COLLEGE OF ELECTRICAL & MECHANICAL ENGINEERING

FINAL YEAR PROJECT REPORT

BATTERY MANAGEMENT SYSTEM INTEGRATION WITH FAST CHARGING

DE-40-EE

SYN-A

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DEDICATION

This project is dedicated to our parents, their efforts and all the prayers were with us during the project. It is also dedicated to our teachers and all the technical staff who really helped us for the completion of this project.

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Abstract

Battery management system and fast charging of lithium-ion battery are two parts of project. Battery management system (BMS) is used in main industrial and commercial systems to make battery operation more efficient and to keep the battery safe from any damage, to increase battery lifetime and its efficiency. For this battery management system is used to measure battery voltage, current, temperature, state of health and battery state of charge and battery life and its performance. In our project battery management system for electric vehicle is implemented. This system will be integrated with battery of electric vehicles and will evaluates and measure the battery temperature if it will get higher then specified value then will make action to keep temperature down, will measure voltage of battery its current, charging and discharging of battery. This system will keep battery safe from over charging and form over discharging and will determine the battery state of health (SOH) and battery state of charge (SOC). This all will be done by sensors which will monitor physical values and will give data in analog value after processing this data with the help of microcontroller the results will be displayed on LCD connected with microcontroller.

Fast charging of lithium-ion battery is now applied in all industrial and commercial used lithium batteries especially it is used in electric vehicles. Fast charging of lithium-ion battery is done by keeping the battery aspects in control so that battery inner reaction may not be unhealthy. Fast charging is done by basically two techniques one is constant current and constant voltage method and other one which is now most modern method and fastest and save method is constant temperature and constant voltage method. We will apply most modern technique constant temperature and constant voltage method in our project. In this method we will change the current dynamically with change in temperature of battery, maximum current will be applied when battery temperature will not cross the specified limit. When battery thermal environment will exceed the specified limit then current will be decreased. In this way battery charging time of battery will reduce up to 25%. Other method which we will apply to decrease charging time is charging battery by pulses in this in dead cycle wave battery will have time to do inner reaction and, in this way, charging time will be decreased. All this will be done by microcontroller, a buck-buck converter and by applying buck boost converter. Therefore, this can easily solve the modern-day issues where we have lesser time to charge our devices and use them for a longer period of time.

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1.1 Introduction

The battery that we have used is the Lithium Ion Battery as mentioned in title, these batteries have a high energy density, enhanced life cycles and higher amount of specific energy as well; most importantly these are environment friendly. Because of all these characteristics, they have been widely used as a regular basis of rechargeable batteries. Every field of electronics, Li-ion batteries are the most used ones. Our aim is to develop Battery management system and its integration with fast charging. A battery management system (BMS) consists of software and hardware designed to enhance the battery lifer and protect it from any hazards. There are different variables of battery to be measured for its management like battery individual cell voltage, cell temperature, battery current and determining the charging and discharging cycle of the battery. There are two main variable of the battery that should be considered for designing of BMS. The first variable is the battery State Of Charge (SOC) which refers to the amount of charge presented in a battery in a charge or discharge cycle of battery and second is Battery state of Health (SOH) which represents the performance of the battery compared to its past and expected in future cycles. Battery Management System basically consist of main three parts one is measuring unit which measure the different parameters of battery called Battey monitoring unit (BMU), the Battery control unit (BCU)which takes data from BMU and process it and display it and third is protection unit which protects the battery from any disruptions.

As for charging, there are various different charging schemes developed for them. One of them we have used here is called as Constant Temperature Constant Voltage (CT-CV) method. This method solely depends upon the temperature of the cell with which the other parameters are varied keeping the lowest charging time as compared to other charging methods. In other techniques which are constant current, constant voltage, and constant current constant voltage the battery is charged up to its full value without caring the cell temperature. These techniques are very time taking as in constant current technique the current is supplied to battery in 0.5C to 1C rate until battery gets full voltage. In these techniques the battery cell voltage may rise up to dangerous level and also its takes long time. The technique we are using is Constant temperature constant voltage method in which voltage is supplied to battery keeping in view the temperature of the battery. At initial stage the battery voltage is kept high as temperature rises the battery input voltage is decreased so that battery temperature remains in safe zone.

If we briefly explain the advantages of proposed scheme here it goes as:

- First of all, it gives a relatively faster charging time, as per our results with comparison with the CC-CV methods. Overall, 25-30% faster, depending upon the time charged.
- If more faster charging is required in some charging scheme, then this can also be applied by raising the set temperature, which will ensure fast charging up till a certain rise of temperatures.
- There is a Closed Loop charging scheme that adjusts the magnitude of charging current with the battery response and internal condition.

1.2 Current State:

“Battery management system and its integration with fast charging” enhance the battery life and decrease the charging time of the battery. This is now in demand in market as now world is transferring to renewable energy source where storing energy is main problem. As there is revolution of electric car so storing energy and decreasing charging time of batteries is most important aspect. So, this project will solve this issue and will create an ease of user to enhance performance of their energy storage bank and its charging time. There are different techniques of BMS and fast charging, but the technique used one in this project are latest one and currently industry is working on this.

1.3 Problem Statement:

There are lot of ambiguities in current Battery management system and charging techniques. In Battery management system there is not proper sensing system for measuring the parameters of the battery and also algorithm which are being used are not efficient enough to deal with battery issues and have good impact on the battery life. As battery banks are very costly so their management is very crucial and also need of time. Second thing is charging of battery which very time taking and also the techniques through which battery is being charged have bad impact on battery life. It damages the battery cell’s cathode and anode internal composition. So, in this project we are using modern techniques for sensing the parameters of the battery and also using constant temperature constant voltage technique for charging which will decrease the battery charging time and also have good impact on the battery life.

CHAPTER 2: LITERATUER REVIEW

The demand response program is in favour of Battery Management System Integration with Fast Charging. In the recent years of 2010 to 2022, the use of electricity has increased very much. The main source of electricity in today's world is fossil fuels There are 2 problems in that. Firstly, the fossil fuels are going to end as they are non-renewable resources. Secondly, they are the main cause of climate changes. The CO2 emission is due to the burning and use of fossil fuels. So, now world is transferring towards renewable energy resources. As the main renewable energy source now a days is solar system so storing energy for night-time uses is main issue. Thus, the demand response program encourages the use of Battery management system and its integration with fast charging. Battery management system measures the parameters of battery and maintain it to enhance its efficiency and to prolong its life. Fast charging schemes reduced the charging time of the battery and also the proposed one which we are using also make ensure that battery life is not being disturbed.

Following is some of the advantages of BMS and its Integration with Fast Charging:

- Efficiency: The efficiency of battery is increased and also its life is improved.
- Reliability: A battery having Battery management system attached with it is more reliable as protection schemes and cooling schemes are implemented.
- Time: BMS integrated with fast charging reduced the charging time, so it decreased the time which one have to wait for charging.

Battery management system and its integration with fast charger are not very old. The idea of BMS Integration with fast charging is still very young. The concept of the modern BMS was first used in the early 1998. From that time, the smart BMS are evolving and are being used all over the world. Now a days in the advanced countries, they have almost all the smart BMS, and fast charger installed at every car charging pump. But in Pakistan now this idea is revolving, and electric pumps are being installed at motorways exits.

CHAPTER 3: METHODOLOGY

3.1 Objectives:

The main objective of our project is increase battery life, enhancing its performance, saving it form any hazards and decreasing the charging time of the battery. In Battery Management System (BMS) we are measuring different variables of the battery using sensors and processing the data getting from sensors. Determining the battery state of charge and battery state of health which are most import parameters of battery for determining its life and its performance. In fast charging part we are using modern technique Constant temperature Constant voltage technique which decrease the charging time of the battery and also have good impact on the battery life.

3.2 Purposed Methodology:

In our project we are not only designing Battery management system (BMS) and its integration with fast charging using modern techniques, but we are also measuring real time value of battery parameters such as battery individual cell voltage, current, temperature and controlling charge from that data and also showing all the parameters on the LCD. We are using Arduino Mega for developing battery algorithm and processing the data which we are getting from the sensors. Charging circuit is also controlled by Arduino mega. After processing the data all the data is being shown on the battery.

All the working of the project is shown in the diagram 1.

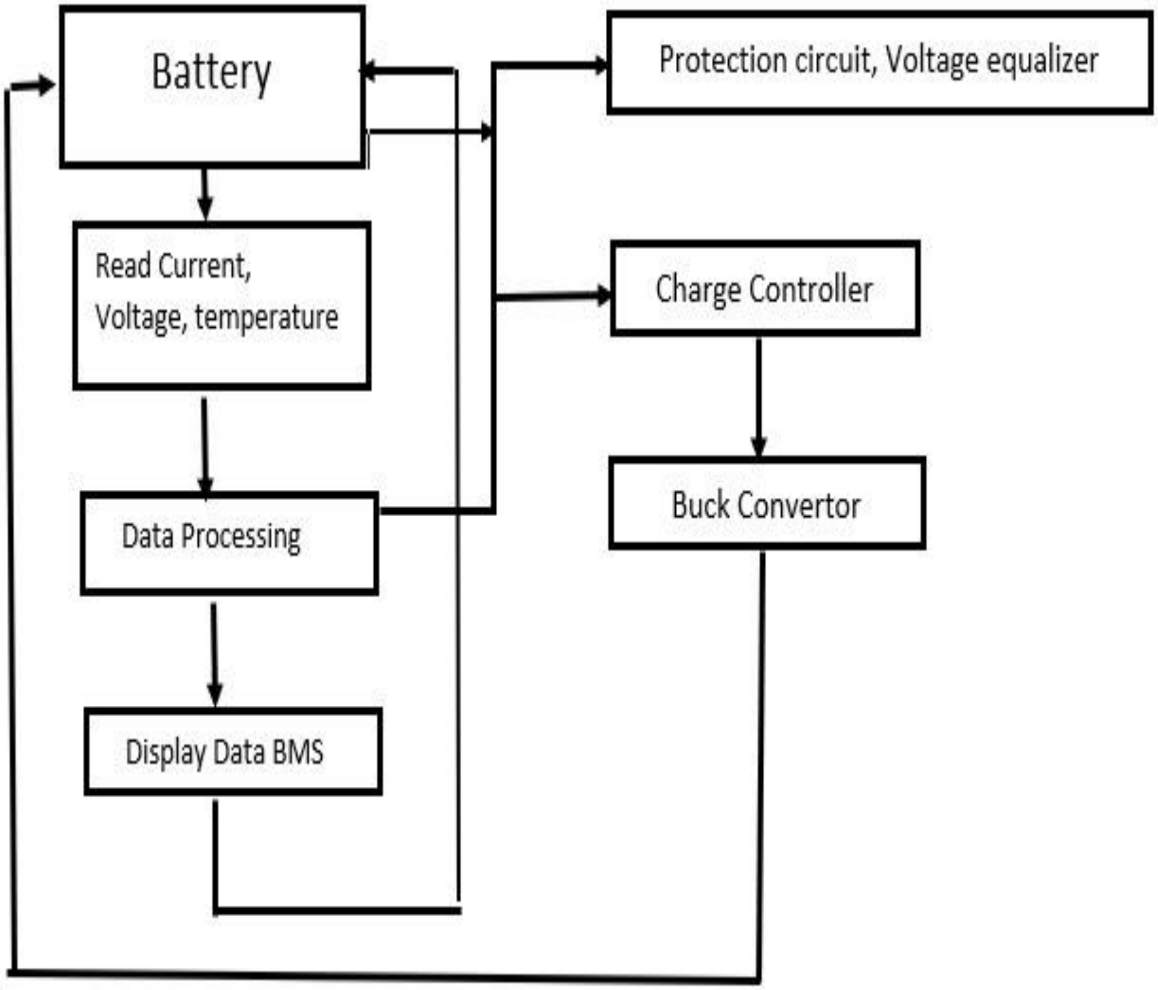


Figure 1 Block Diagram

Chapter 4: Battery Model of LI-ION

4.1 INTRODUCTION:

A lithium-ion battery is a rechargeable battery which is widely used in most common electronic appliances we see every day. The main selling feature is that you do not have to buy the batteries again, but they can be recharged with proper mechanism provided. During the Discharging**,** the lithium ions travel towards the –ve electrode through electrolyte on towards the +ve electrode. During Charging the lithium ions move from +ve electrode to the –ve electrode in the lithium-ion battery.

These batteries have a lithium compound as the main material which is present at the +ve electrode and graphite is present at the –ve electrode. The Lithium-ion Batteries as explained before have no past effect on them and have low self-discharge, with a higher density of energy. The battery used in our circuit is Lithium-ion battery with Lithium Cobalt Oxide as the cathode material which will be explained further on:

The basic functionality of Lithium-ion battery is explained below.

The construction of the battery is made up of a -ve and a +ve current collector, and a +ve and –ve electrodes and separator. The +ve current collector is made up of Aluminium however the negative current collector is made up of copper. The +ve electrode medium used is LiFePO4 & the –ve electrode medium used is LiC0. Separation between them is a material called as Polyolefin porous membrane. The electrolyte in between them is Lithium-Salt which is dissolved in mixture of Ethylene Carbonate and Dimethyl Carbonate.

The chemical equation of this process is as shown below:

$$\mathbf{Li1\text{-}xCoO2\ (s) + x\ Li + + x\ e \rightarrow LiCoO2\ (s)}$$

This is general equation. If we divide it among cathode an anode.

Cathode: $\text{LiyFePO4 (charge)} \rightarrow \text{Liy-zFePO4 + zLi+ + ze-}$

Anode: Lix-z C6 + zLi + ze- (charge)→ Lix C6

The three-dimensional diagram of the Li-Ion Battery is shown below in *figure 4.1*:

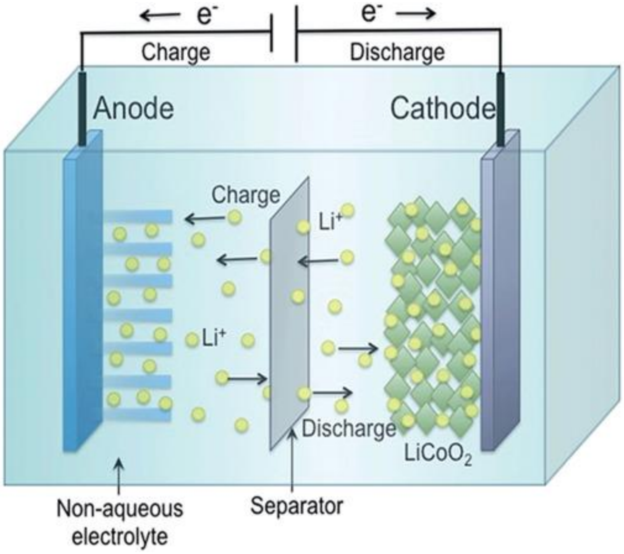


Fig 2 Li-Ion Battery

4.2 Lithium Cobalt Oxide:

Most used Lithium-Ion cathode is the Lithium Cobalt Oxide which has the symbol LiCoO2 which can be abbreviated as LCO. The main material in this which gives out all the outputs is Cobalt. It is used mostly in mobile phones, laptops etc. The reason being its extremely high specific energy value.

It consists of Cobalt Oxide as its cathode and Graphite (carbon) as its anode. In the process of charging the battery, these Lithium ions move from cathode towards the anode via an electrolyte for preparing for the discharging process.

4.3 Charging/Discharging Limits:

Lithium Cobalt batteries should never be charged or discharged at an extremely high current more than its adaptable rating. So, for charging it in a faster way, we must apply a load which is higher than is C-rating, so that it can cause over heating which would result in damaging and demolishing the life span of Li-ion battery. For a faster charging, the rate of current advised is under 1C and most precisely 0.8C.

4.4 Advantages/Limitations

Following are some of the main advantages of the Lithium-Ion battery usage:

- When Lithium-Ion Batteries are disposed of, they are very less harmful.
- These batteries have a much longer life span if compared with other charging batteries
- Li-ion batteries have very high energy density.

Following are some of their limitations:

- Li-ion batteries should not be charged at very low Temperatures.
- They should be charged with breaks in between to maintain their longer life span.
- The very ideal state of charge of these batteries is 40-60%
- Li-Ion Batteries are a little bit expensive as compared to the other batteries.

4.5 Safe Operating Temperature:

We can use lithium-ion battery for a wider range of temperatures starting from 10 degrees centigrade up to 55 degrees centigrade. But their charging should be maintained between 5 degrees and 45 degrees, which in our case we have managed at max 43 degrees. Ideally it should be charged at room temperature which is 20 degrees Celsius.

CHAPTER 5: Elements of Battery Management System (BMS)

5.1: Components of BMS

A BMS may monitor the stateof the battery as represented by various items such as:

- Individual cell voltages
- Battery current in and out
- Temperature of Individual cells
- Battey state of Charge
- Battery state of Health

5.2Battery State Evaluation

Knowledge of the battery state not only helps to determine whether the operational environment is safe and reliable but also provides information about the charge-discharge operation,l whichl isl especiallyl importantl for celll balancing Usually the batteryl statel includesl SOCl andl SOHl determination. SOCl isl similarl tol thel fuell usagel indicationl inl gasolinel cars,l butl thel batteryl isl inaccessiblel forl measuringl andl experiences aging,l varyingl environmentall conditions,l andl charge-dischargel cycles,l whichl willl makesl itl difficultl forl al BMSl tol providel anl accuratel SOCl estimation.l Accordingl to ,l SOHl describesl thel percentagel ofl batteryl lifel remaining.l However,l therel isl nol consensusl onl thel definitionl ofl SOHl becausel itl doesl notl correspondl tol thel measurement of al specific physical quality. Although thel ratiol ofl thel currentl capacityl tol thel maximuml capacityl thatl thel batteryl canl holdl isl usuallyl viewedl asl al healthl indicator,l morel parametersl referringl tol thel fieldl performancel mustl bel consideredl duringl SOHl evaluation.l Thel actuall formulal ofl thel SOHl forl al specificl applicationl isl oftenl al tradel secret.l SOLl isl referredl tol inl thel literaturel asl thel timel whenl thel batteryl mustl bel replacedl .l Itl isl similarl tol SOH,l butl quantifiesl thel remainingl timel untill thel batteryl willl bel unablel tol perform.l Predictionl ofl batteryl performancel helpsl thel engineerl tol planl maintenancel strategies,l andl handlel disposall andl replacementl issues.

5.3 Battery Modelling

Establishing a battery model is difficult due to the complicated electrochemical mechanisms of batteries. From the perspective of chemical characteristics, Scrosati and Garche presented voltage-to-capacity profiles of several Li/Li+ materials. For example, LiFePO4 has a long flat trend when charging, while the voltage profiles of LiMn3O4 and LiCo1/3Mn2/3O2 gradually increase without a flat region. They showed that a generic model for a battery family does not work well for general applications. Currently, battery modeling for SOC determination is commonly developed from various equivalent circuit (RC network) models, which are distinct for different material characteristics and accuracy requirements. Cheng and Tremblay adopted the generic battery model that was integrated in MATLAB . However, the generic model is based on the assumption that the internal resistance is constant during charge and discharge cycles. Thus, the accuracy of this model is subject to challenge. While taking into account SOH estimation, the battery degradation model based on capacity fade was simulated and built . These model parameters were predominantly achieved in terms of the physical characteristics of the specific anode and cathode. However, the external factors, such as environment temperature and discharge current load, will make these stationary models inaccurate in a dynamic environment. As a result, model selection is always focused on in a BMS.

5.4 Cell Balancing

In EVs and HEVs, cells are wired in parallel to form a block to satisfy the requirement of high capacity while several blocks (or cells) are connected in series to provide a high voltage . Each cell is distinct due to manufacturing and chemical offset. Thus, the cells in a series have the same current but different voltage. During charging, capacity fade in cells may result in danger if a cell comes to its full charge easily. In other words, it will suffer from overcharging while all the rest of the cells reach their full charge. Similarly, over-discharge may happen on the weakest cell, which will fail before others during the discharging process. When the battery consists of multi-cells in series, it will be subject to a higher failure rate than any single cell due to a series network. To reduce this effect for prolonging the battery life, an effective cell balancing mechanism that would keep the SOC levels of individual cells in a battery pack as close to each other, should be developed. The mainstream methods of cell balancing can be separated into two kinds: dissipative and non-dissipative. Both of those methods are dedicated to alleviating or even eliminating cell voltage imbalance .However, dissipative equalizers used by resistors facilitate the dissipation of excess energy or current through heat with low efficiency. Non-dissipative equalizers are usually implemented by transformer, inductor or capacitor . They are considered more efficient than dissipative equalizers. However, the exchange of charge or energy among cells makes their charge-discharge profile much more complicated than the conventional profiles. These balancing techniques depend on determining the SOC of each individual cell in the battery.

5.5 State of Charge & Health

SOC is critical, but it is not measurable given the current onboard sensing technologies. The ratio of the currently available capacity to the maximum capacity can be expressed as SOC , which is calculated by Equation

$$SOC = 1 - \frac{\int i\,dt}{C_n}$$

where i is the current, and Cn is the maximum capacity that the battery can hold. SOC reflects the amount of remaining charge that is available to the battery. It is used to determine the driving distance remaining in EVs, while it indicates when the internal combustion engine should be switched on or off in HEVs. Due to the inherent chemical reactions of the battery and different external loads, the maximum capacity of the battery gradually decreases over time. Uncertainty regarding these factors will lead to non-linear, non-stationary battery degradation characteristics. The most straightforward approach for SOC estimation is Coulomb counting, which characterizes the energy in a battery in Coulombs. This method calculates the capacity of a battery by integrating the current flowing in and out of the battery over time. SOC can be obtained by referring to the calibration point at full charge. However, this reference point (i.e., the initial point) will change due to battery aging and coulombic efficiency. Thus, the reference point must be compensated when operating at practice conditions, and the SOC estimation should be updated under different measured voltage.

The extended Kalman filter (EKF) has been successfully applied for the estimation of SOC in HEV BMSs. Plett developed this method on a first-order RC network in a series of papers. The traditional Kalman filter (KF) is used for linear problems, while EKF linearizes the prediction by using partial derivatives and Taylor series expansion. Windarko also adopted the EKF to estimate SOC based on an electrical model with two series RC networks. However, the EKF cannot deal with a highly non-linear system since the first order Taylor series approximation cannot give enough accuracy in highly non-linear characteristics. Salkind et al. utilized Electrochemical Impedance Spectroscopy (EIS) data to estimate SOC with fuzzy logic. Kozlowski et al. input impedance parameters from EIS data into a neural network to estimate SOC. The time series model, autoregressive moving average (ARMA), was also implemented in his work. However, impedance measurement, which is one of the common points of the three methods, suffers from high cost, size constraints and measurement sensitivity.

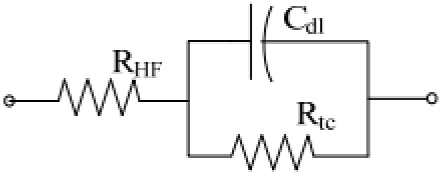
Hansen and Wang applied a support vector machine (SVM) using both classification and regression to estimate the SOC without establishing a battery circuit model. SVM transforms a low-dimensional nonlinear problem into a high-dimensional linear problem. The kernel function in Equation maps the low-dimensional data into high-dimensional data:

$$f(\boldsymbol{x}) = \sum_{i=1}^{N} (\alpha_i - \alpha_i^*) K(\boldsymbol{x}_i, \boldsymbol{x})$$

where αi and * αi are selected during the training process to minimize the loss function. The input vector x included both current and voltage parameters. The estimation of SOC was evaluated under steady state and dynamic state. However, parameter tuning is a tedious process for obtaining the optimal SVM model.

SOH describes the physical condition of a battery, ranging from internal behavior, such as loss of rated capacity, to external behavior, such as severe conditions .Unlike SOC, there is no clear-cut definition of SOH. A general definition of SOH is that it reflects the health condition of a battery and its ability to deliver specified performance compared to a fresh battery. The SOH in EV applications is used to characterize the ability to drive a specific distance or range. SOH in HEV applications is a characteristic of the specified power, such as the cranking power from regenerative braking. Scholars and manufacturers use the percentage of nominal capacity as the health threshold of the battery . When the capacity reduces to 80% of the beginning of life capacity after charge-discharge cycling, it is defined as battery failure. However, studies have defined different rules or indicators to quantify the SOH in terms of battery characteristics, test equipment, and different applications. Pattipati et al. combined capacity fade and power fade as health characteristics. Capacity fade indicates the decrease in the driving range with a fully charged battery pack, and power fade indicates the reduced acceleration capability. Both of these features were input into an auto-regressive Support Vector Regression (SVR) model to estimate SOH. Here, the power fade was due to an increase in cell impedance during aging. The total resistance ( ) R = R R HF tc + was obtained from EIS data using nonlinear least squares. A Randles circuit model of a battery, where RHF and Rtc are the high frequency resistance and the transfer resistance.

Widodo et al.proposed a new feature, sample entropy (SampEn), as input data to predict SOH for target vectors of an intelligent system. SVM and its Bayesian version, relevance vector machine (RVM) , were used to compare the predictive performance.



$$P = \frac{V^2}{R}$$

$$\text{Power Fade} = 1 - \left(\frac{\text{Power}(k)}{\text{Power}(0)}\right) = 1 - \frac{R(0)}{R(k)}$$

$$\text{Capicity Fade}(\%) = 1 - \left(1 - \frac{\text{Capacity}(k)}{\text{Capacity}(0)}\right) \times 100\%$$

SampEn is expressed as Equation

$$\text{SampEn}(m, r, N) = -In\left[\frac{A^m(r)}{B^m(r)}\right]$$

where N is the total number of data points, m is the length of sequences to be compared, r is the tolerance parameters, ( ) m B r is the mean value of two similar signal segments that are composed from input vectors with m points, and ( ) m A r is similar to ( ) m B r and will match for m+1 points. Chao and Chen designed a state of health estimator for lead-acid batteries. Coup de Fouet voltage ,internal resistance and transient current, were input into a modified extension matter-element model to develop intelligent SOH evaluation . The mathematical formula is expressed as in Equation . Here, health is referred to as the “matter”, R, which is described by three elements: N (name), C (characteristic), and V (value of characteristic). Through training the data, the weight of each characteristic was quantified and estimated based on the test data. The result was validated and compared with the extension neural network method:

$$R = (N, C, V) = \begin{bmatrix} N\,C_1\,V_1 \\ C_2\,V_2 \\ C_3\,V_3 \end{bmatrix}$$

CHAPTER 6: CHARGING SCHEME

6.1 Introduction:

The charging scheme that we have proposed here directly depends upon the Temperature of the cell as our main concern regarding the fast charging is a huge increase in temperature which we have to control and maintain. As we know temperature plays an important role in many of our electro-chemical reactions and such mechanisms which constitute inside a Lithium-ion cell. This is displayed in the form of cell performance whether it is enhanced or degraded. There are a lot of disadvantages of high temperature, mainly which can be that it can cause an overall increase in the resistance/impedance of cell, or it can cause its capacity to fade. Keeping all these circumstances in mind, we must maintain a faster charging mechanism while maintaining the temperature of the battery as well. For this purpose, the method we have used is called as Constant Temperature-Constant Voltage. This will basically enable in reduction in the charging time without affecting the life cycle of the battery.

In order for this procedure to take place, the magnitude of charging current has to be controlled in accordance with the temperature of the cell which should be measured.

The control law is basically a simple PID Controller aided with a feed-forward path. It has the following parameters:

$$e(n) = T_{set}(n) - T_{fb}(n) \qquad (1)$$

$$I_p(n) = K_p e(n) \qquad (2)$$

$$I_i(n) = I_i(n-1) + K_i e(n) \qquad (3)$$

$$I_d(n) = K_d[e(n) - e(n-1)] \qquad (4)$$

$$I_{pid}(n) = I_p(n) + I_i(n) + I_d(n) \qquad (5)$$

Here e(n) states the inaccuracy of the controller, T(fb), T(set) is point of setting, Kp, Ki and Kd are the different values of gain for the proportional, integral, and derivative terms respectively.

On the internet, we found a conceptual depiction of comparison between both CC-CV and CTCV methods, the following diagram *(figure 3.1)* illustrates it clearly:

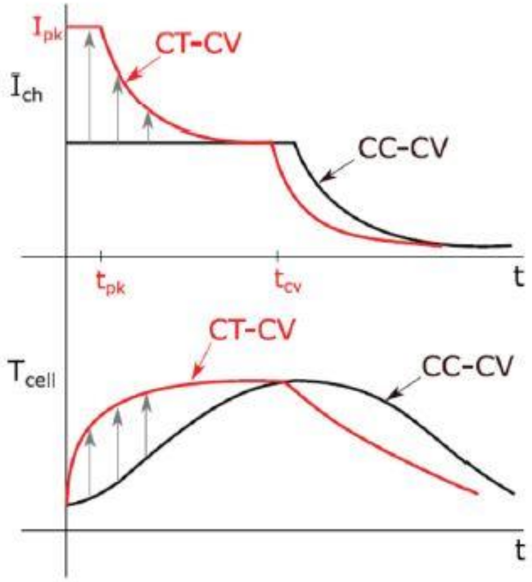


Fig 3 Comparison between CC-CV and CT-CV

This depiction shows the cell temperature and current comparison between both methods. Clearly it shows that the CC-CV method has a lower temperature in the starting phase, but it increases further on at the start of Constant Voltage method. Therefore, explaining the value of increase in the current of charging during the initial stages in Constant Current mode, while minimizing the value of current in Constant Voltage method. Thereby, achieving the value of same temp as in Constant Current-Constant Voltage case.

As depicted, the Constant Current part of the complete Constant-Current Constant Voltage Cycle experiences low temperature and it has a relatively high set of temps while the process is at the end of the CC mode, and also at the beginning of the CV mode as well. This all implies for the charging current and its scope in the initial part of the CC phase, and for reducing the current when it is imminent in the CV mode. Only this way, Constant Current –Constant Voltage charging can meet the equivalent final temp. To avoid Lithium getting plated on the anode, it is necessary that the value of current is minimized during majority of the charging cycle. A very easy method to achieve a certain objective which will meet the fore mentioned requirement to utilize some gradually reducing current value, which goes from the starting value to the ending value, in form of the close-loop term with respect to current.

If current, I(f) is given as:

$$I_{ff} = 2C \qquad : 0 <= t < t_{pk} \tag{6a}$$

$$I_{ff} = C\,(1 + e^{-(t-tpk)/\square}) \qquad : t_{pk} <= t < t_{cv} \tag{6b}$$

$$I_{ff} = x \qquad : t > t_{cv} \tag{6c}$$

The equations 6(a, b, c) can also be known as equation 6 only as a combination of all 3 relations.

Here C denotes the C-rate of the Battery, t(pk) is the instant which makes the value of starting current of charging to be held at its maximum. The initial charging current is held at the peak value. t(cv) is also that instant at which the constant voltage profile is achieved, and next is the time constant of the decay which occurs exponentially. The maximum value of the charging current has been bounded to only (2C) due to safety purposes and for highest rating. Relying on the internal chemistry of the battery, with Lithium Titanite being used as an electrode. It is likely that the temperature rise will be observed with the increased peak current, increased heat and resistance.

This data proposes that the suggested method has the same impact on the chemistry and health ratio of the cell as Constant Current-Constant Voltage mode. A long set of charging and discharging cycles are needed to completely confirm this procedure with the expected outcomes.

Figure 3.2 below shows the model of a simple Li-ion cell:

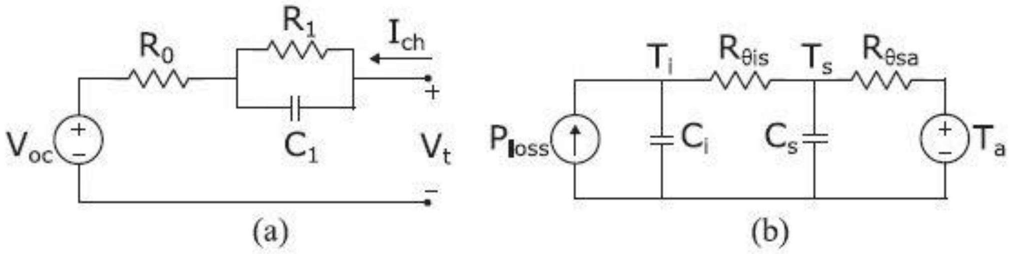


Fig 4 Modelling of Lithium-ion cell

Relying on the results that we obtain from the heat sensor, the controller will look for possible answer in the presence of the closed feed-forward loop so that the temperature of the battery doesn't rise from the initially adjusted value. In the reciprocal cycle of this closed loop term, this transfer function has gains (Kp, Ki, Kd) which are set to a very high value for the controller so that it can pinpoint to a solution very quickly. However, these higher gains are not very much desirable too. This feed forward term helps alleviate the problems.

Once the voltage limit is reached, this charger shifts from CT mode to CV mode and the calculated values from this PID controller and the feed-forward term which is inconsequential (x).

Once in CV mode, the CT-CV protocol is nothing different as explained above justifies for obtaining the following goals measured even the values of constants are randomly selected. Whereas the possibility of further improvement always stays at large of the charging method by measuring the feed-forward term relying on the model of the Lithium ion cell detailing its electrical and heat conditions. Here, V(oc) represents the voltage at the OC, while Vt represents the voltage at the node. Values of R0 and R1 collectively are the constituents of the internal resistance of the battery. C1 is responsible for the transient change during both cycles, however it can be ignored when considering temperature dynamics. Supposing the component of alternating current is negligible, the current of charging passes through R0 and R1 which are ‘’connected in series’’ yielding the dissipated power.

$$\text{Power loss} = I^2(ch)\,[R0 + R1]$$

However, the different values of resistors keep altering the duty of the State of Charge with a typical U-shaped graph, which has a relatively larger value at the charging state. This process yields in the making of a completely non-linear battery that opposes the informative aspect over the transfer function and its analysis. So, by using Zeigler-Nicholls tuning we can find the suitable controller gains. The releasing of the power creates a relatively higher temperature in the internal parameter of the battery area. (Ts) as represented in the second-order temperature model. The differential equation is as follows:

$$C_i\,(dT_i/dt) = P_{loss} – [(T_i - T_s)/R\theta_{is}]$$

$$C_s\,(dT_s/dt) = [(T_i - T_s)/R\theta_{is}] – [(T_s - T_a)/R\theta_{sa}]$$

Where Ci=cell internal heat capacity, Cs= cell surface, Ti=cell

Ts= cell surface, Ta= ambient temperature.

Considering the charger as a controller powering source, which can be calculated through mathematical calculations. The changes in R(int) are basically because of aging and the difference between cell-to-cell. Understanding the above-mentioned differences, a gradual estimation of the current content which has been achieved forms the basis of the feed forward charging content as explained. Then in order to cater for the set temperature requirement, the PID controller will modify the charging current of the next to the feed forward term.The major difference between our proposed model which is Constant Temperature – Constant Voltage model and the commonly used one CC-CV scheme is the controlling technique which is present in our mode. This controlling technique signals the stopping/flowing of current with respect to the increase or decrease in temperature. Therefore, all the temperature increase hazards are also monitored and balanced.

6.2 Major Difference:

The major difference between the proposed CT-CV method and the most conventional charger CC-CV is that CT-CV uses a control technique and is more relatively efficient. Although power devices can handle double the power in CC-CV mode as compared to the proposed one, but at the cost of increased cell temperature to a huge extent. Many current Battery Management Systems use temperature sensing to line out the safety parameters in an apparatus. These same temperature sensors can be used in the build which will slightly increase the cost but will surely increase the efficiency of the system.

6.3 Reason for Proposed Method Usage:

As we know, most of the Electric Devices we use today like mobile phones, laptops, UPS etc. These all have Li-ion batteries inside them which need to be recharged. Now, in the daily routine we need efficiency, we need faster and upgraded version of every gadget. So, the problem arises to charge this devices fast so that they can be used again, and charging them at a much faster rate is the real challenge because time is money.

Charging it fast is easily achievable, but one major concern is the increase in temperature of battery. And also this Fast Charging is not tolerated by every Li-ion battery, so it might effect on the battery life of that particular battery.

‘’So, we have proposed a method to attain fast charging via CT-CV method which monitors the Voltage of the charger with the alteration of Temperature, yielding faster charging and ensuring long lasting battery life.’’

And the method used to apply it is very simple, a transfer function used whose value we have chosen using SISO tool which stabilizes the values of poles and zeros at max. The diagram of this structure is shown below *(figure 5)*, we also have explained it recently in the progress report presentation.

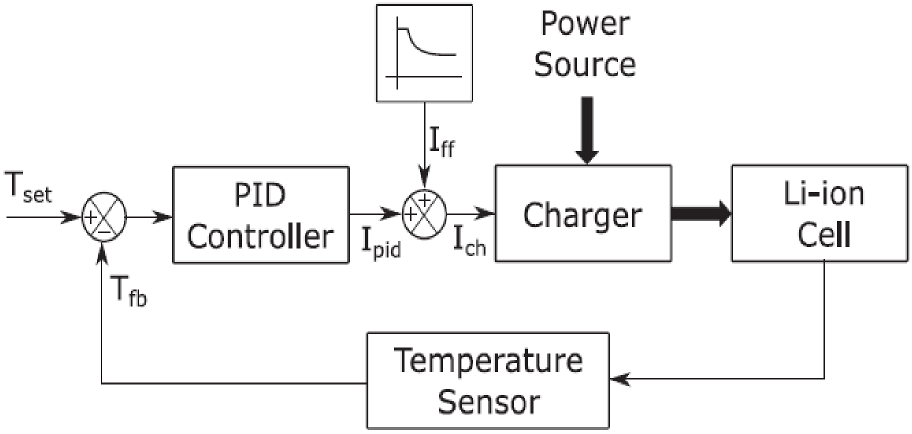


Fig 5 feed forward loop

If explaining it very simply, it is the management of temperature. A PID controller used to supply current through it to an adder, which adds with a pulse and goes into charger, which charges the Li-Ion. Now a Temperature Sensor is connected with this cell, which sends the signal back to the Gate, if certain value of Temperature is reached, just cut off the supply of current to the PID, in this way the faster charging is maintained with the control of temperature as well. This technique is called as CT-CV technique.

The previously mentioned techniques supply a charging current which slowly alters with the passage of time. This adds a chose AC ripple value periodically in the current which formulates two other techniques one of which is called as SRC charging. SRC explains as sinusoidal ripple current and pulse current charging. In both mentioned techniques, the value of charging current has a 2C peak to peak ripple which rides on the 1C dc offset. This ripple can either be a sinusoidal wave or a square wave which will have the same frequency as 900-1200Hz. This frequency is determined based on the cell parameters. With both of these methods, the main goal in consideration is the reduction in charging time, which does actually reduce up to 20%. The key point which differentiates it with the CC-CV method is the reduction of temperature which is also observed as a 50% decrease. These both methods also use an Open Loop approach, in which the profile of charger is predefined.

The optimized MCC charging current algorithms can be used to overcome this problem to a certain extent, but this overcoming takes different cycles of charging and discharging. These cycles can extend up to a week as well. So, making this method not reliable. There is also a chance that certain temperature or voltage variations may come up before it completes its cycles to optimize the algorithm. So, what we need is a scheme that can reduce the close loop time, for example using instantaneous cell voltage or temperature to formulate this error.

So, these all explanations basically demonstrate the need and usage of the method we have proposed below termed as Constant Temperature – Constant Voltage method.

CHAPTER 7: SOFTWARE AND HARDWARE IMPLEMENTATION

7.1 Software Implementation:

We have made prototype of our project using different type of software and after verifying the design of the circuit from software simulation we have implemented our project on hardware. These are following software which we have used in our project while designing and designing hardware.

- Proteus
- MATLAB
- ARDUINO IDE

Proteus and MATLAB were used for simulation work. Initially we have designed our project on proteus and for further testing of batteries we have implemented circuit on MATLAB SIMULINK. We have used MATLAB SIMULINK to have real time values. As in proteus we cannot have battery initial SOC value its temperature and its response time. So, to have real time value we have used Simulink after setting initial values of battery variables so that we can run simulation for specified time can have its responses when two different charging schemes are applied on lithium-ion battery. We have used proteus for the PCB designing. Aurdino IDE is used to write the Battey management system algorithm which is further implemented in hardware using Aurdino Mega.

7.1.1 Circuit Diagram:

Here is complete circuit diagram of the project where Battery management system and fast charging circuit is implemented. Aurdino Mega is used as a controller and for processing of data.

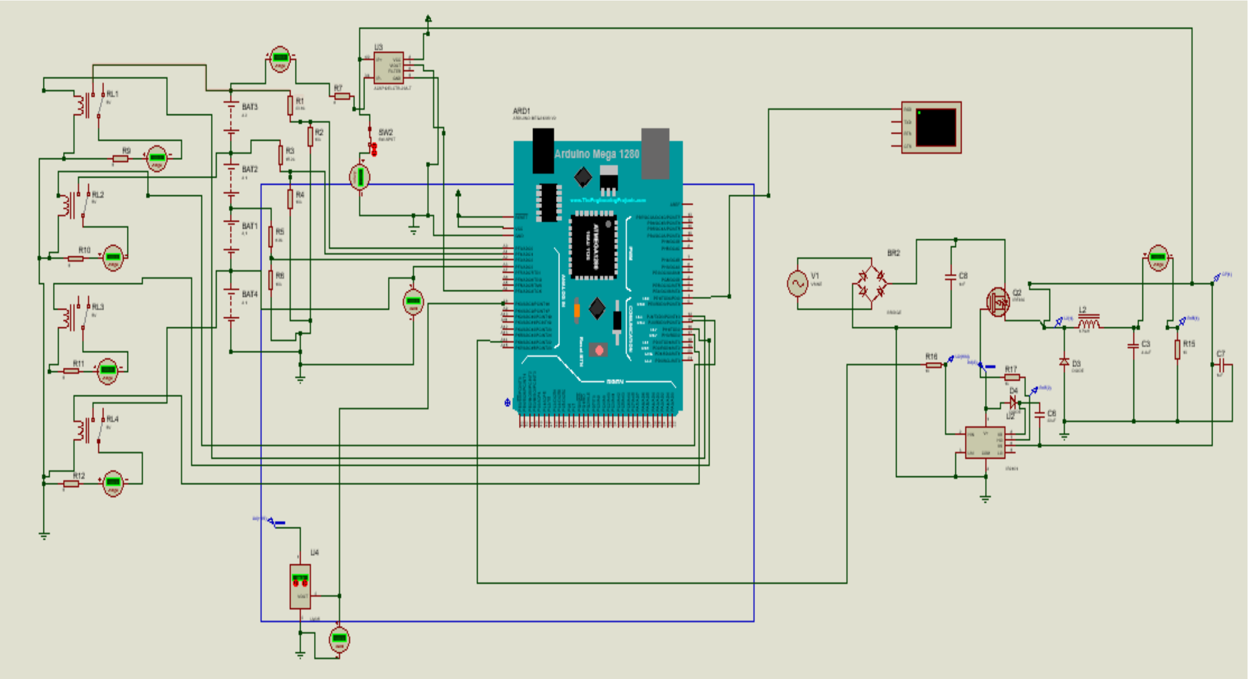


Fig 6 Complete Circuit Diagram

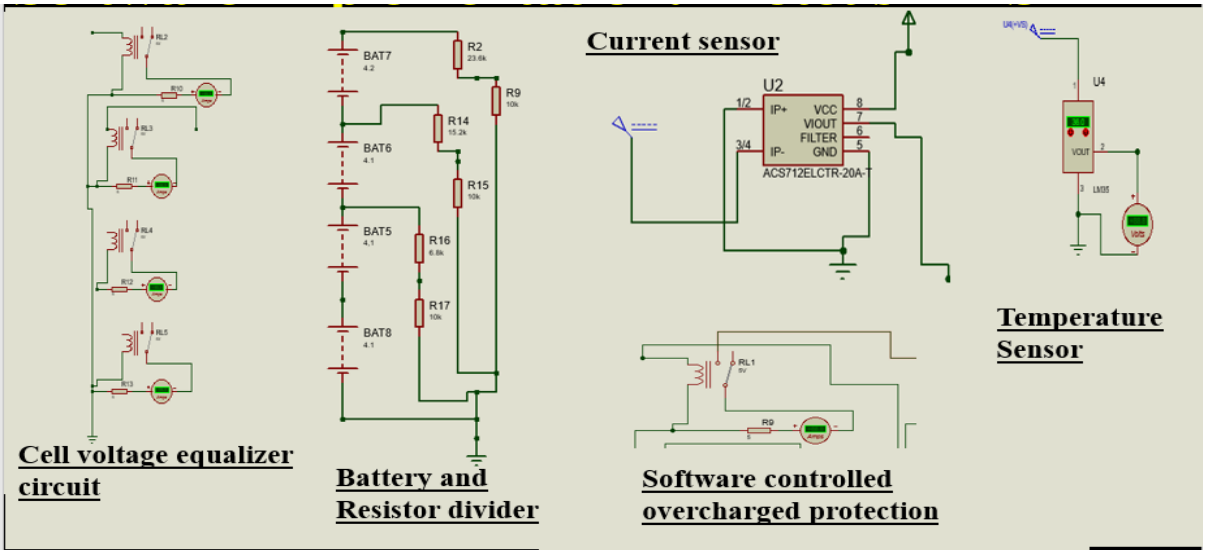


Fig 7 BMS Circuit Diagram

Above circuit is separate circuit of Battery management system where different sensors are used to measure the variable of the battery.

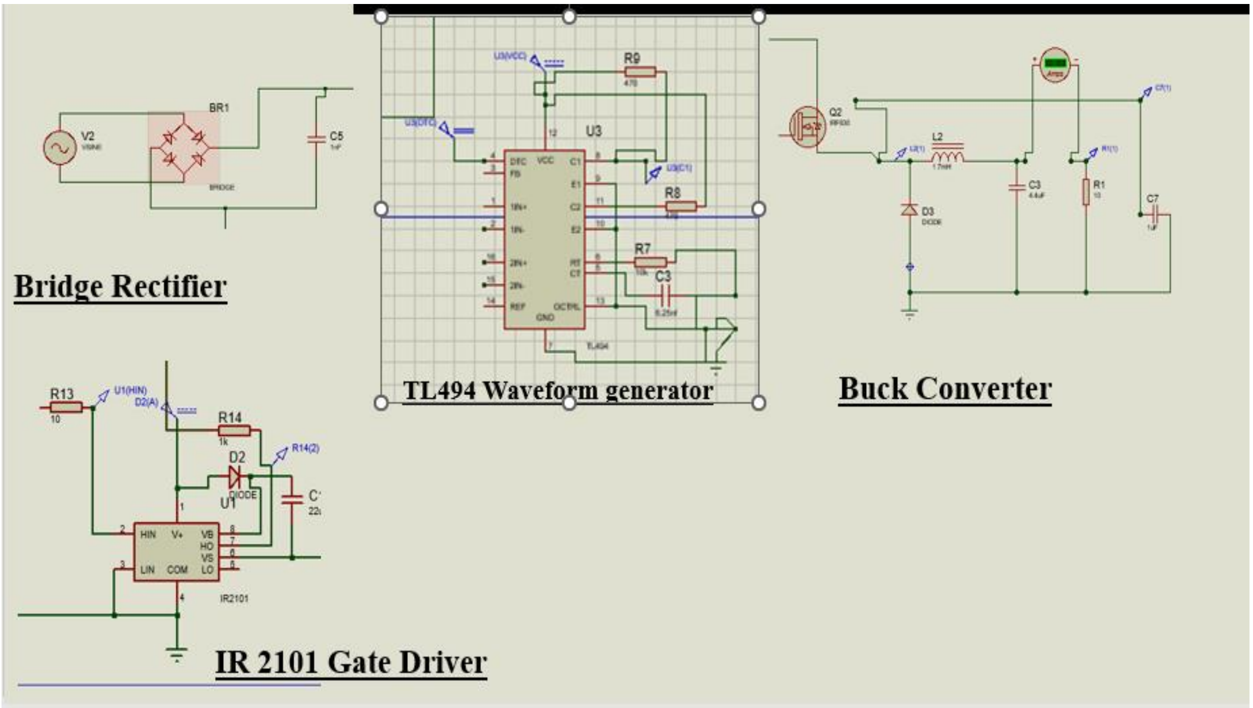


Fig 8 Fast Charging Circuit Diagram

Above diagram is software implementation of charging circuit. In charging circuit, we have used the rectifier for the rectification of AC voltage, Buck converter is used for stepping down of voltage.

7.2 Project Circuit Elements:

Here are details of all the project circuit elements which are used while implementing the design.

7.2.1 Buck Converter:

In many scenarios, the situation is as such that we need an overall lower voltage at the output, so we tend to use a device such as Buck Converter also known as the Step Down Converter.

For example, if we have 12V supply but the output application of it required is only of 3.3V, so in this case the converter used is called the buck converter.

$$P = (V_{in} - V_{out}) * I_{out}$$

This is the power dissipated which is calculated to be around 8.7Watts, and this is a lot of power for a very small linear regulator to dissipate. Calculating its efficiency results out to be very in effective as well therefore the need for a step down converter heavily arises.

The **working of Buck converter** is slightly similar to that of PWM ‘dimming’. We’ve all heard of lights being dimmed by a PWM signal. A small duty cycle means that the average voltage seen by the load is small and when the duty cycle is high the average voltage is high too.

The voltage that is supplied is the average of the overall voltage, and a very raw pulse width modulated signal is generated and there is nothing such delicacy with load. Although we can connect an Resistor Capacitor based filter here which also depends on the duty cycle of the supplied Pulse Width Modulation.

This output of the above PWM shows that the output is clean with minimum distortion. It is a clear depiction of raw PWM signal which is labelled in blue color.

Step1: The switch is turned on which allows the current to flow through it outside the capacitor, also the value of voltage is limited so that its value does not rise above a specific value.

Step2: Afterwards. the switch is turned off, and the inductor utilizes that voltage value, and thereby the inductor acts as a source now. This power allows the capacitor to charge its value, and the value of diode through it. This maintains the output current even when the cycle is switched.

Step3: Now the mosfet is turned off and current to this inductor is stopped. This inductor manages the smooth flow of the current and opposes any sudden change. This responds by the creation of a large voltage which has opposite polarity. If we eliminate the remaining circuit, we an easily notice how the inductor then acts like a voltage source. In this way, the output capacitor is charged at a higher rate and therefore acts as a supplying source.

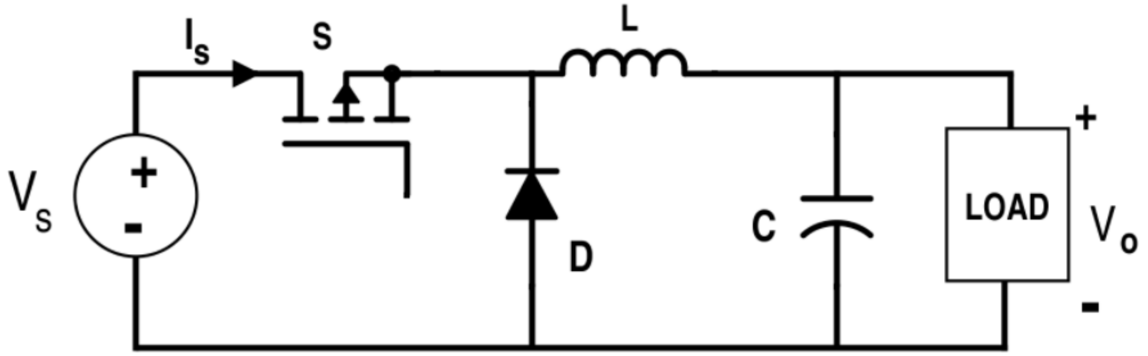


Fig 9 Buck Converter

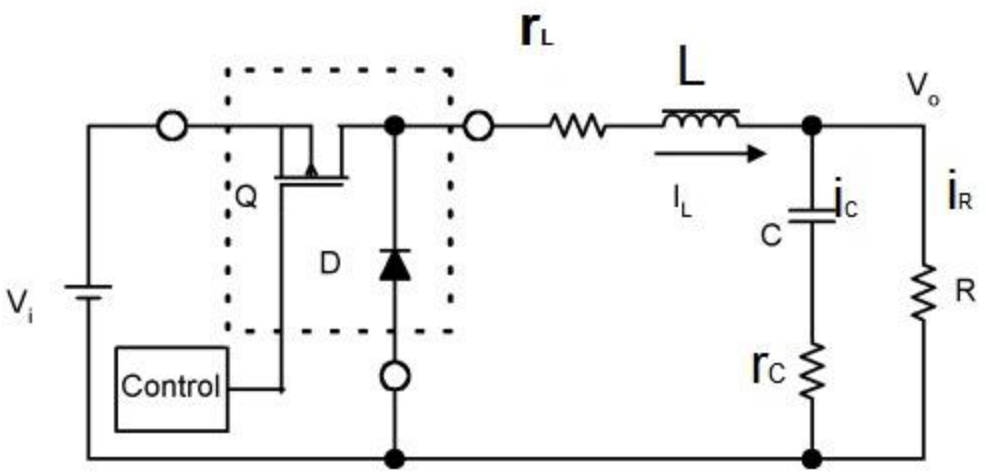
The inductor current :

Switch Closed :

$$v_L = -V_{out} \rightarrow \frac{di_L}{dt} = \frac{V_{in} - V_{out}}{L}$$

Switch Open :

$$v_L = -V_{out} \rightarrow \frac{di_L}{dt} = \frac{-V_{out}}{L}$$



$$i_C(\mathrm{t}) = i_L(\mathrm{t}) - i_R(\mathrm{t})$$
$$i_C(\mathrm{t}) = \frac{\mathrm{C}dV_C(\mathrm{t})}{\mathrm{dt}}$$
$$V_C(\mathrm{t}) = V_O(\mathrm{t}) - r_C i_C(\mathrm{t})$$
$$Vo(t) = \frac{1}{\mathrm{C}}\int i_L(\mathrm{t})dt - \frac{1}{\mathrm{C}}\int \frac{V_O(\mathrm{t})}{\mathrm{R}}dt + r_C i_C(\mathrm{t})$$

$$Vi(t) = Vo(t) + \frac{Ldi_L(\mathrm{t})}{\mathrm{dt}} + r_L i_L(\mathrm{t})$$
$$i_L(\mathrm{t}) = \frac{1}{\mathrm{L}}\int (Vi(t) - Vo(t) - r_L i_L(\mathrm{t}))$$
$$Vo(t) = \frac{1}{\mathrm{C}}\int i_C(\mathrm{t})dt + i_C(\mathrm{t})\mathrm{r_c}$$

so, transfer function of Buck converter is:

$$T_{\mathrm{p}}(s) = \frac{v_{\mathrm{o}}(s)}{d(s)} = -T_{px}\frac{(s+\omega_{zn})(s-\omega_{zp})}{s^2+2\xi\omega_0 s+\omega_0^2}\,\frac{s-(2/T_{\mathrm{d}})}{s+(2/T_{\mathrm{d}})}\,.$$

7.2.2 Controller for Buck Converter

In recent years, digitally regulated power supplies have been the hot topic due to rising demands for DC-DC circuit efficiency and power usage. The analog diagram of the buck converter is shown in the figure below. Buck controller consists of the power stage, error amplifier, comparater, and driver circuit.

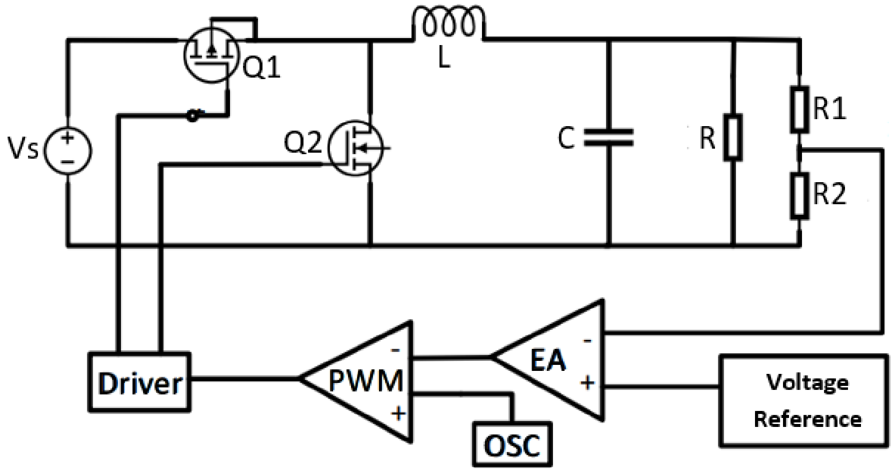


Fig 10 Controller for Buck Converter

Digital control power-supply has advantages of high accuracy, low power consumption, high efficiency, and the small size. They are widely used in various applications in the industry, such as the power management of new energy vehicles, the power adapter of electronic equipment, and the communication industry. This control method is costly, the area of the circuit board is larger, and the circuit reliability is relatively low. The fully integrated digital control power supply proposed in this paper integrates the power levels except for the inductors and the capacitors, and all the digital closed-loop control modules into one chip, which effectively reduces the cost of the chip, the area of the power management chip, at same time, it also increases the reliability of chip. Compared with analog circuit control, the advantages of digital circuit control are high flexibility, high accuracy, and online tuning. Fully integrated digital control chip has gradually become the trend.

7.2.3 DC-DC Converter

The system architecture diagram of the digital DC-DC buck converter. The circuit consists of two switch devices, the PID controller, the PWM modulator, the boost driver, an ADC converter, and the power stage. The two MOSFETs Q1 and Q2 are controlled by two PWM signal with dead time. The output voltage is directly converted to the digital value through the ADC converter. The digital value is compared with the reference value to produce the difference, which is passed The PID algorithm calculates and outputs the corresponding duty value and controls the DPWM module to generate two PWM signal to control the opening and closing of the switching device.

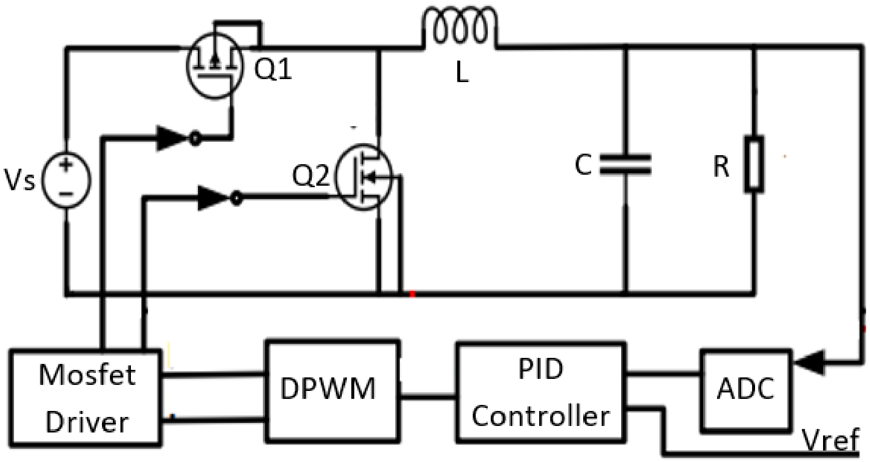
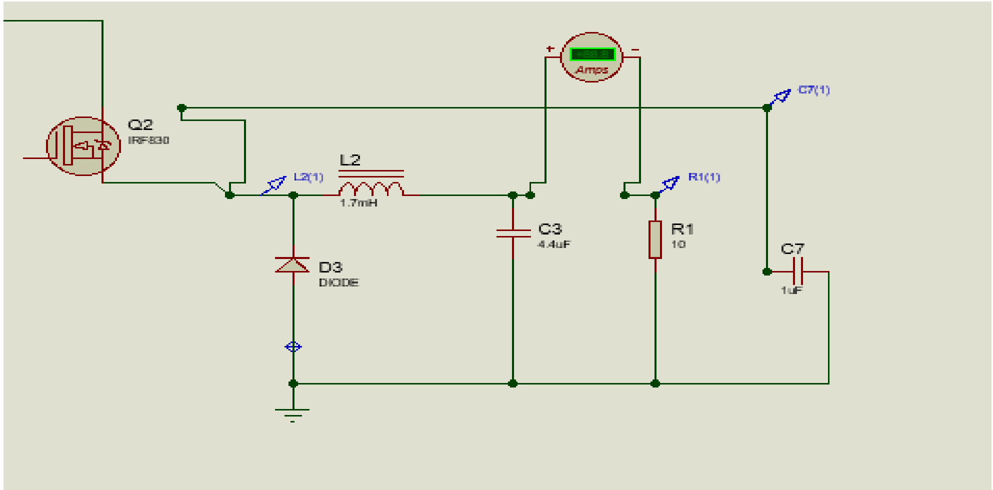


Fig 11 DC to DC Converter

As we know that the output of the buck converter is not pure dc instead it is the train of pulses i.e., when the chopper switch is ON then the output is dc input to the chopper and the output is zero when the chopper switch is OFF. So ,in order convert the chopped dc into pure dc w need an output filter which averages the converter output voltage. The figure shows the simple second order output filter.



Transfer Function is given as

$$G(s) = \frac{R}{RLCs^2 + Ls + R}$$

The calculation of inductor and capacitor values are based on the trial-and-error method. It should be noted that, the inductor should be chosen that it should carry the maximum load current with factor of safety. Based on the 10-20% of the output ripple current as the rule of thumb, first we must choose the inductor value and then find the value of capacitor based on the break frequency of the filter i.e.

$$fr = \frac{1}{2\pi\sqrt{LC}}$$

To get the low output ripple, the switching frequency of the converter should be far high from the break frequency of the output filter.

7.2.4 Designing of Buck Converter

The **buck Converter circuit** consists of the switching transistor, together with the flywheel **circuit** (Dl, L1 and C1). While the transistor is on, current is flowing through the load via the inductor L1. The action of any inductor opposes changes in current flow and also acts as a store of energy.

The first step to calculate the switch current is to determine the duty cycle, D, for the maximum input voltage. The maximum input voltage is used because this leads to the maximum switch current

$$\text{Maximum Duty Cycle: } D = \frac{V_{OUT}}{V_{IN(\max)} \times \eta}$$

VIN(max) = maximum input voltage

VOUT = output voltage

η = efficiency of the converter, e.g., estimated 90%

The efficiency is added to the duty cycle calculation, because the converter also has to deliver the energy dissipated. This calculation gives a more realistic duty cycle than just the formula without the efficiency factor. The next step in calculating the maximum switch current is to determine the inductor ripple current. In the converter's data sheet; normally, a specific inductor or a range of inductors are named for use with the IC. So, use the recommended inductor value to calculate the ripple current, an inductor value in the middle of the recommended range, or if none is given in the data sheet, the one calculated in the Inductor Selection section of this application report

$$\text{Inductor Ripple Current: } \Delta I_L = \frac{\left(V_{IN(max)} - V_{OUT}\right) \times D}{f_S \times L}$$

VIN(max) = maximum input voltage

VOUT = desired output voltage

D = duty cycle

fS = minimum switching frequency of the converter

L = selected inductor value

It now has to be determined if the selected IC can deliver the maximum output current.

If the calculated value for the maximum output current of the selected IC, IMAXOUT, is below the system's required maximum output current, the switching frequency has to be increased to reduce the ripple current or another IC with a higher switch current limit has to be used. Only if the calculated value for IMAXOUT is just a little smaller than the needed one, it is possible to use the selected IC with an inductor with higher inductance if it is still in the recommended range. A higher inductance reduces the ripple current and therefore increases the maximum output current with the selected IC. If the calculated value is above the maximum output current of the application, the maximum switch current in the system is calculated:

$$I_{SW(max)} = \frac{\Delta I_L}{2} + I_{OUT(max)}$$

For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\Delta I_L \times f_S \times V_{IN}}$$

VIN = typical input voltage

VOUT = desired output voltage

fS = minimum switching frequency of the converter

ΔIL = estimated inductor ripple current,

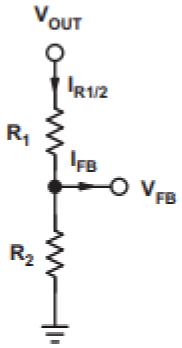
see the following: The inductor ripple current cannot be calculated with Equation 1 because the inductor is not known. A good estimation for the inductor ripple current is 20% to 40% of the output current.

$$\Delta I_L = (0.2 \text{ to } 0.4) \times I_{OUT(max)}$$

To reduce losses, use Schottky diodes. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(max)} \times (1 - D)$$

Almost all converters set the output voltage with a resistive divider network (which is integrated if they are fixed output voltage converters). With the given feedback voltage, VFB, and feedback bias current, IFB, the voltage divider can be calculated.



The minimum value for the input capacitor is normally given in the data sheet. This minimum value is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply. The best practice is to use low-equivalent series resistance (ESR) ceramic capacitors. The dielectric material must be X5R or better. Otherwise, the capacitor loses much of its capacitance due to dc bias or temperature.

The best practice is to use low-ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better. If the converter has external compensation, any capacitor value above the recommended minimum in the data sheet can be used, but the compensation has to be adjusted for the used output capacitance. With internally compensated converters, the recommended inductor and capacitor values must be used, or the recommendations in the data sheet for adjusting the output capacitors to the application in the data sheet must be followed for the ratio of L × C. With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

$$C_{OUT(min)} = \frac{\Delta I_L}{8 \times f_S \times \Delta V_{OUT}}$$

7.3 Bridge Rectifier

7.3.1 Introduction

Sometimes it is necessary for devices to convert input AC voltage to DC voltage before it can be used. A bridge rectifier is a device that is used for conversion of AC to DC. Many devices have in-built bridge rectifier to convert AC to DC.

AC or alternating current needs to first go through a converter before it can be used by devices that require DC input for operation. Mostly they are used in electronic related to power applications and further such processes.

Construction of such rectifiers can vary but usually it is possible to construct them with four or any greater number of diodes, or any other controlled solid-state switches and devices.

7.3.2 Selecting a Bridge Rectifier

A proper bridge proper bridge rectifier is decided upon after considering the requirements of load current. Furthermore, all the specifications and ratings of different components, range of temperatures, breakdown voltage, transient current rating, forward current rating, requirements for mounting and many other such things are to be taken in consideration.

7.3.3 Different types of Bridge Rectifiers

Type of supply, circuit configuration, controlling capability, etc. are used to classify bridge rectifiers into three main types of bridge rectifiers:

- Controlled Rectifiers
- Uncontrolled Rectifiers
- Single phase and Three phase rectifiers

As our design includes constant and fixed power supplies therefore, we will use the Un-controlled bridge rectifier.

7.3.4 Uncontrolled Bridge Rectifier

This type of bridge rectifier uses diodes for rectifying the input AC current. Diodes allow the flow of current in only one direction therefore they are known a unidirectional device.

If the diodes are configured as shown in the figure, then they won't allow the power to vary as the requirements of the load vary.

A simple 4-diode Bridge Rectifier is shown below (*figure 3.3*):

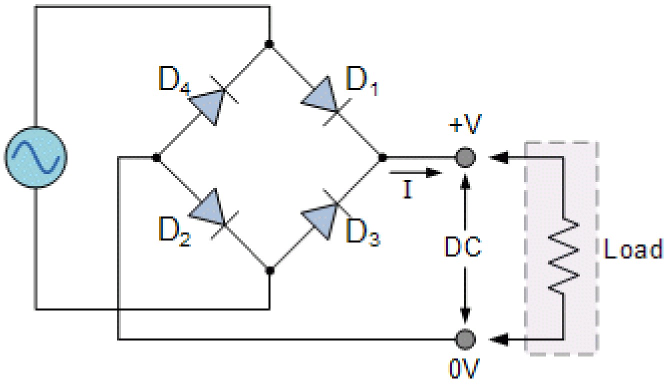


Fig 12Bridge Rectifier

During +ve Half Cycle

D1 and D2 are forward biased while D3 and D4 operate in the reverse biased mode during the first half cycle. Load current starts flowing when the input voltage across D1 and D2 is more than the threshold level of the diodes. This is explained with the help of arrows in the *figure 3.3.1* below.

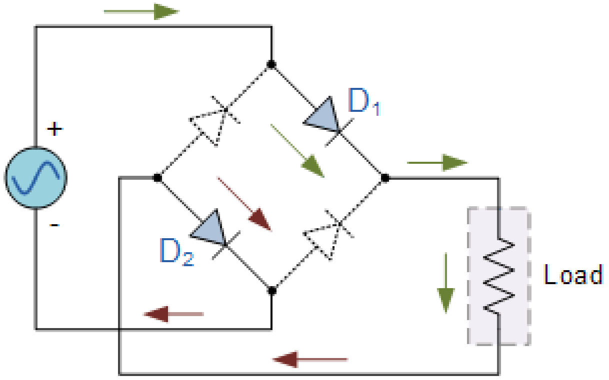


Fig 13 Bridge Rectifier during +ve Half Cycle

During -ve Half Cycle

As the negative AC input is applied, D1 and D2 get reverse biased and in this case D3 and D4 start conducting and load current starts flowing through them. It can be understood more easily with the help of the figure *3.3.2* below.

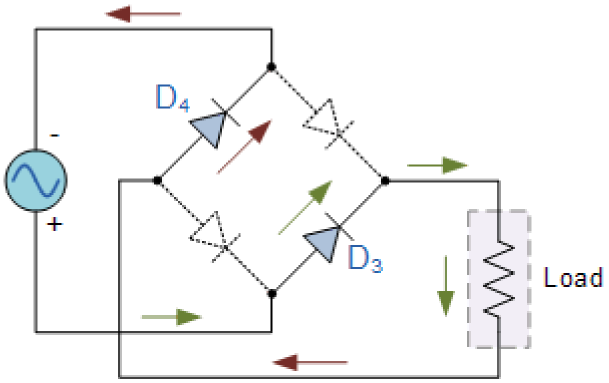


Fig 14 Bridge Rectifier during -ve Half Cycle

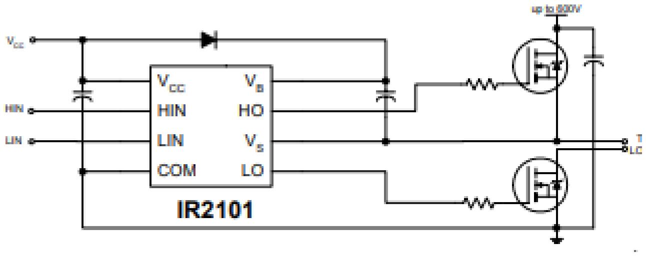
The point to be noted ere is that in both the modes of operation the direction of load current is the same, i.e. it is unidirectional. It shows that the load current is a DC current.

Hence it is shown that the bride rectifier successfully converts AC current into DC current.

7.4SENSORS:

7.4.1 IC 2101 Gate Driver:

The IR2101(S)/IR2102(S) are high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. The logic input is compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts.



Symbol	Definition	Min.	Max.	Units
V_B	High side floating supply absolute voltage	$V_S + 10$	$V_S + 20$	V
V_S	High side floating supply offset voltage	Note 1	600	
V_{HO}	High side floating output voltage	V_S	V_B	
V_{CC}	Low side and logic fixed supply voltage	10	20	
V_{LO}	Low side output voltage	0	V_{CC}	
V_{IN}	Logic input voltage (HIN & LIN) (IR2101) & ($\overline{\text{HIN}}$ & $\overline{\text{LIN}}$) (IR2102)	0	V_{CC}	
T_A	Ambient temperature	-40	125	°C

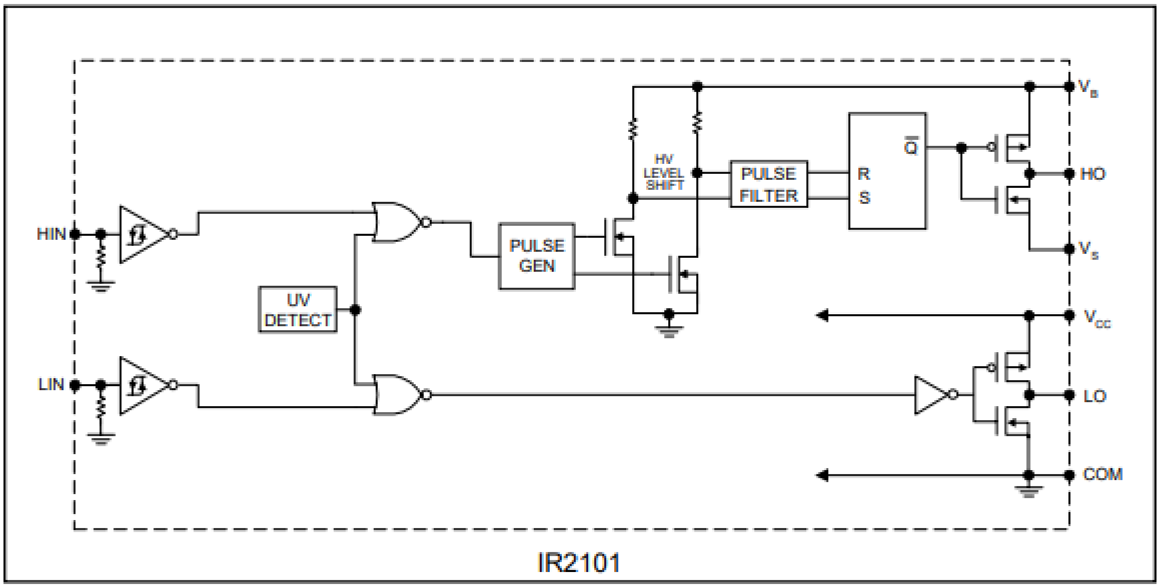


Fig 15 Internal Gate Driver Circuit Diagram

Fig 16 Gate Driver

7.4.2 Temp 36

The TMP35/TMP36/TMP37 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to the Celsius (centigrade) temperature. The TMP35/TMP36/TMP37 do not require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range. The low output impedance of the TMP35/TMP36/TMP37 and its linear output and precise calibration simplify interfacing to temperature control circuitry and ADCs. All three devices are intended for single-supply operation from 2.7 V to 5.5 V maximum. The supply current runs well below 50 µA, providing very low self-heating—less than 0.1°C in still air. In addition, a shutdown function is provided to cut the supply current to less than 0.5 µA. FUNCTIONAL BLOCK DIAGRAM +VS (2.7V TO 5.5V) SHUTDOWN VOUT TMP35/ TMP36/ TMP37 00337-001 Figure 1. PIN CONFIGURATIONS 1 2 3 5 4 TOP VIEW (Not to Scale) NC = NO CONNECT VOUT SHUTDOWN GND NC +VS 00337-002 Figure 2. RJ-5 (SOT-23) 1 2 3 4 8 7 6 5 TOP VIEW (Not to Scale) NC = NO CONNECT VOUT SHUTDOWN NC NC +VS NC NC GND 00337-003 Figure 3. R-8 (SOIC_N) 1 2 3 BOTTOM VIEW (Not to Scale) PIN 1, +VS; PIN 2, VOUT; PIN 3, GND 00337-004 Figure 4. T-3 (TO-92) The TMP35 is functionally compatible with the LM35/LM45 and provides a 250 mV output at 25°C. The TMP35 reads temperatures from 10°C to 125°C. The TMP36 is specified from −40°C to +125°C, provides a 750 mV output at 25°C, and operates to 125°C from a single 2.7 V supply. The TMP36 is functionally compatible with the LM50. Both the TMP35 and TMP36 have an output scale factor of 10 mV/°C.

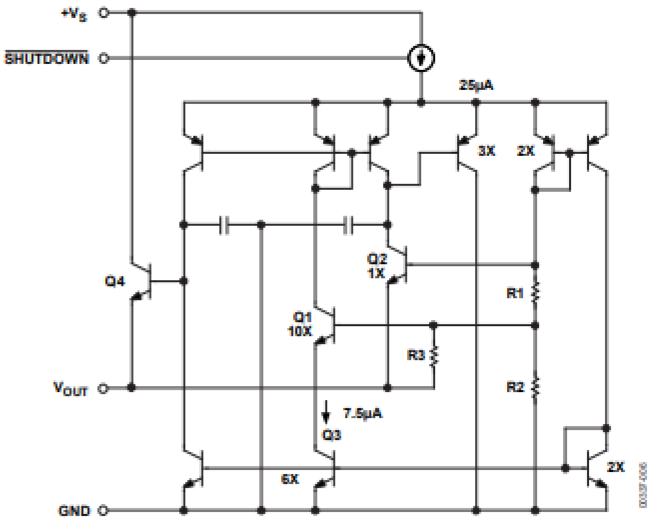


Fig 17 Internal Circuit of Temperature Sensor

Fig 18 Temperature Sensor

7.4.3 Current sensor:

We have used a current sensor ACS712. The rating of the current sensor is 30A. This is a hall effect based current sensor used to calculate the current within the circuit. This sensor uses the capacitor to calculate the current. This current sensor comes in 3 ranges, 30A, 20A and 5A. We have used a sensor of 30A rating. This sensor can be used to measure AC or DC.

Following is the picture of current sensor used.

Figure 19 Current sensor

Characteristics of ACS712

Following are some features of ACS712 due to which we are using this sensor:

- This sensor gives the error of 1.5% at the average temperature of 25 degrees.
- It has the bandwidth of 80KHz.
- It has low noise signal path. Thus, noise interference is minimum.
- It has low internal conductor resistance i.e., 1.2m Ohms.

Working

Sensors mainly work in 2 ways. Either they measure by direct sensing or by indirect sensing. In the case of ACS712, indirect sensing is used. As it is hall effect based current sensor, when the current is passed through the sensor, the hall effect sensor senses the current and produce a magnetic field. That magnetic field then produces a voltage signal that is proportional to the magnetic field. It gives the output signal of 0-5V analog. That voltage signal is then used to measure the current by doing some calculations.

When the current sensor is connected to the Arduino at no load condition when no current is flowing, the sensor gives 2.5V output signal which means zero current. When the current exceeds in one direction, the output voltage increases from 2.5V. And when the current is increased in the opposite direction, the voltage decreases from 2.5V. In this way this sensor can measure both AC and DC.

7.4.4 Relay

Relay is an electromechanical device that uses an electric current to open or close the contacts of a switch. The single-channel relay module is much more than just a plain relay, it comprises of components that make switching and connection easier and act as indicators to show if the module is powered and if the relay is active or not.

Single-Channel Relay Module Pin Description

Pin Number	**Pin Name**	**Description**
1	Relay Trigger	Input to activate the relay
2	Ground	0V reference
3	VCC	Supply input for powering the relay coil
4	Normally Open	Normally open terminal of the relay
5	Common	Common terminal of the relay
6	Normally Closed	Normally closed contact of the relay

Single-Channel Relay Module Specifications

- Supply voltage – 3.75V to 6V
- Quiescent current: 2mA
- Current when the relay is active: ~70mA
- Relay maximum contact voltage – 250VAC or 30VDC
- Relay maximum current – 10A

Fig 20 Relay

7.4.5 Arduino MEGA 2560

We have used an Arduino mega 2560 as a microcontroller in our project. It is based on AT Mega 2560. This microcontroller has 54 digital Input/Output Pins out of which 15 pins can be used as PWM pins. It has 16 analog pins. It has 4 hardware serial communication pins. It also has 16MHz oscillator. This board is compatible with most of the shields. It can be connected with a simple USB cable and perform its operations. Following is the picture of the Arduino Mega 2560.

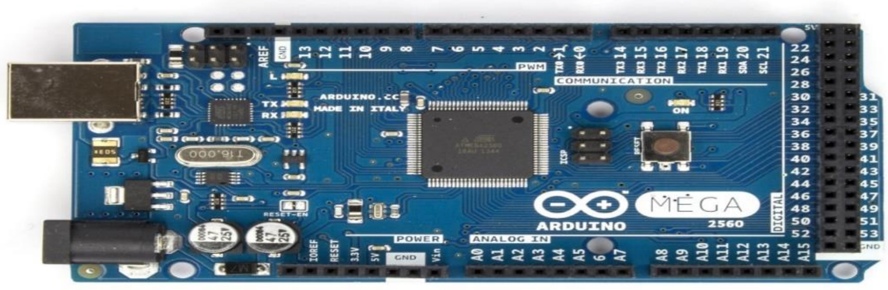


Figure 21 Arduino MEGA

Characteristics of Arduino

Following are the characteristics of Arduino mega.

- Its operating voltage is 5V.
- Its input voltage is 7-12V.
- Its clock speed is 16MHz.

- Its DC current per input output pin is 20mA.
- Its flash memory is 256KB.

Arduino mega instead of Arduino UNO

Arduino UNO is a smaller version of Arduino MEGA. Arduino UNO has less digital and analog pins. The main reason for which we used Arduino MEGA is because we wanted to connect GSM and Bluetooth module at the same time. Whereas in Arduino UNO there is only 1 port for UART communication. Whereas in Arduino MEGA there are 4 serial ports for UART communication. Thus, we used Arduino mega 2560.

Following is the detailed description of pins of Arduino MEGA 2560.

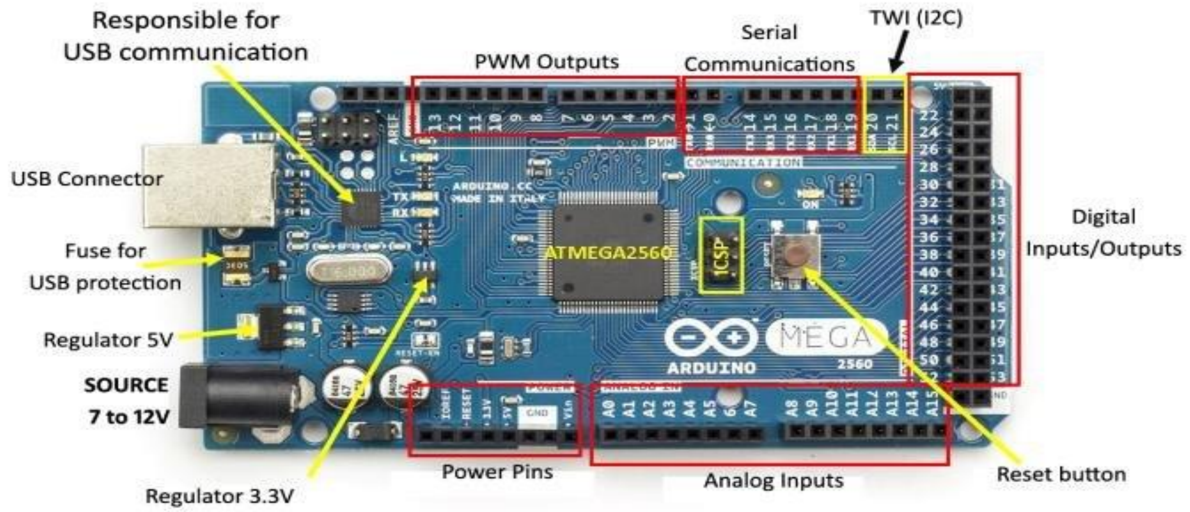


Figure 22 Pin configuration of Arduino

7.5 MATLAB SIMULINK Implementation:

Here is the Simulink implementation of the project where all the components are arranged, and simulation is run for taking the data.

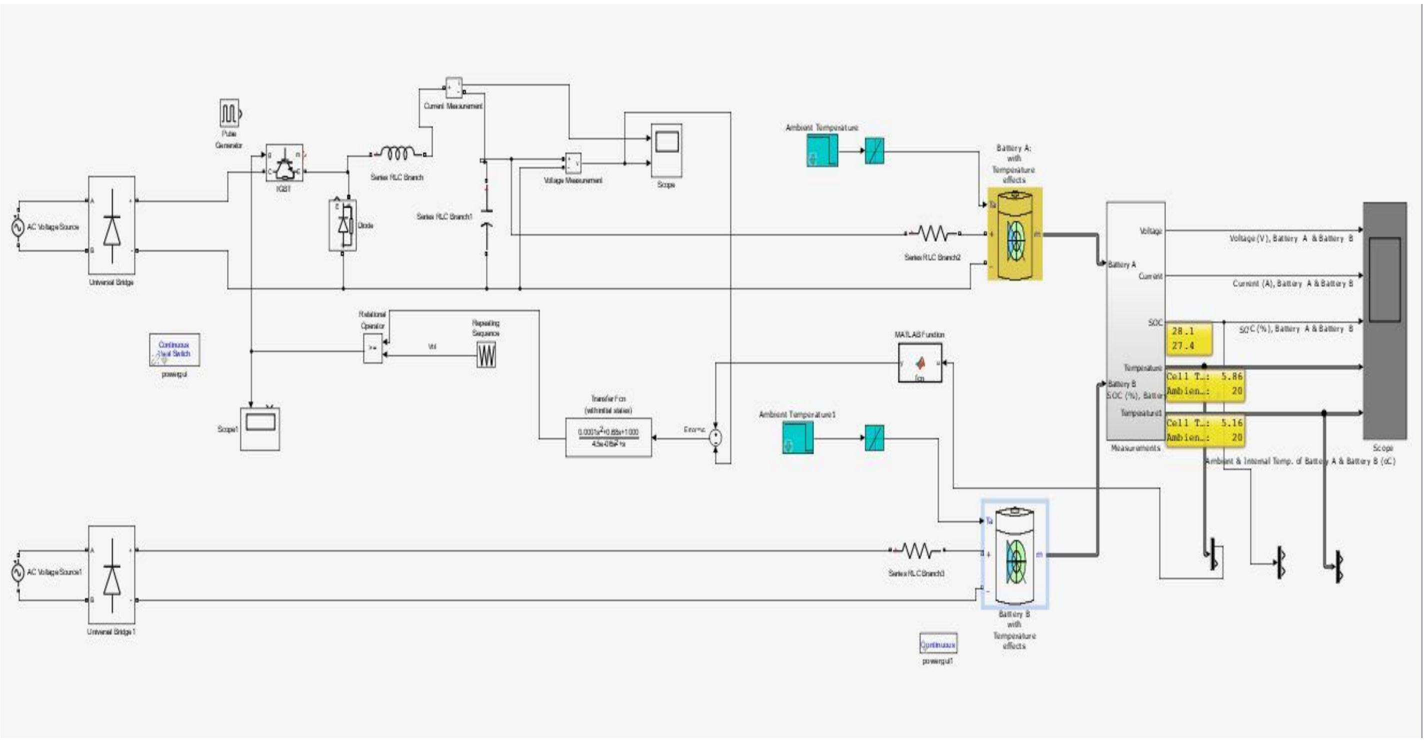


Fig 23 MATLAB Simulink Implementation

The complete circuit (shown above in *figure 3.9*) starting from left side consists of; an AC Source, followed by a Bridge Rectifier which converts AC voltage to DC voltage, then a Buck Converter whose primary functionality is to Step Down the voltage, later on this voltage is supplied to the Battery A. With this, a feed forward path is generated, which relates to a MATLAB function, which is basically sensing temperature from the battery and then signalling the transfer function to cut of the voltage. The Transfer Function relates to the IGBT which acts as a gate/ switch and signals the voltage/current flow to stop. The other AC source is connected directly with Battery B.

Battery A charging with CTCV, Battery B charging with CCCV method.

Most importantly, the Temperature of Battery didn’t exceed the Limit of 45 degrees under which operating it is safe.

Further from the battery, a calculator is connected which basically formulates the real time values of temp, voltage, current and state of charge of batteries.

7.6 Hardware Implementation:

Here is Hardware implementation of the project where all the parts of the project are interconnected with each other, and data is displaying on the lcd.

Hardware BMS

- BMS Circuit is implemented on Bread board and tested its each component.
- Output from different sensors is displayed on LCD.
- All the parts of BMS are integrated and tested in combined form and output is displayed.
- Protection circuit is checked by increasing the input voltage and by discharging the battery below its limit value.

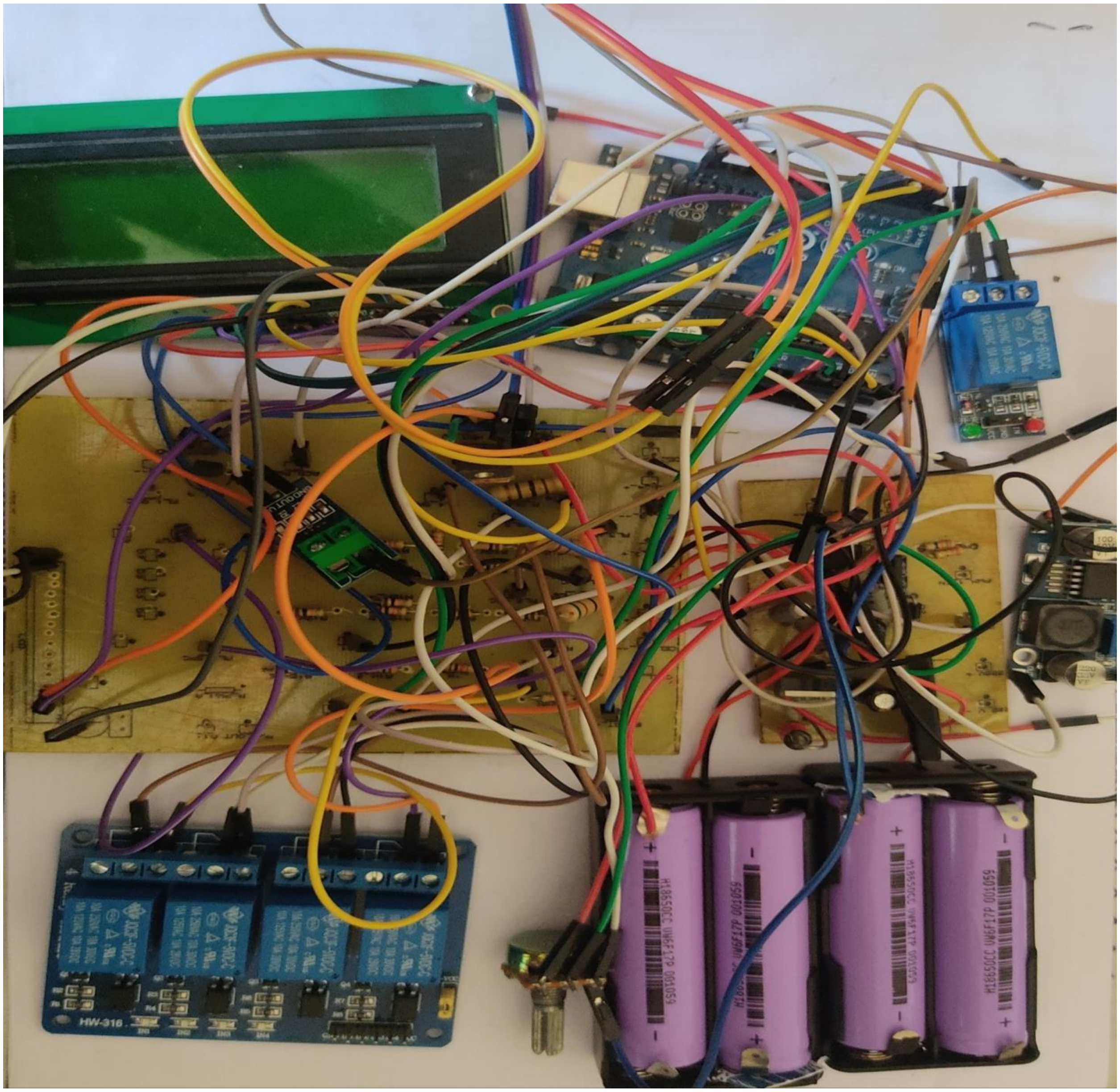


Fig 24 Complete Hardware of Project

Here is the complete hardware designed of project and all the components of project are cased in this casing.

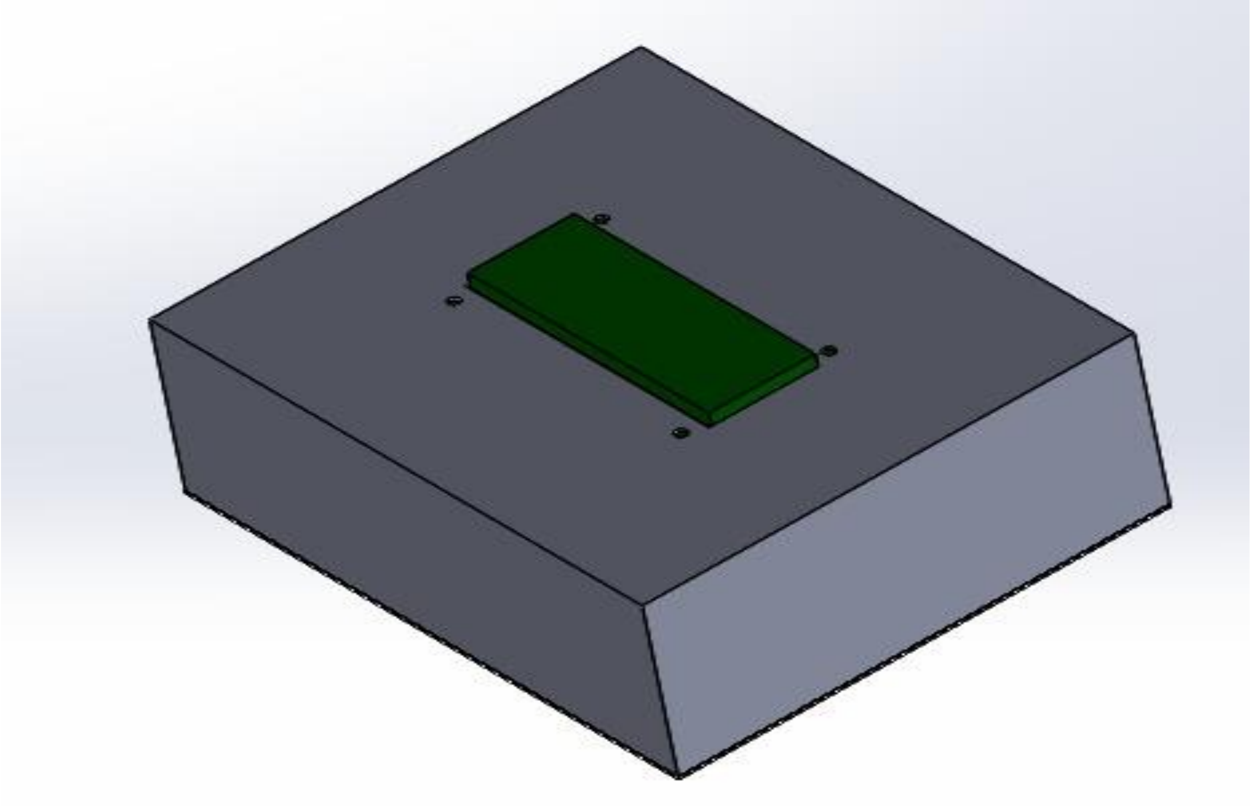
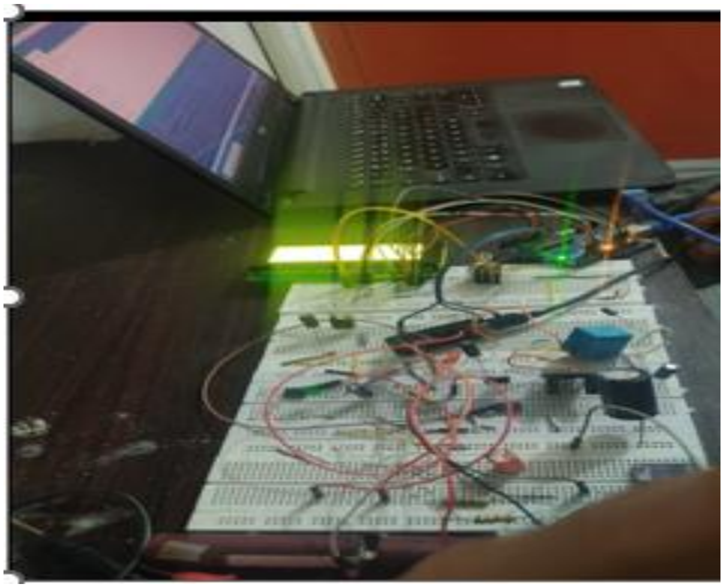


Fig 25 Casing of Hardware

Hardware Fast Charging

- Charging circuit is designed and implemented on bread board.
- Bridge rectifier is used for rectification and buck converter for stepping down the voltage.
- After testing the charging circuit individually, it is integrated with BMS, and values are displayed on LCD.



7.6.1 PCB of Project:

Her is the PCB of the project which we have designed using Proteus. Two PCBs are designed. BMS project is implemented one of these and another one charging circuit is implemented and both PCBs is connected with each other.

Here is BMS PCB we have designed using proteus. Standard model of all components is used. Individual elements names also placed on pcb so that while soldering each component can easily be soldered.

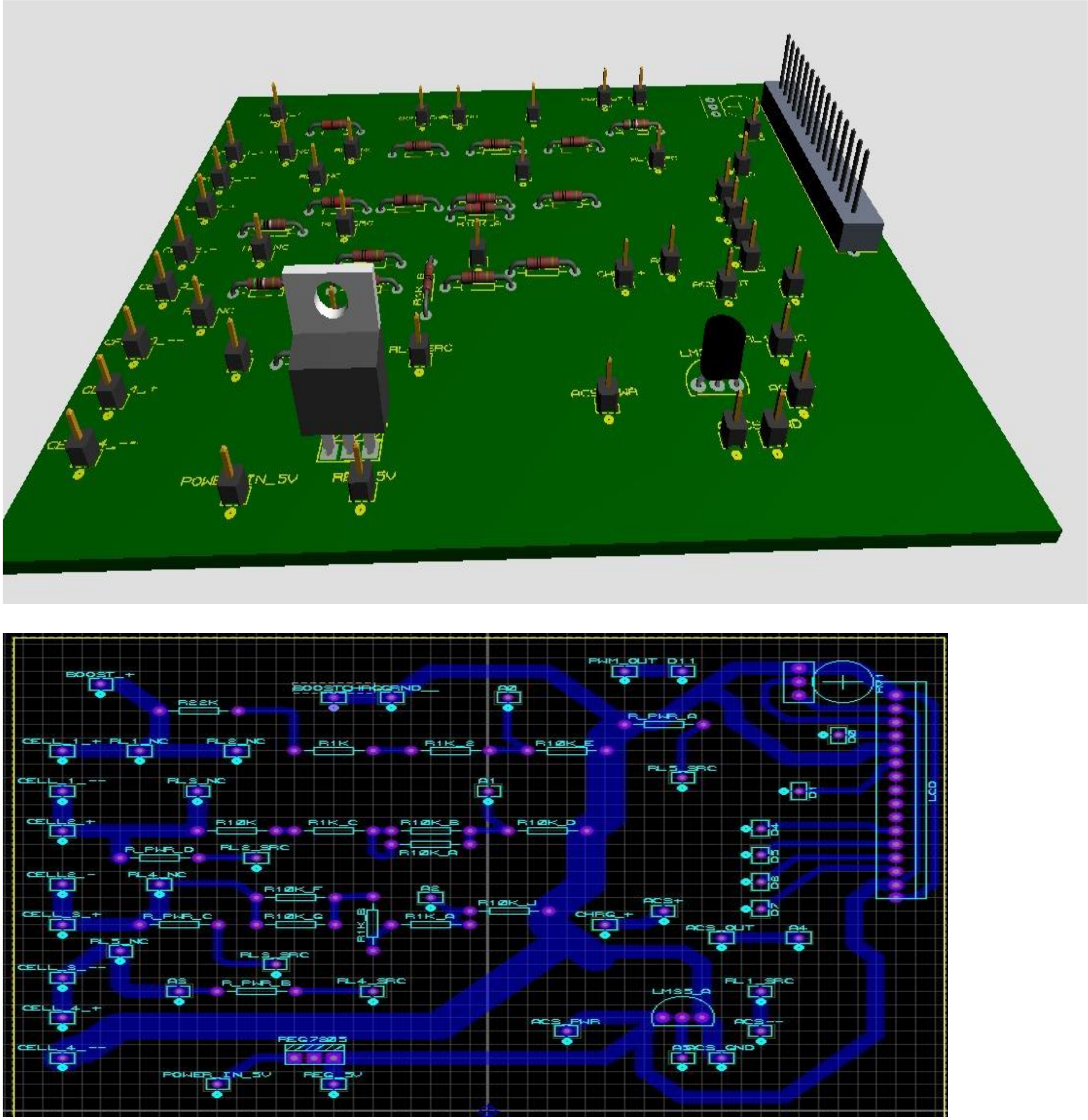


Fig 26 PCB Design of BMS Circuit

PCB Design of Charging Part

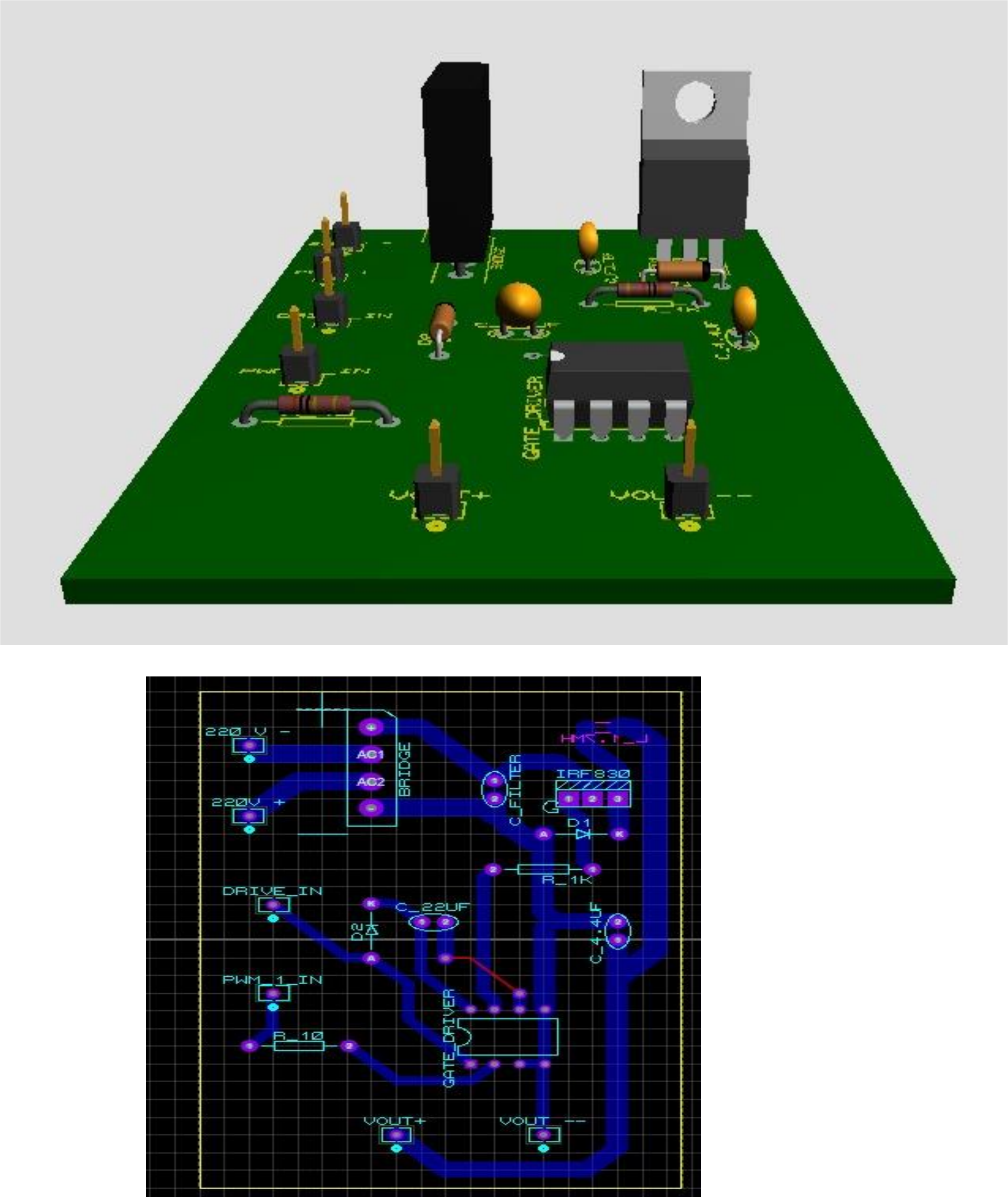


Fig 27 PCB Design of Fast Charging Circuit

CHAPTER 8 CODE

8.1 Coding

The coding of the project was done on Arduino IDE. The part-by-part explanation of the code is done in the next sub section The code on the project is.

```
#include <LiquidCrystal.h>
Liquid Crystal LCD(12,11, 5, 4, 3, 2);


float voltage.
float R1 = 23600.0.
float R2 = 10000.0.
float R3=15200.0;
float R4=10000.0;
float R5=6800.0.
float R6=10000.0;
float cons1=0.016422;
float cons2=0.012316;
float cons3=0.00918;
unsigned long start Millis;  //some global variables available anywhere in the program
unsigned long currentMillis.
const int period = 1000;  //the value is a number of milliseconds
float totalCoulumbs = 0.0;
int count=0;
float SOC=0.0;


void setup()
{
```

```
  pinMode(A0,INPUT);
  pinMode(A1,INPUT);
  pinMode(A2,INPUT);
  pinMode(A3,INPUT);
  pinMode(A4,INPUT);
  pinMode (14,OUTPUT);
  pinMode (15,OUTPUT);
  pinMode (16,OUTPUT);
  pinMode (17,OUTPUT);

LCD.begin(16,2);
LCD.setCursor(0,1);
LCD.print("    ");
LCD.setCursor(0,0);
LCD.print("    ");

//analogReference(INTERNAL);
Serial.begin(9600);
}

void loop(){
  int value;
  float celtemp=analogRead(A8)*.488;
    Serial.print("\r Temperature value = ");
  Serial.println(celtemp);

  float voltage1,voltage2,voltagec1,voltage3,voltagec2,voltage4,voltagec3,voltagec4;
  value = analogRead(A0);
```

```
//  Serial.println("\r value of value=");
 // Serial.print(value);
  voltage1 = value*(5.0/1023)*((R1 + R2)/R2);
 // Serial.println("\r value of voltage 1=");
  //Serial.print(voltage1);
  value=analogRead(A1);
  //Serial.println("\r value of value1=");
  //Serial.print(value1);
  voltage2=value*(5.0/1023)*((R3+R4)/R4);
//  Serial.println("\r value of voltage2 = ");
  //Serial.print(voltage2);
  float voltage= 34.00;
   Serial.print("\r Value of input voltage to battery = ");
  Serial.println(voltage);
  float vol=16.43;
   Serial.print("\r VOltage of Battery = ");
  Serial.println(vol);

  voltagec1=voltage1-voltage2;
  Serial.print("\r Voltagec cell 1 =");
  Serial.println(voltagec1);
  value=analogRead(A2);
  voltage3=value*(5.0/1023)*((R5+R6)/R6);
  voltagec2=voltage2-voltage3;
  Serial.print("\r value of voltagec2 = ");
  Serial.println(voltagec2);
  value=analogRead (A3);
  //Serial.print("\r value of A3 = ");
```

```
//Serial.println(value);
voltage4=value*(5.0/1023.0);
voltagec3=voltage3-voltage4;
Serial.print("\r value of voltagec3 = ");
Serial.println(voltagec3);
voltagec4=voltage4;
Serial.print("\r value of voltagec4 = ");
Serial.println(voltagec4);
if(voltagec1>voltagec2 ||voltagec1>voltagec3|| voltagec1>voltagec4){
  digitalWrite(14,HIGH);}
 else {
  digitalWrite (14,LOW);
}

if(voltagec2>voltagec1 ||voltagec2>voltagec3|| voltagec2>voltagec4){
  digitalWrite(15,HIGH);}
 else {
  digitalWrite (15,LOW);
}

if(voltagec3>voltagec2 ||voltagec3>voltagec1|| voltagec3>voltagec4){
  digitalWrite(16,HIGH);}
 else {
  digitalWrite (16,LOW);
}

if(voltagec4>voltagec2 ||voltagec4>voltagec3|| voltagec4>voltagec1){
  digitalWrite(17,HIGH);}
```

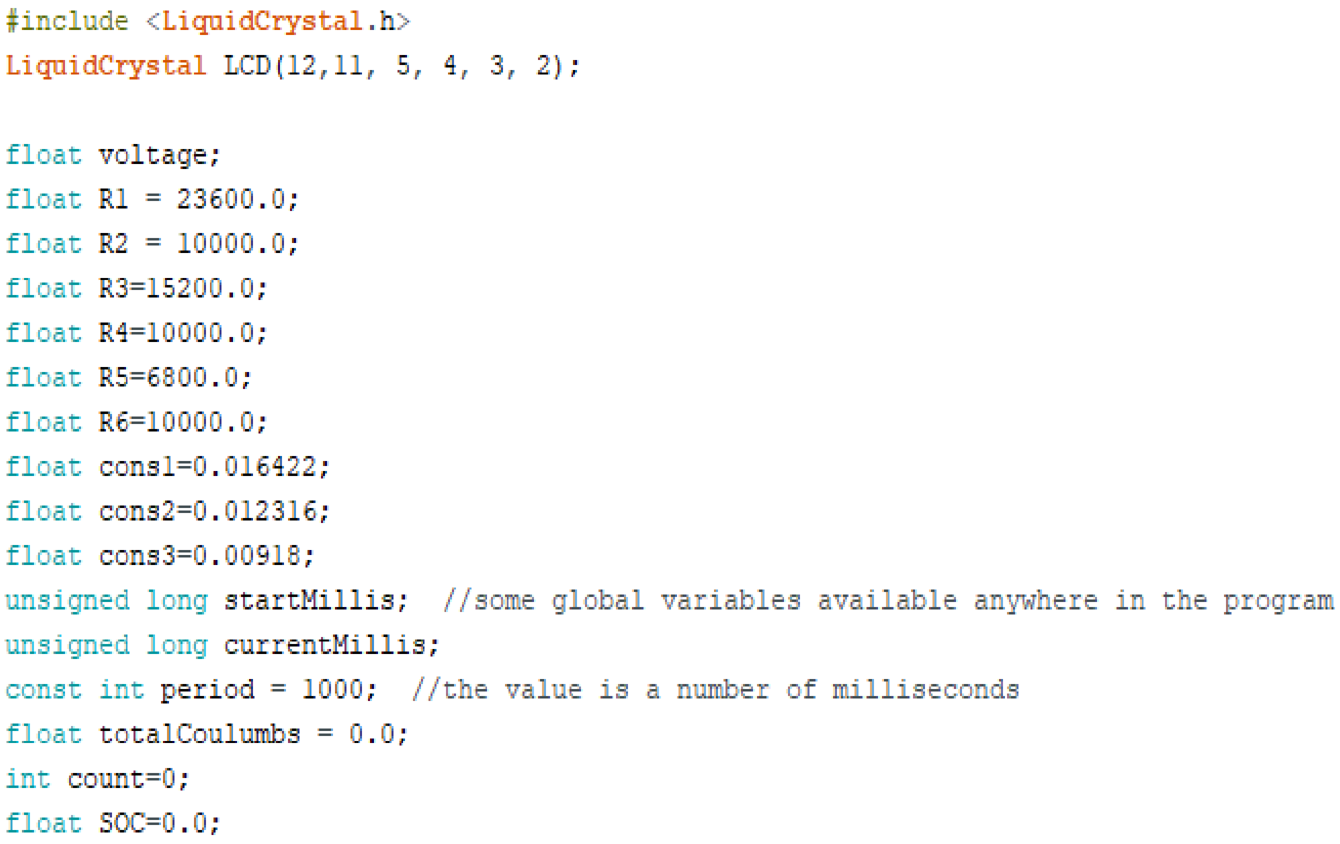
```
  else {
   digitalWrite (17,LOW);
  }



  unsigned int x=0;
float AcsValue=0.0,Samples=0.0,AvgAcs=0.0,AcsValueF=0.0;

  for (int x = 0; x < 150; x++){ //Get 150 samples
  AcsValue = analogRead(A4);     //Read current sensor values
  Samples = Samples + AcsValue;  //Add samples together
  delay (3); // let ADC settle before next sample 3ms
}
AvgAcs=Samples/150.0;//Taking Average of Samples

//((AvgAcs * (5.0 / 1024.0)) is converitng the read voltage in 0-5 volts
//2.5 is offset(I assumed that arduino is working on 5v so the viout at no current comes
//out to be 2.5 which is out offset. If your arduino is working on different voltage than
//you must change the offset according to the input voltage)
//0.185v(185mV) is rise in output voltage when 1A current flows at input
AcsValueF = (2.5 - (AvgAcs * (5.0 / 1024.0)) )/0.100;

  Serial.print("\r value of avg current = ");
  Serial.println(AcsValueF);

delay(50);

  delay(500);
```

```
 LCD.setCursor(0,0);
LCD.print("voltage c1=");
LCD.print(voltagec1);
 LCD.setCursor(0,1);
 LCD.print("  ");

 LCD.print(" C  ");
 delay(200);
 LCD.setCursor(0,1);
 LCD.print("   ");
 currentMillis = millis();  //get the current "time" (actually the number of milliseconds since the
program started)
  if (currentMillis - startMillis >= period)  //test whether the period has elapsed
  {
    count=count+1;

    totalCoulumbs = totalCoulumbs + AcsValueF;


      float TotalAh = totalCoulumbs;



    if(count==60){

   //Serial.print("\r ah = ");
 // Serial.println( TotalAh);
   float  SOC1 = (TotalAh/97.20); /// (2750.0))*100;
```

```
   float SOC=100.0-SOC1;
    // SOH = (max Ah of battery / new batt max AH)*100;
   Serial.print("\soc = ");
  Serial.println(SOC);
   Serial.print("\r count =  = ");
  Serial.println(count);
  count=0;
  }
  }

    startMillis = currentMillis;  //IMPORTANT to save the start time of the current state.

}
```

8.2 Code Explanation

8.2.1 Declaring the Variables

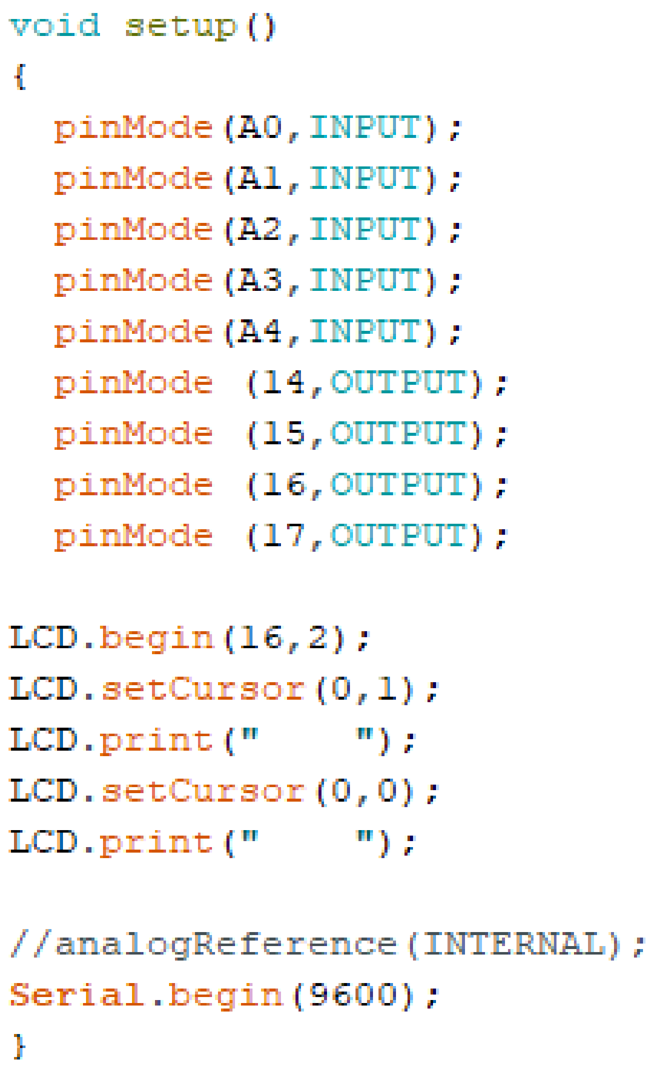


```
#include <LiquidCrystal.h>
LiquidCrystal LCD(12,11, 5, 4, 3, 2);

float voltage;
float R1 = 23600.0;
float R2 = 10000.0;
float R3=15200.0;
float R4=10000.0;
float R5=6800.0;
float R6=10000.0;
float cons1=0.016422;
float cons2=0.012316;
float cons3=0.00918;
unsigned long startMillis;  //some global variables available anywhere in the program
unsigned long currentMillis;
const int period = 1000;  //the value is a number of milliseconds
float totalCoulumbs = 0.0;
int count=0;
float SOC=0.0;
```

In this section variable used in the code are declared and their initial values are set.

- First voltage variables for individual cell voltage measurement are declared.
- Resistor variables are declared which are used for signal conditioning.
- Constant multipliers are declared, and their values are set which will be further used in code.
- For sensing temperature values a variable for storing temperature sensor data is declared.
- For storing data coming from current sensor a variable is declared.
- For calculating the SOC and SOH of the battery variables are declared which will be further used for development of algorithm.
-

8.2.2 SETUP



```
void setup()
{
  pinMode(A0,INPUT);
  pinMode(A1,INPUT);
  pinMode(A2,INPUT);
  pinMode(A3,INPUT);
  pinMode(A4,INPUT);
  pinMode (14,OUTPUT);
  pinMode (15,OUTPUT);
  pinMode (16,OUTPUT);
  pinMode (17,OUTPUT);

LCD.begin(16,2);
LCD.setCursor(0,1);
LCD.print("    ");
LCD.setCursor(0,0);
LCD.print("    ");

//analogReference(INTERNAL);
Serial.begin(9600);
}
```

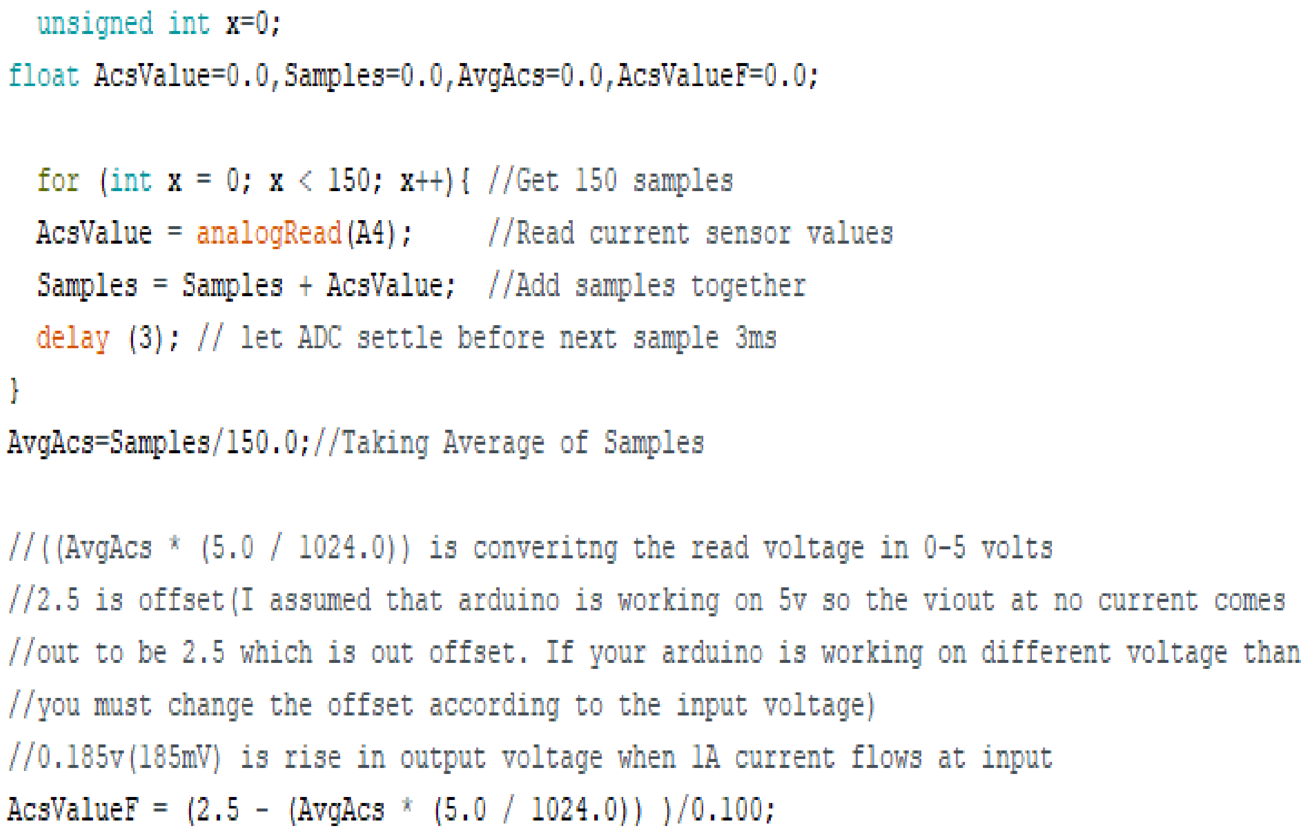
In this section setup of Aurdino and pins is explained.

- First of all, the connection between lcd and Aurdino is set up.
- The pins are set for input and output purposes.
- For sensing data pins are set as input and data is taken from sensors and by further processing of data output is displayed on lcd.

- Output pins are declared through which data is displayed. All the pins which are transmitting data to lcd are set as output.
- As we have used Aurdino for generation of PWM signal for charging control so also that pin is set as output as we are transmitting data from Aurdino to MOSFET gate driver.

8.2.3 Measuring Voltage ,current and Temperature

```
void loop(){
  int value;
  float celtemp=analogRead(A8)*.488;
    Serial.print("\r Temperature value = ");
  Serial.println(celtemp);

  float voltage1,voltage2,voltagec1,voltage3,voltagec2,voltage4,voltagec3,voltagec4;
  value = analogRead(A0);
//  Serial.println("\r value of value=");
 // Serial.print(value);
  voltage1 = value*(5.0/1023)*((R1 + R2)/R2);
 // Serial.println("\r value of voltage 1=");
  //Serial.print(voltage1);
  value=analogRead(A1);
  //Serial.println("\r value of value1=");
  //Serial.print(value1);
  voltage2=value*(5.0/1023)*((R3+R4)/R4);
//  Serial.println("\r value of voltage2 = ");
  //Serial.print(voltage2);
  float voltage= 34.00;
   Serial.print("\r Value of input voltage to battery = ");
  Serial.println(voltage);
  float vol=16.43;
   Serial.print("\r VOltage of Battery = ");
  Serial.println(vol);
```

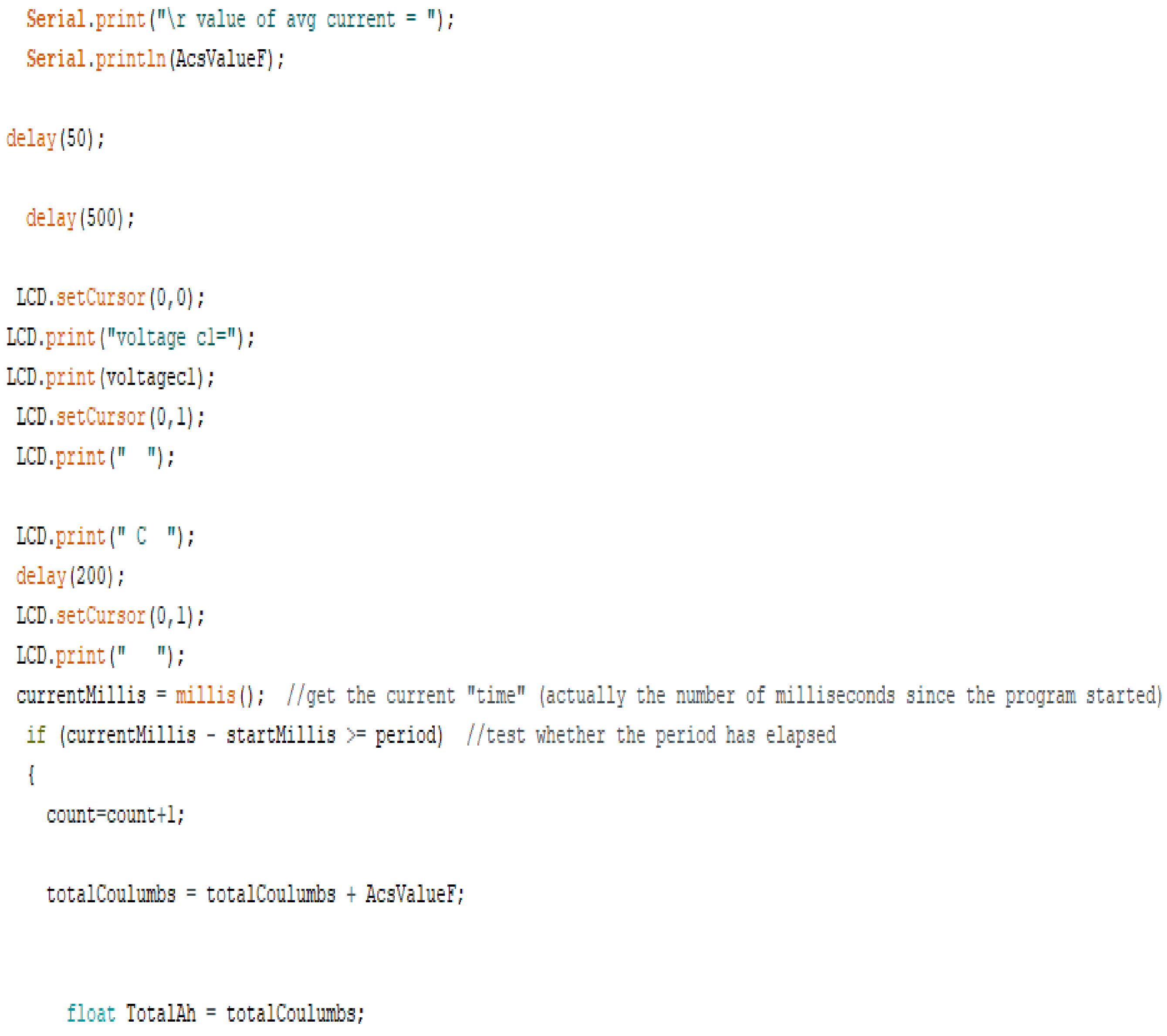


```
  unsigned int x=0;
float AcsValue=0.0,Samples=0.0,AvgAcs=0.0,AcsValueF=0.0;

  for (int x = 0; x < 150; x++){ //Get 150 samples
  AcsValue = analogRead(A4);     //Read current sensor values
  Samples = Samples + AcsValue;  //Add samples together
  delay (3); // let ADC settle before next sample 3ms
}
AvgAcs=Samples/150.0;//Taking Average of Samples

//((AvgAcs * (5.0 / 1024.0)) is converitng the read voltage in 0-5 volts
//2.5 is offset(I assumed that arduino is working on 5v so the viout at no current comes
//out to be 2.5 which is out offset. If your arduino is working on different voltage than
//you must change the offset according to the input voltage)
//0.185v(185mV) is rise in output voltage when 1A current flows at input
AcsValueF = (2.5 - (AvgAcs * (5.0 / 1024.0)) )/0.100;
```

In this section data from different sensor which are placed for measuring battery variables is measured and processed for displaying and for further controls of battery.

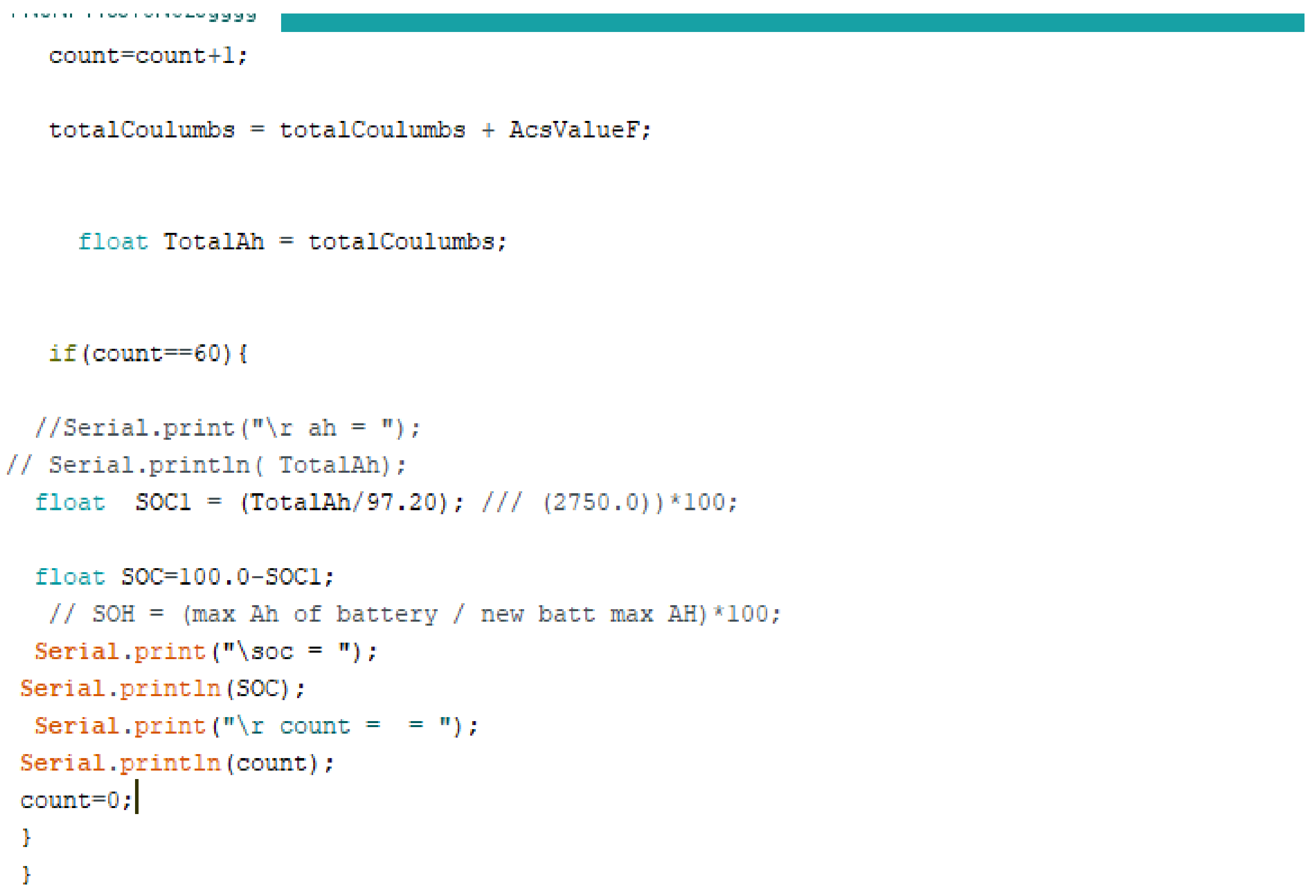
- Individual cell voltage is measured using ADC of the Aurdino .Signal conditioning circuit is designed which feeds data to ADC of Aurdino.
- Battey in and out current is measured using current sensor and its data is stored in Aurdino and also displayed on lcd .
- Temperature of battery is measured using temperature sensor which is further processed for charge control algorithm and also displayed on lcd.

8.2.4 SOC and SOH Estimation:



```
  Serial.print("\r value of avg current = ");
  Serial.println(AcsValueF);

delay(50);

  delay(500);

 LCD.setCursor(0,0);
LCD.print("voltage c1=");
LCD.print(voltagec1);
 LCD.setCursor(0,1);
 LCD.print("  ");

 LCD.print(" C  ");
 delay(200);
 LCD.setCursor(0,1);
 LCD.print("   ");
 currentMillis = millis();  //get the current "time" (actually the number of milliseconds since the program started)
  if (currentMillis - startMillis >= period)  //test whether the period has elapsed
  {
    count=count+1;

    totalCoulumbs = totalCoulumbs + AcsValueF;


      float TotalAh = totalCoulumbs;
```

``



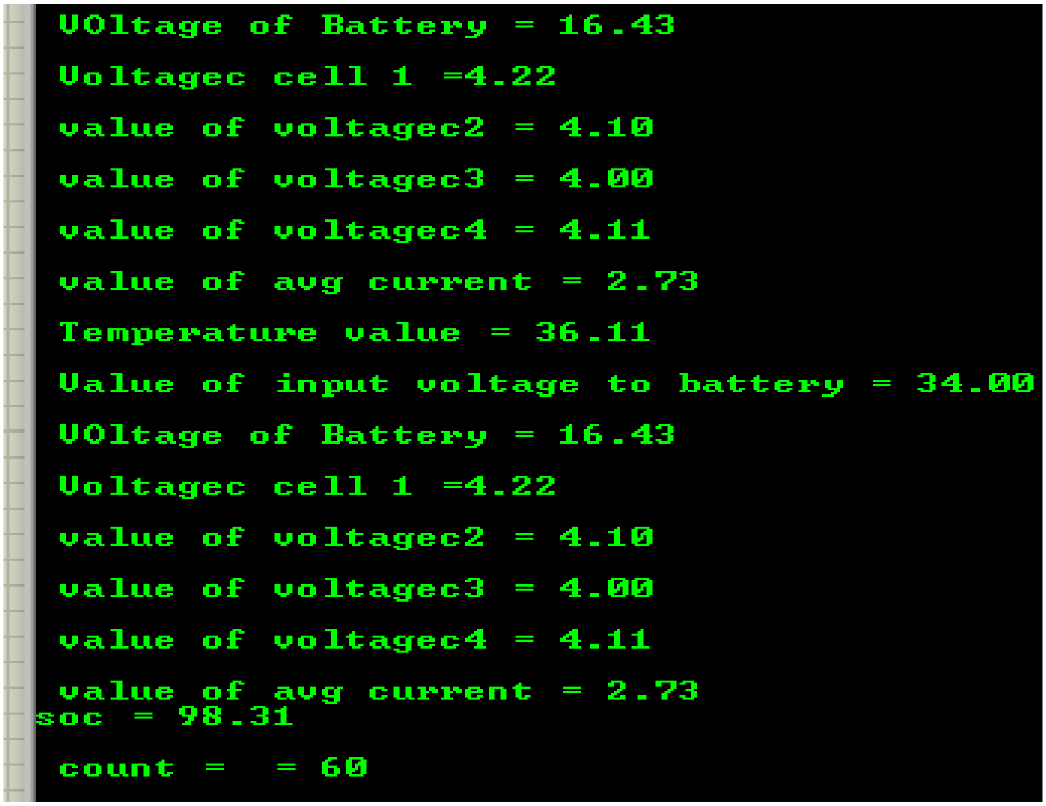
```
   count=count+1;

   totalCoulumbs = totalCoulumbs + AcsValueF;


     float TotalAh = totalCoulumbs;


   if(count==60){

  //Serial.print("\r ah = ");
// Serial.println( TotalAh);
  float  SOC1 = (TotalAh/97.20); /// (2750.0))*100;

  float SOC=100.0-SOC1;
   // SOH = (max Ah of battery / new batt max AH)*100;
  Serial.print("\soc = ");
 Serial.println(SOC);
  Serial.print("\r count =  = ");
 Serial.println(count);
 count=0;
 }
 }

   startMillis = currentMillis;  //IMPORTANT to save the start time of the current state.
```

In this section of code SOC and SOH estimation code in implemented.

The algorithm for SOC and SOH estimation is implemented by processing data which we have took from different sensors.

CHAPTER 9 RESULTS

9.1 Software Results



```
VOltage of Battery = 16.43
Voltagec cell 1 =4.22
value of voltagec2 = 4.10
value of voltagec3 = 4.00
value of voltagec4 = 4.11
value of avg current = 2.73
Temperature value = 36.11
Value of input voltage to battery = 34.00
VOltage of Battery = 16.43
Voltagec cell 1 =4.22
value of voltagec2 = 4.10
value of voltagec3 = 4.00
value of voltagec4 = 4.11
value of avg current = 2.73
soc = 98.31
count =  = 60
```

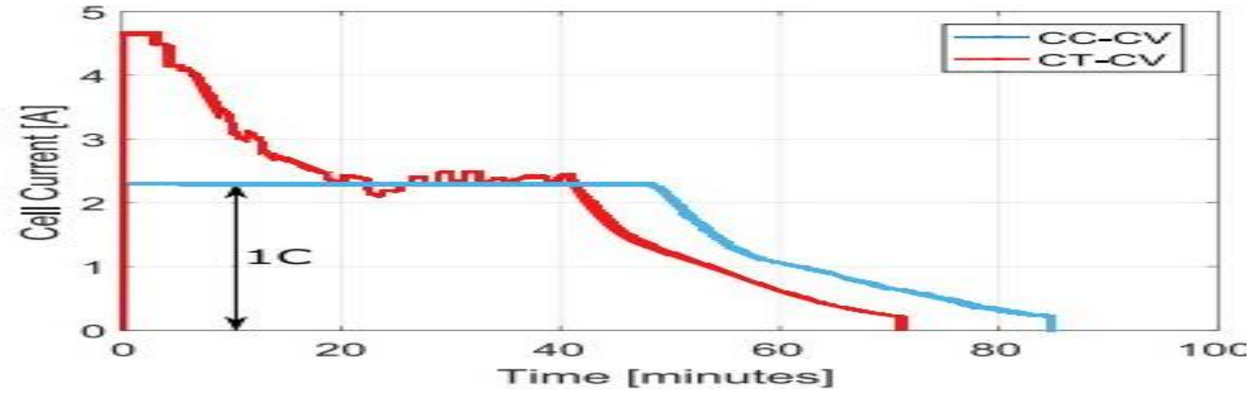
Fig 28 Output Results from Software

- Simulating the Battery management system circuit and checking the value measured by sensors.
- Voltage of each cell and current input and output during charging and discharging is shown.
- Temperature of battery after taking average

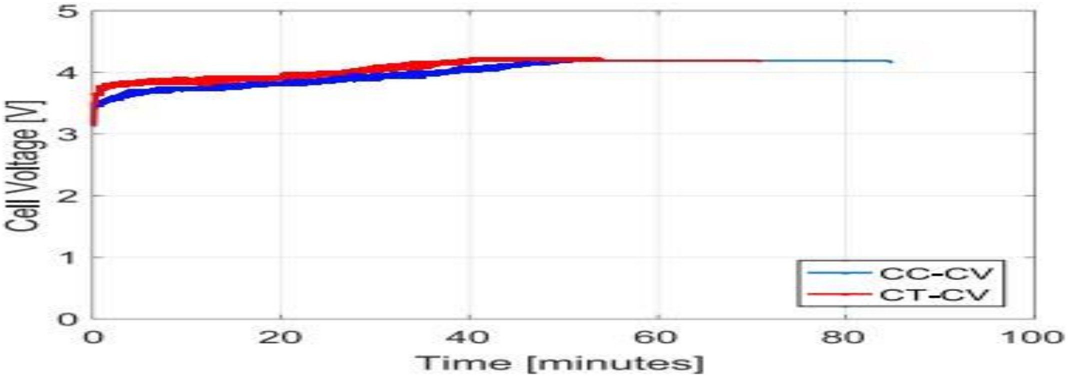
  of each cell temperature is shown.
- SOC of the battery is calculated by

  Columbus counting method and shown.

- Values measured in proteus using measuring instruments is same to value measured using battery algorithm.
- Since we have tested two batteries one with CT-CV and other CC-CV voltage technique different parameters of both batteries are shown.



- Current difference between two batteries is shown.
- Temperature difference between batteries is plotted.



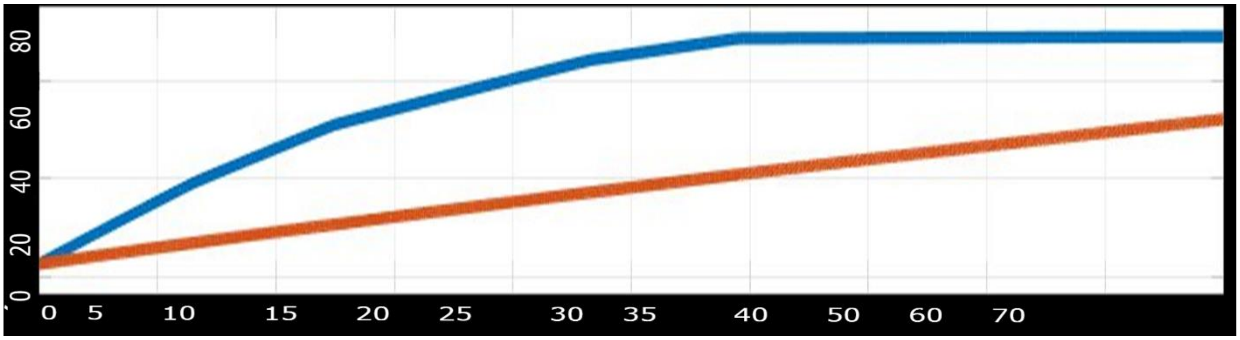


Fig 29 SOC of both batteries is plotted

State of Charge

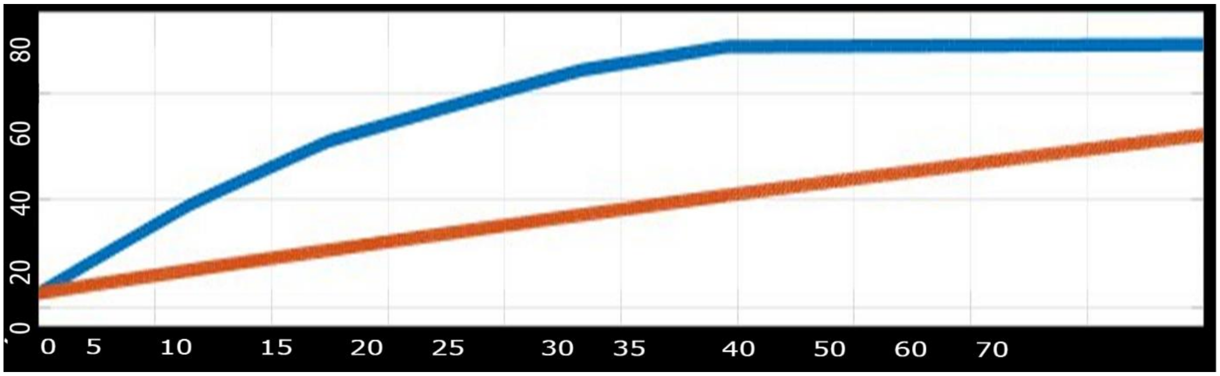


Fig 30 Graphs for State of Charge

The lines show the state of charge of both batteries.

- **The blue line corresponds to the state of charge of Li-ion Battery A and red line to battery B.**

BATTERY A: initial state: 40%, SOC: 88%

BATTERY B: initial state: 40%, SOC: 63%

10.CONCLUSION

An improved battery model was proposed in this project where Battery Parameters are measured and data is processed using Battery algorithm. Charger circuit is designed, and it is controlled by battery algorithm as our proposed scheme is Constant temperature constant voltage method. Battery parameters are thoroughly studied and their impact on battery life are analyzed. The model was simulated using MATLAB/Simulink and the simulation results were discussed. It improved the original system by adding a user interface, a thermal management system and a current-monitoring function. The experimental results of this improved system were subsequently discussed. Finally, the results from a simulation based on an actual Thundersky battery were compared with the results from the experiments on the BMS hardware system.

As focusing on our key aspects about the fast charging, Temperature plays a very important role. Our proposed method known as the Constant Temperature- Constant Voltage scheme has practically proven that it actually carries out the charging of these Lithium-ion batteries at a very faster rate, as we can see Battery A was charged 88% while Battery B was charged 62%. So, the difference between the charging states is considerable, and it managed to process under the temperature limit set by safety standards which is 45 degrees. So summing it up, this proposed method elaborates us the plus points of using this technology at the expense of some extra cost which is quite reasonable as well. Therefore, achieving a very short charging time with minimum/no side effects on battery is admirable.

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