Battery Management System

Project Report

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CERTIFICATE

This is to certify that the project titled **Battery Management System** is a record of the bonafide work done by **Bharadwaaj Varadan** (Reg. No: 150906232) and **Samarth Jain** (Reg. No: 130906266) submitted in partial fulfilment of the requirements for the award of the Degree of Bachelor of Technology (B.Tech) in Electrical and Electronics Engineering (E & E Engg) by Manipal Institute of Technology Manipal, Karnataka (A Constituent College of Manipal Academy of Higher Education), during the academic year 2018-19.

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Abstract

The paper is proposed on Battery Management for a Standalone PV system.The project has 3 main stages:-a solar panel with dc-dc converter ,battery along with its management system with charge controller and the ac load connected across an inverter. The batteries used are Lithium-ion battery which is most commonly chosen power source for many portable applications like mobile, led lightings etc. Advantages of li-ion batteries are they have high energy density, Relatively low self-discharge and can provide very high current to applications which are the driving force behind for using this type of battery. This paper discusses to develop cell Balancing with individual cell equalization, state of charge and Temperature monitoring in order to increase the efficiency by maximizing the available power. The proposed system is verified through software simulation and hardware implementation of the system is also done.

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Chapter 1

INTRODUCTION

A standalone photovoltaic system is defined as an autonomous energy grid system which operates independently of the traditional grid . In accordance with the growing industry trend on renewable energy, microgrid systems integrated with renewable energy resources are becoming widespread in the world . The main component of the Standalone PV system is the battery which is the fuel tank.Battery is by far the most expensive part of the PV system and optimum utilization of the battery and enhancing the battery life is of utmost importance.Battery Management System is being built so that it can provide control of charging and discharging of the battery by monitoring the voltage of individual cell and total current flowing through the battery pack. The Battery Management System(BMS) helves the Batterys Indication, Measurement, Prediction And The Overall Management. The BMS Consists Of Sensors (Voltage, Current And Temperature), Microcontroller-Based Control Unit and Some IO Interface Peripherals. The basic function of the BMS is to monitor the Batterys Working Behaviors such as Voltage, Current And Temperature etc.These parameters are used to determine the SOC,Temperature control and also used in cell equalization or cell balancing.The project focus to implement Microcontroller based BMS to a standalone Photovoltaic System which increases the efficient use of the battery and also the proposed system is more cost effective than other BMS methods.

1.1 Background and Motivation

The theme of the project is to develop a working model of BMS for a standalone solar system for simple household or any portable loads. Battery management systems are present in a variety of applications; from electronic devices like laptops and smartphones, domestic solar power plants to electric vehicles. A good battery management system (BMS) not only informs its users about the state of the battery, but also ensures the safe operation of the cells and its optimum usage. With more and more technology relying on battery packs as their primary source of storing and consuming energy, a well functioning BMS is extremely crucial. In this project, we attempt to build a basic battery management system for a domestic solar power plant. Solar energy is increasingly becoming a economically viable and an abundant source of renewable energy. In tropical countries like India, solar energy can meet most of the domestic demands. Therefore it is essential that we build a cheap system that can efficiently manage the energy harnessed.

1.2 Literature Review

A battery management system consists of various functional blocks including cutoff FETs, fuel gauge monitor, cell voltage monitor, cell voltage balance, real time clocks, temperature monitors and a state machine.[7] Lithium based or Lead acid based cells are the usually the types of cells that are usually preferred. In our project, where we aim to build the BMS for a solar based power plant, the preferred storage device is a lead acid based battery.[15] A simple solar power plant consists of a photovoltaic panel which harnesses the solar energy and a suitable battery to store this energy. The BMS acts as the mediator. When a load is present, the BMS ensures that the energy stored in the battery is provided to satisfy the load.[10] During daytime and no load, the BMS ensures that the battery is charged. More advanced BMS can also supply excess energy back to the grid.[14] .

1.3 Objectives

- To identify the parameters required for a battery management system
- To model the system on MATLAB
- To build a basic working hardware of the system

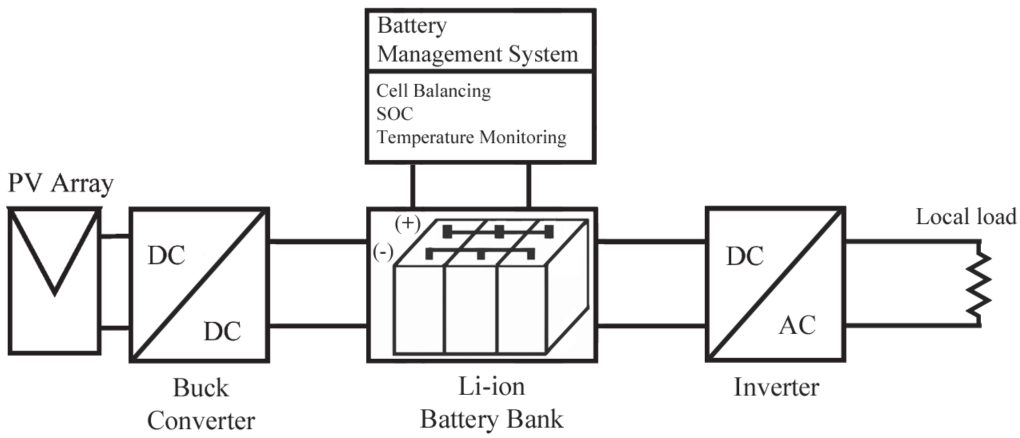

Figure 1.1: Overall System Block Diagram

1.4 Summary

The chapter initiates a discussion about the proposed design where a micro controller is used which performs important tasks of BMS.The chapter also discusses on a standalone PV module and required components to charge the battery pack.A general overview on the concept of cell balancing algorithm and other components in the proposed design has been discussed in the chapter.

Chapter 2

BACKGROUND THEORY

For quick and efficient operation of battery management system, several data inputs are required for PIC micro controller to perform functions according to algorithm. The Overall schematic consists of different individual voltage sensors which works as the required input for the micro controller which in turn operates output relays. A wiring schematic of the system is shown in APPENDIX. There are three major blocks to be discussed:

- Solar panel with DC-DC converter: The input to the system is used for providing charging current to the battery pack. This renewable energy source is dependant on irradiance and temperature. A buck converter brings the voltage to appropriate value required for charging.
- Battery along with its management system and charge controller: A combination of voltage sensors and 4 channel relays act as input and output signals for the micro controller. Batteries are provided with overload, over discharge, over current and short circuit protection with the help of charge controller board.
- Inverter to load : It is used as the AC-AC conversion stage which output is fed to the 5W load as it can handle medium household load applications.

2.1 Solar panel with DC-DC converter

2.1.1 Solar Energy System

Solar energy is the light and radiant heat from the Sun that control Earth's climate and weather and protract life. It is a renewable source of energy and originates with the thermonuclear process that transfers about 650,000,000 tons of hydrogen to helium per second. This action produces lots of heat and electromagnetic radiation. The produced heat remains in the sun and is helpful in upholding the thermonuclear reaction and electromagnetic radiation together with visible, infrared and ultra-violet radiation flow out into space in all directions. Solar energy is in reality nuclear energy. Similar to all stars, the sun is a large gas sphere made up mostly of hydrogen and helium gas. In the internal surface of sun 25% of hydrogen is fusing into helium at a rate of about 7 1011 kg of hydrogen per second.[1] The main benefit of solar energy system is that the sun light is present everywhere free of cost. To produce electricity or convert solar energy to other form of energy first we invest heavy amount for solar panel that convert solar energy to other form but the main advantage is after that installation no any type of maintenance is required for 40 to 50 years.

PV Panels

A single solar cell cannot provide required useful output. So to increase output power level of a PV system, it is required to connect number of such PV solar cells. A solar module is normally series connected sufficient number of solar cells to provide required standard output voltage and power. One solar module can be rated from 3 watts to 300 watts. The solar modules or PV modules are commercially available basic building block of a solar electric power generation system.
Actually a single solar PV cell generates very tiny amount that is around 0.1 watt to 2 watts. But it is not practical to use such low power unit as building block of a system. So required number of such cells are combined together to form a practical commercially available solar unit which is known as solar module or PV module.
Therefore, a storage battery system is an essential component of standalone solar system. But, often this battery system can be omitted from the system if the system is dedicated for the load which to be operated in day times only.Popular examples of standalone solar system are solar lanterns, solar home lighting systems, solar water pumping systems, etc.[1]

2.1.2 Modelling of Photovoltaic cell

Standalone PV Cell

The system which utilizes only Fig 3.1 depicts the simulink model for the charging cycle.solar electric energy as main source of energy is referred as standalone solar electrical system. There are many locations on this earth where no source of electricity is available. At these locations standalone solar electrical system can be the ideal source of electricity. The main advantage of this system is that it does not depend on grid or any other source of electricity.
A solar cell is a building block of solar panel.It is formed by their series and parallel arrangements. A single solar cell is utilised from a current source, a diode and two resistors.This model is called single diode model. The characteristic equation of solar module is dependent on number of cells in parallel and series.It is observed from experimental results taht current variation is less dependent on shunt resistance and more on series resistance.[1]

Effect of variation of solar irradiation

The P-V and I-V curves of solar cells depend on solar irradiation values.The solar irradiance or insolation is intensity of solar radiation on unit area measured in W/m^2. As we know, the solar insolation changes due to daily weather changes.In places like south west coast of India including parts of Maharashtra and Karnataka (Manipal being part of this region), the cloudy weather in Monsoon hinders insolation. Solar input to the cell is directly proportional to irradiance,hence with increase in solar irradiation,open circuit voltage increases.This is due to the fact that, when more sunlight is incident on the solar cell,electrons are supplied with higher excitation energy,thereby increasing electron mobility, hence more power is generated.

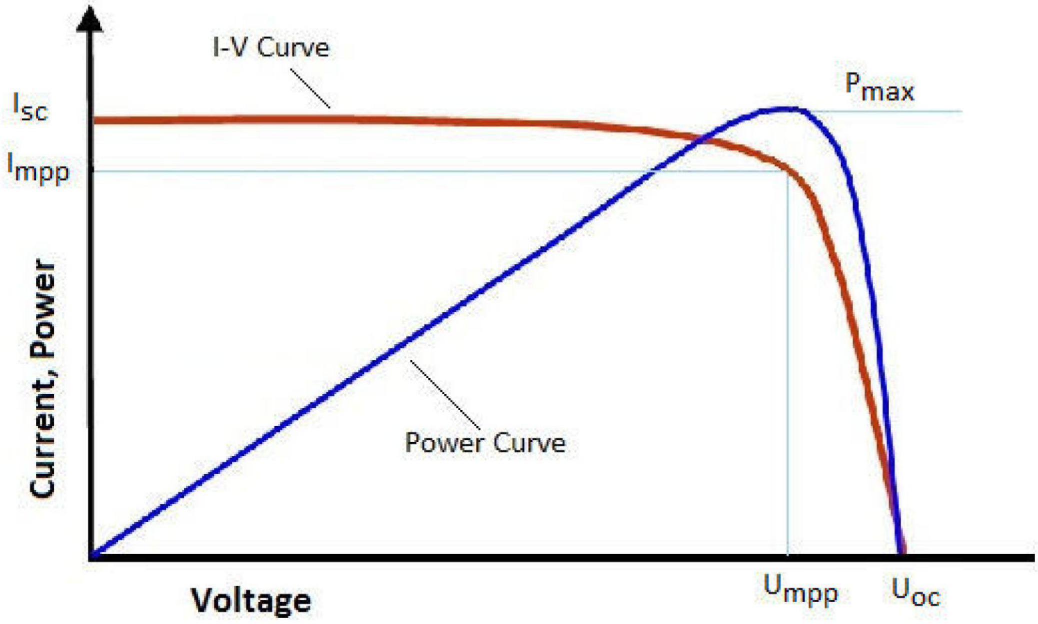

Figure 2.1: PV and IV characteristic Curves [1]

Ratings of Solar Module

Since output from a solar cell depends on surrounding temperature and insolation,the rating of a solar module must be specified under such conditions. It is standardized practice to express rating of PV or solar module at 25^{o}C temperature and 1000 w/m^2 light radiation. The solar modules are rated with their output open circuit voltage (V^{oc}), short circuit current (I_{sc}) and peak power (W_p). These conditions are collectively called Standard Test Conditions. The Standard Test Conditions may not be available at site where the solar modules to be installed. This is because the solar radiations and temperature vary with location and time.

Short circuit current

Under Standard Test Condition positive and negative terminal of a solar module are short circuited, then the current delivered by the module is short circuit current. Although under standard test condition, this current also depends upon the area of the module exposed to the light. As it depends upon area, it is better to express by short circuit current per unit area.

$$J_{sc} = \frac{I_{sc}}{A} \tag{2.1}$$

Hence,Where, A is the area of the module exposed to the standard light radiation (1000w/m^2). Short circuit current of a pv module also depends upon solar cell manufacturing technology.

Open circuit Voltage

The voltage output of a solar module under standard test condition, when the terminals of the modules are not connected with any load. This rating of solar module mainly depends upon the technology used to manufacture solar cells of the module. More Voc indicates that solar module performs better. This open circuit voltage of a solar module also depends upon operating temperature.

PV Equations

As in the diagram, net current output of a solar cell is Kirchoff sum of diode and photocurrent.

$$I = I_{ph} - I_d - I_{rsh} \tag{2.2}$$

I_{ph} photocurrent,produced when solar rays strike silicon layer I_d diode current I_{rsh} current through shunt resistance given by equation

$$I_{rsh} = \frac{V + IR_s}{R_{sh}} \tag{2.3}$$

The diode current is given by:

$$I_d = I_{rs} exp[\frac{q}{AkT}(V + IR_s)] - 1 \tag{2.4}$$

where I_{rs} is reverse saturation current. The reverse saturation current is given by;

$$I_{rs} = I_{rsref}[\frac{T}{T_{ref}}]^3 \, exp[q\frac{E_{si}}{bk}(\frac{1}{T_{ref}} - \frac{1}{T})] \tag{2.5}$$

where I_{rsref} is reverse saturation current with respect to T_{ref} The PV cell Voltage is given by:

$$V_{PVcell} = V_D - R_s I_{ph} \tag{2.6}$$

Taking Ns=Number of cells in series

$$V_{PV} = N_S V_{PVcell} \tag{2.7}$$

2.1.3 DC-DC converter

The Buck Converter is used in SMPS circuits where the DC output voltage needs to be lower than the DC input voltage. The DC input can be derived from rectified AC or from any DC supply. It is useful where electrical isolation is not needed between the switching circuit and the output, but where the input is from a rectified AC source, isolation between the AC source and the rectifier could be provided by a mains isolating transformer.[5] The switching transistor between the input and output of the Buck Converter continually switches on and off at high frequency. To maintain a continuous output, the circuit uses the energy stored in the inductor L, during the on periods of the switching transistor, to continue supplying the load during the off periods. The circuit operation depends on what is sometimes also called a Flywheel Circuit. This is because the circuit acts rather like a mechanical flywheel that, given regularly spaced pulses of energy keeps spinning smoothly at a steady rate. Some design specifications for buck converter application are listed in Table 2.1

Table 2.1: Buck converter design equations[3]

Parameter	Equation
Peak inductor current	i_{pk}
Min inductor current	i_o
Ripple Current	$\Delta i = i_{pk} - i_o$
Duty Cycle	$D = T_{ON}/T$
Switch On Time	$T_{ON} = D/f$
Average and Load Current	$i_{ave} = \Delta i/2$
Output voltage	$V_{IN}T_{ON}/T$

Operation of Buck Converters

A model of a basic step-down converter is used to explain the circuit operation. In the figure, we replace the high-side transistor and low-side diode with switches to explain operation schematically. The circuit principles are the same as those of diode rectification in a DC/DC converter, but the high voltage obtained by rectifying an AC voltage is directly switched to perform step-down voltage conversion, and so the transistor and diode acting as switches must withstand high voltages, for example 600 V or so.

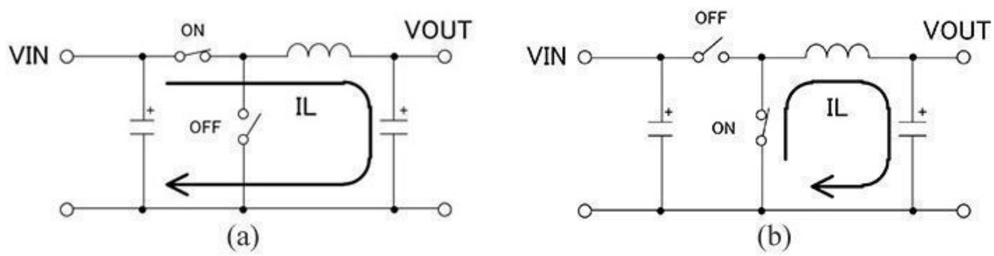

Figure 2.2: Operation of buck converter in continuous mode [2]

In the circuit shown in Figure 2.2 (a) When the high-side switch (the transistor) turns on, a current IL flows in the inductor L, and energy is stored. At this time, the low-side switch (the diode) is turned off. The inductor current IL is expressed by the following equation

$$I_L = \frac{V_{IN} - V_{OUT}}{L} T_{ON} \tag{2.8}$$

In the circuit shown in Figure 2.2 (b) When the high-side switch (the transistor) turns off, the energy stored in the inductor is output through the low-side switch (the diode)

At this time, the high-side switch (the transistor) is OFF The inductor current IL is expressed by the following equation

$$I_L = \frac{V_{OUT}}{L} T_{OFF} \tag{2.9}$$

2.2 Battery management system and charge controller

2.2.1 Lithium-ion Battery

Lithium Ion Batteries are ideal Match for Solar Energy Storage Needs. In the proposed system, multiple cells are used in series to observe the cell balancing effects and also to meet the load demand. The majority of home appliances nowadays use some form of lithium ion chemical composition. Lithium ion batteries are lighter and more compact than lead acid batteries. They also have a higher Depth of discharge and longer lifespan when compared to lead acid batteries. However, lithium ion batteries are more expensive than their lead acid counterparts. Due to the intrinsic instability of lithium metal, especially during charging, non metallic lithium batteries preferred. Although slightly lower in energy density than lithium metal, lithium-ion is safe, provided certain precautions are met when charging and discharging.[6] The most economical lithium-ion battery in terms of cost-to-energy ratio is the cylindrical 18650 (size is 18mm x 65.2mm). This cell is used for mobile computing and other applications that do not demand ultra-thin geometry. If a slim pack is required, the prismatic lithium-ion cell is the best choice. These cells come at a higher cost in terms of stored energy. Reasons for its selection over other batteries:

- Low Maintenance - no periodic discharge is needed; there is no memory.
- High energy density:Its energy density is 100-265W-h/kg
- Specialty cells can provide very high current to applications
- High charging efficiency of 80-90%

Battery parameter

- Nominal voltage (V): The nominal voltage (Vnom) of the battery in V. The nominal voltage represents the end of the linear zone of the discharge characteristics.
- Rated capacity (Ah): The rated capacity (Qrated) of the battery in Ah. The rated capacity is the minimum effective capacity of the battery.
- Initial state-of-charge (%): The initial state-of-charge (SOC) of the battery.Fully charged battery is indicated by 100% SOC and full discharged battery is indicated by 0% SOC. Discharge curve is unaffected by this parameter.

Model assumptions and limitations

- The internal resistance is independent of amplitude of the current and is assumed to be constant during charging and discharging cycles.
- The capacity of the battery does not change with the amplitude of current.
- The battery has no memory effect.
- The minimum no-load battery voltage is 0 V.
- The minimum capacity of the battery is 0 Ah and the maximum capacity is Qmax.

2.2.2 Management system

Voltage sensors

A simple but very useful module which uses a potential divider to reduce any input voltage by a factor of 5. This allows you to use the analogue input of a microcontroller to monitor voltages much higher than it capable of sensing. For example with a 0-5V analogue input range you are able to measure a voltage up to 25V. The module also includes convenient screw terminals for easy and secure connection of a wire. This module is based on principle of resistive voltage divider design, can make the red terminal connector input voltage to 5 times smaller. PIC analog input voltages up to 5 v, the voltage detection module input voltage not greater than 5Vx5=25V (if using 3.3V systems, input voltage not greater than 3.3Vx5=16.5V). PIC chips have 10-bit AD, so this module simulates a resolution of 0.00489V (5V/1023), so the minimum voltage of input voltage detection module is 0.00489Vx5=0.02445V.[3]

Temperature sensors

LM35 is a precision IC temperature sensor with its output proportional to the temperature (in °C). The sensor circuitry is sealed and therefore it is not subjected to oxidation and other processes. With LM35, temperature can be measured more accurately than with a thermistor. It also possess low self heating and does not cause more than 0.1 °C temperature rise in still air. The operating temperature range is from -55°C to 150°C. The output voltage varies by 10mV in response to every °C rise/fall in ambient temperature, i.e., its scale factor is 0.01V/ °C.[4]

Relays

Relay boards are computer boards with an array of relays and switches. They have input and output terminals and are designed to control the voltage supply. Relay boards provide independently programmable, real-time control for each of several on-board relay channels. Product specifications include the number of channels, physical dimensions, input range, and output range. Relay boards with opto-isolators provide isolation between control signals and output controls. Software-based tools can be used to write batch files, and light emitting diodes (LEDs) provide are used as visual indicators. Most relay boards have 2, 4, 8 or 10 channels. Each channel has a relay switch with an output rated up to a limit such as 250 VAC / 5 amps. Some relay boards have an additional socket for a power pack connection. Other can be controlled remotely, or via radio frequency (RF). RF relay boards may use an auto-roll algorithm to prevent the unauthorized interception of transmissions. RF relay boards with transmitters and receivers use multiple channels.[4] figure 2.5 shows the relay

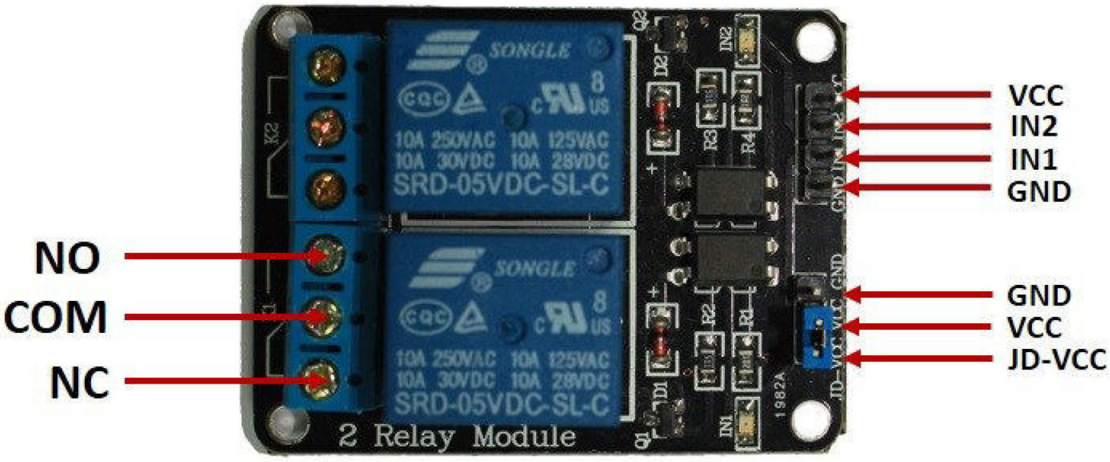

Figure 2.3: Relay Pin Diagram [3]

module pinout.The six pins on the left side of the relay module connect high voltage, and the pins on the right side connect the component that requires low voltagethe Arduino pins. Mains voltage connections The high-voltage side has two connectors, each with three sockets: common (COM), normally closed (NC), and normally open (NO).[4]

- COM: common pin
- NC (Normally Closed): the normally closed configuration is used when you want the relay to be closed by default, meaning the current is flowing unless you send a signal from the Arduino to the relay module to open the circuit and stop the current.
- NO (Normally Open): the normally open configuration works the other way around: the relay is always open, so the circuit is broken unless you send a signal from the Arduino to close the circuit.

Pin wiring : The low-voltage side has a set of four pins and a set of three pins.The set at the right consists of VCC and GND to power up the module, and input 1 (IN1) and input 2 (IN2) to control the bottom and top relays, respectively. The second set of pins consists of GND, VCC, and JD-VCC pins. The JD-VCC pin powers the electromagnet of the relay. The connections between the relay module and the microcontroller are:

- GND: goes to ground
- IN1: controls the first relay (it will be connected to an microcontroller digital pin)
- IN2: controls the second relay (it should be connected to an microcontroller digital pin)

- VCC: goes to 5V

As a rule, each channel has a reset connection for resetting the relay board when the device is used in toggle mode. Relay boards have a general purpose, high-current, or mercury-wetted switching matrix for routing signals and loads. They also provide a wide range of test signal switching options. Constant control relay modules or integrated relay control modules can be used as wide-open throttles in relays that are used in the normally closed (NC) condition. When operation is not required, the relay module is grounded and in a normally open (NO) condition. Constant control relay modules are also used with relay circuits in the cooling fans of engines and the operation of fuel pumps. The relay circuit n these relay boards causes the relay to toggle between the on and off conditions.
Relay boards are used in many different applications. Some products are used to control lights, motors, and other electronic devices in industrial and commercial applications. Others are also used to control heater temperatures, or are used in power switching applications Relay boards that are designed for specific types of industrial equipment are also available.[3]

PIC 18F452

The PIC Processor has a Harvard architecture i.e. separate instruction memory and data memory.
For the 18F452:

- 32KByte Program Memory on chip, (Flash)
- 1792 bytes of Data Memory on chip
- 1536 bytes of static RAM
- 256 bytes of EEPROM

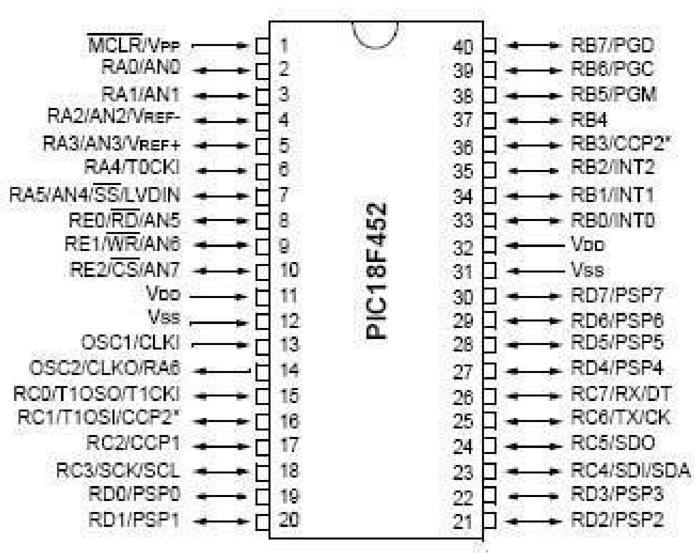

Figure 2.4: Pin Diagram [3]

We have total 40 pins in 18F452 microcontroller as shown in the pin diagram (refer Figure 2.4). Different PIC microcontrollers have different pins and different functions. 18F452 is an 8bit microcontroller. Ports There are total five ports in PIC18F452.Each port is of 1byte (8bits) and so each port has 8 pins of microcontroller except the portE it has 3 pins.These ports are named as :

16X2 LCD Display

LCD modules are very commonly used in most embedded projects, the reason being its cheap price, availability and programmer friendly. Most of us would have come across these displays in our day to day life, either at PCOs or calculators. The appearance and the pinouts have already been visualized above now let us get a bit technical. 162 LCD is named so because; it has 16 Columns and 2 Rows. There are a lot of combinations available like, 81, 82, 102, 161, etc. but the most used one is the 162 LCD. So, it will have (162=32) 32 characters in total and each character will be made of 58 Pixel Dots. A Single character with all its Pixels is shown in the below picture. Now, we know that each character has (58=40) 40 Pixels and for 32 Characters we

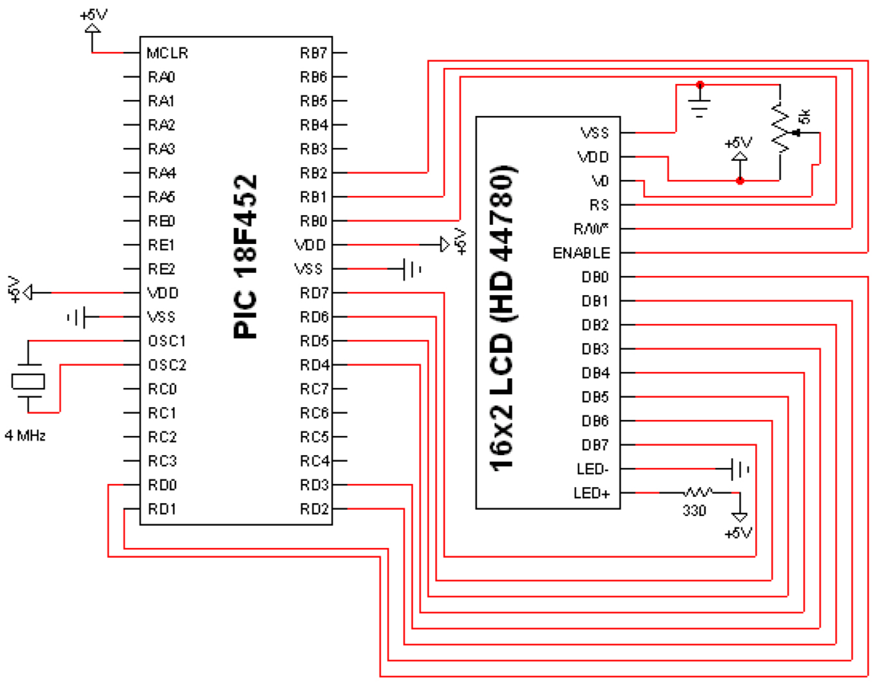

Figure 2.5: Interface of LCD display with microcontroller [4]

will have (3240) 1280 Pixels. Further, the LCD should also be instructed about the Position of the Pixels. Hence it will be a hectic task to handle everything with the help of MCU, hence an Interface IC like HD44780is used, which is mounted on the backside of the LCD Module itself. The function of this IC is to get the Commands and Data from the MCU and process them to display meaningful information onto our LCD Screen.

2.2.3 Charge controller

Lithium-ion and lithium-polymer batteries are increasingly finding their way into portable and mobile devices. These highly efficient battery technologies pack more energy into a smaller size than almost any other battery type. However, such energy efficiency comes at a price lithium batteries are subject to overheating, catching fire, or exploding if theyre overcharged, short-circuited, overheated, or otherwise misused. For safety purposes, some protection circuitry must be incorporated when lithium batteries are designed into a product. In Lithium Battery Charger Board Protection

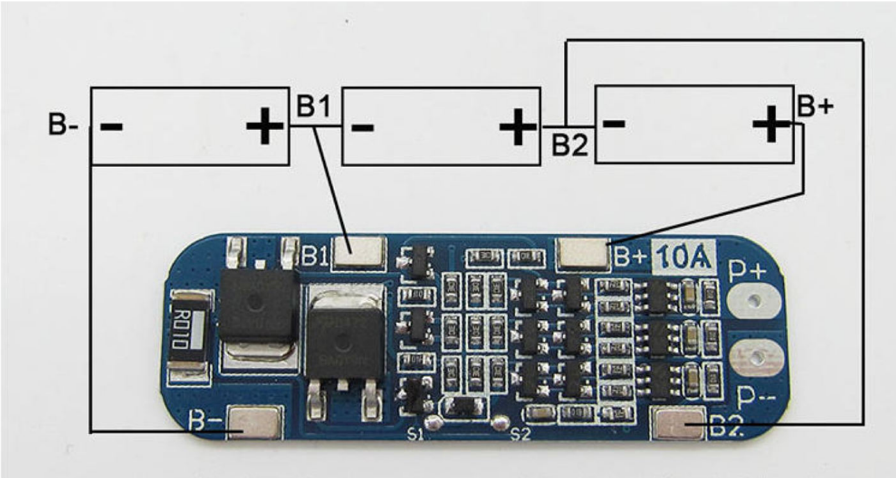

Figure 2.6: Charge controller [3]

Module, batteries or polymer lithium battery are in series combination. With 10.8V rated voltage for polymer battery, 11.1V 18650 or 3.7V lithium battery rated voltage and 12.6V lithium battery can be charged. And discharge 10A (referring to the maximum discharge current limit) Lithium battery protection board it also Comes with over-charge, over-discharge, over-current, short circuit protection

2.3 Inverter to load

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC).A typical power inverter device or circuit requires a relatively stable DC power source capable of supplying enough current for the intended power demands of the system.
The input voltage depends on the design and purpose of the inverter.The input voltage is 12 V DC, for smaller consumer and commercial inverters that typically run from a rechargeable 12 V lead acid battery or automotive electrical outlet.24, 36 and 48 V DC, which are common standards for home energy systems.200 to 400 V DC, when power is from photovoltaic solar panels.300 to 450 V DC, when power is from electric vehicle battery packs in vehicle-to-grid systems.Hundreds of thousands of volts, where the inverter is part of a high-voltage direct current power transmission system.

Operation of inverter

The proposed inverter is MOFSFET based.The main advantage of a MOSFET is that it requires almost no input current to control the load current, when compared with bipolar transistors. In an "enhancement mode" MOSFET, voltage applied to the gate terminal increases the conductivity of the device. In "depletion mode" transistors, voltage applied at the gate reduces the conductivity.

2.4 Summary

Theoretical knowledge obtained from research papers has led to better understanding of the project. The main topics of the project which are battery along with its management system and charge controllers have been briefly discussed. There is an efficiency increase predicted from cell balancing . Hence this is battery management system is proposed. Lastly, implementing a hardware prototype model of the system to observe how the Li-ion battery behaves and its charging and discharging characteristics.

Chapter 3

METHODOLOGY

3.1 Introduction

The chapter contains a brief explanation the methodology and specification of various system associated in design of Battery management system. Also the simulated matlab model and Hardware prototype is discussed for better understanding of the results obtained explained in chapter 4. The software implementation and hardware design of the project will be shown through steps. Simulation has been carried out on the MATLAB-Simulink platform and the coding of algorithm is done in embedded C platform.The software used here is MPLAB.

- Step 1: Simulation and hardware implementation of solar panel and dc-dc converter is done Output waveforms and data were obtained and verified with help from research papers.
- Step 2: Simulation and hardware implementation of battery pack and its management system is done and validated
- Step 3: Simulation and hardware implementation of inverter and load is done and also overall design system is validated in both software and hardware.Real Time data is also being tabulated manually for battery charging and discharging characteristics.

3.2 Proposed Solution

There are various approaches to implement the BMS. Various techniques have been implemented to find the SOC of the battery pack, or use cell balancing to increase the efficiency of the battery pack. Traditional BMS were lot more complicated as they were mostly implemented on Electric/Hybrid vehicle and not used on lower scale. The proposed project concentrates on developing a BMS for standalone PV system. A standalone PV systems main component is the battery pack because the entire solar energy is converted to electrical energy and hence stored in the battery pack. The proposed design uses Microcontroller which is the brain of the BMS. To find the SOC we are using the OCV algorithm. Cell Balancing are of two types:-First is the passive cell balancing and second the active cell balancing. We are implementing an improvised active cell balancing were we wont require LC circuit to store the energy rather we will be implementing algorithm and relays to achieve the same. This reduces the cost and at the same time achieving the goal. Apart from these two parameters we are also monitoring the battery pack temperature so that the pack is not destroyed due to overheating. [13]

3.3 Implementation

The project implementation is divided into 3 stages i.e solar panel output is fed to dc-dc buck converter which steps down the voltage, then the battery is connected across the first stage along with its management system and finally the inverter and load is connected across the battery which is the final stage.

3.3.1 Solar Panel

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. A photovoltaic module is a packaged, connected assembly of solar cells. The solar module can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC).There are 36 solar cells connected in series-parallel configuration to generate the specific values. Solar panel is used to charge the battery pack when the SOC level goes below a certain threshold level. The output of the solar panel mainly depends on two parameters that is Temperature and irradiance. Greater the temperature and irradiance greater will be the output power from the panel.Therefore for the above reason a dc-dc converter is being used to control the output power of the panel which is being supplied to the battery pack to store the energy. The solar panel is being developed in software and is implemented in hardware.[9]Fig 3.1 depicts the simulink model for charging the battery pack. Table 3.1 represents the parameters and value of the solar panel .

Table 3.1: Solar panel Specification [3]

Parameters	Value
Max Power	11.12W
Max Voltage	17.95V
Max Current	0.619A
Short Circuit Current	0.694A
Open Circuit Voltage	21.40V

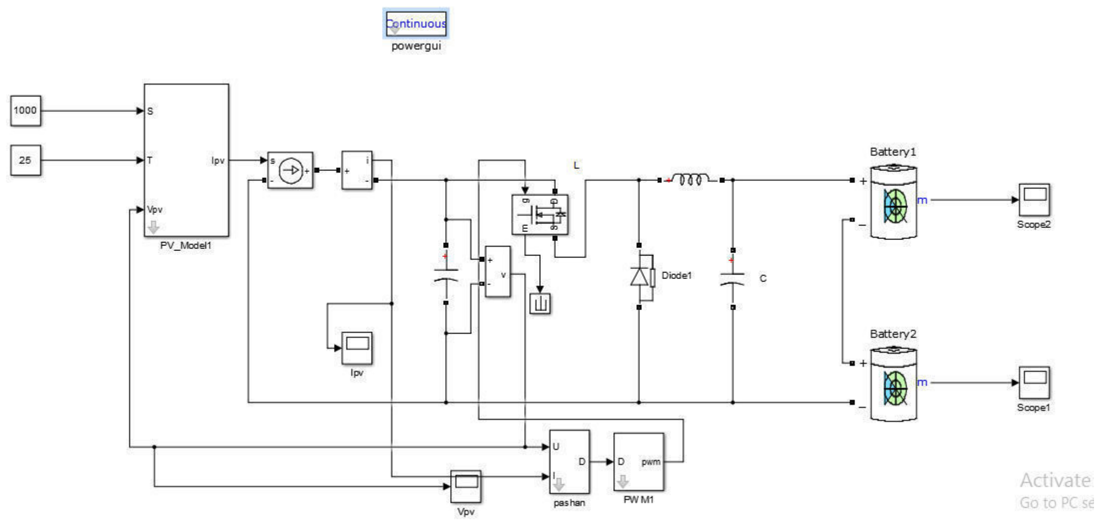

Figure 3.1: Charging model in Simulink

3.3.2 DC-DC Converter

A DC-DC converter is used as a power interface circuit between the PV panel and the battery. The DC-DC converter connects or disconnects conveniently the solar panel from the battery based on PWM signals. Here the buck converter topology is used due to two main advantages of it, first the required input current to the converter is small, hence the rating and the size of the PV panel becomes smaller, and second the charge control operation remains uninterrupted even when the PV panel gives low output current at low level of insolation because the buck converter will boost the current up to the required level of charging. The simulink model and hardware of the dc-dc converter is being implemented. The buck converter is in use when the PV panel voltage is above 12v so that it will step down the voltage to the required voltage to charge the battery.

Table 3.2: Battery Parameters [3]

Parameters	Value
Overall battery Nominal voltage	11.1 V
Single Li-ion cell Nominal Voltage	3.7 V
Rated capacity of battery pack	7.8Ah
Rated capacity of single Li-ion	2.6Ah
Max Charge Voltage	4.2v
Max Battery pack Charge Voltage	12.6v
Operating Temperature	0-60c
Standard charge Current(each cell)	0.52A
Standard discharge Current(each cell)	0.52A
No.of cells in series	3

3.3.3 Lithium Battery and Charge Controller

The battery pack consist of 3 lithium ion cell. Batterys basic task is to store energy obtained from PV Panel and to release it to the load when needed. This enables a portable device to operate without a connection to any power source other than a battery.Table 3.2 is the Battery specification. When a constant voltage applied to the battery, it charges, following a charge characteristics and the discharge characteristics is obtained with battery current is positive and battery discharges.Fig 3.2 is simulink model of battery pack without its BMS.Table 3.2 represents the Battery Parameters A solar charge controller is fundamentally a voltage or current controller to charge the battery and keep electric cells from overcharging. It directs the voltage and current hailing from the solar panels setting off to the electric cell.In 3S 10A 12V 18650 Lithium Battery Charger Board Protection Module, 3S stands for 3 batteries or polymer lithium battery series combination. With 10.8V rated voltage for polymer battery, 11.1V or 3.7V lithium battery rated voltage and 12.6V lithium battery can be charged. And discharge 10A (referring to the maximum discharge current limit) Lithium battery protection board it also comes with over-charge, over-discharge, over-current, short circuit protection.[8]

3.3.4 Battery Management system

1) Microcontroller

The PIC18F series of microcontrollers has larger instruction set, more memory, bigger stack, more external interrupts, higher speed and enhanced I/O port architecture PIC 18f452 controller was selected as central control unit. It has many features like High Speed of operation, inbuilt 10 bit ADC in it, has programmable timer option

The PIC 18f452 microcontroller is used to calculate the State of Charge, Temperature Monitoring and Cell Balancing.
i) State of charge monitoring is done by using Open Circuit Voltage algorithm.(OCV).

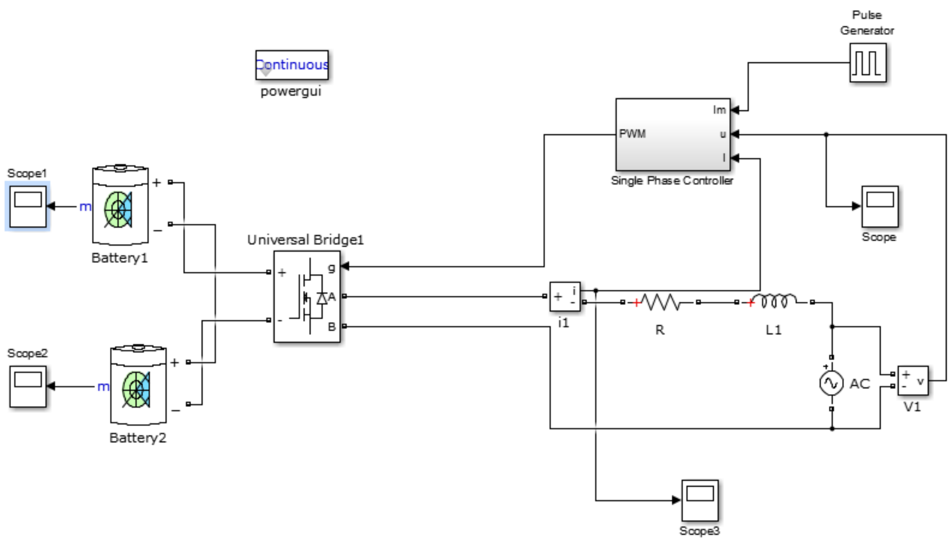

Figure 3.2: Battery pack without BMS Simulink Model

This system continuously measures the voltage and it calculates the SOC of individual cell and also the entire battery. Voltage sensing part is done with the help of voltage divider network.[12] Here input voltage is taken as battery terminal voltage and according to voltage sensor output is given to the ADC port of the controller. SoC algorithm is the main part which describes battery capacity.

ii)Temperature monitoring

Temperature monitoring is done to protect the Li-ion battery from overheating. Lithium-ion performs well at elevated temperatures but prolonged exposure to heat reduces longevity. Charging and discharging at elevated temperatures is subject to gas generation that might cause a cylindrical cell to vent and a pouch cell to swell. Many chargers prohibit charging above 50C (122F).

iii)Cell Balancing

To improve the life of the battery pack and also maximize the available capacity of the battery, it is necessary to equalize the voltage and SoC of the cells in a battery pack. Cell balancing is one of the most important functions of a battery management system.[11]Fig 3.3 depicts the flowchart of the cell balancing algorithm.

2)LCD Display

A 16*2 LCD is used to get the results from the controller and it can be used to display the results.[3] .
Specifications: -
i) Module Dimension 80.0 x 36.0 mm
ii) Viewing Area 66.0 x 16.0 mm
iii) Dot Size 0.56 x 0.66 mm
iv) Character Size 2.96 x 5.56 mm

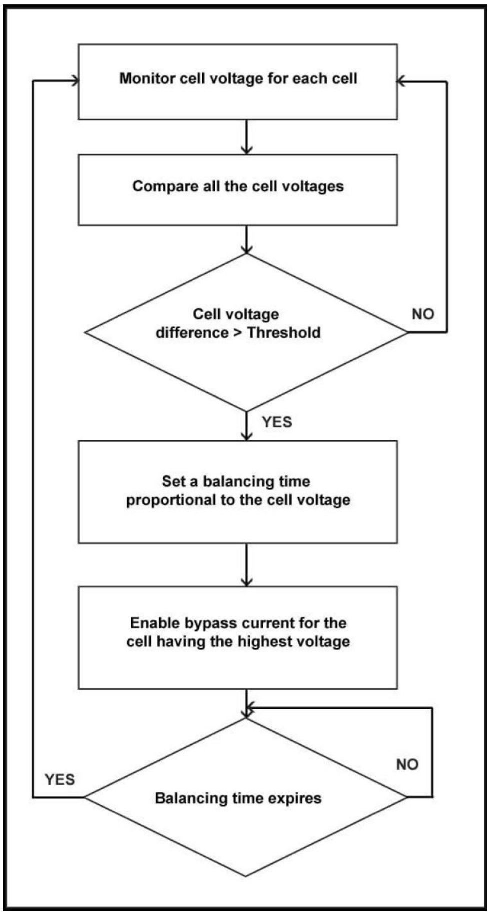

Figure 3.3: Cell Balancing Algorithm

v) Operating Voltage is 4.7V to 5.3V
vi) Current consumption is 1mA without backlight
vii) Alphanumeric LCD display module, meaning can display alphabets and numbers
viii)Consists of two rows and each row can print 16 characters.
ix)Each character is build by a 58 pixel box
x)Can work on both 8-bit and 4-bit mode

3)Tepmerature Sensor

LM35 temperature sensor is used to sense the temperature of the battery while charging and discharging. The sensor is interfaced with the microcontroller[3]

- Calibrated Directly in Celsius (Centigrade)
- Linear + 10-mV/C Scale Factor
- 0.5C Ensured Accuracy (at 25C)
- Rated for Full 55C to 150C Range
- Suitable for Remote Applications
- Low-Cost Due to Wafer-Level Trimming

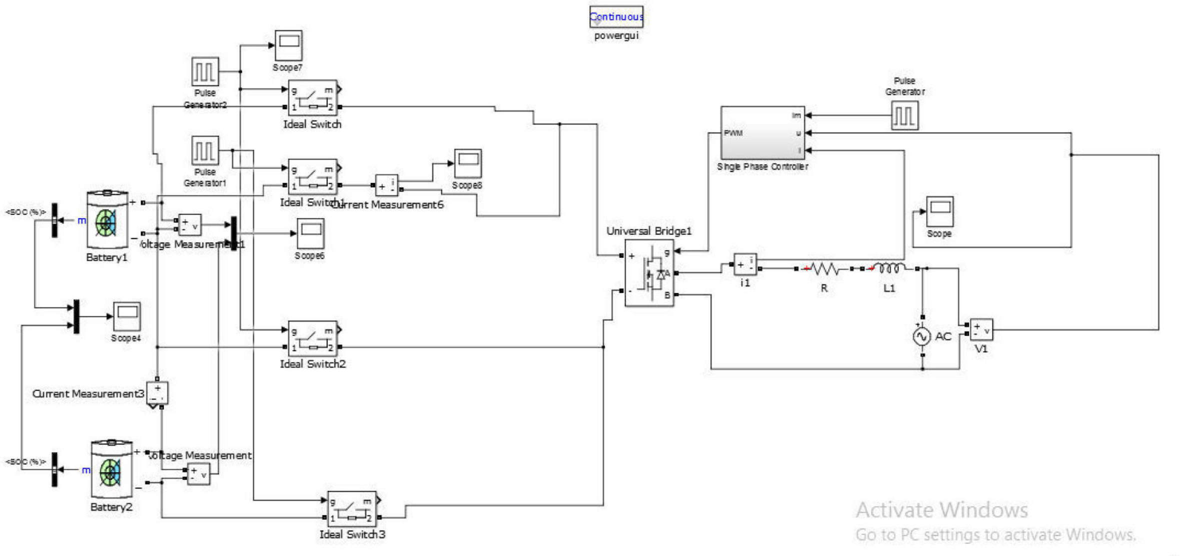

Figure 3.4: Battery pack with BMS Simulink Model

- Operates From 4 V to 30 V
- Less Than 60-A Current Drain
- Low Self-Heating, 0.08C in Still Air
- Non-Linearity Only C Typical
- Low-Impedance Output, 0.1 for 1-mA

4)Voltage Sensor

Voltage sensing part is done with the help of voltage divider network. Here input voltage is taken as battery terminal voltage and according to the design resistors are placed and output is given to the ADC port of the controller. It is then given to the controller. The Arduino analog input is limited to a 5 VDC input. It is fundamentally a 5:1 voltage divider using a 30K and a 7.5K Ohm resistor.Total 5 voltage sensors are used.Voltage sensor 1 is used to sense to solar panel voltage.3 sensor are used to sense voltage of li-ion cell and last is to calculate the total battery pack voltage .Table 3.3 represents the specifications of voltage sensor[3]

5)Relay

Relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. This 4 Road/Channel Relay Module (with light coupling) 12V module meet the safety standard as control areas and load area have the isolation groove. Optical coupling isolation module. The triggering of 4 Road/Channel Relay Module is reliable, more stable. The double FR4 circuit board design, high-end SMT process. It has power and relay operation instructions. Relays

Table 3.3: Voltage Sensor Parameters [4]

Parameters	Value
Input Voltage (V)	0to 25
Voltage Detection Range (V)	0.02445 to 25
Analog Voltage Resolution (V)	0.00489
Length (mm)	28
Width (mm)	14
14 Height (mm)	13
Weight (gm)	4

terminals (C, NC, NO) are accessible through screw terminals which makes wiring up the board very easy.The inputs of 4 Channel 12V Relay Module are isolated to protect any delicate control circuitry. Total of 5 relays is being used in the system.1 relay is used in charging purpose where when the output voltage of solar is greater than 12 volt at that time relay 1 will conduct else it will disconnect the charging circuit.3 relays are used in cell balancing where each cell and relay is connected according to the algorithm.Last relay is connected to the load.When the load is turned on then it will conduct and also prevents reverse flow of cuurent.

3.3.5 Inverter and Load

The single Phase Inverter is implemented on Simulink and hardware model is being used in the system. A single phase inverter is used to convert DC to AC to power the load. The input to the inverter system is 12VDC and output is 220VAC at 50Hz frequency. The PWM generator is used to trigger the switches with switching frequency of 5Khz.The load used here is a 5-10 Watts household AC load. A lighting system of 5-10W is being used in hardware. The load is operated across the output of the inverter which is 230VAC and 50hz frequency.

3.3.6 Overall Design

The overall system design depends on the outputs of individual subsystem because the output of the solar panel varies according to the environment which present a DC output voltage roughly around 12V-17V.This output is the fed to the dc-dc converter to step down the voltage to protect the battery pack from overvoltage. The output of buck converter has a ripple of roughly 2.5%.The battery pack is then used to power the load with a parallel system used to manage the parameters of the battery pack. This subsystem is used to monitor the SOC level, Temperature, Voltage and implement Cell Balancing to protect the battery and at the same time increase its efficiency. A 5W led light is being connected across the inverter which produces an output of 220VAC at 50hz frequency when an input of 12VDC is given. The efficiency of the inverter is around 85% with 3% ripple in the output.

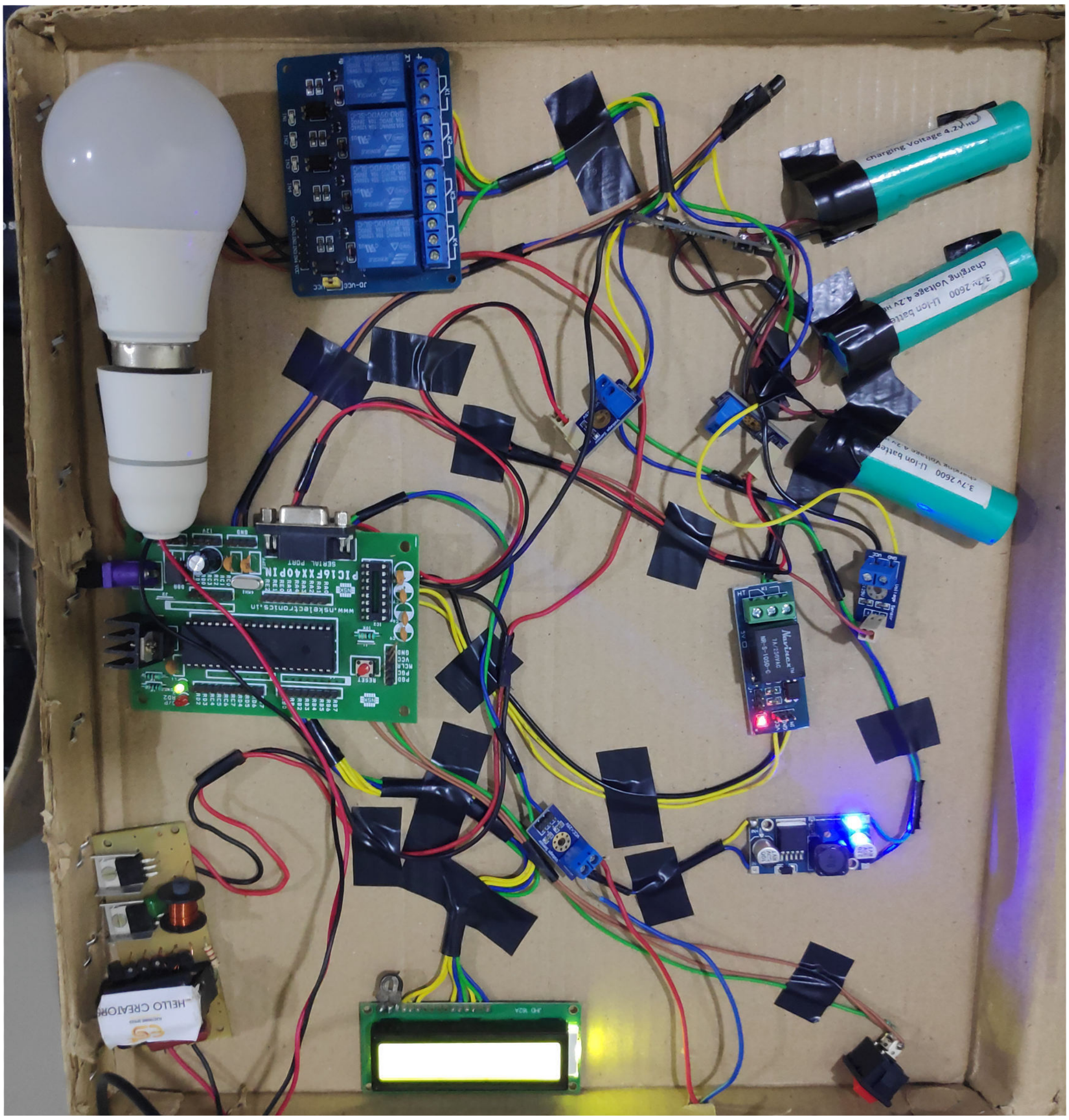

Figure 3.5: Overall Design

3.4 Summary

The chapter discusses a detailed analysis of the project is done. Software implementation and hardware development of the Battery Management System for a standAlone PV design is done in the chapter. The project was initially focused on the simulation li-ion battery model for understanding the charging and discharging characteristics.It is comparative study when the load is powered by battery without its BMS and in the second scenario battery pack with its BMS . The values of the components that were chosen were through theoretical calculations and components availability in the market.

Chapter 4

RESULT ANALYSIS

4.1 Introduction

In this section results of the simulated model and real time data from the hardware implementation of Battery pack, solar panel and other parameters are analyzed and observations are recorded.

4.2 Result Analysis

The overall system is simulated and validated in MATLAB and hardware implementation is analyzed in 3 sections where various output graphs such as State of charge without Battery arrangement system ,State of charge without Battery arrangement system and charging graph is projected based of the readings.

4.2.1 Charging Characteristics

In Table 4.1, the initial LCD display reading of SOC are taken as starting of observation. In this test scenario input is maintained at 12V and 2amps. Readings upto 28 percent of SOC are not displayed due to hardware limitations Charging table of Battery pack when 12V and 2amps adapter is used.

Table 4.1: Charging table of Battery pack when 12V & 2amps adapter is used

TIME(in minutes)	**SOC**(%)
0	28
15	34.464
30	40.928
45	47.392
60	53.87
75	60.4
100	69.71
125	79.1
150	86.2
175	89.4
200	90.3

The reading from the tabular column are used to generate a graphical representation of charging cycle in Fig 4.1. A linear relation can be observed from 30 percent SOC to around 80 percent of SOC. Thereafter, the SOC goes into nonlinear relationship with respect to time. This observation displays constant voltage (CV) stage of charging

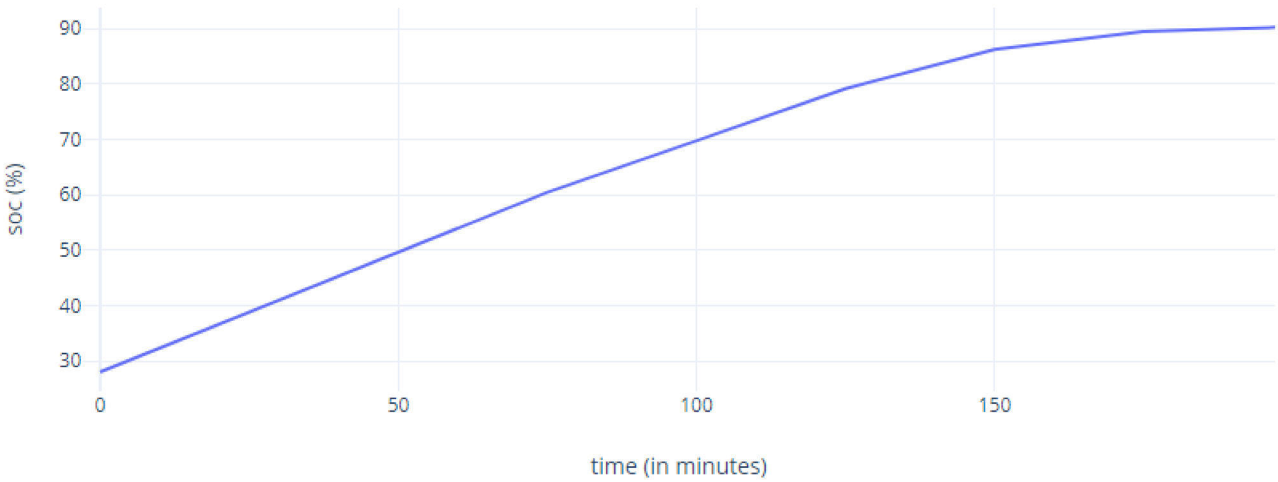

Figure 4.1: Charging Graph

4.2.2 Discharging Characteristics

During the charging cycle SOC peaks at 92.88 percent after extended time. This ceasing in increase of SOC is due to hardware limitations.The discharging characteristics of the battery are observed by allowing the cells to discharge through a 5 Watts load shown in 2 phases first without BMS and then with BMS.

In Table 4.2, displaying discharge table of Battery pack without BMS, it was observed that after around 10 minutes of discharging the load bulb starts flickering at a decreasing rate with respect to time. Reading are taken upto the time when load illumination stops completely.

Table 4.2 : Table for discharge of battery pack without BMS

TIME(in minutes)	**SOC**(%)
0	92.88
1	91.63
2	90.23
3	89.45
4	88.67
5	87.1
6	85.33
7	84.39
8	83.72
9	82.67
10	81.1
11	80.25
12	79.34
13	77.2
14	76.65
15	75.72
16	74.2
17	73.88
18	72.45

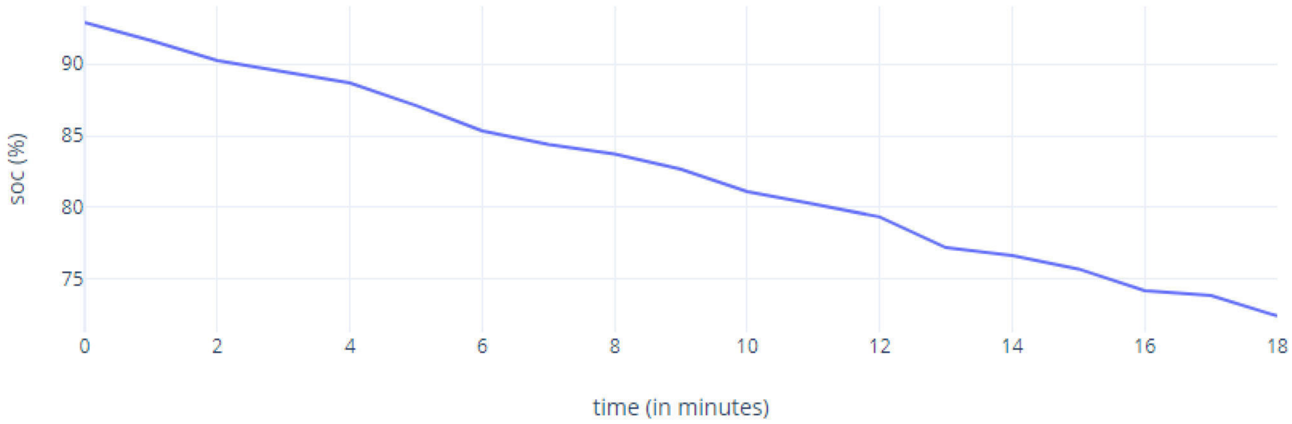

Figure 4.2: Graphical representation of discharging without cell balancing

The reading from Table 4.2 are graphically represented in Figure 4.2. displays the graphical representation of discharging table without BMS. The illuminations stops at around 25 minutes with an almost linear dip in SOC with time.

Discharge table of Battery pack with BMS is displayed in Table 4.3. In this case, a bypass current is flown if there is cell voltage imbalance. This improves the duration for the illumination of load lamp to 25 minutes.

Table 4.3: Table for discharge of battery pack with BMS

TIME(in minutes)	**SOC**(%)
0	93.17
1	92.64
2	91.23
3	90.56
4	89.88
5	88.42
6	87.37
7	86.12
8	85.23
9	84.39
10	83.92
11	82.44
12	81.3
13	80.82
14	79.77
15	78.46
16	77.62
17	76.82
18	76.28
19	75.37
20	74.12
21	73.97
22	73.4
23	72.84
24	72.51
25	72.13

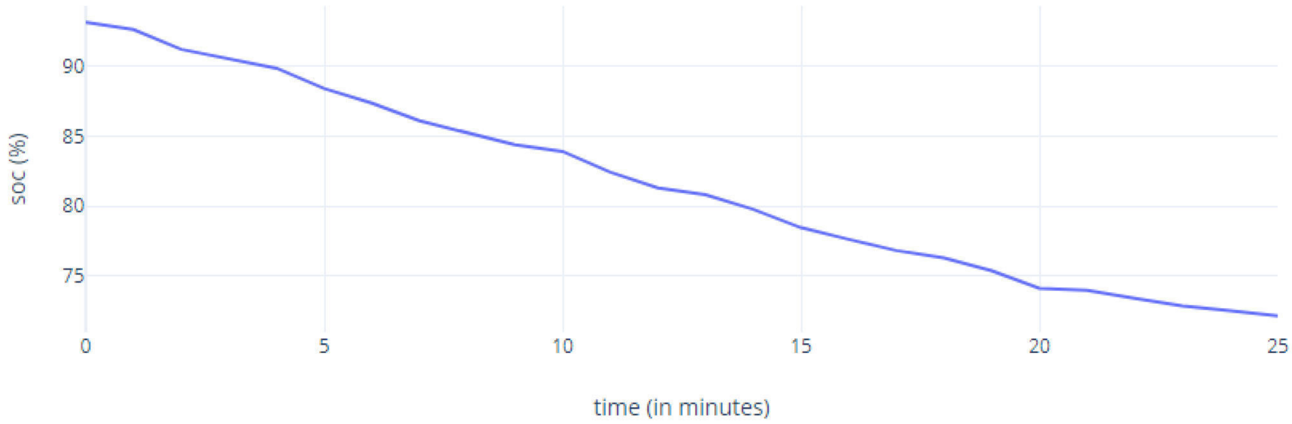

Figure 4.3 Graphical representation of discharge with cell balancing

Figure 4.3 displays the graphical representation of discharging table with BMS. The nature of the curve is observed to be same as discharge without BMS but the discharge time to reach 72.13 percent of SOC has increased. This observation suggests increase in efficiency of the system.

4.2.3 Overall Design

The overall design results majorly depends on the output of the individual stages of the systems.First is the charging cycle where the pack is being charged by a DC adapter

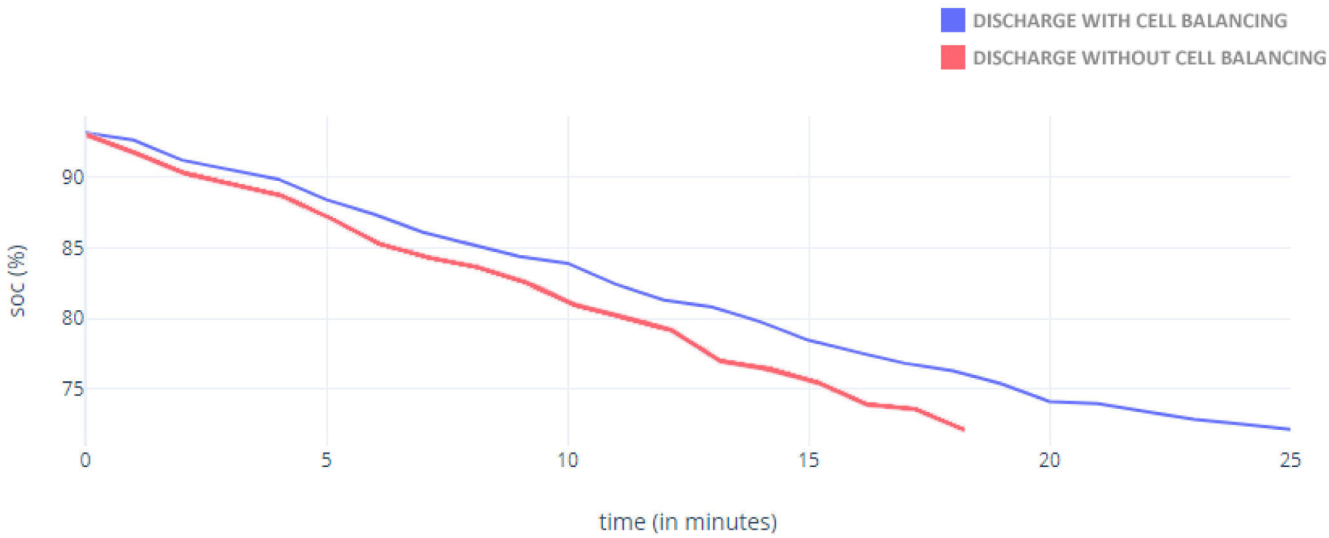

Figure 4.4: Comparison Waveform

which is 12V and 2amps.It requires around 3 hours to charge the battery from 28% to 90% which is observed on LCD. Then is discharge case without BMS where it takes around 18 minutes to discharge the battery from 93% to 72% across an 5w AC load as observed in Figure 4.4. Finally it is the discharge condition with BMS where it takes 25 minutes to discharge the battery from 93% to 72%.Therefore by using BMS the efficiency of battery increased by 5.2%.

4.3 Summary

The chapter discusses extensively on the results obtained when the battery pack is in charging stage,the pack is in discharge stage without its BMS and discharging stage with BMS. the initial LCD display reading of SOC are taken as starting of observation. In this test scenario input is maintained at 12V and 2amps. Readings upto 28 percent of SOC are not displayed due to hardware limitations.During the charging cycle SOC peaks at 92.88 percent after extended time. This ceasing in increase of SOC is due to hardware limitations.Though the results are quiet expected,there are some deviation from true value as the algorithms may further be improved.

Chapter 5

CONCLUSION AND FUTURE WORK

5.0.1 Conclusion

The project deals with discussion of simulation and hardware implementation of Battery Management System for standalone PV system. A MATLAB based simulation model of proposed configuration and working hardware model has been developed to evaluate the feasibility of the system with the proposed configuration. The voltage obtained from solar panel is stepped down with help of dc-dc converter and battery charge-controller which feeds power to the battery pack. The BMS works parallel to the main circuit and monitors the parameters. Finally software simulation and hardware implementation of the overall design is done showing that required parameters are monitored thus increasing the efficiency by 5.2%.

5.0.2 Future Scope

The benefit of using solar is that it is a renewable source of energy. In standalone system solar panel is one of the main component. Although the efficiency of solar panel Is very low which is around 15-20% it is the battery pack which plays a very important role. Therefore it is wise enough to increase the battery efficiency as high as possible. One of the future scope which can be implemented is the System-User interface. In our project we are using the traditional LCD display as the means of communication with the user. The project can be integrated with mobile phones and hence an Android application can be built to view the data. Also using a GSM Modem, we can collect this raw data and sent as an SMS message to mobile phones. With the help of mobile phones, the data can be collected and viewed even from remote locations, where Internet connection is weak Apart from this, with adequate research in this field ,the proposed design can also be implemented in Solar powered Electric/hybrid vehicle .

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