Design and Development of Efficient Battery Charging and Cell Balancing for Battery Management System

Namith T. [1]**, Ms. Preetham Shankpal**[2]
1- M. Sc. [Engg.] Student, 2-Asst. Professor,
Electronics and Electrical Engineering,
M. S. Ramaiah School of Advanced Studies, Bangalore- 560 058

Abstract

Lead-acid batteries are the most commonly chosen power source for many portable applications. Advantages like high energy density, high nominal voltage, less maintenance, and low self discharge rate are the driving force behind this choice. Although they have many advantages lead-acid batteries have not been used in various applications because of the difficulty of using them well and keeping the individual cells balanced in a series-connected battery pack. This provides the motivation to develop a Battery Charging and Cell Balancing (BCCB) with individual cell equalizers and state of charge (SoC) observers. The main purpose of a BCCB is to monitor the cells in a battery pack to ensure proper operation and balance the voltage and charge in the cells in a battery pack in order to maximize the available energy.

A BCCB is developed for a lead-acid battery pack with two cells connected in series. The BCCB monitors individual cell parameters like voltage and current to ensure proper operating conditions. Battery model equations are derived, which serve as a SoC observer, to predict and correct the charge stored in the cell. A novel dissipative equalization scheme is proposed to achieve cell equalization among the series connected cells in terms of both voltage and charge. The circuit schematic for the BCCB is designed and simulated by using Proteus and NI Multisim. The proposed battery management system is implemented in hardware to demonstrate its operation of two batteries with 12V 7.2 Ah.

Experiments conducted using the implemented BCCB show that a charging strategy that includes cell equalization in terms of voltage allows 31% more energy to be stored in the pack than does a simpler strategy that stops charging once the strongest cell in the battery pack reaches the maximum allowable cell voltage. A charging strategy that includes cell equalization in terms of both voltage and stored charge allows 39% more energy.We conclude that the present study has achieved significant improvements in battery charging and cell balancing efficiencies.

Keywords: Battery Charging, Cell Balancing , Hybrid Electric Vehicle

Abbreviations

AC	Alternating Current
ADC	Analogue to Digital Converter
BMP	Battery Monitoring and Protection
BMPS	Battery Monitoring and Protection System
BMS	Battery Management System
BMU	Battery Management Unit
CAN	Controller Area Network
CC	Constant Current
CV	Constant Voltage
DC	Direct Current
Emf	Electromotive Force
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
LCD	Liquid Crystal Display
LED	Light Emitting Diode
PM	Power Module
PWM	Pulse Width Modulation
SoC	State of Charge

1. INTRODUCTION

The main component of the electric car is the battery which is the fuel tank of the electric car. Battery is by far the most expensive part of the car and optimum utilization of the battery and enhancing the battery's life-time is of utmost importance. The battery lifetime can be enhanced by controlled charging and discharging of the batteries. Battery monitoring system is being built to provide total control of the charging and discharging of the batteries by monitoring the voltage of individual batteries and the current flowing through the battery pack. Apart from these basic parameters the battery monitoring system on a whole is being built to monitor the temperature, the charging time and other critical system and statistical parameters.

Series connected battery packs in electric vehicles (EVs) and hybrid electric vehicles (HEVs) require monitoring equipment that is capable of measuring the voltages of individual segments (several modules/cells connected in series) in order to prevent damage and identify defective segments. All types of batteries can be damaged by excessively high or low voltages, and in some cases the results can be catastrophic. Lithium ion cells, for example, will ignite if they are overcharged. Figure 1 shows the block diagram for BMS. It includes battery, charger, microcontroller, switch, energy source, temperature sensor, load and ADC.

During the normal working of the battery pack, the cells might reach a situation of non-uniform cell voltages (Electropedia, 2005). This might be due to manufacturing tolerances or due to unequal aging of cells over a period of time. Unequal voltages of cells, which are electrically near, might lead to circulating currents and also could aggravate the aging dynamics. As such, it is essential to balance terminal voltages of individual cells. This functionality termed as cell balancing.

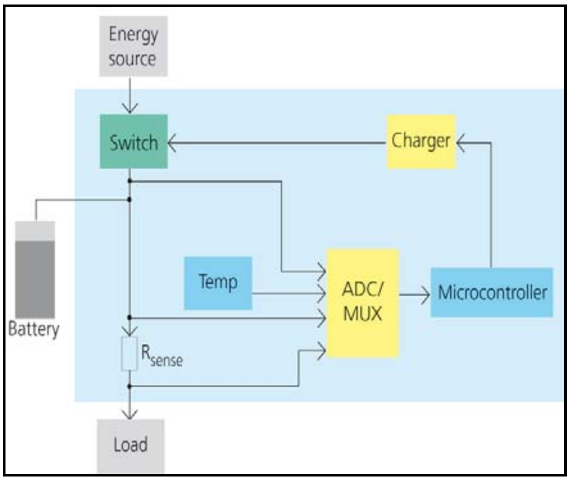

Fig. 1 Battery management system

More efficient use of the energy inside a battery is becoming increasingly important in the rapidly growing market for portable products. Manufacturers of portable devices are consequently paying even more attention to battery management. This is reflected in many commercial electronics magazines, such as Electronic Design. In practice, battery management functions are implemented in portable devices by electrical engineers. These engineers usually treat the battery as a black box. It is usually assumed that the battery is a voltage source with some series resistance. However, in order to improve the functionality of a BMS, at least some understanding of battery behavior in the system is needed. A prototype of the portable device is needed for measurements of actual battery charge and discharge behavior. On the other hand, simulation is a helpful tool in obtaining a better understanding of the behavior of complex systems under a wide variety of conditions.

The intelligence in the BMS is included in monitor and control functions. The monitor functions involve the measurement of battery voltage and charger status or load activity. The control functions act on the charging and discharging of the battery on the basis of these measured variables. Implementation of these monitor and control functions should ensure optimum use of the battery and should prevent the risk of any damage being inflicted on the battery. The degree of sophistication of the BMS will depend on the functionality of the monitor and control functions. In general, the higher this functionality, the better care will be taken of the battery and the longer its life will be. The functionality depends on several aspects.

1.2 Need for Battery Management System

More efficient use of the energy inside a battery is becoming increasingly important in the rapidly growing market for portable products. Manufacturers of portable devices are consequently paying even more attention to battery management. This is reflected in many commercial electronics magazines, such as Electronic Design. In practice, battery management functions are implemented in portable devices by electrical engineers. These engineers usually treat the battery as a black box. It is usually assumed that the battery is a voltage source with some series resistance. However, in order to improve the functionality of a BMS, at least some understanding of battery behavior in the system is needed. A prototype of the portable device is needed for measurements of actual battery charge and discharge behavior. On the other hand, simulation is a helpful tool in obtaining a better understanding of the behavior of complex systems under a wide variety of conditions.

2. PROBLEM DEFINITION

Battery Management system can calculate the SoC of the battery and according to the SoC level it can monitor and control the charging from a DC source. In this chapter, the basic objectives and methodologies of the battery charging and cell balancing system is derived and specified.

- To review the literature on Battery Management System(BMS), type of batteries, BMS standards, techniques for efficient Battery Charging and Cell Balancing(BCCB) for hybrid/electrical vehicle
- To develop a top level block diagram for efficient battery charger and cell balancing to BMS and identify the design specifications for BCB
- To identify algorithms and architecture for efficient battery charging and cell balancing logic and develop software reference model
- To evaluate performance of developed algorithms for battery charging and cell balancing unit and improve its performance by proposing novel architecture
- To design and implement the proposed novel architecture for battery charging and cell balancing
- To build prototype model and test its performance against software reference model

2.1 Methods and Methodology

- Literature review for Battery Management System(BMS), type of batteries and hybrid/electrical vehicles has been done by referring reviewed journals, books, manuals and related documents
- Design of block diagram to meet the design specifications has been done by referring to literature
- Algorithm has been developed for designed block diagram

- Hardware modules required to develop BCCB has been identified , schematics for BCCB has been developed
- Software programs for configuring hardware modules has been done in Proteus/Multisim and verified
- Selection of components has been done based on the required design specification
- Integration of hardware and software has been done and tested by using different parameters
- Testing and validation has been done on the developed system.

3 DESIGN

3.1 Detailed Block Diagram

The structure of a general BCCB is shown in Figure 2. The partitioning of intelligence is symbolized by placing a ‘Monitor and Control’ block in every system part. The block diagram of BCCB shown in Figure 2 also controls a Battery Status Display. An example is a LCD that indicates the ‘battery low’ status. It consists of controller, charging system, input sensors, battery and a LCD display. Controller has all the algorithms to control the charging and cell balancing. Monitoring algorithm will monitor battery voltage, charging current and SoC level of the battery. Charging control algorithm controls charging voltage and current as required. Cell balancing algorithm used to control the unbalancing of cell voltage.

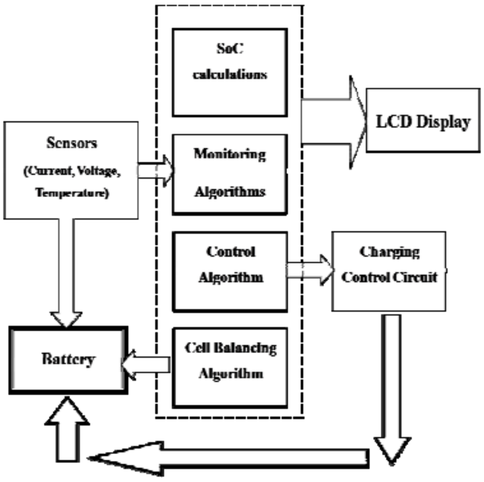

Fig. 2 Battery management systems

3.2 Charge Control

Charge control is an essential feature of a BMS. More batteries are damaged due to inappropriate charging than due to all other reasons combined. As discussed earlier, the voltage across a Lead-Acid cell should be within the maximum/minimum limits during charging and discharging.

3.3 The Battery

A battery’s basic task is to store energy obtained from the mains or some other external power source 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. Different battery systems with different chemistries and different characteristics exist. Examples of some commonly encountered battery systems are nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and lithium-ion (Li-ion) batteries. Lead-acid batteries have been used in this study. Figure 3 shows the lead-acid battery. Table 1 shows the specification of lead-acid battery.

Fig. 3 AP7.2-12 lead-acid batteries

Table. 1 Lead-acid battery specification

Battery type	Capacity	Nominal filled weight	Charging current (A)
Ap7.2-12	7.2Ah	2.50(kg)	1.5

3.4 State of Charge (SoC) Determination

SoC monitoring done by using a look-up table of battery's Open Circuit Voltage (OCV). This system continuously measures the voltage, current and it calculates the SoC of the battery with its SoC algorithms. This will be displayed in the LCD so that driver can know the capacity of the battery. Figure 4 represent the SoC v/s OCV graph.

SoC algorithm is the main part which describes battery capacity. In this case as we already described above, initial capacity is taken as V_{in}/V_{batmax}.

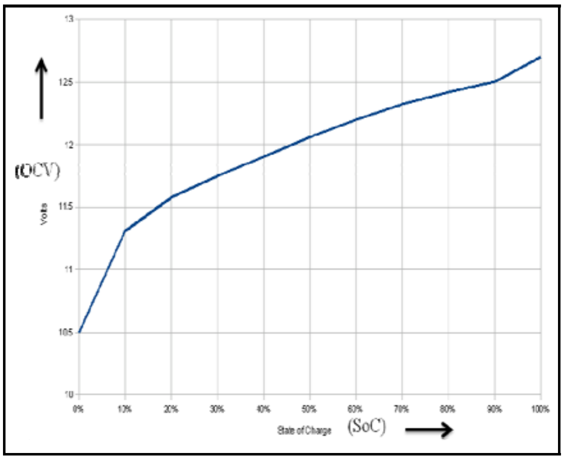

Fig. 4. Open circuit voltage v/s state of charge level graph

3.5 Cell Equalization

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 equalization is one of the most important functions of a battery management system.

3.6 Voltage Detection

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.

As per voltage divider rule $V_{out} = V_{in} * R_2/(R_1+R_2)$ ---[Eq. 1]

$$= 13*4K(8K+4K)$$

$$= 4.3V$$

3.7 Current Sensor WCS1702

The Winson WCS1702 provides economical and precise solution for both DC and AC current sensing in industrial, commercial and communications systems. The unique package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, over-current fault detection and any intelligent power management system etc.

The WCS1702 consists of a precise, low-temperature drift linear hall sensor IC with temperature compensation circuit and a current transformer with 0.19 Ω typical internal conductor resistance. This extremely low resistance can effectively reduce power loss, operating temperature and increase the reliability greatly. Applied current flowing through this conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage.

The terminals of the conductive path are electrically isolated from the sensor leads. This allows the WCS1702 current sensor to be used in applications requiring electrical isolation without the use of opto-isolators or other costly isolation techniques and make system more competitive in cost. Figure 5 shows the specification of WCS1702

.

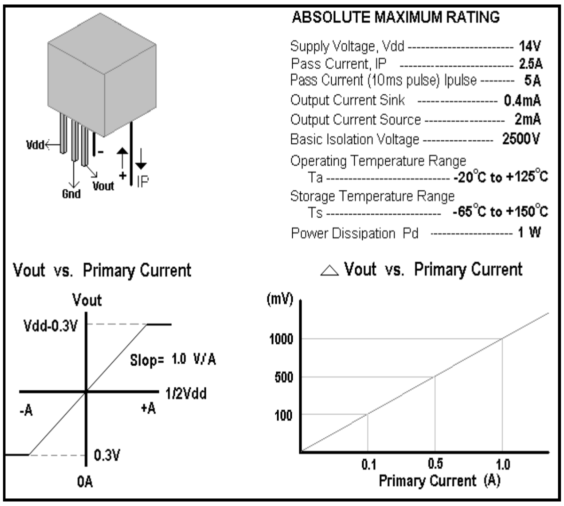

Fig 5. WCS1702 current sensor specification

3.8 Relay

A 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. A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contractor. Relay has been used for cell balancing. Figure 5 shows the relay.

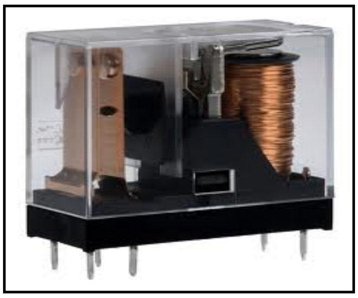

Fig. 6 Relay

3.9 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. Figure 7 represent the PIC 18f452 pin configuration. PIC 18f452 controller was selected as central control. It has many features like

- High Speed of operation
- It has 17 independent interrupt sources
- It has 2 CCP/PWM modes
- It has inbuilt 10 bit ADC in it
- It has programmable timer option

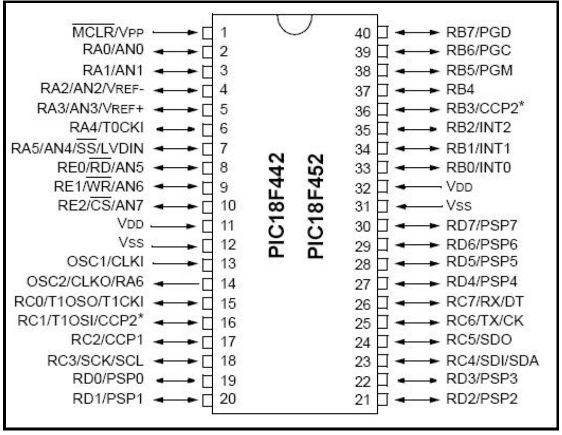

Fig. 7 PIC 18f452 pin configuration

3.10 LCD Display

A 20*4 LCD is used to get the results from the controller and it can be used to display the results in the car dashboard. It has features like. Figure 8 shows the 20 x 4 LCD display.

- Overall Module Size 98.0mm(W) x 60.0mm(H) x max 14.0mm(D) for LED backlight version
- 98.0mm(W) x 60.0mm(H) x max 9.5mm(D) for reflective version
- Dot Size 0.55mm(W) x 0.55mm(H)
- Dot Pitch 0.60mm(W) x 0.60mm(H)
- Duty 1/16
- Controller IC KS0066
- LC Fluid Options TN, STN
- Polarizer Options Reflective, Transflective, Transmissive
- Backlight Options LED
- Temperature Range Options Standard(0ºC ~ 50ºC), Wide(-20ºC ~ 70ºC)

Fig. 8 4x20 LCD display

3.11 Buck Convertor Design for the DC-DC Conversion

Figure 9 shows the power electronic circuit for the DC-DC buck convertor and here we can see that a DC source is simulated for the SMPS input which is of 30V. This input is connected to the drain of the MOSFET. IRF 540n is used here for the switching purpose. This MOSFET was chosen as per the requirements for the study. This need to be working under high current applications and IRF540n gives best results under these conditions. In the circuit source is grounded and to the gate PWM pulse is given. In the hardware circuit transistors are used to switch the MOSFET according to the PWM pulses from the controller. After the MOSFET it is given to the basic buck circuit which consists of Inductor, diode and capacitor. Figure 9 is a buck converter circuit. +Vin represents the input DC voltage of buck converter. Cin is the input filter capacitor. PWM has given to the Q1 mosfet to control the output voltage. L1 is the inductor and D1 is the diode for buck converter. Vout is the output voltage.

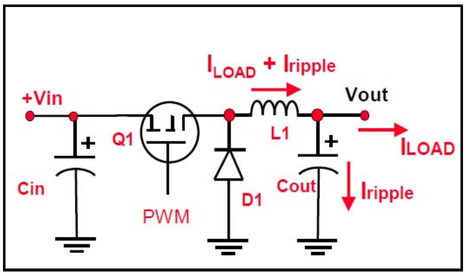

Fig. 9 Buck converter

Here PWM pulses of 90% on time 10% off time is given for switching the MOSFET. After the design, hardware circuit is made and it is giving reduced DC output of 25.2V. This also controls the current to 2A which is preferred by the manufacturer. A 6A diode is placed in the circuit at the output terminal because it can prevent any kind of back emf to the system from the battery. A normal 1N4007 diode is also placed after the controller so that any kind of back emf should not affect PIC controller from battery. Inductor is placed as per the design. Equation 2 used to find the I_{ripple} value. Equation 3 used to find the voltage across the inductor. Equation 4 used to find the out put capacitor value.

As V_{in}= 30V, V_{out}= 25.2V, I_{load}=2A, F_{sw}=32KHz, D= V_{out}/V_{in}=0.9

$I_{ripple} = I_{load}*30\%$ ---- [Eq. 2]

$= 2A*0.3$

$= 0.6Amps$

Voltage across inductor= L di/dt

$L= ((V_{in}- V_{out})* (D/F_{sw}))/ I_{ripple}$ ---- [Eq. 3]

$= ((30-25.2)*(0.9/32\ KHz))/0.6$

$= 0.000197$ H

Capacitor is also placed as per the design.

For the capacitor,

$\delta V = \delta I * (ESR + \delta T / C + ESL / \delta T)$

Ripple voltage was defined as 50mV.

$\delta I = 0.6A$, ESR(Effective Series Resistance)= 0.03Ohms, ESL= 0,

$\delta T = 1.04\mu$seconds

ESL is assumed as 0 then,

$\delta V = \delta I * (ESR + \delta T / C)$ So this becomes,

$C = (\delta I * \delta T) / (\delta V - (\delta I * ESR))$ ---- [Eq. 4]

Cout $= (0.6A * 1.04\ \mu sec) / (0.05V-(0.6A * 0.03))$

Cout $= 19.5\ \mu F$ (minimum)

IRF540n MOSFET is selected because of its very features like,

- Fast switching
- Ultra low-on resistance
- Maximum pulsed drain current of 110A
- Continuous drain current of 33A.

Its gate to source voltage also suits for this study as it can withstand ±20V.
197µH is the designed inductor value but as per the requirement, tests carried on the circuit and market availability 47µH is selected. As per this design minimum of 19.5 µF need to be used for the circuit. After the tests on the circuit, it is found that 47 µF capacitor can be used. For the requirement of the system diodes of 6A power diodes are selected.

4. Battery Charging Algorithm

The Constant Current - Constant Voltage (CC-CV) algorithm is used for the DC-DC conversion during battery charging. A constant current will be drawn by the battery when it is in fully discharged condition. When the battery is charged up to 80% of its SoC its charging is switched to a constant voltage phase. According to the battery conditions, modes of charging are selected. As per the SoC of the battery, continuous charging, trickle charging and no charging will be undertaken. This algorithm is explained in the flow chart of Figure 10. First the controller will read voltage and current parameters. By using this measured voltage processor will calculate the SoC level. Then the processor will select the CC/CV mode charging. Initial battery charging current will be constant and once it reaches at a particular point current reduce gradually. This time processor will select CV charging. Once the SoC level reaches 85% controller will go for trickle charging. Trickle charging is used for overcome the battery self discharge. PWM pulse is used to control the CC and CV charging mode.

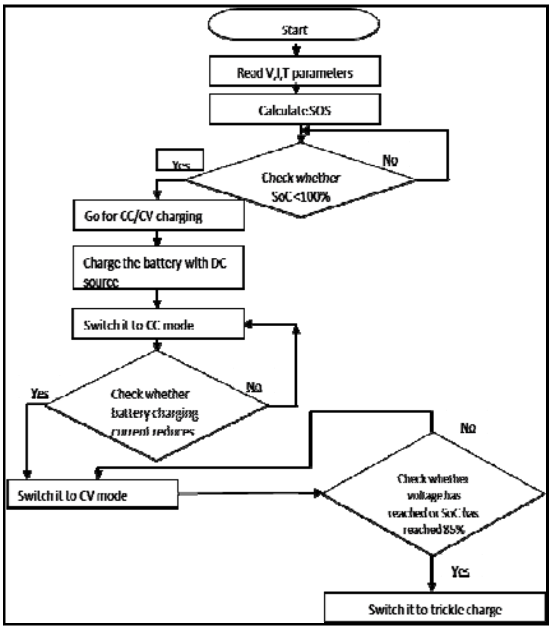

Fig. 10 Battery charging algorithm

4.2 Cell Balancing Algorithm

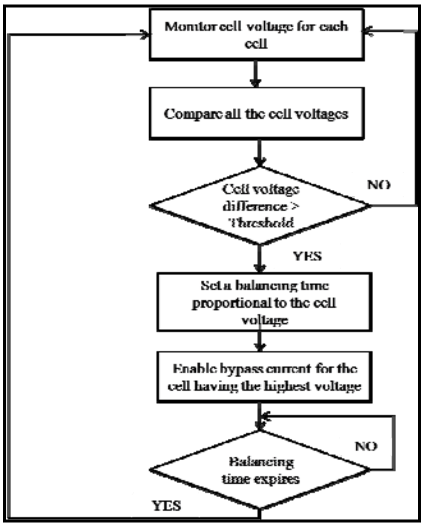

Fig. 11 Cell balancing algorithm

Figure 11 represent the cell balancing algorithm. First the controller reads the individual battery voltage and find out the difference between the batteries. After finding the difference it compare with the threshold voltage. If the difference is more than threshold value the controller will set a balancing time proportional to the cell voltage. It enables the bypass current for the cell having the highest voltage.

5. Hardware Modeling

5.1 Buck Converter

Buck converter has been developed in Proteus and the working has been verified by developed the hardware. Figure 12 is a buck converter that has been designed in Proteus. Figure 13 is a cell balancing circuit that has been designed in Proteous. In this circuit Q1 is the IRF 540 mosfet.

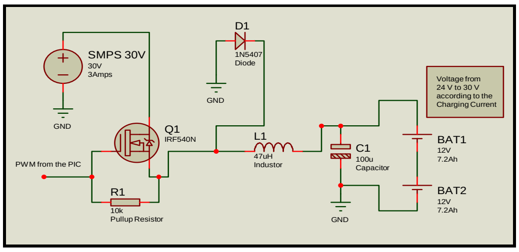

Fig. 12. Buck converter circuit

5.2 Cell balancing

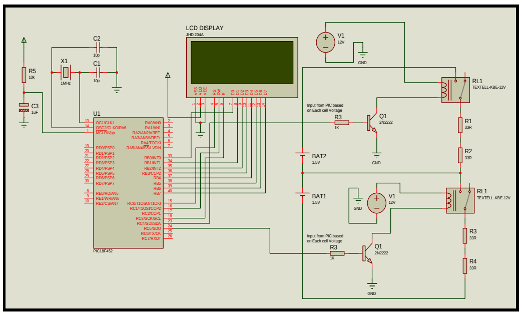

Fig. 13. Cell balancing circuit

5.3 Discussion on Implementation

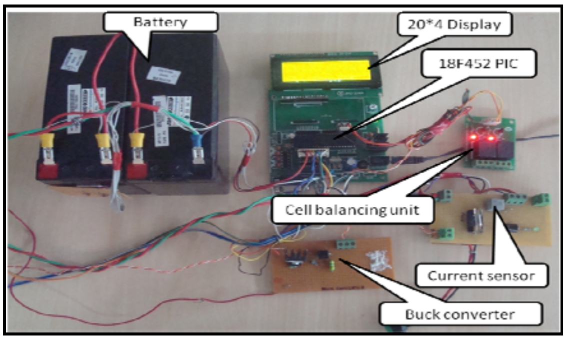

Fig. 14. Total BCCB system

Figure 14 shows the entire set up of BCCB. In the figure we can see the different components, sensors, battery and display unit of the BCCB. The figure also shows the individual sub-system of BCCB. The entire system has been developed as per the design. All the input sensors connected to the controller by wires. The LCD display has been interfaced to the controller. All the subsystems has been tested individually before interfacing with the controller.

6. CONCLUSIONS

The results for the implementation of the proposed cell equalization scheme show that an additional energy of 31% due to cell equalization in terms of voltage and 39% of additional energy due to cell equalization in terms of stored charge can be put into the battery pack during charging when compared to the simpler strategies which end charging once the strongest cell in the battery pack reaches maximum voltage. We conclude that the present study has achieved significant improvements in battery charging and cell balancing efficiencies.

7. REFERENCES

[1] Bergveld H J., (2003) '*Battery Management Systems Design By Modelling'* [online] available from <http://doc.utwente.nl/41435/1/thesis_bergveld.pdf>, [15 November 2011].

[2] Bharath Pattipati., Krishna Pattipati., Jon P. Christopherson., Setu Madhavi Namburu., Danil V. Prokhorov and Liu Qiao., (2008) '*Automotive Battery Management Systems',Proceedings* of AUTOTESTCON, IEEE, Salt Lake Cirty, UT, [15 November 2011].

[3] Dorffel. Dennis, (2006) 'Energy Management of Hybrid Electric Vehicles', Miphil/PhD study 9 months report," *Dissertation Report*, University of South Hampton School of Eng. Sciences [online] available from <http://eprints.soton.ac.uk/822/01/9months_report.pdf>. [15 November 2011].

[4] Electropedia (2005) '*Battery and Energy Technologies*' [online] available from http://www.mpoweruk.com/bms.htm> [15November 2011].

[5] Electrapack '*lead acid cell-battery'* [online] available from <http://electrapk.com/lead-acid-cell-battery/> [15 November 2011].

[6] Harold Haskins.,Vince Battaglia., Jon Christophersen., Ira Bloom., Gary Hunt and Ed Thomas., (2005) '*Battery Technology Life verification test manual*' [online] available from <http://avt.inel.gov/battery/pdf/tech_life_verification_test_manual_feb_2005.pdf> February 2005, [20 November 2011].

[7] Isidor Buchmann., (2001) '*What is the Perfect Battery'*, [online] available from <www.buchmann.ca>, [16 November 2011].

[8] Jossen. A., Garche. J., Spath. V and Doring.H., (1999) '*Battery Management Systems (BMS) for Increasing battery life time*', Proceedings of Telecommunication Energy Conference, Copenhagen, [15 November 2011].

[9] M.J. Isaacson, R.P. Hollandsworth, P.J. Giampaoli, F.A. Linkowsky, A. Salim, and V.L. Teofilo, (2000) '*Advanced Lithium*

Ion Battery Charger', The Fifteenth Annual IEEE Battery Conference on Applications and Advances, pp. 193-198, [15 November 2011].

[10] Operatingtech, (2009)"*A guide to battery charging, Operating Technical Electronics*" [online] available from <http://www.operatingtech.com/lib/pdf/A%20Guide%20to%20battery%20Chargi ng.pdf> [15 November 2011].

[11] Plett L. Gregory (2004) '*Extended Kalman Filtering for Battery Management Systems of LiPBbased HEV Battery Packs, Part 2: Modeling and Identification'*, Journal of Power Sources, vol.134, no. 2, pp. 262-276, [15 November 2011].

[12] Thomas Stuart, Fang Fang, Xiaopeng Wang, Cyrus Ashtiani, and Ahmad Pesaran (2002) *'A Modular Battery Management System for HEVs',* National Renewable Energy Laboratory [15 November 2011].