CHAPTER NO. 4

Battery Management and Performance Monitoring

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Developing a smart electronic system for an electric vehicle is often about making the right choice of the system architecture for efficient design. Initial experiments were carried out to understand the battery handling, reading electrical parameters, charging and discharging, self discharging, active load and passive load discharging and capacity testing for flooded and valve regulated lead acid (VRLA) batteries. An eight channel analog input, two analog out and twelve digital input/output channels data acquisition system supplied by National instrumentations and USB data logger supplied interfaced to PC has been employed for pilot experimentation. Battery has been charged and discharged with incandescent lamps as a passive load and high power MOSFET as an active load to understand battery capacity and battery efficiency. Self discharge rate of flooded and VRLA batteries have been monitored continuously over a period of month. In this self discharging experiment it has been observed that self discharge rate of flooded batteries are more than VRLA batteries and also validated from secondary data.

This chapter describes initial and final experimentation with different stages of hardware design for battery parameter measurement. For all electrical vehicles, battery pack and its precise management is an essential component of the design process. The development of the batter performance parameter and battery management system software using LABVIEW tool is explained for further data processing and analysis.

A new approach to for online recognition of state of charge of flooded battery like lead acid battery a fiber optic sensor i.e. FOS-SOC has been designed and implemented the system. Monitoring the state of charge (SOC) of any battery is important to understand the remaining or residual electrical energy. Usage of the battery for driving electric load leads to reduce the charge content of active
electrolyte. This will change refractive index of the electrolyte. The SOC of battery is monitored for different loads. Mainly terminal voltage, temperature and depth of discharge have been measured using a LABVIEW based data acquisition system.

This chapter also describes development of portable embedded battery management systems for electrical vehicle. In addition, an extensive battery performance parameter monitoring and management using LabVIEW tool has been developed. The microcontroller based battery management system has advantage over LabVIEW based system that design is low cost, simple to use, easy to install and portable for electrical car for displaying battery performance parameters. The different experiments were carried out for displaying battery performance parameters (BPP) like VOC, discharging current, temperature, specific gravity, SOC, DOD and internal resistance or impedance using LabVIEW.

4.1. Development of PC based measurement system

PC based instruments are in standalone and modular form. Traditionally measurement of electrical parameters and control on hardware are done using standalone instrument. The measurement and automations are automated by exchanging data between the designed hardware or instrument and computer [1]. PC based systems are used in a variety of applications. These are used in research laboratories, manufacturing industries and observatories. These instruments are well suited for measurement of current and voltage signals and acts as a general purpose measurement tool. PC based measurement system involves data acquisition hardware and appropriate application hardware. The national instrument USB 6009 used as a data acquisition hardware and Measurement and automation Explorer used as application software. The measured electrical signals or system data can be saved in data files in a disk and it enables future analysis.
Since DAQ system support data acquisition, digital I/O and timer function. It is possible to control various modules in an instrumentation system and automate the measurement process.

**System**

![Block diagram of PC based measurement system](image)

**Fig. 4.1:** Block diagram of PC based measurement system

Data acquisition is the process of measuring a physical or electrical parameters i.e. voltage, current, temperature, pressure using computer. A data acquisition system consists of sensors, signal conditioning circuits or measuring hardware, and application software. Compared to traditional measurement systems, Computer based data acquisition systems make use of the power, productivity, display, and connectivity capabilities. Here data acquisition is used to read battery parameters continuously and predict required parameters of the electrical vehicles.

Since the functionality is defined mainly by acquisition, analysis and display the routines in the system. It is possible to achieve various measurements system by using the same DAQ system and with the different algorithms in the software. The personal computer is used in measurement systems are dedicated to the measurement applications. The general conceptual block diagram of PC based measurement system is given in above figure 4.1

LabVIEW and embedded based battery monitoring system has been developed for electrical car and ready to use for any battery powered system to adopt safety, convenience and pleasure. The developed LabVIEW and embedded based system has
been utilized for battery management and monitoring of different parameters. The developed system is an essential for optimum utilization and safety reason in the electrical vehicles. This system will be useful for manufacturer and user of the electrical car to understand condition and health of the rechargeable battery so that it is easy to take decision of recharging the battery or replace the battery. Real-time systems are PC based systems that are prone to display, respond to external electrical parameters. The measured electrical signals or system data can be saved in data files in a disk and it enables future analysis. Since DAQ system support data acquisition, digital I/O and timer function. It is possible to control various modules in an instrumentation system and automate the measurement process.

**4.1.1 Data acquisition System**

PC based systems are not accepting analog signals directly from the sensor or transducer. Hence between sensors and system, analog to digital converters are required to transfer data to the computer. A data acquisition system consists of sensors, measuring hardware, and application software. As compared to traditional measurement systems, PC-based data acquisition systems exploit the processing power, productivity, display, and connectivity capabilities [1].

![Block diagram of data acquisition system](image)

**Fig. 4.2:** Block diagram of data acquisition system

Here data acquisition is used to read battery parameters continuously and predict required parameters of the electrical vehicles. This is the general block diagram of
data acquisition system, which consists of sensors, data acquisition hardware and computer. The components of data acquisition systems include sensor, signal conditioning circuit and ADC/DAC.

The sensors in data acquisition system convert physical signal to electrical signals into a suitable form. This formatted signal further converted to digital values with the help of Analog-to-digital converters. This digital converted sensor signal is given to the computer for further processes in computer as shown in figure 4.2.

Here in the section of data acquisition, the data acquisition card i.e. USB 6008 and 6009 are studied and used for experimentation. These both cards are studied theoretically and experimentally. These data acquisition cards have been used for reading many electrical parameters like current, voltage and temperature of the battery.

![USB 6009 data acquisition card](image)

**Fig 4.3:** USB 6009 data acquisition card

The NI USB-6008/09 provides eight analog input, two output, twelve digital input/output channels, and 32-bit counter with USB interface [2]. NI USB-6008/09 card are manufacture and supplied by National Instruments provides basic data acquisition facility for various applications such as data logging, portable USB based
measurements, and laboratory experiments. Hence NI USB-6008 and NI USB-6009 are useful for beginners and researcher to use for primary or pilot experimentation.

In LabVIEW one can create specific measurement application by programming the USB data acquisition card using LabVIEW and NI-DAQmx driver software for Windows. The USB 6008/09 actual system photograph and analog input circuit is given in the figures 4.3 and figures 4.4 respectively.

![Analog input circuitry of USB 6009 data acquisition card](image)

**Fig. 4.4:** Analog input circuitry of USB 6009 data acquisition card

In analog input circuitry of USB 6009 shows different blocks like multiplexer, programmable gain amplifier (PGA), analog to digital converter (ADC) and analog input first in first output (FIFO) [2]. The brief explanation of main sections of USB 6008/6009 is given below to understand functioning of the card.

**a) Multiplexer (MUX)**

Multiplexing in data acquisition system is the process of scanning through a number of input channels, and sampling each in rotation. In multiplexed systems, single ADC is needed to acquire data from various channels. In a multiplexed system, multiple data streams are merged into a time-division multiplexed signal, which is then
sampled. Multiplexing techniques allows one ADC to do the work of several in a multichannel system. Rather than dedicating an ADC to each channel, a single converter can read every channel in sequence. This technique can save sufficient power, since ADCs can consume a significant amount of power while switches use very little. Therefore it can save cost, since switches are much cheaper than ADCs. The NI USB-6009 has one analog-to-digital converter (ADC) and eight to one multiplexer section. The input signals of multiplexers are modified by resistors shown in the figure. The eight channels are labeled as AI0 to AI7. The multiplexer (MUX) routes one AI channel at a time to the programmable gain amplifier (PGA)

b) Programmable gain amplifier (PGA)

A programmable-gain amplifier is an electronic amplifier whose gain can be controlled by external digital or analog signals. Typically PGA uses an operational amplifier for amplification. Operational amplifiers with programmable gain from multi channel systems can be integrated in a variety of system setups for experimentations. The programmable gain amplifier in NI USB-6009 provides input gains of 1, 2, 4, 5, 8, 10, 16, or 20 when configured for differential measurements and gain of 1 when configured for single-ended measurements. The PGA gain is automatically calculated based on the voltage range selected in the measurement application.

c) Analog to Digital Converter (ADC)

Data acquisition system often contains multiple components like multiplexer, ADC, DAC, TTL-IO, high speed timers and RAM. These components are accessible through a bus by a microcontroller, which can run on small programs. The signal conditioning circuitry to convert sensor signals into a particular form that can be
converted to digital values with the help of ADC. The analog-to-digital converter (ADC) digitizes the analog (AI) signal by converting the analog voltage into a digital code for further process.

d) **Analog input first in first out (FIFO)**

The FIFO stands for "First-In, First-Out", and functions like a "buffer" memory - an important role in data acquisition devices. Today's multi-tasking operating system can deal with more than one task at a time. The FIFO memory type, the restraint on sampling rates and can be relieved, and devices becomes faster with data acquisition by interrupt or DMA functions. This NI USB-card perform both single and multiple A/D conversions of a fixed or infinite number of samples. A first-in-first-out (FIFO) buffer holds data during AI acquisitions to ensure that no data is lost.

The NI 6008/09 is USB portable so it can be easily connected to the computer. The above block diagram consists of USB external power supply, microcontroller, 8 channels (12/14b) ADC, 12bit DAC, analog input and analog output pins.

e) **Acquiring a Signal with DAQ**

Following are the steps used to acquire analog or digital signal with the help of USB 6008/09. The driver software of measurement and automation has to be installed first on computer system along with application software LabVIEW. Further USB data acquisition card has to be connected to the computer, once this card detects then follow given steps for data acquisition.

1. Launch LabVIEW software.
2. In the Getting Started window, click the New or VI from Template link to display the New dialog box.
3. Open a data acquisition template. From the Create New list, select VI»From Template»DAQ»Data Acquisition with NI-DAQmx.vi and click “OK”.

4. Display the block diagram by clicking it or by selecting Window»Show Block Diagram. Read the instructions written there about how to complete the program.

5. Double-click the DAQ Assistant to launch the configuration wizard.

Configuration of DAQ card for an analog input operation.

1. Choose Analog Input»Voltage.

2. Choose Dev1 (USB-6008)»ai0 to acquire data on analog input channel 0 and click “Finish.”

3. In the next window you define parameters of your analog input operation. To choose an input range that works well with microphone, on the settings tab enter 2 Volts for the maximum and –2 Volts for the minimum. On the task timing tab, choose “Continuous” for the acquisition mode and enter 10000 for the rate. Leave all other choices set to their default values. Click “OK” to exit the wizard.

Place the Filter Express VI to the right of the DAQ Assistant on the block diagram. From the functions palette, select Express»Signal Analysis»Filter and place it on the block diagram inside the while loop. When you bring up the functions palette, press the small push pin in the upper left hand corner of the palette. This will tack down the palette so that it doesn’t disappear. This step will be omitted in the following exercises, but should be repeated. In the configuration window under Filtering Type, choose “Highpass.” Under Cutoff Frequency, use a value of 300 Hz. Click “OK.”.
4.1.2 Signal conditioning circuits

The signal conditioning circuits are required for temperature and high current sensing applications like ampere hour measurements. The signal conditioning circuits are designed and experimented. The rechargeable battery has been studied for self discharge rate so that exact estimation of remaining power would be calculated. Different experiments on actual rechargeable battery are carried out and completed and some readings are taken for knowing some of the battery parameters.

4.1.2.1 Battery temperature measurement

In order to improve the performance of battery packs at cold temperatures, battery electrolyte has to be warmed up because battery internal resistance increases in cold environment. Moreover, if the battery pack is allowed to reach a very low temperature, these methods require significant amount of time for warming the batteries. This will lead to change battery charging voltage with change in temperature. The charging voltage may vary from about 2.74 volts per cell (16.4 volts) at -40 °C to 2.3 volts per cell (13.8 volts) at 50 °C. Even though battery capacity at high temperatures is higher, battery life is shortened. Battery capacity is reduced by 50% at -22 °F but battery life increases by about 60%. Battery life is reduced at higher temperatures for every 15 degrees F over 77%, battery life is cut in half [3, 4]. Hence battery temperature measurement or control is very much important.

![Diagram](image)

**Fig. 4.5:** LM 35 temperature sensor signal conditioning
The LM35 is an integrated circuit sensor used to measure temperature of the battery with an electrical output proportional to the temperature in degree Celsius (°C). The output resistor $R_a$ is used at the output section of the sensor. The output impedance of the sensor is very low hence the external resistor of $1\Omega$ is connected to the output terminal and ground. This is signal conditioning section of the temperature measurement. The output of the signal conditioning section is connected to the data acquisition card for accurate measurement of the battery temperature.

Temperature sensor LM-35 is used for battery temperature measurement because of the following electrical specifications

1. Temperature measurement is more accurately than a using a thermostat.
2. The sensor circuitry is sealed and hence not subject to oxidation, etc.
3. The LM35 generates a higher output voltage ($10 \text{ mV/}°\text{C}$) than thermocouples and may not require that the output voltage be amplified
4. LM 35 has an output voltage that is proportional to the Celsius temperature. The scale factor $0.1\text{V/}°\text{C}$
5. The LM35 does not require any external calibration or trimming and maintains an accuracy of +/-0.4 °C at room temperature and +/- 0.8 °C over a range of 0 °C to +100 °C.

### 4.1.2.2 High discharge current measurement

Ampere hour measurement of the battery is necessary to know exact amount of power left in the rechargeable battery. High power batteries and type of electrical load will decide the current flowing through the external load. Generally for electrical vehicle current range is in tens of ampere. Hence the signal conditioning circuit for high side current measurements needed for ampere hour measurement. Higher side current monitoring of the battery is very much important because many electrical loads
consume current in amperes. The data acquisition (DAQ) card is not capable of handling high side current because it reads current up to 5mA only. Hence it is necessary to attenuate the load current and in the programming code that attenuated amount is adjusted so that same measured value displayed on the computer monitor.

![Current measurement circuit](image)

**Fig. 4.6:** Current measurement circuit

The technique used for current measurement is to measure voltage drop across the small value shunt resistor, instead of measuring current [6, 7]. The shunt resistor and electrical load are connected in series with the high capacity rechargeable battery. As the electrical load varies current consumption changes and by default the voltage drop across shunt resistor varies. This concept was taken in to account and instead of measuring current voltage of the circuit is measured. It is found that voltage drop across the shunt resistor is directly proportional to the current passing through the circuit. The current sensor monitors the current flow by measuring the voltage drop across a resistor placed in the current path. The current sensor output either voltage or current that is proportional to the circuit current. The current sensing is more and more important as a way to monitor performance. Such circuits can be used frequently for over current protection, supervising circuits, programmable current sources, battery charger and SMPS. The traditional approach for high side current measurement has been the use of a differential amplifier, which is employed as a gain
amplifier. The operational amplifier OP-07 is used because of its high CMRR and other properties.

![Differential amplifier diagram](image)

**Fig. 4.7:** Differential amplifier for measurement of load current

The smallest difference is to be detected and amplified with the designed differential amplifier using operational amplifier OP-07 and gain adjustable resistors as shown in the figure 4.7. The amount of electrical load decides the voltage levels of e1 and e2. The voltage difference between the node e1 and node e2 becomes very small and hence differential amplifier with high CMRR operational amplifier is used.

\[
e^− = e_2 \frac{R_2}{R_1 + R_2} + e_0 \frac{R_1}{R_1 + R_2} \quad (1)
\]

\[
e^+ = e_1 \frac{R_2}{R_1 + R_2} \quad (2)
\]

If \( e^− \) and \( e^+ \) are the equal then output of the differential amplifier is \( e_0 \) can be written as follows

\[
e_2 \frac{R_2}{R_1 + R_2} + e_0 \frac{R_1}{R_1 + R_2} = e_1 \frac{R_2}{R_1 + R_2}
\]
\[ e_0 = \frac{R_2}{R_1} (e_1 - e_2) \] (3)

The resistors selected R1, R2, R3 and R4 decides gain of the differential amplifier. In this circuit R1 and R2 are considered equal with value 10KΩ and R3 and R4 are also equal with value 15KΩ for gain 1.5. The high power shunt resistor R_s is used in the above current measuring circuit figure 4.7, as a current sensing part. The shunt resistor value is taken for experimentation is 1Ω and 20W value. Similarly electric load is used as 150W and 10Ω of potentiometer.

4.2 Pilot experimentation on rechargeable battery

A pilot, or feasibility experimentation, is a small experiment designed to test logistics and gather information prior to a larger study, in order to improve the latter’s quality and efficiency of the study. A pilot experiment can expose deficiencies in the design of a proposed experiment and these can then be addressed before time and resources are expended on large scale studies. A pilot study is normally small in comparison with the main experiment and therefore can provide only limited information on the sources and magnitude of variation of response measures. The pilot study may, however, provide vital information on the nastiness of proposed procedures or treatments. Here in this chapter different pilot experiments were carried out on rechargeable battery for various issues. To design simple and useful experiments for battery, the data acquisition system has been experimented and used for reading various parameters of the battery. The data acquisition programs are written in LabVIEW and executed successfully according to the requirement of research work. The signal conditioning circuits are required for temperature and high current sensing applications like ampere hour measurements. The signal conditioning circuits for high current measurement and high current up to 40A is measured. This hardware is linked
to the LabVIEW and both parts are tested and results are presented. The Flooded and VRLA rechargeable battery has been studied for self discharge rate so that exact estimation of remaining power would be calculated.

4.2.1 Effect of an Dynamic and Active Loads of Battery

In case of understanding battery parameters it is very necessary to study battery charging and discharging action. Normally the batteries are discharged in constant load, constant current and constant power modes.

![Discharging curves for constant load, constant current and constant power modes](image)

**Fig. 4.8:** Discharging curves for constant load, constant current and constant power load.
In constant load discharge method the battery delivers energy to a load of constant resistance. So the load current decreases as battery voltage does. In constant current discharge method the current drawn from the battery is kept constant to a load that continuously reduces its resistance, the discharge duration in this mode is shorter due to average current is higher. The voltage drops faster than that in constant load. The above discharge curves for constant load, constant current and constant power shows current, voltage relation with discharge time of the battery can be seen in figure 4.8. In constant current mode of discharge transistors and MOSFETs are used as electrical load. These loads are referred as active loads. While in constant power mode of battery discharge, constant electrical power is drawn by the load from the battery; such that the load current will be increasing to compensate for decreasing battery voltage. The constant power model of discharging has shortest discharge time.

A. Battery discharging with dynamic load

In the preliminary experiments for battery discharging, batteries are discharged using constant load and constant current methods. In constant load mode of battery discharge different candescent lamps are used as an electrical load.

![Battery discharging connection with dynamic load of 35W](image)

**Fig. 4.9:** Battery discharging connection with dynamic load of 35W
Here constant load is said as dynamic load. Such dynamic loads are also termed as passive loads. Initially some experiments are carried out on passive loads.

The incandescent lamps are used as resistive or passive loads. Incandescent means the state of being white hot. Different power ratings 12V Lamps are used for battery discharging purpose. For the experiment, incandescent lamps of 20W, 35W and their combinations and Lead acid battery of 7.5AH are used.

Initially the battery is fully charged using constant current charger. The terminal voltage of the battery is measured with the help of digital multimeter or voltmeter. The flowing circuit current is measured by ammeter. The reading of terminal voltage and currents are recorded with some specific time interval. The electrical connection for discharging of the battery is given below.

**Table 4.1:** Discharging of 7.5AH battery with load of 35Watt

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Time (min)</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.23</td>
<td>2.80</td>
<td>120</td>
<td>09.85</td>
<td>2.50</td>
</tr>
<tr>
<td>5</td>
<td>12.22</td>
<td>2.80</td>
<td>140</td>
<td>08.86</td>
<td>2.30</td>
</tr>
<tr>
<td>10</td>
<td>12.19</td>
<td>2.80</td>
<td>150</td>
<td>06.50</td>
<td>1.90</td>
</tr>
<tr>
<td>20</td>
<td>12.13</td>
<td>2.85</td>
<td>160</td>
<td>05.50</td>
<td>1.65</td>
</tr>
<tr>
<td>30</td>
<td>12.08</td>
<td>2.85</td>
<td>170</td>
<td>05.00</td>
<td>1.50</td>
</tr>
<tr>
<td>40</td>
<td>12.00</td>
<td>2.85</td>
<td>180</td>
<td>04.57</td>
<td>1.40</td>
</tr>
<tr>
<td>50</td>
<td>11.87</td>
<td>2.80</td>
<td>190</td>
<td>04.25</td>
<td>1.35</td>
</tr>
<tr>
<td>70</td>
<td>11.74</td>
<td>2.80</td>
<td>200</td>
<td>04.00</td>
<td>1.30</td>
</tr>
<tr>
<td>90</td>
<td>11.58</td>
<td>2.70</td>
<td>210</td>
<td>03.50</td>
<td>1.15</td>
</tr>
<tr>
<td>100</td>
<td>11.18</td>
<td>2.65</td>
<td>220</td>
<td>03.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
The dynamic load means incandescent lamp is connected to the fully charged 7.5AH rechargeable battery. The current meter and voltmeters are connected in the circuit for measurement of battery current and terminal voltage respectively. The continuous readings are taken and graphs are plotted. From the graphs and readings actual discharging time of the battery is calculated for connected load of 35W. It is observed that the discharging time of the battery is different for different electrical loads. The battery is fully discharged from 12.23 to 3.00V i.e. terminal voltage. The discharging current is varied from 2.8A to 1.0A. The change of discharging current and terminal voltage shows same trend on the plotted curve. Hence this experiment is of constant load. The readings of the said experiments are given in tabular form as shown in table 4.1

![Graph showing battery discharging with dynamic load of 35W]

**Fig. 4.10:** Battery discharging with dynamic load of 35W

**Observations:** From this pilot experimentation, it is observed that to discharge of lead acid battery of 12V, 7.5AH with incandescent lamp of 35W. The discharge time of the said battery required is 219 minutes i.e. 3hrs 40min for terminal battery voltage from 12V to 3V i.e. deep discharge as shown in above figure
4.10. The deep discharge of the battery is not preferred in order to protect battery from fade effect.

![Graph of Battery discharging with dynamic load of 70W](image)

**Fig. 4.11:** Graph of Battery discharging with dynamic load of 70W

The second set of readings are taken for same lead acid battery of 12V and 7.5AH capacity and load current varied by using another incandescent Lamp of 70W. The observed readings and graphs are given in the figures no.4.11.

**Observations:** From this pilot experimentation, it is observed that to discharge lead acid battery of 12V, 7.5AH with incandescent lamp of 70W. The discharge time of the said battery measured is 141 minutes i.e. 2hrs 21min for terminal battery voltage from 12V to 3Vi.e deep discharge as shown in the figure 4.11.

**B. Battery discharging with active load**

In these preliminary experiments for battery discharging, batteries are discharged using constant current methods. In this experiment constant current source is designed with the help of transistors and MOSFET. Using this active element of component and constant current source the load is termed as active load for the battery. Initially many experiments are carried out on active load of different discharging currents. The
MOSFET and threshold voltage decides discharging current of the battery. Different power ratings are used for battery discharging purpose. An active load is nothing but circuit element which consumes constant current from power source.

![Fig. 4.12: Transistorized active load](image1)

![Fig. 4.13: Ideal current source or active load](image2)

The active load is designed from active devices, such as transistors and MOSFETS for high small-signal impedance. Most commonly the active load is the output part of a current mirror and is represented in an idealized manner as a current source. Usually, it is only a constant-current resistor that is a part of the whole current source including a constant voltage source as well.

The above figure 4.12 and figure 4.13 shows transistorized active load connected load with a resistor $R_c$, and the current passing through the resistor $R_c$ is calculated by following formula.

$$I_c = \frac{V_{CC} - V_{out}}{R_c} \quad (4)$$

As a consequence of this relation, the voltage drop across the resistor is tied to the current at the quiescent point of the transistor [8]. If the bias current of the transistor is
fixed for some performance reason, any increase in load resistance automatically lower the value of voltage i.e. $V_{\text{out}}$, which in turn lowers the voltage drop $V_{\text{CB}}$ between collector and base, limiting the signal swing at the amplifier output. Whereas the active load shown in the figure 4.13, the AC impedance of the ideal current source is infinite regardless of the voltage drop $V_{\text{CC}} - V_{\text{out}}$, which allows even a large value of $V_{\text{CB}}$ and consequently a large output signal swing. Hence this is used to designing active load.

For the rechargeable battery testing such circuits could be used to discharge battery for different current rate without changing the circuit elements. The biasing voltage of the transistor decides the output voltage and consequently the collector current of the transistor. For higher values of current, power transistors and MOSFET are used as active load. Actual circuit of active load using MOSFET and high power resistor $R_2$ are as shown in figure 4.14.

![MOSFET Based active load for battery discharge](image)

**Fig. 4.14:** MOSFET Based active load for battery discharge
The selection of this resistor is very much important in this circuit because resistor $R_2$ decides current drawing capacity of the circuit. In the designed circuit, the resistor $R_2$ of $0.33 \ \Omega$ and power rating is 100W. This resistor is specially designed for high current application. The threshold voltage of MOSFET is decided by $R_2$.

![Ideal constant current source and active load curve](image)

**Fig 4.15**: Ideal constant current source and active load curve

MOSFET (IRFZ44N) has been used for experimentation because it has 40A maximum current drawing capacity. A current source is required to discharge battery and it is an electronic circuit that delivers or absorbs an electric current which is independent of the voltage across it. The term constant-current or sink is sometimes used for sources fed from a negative voltage supply. Figure 4.15 shows the graphical representation of an ideal current source, driving a resistor load. In MOSFET based designing for constant current source constant current term is decided by the non-inverting of an operational amplifier. Normally there are two types of current sources i.e. independent and dependant current source. The independent current source delivers a constant current to the connected load whereas dependent current source delivers a current which is proportional to some other voltage or current in the circuit. The rechargeable battery is assumed as dependant current source because energy of the battery depends on charging status of the battery.
Designing of active load for constant current discharge

The current equation of MOSFET in triode region is given below (5) and this equation tells that the drain current is directly proportional to gate and source voltage. If $V_{GS} \geq V_{TH}$ then MOSFET conducts and goes in to triode region otherwise it will be in cut-off region.

$$I_D = \mu_n C_{ox} \frac{W}{2} \left[ (V_{GS} - V_{TH}) V_{DS} - \frac{L}{2} V_{DS}^2 \right]$$  \hspace{1cm} (5)

Where, $\mu_n$ = Mobility of the electrons, $C_{ox}$ = Capacitance of the oxide layer, $W$ = Width of the gate area, $L$ = Length of the channel, $V_{GS}$ = Gate to Source voltage, $V_{TH} =$ Threshold voltage and $V_{DS} =$ Drain to Source voltage.

For the experimentation different batteries are different AH ratings are used for battery discharging with active load. The batteries used are 12V/7.5AH, 12V/17AH and 12V/35AH.

![Active Load](image)

**Fig. 4.16:** Designed circuit boards of active load
Initially 12V/7.5AH lead acid rechargeable battery is used for the experimentation and it is observed that the discharging current of the battery remains constant till the full discharge of the battery.

The discharging current of the battery is adjusted by varying input of the operational amplifier and current is set. This set current is the discharging current of the battery. Through designed active load up to the 40A. The threshold resistor must be with higher power rating. Hence power resistor of APR 100W/0.33Ω is used for the experimentation.

The snap shots of circuit boards of active load and developed prototypes are shown in the figure 4.16 and figure 4.17.
Observations for active load on different capacity batteries

I. 12V/2.5AH/Local Made Murphy Battery

![Discharging curve of 2.5AH battery with active load (1.5A)](image1)

*Fig. 4.18:* Discharging curve of 2.5AH battery with active load (1.5A)

II. 12V/7.5AH /AKARI Battery

![Discharging curve of 7.5AH battery with active load (1.5A)](image2)

*Fig. 4.19:* Discharging curve of 7.5AH battery with active load (1.5A)
### III. 12V/17AH EXIDE Battery

![Discharging curve of 17AH battery with active load (1.5A)](image1)

**Fig. 4.20:** Discharging curve of 17AH battery with active load (1.5A)

### IV. 12V/35AH AMRON Battery

![Discharging curve of 35AH battery with active load (1.5A)](image2)

**Fig. 4.21:** Discharging curve of 35AH battery with active load (1.5A)
Result and discussion

The lead acid flooded batteries used are 2.5AH and 35AH and VLRA batteries used are 7.5AH, 17AH, 18AH and 46AH of different manufacturer like EXIDE and AMRON. These batteries are discharged with constant current from 1.5A to 6.5A using active loads. These batteries are initially fully charged by standalone constant voltage battery charger. The battery efficiency is calculated from input and output battery power. Battery efficiency is the ratio of obtained battery capacity to the rated battery capacity. It is measured in percentage. Values of battery efficiency gives exact power battery capacity. Figure 4.22 show battery discharge curves for 35AH flooded battery. In these discharge curves, current from 1.5A to 6.5A is selected for constant discharge purpose. Lower is the discharge current, greater will be discharge time and larger is the discharge current, smaller will be the discharge time.

![Discharge curve for 35AH battery](image)

**Fig. 4.22:** Discharge curve for 35AH battery
Fig. 4.23: MOSFET Based active load setup

Fig. 4.24: Battery efficiency for 35AH

... All the products of Ampere and Time to the discharge are same for different discharge current as per expectations. For discharge current 6.5A, discharge time...
observed is 179 minutes and for discharge current 1.5A, discharge time observed is 793 minutes. Figure 4.24 shows battery efficiency graph for 35AH flooded battery for discharge current from 1.5 to 6.5A. Efficiency observed for 35AH capacity battery is 55% to 64%. The battery efficiency also depends on other parameters like temperature, number of charging and discharging cycles, aging effect and method of charging and discharging, terminal voltage and C rate. If battery terminal voltage is not observed properly then obtained power will be more or less than expected value. It is observed that if terminal voltage is 12.4V then battery efficiency is 55% to 57% only. When terminal voltage is 13.18V then observed battery efficiency is 64%. Actual status of the battery efficiency 7.5AH, 17AH, 18AH, 26AH, 35AH and 65AH flooded and VLRA batteries are calculated. Two batteries of 2.5AH and 17AH showed very low efficiency i.e. 10% and 30%, which indicates that time has come to replace the battery whereas other two batteries 26AH and 65AH showed efficiency 82% and 90%, which is more enough to sustain for long time and can be used for electrical vehicle. Finally this study has given direction to the electrical car mileage prediction and battery management system work.

Table 4.2: Efficiencies of different capacity batteries

<table>
<thead>
<tr>
<th>Discharging Current (Amp)</th>
<th>Rated Battery Capacity (AH)</th>
<th>Observed Discharging Time (min)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>2.5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>2.5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1.5</td>
<td>7.5</td>
<td>100</td>
<td>33</td>
</tr>
<tr>
<td>2.5</td>
<td>7.5</td>
<td>107</td>
<td>59</td>
</tr>
<tr>
<td>3.5</td>
<td>7.5</td>
<td>60</td>
<td>47</td>
</tr>
<tr>
<td>1.5</td>
<td>17</td>
<td>198</td>
<td>29</td>
</tr>
<tr>
<td>2.5</td>
<td>17</td>
<td>118</td>
<td>29</td>
</tr>
<tr>
<td>3.5</td>
<td>17</td>
<td>56</td>
<td>19</td>
</tr>
<tr>
<td>4.5</td>
<td>17</td>
<td>54</td>
<td>24</td>
</tr>
</tbody>
</table>
### 4.2.2 Self discharge of Flooded and VRLA batteries

To understand and study self discharge effect of flooded and non flooded VRLA batteries are used for experimentation. The experiment is carried out four Lead acid batteries for one month. The 2.5AH flooded batteries is used and three unflooded batteries i.e.7.5AH, 17AH and 26AH. All these batteries are fully charged with constant current laboratory charger. After charging these batteries are kept in the laboratory with laboratory available normal conditions. Total one month readings of terminal voltages are recorded for all these batteries. Self-discharge of the battery is a phenomenon in batteries in which internal chemical reactions reduces the stored charge of the battery without any connection between the electrodes with load. Self-discharge decreases the shelf-life of batteries and causes them to initially have less than a full charge when actually put to use.

<table>
<thead>
<tr>
<th>Discharging Current (Amp)</th>
<th>Rated Battery Capacity (AH)</th>
<th>Observed Discharging Time (min)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>17</td>
<td>37</td>
<td>20</td>
</tr>
<tr>
<td>6.5</td>
<td>17</td>
<td>30</td>
<td>19</td>
</tr>
<tr>
<td>1.5</td>
<td>18</td>
<td>312</td>
<td>43</td>
</tr>
<tr>
<td>2.5</td>
<td>18</td>
<td>246</td>
<td>57</td>
</tr>
<tr>
<td>3.5</td>
<td>18</td>
<td>167</td>
<td>54</td>
</tr>
<tr>
<td>4.5</td>
<td>18</td>
<td>128</td>
<td>53</td>
</tr>
<tr>
<td>2.5</td>
<td>26</td>
<td>302</td>
<td>48</td>
</tr>
<tr>
<td>3.5</td>
<td>26</td>
<td>301</td>
<td>68</td>
</tr>
<tr>
<td>4.5</td>
<td>26</td>
<td>285</td>
<td>82</td>
</tr>
<tr>
<td>6.5</td>
<td>26</td>
<td>193</td>
<td>80</td>
</tr>
<tr>
<td>1.5</td>
<td>35</td>
<td>793</td>
<td>57</td>
</tr>
<tr>
<td>3.5</td>
<td>35</td>
<td>383</td>
<td>64</td>
</tr>
<tr>
<td>5.5</td>
<td>35</td>
<td>245</td>
<td>64</td>
</tr>
<tr>
<td>6.5</td>
<td>35</td>
<td>181</td>
<td>56</td>
</tr>
<tr>
<td>3.5</td>
<td>65</td>
<td>954</td>
<td>86</td>
</tr>
<tr>
<td>6.5</td>
<td>65</td>
<td>327</td>
<td>55</td>
</tr>
</tbody>
</table>
Primary batteries, which cannot be recharged and hence have much lower self-discharge rates than secondary batteries. Self-discharge is nothing but a chemical reaction occurred without connecting any load and tends to occur faster at higher temperatures. Storing batteries at lower temperatures reduces the rate of self-discharge and preserves the initial energy stored in the battery hence batteries are stored at cool place.

Self-discharge rate in a battery depends on the type of battery, state of charge, charging current, ambient temperature and other factors. Typically, amongst all rechargeable batteries, lithium batteries suffer the least amount of self-discharge (2% to 3% discharge per month) while nickel-based batteries are more seriously affected by the phenomenon, nickel cadmium (15% to 20% per month), nickel metal hydride (30% per month), with the exception of Low self-discharge Ni-MH batteries i.e. 2% to 3% per month. It observed that batteries with flooded electrolyte show very rate of discharge than unflooded batteries. In this group of batteries 2.5AH flooded battery showed high rate of discharge than unflooded batteries like 7.5AH, 17AH and 28AH as shown in figure 4.25.

Table 4.3: Self discharge of flooded and VRLA batteries, terminal voltages

<table>
<thead>
<tr>
<th>No of Days</th>
<th>2.5AH</th>
<th>7.5AH</th>
<th>17AH</th>
<th>26AH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.67</td>
<td>12.73</td>
<td>12.51</td>
<td>12.77</td>
</tr>
<tr>
<td>8</td>
<td>12.02</td>
<td>12.45</td>
<td>12.38</td>
<td>12.54</td>
</tr>
<tr>
<td>15</td>
<td>6.61</td>
<td>12.84</td>
<td>12.75</td>
<td>12.9</td>
</tr>
<tr>
<td>21</td>
<td>6.4</td>
<td>12.4</td>
<td>12.32</td>
<td>12.46</td>
</tr>
</tbody>
</table>
### No of Days vs Self discharge of following capacity batteries

<table>
<thead>
<tr>
<th>No of Days</th>
<th>2.5AH</th>
<th>7.5AH</th>
<th>17AH</th>
<th>26AH</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>6.37</td>
<td>12.4</td>
<td>12.32</td>
<td>12.44</td>
</tr>
<tr>
<td>30</td>
<td>6.35</td>
<td>12.4</td>
<td>12.31</td>
<td>12.42</td>
</tr>
</tbody>
</table>

**Fig. 4.25:** Self discharge curves of flooded and VRLA batteries
4.2.3 Battery-charging and discharging

The discharging of the battery with constant current source i.e. active load and without constant current source i.e. dynamic load is studied and experimented in the previous section. Peukerts law verification, efficiency calculation etc. are also experimented to understand battery parameters. The battery charging also types depends on the battery capacity and type of the battery. Some typical batteries very have high tolerance for overcharging and can be recharged by connection to a constant voltage source or a constant current source type of the battery charger. Therefore for the battery charging different types of charging modes and charging methods are used.

There are various methods for charging battery and battery packages. In this document total seven methods are given and discussed in brief. There are various charging method used in different types of chargers.

The name of chargers are simple charger, trickle charger, time based charger, intelligent charger, Fast charger, Pulse charger and Inductive charger.

![Battery charger and discharger](image)

Fig.4.26: Battery charger and discharger
4.2.3.1 Simple Charger

Simple types of charger require manual disconnection at the end of the charge cycle or may have a timer to cut off charging current at a fixed time. A simple charger works by supplying a constant DC or pulsed DC power source to a battery being charged. The simple charger does not alter its output based on time or the charge on the battery. This simplicity means that a simple charger is inexpensive, but there is a tradeoff in quality. These chargers can supply either a constant voltage or a constant current to the battery.

4.2.3.2 Trickle charger

A trickle charger is a low-current (5–1,500 mA) battery charger. A trickle charger is normally used for charging low capacity batteries. These types of battery chargers are also used to maintain larger capacity batteries (> 30 Ah) that are typically used in cars, boats and other related vehicles. In larger applications, the current of the battery charger is sufficient only to maintenance or trickle current. These battery chargers are left connected to the battery without causing the battery damage hence they are also referred to as smart or intelligent chargers.

4.2.3.3 Timer-based charger

The output of a timer charger is terminated after a pre-determined time. Often a timer charger and set of batteries could be bought as a bundle and the charger time was set to suit those batteries. If the batteries of small capacity were charged then they would be overcharged, and if batteries of higher capacity were charged they would be only partly charged. Timer based chargers also had the drawback that charging batteries that were not fully discharged, even if those batteries were of the correct capacity for the particular timed charger, would result in over-charging.
4.2.3.4 Intelligent charger

A smart battery generally requires a smart charger it can communicate with. A smart charger is defined as a charger that can respond to the condition of a battery, and modify its charging actions accordingly. Intelligent charger has temperature or voltage sensing circuits and a micro controller to adjust the charging current, and cut off at the end of charge. A trickle charger provides a relatively small amount of current, only enough to counteract self-discharge of a battery that is idle for a long time.

4.2.3.5 Fast charger

Fast chargers make use of electronic control circuitry in the batteries being charged to rapidly charge the batteries without damaging the cells' elements. Most such chargers have a cooling system or cooling fan to help keep the temperature of the cells under control.

4.2.3.6 Pulse charger

This type chargers uses pulse technology in which a series of voltage or current pulses is fed to the battery. The DC pulses have a strictly controlled rise time, pulse width, pulse repetition rate and amplitude. This technology is said to work with any capacity, voltage, capacity or chemistry of batteries, including automotive and valve-regulated batteries. With pulse charging, high instantaneous voltages can be applied without overheating the battery. In a Lead–acid battery, this breaks down lead-sulfate crystals, thus greatly extending the battery service life.

4.2.3.7 Inductive charger

Inductive types of battery chargers uses electromagnetic induction to charge batteries. A charging system sends electromagnetic energy through inductive
coupling to an electrical device, which stores the energy in the batteries. This is achieved without the need for metal contacts between the charger and the battery. Slow battery chargers may take several hours to complete a charge; high-rate chargers may restore most capacity within minutes or less than an hour, but generally require monitoring of the battery to protect it from overcharge.

**Fig. 4.27:** Conceptual diagram of battery charger and discharger

Electric vehicles need high-rate chargers for public access; installation of such chargers and the distribution support for them is an issue in the adoption of electric cars. Proper charging and types of battery charging is also important. For battery charging laboratory battery chargers are used. Using this battery charges two batteries are simultaneously charged. The maximum current capacity of Laboratory chargers is 10A. The charging current of the batteries depending on capacity of the batteries. The figure 4.27 shows the basic circuitry of charging and discharging action of the rechargeable battery. This circuit consists of relay circuits for controlling battery charging and discharging. In the charging, the charge relay A is ON, while the discharge relay B is OFF, hence current flows from charger to the battery. In discharging, the charge relay is OFF, while discharge relay is ON, hence discharging current flows from battery to the load. When charging relay A and
discharging relay B are activated simultaneously then battery charging and discharging occurs. This type of phenomenon is used the uninterrupted power supply when utility power presents. The charge relay and discharge relay controls current flow so that battery voltage reaches upto 14.5V, the device switch over to the discharging and, when voltage drop to 10.5V, it switches to back charging. The charge and discharge relays are functioning according to the voltages.

![Battery connections diagram to the charger 24V/10A](image)

The voltages are set at maximum value 14.5V and minimum to 10.5V. When battery voltage reaches to these voltage levels then switching action of relay takes place. In the above circuit the controlling circuits for relays are not shown. The controlling circuit will come be before the switching relays. For the laboratory experimentation, Power plus 24V/10A Company made charger is used. The charger is 24V hence two batteries are charged simultaneously.

Two batteries of 35AH and 2.5AH different size and capacity batteries are used. Both the batteries are discharged by electrical load before experimentation. Two batteries are connected in series as shown below diagram and said charger is connected to these batteries. The corresponding voltages of these batteries are recorded with prescribed time intervals. In this battery charging experiment, it is
observed that voltages across the batteries are different and depends on capacity of batteries. In the following observation Table 4.4 T0, T1, T2, T3 and T4 are the time interval in minutes for the recording battery readings while charging.

Table 4.4: Readings of unequal capacity battery charging

<table>
<thead>
<tr>
<th>Charging Time (Min)</th>
<th>Charger voltages across the Batteries during charging (Battery A=35AH, Battery B=2.5AH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Battery A (V_A)</td>
</tr>
<tr>
<td>T0</td>
<td>8.94V</td>
</tr>
<tr>
<td>T1</td>
<td>10.80V</td>
</tr>
<tr>
<td>T2</td>
<td>12.13V</td>
</tr>
<tr>
<td>T3</td>
<td>12.01V</td>
</tr>
<tr>
<td>T4</td>
<td>11.90V</td>
</tr>
</tbody>
</table>

Battery A of 35AH capacity shows lower voltage across it and Battery B of 2.5AH shows higher voltage across it. It means battery with lower capacity shows more charger voltage than lower capacity battery. In this type of charging there is possibility of overcharging and undercharging of the batteries. This will lead to reduce the battery life; hence smart battery charger of 12V/2.5A is designed and used for single battery charging purpose. This intelligent battery charger avoids overcharging of the battery because this charger cuts the charging supply when battery gets fully charged. Therefore smart charger is designed for single battery charging purpose. The designed charger designed is an intelligent charger (12V/2.5A) which monitors the battery voltage continuously and stops charging at the set point (12.5V).
Thus this charger avoids the battery to be overcharged ultimately and therefore increasing the efficiency and life of the battery. The developed smart charger circuit diagram is as follows,

![Circuit Diagram](image)

**Fig. 4.29:** Circuit diagram of developed battery charger

From the circuit it can be seen that its heart is IC LM311, which is connected as comparator. Usually the voltage at pin 3 will be equal to 6V with the zener diode ZD1-6V. When the battery is fully charged, the output voltage at pin 6 becomes negative and make the transistor BC337-Q1 off thus the coil of Relay-RY1 is not energized. So The AC voltage input to the transformer-T1 will be cut off. The reduction of the battery voltage causes the voltage at pin 2 to become less than the voltage at pin 3. This makes the voltage at pin 6 of IC1 to become positive and if it is higher than 3.3V, it will result in the switching on the transistor Q1 and the relay coil is energized, thus the contact of relay will connect the DCV to the capacitor C1 and thus battery starts charging. A pot is provided to set upper charging point of the battery.
After this charger is made ready it is tested to charge the battery of 7.5 AH/AKARI. The readings are taken for specific period and given in following Table 4.5. The output current of charger is 1.5A because battery was not fully discharged and shown initial terminal voltage was 10.36V, the charger starts charging battery from above terminal voltage. This smart charger charges battery up to 14V and every time it gives indication that battery is fully charged after particular value reached it stops charging in order to avoid overcharging. Following table shows the readings for the same.

**Table 4.5: Observations of developed battery charger**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Current (A)</th>
<th>Battery voltage (V&lt;sub&gt;A&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>10.36</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>12.24</td>
</tr>
<tr>
<td>30</td>
<td>1.5</td>
<td>12.48</td>
</tr>
<tr>
<td>60</td>
<td>1.5</td>
<td>12.77</td>
</tr>
<tr>
<td>90</td>
<td>1.5</td>
<td>13.07</td>
</tr>
<tr>
<td>120</td>
<td>1.5</td>
<td>13.50</td>
</tr>
<tr>
<td>150</td>
<td>1.2</td>
<td>14.02</td>
</tr>
<tr>
<td>180</td>
<td>1.0</td>
<td>14.18</td>
</tr>
</tbody>
</table>
Thus a charger circuit is designed and the battery is allowed to charge for a specific voltage avoiding the overcharging and increasing the lifetime of the battery.

**Fig. 4.30:** Battery connections diagram to the charger 12V/2.5A

**Fig. 4.31:** Battery Charger and Discharger Prototype
4.3 **Portable Battery Management System (BMS) for electrical vehicles**

The battery management system (BMS) is a critical and important component of electric and hybrid electric vehicles. The function of the BMS is to assure safe and reliable battery operation. To maintain the safety and consistency of the battery, state monitoring and evaluation, charge control, and cell balancing are functionalities that have been implemented in BMS. As an electrochemical product, a battery acts differently under different operational and environmental conditions. The uncertainty of a battery’s performance poses a challenge to the implementation of these functions. This chapter addresses concerns for current BMS. State evaluation of a battery, including state of charge, state of health, and state of life, is a critical task for a BMS.

![Electric vehicle system diagram](image)

**Fig. 4.32:** Electric vehicle system diagram

The battery management system manages complete battery precisely. The above electric vehicle system diagram shows BMS is connected to the heavy vehicle rechargeable battery and main controller system of the vehicle. The controller of the
vehicle is controlling almost all electronic sections and devices like inverter, DC/DC converter and charger. The BMS of the vehicle displays important parameter of the battery on car dashboard. The BMS control unit takes cares of indication of SOC, safety devices, status report, measurement of current, voltage and temp, heating and cooling system, regenerative braking and maximum power control. Therefore BMS manages the car battery precisely. The BMS is also useful knowing fuel status of the battery. The various sections and controlling units can been seen in following generalized block diagram of Battery Management System.

![Generalized Battery Management System](image)

**Fig. 4.33:** Generalized Battery Management System

Every time software simulation is not useful prior to actual testing of the system, because this simulation does not run on real time mode. The Battery Monitoring
System is a cheap, simple-to-install and easy-to-use device that solves this issue effectively.

This battery management system monitors important battery performance parameters i.e. Temperature, Terminal voltage, State of charge (SOC) of the rechargeable battery of the electrical vehicle. The battery management system is an electronic system that manages battery. The BMS system monitors very important battery parameters like state of charge, state of health, coolant flow for air or fluid, ampere hour counting, terminal voltage and flowing current. The advantage of BMS systems are also found in gasoline vehicles for preventing the discharge of a car battery beyond the point of

**Fig. 4.34:** Features of battery management system
restarting the car. This is a common issue that can leave a person stranded and highly inconvenienced.

Also, draining a battery drastically reduces the life of a car battery. Cars run on lead-acid batteries and so disposal of them is very bad for the environment. It is also costly and time-consuming to get a battery replaced. Finally, running on a bad battery can reduce the life span of the car’s alternator. In general, there are many costs and inconveniences that arise from discharging a car battery. The safety devices, motor controllers and heating or cooling elements are controlled by BMS main control unit. Controlling of different sections depends on battery status and battery health. Hence readings of battery parameters are very important and utilized for different sections of BMS. The SOC information of the battery is used for regenerative braking and maximum power control sections of the motor controller. Through SOC regenerative mechanism will decide charging of the battery. The auxiliary charger is used for charging the battery. The report of the battery is stored in the computer for further analysis. The metric of development and test efficiency is typically consists of factors i.e. cost, duration, safety and feasibility. The BMS is also used for calculating secondary reports and reporting the generated data. The BMS also helps in controlling or balancing battery environment. The figure 4.34 shows different features of Battery Management System.

4.3.1 Microcontroller based BMS

In this section low cost microcontroller based system for battery management system (BMS) developed for electrical vehicle is explained. The developed embedded system will control and monitor different parameters of the rechargeable battery. The designed system is very much essential for optimum utilization of the rechargeable battery. This system will be useful for user of the electrical car to understand condition and health of
the rechargeable battery so that it is easy to take decision of recharging the battery or replace the battery. A real-time computer system may be a component of a larger system in which it is embedded; reasonably, such a computer component is called an embedded system. Real-time systems are computer systems that are prone to monitor, respond to, or control external environmental parameters. This embedded system comprises real time microcontroller platform and electrical emulation of sensors and actuators for read, process, monitor, control and stores the acquired data for further analysis. This developed embedded system is useful in every battery powered systems and vehicle for fuel status or battery capacity. The block diagram of experimental setup of designed battery management system for renewable energy source or car battery is shown in figure 4.35. This system includes different signal conditioning sections like high current sensing, temperature sensing and voltage sensing circuits. The IC 8052 microcontroller is used to read various parameters of the battery.

**Fig. 4.35**: Embedded based battery management system

The different assembly programs are written to read and monitor battery management parameters on the LCD. In the setup ADC 0809 chip is used for converting data from
analog to digital. This converted data is given to the controller section. The I²C EPROM is used to store the data for report generation. The memory available for the developed embedded system is 512KB. The results generated by embedded systems are compared with LabVIEW results.

4.3.2 Performance Testing

The battery management system is an electronic system that manages battery of appliances. The BMS system monitors important parameters of the battery like state of charge, state of health, coolant flow for air or fluid, ampere hour counting, terminal voltage and flowing current. The metric of development and test efficiency is typically consists of factors i.e. cost, duration, safety and feasibility. Every time software simulation is not useful prior to actual testing of the system, because such simulation does not run on real time mode.

![Prototype of embedded battery management system](image)

**Fig 4.36**: Prototype of embedded battery management system

Normal cars run on lead-acid batteries and disposal of lead acid battery is very bad for the environment due to hazardous components in the battery. Recycling of batteries is
costly and time-consuming to get a battery replaced. The developed Battery Monitoring System (BMS) using microcontroller is a cheap, simple-to-install and easy-to-use device in the system such that it solves the issue effectively.

![Battery Monitoring System](image)

**Fig. 4.37:** Display of Prototype AH, terminal voltage, discharge current and temperature

This developed embedded system is useful in every battery powered systems as shown in fig. 4.35 and vehicle for fuel status or battery capacity. Fig 4.36 shows developed prototype of embedded battery management system for electrical vehicle. The generated report of battery management system is transferred in PC through the serial interface and given in figure 4.40

This report gives real time data of the 35AH battery information which includes the exact time, consumed ampere hour, terminal voltage, battery discharging current and battery temperature. The report shows current status of the battery like time 17:58:21, terminal voltage is 11.8V, battery discharging current is 10A and Temperature is 26°C. The figure 4.37 shows the display of developed microcontroller Battery management system. This LCD displays real time battery parameter i.e. consumed AH, terminal voltage, discharge current and temperature of BMS. This displayed data is stored in EPROM. The I²C EPROM is used to store the data for report generation. The memory available for the developed embedded system is 512KB. Further EPROM data is transferred on computer through serial port of microcontroller.
Finally, running on a bad battery can reduce the life span of the car’s alternator. In general, there are many costs and inconveniences that arise from discharging a car battery. The BMS is used for calculating secondary reports and reporting the generated data. The generated report can be analyzed and presented for further process of estimation. The embedded BMS also helps in controlling, balancing and protecting the battery environment. The developed BMS may include Monitoring, Electrical Vehicle System: Energy Recovery, Computation, Communication, Protection, Optimization and Topologies.

**Fig. 4.38**: BMS report on serial port
4.3.3 LabVIEW based BMS

The battery management system of the electrical vehicle ensures that whether the car battery is being charged or discharged. Committed electronic systems are installed in the car for safety, convenience, comfort and pleasure. These systems have been greatly added to the demands on the battery in modern electrical cars. LabVIEW based battery monitoring system has been developed for electrical car and ready to use for any battery powered system to adopt safety, convenience and pleasure. The developed LabVIEW based battery management monitors different parameters of the rechargeable battery. The developed system is very much essential for optimum utilization of the rechargeable battery. This system will be useful for manufacturer and user of the electrical car to understand condition and health of the rechargeable battery so that it is easy to take decision of recharging the battery or replace the battery.

Fig. 4.39: Block diagram of Battery management system using LabVIEW
Real-time systems are computer systems that are prone to monitor, respond to, or control external environmental parameters. In this research work of BMS the attempt is made to design a battery management system (BMS) of the electrical vehicles using LabVIEW. This system comprises real time platform and electrical emulation of sensors and actuators for read, process, monitor, control and stores the acquired data for further analysis. This developed system is useful in every battery powered systems and electrical vehicle for fuel status or battery capacity.

The data acquisition system acquires battery voltage, battery temperature and discharging current from the battery through developed signal conditioning circuits. This signal conditioning circuits for battery parameters sensing has already experimented in the previous sections of this chapter. The various inputs and outputs sections can be seen in the block diagram of the battery management system. Alarm indicator, backup time, battery temperature, state of charge status and terminal voltage are the outputs of the BMS whereas efficiency and ampere-hour value of the battery are the inputs of the BMS system as shown in figure 4.39. The system user has to feed appropriate information to the system and then system setup will provide proper information to the user.

The experimental setup of designed battery management system for car battery or renewable energy source is shown in figure 4.40. This developed system includes different signal conditioning sections like high current sensing, temperature sensing and voltage sensing circuits.

A regenerative brake is nothing but an energy recovery mechanism used in the car. When car gets slow down, the kinetic energy that was propelling it forward has to go somewhere. Most of it simply dissipates as heat and becomes useless. That energy, which could have been used to do work, is essentially wasted. The braking system
recaptures unused kinetic energy and converts it into electricity. This converted electricity can be used to recharge the car's batteries effectively. This system is called regenerative braking. At present, these kinds of brakes or braking system are primarily found in hybrid vehicles and in fully electric cars. In vehicles like these, keeping the battery charged is of considerable importance.

![Image of system setup](image)

**Fig. 4.40:** Developed system setup for LabVIEW based BMS

Hence this regenerative mechanism is controlled by BMS. This regenerative mechanism is not implemented in the current system setup. The developed setup for BMS is given below and different electrical loads are connected to the battery and battery parameters are monitored.

### 4.3.4 Performance Testing

On electric vehicle dash board electronic systems with safety, convenience, comfort and pleasure are demanded from the customer to the car manufacturer. Therefore the LabVIEW based battery monitoring system has been developed for especially for
electrical car to monitor battery parameters and gives convenience to the driver. This developed system is a ready to use for any battery powered system to adopt safety, convenience and pleasure. The developed LabVIEW based battery management monitors different parameters of the rechargeable battery i.e. terminal voltage, discharging current, temperature, state of charge and depth of discharge. The front panel of this designed system has two different windows popped one after other. One of the window will give iconic or symbolic information along with digital numbers whereas second window gives graphical information of AH, load current, terminal voltage and state of charge along with battery discharging time. The different batteries are used to study and experiment with developed prototype of LabVIEW based Battery management system right from 2.5AH to 65AH flooded and unflooded types. All these readings are directly recorded in to the different files of excel format.

![Battery Management System for Electrical Car](image)

**Fig. 4.41:** LabVIEW based BMS for electrical car
The battery management system (BMS) of the electrical vehicles using LabVIEW is designed and experimented for different capacity batteries for different load currents. This developed system BMS consists of sensors and actuators for read, process, monitor, control and stores the acquired data for analysis. In the analysis the SOC is estimated and shown using indicator for the user. The SOC is estimated from the consumed AH of the battery and subsequently depth of discharge is also calculated and displayed for user.

**Fig. 4.42:** LabVIEW based results of BMS for electrical car

This developed system is useful in every battery powered systems and electrical vehicle for fuel status or battery capacity. This is the experimental outcome of the performed experiment for battery management system, where car user will get all battery related information on the car dashboard. The results are classified as numerical results and graphical results. The main battery parameters shown on the screen are the numerical results i.e. terminal voltage, load current, battery temperature.
and SOC/DOD. The graphical results show battery consumption AH with to the respective to the discharging time. The terminal voltage, discharging current is also plotted against discharging time of the battery. The figure 4.41 and 4.42 shows the result of the BMS setup using LabVIEW respectively.

### 4.4 Battery Performance Parameters (BPP) Monitoring System

Battery monitoring system has become a very popular today and manufacturing companies are in the process of evaluating such systems. The battery monitoring systems were primarily designed to reduce battery maintenance hours and replace inexperienced maintenance personnel. Since those early days, a lot more has been learned about why and how batteries are failed and a whole new set of battery problems has arrived with the introduction of VRLA batteries. Car manufacturer realized importance of battery monitoring, and management. Hence they have been added battery sensors that measure voltage, current and temperature. These sensors are packaged in small battery housing that forms part of the positive clamp. The electronic battery monitor system provides useful information about the battery and provides an accuracy of about ±15% when the battery is new. To solve this problem, battery management system would need to know the state-of-health of the battery, and that includes the all-important capacity.

#### 4.4.1 LabVIEW Based System

There are many reasons to monitor battery performance parameters and especially in the electrical vehicles. The reasons are identified as to increase system reliability, saving of cost for maintenance hours, and optimization of battery life.

Battery monitoring improves system reliability by detecting battery problems at an early stage, before they can cause an abrupt system failure.
Fig. 4.43 (a): LabVIEW based battery monitoring system

The traditional techniques of battery monitoring are result in time-consuming and require manual intervention. However, these systems are often complicated and require specialized hardware and software, which means one, has to make a great effort to construct such systems. Recently, many commercial data acquisition cards are available and very powerful. Data acquisition cards can be engaged to read data continuously and reducing the overheads of computers. Owing to the improvement of computing power, computer-aided multi-unit acquisition and separation rapidly proliferated during the last two decades. To utilize this technology is, however, not easy since task-specific designs are usually mandatory. To conquer this barrier, a commercially available National Instrument (NI) USB 6008, data acquisition systems
are used to evaluate whether it is possible to accomplish the task of multi-unit acquisition without the aid of these devices.

**Fig. 4.43 (b):** Block diagram of battery monitoring system

This data acquisition system (DAS) used to read battery parameters continuously with number of samples per second. The charging or discharging rate of the electrical car battery is low or not constant as compare to other physical systems. The designed system utilizes a data acquisition module of National Instrumentation (NI) system USB 6008 to read battery parameters continuously, signal conditioning section and LabVIEW software. The 10,000 samples per second, maximum sampling rate is possible for reading data with this card. In case of battery parameter reading process needs lower sampling rate and can be adjusted through DAQ assistant setting of the card through the software. The type of reading data i.e. differential or single ended is decided through software. Data acquisition applications are controlled by software programs developed using specialized software LabVIEW used for building large
scale data acquisition systems for rechargeable battery and its graphical programming environments for visualization. The battery temperature is read through the sensor LM35 and corresponding output voltage is directly given to the DAS with signal conditioning output of the sensor.

The battery temperature is read through the sensor LM35 and corresponding output voltage is directly given to the DAS with signal conditioning output of the sensor. Similarly the current and voltage part is also connected to the DAS system in order to make system ready for reading data continuously. In this setup the provision is made to display various battery performance parameters. Battery indications are also included in the software code like temperature of battery, lower/higher voltages, Total power of the battery, Remaining power of the battery and Charge holding time, Nominal Voltage and High temperature indications of the battery through emergency indicators. The different loads connected to the battery can be manipulated through software and corresponding load switching unit can be activated in order to use battery for optimum utilization. All loads shown in the block diagram are power by same battery which is shown in the setup. For real time measurement LabVIEW software is used and shown all battery related parameters on the screen of Laptop or Personal computer.

4.4.2 Performance Testing

Real time monitoring system provides key information to the user in an electrical car or battery operated systems or electrical power system in deciding mileage, range, specifications and other related parameters. Multi-parameter reading or recording is an important method for studying the functions the rechargeable battery so that monitoring of the battery performance parameters gives much information about the battery and status of the battery. It is also possible to keep continuous track on battery
performance.

The user of battery operated system will get exact value of charge holding time of the battery and required indications through indicators like displays and emergency alarms. This experimental data is used to know certain parameters of battery like rate of charging, rate of discharging and power drawn by electrical loads and some other related parameters like specific density and energy density etc can be predicted from readings taken using this setup. Real time monitoring system provides key information to the user in an electrical car or battery operated systems or electrical power system in deciding mileage, range, specifications and other related parameters.

The real time monitoring system for measurement of battery parameters are implemented with the help of software Lab VIEW 8.5 and DAS USB 6008 with some extra electronics for high side current sensing section and temperature sensor circuitry. The extra hardware required for current sensing section of the setup because the high current of battery cannot be given directly to the DAS card because of current measurement limitations of the card i.e. 50mA and electrical load takes current in terms of tens of ampere. Hence the high side current circuit is designed with suitable gain of the amplifier. Furthermore, the resolution should be kept less than 8 bits because the peak amplitude is a critical parameter for unit classification. Moreover, under persistent high-speed acquisition, the amount of data could be massive and difficult to handle. Hence, utilizing the technique of on demand sample acquisition may resolve this problem. The load current is converted in to corresponding voltage and then given to the DAS card i.e. USB 6008. The DAS driver software is needed to work DAS hardware on PC or Laptop. The device driver performs low-level register writes and reads on the hardware, while exposing a standard API for developing user applications. In this work LabVIEW tool is used more effectively and data stored in
particular file for reference and for comparison of previous and current data. The front panel of the designed system for measurement of battery parameters is given as shown in figure 4.44 and readings for different parameters are monitored as real time setup.

![Real-Time Battery Parameter Monitoring System](image)

**Fig. 4.44:** Front panel of Real-Time Monitoring System

The actual graphical programming code for the developed system setup is given below in figure 4.45 in which different blocks is shown in order to arrange and modify the data in proper way and displayed using proper indicators and graphs facility available in the LabVIEW tool. The different parameters of the DAQ assistant card are set according to the requirement. The Measurement and automation explorer is used to select number of channels used for reading data and selected channel are saved with some file.
4.5 Measurement and Monitoring of BPP

Conventional techniques of battery monitoring are time-consuming and require manual intervention and need to keep continuous track on it. However, these systems are often complicated and require specialized hardware and software, which means one, has to make a great effort to construct such systems. Today, it has become obvious to users that battery performance parameter cannot be taken for granted. There are many reasons to measure and monitor battery performance parameters and especially in the electrical vehicles. The reasons are identified as to increase system reliability, saving of cost for maintenance hours, and optimization of battery life that justifies initial investments and human safety. Battery monitoring improves system
reliability by detecting battery problems at an early stage, before they can cause an abrupt system failure. The developed system of measurement and monitoring of battery performance parameters and provides information regarding health of the rechargeable battery. Through this LabVIEW based system it is possible to keep continuous track on battery performance parameters and preventive action may be suggested through the prototype. LabVIEW based battery monitoring system consists of current, temperature and voltage sensing sections followed by its signal conditioning blocks. This LabVIEW based BMS system is reconfigured as battery measurement and monitoring system. The necessary settings are made according to the requirement of the system temperature measurement parameters is very much important because temperature term decides internal resistance of the battery and rate of charging and discharging, and some required electrical quantities or parameters of the battery. The experimental data may be used to know certain parameters of battery like rate of charging, rate of discharging and power drawn by electrical loads. The battery measurement system monitors important battery performance parameters i.e. terminal voltage, discharging current, discharging time, state of charge (SOC) and temperature of the rechargeable battery. The battery performance parameters are computed continuously with designed hardware and software setup.

Table 4.6: Measured Battery Performance Parameters

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<th>AH</th>
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</table>

- **Electrical Battery Performance Parameters**

To understand battery technology and its measurement it is necessary to know various battery parameters. The battery performances parameter can be are classified as electrical and non electrical i.e. physical parameter. In this section of the chapter various electrical and non electrical battery parameters are explained in brief for measurement and monitoring purpose.

### 4.5.1 State of Charge (SOC) /DOD and Effect of Temperature

This section of the content explains very much important parameters of the battery which are directly associated to electrical car and maintaining proper health of the battery.
### 4.5.1.1 State of Charge (SOC)

A key parameter of a battery use in an EV system is the battery state of charge (SOC). The SOC is defined as the fraction of the total energy or battery capacity that has been used over the total available from the battery. Battery state of charge (SOC) gives the ratio of the amount of energy presently stored in the battery to the nominal rated capacity. For example, for a battery at 80% SOC and with a 500 Ah capacity, the energy stored in the battery is 400 Ah. A common way to know SOC is to measure the terminal voltage of the battery and compare this voltage of a fully charged battery. However, as the battery voltage depends on temperature as well the state of charge of the battery; this measurement provides only a rough idea of battery state of charge.

![SOC and DOD relation](image)

**Fig. 4.46:** SOC and DOD relation

### 4.5.1.2 SOC Estimation by Coulomb Counting Method

The energy contained in an electric charge is measured in Coulombs and is equal to the integral over time of the current which delivered the charge. The remaining capacity in a cell can be calculated by measuring the current entering (charging) or leaving (discharging) the cells and integrating (accumulating) this over the time. The calibration reference point is a fully charged cell, not an empty cell, and the SOC is
obtained by subtracting the net charge flow from the charge in a fully charged cell. This method, known as Coulomb counting, provides higher accuracy than most other SOC measurements since it measures the charge flow directly. However it still needs compensation to allow for the operating conditions as with the voltage based method.

4.5.1.3 Depth of Discharge (DOD)

In any type of batteries, the full energy stored in the battery cannot be withdrawn or cannot be fully discharged without causing serious and often irreparable damage to the battery. Depth of Discharge is the amount of energy that has been removed from a battery.

![Fig. 4.47: Depth of Discharge verses Number of cycles](image)

Depth of discharge is expressed in a percentage of the total battery capacity. For example, 25% depth of discharge means that quarter of the energy in the battery has been used. The 90% of DOD means that eighty percent of the energy has been discharged, so the battery now holds only 10% of its full charge. The depth of discharge and number of charging and discharging cycles are directly proportional to each other. The percentage value of depth of discharge or state of charge decides
usage of the battery. In the figure 4.47 where DOD is 30% it means the battery is used for more than 1200 cycles and when DOD is 100% means battery is used for less than 200 cycles. It means the condition or health of battery is good at 100% DOD and health is completely declined at 100% DOD.

4.5.1.4 Effect of Temperature:

Battery capacity is diminished at low temperatures. At 62°F, capacity is approximately 90%. At low temperatures, a higher float voltage is required to maintain full charge.

![Graph showing battery capacity versus operating temperatures](image)

**Fig. 4.48:** Battery capacity versus operating temperatures

If the charger is not adjusted properly, cells may be undercharged, leading to the problems described under low voltage. High temperature causes loss of battery life. Battery life is cut in half if operated at greater than 92°F. The graph of temperature dependence is shown in figure 4.48 and used to understand how the life of high capacity tubular Lead Acid batteries used in standby applications over years may vary with the operating temperature. Note that running at 35 °C, the batteries will deliver more than their rated capacity but their life is relatively short, whereas an extended
life is possible if the batteries are maintained at 15 °C. High temperature also
increases float current, which results in loss of water in flooded cells, and dry out and
thermal runaway in VRLA cells. These problems lead to increase in cell resistance.
The high temperature of the battery leads to gassing, thermal runaway and equalization
problem and are given as below.

a. Gassing

Batteries start to release gas when it is attempted to charge or discharge faster than
recommended Crate. The excess energy is turned into heat, which then causes the
electrolyte to boil and evaporate. Due to evaporation of electrolyte, the gassing
occurs. To recharge such batteries special purpose chargers are used with temperature
probe on the battery to ensure that the battery does not get too hot. As the battery
heats up, the charging current is reduced to prevent thermal runaway, a very
dangerous condition.

b. Thermal Runaway

This is a very dangerous condition that can occur in batteries if they are charged too
fast. One of the byproducts of gassing is Oxygen and Hydrogen. As the battery heats
up, the gassing rate increases as well and it becomes increasingly likely that the
Hydrogen around it will explode. The danger posed by high Hydrogen concentrations
is one of the reasons therefore batteries are to be installed in separate, well-ventilated
areas.

c. Equalization

Sulphation layers form barrier coats on the lead plates in batteries that inhibit their
ability to store and dispense energy. The equalization step is a last resort to break up
the Sulfate layers using a controlled overcharge. The process will cause the battery
electrolyte to boil and gas, so it should be only done under strict supervision and with
the proper precautions. It is much trickier to equalize a VRLA battery than a flooded battery with removable caps.

4.5.2 Internal Resistance/Impedance

The internal resistance of a battery provides useful information about its performance and health status. High resistance values are often the triggering point to replace an aging battery, and determining resistance is especially useful in checking stationary batteries. However, resistance comparison alone is not only effective, because the value between batches of lead acid batteries can vary by eight percent. Because of this relatively wide tolerance, the resistance method only works effectively when comparing the values for a given battery from new to fade battery. Measuring the internal resistance is done by reading the voltage drop on a load current or by AC impedance. The internal resistance results are in ohmic values. There is an impression that internal resistance is related to capacity, and this is false. The resistance of many batteries stays flat through most of the service life. Different methods of measuring the internal resistance of a battery are considered by pure resistance measurement and impedance measurement. The difference between resistance (R) and impedance (Z) is due to reactive elements such as coils and capacitors in the battery. Both values are given in Ohms. Most of the electrical loads and batteries have internal impedance. Impedance of battery consists of a capacitive reactance component and an inductive reactance component. Capacitive reactance decreases with increasing frequency, while inductive reactance increases with increasing frequency. A battery has resistive, capacitive and inductive resistance, and the term impedance includes all three in one. The inductive component only shows up at high frequencies when the inductive reactance of the conductors inside the battery becomes a factor in the overall impedance. Impedance can best be illustrated with the Randles model.
Figure 4.49: Randles model of a lead acid battery

Figure 4.49 shows basic model of a lead acid battery, which includes resistors and a capacitor (R1, R2 and C). The inductive reactance is commonly not used because it plays a minor role in a battery, especially at a low frequency. A practical electrical power source which is a linear electric circuit according to Thevenin’s theorem and it can be represented as an ideal voltage source in series with impedance. This battery resistance is called as internal resistance of the source. When the power source delivers current to the battery, the measured e.m.f. is lower than the no-load voltage.

The concept of internal resistance applies to all kinds of electrical sources and is useful for analyzing many types of electrical circuits. Internal resistance can be caused by a number of outcomes, though a possible cause is by interior chemical installment. When thermal energy is applied to provide the current, that applied energy is most of the power source’s energy which produces the chemicals. The load current is delivered in a lap and returns to the battery (voltage source) and then performs resistance.

Batteries are approximately modeled as a voltage source in series with a internal resistance. Internal resistance of a battery is dependent on the specific battery's size, chemical properties, age, temperature and the discharge current. Measurement of the battery internal resistance is a guide to its health condition, but may not apply at other than the test conditions. Internal resistance also depends upon temperature. i.e. Fresh Energizer E91 AA alkaline primary battery drops from about 0.9 ohms at -40
°C to about 0.1 ohms at 40 °C. The internal resistance of a battery can be calculated from its open circuit voltage, voltage on-load, and the load current technique.

\[
R_i = \frac{V_{\text{without load}} - V_{\text{with load}}}{V_{\text{with load}} + R_{\text{load}}}
\]  

Internal resistance increases with increase in age of a battery, but for most battery types ranges from a fraction of an ohm to a few ohms.

In use the useful voltage produced by a disposable battery decreases until it drops so far that the battery must be discarded. This is largely due to an increase in internal resistance rather than a drop in the voltage of the equivalent source.

In this diagram the voltage source (E) is to be considered as battery and battery has internal resistance i.e. \(R_{\text{in}}\). The equivalent circuit of any source of voltage is as shown in figure 4.50.

![Fig. 4.50: Equivalent Circuit of Battery](image)

Ideal voltage source has no internal resistance, so the voltage at the output is E volts with no load or full load. However, in practical case the output voltage will be E volts only when no load condition \((I_L=0)\) exist. When a load is connected the output voltage of the voltage source will decrease due to the voltage drop across the internal resistance. Now observe the figure 4.51 and the load \(R_L\) is connected across the voltage source.
According to the Kirchhoff’s Voltage Law (KVL), the network of figure 4.51 can be written as:

\[ E - IL \times Rin - VL = 0 \]  \hspace{1cm} (7)

If no load (i.e. \( IL = 0 \)) at the output then the above equation can be written as follows:

\[ E - 0 - VNL = 0 \]
\[ E = VNL \]

The equation (7) can be written as:

\[ VNL - IL \times Rin - VL = 0 \]

\[ VL = VNL - IL \times Rin \] \hspace{1cm} (8)

The equation (8) says that the \( V_L \) is always less than \( V_{NL} \) by the term \( IL \times Rin \).

The value of \( Rin \) can be calculated by solving the above equation,

\[ Rin = \frac{VNL - VL}{IL} = \frac{VNL}{IL} - \frac{IL \times RL}{IL} \]
\[ R_{in} = \frac{V_{NL}}{I_L} - R_L \] (9)

4.5.3 Specific Gravity and State of Health (SOH)

Knowing actual capacity and battery health are major factor in deciding battery replacement, charging rate and age of the battery.

4.5.3.1 Specific Gravity

The specific gravity of the rechargeable battery is also important to know current capacity of the battery. The specific gravity of electrolyte depends on measuring changes in the weight of the active chemicals. As the battery discharges the active electrolyte is consumed and the concentration of the sulphuric acid in water is reduced. This in turn reduces the specific gravity of the solution in direct proportion to the state of charge.

The actual specific gravity of the electrolyte indicates the state of charge of the rechargeable battery. Generally specific gravity measurements cannot be taken on sealed lead-acid batteries hence open circuit voltage has been used as an indication of the state of charge.

Determination of the state of charge of sealed batteries is under development. The SOC and DOD can be estimated with the help of terminal voltage of the battery for sealed lead acid battery. The results can be vary widely because it is depending on actual voltage level, temperature, discharge rate and the age of the cell and compensation for these factors must be provided to achieve a reasonable accuracy.

The energy contained in an electric charge is measured in Coulombs and is equal to the integral over time of the current which delivered the charge.
The remaining capacity in a cell can be calculated by measuring the current entering (charging) or leaving (discharging) the cells and integrating (accumulating) this over the time. The designed system utilizes a data acquisition card of manufacturer National Instrument (NI) along with LabVIEW tool to read battery parameters. The SOC of the battery determines the available capacity of the battery and is expressed as a percentage of some reference, sometimes its rated capacity but more likely its current capacity. For estimation of SOC coulomb counting technique is used and accurate values of ampere hour is displayed. The depth of discharge has a major effect on the life expectancy of a battery.

The experimental setups for measuring battery parameters are given in previous section. In that experimental setup LabVIEW and MATLAB tool were used effectively to estimate some of the battery parameters.

Therefore, during fully charged steady-state operation and on discharge, measurement of the specific gravity of the electrolyte provides an approximate indication of the state of charge of the cell.

**Fig. 4.52:** Schematic of Hydrometer
The specific gravity measurements cannot be taken on sealed lead-acid batteries hence open circuit voltage has been used as an indication of the state of charge of a sealed battery.

Determining the state of charge of sealed batteries is under development. Specific gravity varies with temperature and the quantity of electrolyte in a cell. The following equations permit electrical monitoring of approximate specific gravity.

\[
\text{Specific Gravity} = \text{open circuit voltage of single cell} - 0.845
\]  

(10)

If single cell open circuit voltage is 2.13V then specific gravity will be 1.285. The specific gravity of a fully charged industrial battery, or traction battery, is generally 1.285, depending on the manufacturer and type. Some manufacturers use specific gravities as high as 1.320 in an attempt to gain additional Ah capacity, but at the cost of a shorter cycle life.

The following is a conventional procedure for performing a state-of-charge test using suction type of hydrometer.

1. Remove vent caps or covers from the battery cells.
2. Squeeze the hydrometer bulb and insert the pickup tube into the cell closest to the battery's positive (+) terminal.
3. Slowly release the bulb to draw in only enough electrolytes to cause the float to rise. Do not remove the tube from the cell.
4. Read the specific gravity indicated on the float. Be sure the float is drifting free, not in contact with the sides of top of the barrel. Bend down to read the hydrometer a eye level. Disregard the slight curvature of liquid on the float.
5. Read the temperature of the electrolyte.
6. Record your readings and repeat the procedure for the remaining cells

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Terminal Voltage (12V Battery)</th>
<th>Percentage of Charge (%)</th>
<th>Specific Gravity</th>
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In previous time batteries primarily batteries were checked or tested by color observation. This methodology of testing batteries is given below figure 4.53.

The system was fitted in the battery at the time of manufacturing battery and through sight glass of the system battery has to investigate. The system mechanism consists of green ball fitted in the bottom of the setup. The different colors are indentified for different status of the battery. When green color spot is seen through sight glass it
means the battery is in good condition whereas when dark green color spot is invisible means battery has to be charged and then test the battery.

![Battery Management System Diagram](image)

**Fig. 4.53:** Color indications of the battery

When color spot is turned to yellow or light in color then battery has to be replaced. Hence level of electrolyte and state of charge or electrolyte strength of the battery was approximated from color indicators without any electrical or electronic intervention in the battery. This color indication system was very much popular in these days.

**Table 4.8:** Range of Specific gravity and its understanding

<table>
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<tr>
<th>Sr. No.</th>
<th>Specific Gravity</th>
<th>Battery Understanding</th>
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<tr>
<td>1</td>
<td>1.10</td>
<td>Battery Low</td>
</tr>
<tr>
<td>2</td>
<td>1.15</td>
<td>Battery Low</td>
</tr>
<tr>
<td>3</td>
<td>1.20</td>
<td>Battery Full Charge</td>
</tr>
<tr>
<td>4</td>
<td>&gt;=1.30</td>
<td>Battery Overcharge</td>
</tr>
</tbody>
</table>
Fig. 4.54: Expected and observed values of the Specific Gravity

Fig. 4.55: Expected and observed values of State of charge (SOC)
4.5.3.2 State of Health (SOH)

It is a figure of merit of condition of the battery compared to the ideal conditions of the battery. The unit of SOH is percent points (100% Battery condition match the battery specification). Typically SOH is 100% at the time of manufacture and will decrease over time and battery use. SOH does not correspond to a particular physical quantity; there is no consensus in the industry on how SOH should be determined. The designer of battery management system may use any of the following parameter to derive an arbitrary value of SOH i.e. internal resistance or impedance or capacitance, capacity, voltage, discharge, ability to accept charge and number of charge discharge cycles.

4.6 Measurement of SOC using Refractometric Fiber Optic Sensor

Electric vehicles, robotic systems, wheel chairs and submarine devices are typical examples where knowing the State of charge (SOC) is critical in order to optimize energy management and increase battery life. The SOC represents the fuel gauge of battery. Various techniques are used to determine SOC of battery either needs manual intervention or sophisticated equipments. Optical sensors are also used for monitoring SOC because of its numerous advantages such as small size, light weight, immunity to EMI and RFI and ease of installation at the sight. There are few approaches of monitoring SOC based on optical sensors. Among those techniques some of them are measurement of specific gravity based on the principle of variation of the critical angle of reflection due to change in the density of the surrounding sensor electrolyte and monitoring the change of absorption of electrolyte due to variation of its chemical properties. These optical sensors need special arrangements and are not convenient for in-situ monitoring.
This is an implemented refractometric fiber optic sensor probe for in-situ monitoring of SOC of the lead acid battery. Various battery parameters such as terminal voltage, discharge current, ampere-hour (AH), battery temperature, SOC and Depth of discharge (DOD) are also measured using designed hardware and data acquisition system USB6009 for different electric loads. The measured battery performance parameters are continuously monitored using LabVIEW tool. The recorded value of SOC using fiber optic sensor is compared with SOC value calculated using conventional terminal voltage and coulomb counting method.

4.6.1 Operating Principle of Fiber Optic Sensor (FOS)

Refractometric fiber optic sensor is useful in detection of change in the refractive index of liquids. The developed fiber optic sensor consists of two parallel fibers with a reflector at a distance. The light is launched into one of the fibers called transmitting fiber. The cone of emission from this fiber depends on numerical aperture (NA) of the fiber given by

\[ \theta_{NA} = \sin^{-1} \frac{NA}{n_1} \]  

(11)

Where \( \theta_{NA} \) is a cone of emission, NA is the numerical aperture, \( n_1 \) is the refractive index of the medium.

Fig. 4.56: Basic Principle of Refractometric Fiber Optic Sensor
Operating principle of refractometric fiber optic sensor is as shown in figure 4.58. The region between the fiber end faces and the reflector is filled with liquid having refractive indices n1 and n2 where n1>n2. Using equation (12), \( \theta_{\text{NA}(n1)} < \theta_{\text{NA}(n2)} \). With medium having refractive index n1, emitted light energy density is more than that for the medium having refractive index n2. Thus received light intensity after reflection is more with medium having refractive index n1 than for the medium having refractive index n2. Hence received light intensity is directly proportional to the change in refractive index of medium.

### 4.6.2 Theoretical background:

Clausius-Mossotti relation and Maxwell’s formula relates the refractive index of substance to its polarizability given by equation (12)

\[
\frac{n^2 - 1}{n^2 + 1} = \frac{4\pi}{3} N\alpha
\]

(12)

Where ‘n’ is refractive index of substance

‘N’ number of molecules per unit volume and \(\alpha\) is the mean polarizability

This equation is valid for the crystal structures and also for polarized liquids. Density of substance is given as number of molecules per unit volume (N). Specific gravity of electrolyte is given by the ratio of densities of electrolyte to density of equal quantity of water and is given by equation (13)

\[
\rho = \frac{N_{\text{Electrolyte}}}{N_{\text{H}_2\text{O}}}
\]

(13)

Where \(\rho\) is specific gravity of substance, Electrolyte is number of molecules of electrolyte per unit volume, \(N_{\text{H}_2\text{O}}\) is number of molecules of water per unit volume.

Hence
Substituting this in equation (12) and rearranging the terms, relation between the specific gravity and refractive index as given by equation (15)

\[ n = \sqrt{\frac{\beta \rho + 1}{1 - \beta \rho}} \] (15)

Where \( \rho \) is specific gravity of electrolyte and \( \beta = \frac{4\pi}{3} \alpha N_{H_2O} \). The specific gravity provides a useful means of determining the concentration of constituents in the water.

In lead acid battery the SOC or energy content is linearly related to the concentration of the electrolyte i.e. sulfuric acid solution. As the battery is charged or discharged the concentration of the sulfuric acid changes depending upon the type of battery. In the sulfuric acid solution the refractive index of the solution is linear with the concentration of acid in the solution. Therefore the battery charge level or discharge level is proportional to the acid concentration in the solution and this can be directly derived from the relative change in refractive index of the battery electrolyte. The lead acid battery uses lead dioxide (PbO\(_2\)) as the active material in the positive electrode, and metallic lead (Pb) of a very porous structure, as the active material in the negative electrode. The electrolyte is formed by sulphuric acid (H\(_2\)SO\(_4\)) diluted in water (H\(_2\)O), with concentrations between 8% and 40% depending upon state of charge and the type of the battery. The electrochemical reactions which occur during the process of charging and discharging are described in equations (16) to (21)

**During the charge:**

Anode (+): PbSO\(_4\) + 2H\(_2\)O → PbO\(_2\) + H\(_2\)SO\(_4\) + 2H\(^+\) +2e\(^-\) (16)

Cathode (-): PbSO\(_4\) + 2e\(^-\) → SO\(_4^{2-}\) +Pb (17)

Global reaction: 2 PbSO\(_4\) + 2H\(_2\)O → Pb + PbO\(_2\) + 2H\(_2\)SO\(_4\) (18)
During the discharge:

Anode (+): Pb + SO$_4^{2-}$ → PbSO$_4$ + 2e$^-$  \hspace{1cm} (19)

Cathode (-): PbO$_2$ + H$_2$SO$_4$ +2H$^+$ +2e$^-$ → PbSO$_4$ + 2H$_2$O \hspace{1cm} (20)

Global reaction: Pb + PbO$_2$ + 2H$_2$SO$_4$ → 2PbSO$_4$ + 2H$_2$O \hspace{1cm} (21)

According to equation (19) to (21) during the discharging process both electrodes transform the active material into lead sulfate (PbSO$_4$), with consequent consumption of H$_2$SO$_4$ and the release of water to electrolyte. As result the concentration of 2e$^-$ in the electrolyte is decreased which in turn reduce the refractive index. In the charging process, equations (16) to (18), the opposite reaction occurs since H$_2$SO$_4$ is released and water is consumed thereby increasing the refractive index of the electrolyte.

4.6.3 Sensor Structure:

FOS-SOC sensor is developed for on line detection of State-of-Charge of lead acid battery. It consists of two parallel fibers having specifications viz. fiber diameter (fd)=2.2mm, NA =0.47, core diameter=1mm and cladding thickness=0.612mm. Fibers are encapsulated in the T shaped glass tube as shown in figure 4.57.

![Fig 4.57: Schematic of FOS-SOC sensor and actual Photograph of FOS-SOC sensor](image-url)
Cylindrical glass cavity is fused with the glass tube. Mirror is fixed at the base of cylindrical cavity with diameter 6 mm. This is distance between end face of fibers and reflector. The structure is immersed in the lead acid battery consisting of electrolyte. As is the electrolyte is solution of acid and water sensor structure is fabricated in glass. Light is launched in one of fibers called transmitting fiber using high bright RED LED with wavelength 633nm. Cone of light emitted by transmitting fiber depends on the refractive index of electrolyte of lead acid battery. Light reflected from mirror is collected by the receiving fiber. The received light is converted in electrical signal using photo detector L14G3. The amount of light received is a function of refractive index of electrolyte. As discussed earlier refractive index is linear with specific gravity which is in turn related to the state of charge of lead acid battery. Figure 4.57 shows photograph of the developed fiber optic sensor for measuring state of charge of lead acid battery.

4.6.4 Experimental Setup

The light from high bright red light emitting diode was launched into one of the optical fiber i.e. transmitting fiber. The light reflected from the mirror is collected by another optical fiber i.e. receiving fiber. Collected light is converted to electrical form by using the photo detector (L14G3). The assembly is enclosed in the glass structure so that there will be no corrosion effects on the optical fibers. The local made lead acid battery having specifications as 12V/35Ah is used for experimentation. Initially, battery is fully charged using charger 12V with 5A charging current for period of 7 hours. After the rest period of 1 hour, battery is connected to different electrical load for discharging. Considering the specific case for the load of 50Watt (halogen lamp) measurements are taken.
During this, FOS-SOC sensor is immersed into one of the cells of the battery. Temperature sensor LM 35 is used to sense the battery temperature during discharging of the battery. The discharging current is also measured using the developed hardware for coulomb counting to display ampere-hour consumption of the battery. The battery data i.e. current, temperature, sensor output and terminal voltage are acquired using data acquisition card of National Instrument USB 6009 of having sampling rate of 20k samples/s.

The Lead acid battery 12V/35AH battery (Murphy Company) is used for experimentation purpose. Figure 4.58 shows experimental setup for on line monitoring of the SOC of lead acid battery. Fig 4.61 shows sensor mounting on the battery for on line monitoring purpose. The data acquisition module of NI USB 6009 card is used to read sensor output, terminal voltage, discharging current and temperature of the battery. The acquired data is processed and analyzed. Front panel developed in LABVIEW shows performance parameters of lead acid battery viz.
terminal voltage, current, temperature, Ampere/hour, backup time, SOC and DOD. Current up to 50A can be measured using the developed hardware. This current is integrated over the fixed period of time and ampere hours are calculated and displayed. Backup time of battery is calculated from the ampere hour and displayed. State of charge (SOC) and depth of discharge (DOD) is estimated from the output of FOS-SOC sensor.

4.6.5 Results and Discussion

Present methods available for measuring the SOC of battery are either offline or indirect.

![Graph showing variation of sensor output with SOC](image)

**Fig 4.59:** Variation of sensor output with SOC

Few on line measurement methods are reported but it requires modification in the structure of battery itself. Such modification in the battery structure is not required by the FOS-SOC sensor. It is direct and online methods of measurement of SOC of lead acid battery. Experiments were carried out with FOS-SOC sensor by discharging battery with different loads. The sensor shows good sensitivity for this. Thus the sensor is useful for online determination of the SOC of the lead acid battery.
The SOC of battery can be determined by measuring optical property of the electrolyte. When the load is connected to the charges in the battery get consumed. This changes the concentration of electrolyte which in turn changes the refractive index of it. Thus number of charges remained in a battery i.e. SOC (State-of-Charge) is determined by concentration of charges left in the battery electrolyte.

Equation (15) shows direct proportionality of concentration of charges with the refractive index. Therefore SOC can be determined by change in the refractive index of the electrolyte. Developed FOS-SOC sensor is refractometric retro-reflective fiber optic sensor. It is immersed into one of the cell of the battery for measuring the refractive index of the active electrolyte which changes during the charge and discharge process of battery. SOC of the battery is monitored when battery is connected to the load i.e. during the discharge. Figure 4.59 shows that FOS-SOC sensor output is direct measure of SOC of battery as when battery is connected to the load of 100Watt for the period of 5hours with discharging current of 5A/hour.

**Fig 4.60:** Variation in sensor output voltage during discharge for different loads
Similar readings are taken by connecting different loads to the battery viz. 50Watt, 86Watt, 100Watt. Figure 4.59 shows the variation in the sensor output voltage during discharge for different loads taken over the time period of 1 hour. It is observed that as the load value is decreased from 100Watt to 50Watt the sensor output voltage more for the same time interval. This is because for smaller values of load, the charge remained in the electrolyte is more compared to that for the larger values of load. Thus this sensor is used to directly measure the battery SOC. Other parameters such as temperature, discharge current, DOD, battery terminal voltage are also monitored by using the LABVIEW.

4.7 Conclusion

PC based measurement system has been developed for battery performance monitoring. The data acquisition system and necessary the signal conditioning circuits for temperature, high current and AH measurement has been developed and
experimented successfully for the said measurements for the car battery. To know and understand rechargeable battery various experiments were carried out using dynamic and active load. Some experiments were carried to understand leakage current of the different rechargeable flooded and VRLA batteries. These experiments were helped in designing necessary hardware for battery management system. The software for BMS is also developed using LabVIEW to acquire real time data of battery with the help of designed hardware. The portable embedded based battery management system for electrical vehicle has been developed and experimented successfully before LabVIEW based system. The embedded based BMS system showed only few battery parameters like AH and total power consumption but LabVIEW based BMS system showed almost all battery parameters are significantly required for electrical vehicles or hybrid vehicles. The microcontroller based battery management system has advantage over LabVIEW based system because of the low cost, simple to use, easy to install and portable for electrical car. Different experiments were carried out for displaying battery performance parameters (BPP) like terminal voltage (VOC), discharging current, temperature, specific gravity, SOC, DOD and internal resistance or impedance using LabVIEW. The state of charge of battery is measured using ampere hour counting method in BMS and BPP. Online measurement of SOC using fiber optic sensor has been experimented. The fiber optic sensor has specially designed only for measurement of battery SOC. The results of SOC monitoring using RFOS sensor are also given in the respective topic. The results of BMS, BPP and RFOS are given at appropriate sections of this chapter.
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