contributions of existing Renewable Energy based electricity productions. The Renewable Energy Policy envisions that 5% of total energy production will have to be achieved by 2015 and 10% by 2020. To achieve this target, GOB is looking for various options preferably Renewable Energy resources. Under the existing generation scenario of Bangladesh, Renewable Energy has a very small share to the total generation. The share of Renewable Energy exceeds more than 1% till now. The present Government is placing priority on developing Renewable Energy resources to improve energy security and to establish a sustainable energy regime alongside of conventional energy sources. Government has already launched "**500 MW Solar Power Mission**" to promote the use of Renewable Energy to meet the increasing demand of electricity.

Solar Energy, radiation produced by nuclear fusion reactions deep in the Sun's core. The Sun provides almost all the heat and light Earth receives and therefore sustains every living being. Bangladesh being a country being concerned about environmental problems, sustainable energy sources is becoming more and more popular here.

Photovoltaic (PV) is the direct process of converting solar energy into electricity. It is considered as a clean and environmental-friendly source of energy. Photovoltaic power systems, a promising source of energy for the future, are actually solar panels are referred to by the industry as solar electric modules or photovoltaic (PV) modules. Module or panel, they are flat arrangements of series-connected silicon solar cells. There are generally 30 to 36 solar cells per module. The modules can be wired as series or parallel arrays to produce higher voltages and currents. Typical small PV systems use a single panel to charge a 12-volt battery. In general, a PV system consists of a PV array, which converts sunlight to direct-current electricity, a control system, which regulates battery charging, and operation of the load, energy storage in the form of secondary batteries and loads or appliances. A charge controller is one of functional and reliable major components in PV systems. Since the brighter, the sunlight, the more voltage the solar cells produce, the excessive voltage and current could damage the batteries. A charge controller is used to control charging and discharging function to prevent damage and long-life of batteries. As the input voltage from the solar array varies with time, the charge controller regulates the charge to the batteries preventing any overcharging. The charge controller also prevent over discharging of batteries as load are connected with it always. Therefore, a good, solid and reliable PV charge controller is a key component of any PV battery charging system to achieve low cost and the benefit that user can get from it. The algorithm or control strategy of a battery charge controller determines the effectiveness of battery charging and PV array utilization, and ultimately the ability of the system to meet the load demands. An intelligent charge controller should be designed to prolong the battery's lifetime and stabilize the voltage from is has photovoltaic panel.

Important functions of battery charge controllers and system controls are

**Prevent Battery Overcharge:** To limit the energy supplied to the battery by the PV array when the battery becomes fully charged.

**Prevent Battery Over-discharge:** To disconnect the battery from electrical loads when the battery reaches low state of charge.

**Provide Load Control Functions:** To automatically connect and disconnect an electrical load at a specified time, for example operating a lighting load from sunset to sunrise.

**Prevent Battery Undercharge:** The battery industry pays less attention to undercharging than to overcharging. Still it is better to prevent undercharging.

Figure 1.1 shows the block diagram for a controller that employs hysteresis on charge and discharge, selective load disconnect.

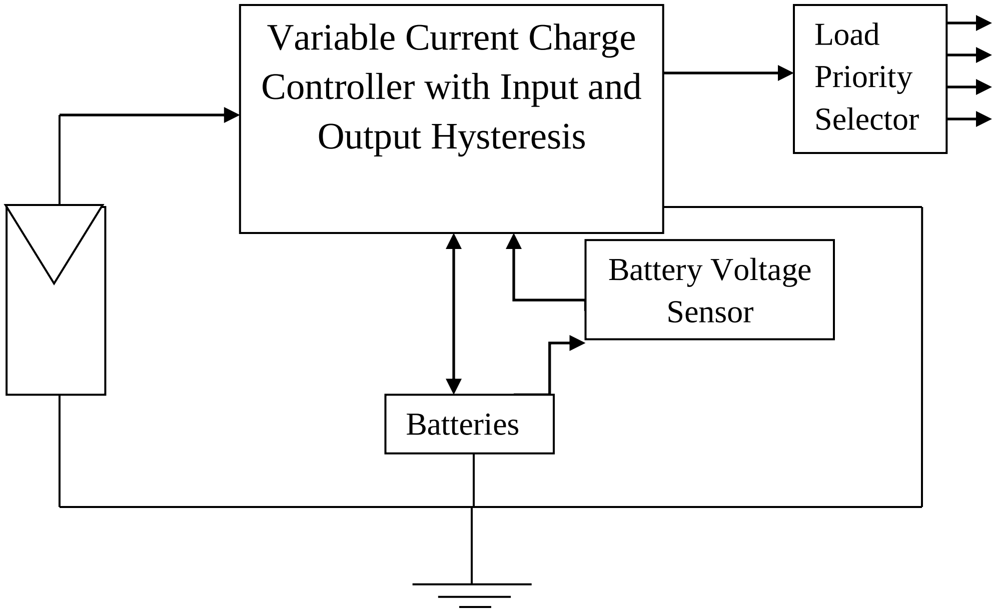


**Figure-1.1**: Block diagram of a charge controller

Ideally, a charge controller will make full use of the output power of the PV array, charge the batteries completely and stop the discharge of the batteries at exactly the prescribed set-point, without using any power itself.

## 1.2 OBJECTIVES OF THE PROJECT

- To design an automatic charge controller circuit with variable set-points
- Use hall current sensor  to vary the set points according to the amount of current
- To construct a intelligent charge controller circuit intelligent in the breadboard
- Test for its functionality

## 1.3 PURPOSES OF THE PROJECT

Batteries are often blamed for power system failures, but batteries are only the most vulnerable part of the system. No battery can overcome the faults of a bad charging system. Best battery performance is achieved when the characteristics of the battery are matched to the charging source. This is the job of the charge control system. Small PV power systems at remote sites face two charge control problems that indoor float systems connected to the power grid do not. First, the amount of solar power is highly variable and influenced by uncontrollable factors such as the weather. Second, the power system may have to cope with temperature extremes. Both of these can cause too much or too little battery charging. Premature battery failure is the result.

A battery becomes **overcharged** when it is forced to accept more current than it can chemically store. This happens either when charging currents are too high or when the battery is fully charged and current continues to flow through the battery. Overcharging damages batteries through electrolyte water loss and grid corrosion. One of the ways a battery dissipates overcharge current is to use it to decompose electrolyte water. Water is broken down into hydrogen and oxygen gases. This process is referred to as **gassing**. Unless the gases are recycled or the water is replaced, the loss is permanent. Battery capacity is permanently lost when the electrolyte dries out.

In small PV systems, undercharging is as responsible as overcharging for early battery failure [14].

The problem with undercharging is **salfation**. As a battery discharges, the active material on both plates is changed to lead sulfate. When the battery recharges, the lead sulfate is changed back to active material and sulfate ions return to the electrolyte. Sulfate ions do this easily if they are not part of a larger lead sulfate crystal structure. However, if recharge is delayed, there is time for crystal growth and it can become difficult or impossible to change the entire lead sulfate back into active material. Battery self-discharge contributes to crystal growth. By delaying full recharge, undercharging allows lead sulfate to form more perfect crystal structures. In extreme cases, surface lead sulfate crystal barriers block whole plates and the battery is unable to recharge. Such a battery is said to have "sulfated" because its plates have "hardened".

**Electrolyte freezing** is another problem caused by severe undercharging. Electrolytes with low specific gravities freeze at higher temperatures. Frozen electrolytes expand and injure plates. Table 1 shows the freezing point of electrolytes with different specific gravities.

| SPECIFIC GRAVITY | FREEZING POINT ℃ |
|---|---|
| 1.300 | -70 |
| 1.280 | -68 |
| 1.260 | -58 |
| 1.240 | -44 |
| 1.220 | -34 |
| 1.200 | -25 |
| 1.180 | -21 |
| 1.160 | -16 |
| 1.140 | -12 |
| 1.120 | -10 |
| 1.100 | -08 |
| 1.000 | 0 |

**Table 1** Electrolyte freezing point at various specific gravities (BCI, 1995)

Some of the other critical issues are listed in the following.

- Premature failure and lifetime prediction of batteries are major concerns within the PV industry.
- Batteries experience a wide range of operational conditions in PV applications, including varying rates of charge and discharge, frequency and depth of discharges, temperature fluctuations, and the methods and limits of charge regulation. These variables make it very difficult to accurately predict battery performance and lifetime in PV systems.
- Battery performance in PV systems can be attributed to both battery design and PV system operational factors. A battery, which is not designed and constructed for the operational conditions experienced in a PV system, will almost certainly fail prematurely.

- Battery manufacturers’ specifications often do not provide sufficient information for PV applications. The performance data presented by battery manufacturers is typically based on tests conducted at specified, constant conditions and is often not representative of battery operation in actual PV systems.

On the other hand, during periods of below average isolation and/or during periods of excessive electrical load usage, the energy produced by the PV array may not be sufficient to keep the battery fully recharged. When a battery is deeply discharged, the reaction in the battery occurs close to the grids, and weakens the bond between the active materials and the grids. When a battery is excessively discharged repeatedly, loss of capacity and life will eventually occur. In some cases, the electrical loads in a PV system must have sufficiently high enough voltage to operate. If batteries are too deeply discharged, the voltage falls below the operating range of the loads, and the loads may operate improperly or not at all

Therefore, a charge controller is important to prevent battery overcharging, excessive discharging, reverse current flow at night and to protect the life of the batteries in a PV system. Charge controllers prevent excessive battery overcharge by interrupting or limiting the current flow from the array to the battery when the battery becomes fully charged and prevent battery over-discharge by open-circuiting the connection between the battery and system load once the battery reaches a low state of charge condition. Consequently overcharge and over-discharge effects can be removed.

## 1.4 LITERATURE SURVEY

Before proceeding with our work, a literature survey has been conducted.  Among them the following topics, which are closely related with our work, are given below. As our thesis work is commercial project (related to application of microcontroller) it is difficult to know more about which technique is used to make such product only their application or operation is given on company website.

Such companies are:

1. **Company name:** Outback Power System

   *Website:* http://www.outbackpower.com/products/charge_controllers/flexmax/

   **Product name**: FLEXmax-Continuous Maximum Power Point Tracking Charge Controllers

   **Product Model:** FLEXmax 80

   **Features:**

   - Increases PV Array Output by up to 30%
   - Advanced Continuous Maximum Power Point Tracking
   - Full Power Output in Ambient Temperatures up to 104°F (40°C)
   - Battery Voltages from 12 VDC to 60 VDC
   - Fully Out Back Network Integrated and Programmable
   - Programmable Auxiliary Control Output
   - Built-in 128 days of Data Logging

   **Cost – 539$**

2. **Company name:** Sunforce

   **Website:** http://www.sunforceproducts.com/product_details.php?PRODUCT_ID=152

   **Product name:** 10 Amp Digital Charge Controller

   **Features:**

   - Protect battery form Overcharge and Discharge
   - For use with 12V solar panels and batteries only
   - Handles up to 10 Amps of current
   - Handles up to 50 Watts of Solar Power
   - Maintenance Free Protection of your solar panels and batteries
   - LCD digital display

   **Cost – 87.23$**

3. **Company name:** Xantrex Technology Inc.

   **Website:**http://www.wholesalesolar.com/products.folder/controllerfolder/xantrexXWSCC.html

   **Product name:** XW Solar Charge Controller

   **Product model:** XW-MPPT 60-150

**Features and General Information:**

- Maximum Power Point Tracking (MPPT) delivers maximum available power from PV array to battery bank
- Integrated PV ground-fault protection
- Ultra-reliable, convection-cooled design does not require a cooling fan - large, aluminum, die-cast heat-sink allows full output current up to 45°C without thermal derating
- Selectable two or three-stage charging algorithms with manual equalization to maximize system performance and improve battery life
- Configurable auxiliary output
- Two-line, 16-character liquid crystal display (LCD) and four buttons for configuration and system monitoring
- Input over-voltage and under-voltage protection, output over-current protection, and back feed (reverse current) protection (warning and fault messages appear on LCD when unit shuts down as a protective measure)
- Over-temperature protection and power derating when output power and ambient temperature are high 18
- Battery Temperature Sensor (BTS) included - automatically provides temperature compensated battery charging
- **Cost- $475.00$**

4. **Company name:** Beijing EPsolar Technology Co. Ltd

**Website:** http://www.epsolarpv.com/en/index.php/Product/pro_content/id/233/am_id/136

**Product name:** eTracer series MPPT Solar Charge Controller (45A/60A) & (12/24/36/48V)

**Product model:** LS1024RP / LS2024RP

**Features:**

- Waterproof design
- High efficient Series PWM charging
- Gel, Sealed and Flooded battery type option
- Widely used, automatically recognize day/night

- Intelligent timer function with 1-15 hours option
- Use MOSFET as electronic switch
- Digital LED menu with simple setting and easy using
- Temperature compensation
- Reverse protection: any combination of solar module and battery
- Prevent Over discharging, Over charging and Overheating
- Prevent Load overload and Load short circuit and PV short circuit

In our project, we are designing a series controller. The most simple series controller is the series-interrupting type, turning the array charging current either on or off. The charge controller constantly monitors battery voltage, and disconnects or open-circuits the array in series once the battery reaches the regulation voltage set point. When battery voltage drops to the array reconnect voltage set point, the array and battery are reconnected, and the cycle repeats.

Assume that the battery is fully charged when the terminal voltage reaches 14 volts with a specific charging current. Assume also that when the terminal voltage reaches 14 volts, the array will be disconnected somehow from the batteries and that when the terminal voltage falls below 14 volts, the array will be reconnected. Now note that when the array is disconnected from the terminals, the terminal voltage will drop below 14 volts, since there is no further voltage drop across the battery internal resistance. The controller thus assumes that the battery is not yet charged and the battery is once again connected to the PV array, which causes the terminal voltage to exceed 14 volts, which causes the array to be disconnected. This oscillatory process continues until ultimately the battery becomes overcharged or until additional circuitry in the controller senses the oscillation and decreases the charging current. One way to eliminate overcharging resulting from the oscillatory process is to introduce hysteresis into the circuit, so that the array will not reconnect to the batteries until the batteries have discharged somewhat.

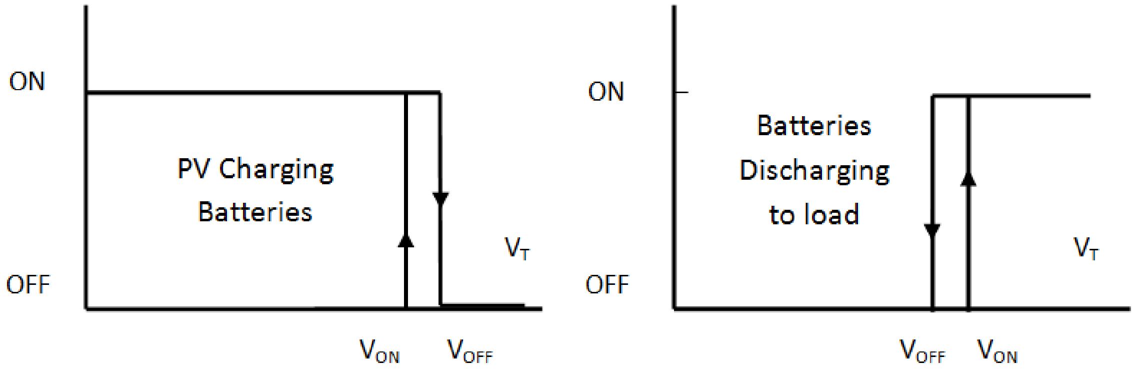


**Figure 1.2** Hysteresis loops in charge controller for voltage sensing

Now consider the discharge part of the cycle. Assume the battery terminal voltage drops below the prescribed minimum level. If the controller disconnects the load, the battery terminal voltage will rise above the minimum and the load will turn on again, and once again, an oscillatory condition exists. Thus, once again an application for hysteresis is identified.

Generally, charge controller is divided into 3 main portions, which are Atmega328 microcontroller, input parts and output parts. The input part for the charge controller is battery voltage sensing circuit. It is used to detect the voltage of the battery and send the data to the Atmega328 microcontroller to analyze and Atmega328 microcontroller will operate according to the program written inside its memory. For the output part, it consists panel-battery connect/ disconnect circuit, sources load connect/ disconnect circuit, low voltage warning, fully charged indicator and normal indication. A crystal oscillator of 4MHz/20MHz clocks the microcontroller. Circuit power at 5V is derived from a L7805 voltage regulator connected to the battery. Two power MOSFETs (IRF540) are used as solid-state switch for the panel-battery line and battery-load line. LEDs of differing colors are used to display the system status.

**Here, Atmega328 microcontroller is used to control the operation of charging control and data acquisition task in this project. Atmega328 contains 19 I/O ports which are suitable for the development of the charge controller. Port A to is used to perform the analog to digital conversion, which is used in input parts like battery voltage sensing circuit and current sensing circuit. Port C controls disconnect or reconnect operations for photovoltaic panel or load and provide the information of battery charging status. Port B is used as to show different battery voltage condition indicated by LEDs. Block diagram of charge controller is shown in Figure 1.0

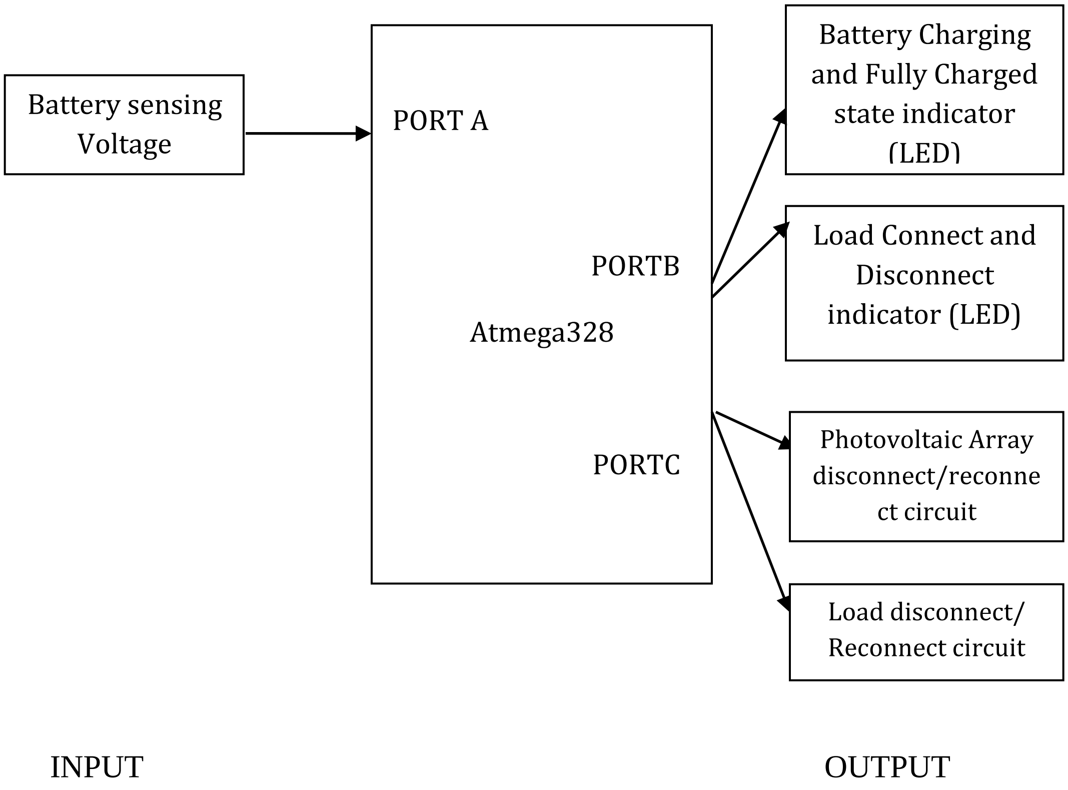


**Figure-1.3** Block diagram of Microcontroller based charge controller**

The other features of this designed charge controller are listed as below.

- Solar charging current: 50 Amps continuous
- Nominal battery voltage: 12V
- Photovoltaic panel voltage ratings: Up to 50 KWP
- Battery type: lead-acid
- Hysteresis Control Option
- Over voltage and under voltage protection
- Excess temperature protection
- Battery voltage status indication by LEDs

- Three LED indicators to show the status of the charge controller which are battery charging, battery discharging, and charging & discharging
- Adjustable output voltage

## 1.5 THESIS OUTLINES

This project is divided into 4 chapters:

**Chapter 1:** An introduction of charge controller. Some recent works related to our project are studied. The basic elements of the proposed system are described in short.

**Chapter 2:** In the 2nd chapter, we have studied the theories in details related to this work. Definition of microcontroller, Families of microcontroller, the internal architecture of Atmega328 microcontroller are described. MCU needs to configure at first, how it should be configured is discussed in this chapter.

**Chapter 3:** Mainly focused on methodologies for the design & development of Photovoltaic Charge Controller. This chapter also includes the development & testing process of the program.

**Chapter 4:** This chapter includes the Simulation and Practical Result of the program. Details on the progress of the thesis are explained in this chapter.

# CHAPTER 2

# THEORETICAL BACKGROUND

## 2.1 INTRODUCTION

In this chapter about different basic types of charge controllers, led acid battery, Hall current sensor and microcontroller have been discussed.

To construct a charge controller here we use microcontroller for making decisions precisely and a hall current sensor for set the connecting disconnecting points of load and battery according to the voltage and current flow.

In this project, we have used a series on/off charge controller, also known as two-stage charge controller. The theory behind two-stage charge controller is given below.

## 2.2 BASICS OF CHARGE CONTROLLER THEORY

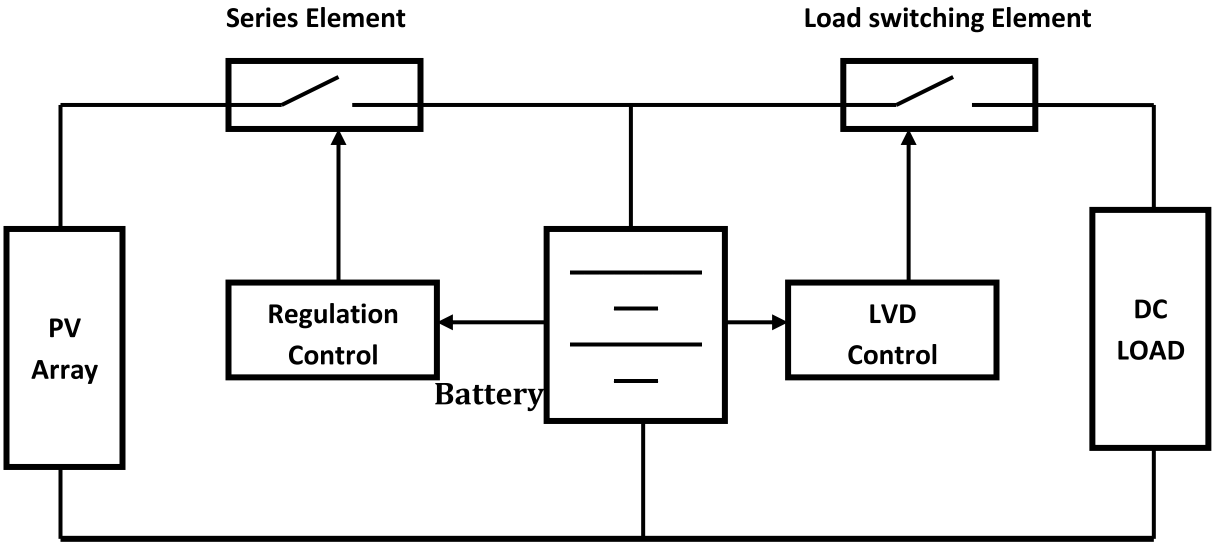


**Figure 2.1 Two stage series charge controller**

**2.2.1 Two stage charge controller:** One of the most popular types of charge controllers uses a simple ON/OFF series switch. Show in the Figure 2.1. The state of the switch is determined by two voltage thresholds. When the battery is bulk charging, the load switch is open and the full solar panel output is applied to the battery shown in Figure 2.1. When the upper threshold is reached, the load switch closes and the battery discharges through the load until the lower threshold is reached and the switch opens allowing the battery to charge once again.

In a series controller design, a relay or solid-state switch either opens the circuit between the array and the battery to discontinuing charging, or limits the current in a series-linear manner to hold the battery voltage at a high value. As these on-off charge cycles continue, the ‘on’ time becoming shorter and shorter as the battery becomes fully charged. Because the series controller open-circuits rather than short-circuits the array as in shunt-controllers, no blocking diode is needed to prevent the battery from short-circuiting when the controller regulates.

While the specific control method and algorithm vary among charge controllers, all have basic parameters and characteristics. Manufacturers' data generally provide the limits of controller application such as PV and load currents, operating temperatures, losses, set points, and set point hysteresis values. In some cases, the set points may be dependent upon the temperature of the battery and/or controller, and the magnitude of the battery current. A discussion of the basic charge controller set points follows:

The battery voltage levels at which a charge controller performs control or switching functions are called the controller set points. Four basic control set points are defined for most charge controllers that have battery overcharge and over discharge protection features.The voltage regulation (VR) and the array reconnect voltage (ARV) refer to the voltage set points at which the array is connected and disconnected from the battery. The low voltage load disconnect (LVD) and load reconnect voltage (LRV) refer to the voltage set points at which the load is disconnected from the battery to prevent over discharge. Figure 2.2 shows the basic controller set points on a simplified diagram plotting battery voltage versus time for a charge and discharge cycle. A detailed discussion of each charge controller set point follows.

**2.2.2 Voltage Regulation (VR) Set Point:** The voltage regulation (VR) set point is one of the key specifications for charge controllers. The voltage regulation set point is defined as the maximum voltage that the charge controller allows the battery to reach, limiting the overcharge of the battery. Once the controller senses that the battery reaches the voltage regulation set point, the controller will either discontinue battery charging or begin to regulate (limit) the amount of current delivered to the battery.

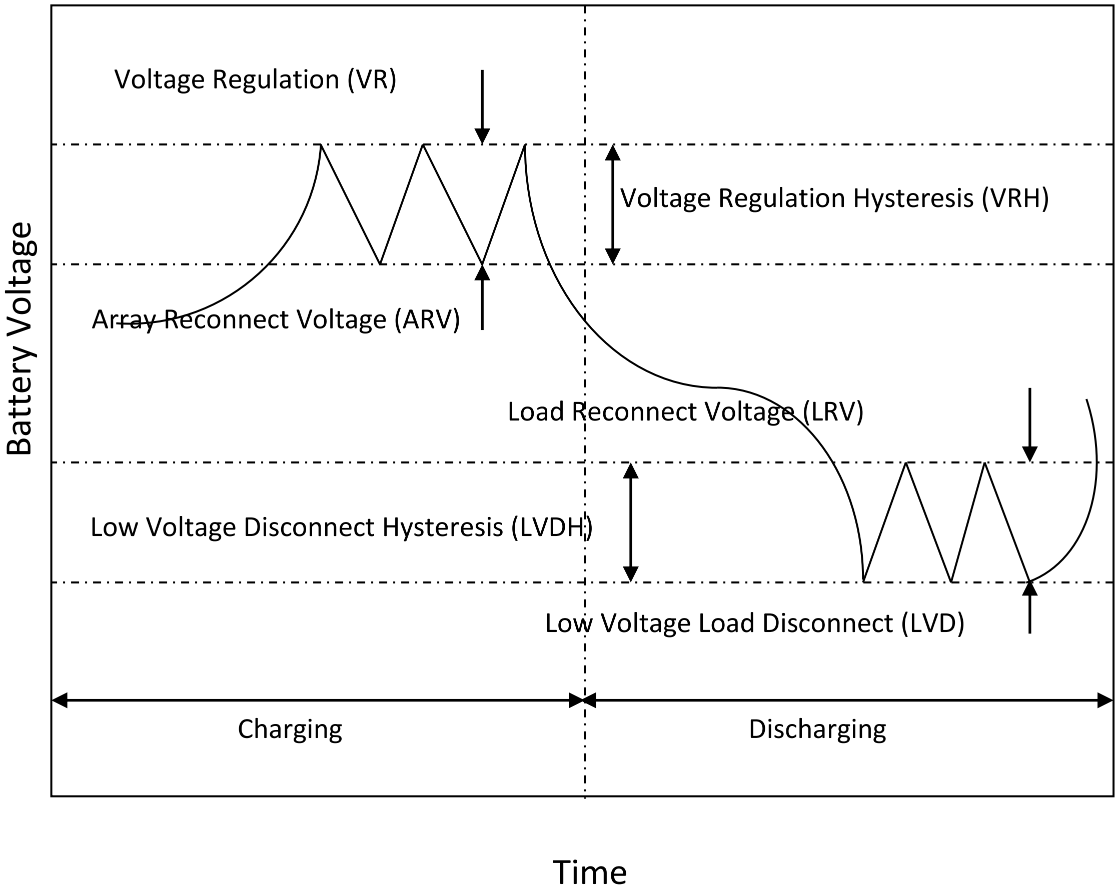


**Figure 2.2 Controller set points**

**2.2.3 Array Reconnect Voltage (ARV) Set Point:** In interrupting (on-off) type controllers, once the array current is disconnected at the voltage regulation set point, the battery voltage will begin to decrease. The rate at which the battery voltage decreases depends on many factors, including the charge rate prior to disconnect, and the discharge rate dictated by the electrical load. If the charge and discharge rates are high, the battery voltage will decrease at a greater rate than if these rates are lower. 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. If the array were to remain disconnected for the rest of day after the regulation voltage was initially reached, the battery would not be fully recharged. By allowing the array to reconnect after the battery voltage reduces to a set value, the array current will ‘cycle’ into the battery in an on-off manner, disconnecting at the regulation voltage set point, and reconnecting at the array reconnect voltage set point.

**2.2.4 Voltage Regulation Hysteresis (VRH):** The voltage span or difference between the voltage regulation set point and the array reconnect voltage is often called the voltage regulation hysteresis (VRH). The VRH is a major factor, which determines the effectiveness of battery recharging for interrupting (on-off) type controllers. If the hysteresis is to 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. The designer must carefully determine the hysteresis values based on the system charge and discharge rates and the charging requirements of the particular battery.

**2.2.5 Low Voltage Disconnect (LVD):** The voltage at which the load is disconnected from the battery to prevent over-discharge. The LVD defines the actual allowable maximum depth-of-discharge and available capacity of the battery. The available capacity must be carefully estimated in the PV system design and sizing process. Typically, the LVD does not need to be temperature compensated unless the batteries operate below 0°C on a frequent basis. The proper LVD set point will maintain good battery health while providing the maximum available battery capacity to the system.

**2.2.6 Load Reconnect Voltage (LRV) Set Point:** The battery voltage at which a controller allows the load to be reconnected to the battery is called the load reconnect voltage (LRV). After the 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 or a backup source, 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. The selection of the load reconnect set point should be high enough to ensure that the battery has been somewhat recharged, while not to high as to sacrifice load availability by allowing the loads to be disconnected too long. If the LRV set point is selected too low, the load may be reconnected before the battery has been charged, possibly cycling the load on and off, keeping the battery at low state of charge and shortening it's lifetime. As in the selection of the other controller set points, the designer must consider the charge rates for the loads and array and how these rates affect battery voltage at different states of charge.

**2.2.7 Low Voltage Disconnect Hysteresis (LVDH):** The voltage span or difference between the LVD set point and the voltage at which the load is reconnected to the battery. If the LVDH is too small, the load may cycle on and off rapidly at low battery state-of-charge (SOC), possibly damaging the load and/or controller. If the LVDH is too large, the load may remain off for extended periods until the array fully recharges the battery. With a large LVDH, battery health may be improved due to reduced battery cycling, but with a reduction in load availability. The proper LVDH selection for a given system will depend on the battery chemistry and size, and PV and load currents.

## 2.3 EFFECT OF BATTERY INTERNAL RESISTANCE

**2.3.1 Battery Internal Resistance:** The internal resistance (IR) of a battery is defined as the opposition to the flow of current within the battery. There are two basic components that impact the internal resistance of a battery. They are (a) Electronic resistance and (b) Ionic resistance. The summation of those two is called a total effective resistance.

The internal resistance of a battery can be calculated from its open circuit voltage, voltage on-load, and the load resistance:

$$R_{int} = \left(\frac{V_{NL}}{V_{FL}} - 1\right) R_L$$

Where

$R_{int}$ = Internal resistance

$V_{NL}$= No Load Battery Voltage

$V_{FL}$= Full Load Battery Voltage; $R_L$= Load Resistance

**(A) The Electronic Resistance:** The Electronic Resistance encompasses the resistivity of the actual materials such as the metal cover and internal components; as well as how well this materials make contact with each other. The effect of this portion of the total effective resistance occurs very quickly and can be within first few milliseconds after a battery placed under load.

**(B) Ionic resistance:** Ionic resistance the resistance to the current follows within battery due to various electrochemical factors such as electrolyte conductivity, ion mobility, and electrode surface area. These polarization effect occur more slow then electronic resistance with the contribution to total effective resistance typically starting a few milliseconds or more after a battery is placed under load.

**2.3.2 Effect of IR and Charging or Discharging Current:** The VRH and LVDH are constant (Such as, VRH=1v and LVDH=1v) in the conventional charge controller which we buy from our local market. User cannot change these two factors. But when we connect the charge controller with solar system the VRH and LVDH can be changed by the internal resistance, charging or discharging current and the connecting wires resistance. As there is no probability to charge the battery at night, so the LVDH does not make serious problem. However, if the VRH is not sufficient then the switching MOSFET’s turn off and on so frequently and damaged. As user cannot change the VRH, so if this problem occurs it cannot be solved. For that, the charge controller is damaged within some days. Therefore, for a long-life of a solar system, charge controller need to have a feature that user can change VRH and LVD or Set-points. Our charge controller has such feature to solve this problem.

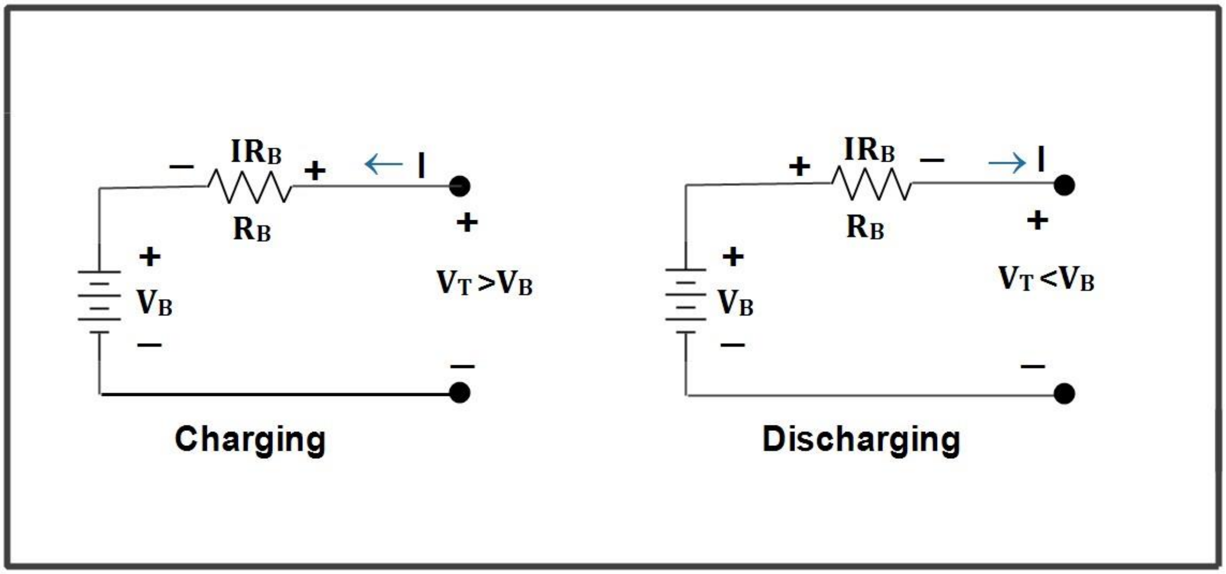


**Figure 2.3 Battery Terminal ($V_T$) voltage during Charging and Discharging**

Now we can say that the voltage drop across IR is approximately 14.4V - 13.4V = 1V. In conventional charge controller, the voltage drop across IR is considered same (1V) although the IR varies from battery to battery. The battery with grater Ampere-Hour capacity has low IR and vice versa. Normally the batteries are charged @ 10h, which means batteries are charged at one-tenth ($\frac{1}{10}$) current of its total Ampere-Hour capacity.

But when we charge battery by PV panel we do not maintain @ 10h charge time. Because in morning and evening the charging current is low and at noon charging current is high. So that if we maintain @ 10h charging time at a constant current then the solar power get loss. But the problem is if the battery charging does not off at noon (normally it does not happen) then battery charging do not stop at evening when charging current is low although the battery is fully charged. Because of low charging current the voltage drop across IR is low for that although the battery voltage 13.2V but charge controller sense terminal voltage bellow 14.4v and don't stop charging and battery get over charged.

We can give an example to clarify the fact. Let we consider a battery with 100Ampere-Hour capacity. Normally we charge the battery @10h by 10A current. If internal drop is 1.2V then the value of IR=1.2V÷10A = 0.12 Ω ≈0.12 Ω. Now if the charging current is 10A then when the battery voltage is 13.2v the terminal voltage is 14.4v (as shown in Fig: 2.3) and charge controller stop charging battery. That means the battery do not get voltage more than 13.2V forever although battery does not fully charged. Now if we charge the battery by solar panel then we consider highest current (let 8A) at noon, that time voltage drop across IR is 8A×0.12Ω=.96V and terminal voltage 14.16v so that charge controller do not stop charge battery (as VR 14.4V). After noon, the charging current starts to decrease and voltage drop across IR also decreased. Consider a time when charging current is 5A, then voltage drop across IR is 5A×0.12Ω=0.6V and terminal voltage is 13.8V, charging do not stop by charge controller (as VR 14.4V) although the battery fully charged at 13.2V. By this way batters get overcharged and reduce the lifetime.

So that to charge the battery by solar panel we need a charge controller that is capable to sense the current and can change VR according to the current to prevent overcharged the battery.

Another problem is constant LVD. All conventional charge controllers have fixed 10.8V as a LVD. But we know that the depth-of-discharge (DoD) vary from battery to battery. So that if we buy a charge controller from local market and set it with solar system, then we cannot change DoD. If we cannot change DoD according to the corresponding battery then it reduces the lifetime off the battery. So that we need a special charge controller with features that user can change DoD.

In my thesis, I try to solve all problem of conventional charge controller. This charge controller can sense charging current and discharging current, it can change IR and DoD according to the battery which is connected with it. For this purpose we will use hall current sensor.

## 2.4 HALL CURRENT SENSOR

### 2.4.1 Introduction:

Sensing and controlling current flow is a fundamental requirement in a wide variety of applications including, over-current protection circuits, battery chargers, switching mode power supplies, digital watt meters, programmable current sources, etc. One of the simplest techniques of sensing current is to place a small value resistance (also known as Shunt resistor) in between the load and the ground and measure the voltage drop across it, which in fact, is proportional to the current flowing through it. Whereas this technique is easy and straightforward to implement, it may not be very precise because the value of the shunt resistor slightly varies with its temperature, which in fact is not constant because of the Joule heating. Besides, this simple technique does not provide isolation between the load and current sensing unit, which is desirable in applications involving high voltage loads. Today, we will talk about Allegro ACS712 device which provides an economical and precise way of sensing AC and DC currents based on Hall-effect.

### 2.4.2Theory:

The current sensing technique based on a shunt resistor is described in How to measure dc current with a microcontroller? and implemented in the Multi-functional power supply project. The major disadvantages of this technique are

- load is lifted from the direct ground connection
- non-linearity in the response due to Joule heating that drifts the resistance value
- lack of electrical isolation between the load and the sensing part

The Allergo ACS712 current sensor is based on the principle of Hall-effect, which was discovered by Dr. Edwin Hall in 1879. According to this principle, when a current carrying conductor is placed into a magnetic field, a voltage is generated across its edges perpendicular to the directions of both the current and the magnetic field. It is illustrated in the figure shown below. A thin sheet of semiconductor material (called Hall element) is carrying a current (I) and is placed into a magnetic field (B) which is perpendicular to the direction of current flow. Due to the presence of Lorentz force, the distribution of current is no more uniform across the Hall element and therefore a potential difference is created across its edges perpendicular to the directions of both the current and the field. This voltage is known Hall voltage and its typical value is in the order of few micro-volts. The Hall voltage is directly proportional to the magnitudes of I and B. So if one of them (I and B) is known, then the observed Hall voltage can be used to estimate the other.

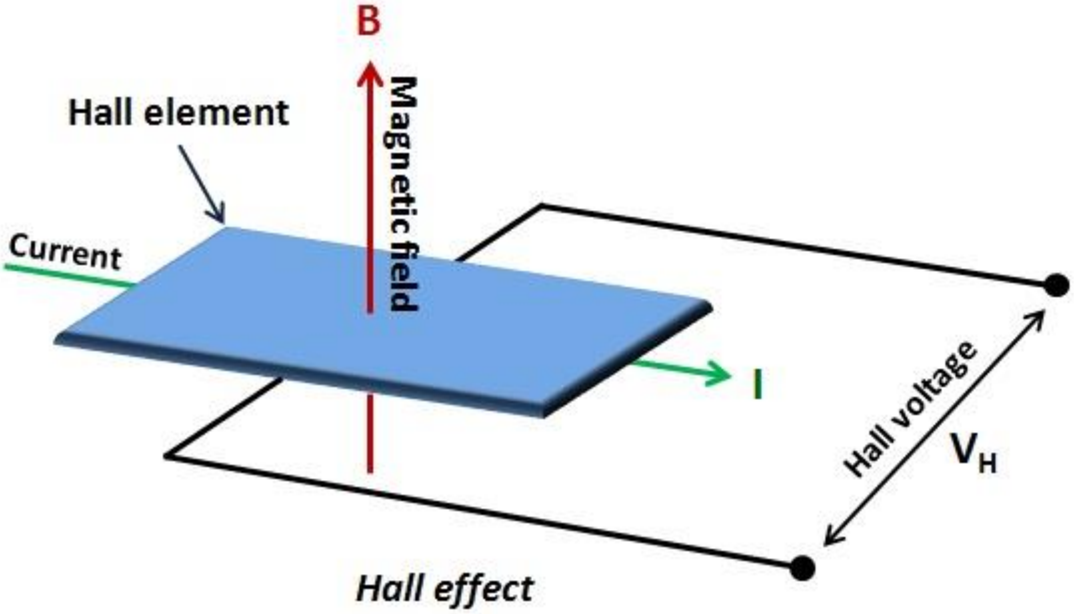
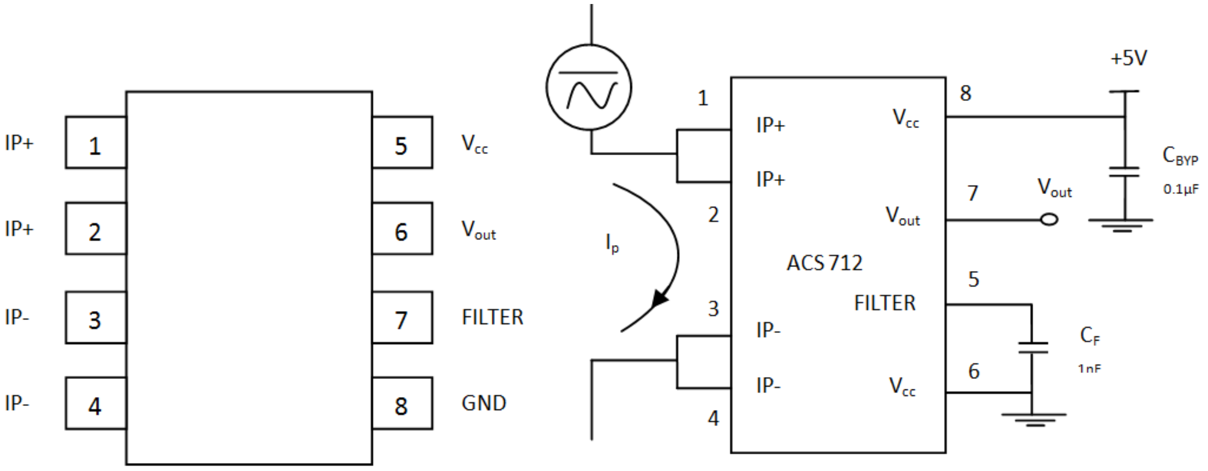


**Figure 2.4** Principle of Hall-effect

The ACS712 device is provided in a small, surface mount SOIC8 package. It consists of a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. When current is applied through the copper conductor, a magnetic field is generated which is sensed by the built-in Hall element. The strength of the magnetic field is proportional to the magnitude of the current through the conduction path, providing a linear relationship between the output Hall voltage and input conduction current. The on-chip signal conditioner and filter circuit stabilizes and enhances the induced Hall voltage to an appropriate level so that it could be measured through an ADC channel of a microcontroller. The pin diagram of ACS712 device and its typical application circuit is shown below. Pins 1, 2 and 3, 4 form the copper conduction path which is used for current sensing. The internal resistance of this path is around 1.2 mohm, thus providing low power loss. As the terminals of this conduction path are electrically isolated from the sensor leads (pins 5 through 8), the ACS712 device eliminates the risk of damaging the current monitoring circuit due to the high voltage on the conduction side. The electrical isolation between the conduction current and the sensor circuit also minimizes the safety concerns while dealing with high voltage systems.



Pin-out Diagram

Typical Application

**Figure 2.5** Pin diagram and a typical application circuit of ACS712

In low-frequency applications, it is often desirable to add a simple RC filter circuit at the output of the device to improve the signal-to-noise ratio. The ACS712 contains an internal resistor ($R_F$) connected between the output of the on-chip signal amplifier and the input of the output buffer stage (shown below). The other end of the resistor is externally accessible through pin 6 (Filter). With this architecture, users can implement a simple RC filter through the addition of an external capacitor ($C_F$) between the Filter pin and ground. It should be noted that the use of external capacitor increases the rise time of the sensor output, and therefore, sets the bandwidth of the input signal. The maximum bandwidth of the input signal is 80 KHz at zero external filter capacitor. The bandwidth decreases with increasing $C_F$. The datasheet of ACS712 recommends using 1 nF for $C_F$ to reduce noise under nominal conditions.

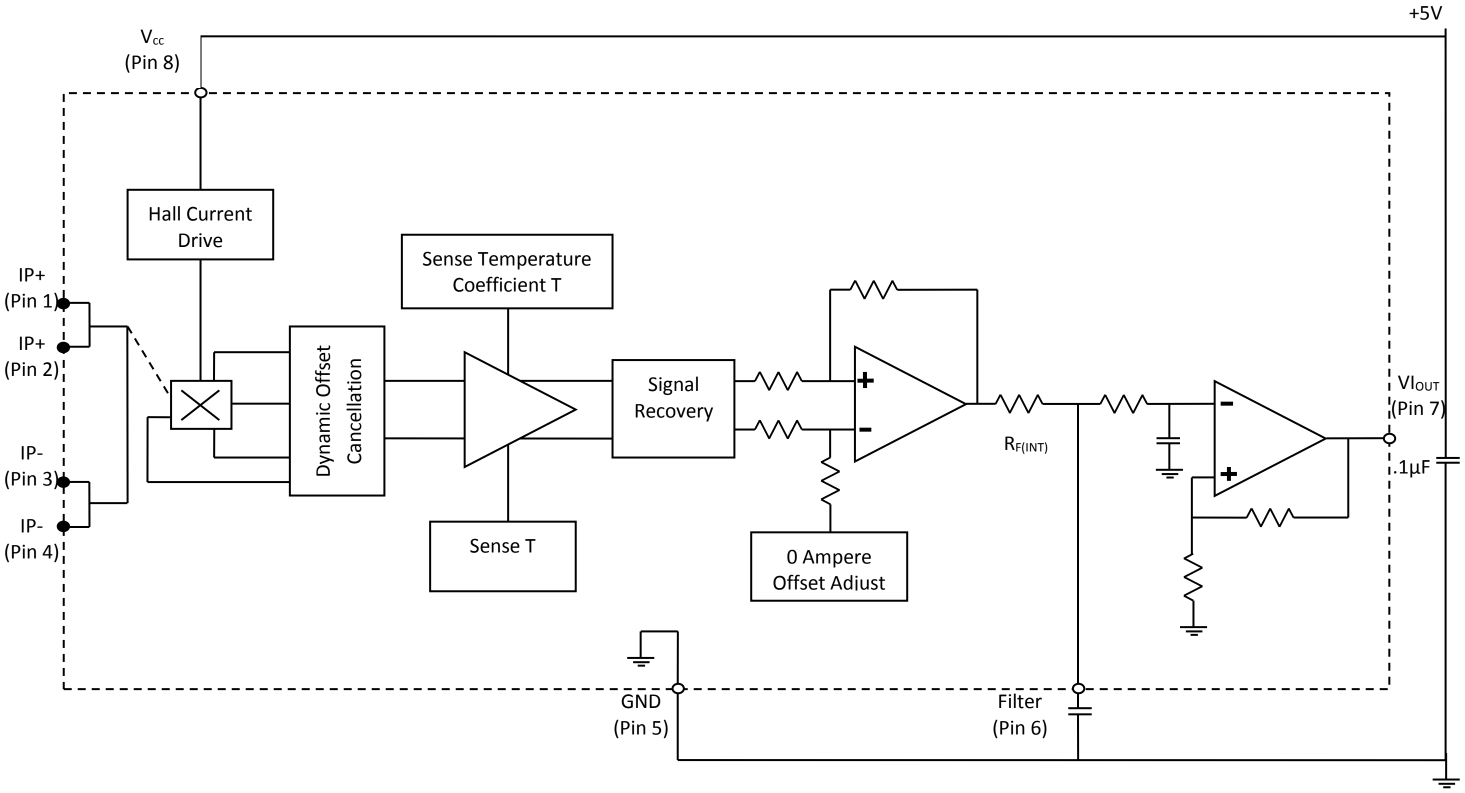


**Figure 2.6** Functional block diagram of ACS712

### 2.4.3 Sensitivity and output of ACS712:

The output of the device has positive slope when an increasing current flows through the copper conduction path (from pins 1 and 2, to pins 3 and 4). The ACS712 device comes in three variants, providing current range of±5A (ACS712-05B), ±20A (ACS712-20B), and ±30A (ACS712-30A). The ACS712-05B can measure current up to ±5A and provides output sensitivity of 185mV/A (at +5V power supply), which means for every 1A increase in the current through the conduction terminals in positive direction, the output voltage also rises by 185 mV. The sensitivities of 20A and 30A versions are 100 mV/A and 66 mV/A, respectively. At zero current, the output voltage is half of the supply voltage (Vcc/2). It should be noted that the ACS712 provides ratio metric output, which means the zero current output and the device sensitivity are both proportional to the supply voltage, $V_{CC}$. This feature is particularly useful when using the ACS712 with an analog-to-digital converter. The precision of any A/D conversion depends upon the stability of the reference voltage used in the ADC operation. In most microcontroller circuits, the reference voltage for A/D conversion is the supply voltage itself. So, if the supply voltage is not stable, the ADC measurements may not be precise and accurate. However, if the reference voltage of ADC is same as the supply voltage of ACS712, then the ratio metric output of ACS712 will compensate for any error in the A/D conversion due to the fluctuation in the reference voltage.

Let us explain this with an example. Suppose, an ADC chip uses $V_{cc}$ = 5.0V as a reference for A/D conversion and the same supply voltage powers an ACS712 sensor chip. The analog output of the ACS712 will be digitized through the ADC chip. When there is zero current through the current sensor, the output is $V_{cc}/2$ = 2.5V. If the ADC chip is 10-bit (0-1023), it will convert the analog output from the ACS712 sensor into digital value of 512 counts. Now, if the supply voltage drifts and becomes $V_{cc}$ = 4.5V, then, due to the ratio metric nature, the new output of the ACS712 sensor will be 4.5/2 = 2.25V, which will still be digitized to 512 by the ADC as its reference voltage is also lowered to 4.5V. Similarly, the sensitivity value will also be lowered by a factor of 4.5/5 = 0.9, which means if the ACS712-05B is powered with a 4.5V supply, the sensitivity is reduced to 166.5 mV/A, instead of 185mV, A. This concludes that any fluctuation in the reference voltage will not be a source of error in the analog-to-digital conversion of the ACS712 output signals.

The curve below shows the nominal sensitivity and transfer characteristics of the ACS712-05B sensor powered with a 5.0V supply. The drift in the output is minimum for a varying operating temperature, which is attributed to an innovative chopper stabilization technique implemented on the chip.

## 2.5 MICROCONTROLLER

Micro suggests that the device is small, and controller means the device might be used to control objects, processes, or events. A microcontroller (sometimes-abbreviated µC, uC or MCU) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal or other general-purpose applications. That is, a MCU combines onto a same microchip:

1. The CPU core
2. Memory (both RAM and ROM)
3. Some parallel digital I/O and others

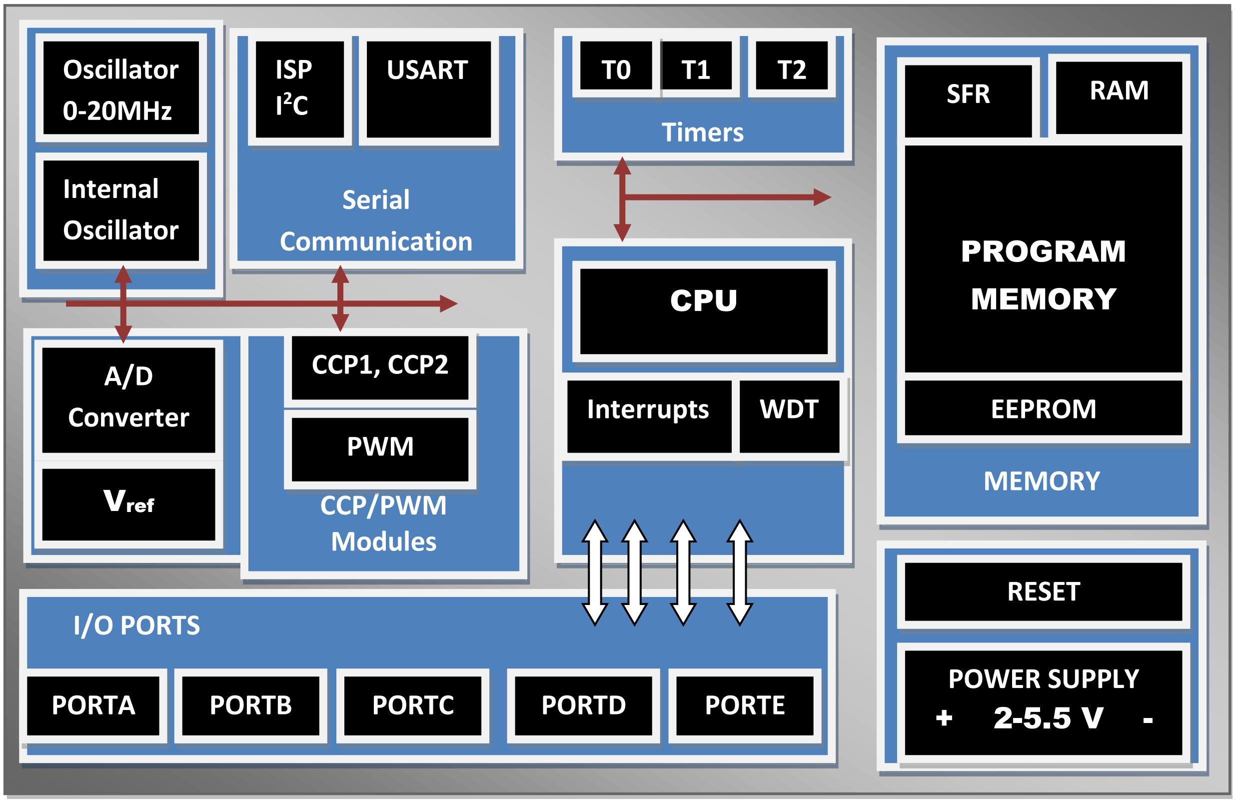


**Figure 2.7** Microcontroller's fundamental components

(All components are on a single chip)

Other components of a microcontroller are given bellow:

1. A timer module to allow the microcontroller to perform tasks for certain time period.
2. A serial I/O port to allow the data to flow between microcontroller and other devices that support serial interfaces such as PC or others microcontroller.
3. An ADC to allow the microcontroller to accept analogue input data for processing.

### 2.5.1 Importance of Microcontroller:

- Low cost, small packaging
- Low power consumption
- Programmable, re-programmable
- Lots of I/O capabilities
- Easy integration with circuits
- For applications in which cost, power and space are critical
- Single-purpose

### 2.5.2 Microcontroller versus Microprocessor:

Microcontroller is an embedded controller for the purpose of dealing with specific tasks, where as microprocessor is not an embedded controller and it can deal with various tasks.

Comparison of Microcontroller and Microprocessor are given bellow.

**Microcontroller:**

1. Microcontroller having inbuilt RAM or ROM and inbuilt timer.
2. Input and output ports are available.
3. Inbuilt serial port.
4. Separate memory to store program and data.
5. Does a specific task.
6. Boolean operation directly possible.
7. It takes few instructions to read and write data from external memory.
8. Generally lower core clock frequency.

9. Microcontroller are less costly then microprocessor.
10. Microcontroller uses less power, generally built using a technology known as Complementary Metal Oxide Semiconductor (CMOS). This technology is a competent fabrication system that uses less power and is more immune to power spikes than other techniques.

**Microprocessor:**

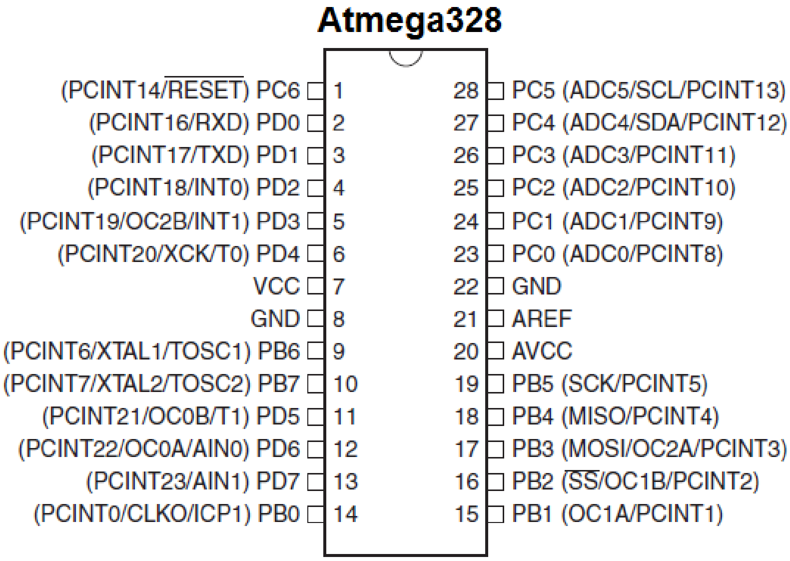
1. Do not have inbuilt RAM or ROM and timer.
2. Input and output ports are not available, requires extra device like 8155.
3. Do not have inbuilt serial port, requires 8250 device.
4. Program and data are stored in same memory.
5. Does multiple tasks.
6. Boolean operation is not possible directly.
7. It takes many instructions to read and write data from external memory.
8. Generally higher core clock frequency.
9. Microprocessor is more costly then microcontroller.
10. Microprocessor uses more power than microcontroller.

### 2.5.3 Architecture of Atmega328:

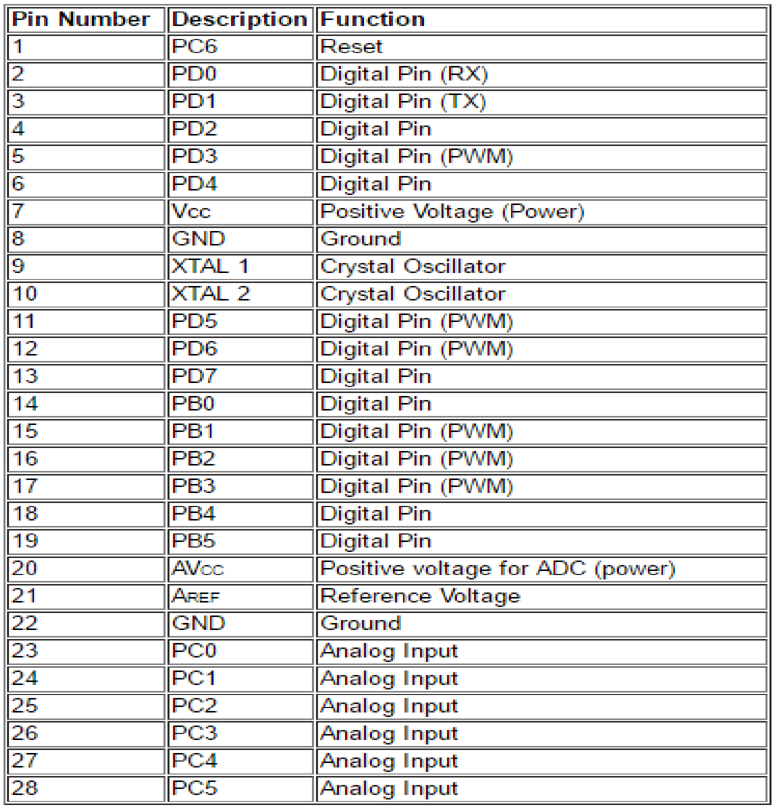
The Atmega328 is a very popular microcontroller chip produced by Atmel. It is an 8-bit microcontroller that has 32K of flash memory, 1K of EEPROM, and 2K of internal SRAM.The Atmega328 is one of the microcontroller chips that are used with the popular Arduino Duemilanove boards. The Arduino Duemilanove board comes with either 1 of 2 microcontroller chips, the Atmega168 or the Atmega328. Of these 2, the Atmega328 is the upgraded, more advanced chip. Unlike the Atmega168 which has 16K of flash program memory and 512 bytes of internal SRAM, the Atmega328 has 32K of flash program memory and 2K of Internal SRAM.

The Atmega328 has 28 pins.

It has 14 digital I/O pins, of which 6 can be used as PWM outputs and 6 analog input pins. These I/O pins account for 20 of the pins.



The table below gives a description for each of the pins, along with their function.



| Pin Number | Description | Function |
|---|---|---|
| 1 | PC6 | Reset |
| 2 | PD0 | Digital Pin (RX) |
| 3 | PD1 | Digital Pin (TX) |
| 4 | PD2 | Digital Pin |
| 5 | PD3 | Digital Pin (PWM) |
| 6 | PD4 | Digital Pin |
| 7 | Vcc | Positive Voltage (Power) |
| 8 | GND | Ground |
| 9 | XTAL 1 | Crystal Oscillator |
| 10 | XTAL 2 | Crystal Oscillator |
| 11 | PD5 | Digital Pin (PWM) |
| 12 | PD6 | Digital Pin (PWM) |
| 13 | PD7 | Digital Pin |
| 14 | PB0 | Digital Pin |
| 15 | PB1 | Digital Pin (PWM) |
| 16 | PB2 | Digital Pin (PWM) |
| 17 | PB3 | Digital Pin (PWM) |
| 18 | PB4 | Digital Pin |
| 19 | PB5 | Digital Pin |
| 20 | AVcc | Positive voltage for ADC (power) |
| 21 | AREF | Reference Voltage |
| 22 | GND | Ground |
| 23 | PC0 | Analog Input |
| 24 | PC1 | Analog Input |
| 25 | PC2 | Analog Input |
| 26 | PC3 | Analog Input |
| 27 | PC4 | Analog Input |
| 28 | PC5 | Analog Input |

## 2.6 BATTERY

Small PV power systems require some means of storing the electrical energy collected by solar panels. The usual choice for this job is the lead-acid battery. While far from perfect, lead-acid batteries offer good performance over a wide temperature range when compared to other battery types. They are also relatively inexpensive and widely available. Again, no one type of battery is ideal for PV system applications. The designer must consider the advantages and disadvantages of different batteries with respect to the requirements of a particular application. Some of the considerations include lifetime, deep cycle performance, tolerance to high temperatures and overcharge, maintenance and many others. Table 3 summarizes some of the key characteristics of the different battery types discussed in the preceding section.

| **Battery Type** | **Advantages** | **Disadvantages** |
|---|---|---|
| **Flooded Lead-Acid** | | |
| Lead Antimony | Low cost, wide availability, good deep cycle, and high temperature performance, can replenish electrolyte | High water loss and maintenance |
| Lead-Calcium Open Vent | Low cost, wide availability, low water loss, can replenish electrolyte | Poor deep cycle performance, intolerant to high temperatures and overcharge |
| Lead-Calcium Sealed Vent | Low cost, wide availability, low water cost | Poor deep cycle performance, intolerant to high temperatures and over charge, can not replenish electrolyte |
| Lead Calcium/Antimony Hybrid | Medium cost, low water loss | Limited availability, potential for stratification |
| **Capacitive Electrolyte Lead-Acid** | | |
| Gelled | Medium loss, little or no maintenance, less susceptible to freezing, install in any orientation | Fair deep cycle performance, intolerant to over charge and high temperature, limited availability |
| Absorbed Glass Mat | Medium loss, little or no maintenance, less susceptible to freezing, install in any orientation | Fair deep cycle performance, intolerant to over charge and high temperature, limited availability |

| | | |
|---|---|---|
| **Nickel-Cadmium** | | |
| Sealed Sintered-Plate | Wide availability, excellent low and high temperature performance | Only available in low capacities, high cost, suffer from ‘memory effect’ |
| Flooded Pocket-Plate | Excellent deep cycle and low and high temperature performance, tolerance to over charge | Limited availability, high cost, water addition required |

**Table 3** Battery Characteristics

### 2.6.1 Active Material:

The active materials in a battery are the raw composition materials that form the positive and negative plates, and are reactants in the electrochemical cell. The amount of active material in a battery is proportional to the capacity a battery can deliver. In lead-acid batteries, the active materials are lead dioxide ($PbO_2$) in the positive plates and metallic sponge lead (Pb) in the negative plates, which react with a sulfuric acid ($H_2SO_4$) solution during battery operation.

# CHAPTER 3

# DESIGNS AND DEVELOPMENT OF THE SYSTEM

## 3.1 HARDWARE DESIGN

A charge controller is an electronic circuit. The whole system can be divided into the following subsections.

1. Voltage sensing circuit
2. Current sensing circuit
3. Voltage regulator section
4. Control section
5. Switching section

The complete working circuit diagram is given bellow and described in the following subsections.:

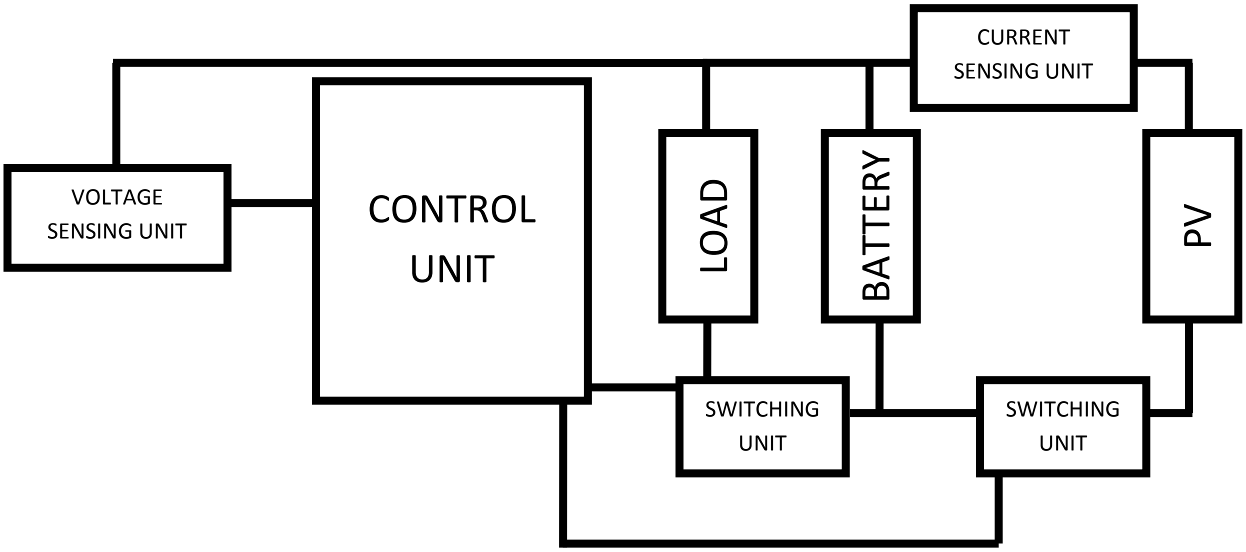


**Figure 3.1** Block diagram of working circuit

### 3.1.1 Voltage sensing circuit

To sense the battery voltage a voltage divider circuit is used. We have designed this circuit to sense the maximum battery voltage 16 Volts. The output voltage V1 (range 0-5 V) of this circuit is fed to the microcontroller ADC1 or pin A0. This input voltage is sense by microcontroller and sense the Set-points. The voltage divider circuit is shown below:

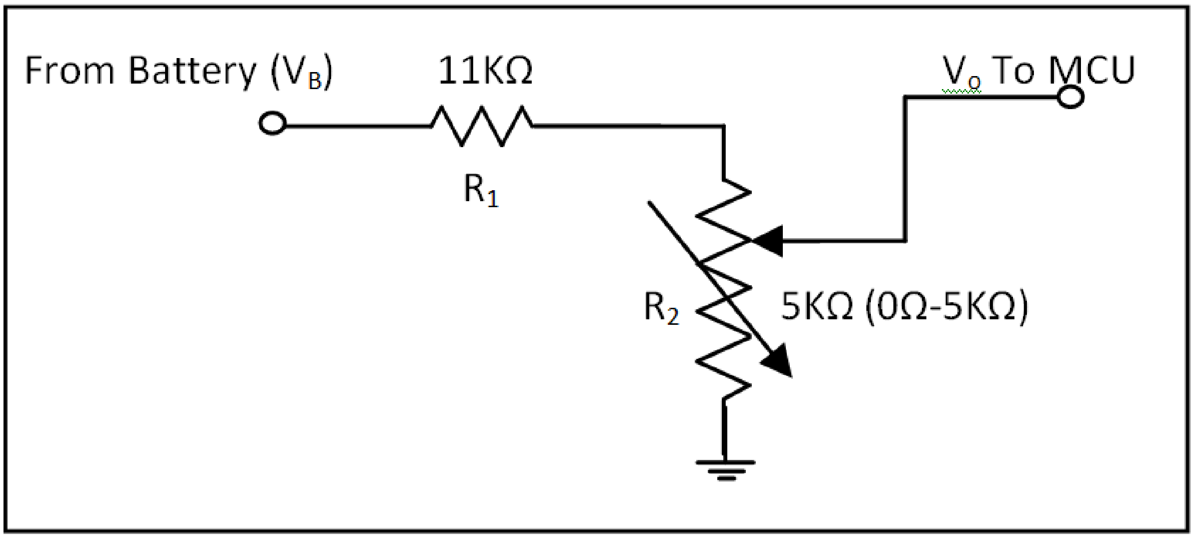


**Figure 3.2** Voltage sensing circuit

According to the voltage divider rule the output voltage ($V_o$) is:

$$V_o = \frac{R2}{R1} \times V_B$$

Where, $V_B$= Battery voltage

### 3.1.2 Current sensing section

According to the section 2.3.2, we know that the Set-points are change with charging or discharging current. Therefore, for an intelligent charge controller we need to sense the current and in put the result to the control unit. The control unit takes an input data and makes decision to change the Set-points. The current sensing section is shown in fig 3.1. The current is sense by a hall sensor which is discussed in detail in section 2.4.

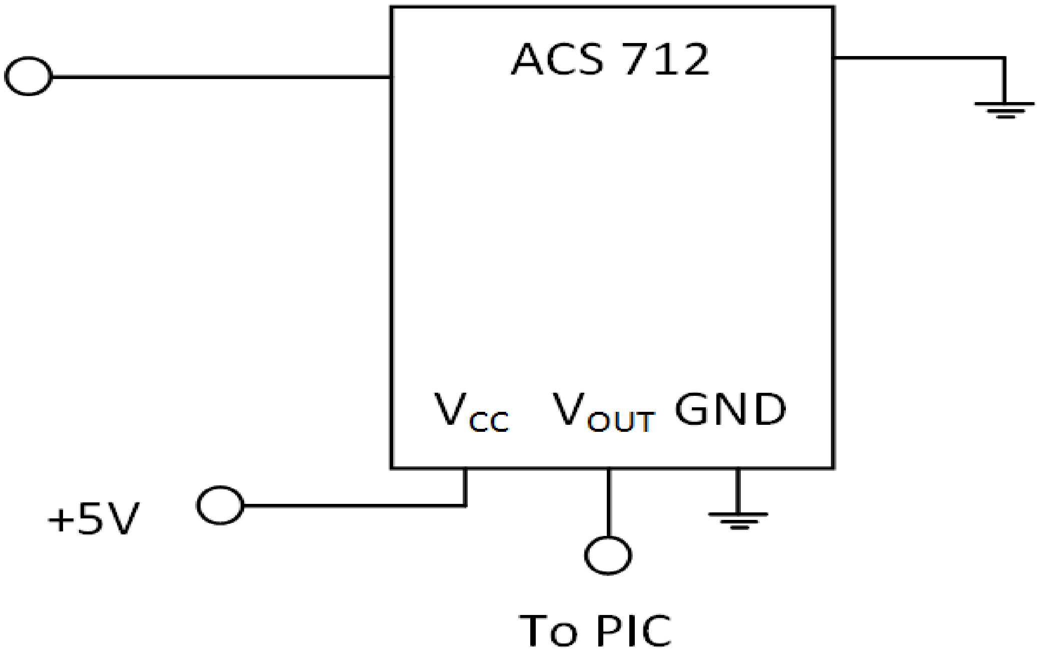


**Figure 3.3** Hall current Sensor

### 3.1.3 Voltage regulator section

In this charge controller, we have used voltage regulation & for voltage regulation, we have used LM7805 converts 12V to 5V. The microcontroller & drive the Atmega328 is operated by this 5V. Therefore, in summary we say that battery voltage is used to drive the microcontroller. This section is not shown in fig 3.1 because it is a separated section to power the whole circuit.

**LM7805:** LM7805 is a linear voltage regulator. These linear voltage regulators are monolithic integrated circuits designed as fixed-voltage regulators for a wide variety of applications including local, on-card regulation. These regulators employ internal current limiting, thermal shutdown, and safe-area compensation. With adequate heat sinking they can deliver output currents in excess of 1.0 A. Although designed primarily as a fixed voltage regulator, these devices can be used with external components to obtain adjustable voltages and currents. Some feature of this IC is given bellow:

- Output voltage 5 V
- Output Current in Excess of 1.0 A
- No External Components Required
- Internal Thermal Overload Protection
- Internal Short Circuit Current Limiting
- Output Transistor Safe-Area Compensation
- Output Voltage Offered in 1.5%, 2% and 4% Tolerance
- Pb-Free Packages are Available

The pin configuration and photography of L7805 is given bellow:

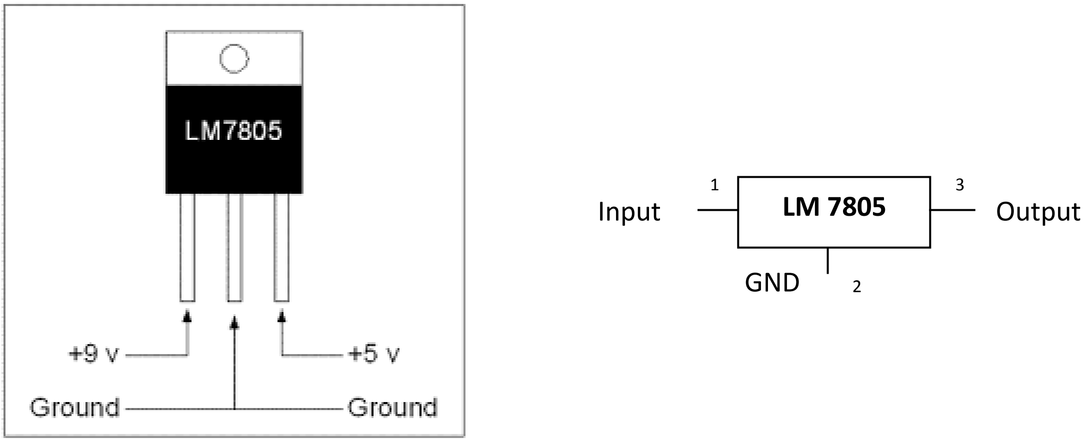


**Figure 3.4** The pin configuration and photography of LM 7805

### 3.1.4 Switching Section

The switching function of our charge controller is done by two power transistor (IRF540N). The switching sections block is shown in Fig 3.1. Transistors are work as a switch and this switching is control by the control unit. When the gate of the transistor (IRF540N) is high (5V) then they work like a short circuited switch. When gate voltage is low the work like an open circuit switch [13].

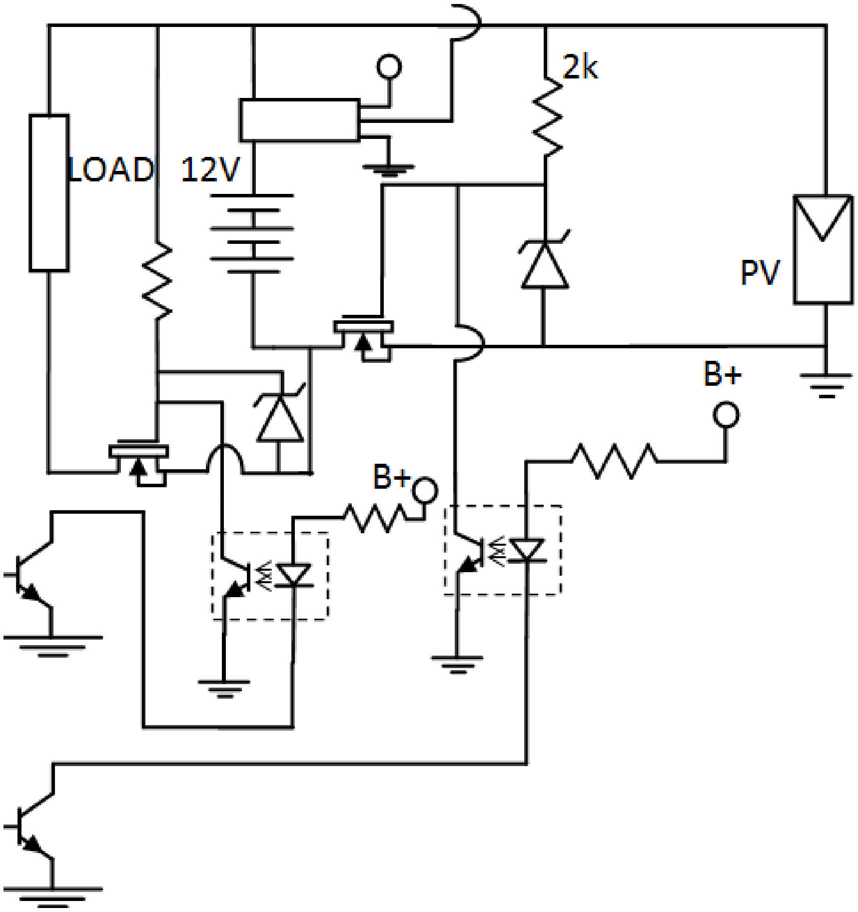


**Figure 3.5** Switching Unit

#### 3.1.4.1 Switching unit between PV and Battery

Here we use MOSFET IRF540N for switching function between battery and PV system. For switching we also use opto-coupler and transistor. When the output of control unit will zero then the transistor will not conduct and also the opto-coupler and the MOSFET gate voltage will high and it switched on so battery will charging. On the other hand, when the output of control unit will nonzero (high) then the transistor will conduct and also the opto-coupler and the MOSFET gate voltage will low and it switched off so battery will stop charging.

### 3.1.4.2 Switching unit between Load and Battery

Here we use MOSFET IRF540N for switching function between battery and Load. For switching we also use opto-coupler and transistor. When the output of control unit will zero then the transistor will not conduct and also the opto-coupler and the MOSFET gate voltage will high and it switched on so battery will discharging. On the other hand, when the output of control unit will nonzero (high) then the transistor will conduct and also the opto-coupler and the MOSFET gate voltage will low and it switched off so load will disconnected.

### 3.1.4.3 Opto-coupler

In electronics, an opto-isolator, also called an optocoupler, photocoupler, or optical isolator, is a component that transfers electrical signals between two isolated circuits by using light. Opto-isolators prevent high voltages from affecting the system receiving the signal. Commercially available opto-isolators withstand input-to-output voltages up to 10 kV and voltage transients with speeds up to 10 kV/μs.

A common type of opto-isolator consists of an LED and a phototransistor in the same opaque package. Other types of source-sensor combinations include LED-photodiode, LED-LASCR, and lamp-photoresistor pairs. Usually opto-isolators transfer digital (on-off) signals, but some techniques allow them to be used with analog signals.

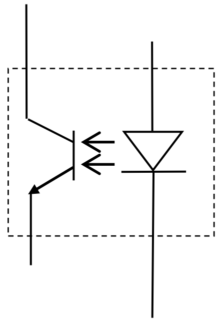


**Figure 3.6** Opto-coupler internal circuits

An opto-isolator contains a source (emitter) of light, almost always a near infrared light-emitting diode (LED), that converts electrical input signal into light, a closed optical channel (also called dialectical channel), and a photosensor, which detects incoming light and either generates electric energy directly, or modulates electric current flowing from an external power supply. The sensor can be a photoresistor, a photodiode, a phototransistor, a silicon-controlled rectifier (SCR) or a triac. Because LEDs can sense light in addition to emitting it, construction of symmetrical, bidirectional opto-isolators is possible. An opto-coupled solid state relay contains a photodiode opto-isolator which drives a power switch, usually a complementary pair of MOSFETs. A slotted optical switch contains a source of light and a sensor, but its optical channel is open, allowing modulation of light by external objects obstructing the path of light or reflecting light into the sensor.

### 3.1.5 Control Section

The purpose of this section is to control the whole hardware. So a microcontroller (Atmega328)is used to control the system. 5V is fed to PORTA (A0) of the microcontroller. Output of the voltage sensing circuit is fed to the microcontroller .Thus PORTA is configured as input port. Two pins (Pin8 and Pin9 ) of PORTC are configured as output. Pin8 and Pin9 are used to control current flow between PV to battery and Battery to load of charge controller respectively. Two pins of PORTB are used for LED indicator. Where normal condition refers to both charging & discharging of battery simultaneously. The charging and discharging condition is expressed by LEDs. The successful control is achieved by loading a program to the program memory of the microcontroller.

### Calculation of different battery voltage and current level:

We calculate the maximum voltage of our charge controller 16V=5V in ADC1 input (for 10A).

| Battery voltage (V) | Set-points | ADC1 input(V) |
|---|---|---|
| 16 | Maximum Voltage | 5 |
| 14.4 | Voltage regulation(VR) | 4.5 |
| 13 | Array reconnect voltage (ARV) | 4.0625 |
| 12.5 | Load reconnect voltage (LRV) | 3.90625 |
| 10.8 | Low voltage load disconnect voltage(LVD) | 3.375 |

**Table 4** Conversion of voltage for battery voltage sensing

The Hall current sensor output is given below (Using, $V_{out} = \frac{V_{in}}{2} + 0.05865I$)

| Charging or discharging currents (A) | Current sensing voltage at ADC2 (V) |
|---|---|
| 30 | 4.26 |
| 25 | 3.97 |
| 20 | 3.67 |
| 15 | 3.38 |
| 10 | 3.09 |
| 5 | 2.79 |
| 0 | 2.5 |

**Table 5** Conversion of voltage for battery current sensing

Now if we consider a system, which has a battery with IR = 0.10Ω then the Set-points variations is depend only on currents.

Without internal resistance the set points are given below:

| Set points | Battery Voltage(With IR) | Battery Voltage(Without IR) |
|---|---|---|
| Voltage regulation(VR) | 14.4 | 13.4 |
| Array reconnect voltage (ARV) | 13 | 12 |
| Load reconnect voltage (LRV) | 12.5 | 13.5 |
| Low voltage load disconnect voltage(LVD) | 10.8 | 11.8 |

**Table 6** Value of different set points with and without IR

Say that for 20A current the voltage drop across IR is 2V. Now the new level of Set-points is given bellow:

| Set-points | Set-points voltage(V) | Converted voltage at ADC1(V) | Voltage across IR (V) | New level of Set-points(V) | New level of Converted voltage at ADC1(V) |
|---|---|---|---|---|---|
| **During Charging ($V_T>V_B$)** | | | | | |
| VR | 13.4 | 4.187 | 2 | 15.4 | 4.812 |
| ARV | 12 | 3.75 | 2 | 14 | 4.375 |
| **During Discharging($V_T<V_B$)** | | | | | |
| LRV | 13.5 | 4.218 | 2 | 15.5 | 4.84 |
| LVD | 11.8 | 3.687 | 2 | 13.8 | 4.31 |

**Table 7** Variation of Set-points for **20A** currents

## 3.2:THE FLOWCHART FOR THE PROGRAM

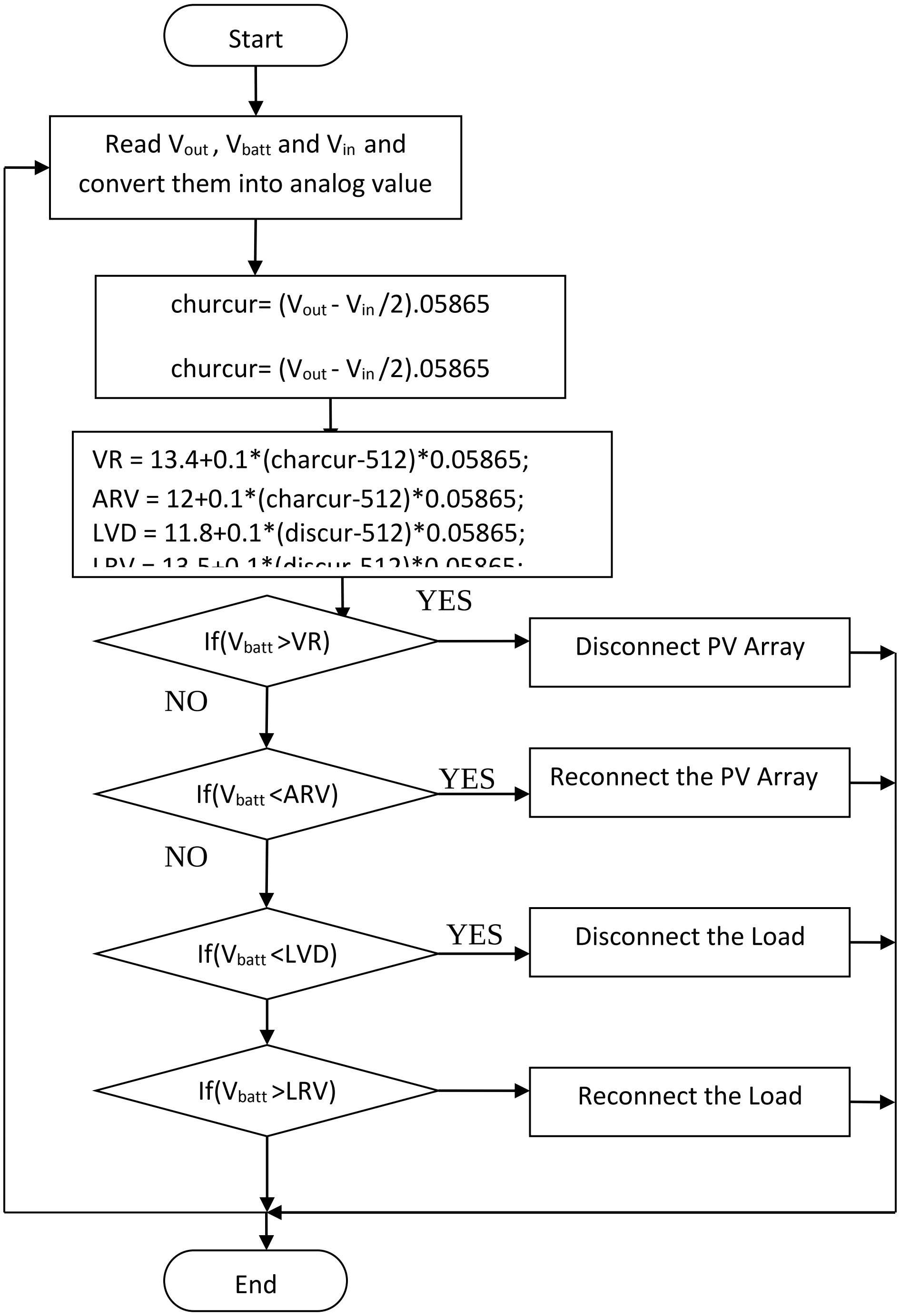


**Figure 3.7** Flowchart of Program

## 3.3 SCHEMATIC DIAGRAM OF THE SYSTEM

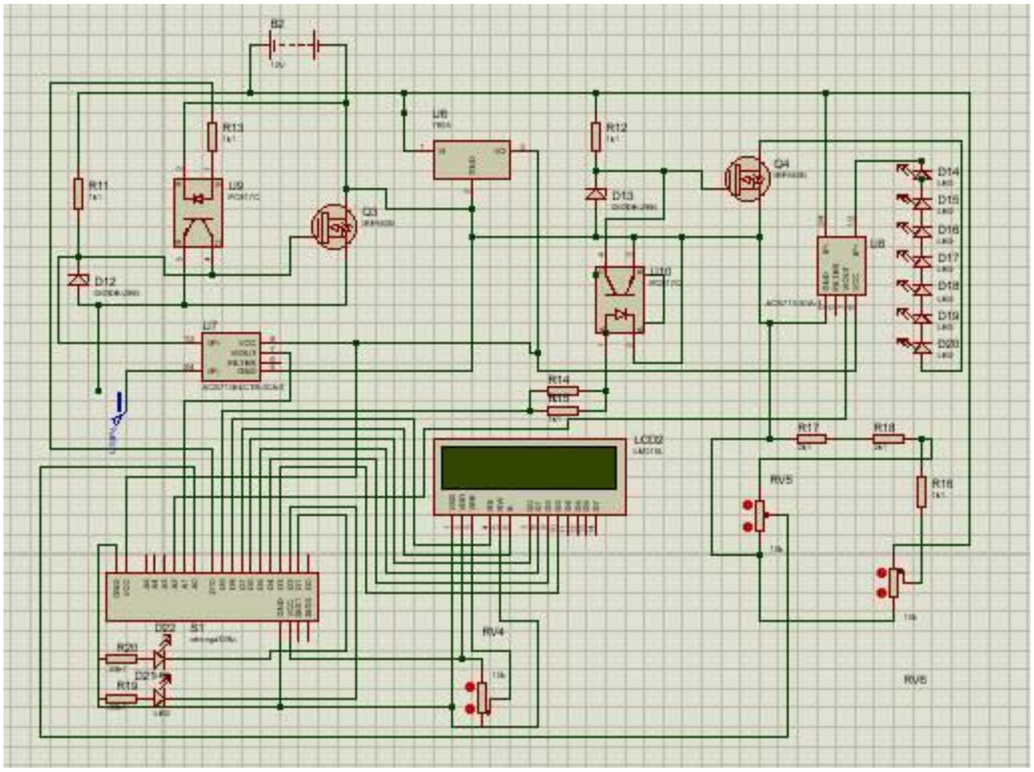


**Figure 3 .8** Complete working circuit

## 3.4 SOFTWARE DESIGN

A microcontroller is a small computer on a small integrated circuit, which consist of a CPU (Central Processing Unit), RAM (Random Access Memory), EPROM/PROM/ROM (Erasable Programmable Read Only Memory) Parallel and Serial I/O (Input /Output). All of its components are placed on a single board. Microcontrollers are designed for embedded applications. A microcontroller internally consists of all features required for computing system and functions as a computer without adding any external digital parts in it. Most of the pins in the microcontroller chip can be made programmable by the user. It is capable of handling Boolean functions and it has many bit handling instructions that can be easily understood by programmer. It is easy to design, small in size and low cost. Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, toys and other embedded systems.

**Figure 3.9** ATmega328 Microcontroller

### 3.4.1 Programming Language:

Before we can start doing anything with the Arduino, we have to download and install the Arduino IDE (integrated development environment). Arduino IDE is referred as the Arduino Programmer. The Arduino Programmer is based on the Processing IDE and uses a variation of the C and C++ programming languages.

An Arduino program is called a sketch. All code in an Arduino sketch is processed from top to bottom. Adriano sketches are typically broken into five parts.

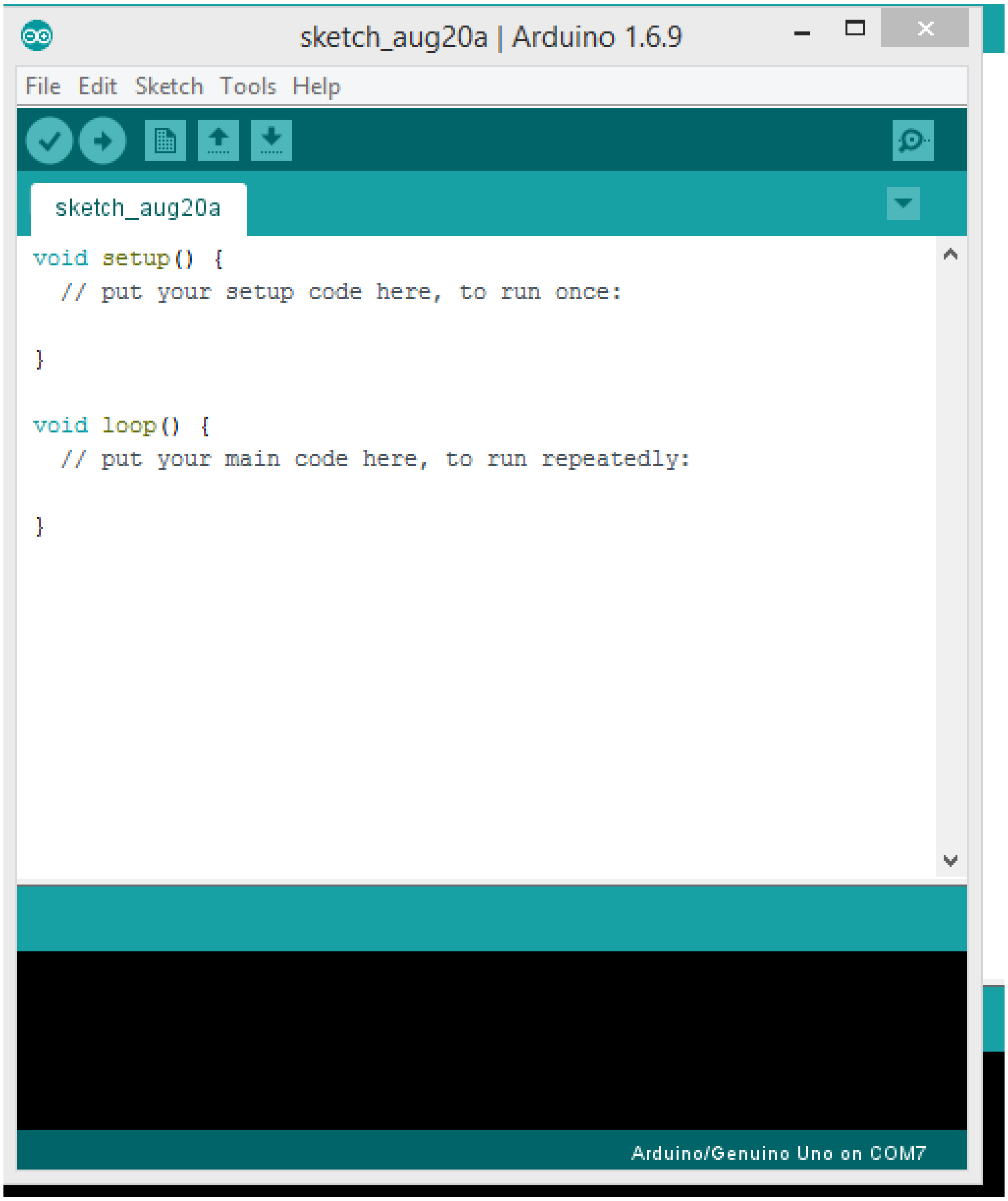
The sketch usually starts with a header that explains what the sketch is doing, and who wrote it. Next, it usually defines global variables. Often, this is where constant names are given to the different Adriano pins.

After the initial variables are set, the Adruino begins the setup routine. In the setup function, we set initial conditions of variables when necessary and run any preliminary code that we want to run once. This is where serial communication is initiated, which is required for running the serial monitor.

From the setup function, we go to the loop routine. This is the main routine of the sketch. This is not only where the main code goes, but it will be executed over and over, so long as the sketch continues to run.

Below the loop routine, there is often other function listed. These functions are user-defined and only activated when called in the setup and loop routine. When these functions are called, the Adriano processes all of the code in the function from top to bottom and then goes back to the next line in the sketch where it left off when the function was called. Functions are good because they allow us to run standard routines - over and over - without having to write the same lines of code over and over. We can simply call upon a function multiple times, and this will free up memory on the chip because the function routine is only written once. It also makes code easier to read.

All of that said, the only two parts of the sketch which are mandatory are the Setup and Loop routines. Code must be written in the Arduino Language, which is roughly based on C. Almost all statements written in the Arduino language must end with a semicolon (;). Conditionals (such as if statements and for loops) do not need a semicolon (;). Conditionals have their own rules and can be found under "Control Structures" on the Arduino Language page.



```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

### 3.4.2 About Arduino:

An Arduino is an open-source microcontroller development board. Arduino consists of both a physical programmable circuit board and a piece of software or IDE (Integrated Development Environment) that runs on the computer, used to write and upload computer code to the physical board.

Arduino can be used to read sensors and control things like motors and lights. This allows us to upload programs to this board which can then interact with things in the real world. With this, we can make devices can be made which respond and react to the world at large.

For instance, we can read a humidity sensor connected to a potted plant and turn on an automatic watering system if it gets too dry. Or, we can make a stand-alone chat server which is plugged into our internet router. Or, we can have it tweet every time our cat passes through a pet door. Or, we can have it start a pot of coffee when the alarm goes off in the morning.

Basically, if there is something that is in any way controlled by electricity, the Arduino can interface with it in some manner. And even if it is not controlled by electricity, we can probably still use things which are (like motors and electromagnets) to interface with it.

The possibilities of the Arduino are almost limitless. I've done my best to give a basic overview of the fundamental skills and knowledge that one need to get an Arduino up and running. If nothing more, this should function as a springboard into further experimentation and learning.

### 3.4.3 Why Arduino

There are many other microcontrollers and microcontroller platforms available for physical computing. Parallax Basic Stamp, Netmedia's BX-24, Phidgets, MIT's Handy board and many others offer similar functionality. All of these tools take the messy details of microcontroller programming and wrap it up in an easy-to-use package. Arduino also simplifies the process of working with microcontrollers, but it offers some advantage for teachers, students, and interested amateurs over other systems:

- Inexpensive: Arduino boards are relatively inexpensive compared to other microcontroller platforms. The least expensive version of the Arduino module can be assembled by hand, and even the pre-assembled Arduino modules cost less than BDT 800.
- Cross-platform: The Arduino software runs on Windows, Macintosh OSX, and Linux operating systems. Most microcontroller systems are limited to Windows.
- Simple, clear programming environment: The Arduino programming environment is easy-to-use for beginners, yet flexible enough for advanced users to take advantage of as

well. For teachers, it's conveniently based on the Processing programming environment, so students learning to program in that environment will be familiar with the look and feel of Arduino.

- Open source and extensible software: The Arduino software is published as open source tools, available for extension by experienced programmers. The language can be expanded through C++ libraries and people wanting to understand the technical details can make the leap from Arduino to the AVR C programming language on which it's based. Similarly, AVR-C code can be added directly into the Arduino programs if one wants to.
- Open source and extensible hardware: The Arduino is based on Atmel's ATMEGA8 and ATMEGA168 microcontrollers. The plans for the modules are published under a Creative Commons license, so experienced circuit designers can make their own version of the module, extending it and improving it. Even relatively inexperienced users can build the breadboard version of the module in order to understand how it works and save money.

# CHAPTER 4

# SIMULATION AND PRACTICAL RESULT

## 4.1INTRODUCTION

We will discuss about the simulation and practical system design and data collection.

The whole control system operates into four operational modes. Voltage Regulation (VR) Set-point, Array Reconnect Voltage (ARV) Set-point, Low Voltage Disconnect (LVD) and Load Reconnect Voltage (LRV) Set-point. Every mode is described in the "Theoretical Backgrounds" chapter (Chapter Three). In this chapter we have shown the simulation circuit diagram and simulated output. In addition to that, we have also shown practically implemented circuit diagram of each unit. Finally, we have shown the performance analysis of the entire control system and discussed results. For simulation of the circuits the Proteus software has been used.

## 4.2 SIMULATION PART

In this section, we have shown the simulated circuits and their output of each unit by using Proteus simulator.

### 4.2.1 Voltage Regulation (VR) Set-point:

In this mode whenever the battery voltage is increase over the voltage regulation set-point at some specific current then battery will disconnect from the PV system. In simulation the green Led is used to indicate the battery charging and fully charged condition. Here the green Led is switch off as the battery voltage is higher than VR set-point. That means the battery is fully charged. Up to this VR set-point the battery will charging.

### 4.2.2 Array Reconnect Voltage (ARV) Set-point:

In this mode whenever the battery voltage is decrease lower than Array Reconnect Voltage (ARV) at some specific current then battery will reconnect with the PV system. In simulation the green Led is used to indicate the battery charging and fully charged condition. Here the green Led is switch on as the battery voltage is lower than ARV set-point. That means the battery is start charging. Up to this VR set-point the battery will charging.

### 4.2.3 Low Voltage Disconnect (LVD):

In this mode whenever the battery voltage is decrease lower than Array Low Voltage Disconnect (LVD) at some specific current then Load will disconnect from the battery. In simulation a white Led is used to indicate the load connecting and disconnecting condition. Here the Led is switch off as the battery voltage is lower than LVD set-point. That means the Load is disconnecting from battery to protect the battery from over discharge

### 4.2.4 Load Reconnect Voltage (LRV) Set-point:

In this mode whenever the battery voltage is increase higher than Load Reconnect Voltage (LRV) at some specific current then Load will reconnect with the battery.

In simulation the Led is used to indicate the load connecting and disconnecting condition. Here the Led is switch on as the battery voltage is higher than LRV set-point. That means the Load is reconnecting with battery to supply current flow through load.

### 4.2.5 Result:

For 10A current:

| Battery Voltage | Controller indicator |
|---|---|
| 14.70 | Charging OFF<br>Load ON |
| 13.12 | Charging ON<br>Load OFF |
| 13.47 | Charging ON<br>Load ON |
| | |

**Table 11** Variation of Set-points for 10A currents (Simulation)

## 4.3 PROTOTYPE TESTING

After designing the software and the hardware architecture part, we implement the working circuit diagram on the breadboard/project board for testing purpose. Here input voltage generated by power supply and two voltage divider circuits that represent the voltage and current sensing voltage respectively and we see that microcontroller output state changes according to the application of input voltage with some practical error. In addition, we can see battery voltage levels indicating by LEDs are also operating properly.

## Charging OFF & Load ON:

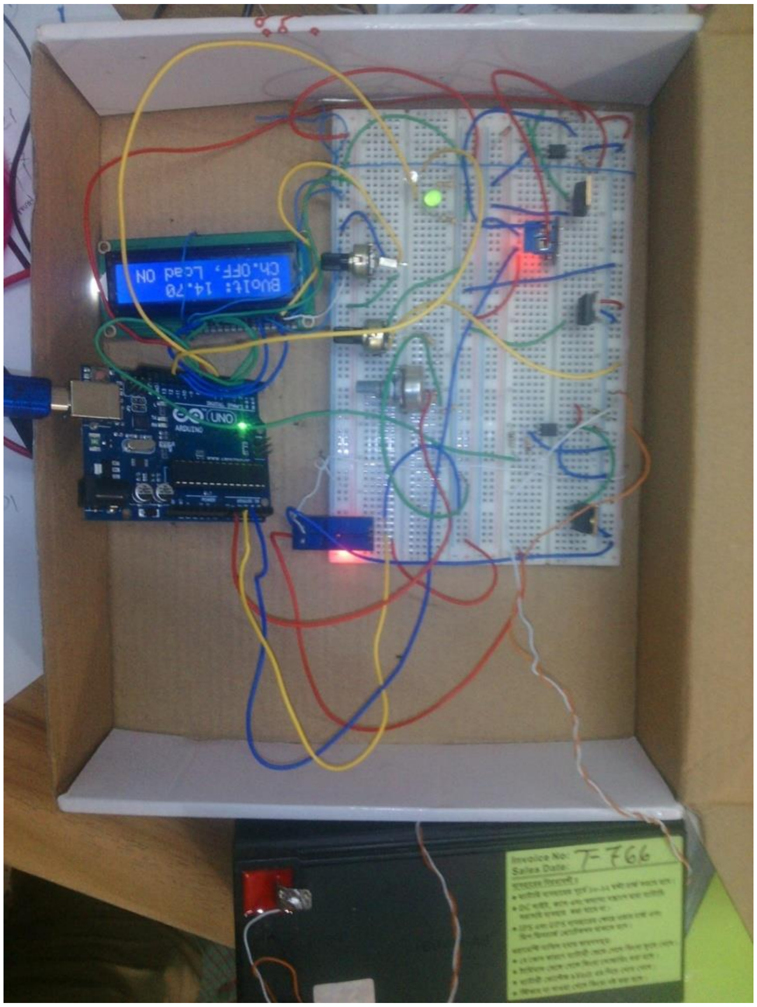


Fig:LR and LRV measurement

When sensor value/battery voltage is gather than VR then charging OFF and sensor value is gather then LRV then load ON.

### Charging ON & Load OFF:

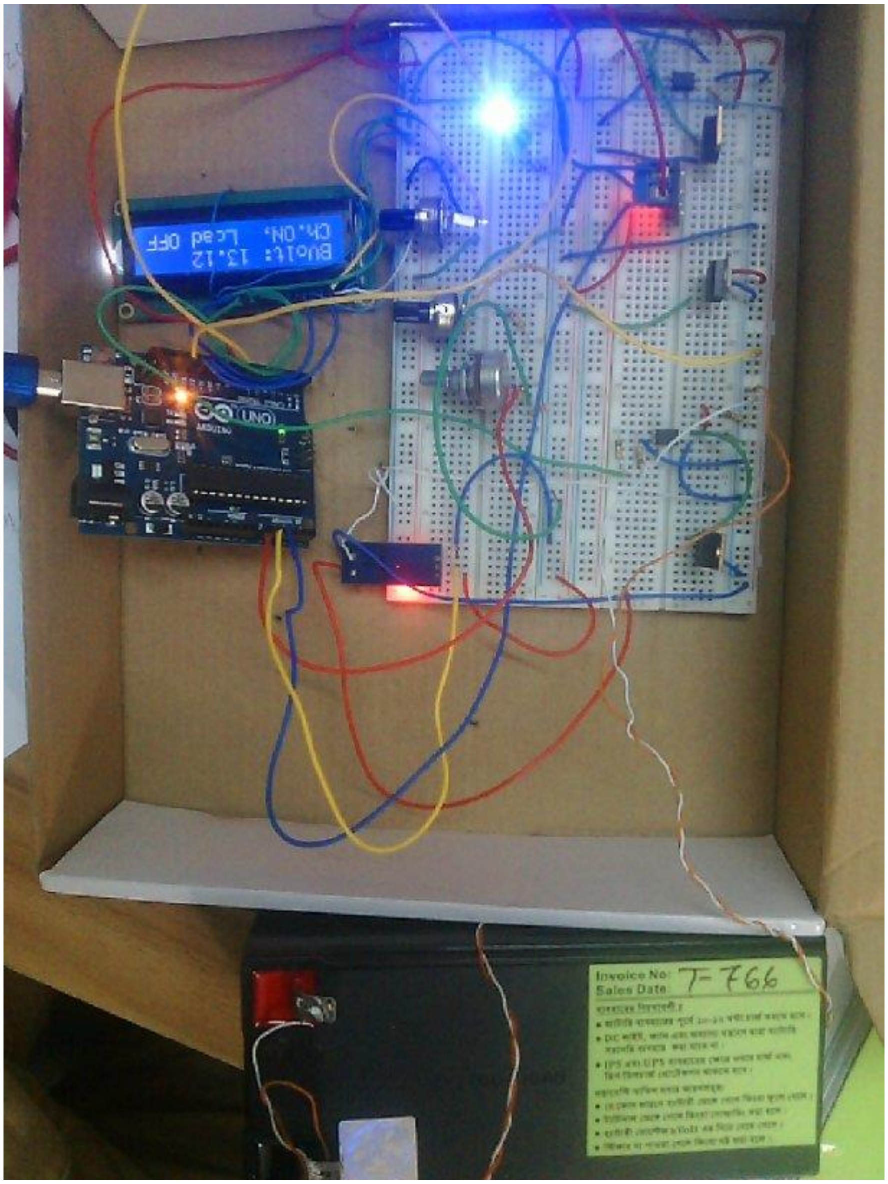


Fig:ARV & LVD Measurement

When sensorValue<ARVthen charging ON and sensorValue<LVD then Load OFF.

### Charging ON & Load ON:

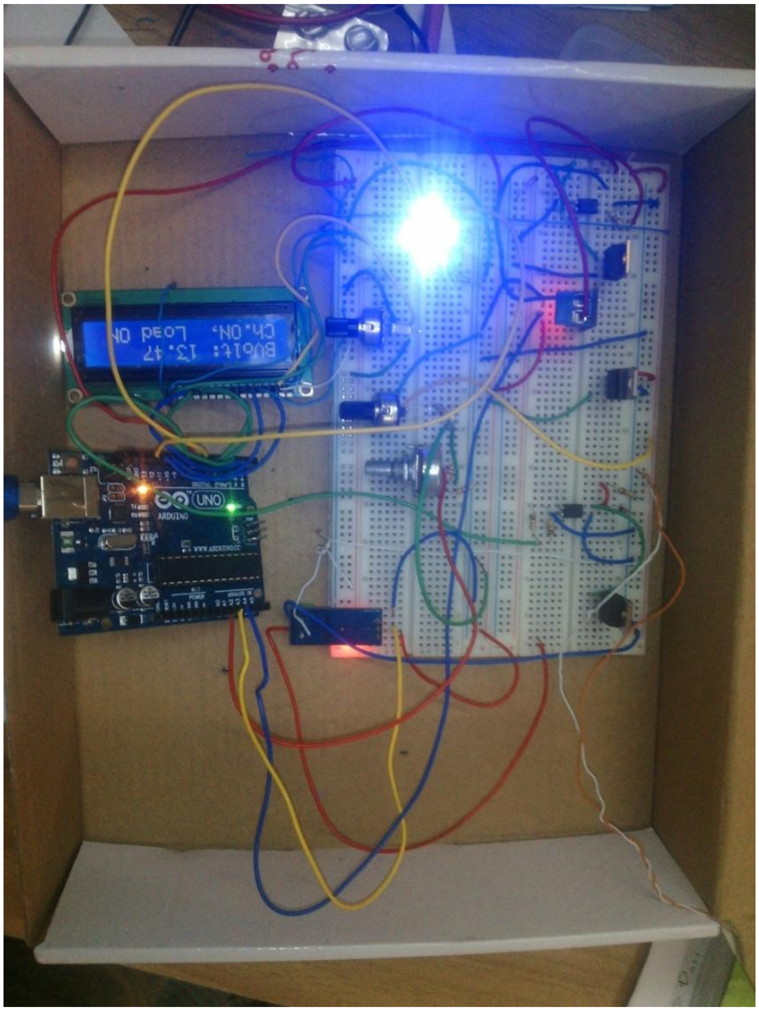


**Fig:ARV & LRV Measurement**

# CHAPTER 5

# CONCLUSION AND FUTURE WORK

## 4.1 CONCLUTION

In future, the world will have to depend on renewable energy. The only source available around us is sunlight, and we can easily convert sunlight energy into electrical energy by using solar system. The life of the battery mainly depends on charge controller. To implement the solar system in general purpose we need an efficient and smart solar charge controller. Our charge controller has a simple circuit but can properly determine the State of Charge (SOC) of the battery. Hence, it keeps the battery always at the highest possible SOC and protect from over-discharging by the load.

The work described in this project has been concern with Design & Developing of a Microcontroller Based Intelligent Solar Charge Controller with Variable Set-Points. We make a charge controller prototype that have feature to sense the voltage and current of battery and change the set-points according to this current. It ensures that the battery is charged properly and it prevent over discharging. Thus it prolongs the battery life as well as the whole solar system.

In our prototype design, we have some error, which are the set-points are change a little. It happens for that we use voltage divider circuit. We can remove the error by using differential amp or little correction program code.

We could not test the prototype for higher current as we haven’t high current source, but tested it in simulation and it works correctly.

## 4.2 FUTURE WORK:

In our project, we construct a prototype of an intelligent charge controller, in future we can design and construct PCB and make a complete package for commercial production. The prototype made for with 16V and 30A. We can make it for high voltage and current to implement this on industrial purpose.

We can use it on hybrid car or the solar vehicle. Our charge controller is good for commercial use. If we work with this, remove all error and make a complete package then it has a great future in industrial and commercial implementation.

## GLOSSARY

**Battery -** A device that converts the chemical energy stored in its active materials to electrical energy. A battery is composed of one or more electrochemical cells. A primary battery can only discharge this energy. The chemical reaction in a secondary battery is reversible and the battery can be recharged.

**Charge controller -** A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries.

**Corrosion -** The result of a destructive chemical reaction. Grid corrosion in lead-acid batteries is caused by sulfuric acid attacking lead in the plate grids and changing it to lead dioxide.

**Bulk Charge -** The first period of battery recharge from a moderate or deep discharge when a battery can easily store all the current from a charging source.

**Discharge -** The release of stored chemical energy as electric current. The rate of discharge is measured in amperes or as a fraction of the cell capacity, for example C/20 where C is 90 Ah is a current of 4.5 amps.

**Overcharge -** A battery that is forced to accept more current than it can store is in an overcharge condition. If a battery is recharged at high rate, the chemical reactions that store the energy may not be fast enough to keep up with the charger. A second form of overcharge occurs when a fully charged battery is forced to accept additional current. Large overcharges damage batteries. Occasional small overcharges of lead-acid batteries can be beneficial.

**Sulfation -** When lead sulfate remains on battery plates for enough time, crystal structures form and sulfation occurs. It is difficult to change lead sulfate into active material and return sulfate ions to the electrolyte by recharging once lead sulfate crystallizes.

**Undercharge -** A battery that is not given enough charging current or time to fully recharge is undercharged. Lead sulfate remains on the plates of undercharged batteries. This crystallizes and the battery sulfates

# REFERENCES

**[1]** Roger A. Messenger, Jerry Ventre, Photovoltaic System Engineering, 3rd edition, CRC press, 2005, p 73,74.

**[2]** In the Internet: [ http://www.wholesalesolar.com/solar-information/charge-controller-article] “An introduction to Charge controller”.

**[3]** James P. Dunlop, P.E., Batteries and Charge Control in Stand-Alone Photovoltaic Systems Fundamentals and Application, Florida Solar Energy Center.

**[4]** Microcontroller-Based Solar Charger, KS Project Manual EFY September 2009.

**[5]** P. J. McChesney, Solar Electric Power For Instruments At Remote Sites, Open File Report 00-128, 2000, USGS.

**[6]** Nowshad Amin, Lam Zi Yi, and Kamaruzzaman Sopian, Masters Thesis, Microcontroller Based Smart Charge Controller for Standalone Solar Photovoltaic Power System, National University Of Malaysia, 2009.

**[7]** Iovine, John, PIC Microcontroller Project Book, eBook, McGraw-Hill.

**[8]** In the Internet: [ http://www.batterytender.com/Intro-to-Lead-Acid-Batteries/] “Introduction to Led Acid Batteries”.

**[9]** In the Internet: [http://www.engineersgarage.com/electronic-components/7805-voltage-regulator-ic] “Voltage regulator IC”.

**[10]** In the Internet: [http://www.microchip.com/wwwproducts/en/Atmega328] “Datasheet of Atmega328”.

**[11]** In the Internet: [http://www.datasheetcatalog.com/datasheets_pdf/I/R/F/2/IRF540.shtml] “Datasheet of IRF540 MOSFET”.

**[12]** Hund, Tom, no date, Battery Testing for Photovoltaic Applications: Albuquerque, Sandia, National Laboratories, p.1 (Sandia National Laboratories Website: 71 http://www.sandia.gov/pv/lib/bospub.htm)

**[13]** In the Internet: [http://data.energizer.com/PDFs/BatteryIR.pdf] "Battery Internal Resistance".

**[15]** In the Internet: [http://en.wikipedia.org/wiki/Microcontroller] "About Microcontroller".

**[16]** In the Internet: [http://www.onsemi.com/PowerSolutions/product.do?id=MC7805]

**[17]** In the Internet: [http://en.wikipedia.org/wiki/Internal_resistance]

**[18]** In the Internet: [https://energypedia.info/wiki/Charge_Controllers] "Charge Controllers".

**[19]** In the Internet: [http://sinovoltaics.com/learning-center/components/solar-charge-controllers-need-know/]

**[20]**In the Internet: [http://www.blueskyenergyinc.com/reviews/article/what_is_a_charge_

controller]

**[21]** In the Internet: [ww1.microchip.com/downloads/en/devicedoc/39597b.pdf]

**[22]** In the Internet: [http://embedded-lab.com/blog/a-brief-overview-of-allegro-acs712-current-sensor-part-1/]

**[23]** In the Internet: [embedded-lab.com/uploads/datasheets/ACS712-Datasheet.pdf]

**[24]**In the Internet: [http://www.engineersgarage.com/tutorials/difference-between-microprocessor-and-microcontroller]

**[25]** Milan Verle, PIC Microcontrollers – Programming in C, MikroElektronika. January 1, 2009.

**[26]** In the Internet: [https://en.wikibooks.org/wiki/Embedded_Systems/8051_Microcontroller].

**[27]** In the Internet: [https://en.wikipedia.org/wiki/Atmel_AVR]

**[28]** In the Internet: [https://en.wikipedia.org/wiki/Opto-isolator] "About Optocoupler".