Government Polytechnic West Champaran

Electrical Engineering

Electric Vehicle (Advance) (2000608G) Lab Manual

Scheme of Studies:

Board of Study	Course Code	Course Title	Scheme of Study (Hours/Week)					
			Classroom Instruction (CI)		Lab Instruction (LI)	Notional Hours (TW+ SL)	Total Hours (CI+LI+TW+SL)	Total Credits (C)
			L	T				
	2000605G/ 2000608G/ 2000611G	Electric Vehicle (Advanced)	03	-	04	02	09	05

Scheme of Assessment:

Board of Study	Course Code	Course Title	Assessment Scheme (Marks)						Total Marks (TA+TWA+LA)
			Theory Assessment (TA)		Term Work & Self-Learning Assessment (TWA)		Lab Assessment (LA)		
			Progressive Theory Assessment (PTA)	End Theory Assessment (ETA)	Internal	External	Progressive Lab Assessment (PLA)	End Laboratory Assessment (ELA)	
	2000605G/2000608G/2000611G	Electric Vehicle (Advanced)	30	70	20	30	20	30	200

Suggested Laboratory (Practical) Session Outcomes (LSOs) and List of Practical (2000608G)

Practical/Lab Session Outcomes (LSOs)	S. No.	Laboratory Experiment/Practical Titles	Relevant COs Number(s)
LSO 2.1 Test the operation of the Control Disc Braking system and control the regenerative braking system using a test rig. LSO 2.2 Test the performance (Speed v/s Braking Torque) of the Disc Braking System in Half step and Full step braking modes.	1.	• Testing of Control Disc Braking system and Control Regenerative Braking system.	CO2
LSO 2.3 Test the performance of different types of propulsion motors.	2.	• Testing of Motors	
LSO 2.4 Test the continuity of the automotive wiring system in the EV	3.	• Testing of the automotive wiring system.	
LSO 3.1 Test the performance of a new set of batteries and aged batteries. LSO 3.2 Compare the performance of the battery and find the Fuel Gauge after discharging the battery. a. 0% - 100% b. 30% - 100% c. 50% - 100% LSO 3.3 Evaluate the following parameters of the given EV battery. a. Specific power b. Specific energy	4.	• Testing of Batteries used in EVs	CO2, CO3

Practical/Lab Session Outcomes (LSOs)	S. No.	Laboratory Experiment/Practical Titles	Relevant COs Number(s)
c. Life span and d. Cost parameters LSO 3.4 Evaluate the State of Health (SoH) of the given EV Battery after several charge/discharge cycles.			
LSO 3.5 Test the dynamic performance of the given motor; a) Speed and torque spectrum. b) Speed and torque oscillation c) Friction torque friction spectrum. LSO 3.6 Test the following speed-controlled performance characteristics of the given motor; a. Motor voltage over time b. Motor current over time. c. Speed and torque over time. d. Torque over speed. e. Current over speed. f. Electrical input power and the mechanical input power over speed	5.	• Speed control of Electrical Motors	
LSO 4.1 Connect the components of the EC Units with EV subsystems. LSO 4.2 Troubleshoot basic faults in the electronic control unit of EV.	6.	• Connection of Electronic Control Unit components • Troubleshooting of electronic control unit	**CO4**
LSO 5.1 Evaluate the impact of the Grid on Vehicle Charging and Vehicle Charging on the Grid.	7.	• Impacts of G2V and V2G	**CO 5**
LSO 5.2 Prepare a layout of a charging station	8.	• Demonstration of Charging stations	

List of Experiments/ Practical's-

1. **To Study of Lead Acid Battery.**
2. **To Study of Lithium Iron Phosphate Battery.**
3. **To Study of Battery Charger Enable in Battery Characteristics Trainer.**
4. **To Study of Charging & Discharging Characteristics of Lead-Acid Batteries in Battery Characteristics Trainer.**
5. **To Study of Charging and discharging Characteristics of Li-iron Phosphate Batteries in Battery Characteristics Trainer.**
6. **Comparative study of Lead-Acid and Lithium Iron Phosphate Battery.**
7. **Study of Battery Management System (BMS) Operation and Display Setting.**
8. **Study of Cell Voltage test by Multimeter.**
9. **Study of Normal Battery Charging.**
10. **Study of Balanced Battery charging and its types.**
11. **Study of Passive cell balancing.**
12. **Study of Battery discharge using Load (BLDC Motor).**
13. **Study of Thermal Cell cut-off.**

Experiment 1

Aim: To Study of Lead Acid Battery.

Apparatus Required:

- **Battery Characteristics Trainer (MI-EV02).**

Theory:-

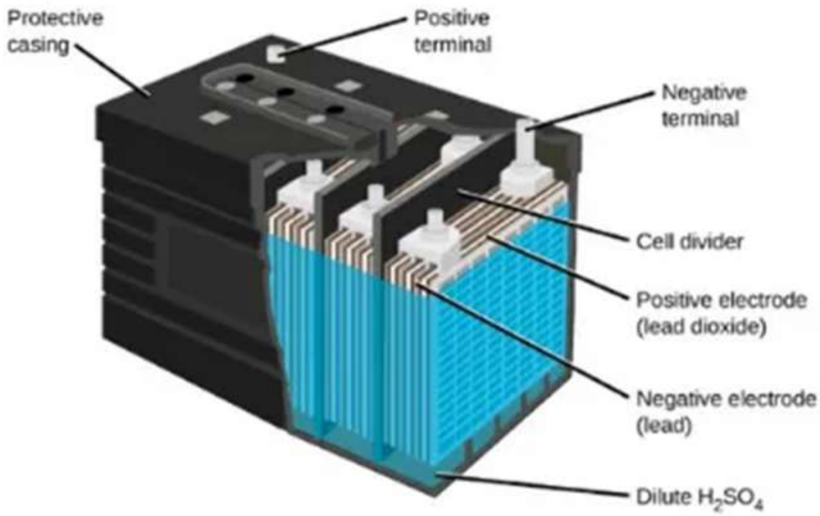
The storage battery or secondary battery is such a battery where electrical energy can be stored as chemical energy and this chemical energy is then converted to electrical energy as and when required. The conversion of electrical energy into chemical energy by applying external electrical source is known as charging of battery. Whereas conversion of chemical energy into electrical energy for supplying the external load is known as discharging of secondary battery.

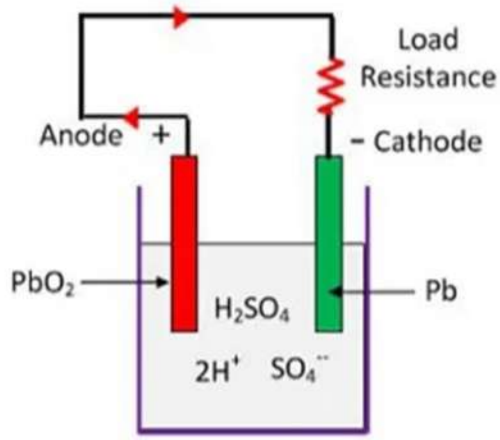
During charging of battery, current is passed through it which causes some chemical changes inside the battery. This chemical changes absorb energy during their formation.
When the battery is connected to the external load, the chemical changes take place in reverse direction, during which the absorbed energy is released as electrical energy and supplied to the load.

Lead acid battery which is very commonly used as storage battery or secondary battery.

The Lead-acid battery is one of the oldest types of rechargeable batteries. These batteries were invented in the year 1859 by the French physicist Gaston Plante.

Lead-Acid Battery





Despite having a small energy-to-volume ratio and a very low energy-to-weight ratio, its ability to supply high surge contents reveals that the cells have a relatively large power-to-weight ratio.

Lead-acid batteries can be classified as secondary batteries. The chemical reactions that occur in secondary cells are reversible. The reactants that generate an electric current in these batteries (via chemical reactions) can be regenerated by passing a current through the battery (recharging).

The chemical process of extracting current from a secondary battery (forward reaction) is called discharging. The method of regenerating active material is called charging.

Sealed Lead Acid Battery

- The sealed lead-acid battery consists of six cells mounted side by side in a single case. The cells are coupled together, and each 2.0V cell adds up to the overall 12.0V capacity of the battery.

- Despite being relatively heavy, lead-acid batteries are still preferred over other lightweight options owing to their ability to deliver large surges of electricity (which is required to start a cold engine in an automobile).
- A completely charged lead-acid battery is made up of a stack of alternating lead oxide electrodes, isolated from each other by layers of porous separators.
- All these parts are placed in a concentrated solution of sulfuric acid. Intercell connectors connect the positive end of one cell to the negative end of the next cell hence the six cells are in series.

Materials used for Lead Acid Storage Battery Cells

1. Lead peroxide (PbO_2).
2. Sponge lead (Pb)
3. Dilute sulfuric acid (H_2SO_4).

Lead Peroxide (PbO_2):-The positive plate is made of lead peroxide. This is dark brown, hard and brittle substance.

Sponge Lead (Pb):-The negative plate is made of pure lead in soft sponge condition.

Dilute Sulfuric Acid (H_2SO_4):-Dilute sulfuric acid used for lead acid battery has a ratio of water: acid = 3:1.

Chemical Reaction for Discharging

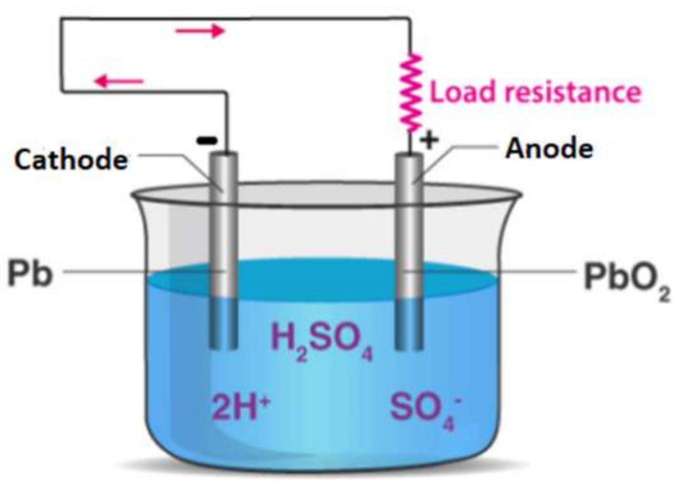
When the battery is discharged, it acts as a galvanic cell and the following chemical reaction occurs.

Negative:

$Pb(s) + HSO_4^- + H_2O(l) \rightarrow 2e^- + PbSO_4(s) + H_3O^+(aq)$ (oxidation)

Positive:

$PbO_2(s) + HSO_4^-(aq) + 3H_3O^+(aq) + 2e^- \rightarrow PbSO_4(s) + 5H_2O(l)$ (reduction)



Lead-Acid Battery Discharging

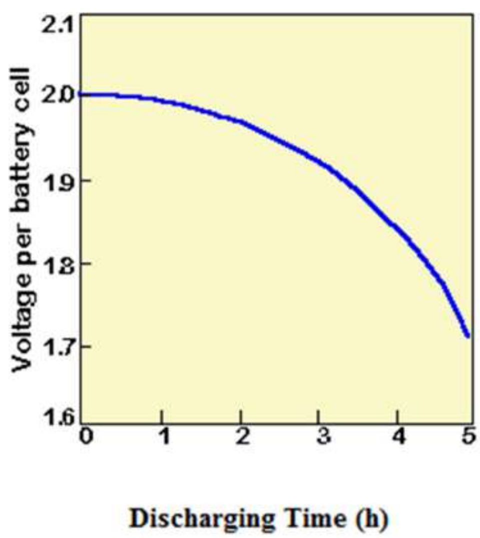
Lead sulfate is formed at both electrodes. Two electrons are also transferred in the complete reaction. The lead-acid battery is packed in a thick rubber or plastic case to prevent leakage of the corrosive sulphuric acid.

The **lead acid storage battery** is formed by dipping lead peroxide plate and sponge lead plate in dilute sulfuric acid. A load is connected externally between these plates. In diluted sulfuric acid the molecules of the acid split into positive hydrogen ions (H^+) and negative sulfate ions (SO_4^{--}). The hydrogen ions when reach at PbO_2 plate, they receive electrons from it and become hydrogen atom which again attack PbO_2 and form PbO and H_2O (water). This PbO reacts with $H_2 SO_4$ and forms $PbSO_4$ and H_2O (water).

$$PbO_2+2H \text{----->} PbO+H_2O$$

$$\frac{PbO + H_2SO_4 --\rightarrow PbSO_4 + H_2O}{PbO_2 + H_2SO_4 + 2H --\rightarrow PbSO_4 + 2H_2O}$$

SO_4^{--} ions are moving freely in the solution so some of them will reach to pure Pb plate where they give their extra electrons and become radical SO_4. As the radical SO_4 cannot exist alone it will attack Pb and will form $PbSO_4$. As H^+ ions take electrons from PbO_2 plate and SO_4^{--} ions give electrons to Pb plate, there would be an inequality of electrons between these two plates. Hence there would be a flow of current through the external load between these plates for balancing this inequality of electrons. This process is called discharging of lead acid battery.



The lead sulfate ($PbSO_4$) is whitish in color. During discharging,

1. Both of the plates are covered with $PbSO_4$.
2. Specific gravity of sulfuric acid solution falls due to formation of water during reaction at PbO_2 plate.
3. As a result, the rate of reaction falls which implies the potential difference between the plates decreases during discharging process.

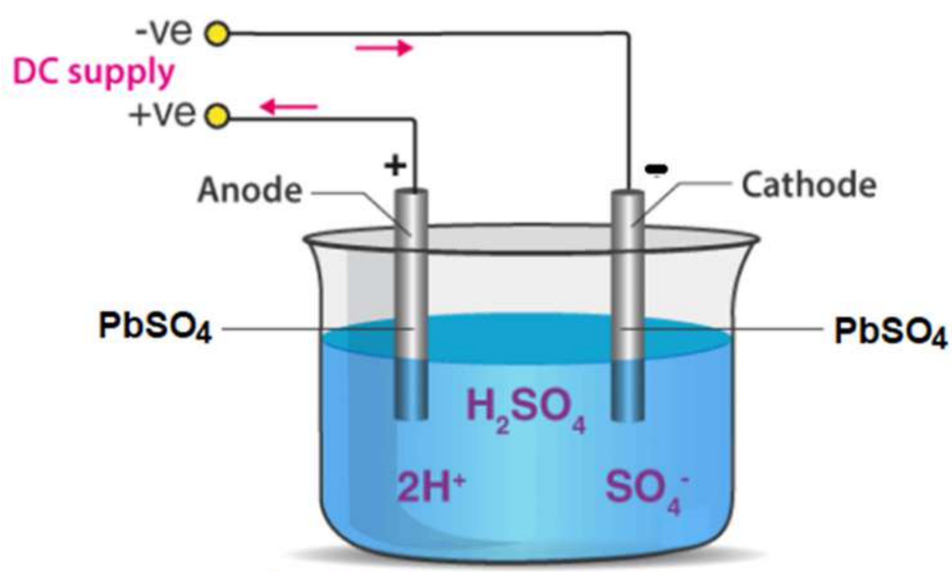
Lead Acid Battery Charging

Now we will disconnect the load and connect $PbSO_4$ covered with PbO_2 plate with positive terminal of an external DC source and PbO_2 covered with Pb plate with negative terminal of that DC source. During discharging, the density of sulfuric acid falls but there still sulfuric acid exists in the solution. This sulfuric acid also remains as H^+ and SO_4^{--} ions in the solution. Hydrogen ions (cation) being positively charged, move to the electrode (cathode) connected with negative terminal of the DC source. Here each H^+ ion takes one electron from that and becomes hydrogen atom. These hydrogen atoms then attack $PbSO_4$ and form lead and sulfuric acid.

$$PbSO_4+2H{-}{-}\rightarrow H_2SO_4+Pb$$

SO_4^{--} ions (anions) move towards the electrode (anode) connected with positive terminal of DC source where they will give up their extra electrons and become radical SO_4. This radical SO_4 cannot exist alone hence reacts with $PbSO_4$ of anode and forms lead peroxide (PbO_2) and sulfuric acid (H_2SO_4).

$$PbSO_4+2H_2+SO_4{-}{-}{-}{-}\rightarrow PbO_2+2H_2SO_4$$



Lead-Acid Battery charging

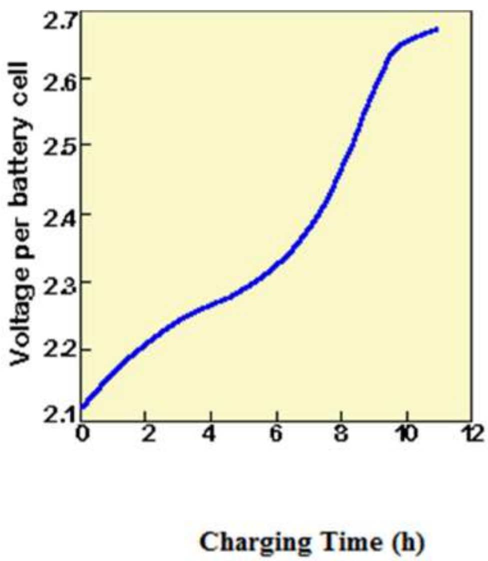
Hence by charging the lead acid storage battery cell,

1. Lead sulfate anode gets converted into lead peroxide.
2. Lead sulfate of cathode is converted to pure lead.
3. Terminal; potential of the cell increases.
4. Specific gravity of sulfuric acid increases.

The sulphuric acid existing in the lead discharge battery decomposes and needs to be replaced. Sometimes, the plates change their structure by themselves. Eventually, the battery becomes less efficient and should be charged or changed.

When car batteries spend considerable durations of time in their discharged states, the lead sulfate build-up may become extremely difficult to remove. This is the reason why lead-acid batteries must be charged as soon as possible (to prevent the building up of lead sulfate). Charging of the lead batteries is usually done by providing an external current source.

A plug is inserted which is linked to the lead-acid battery and the chemical reaction proceeds in the opposite direction. In cases where the sulphuric acid in the battery (or some other component of the battery) has undergone decomposition, the charging process may become inefficient. Therefore, it is advisable to check the battery periodically.



Chemical Reaction for Recharging

The chemical reaction that takes place when the lead-acid battery is recharging can be found below.

Negative:

$2e^{-} + PbSO_4(s) + H_3O^{+}(aq) \rightarrow Pb(s) + HSO_4^{-} + H2O(l)$ (reduction)

Positive:

$PbSO_4(s) + 5H_2O(l) \rightarrow PbO_2(s) + HSO_4^{-}(aq) + 3H_3O^{+}(aq) + 2e^{-}$ (oxidation)

While recharging, the automobile battery functions like an electrolytic cell. The energy required to drive the recharging comes from an external source, such as an engine of a car. It is also important to note that overcharging of the battery could result in the formation of by-products such as hydrogen gas and oxygen gas. These gases tend to escape from the battery, resulting in the loss of reactants.

Applications:

- Motor vehicles- to power engine starter motor.
- Uninterrupted power supply to critical load e.g. hospital equipment, data centre and office computers.
- Solar panel energy storage for night use.
- Mobile equipment that cannot be connected to grid power e.g. entertainment and media automobiles.
- Electric power diesel generators starting system.
- Used in electric motors
- Submarines
- Nuclear submarines

Advantages

1. Able to produce high current
2. Rechargeable once discharged.
3. Low voltage rating.
4. Available and affordable in different sizes.
5. Low-cost and simple manufacture Low cost per watt-hour
6. High specific power, capable of high discharge currents Good performance at low and high temperatures
7. No block-wise or cell-wise BMS required

Disadvantages

1. Short line-span – about 3-5 years
2. Oriented limited to vertical position due to spillage risk.
3. Charging takes time
4. The lead electrode used is poisonous and pose a disposal challenge.
5. Low specific energy; poor weight-to-energy ratio
6. Slow charging: Fully saturated charge takes 14–16 hours Need for storage in charged condition to prevent sulfation Limited cycle life; repeated deep-cycling reduces battery life Watering requirement for flooded type
7. Transportation restrictions for flooded type

Conclusion: The lead-acid battery has been a blessing in the electrical engineering world. It has revolutionized and power industry and brought forth efficiency that cannot be imagined in another way.

Experiment 2

AIM: To Study of Lithium Iron Phosphate Battery.

Apparatus Required:

- **Battery Characteristics Trainer (MI-EV02).**

Theory:

LiFePO4 stands for lithium Iron phosphate battery or LFP battery. You may be under the belief that all other lithium batteries are the same, but that is not strictly true.

Compared to other lithium batteries and lead acid batteries, LiFePO4 batteries have a longer lifespan, are extremely safe, require no maintenance, better charge efficiency, and improved discharge. They might not be the cheapest lithium ion batteries solution, but they are a smart investment.

The most common are built using:

- Lithium Cobalt Oxide (LiCoO2)
- Lithium Nickel Cobalt Aluminium Oxide (LiNiCoAlO2)
- Lithium Manganese Oxide (LiMn2O4)
- Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2 or NMC)
- Lithium Iron Phosphate (LiFePO4)

What is the difference between lithium ion batteries and LiFePO4 batteries?

Lithium batteries have a wealth of applications, from wearable devices such as watches through to electric vehicles, electric tools, and medical equipment.

Compared to other lithium-ion batteries, the LiFePO4 has a lower energy density. This feature makes it unsuitable for small electronic devices but the perfect match for Rvs, bass boats, golf carts, electric motorcycles, and solar energy systems.

Before we look at the differences, let's look at what makes them similar. Both battery types operate using a similar principle. The lithium ion the batteries contain moves between the positive and negative electrode to discharge and charge.

Another similarity is that they are both rechargeable batteries. Finally, both use graphitic carbon electrodes with a metallic backing as the anode.

Now time for the differences:

- **Different makeup, chemically**: You've probably already noticed this, thanks to their different names. A lithium ion battery will usually have a lithium manganese oxide or a lithium cobalt dioxide cathode. A lithium iron phosphate (LiFePO4) battery is made using lithium iron phosphate (LiFePO4) as the cathode. One thing worth noticing with regards to the chemical makeup is that lithium iron phosphate is a nontoxic material, whereas LiCoO2 is hazardous in nature. This factor makes their disposal a big concern for users and manufacturers.
- **Newer technology**: The technology used in lithium iron phosphate batteries is new than lithium-ion batteries. It has much better chemical and thermal stability. It is less likely to be combustible than a lithium-ion battery, even if you handle it incorrectly.
- **Different life cycles**: You can expect a much longer life cycle with phosphate chemistry. Both batteries already have a fairly long life span. However, lithium iron batteries are more stable if overcharged or short circuited, making them more long-lasting.

Technical Specifications of Lithium Iron Phosphate batteries

Cell voltage:

- **Minimum discharge voltage** = 2.5 V[19]
- **Working voltage** = 3.0 ~ 3.2 V
- **Maximum charge voltage** = 3.65 V[20]
- **Volumetric energy density** = 220 Wh/L (790 kJ/L)
- **Gravimetric energy density** > 90 Wh/kg [21] (> 320 J/g). Up to 160 Wh/kg [1] (580 J/g).
- **Cycle life**: from 2,700 to more than 10,000 cycles depending on conditions.

Deep cycle of LiFePO4

- Lithium iron phosphate batteries have the ability to deep cycle but at the same time maintain stable performance. A deep-cycle is a battery that's designed to produce steady power output over an extended period of time, discharging the battery significantly. At that point, the battery must be recharged to complete the cycle.
- This makes LFP batteries an ideal solution for deep cycle leisure applications that require energy over extended periods, especially when they are only charged occasionally, such as solar and off-grid applications.

LiFePO4 batteries are a new type of lithium ion technology that uses lithium iron phosphate as the positive electrode material. They are becoming an increasingly popular type of lithium battery for the following reasons:

- **High discharging and charging efficiency**: Charge and discharge efficiency can reach as much as 90%, compared to only 80% for lead-acid batteries.
- **High safety performance**: Stable construction that doesn't decompose heat up or collapse like other lithium ion battery materials.
- **Long battery life cycle**: Has a life cycle of over 2,000 times compared to 300 times for long-life lead acid batteries. Theoretically, it could last between 7 and 8 years.
- **Performs well at temperatures**: The LiFiPO4 battery performs well at extremes of temperature with an operating range of -20C to +75C. Heating peak can reach 350°C-500°C
- **High capacity battery**: Compared to lead acid batteries and other lithium-ion batteries, the LiFiPO4 battery has a much larger capacity of between 5AH and 1000AH.
- **Zero memory effect**: LiFiPO4 batteries have no memory effect, unlike other rechargeable batteries.
- **Lightweight**: A LiFePO4 battery weighs one third that of lead-acid batteries.
- **Environmentally-friendly battery**: Generally considered free of rare and heavy metals, non-polluting, non-toxic, and in compliance with European RoHS requirements.
- LiFePO4 batteries are inherently non-combustible
- LiFePO4 batteries are safer
- LiFePO4 batteries come with many benefits that are perfect for high power applications
- Lithium Iron Phosphate batteries have a slightly lower energy density

Excellent Performance and Efficiency

LiFePO4 batteries have an excellent reputation when it comes to performance and efficiency. Here are some stats to explain:

- They reach a full charge in two hours and sometimes even less.
- Self-discharge rate is a mere 2% per month, compared to lead acid batteries which are 30%.
- Compared with other lithium-ion and lead acid batteries, runtime is much higher.
- Power is consistent even when the battery life is below 50%.
- Zero maintenance.

Working:

As shown in below Figure, the LiFePO4 Battery consists of an anode, cathode, separator, electrolyte, and positive and negative current collectors. The positive terminal of a Battery is called the cathode, whereas the negative terminal is termed as the anode. The anode terminal acts as the source of lithium ions. The electrolyte carries positively charged lithium ions from the anode to the cathode and vice versa through the separator. The movement of the lithium ions creates free electrons in the anode and as a result, electrons will flow through an external circuit to the cathode i.e. positive terminal, and accordingly, a current will flow from the positive terminal to the negative terminal when an electric load is connected across the Battery. The cell consists of concentric alternating layers of the negative and positive electrode materials between which separator layers are situated. The cell is then filled with electrolyte to allow ion conduction.

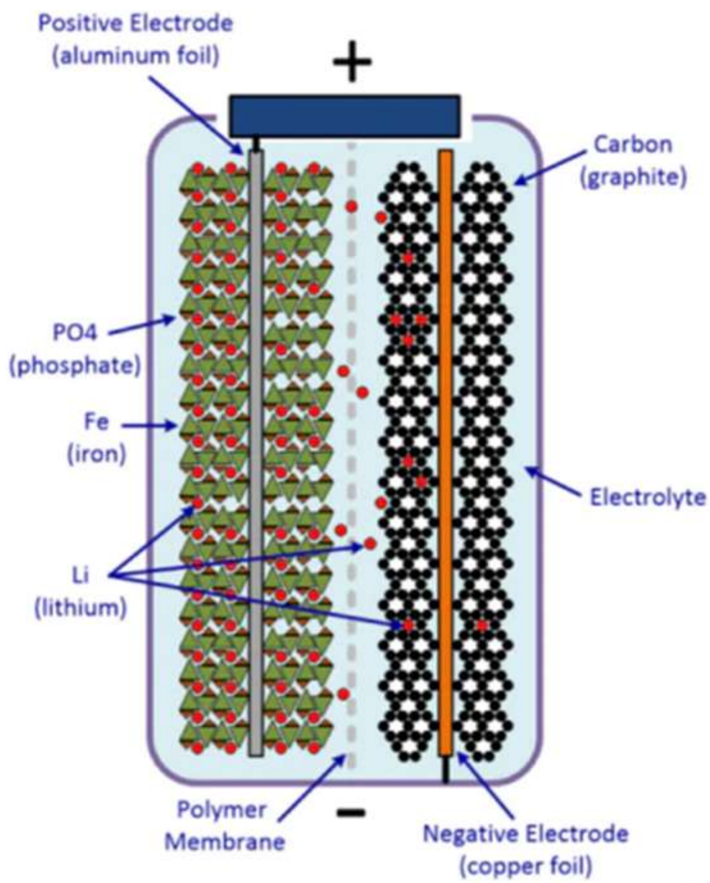


Figure1: Schematic diagram of LiFePO4 Battery.

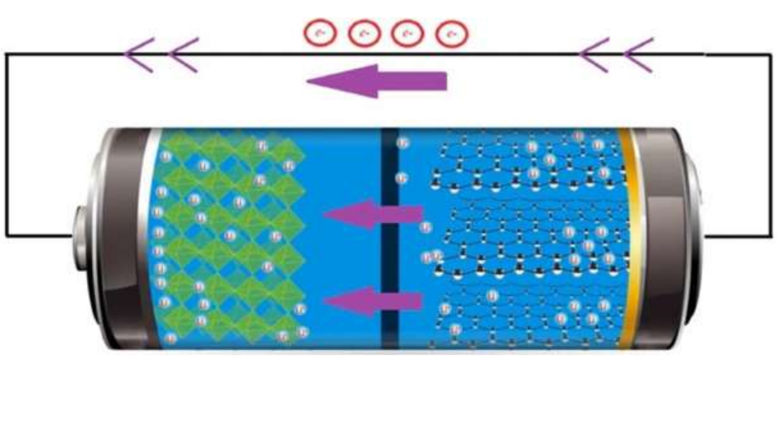


Figure 2: Charging state of a LiFePO4 Battery.

Charging State: when the Battery is getting charged, these lithium ions get pulled through the membrane and reach the negative graphite electrode that can trap and hold these cross over lithium ions. The membrane is made of a type of polymer (plastic) that has lots of tiny little pores to make it easy for the lithium ions to pass through. The Battery will be fully charged when all the positive lithium ions available in the cathode terminal reach the anode terminal.

The typical charging profile of a LiFePO4 Battery is illustrated in Figures 3 and 4. To make the analysis easier, The charging of LiFePO4 batteries can be classified into two stages as discussed below:

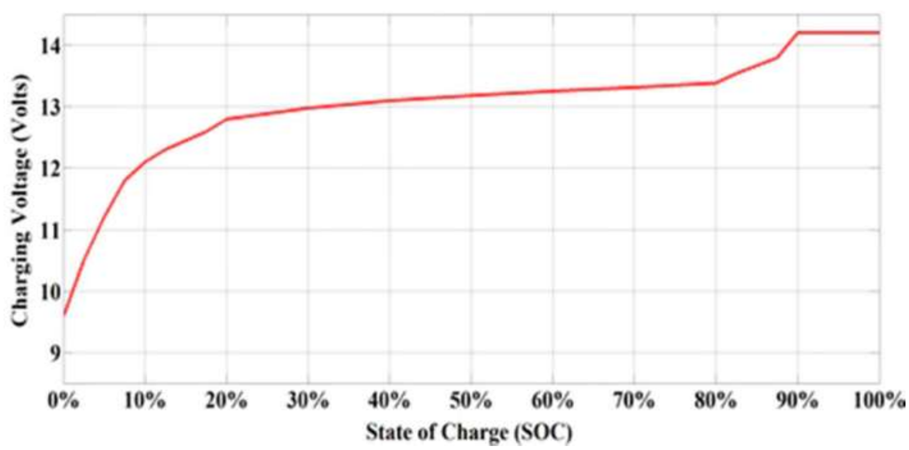


Figure 3: Charging curve of a LiFePO4 Battery (Charging voltage Vs SOC).

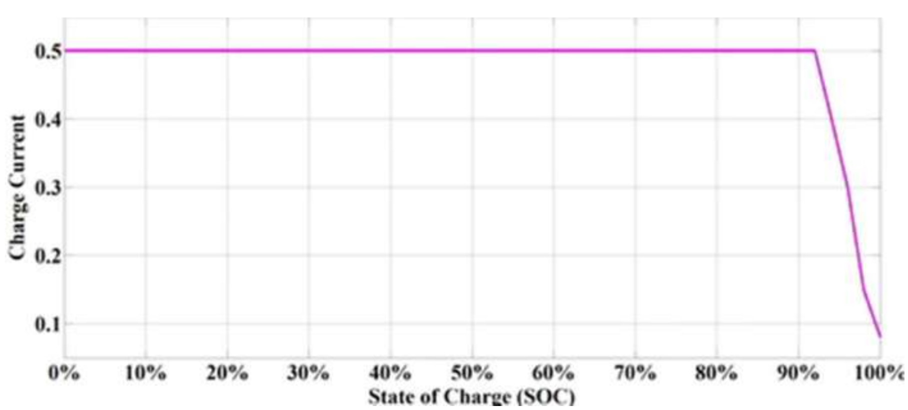


Figure 4: Charging curve of a LiFePO4 Battery (Charging current Vs SOC).

- Constant current charge: In the first stage of charging, the current is kept constant at a charge rate of 0.5C as shown in Figure 4, indicating that the Battery will get charged at a charge rate of half of its capacity. In the charging voltage of the Battery will slowly rise during the constant current charging period and the value of voltage will reach the 'absorb' Voltage.

- Saturation Charge: Once the Battery is 90% charged i.e. the absorb voltage is reached, the Battery is entered into a second stage of charging known as the saturation charge. At this point, the Battery voltage is kept constant and the current will steadily fall.

Discharging State: As discussed earlier, during the charging cycle of a LiFePO4 Battery, the released positive lithium ions from the positive electrode move to the negative electrode through the electrolyte and remain stored there. When all the available lithium ions reach the negative terminal, the Battery is said to be completely charged. Due to the presence of an insulating barrier (i.e. the separator), the electrons cannot flow through the electrolyte. When the Battery is fully discharged, all the lithium ions have moved back to the lithium-iron-phosphate electrode.

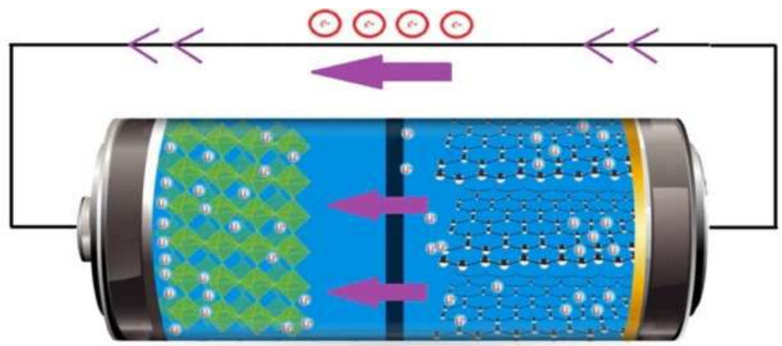


Figure 5: Discharging state of a LiFePO4 Battery.

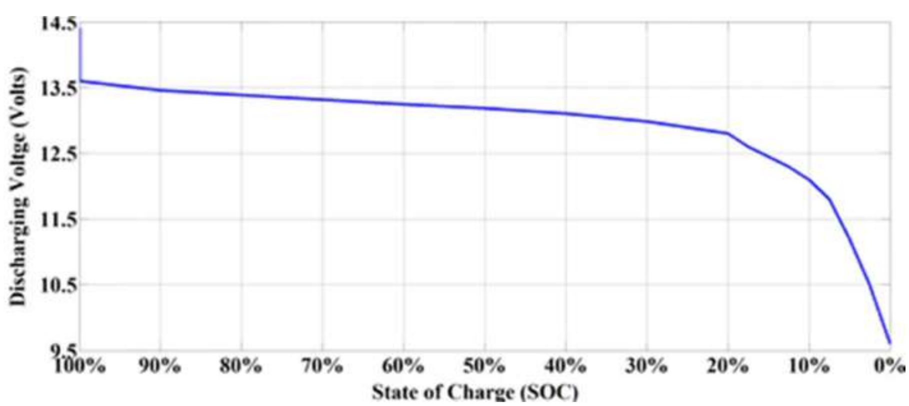


Figure 6: Discharging curve of a LiFePO4 Battery.

It is clear from the discharge cycle of the LiFePO4 Battery that the curve remains almost flat during the discharge from 100% SOC to nearly 20% SOC. but LiFePO4 batteries can be discharged all the way down to 0% for many cycles. However, the Battery cycle life can be hampered if the Battery is continuously discharged to 0% SOC.

The charging and discharging of lithium-ion batteries is the key to their operations and long-term performances. Therefore, it is essential to ensure that the batteries are charged and discharged in an appropriate manner. This system will automatically stop charging the Battery to prevent overcharge and on the other hand, this system will also ensure the Battery is not discharged beyond the specified limit. Operational environment: temperature, humidity etc.

Cell Specification

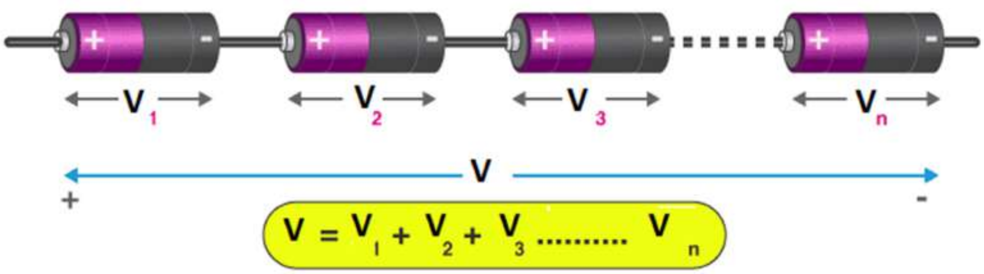
Chemistry	LiFePo4
Rechargeable	Yes
Nominal Capacity (mAh)	2000
Nominal Voltage (V)	3.2
Color	Blue
Length (mm)	65
Width (mm)	22
Weight (gm)	60
Shipment Weight	0.064 kg
Shipment Dimensions	10 × 5 × 5 cm

LIFEPO4 Single-cell IFR 22650 3.2V 2000mAh is one of the best rechargeable batteries, it consists of a huge Battery capacity of 2000mAh & it has a capacity of 3.2-volt output.

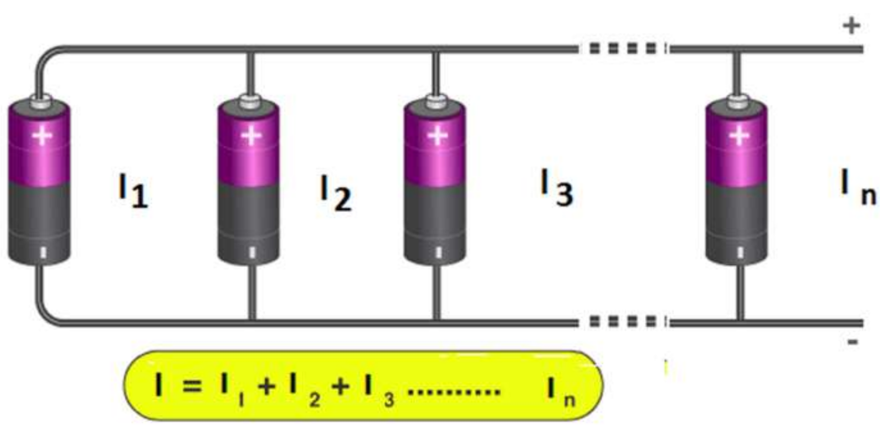
Connecting Lithium Iron Phosphate Cells in Series and Parallel

Most Lithium Iron Phosphate cell chemistries have a Nominal voltage lower than 3.2 Volts. So, in order to make it usable for higher voltage applications, we might have to use a boost converter or we can design a Battery pack that provides the required output voltage by arranging the cells in a combination of series and parallel connections.

Connecting cells in Series: When the positive terminal of one Battery is connected with the negative terminal of the second Battery, the Battery is considered to be connected in a series connection. In the case of a series connection, the total voltage of the Battery is increased and is given by the sum of the voltage of all the batteries connected in series. The image below shows how a series connection looks like.



Connecting cells in Parallel: When the positive terminal of the first Battery is connected to the positive terminal of the second Battery and similarly the negative terminal of the 2 cells are connected together, the Battery is said to be connected in a parallel connection. In the case of a parallel connection, the total capacity of the Battery is increased while the voltage remains the same. The image below shows how cells in a parallel connection look like.



Advantages:

1. Longer life span
2. no maintenance
3. extremely safe
4. lightweight
5. improved discharge and charge efficiency
6. Very safe and secure technology (No Thermal Runaway)
7. Very low toxicity for environment (use of iron, graphite and phosphate)
8. Operational temperature range :up to 70°C
9. Very low internal resistance. Stability or even decline over the cycles
10. Ease of recycling
11. Constant power throughout the discharge range.

Applications:

1. Smart phones, PCs & Digital cameras.
2. Vehicles such as electric bicycles & motor cycles.
3. Storing electricity generated during the day using a solar power generation system at home.
4. In medical fields.

Experiment 3

AIM: To Study of Battery Charger Enable in Battery Characteristics Trainer.

Apparatus Required:

- **Battery Characteristics Trainer (MI-EV02).**
- Patch Cords
- Power Cable

Theory: Battery Charger is the upgraded version from previous Charger/Discharger. Compared with others, it is more accurate and stable and also has some new features and functions. Users could set the terminal voltage by themselves and connect it to PC for PC control and firmware upgrade. Users could also use it as Lithium Battery Meter and Battery Internal Resistance Meter. There are Automatic Charging Current Limit, Capacity Limit, Temperature Threshold and Processing Time Limit which makes the charger safer than others.

EV02 Battery Charger is a high-performance, microprocessor control charge/discharge station with battery management suitable for use with all current battery types, with integral equalizer for six-cell Lithium-Polymer (LiPo), Lithium High Voltage, Lithium iron phosphate(LiFe) and Lithium-Ion (LiIon) batteries; maximum 6A charge current and maximum 50W charge power.

Features

- Dual Power AC/DC Input
- Temperature Probe Socket: If the temperature limit is reached, the process will be terminated.
- 2-6S XH Plug-in Balance Sockets
- LiHV Mode Available: The additional LiHV mode is able to charge the new generation of LiPo batteries with an end of charge voltage of 4.35 V.
- Different Charging Modes: Depending on different kinds of batteries, there are different charging modes to meet users' request.
- PC Control: The user can monitor pack voltage, cell voltage and other data during the charging, view charge data in real time graphs, and can also control the charger from "Charge Master"
- Smart Phone Control & Monitor via Module: This charger can be controlled and operated by smart phones via WiFi module (both iOS and Android).

Specifications

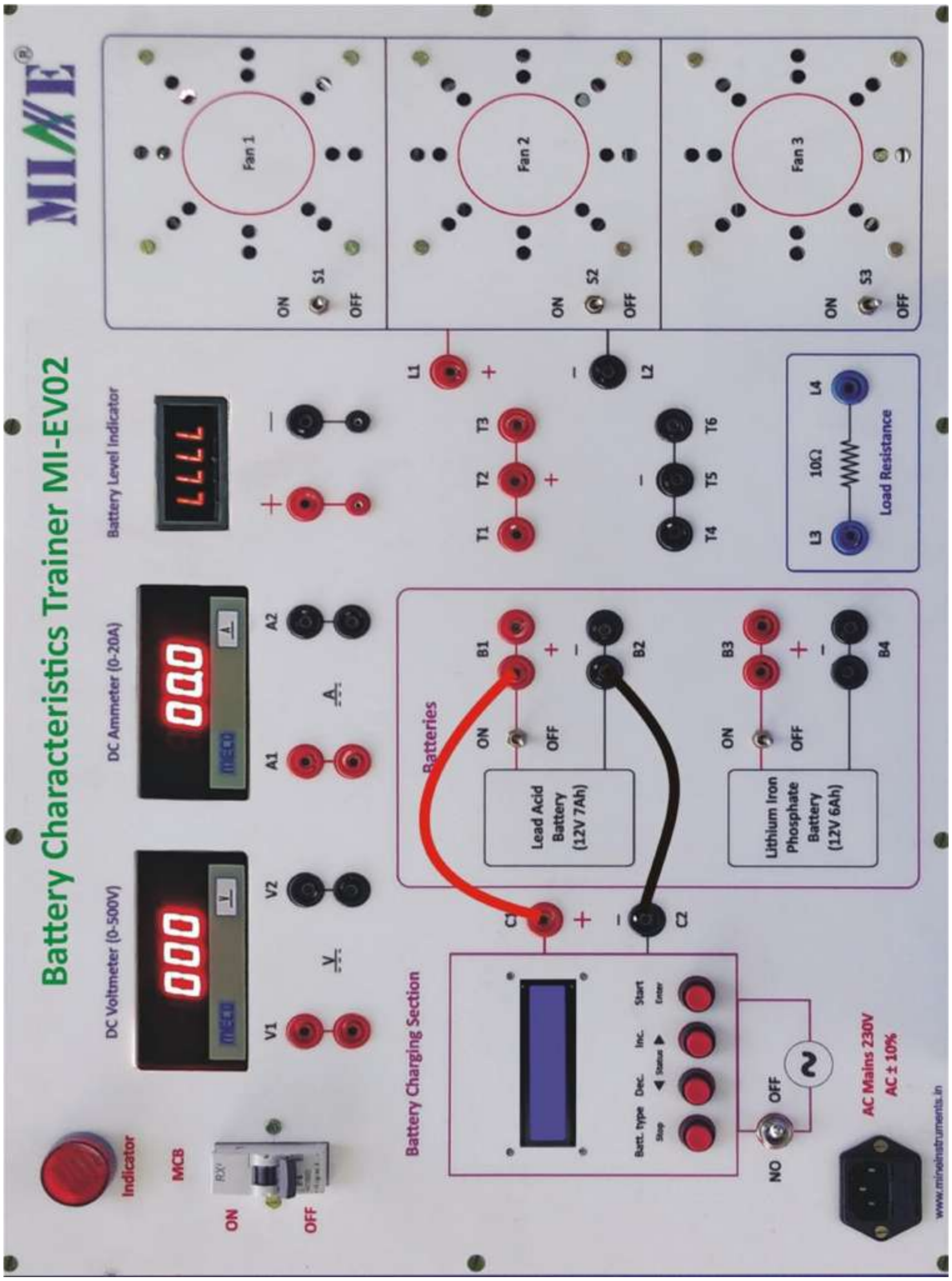
- AC Input Voltage: 100-240V
- DC Input Voltage: DC11-18V
- Max Charge: 50W
- Max Discharge: 5W
- Charge Current Range: 0.1-6.0A
- Discharge Current Range: 0.1-2.0A

- LiPo/LiFe/LiIon Cells: 1-6S
- NiMH/NiCd Cells: 1-15S
- Pb battery Voltage: 2-20V

Safety Precautions:

- Make all the connection before power ON the trainer.
- All connection should be tight.
- The circuit should be OFF while changing the connection.
- Switch OFF the supply of trainer and remove all connections after completing the experiments.

Connection Diagram:



Procedure:

- First of all, connect the Battery Charging Section C1 +V & C2 -V to the Lead Acid Battery B1 +V & B2 -V terminal via patch cords. (Either connect Lead Acid or LiFePo4)
- Connect AC mains to EV02 Trainer board.
- Make sure all toggle fault switches are in OFF condition.
- After connecting Battery terminals and mains AC plug put toggle and MCB switch ON for supply.
- Now both Toggle switches ON in Lead Acid Battery section and Battery Charger section.
- You can see the battery charger section is enabling to read data.
- After enabling of Battery charger section press the Battery type (Stop) key then Battery Program is shown on display.

- First, set the BATT PROGRAM select System setting. And set the Bal. Connection in OFF condition.

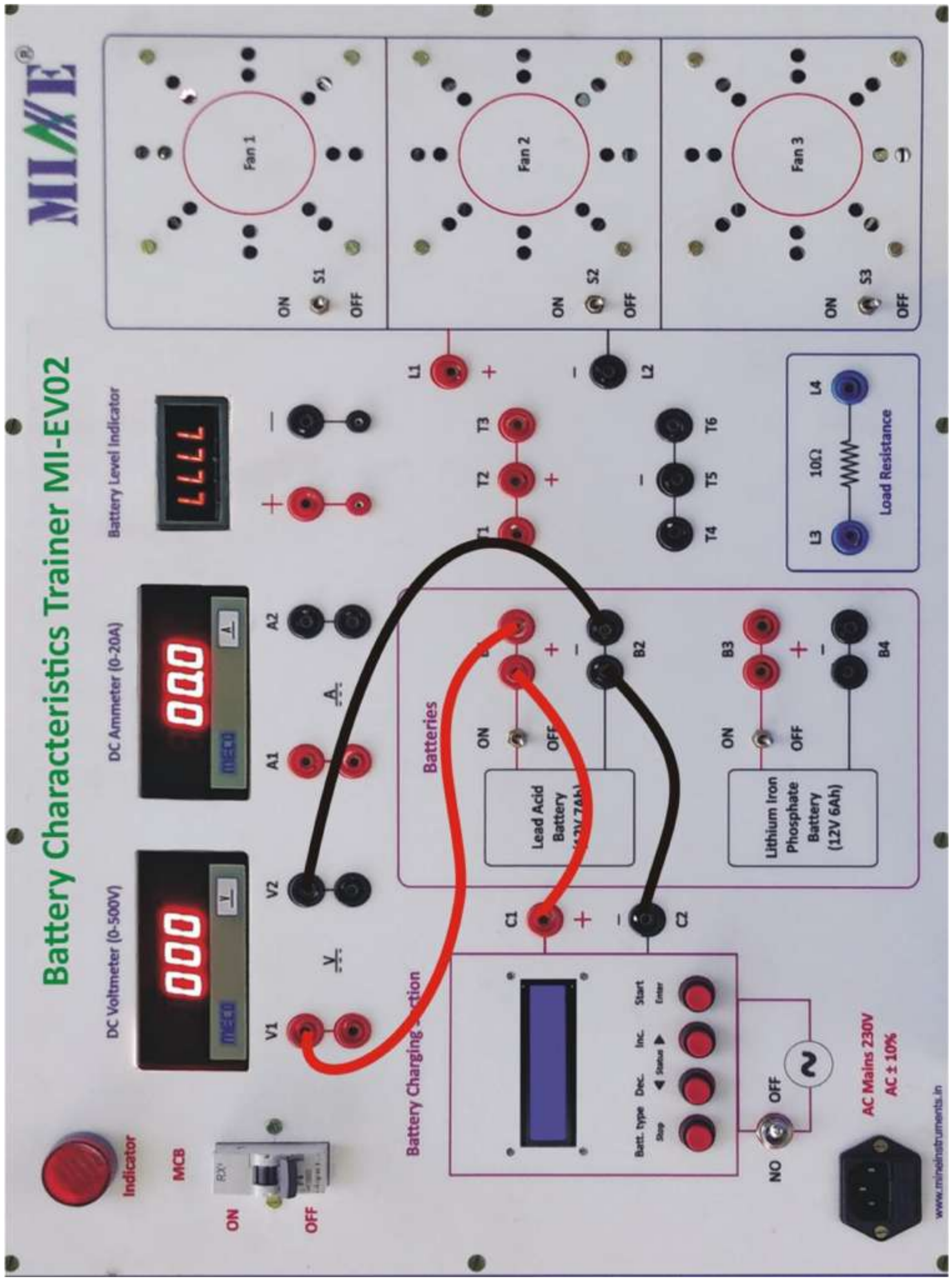
- In BATT/PROGRAM have many options so first select BATT METER using by Inc. & Dec. status key and then press Enter.

- After that you can see the appropriate Battery voltage value of charger shown on display.

- Next select resistance from BATT PROGRAM for find the internal resistance value of a battery shown on display.

- As per above process your Battery charger is enable as per requirements.

- Apart from above process, you can check voltage by DC Voltmeter.



- Connect DC Voltmeter V1 +Ve & V2 –Ve to the battery +Ve & -Ve terminal via patch cords.
- Observe the Battery voltage using by DC voltmeter.

Experiment 4

AIM: To Study of Charging & Discharging Characteristics of Lead-Acid Batteries in Battery Characteristics Trainer.

Apparatus Required:

- **Battery Characteristics Trainer (MI-EV02).**
- Patch Cords
- Power Cable

Theory:

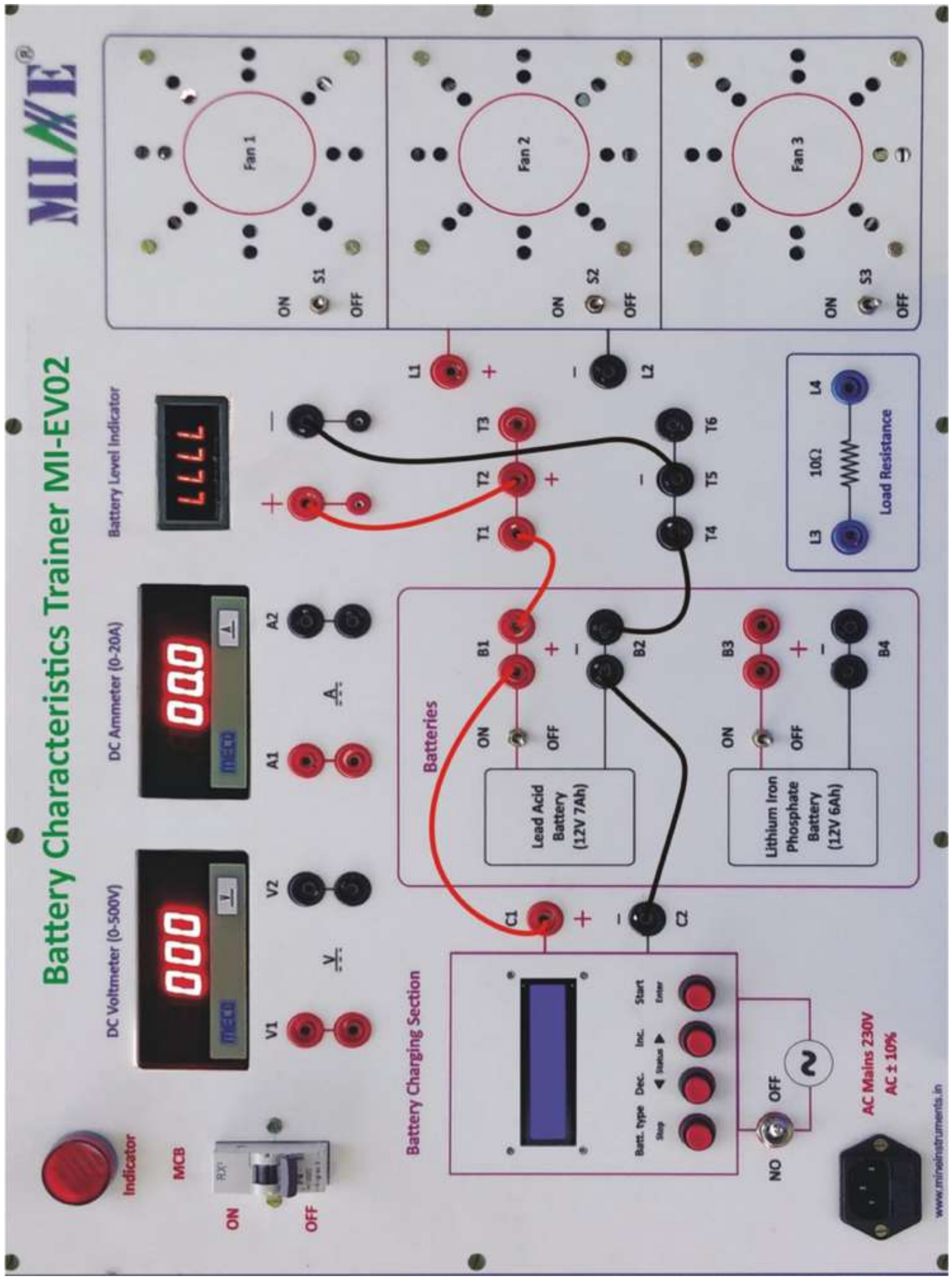
Simple guidelines for charging Lead Acid Battery

- Charge in a well-ventilated area. Hydrogen gas generated during charging is explosive.
- Choose the appropriate charge program for flooded, gel and AGM batteries. Check manufacturer's specifications on recommended voltage thresholds.
- Recharge lead acid batteries after each use to prevent sulfation. Do not store on low charge.
- The plates of flooded batteries must always be fully submerged in electrolyte. Fill the battery with distilled or de-ionized water to cover the plates if low. Never add electrolyte.
- Fill water level to designated level after charging. Overfilling when the battery is on low charge can cause acid spillage during charging.
- The formation of gas bubbles in a flooded lead acid indicates that the battery is reaching full state-of-charge. (Hydrogen appears on negative plate and oxygen on positive plate).
- Lower the float charge voltage if the ambient temperature is higher than 29°C (85°F).
- Do not allow a lead acid to freeze. An empty battery freezes sooner than one that is fully charged. Never charge a frozen battery.
- Avoid charging at temperatures above 49°C (120°F).

Safety Precautions:

- Make all the connection before power ON the trainer.
- All connection should be tight.
- The circuit should be OFF while changing the connection.
- Switch OFF the supply of trainer and remove all connections after completing the experiments.

Connection Diagram:



Procedure:

Charging of battery

- First of all, connect the Battery Charging Section C1 +Ve & C2 -Ve to the Lead Acid Battery B1 +Ve & B2 -Ve terminal via patch cords.
- Connect B1 to T1 +Ve & B2 to T4 –Ve.
- Connect T2 & T5 to +Ve & -Ve of Battery level indicator terminal.
- Connect AC mains to EV02 Trainer board.
- Make sure all toggle fault switches are in OFF condition.
- After connecting Battery terminals and mains AC plug put toggle and MCB switch ON for supply.
- Now both Toggle switches ON in Lead Acid Battery section and Battery Charger section.
- You can see the battery charger section is enabling to read data.
- After enabling of Battery charger section press the Battery type (Stop) key then Battery Program is shown on display.

- First set the BATT PROGRAM select System setting. And set the Bal. Connection in OFF condition.

- In BATT/PROGRAM have many options so first select BATT METER using by Inc. & Dec. status key and then press Enter.

- After that you can see the appropriate Battery voltage value of charger shown on display.

- Next select resistance from BATT PROGRAM for find the internal resistance value shown on display.

- Now select the Lead Acid Battery (Pb) from BATT PROGRAM for charging process.

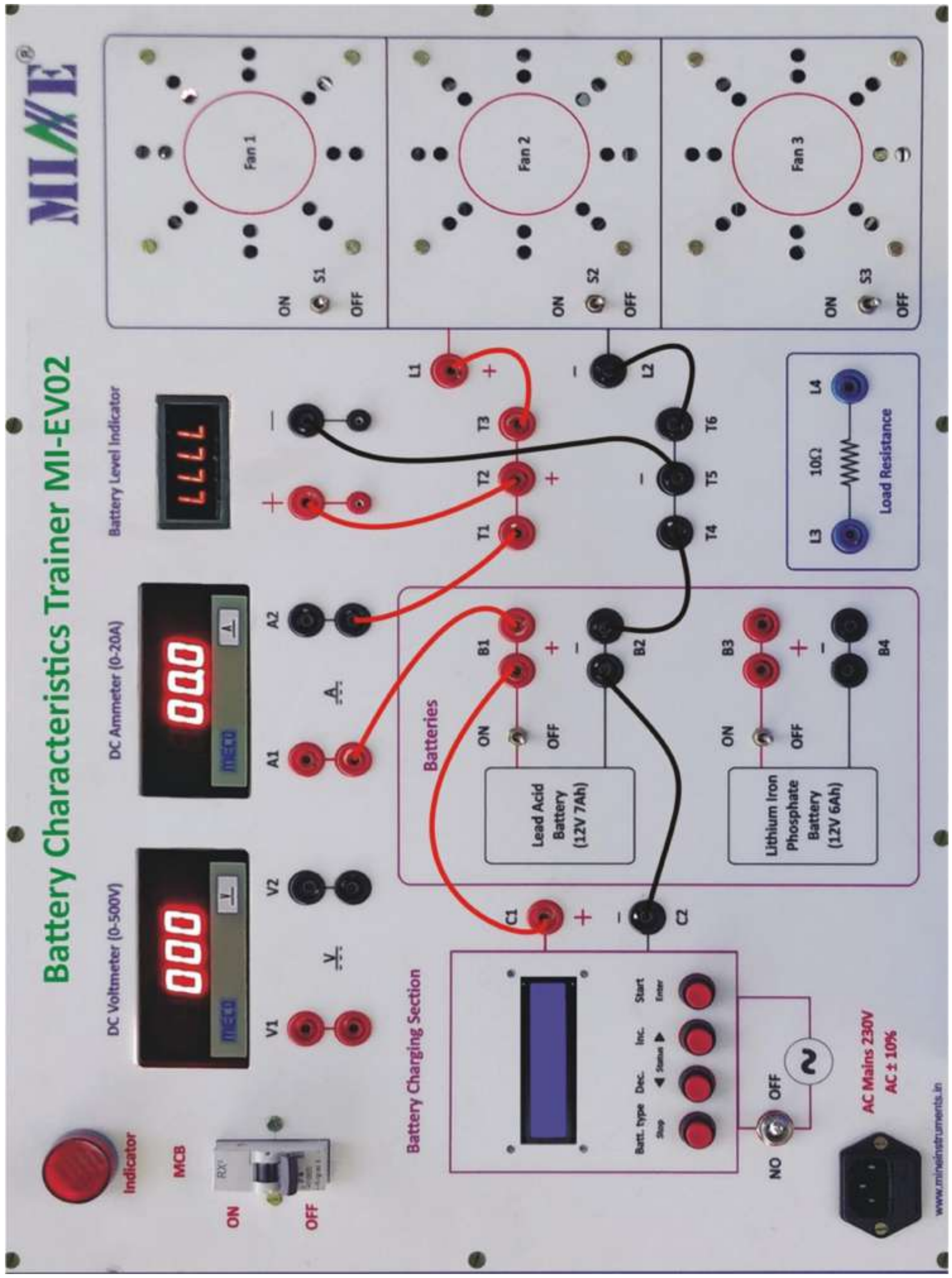
- Select Pb charge & set the current 0.5A & voltage 12V by using of Inc. Dec. key.

- Long press of Enter key for charging of Pb.
- Now charging voltage is shown on display.

- The voltage values are same of charger display and battery level indicator.

Conclusion: As per above process charging is enable for Pb (Lead Acid Battery).

Discharging of battery



Procedure:

- Follow the previous connections.
- Connect DC Ammeter A1 to B1 and A2 to the any of (T1, T2 & T3) terminal.
- Additionally now connect the T3 (+V) & T6 (–V) to the load L1 & L2 for Fan.
- All Toggle switch ON to the S1, S2 & S3 so all Fan are in running condition.
- Now select the Lead Acid Battery (Pb) from BATT PROGRAM for discharging process.

- Select Pb discharge and set the current 0.5A & voltage 12V by using of Inc. Dec. key.

- Long press of Enter key for discharging of Pb.
- Now discharging Battery voltage is shown on display and Battery level indicator.

- The Battery voltage values are same of charger display and battery level indicator.
- Also Ammeter show the current value.(If single Fan is run current value is shown 1.5A, when 2 Fan are run 2.5A and 3Fan are running the value are approx 3.5A.If load L3 & L4 connected the total current shown on meter is 5A).

Conclusion: As per above process Discharging is enable for Pb (Lead Acid Battery).

Experiment 5

AIM: To Study of Charging and discharging Characteristics of Li-iron Phosphate Batteries in Battery Characteristics Trainer.

Apparatus Required:

- **Battery Characteristics Trainer (MI-EV02).**
- Patch Cords
- Power Cable

Theory:

The battery is storage and energy conversion components which can be stored in the original physical energy, chemical energy or other type energy and that can be converted into electricity and released to attach circuit for application [1, 2]. In accordance with the energy storage and release methods that can be divided into physical batteries and chemical batteries. The former are convert from the light, heat and other renewable energy to electricity and to storage in batteries or release in transmission line to loadings and consumption the power which the description type are such as solar cell [3], wind power[4], atomic force batteries and so on. Chemical batteries are chemical substances through the material of the redo reaction which by the active substances reactive effect convert from chemical energy to electricity that base on the charging and discharging apply recycle can divided into primary battery and secondary battery. Primary battery just can only discharge once and till to not drive the electrical loading so far. At the end of time in discharging mode that the battery does not chemical substances all played a chemical effect can no longer be able to provide electricity and it cannot be provided by the external power supply at after the full discharge make this battery useless. That is because its electrochemical reaction is irreversible by the reasons of electrolyte cannot be restored by recharging step.

The secondary battery is chemically converted into electrical energy and can be recharged into a battery by recharging the battery that effect is re-converted into chemical energy and it can be reused. The number of times uses will vary with the material and the application. In general, that exists in the market such as the lead-acid batteries, nickel-cadmium batteries, nickel-metal hydride batteries and lithium family batteries [5]. Different chemical type batteries rely on its working voltage, capacitance and safety of the relationship that made different applications. A lithium battery mainly refers to lithium-ion batteries. At present in the market can be found for the lithium cobalt material, lithium manganese material but the both in the use of security on the doubt there will be cause high temperature resulting in explosion or the decline in capacity of the problem. To improve the lithium batteries to lithium phosphate iron ($LiFePO_4$) batteries [6, 7, 8] for these problems, can eliminate the user's security concerns. In this experiment we will study of, the charging and discharging characteristics of power type $LiFePO_4$ batteries pack will be by the actual experiment to verify.

Comparison with the LiFePO4 and the other different secondary battery

Currently on the market mainly using the most extensive secondary battery are lead acid batteries pack, and lithium batteries such as lithium-cadmium batteries, nickel-metal hydride battery, lithium cobalt battery and LiFePO4 battery packs. Lead-acid battery because of the widely operating temperature, simple structure, technology is mature and low price characteristics to form the higher usage rate but the lower cycle life and discharge coefficient (or called Crate), higher internal resistance and high toxicity caused by high pollution shortcomings to make the replace effect by other chemical Battery packs. in this paper, it is discussed the LiFePO4 battery packs which have the advantages of high capacitance, low toxicity and no pollution, high temperature environment and good circulation performance under heavy duty charge and discharge mode, and wide sources of raw materials. Compared with other lithium family batteries packs which LiFePO4 battery packs have high efficiency energy conversion up to 95% and possess the more life cycle up to 2000 times than the other lithium family batteries packs life cycle about from 400 to 500 times. LiFePO4 battery packs is also very suitable with power supply for electric motors and for power management such as electricity scooter, pure electricity scooter and hybrid cars applications and so on, and in the future will become the mainstream of electric vehicles.

Internal resistance varying characteristics in charging and discharging mode of LiFePO4 battery pack

In Figure 1 which Vb is inside voltage of battery pack and Rin is inner resistance of battery pack. Generally, battery equivalent circuit will not show Rcov and C. The resistance Rcov and capacitor C in parallel configuration and in series with the former circuit that simulation the in over-voltage states will produce the phenomenon. So that made the analogy charging process of this battery equivalent circuit is more realistic and therefore improves the shortcomings of the linear model and is therefore more accurate than the linear model. And

Req is the equivalent battery resistance seen by side of the voltage source, since the capacitance C is the open state so that equivalent over-voltage will produce the phenomenon, and the general battery equivalent resistance Req is equal as equation (1).

Req=Rin+Rcov ……….(1)

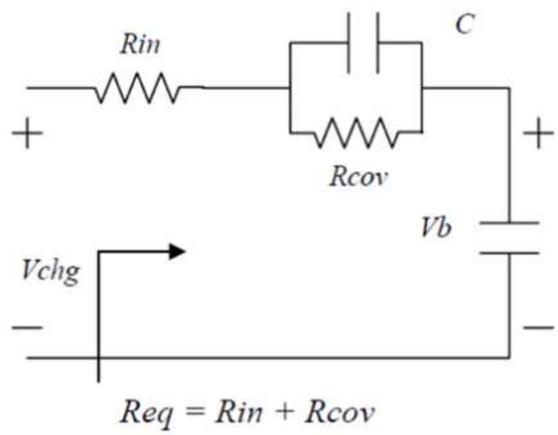


Fig. - Battery pack equivalent circuit diagram.

Battery pack equivalent circuit diagram. Form view of the battery pack capacity in fixed that the capacity is full or not with its battery pack inner resistance is closely related in charging mode or proceeding. In general, each battery pack capacity of the full percentage greater relative inner resistance will be made greater. In contrast, the smaller the degree of filling of each battery packs company with the smaller its internal resistance. The relationship between the external voltage and the magnitude of the battery pack resistance is by the actual circuit to test and explain**.**

The relationship between with the charging voltages and currents

Based on the specification of A123 26650 LiFePO4 battery cell as shown in the Table 1.

LiFePO4 battery cell specification:-

Type	A123
Rate voltage	3.3V
Rate capacity	2300mAh
Weight	73g
Charging time	Conventional charging about 1C-2C or 3-4A and fast charging about 5C or 10A

A constant voltage charging circuit is designed for a 12V 10Ah LiFePO4 battery pack to keep the charging voltage constant and allow the charging current to be less than 3C which let charging current between in conventional charging and fast charging areas. The charging data is shown in Table 2. When the time is 0 for start, the initial value of the voltage is 11.48V and charging current is 30A. When the time passes 5 seconds, the voltage rose to 11.66V and then the charging current dropped to 25A. When the time after 50 seconds which the inside battery pack voltage rose to 12.22V and then the charging current is14A. According to the design of charging voltage for the battery pack, when the battery pack inside voltage reach the charging voltage will let the charging current become about 0A, that is called full charging. When the time passes 100 seconds, the voltage rose to 12.61V and then the charging current is 11.7A.When the time passes 230 seconds, the voltage rose to 13.00V and then the charging current dropped to 8.5A. And the time after 240 seconds, voltage rose to 13.00 V and then the charging current dropped to 3.2A we can see that when the battery slowly filling the voltage will stabilize, the current will slowly decline. Base on the data we can drown the charging curve shown in Figure 2.

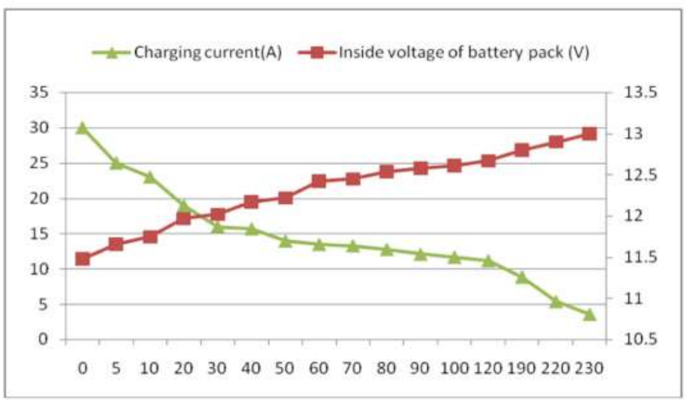


Fig. - LiFePO4 battery pack charging.

Table 2. LiFePO4 batteries pack charging trace constant with voltage method.

Time(second)	Inner voltage of battery pack (V)	Charging current(A)
0	11.48	30
5	11.66	25
10	11.75	23
20	11.27	19
30	12.02	16
40	12.17	15.7
50	12.22	14
60	12.42	13.5

70	12.45	13.3
80	12.54	12.8
90	12.58	12.1
100	12.61	11.7
120	12.67	11.2
190	12.8	8.9
220	12.9	5.4
230	13	3.6
240	13	3.2

3.2 Calculation the dynamic internal voltage and equivalent inner resistance of the battery pack Figure 3 is a 12V10AHLiFePO4 battery pack for the power source supply and by series with a DC motor which internal resistance RM is 0.07 ohm to form a closed loop for measure the battery pack dynamic inner resistance in discharge mode under different voltage equalization. The equivalent resistance Req seen from the power supply side is shown in equation (2) and the dynamic internal resistance Rin of the battery pack is shown in equation (3). According to the discharge battery pack voltage level is divided into 13 measurements points sown in table 3. At first time the battery pack side voltage 13.2V, current is 2.8A, supply side equivalent resistance Req is 4.71 ohm and the battery pack internal resistance Rin is 4.64 ohm. At sixth time the battery pack side voltage 12.8V, current is 3.3A, supply side equivalent resistance Req is 3.88 ohm and the battery pack internal resistance Rin is 3.81 ohm. And at the last time the battery pack side voltage 10.7V, current is 3.3A, supply side equivalent resistance Req is 3.24 ohm and the battery pack internal resistance Rin is 3.17 ohm. From the table 3, it is made a result which is the higher the supply voltage with the smaller the discharging current will reach the resistance larger by loading with unchanged or fixed resistance

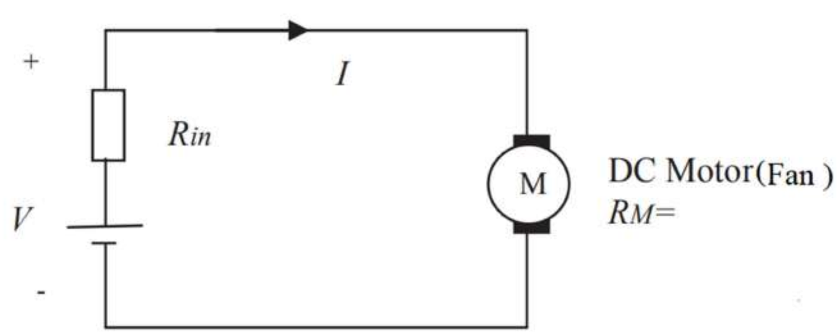


Fig. - LiFePO4 battery pack charging.

Req=V/I=Rin+RM………. (2)

$$\text{Rin} = \text{Req} - \text{RM} \ldots\ldots\ldots\ldots (3)$$

With the relationship between the battery internal resistance Rin and the voltage V in Table 3 that by using the third-order polynomial mathematical model of voltage V is used to approach the internal dynamic internal resistance Rin and predictive internal resistance M - + I V Rin DC Motor RM=0.07 ohm 5 MATEC Web of Conferences 185, 00004 (2018) https://doi.org/10.1051/matecconf/201818500004 ICPMMT 2018 value of the battery, as shown in equation (4). Using the relative error REv% as shown in equation (5) to confirm the accuracy of the mathematical model and the Table 4 is shown in the table for each voltage class approaching the battery block internal resistance and relative error.

$$\text{Rin} = a_0\, a_0 + a_1 XV + a_2 XV^2 + a_3 XV^3 \ldots\ldots\ldots\ldots (4)$$

Where

Rin: internal resistance of battery pack

V: discharging voltage 100%,

$$\text{REv}\ \% = \frac{|\text{ Rin actual} - \text{Rin ,fit }|}{\text{Rin actual}} X100\% \ldots\ldots\ldots\ldots (5)$$

Where

Rin, actual: internal resistance of battery pack which equal to Rin

Rin, fit: internal resistance approach by polynomial mathematic model.

Table 3 LiFePO4 battery packs charging trace constant voltage method.

Order/Perameters	Voltage (V)	Current (A)	Req (ohm)	Rin (ohm)
1	13.2	2.8	4.71	4.54
2	13.0	2.7	4.81	4.74
3	13.0	2.9	4.48	4.41
4	12.9	3.1	4.16	4.09
5	12.9	3.3	3.91	3.84
6	12.8	3.3	3.88	3.81
7	12.8	3.5	3.66	3.59
8	12.8	3.6	3.56	3.49
9	12.4	3.5	3.54	3.47
10	11.7	3.4	3.44	3.37
11	11.5	3.4	3.38	3.31
12	11.1	3.3	3.36	3.29
13	10.7	3.3	3.24	3.17

It can be seen from Table 4 that the results of the polynomial calculated by the relative error formula (5) and the measured internal resistance of the battery are within 2.21% which the maximum difference value is 0.07ohm and REV% is 2.21%, and the minimum difference value is only 0.01ohm and REV% is 0.26% and the total average REV% is 1.41% , so it can be resulted, the calculation result of formula (3) is very close to the actual value of internal resistance of battery pack. Figure 4 is relative error chart by polynomial mathematic model.

Table 4. The relative error by polynomial mathematic model

Order/Perameters	Voltage (V)	Rin actual (ohm)	Rin fit (ohm)	Rev%
1	13.2	4.64	4.59	1.08%
2	13.0	4.26	4.31	1.17%
3	12.9	4.09	4.02	1.71%
4	12.8	3.81	3.80	0.26%
5	12.4	3.47	3.44	0.86%
6	11.7	3.37	3.32	1.48%
7	11.5	3.31	3.24	2.11%
8	11.1	3.29	3.23	1.82%
9	10.7	3.17	3.10	2.21%
average				1.41%

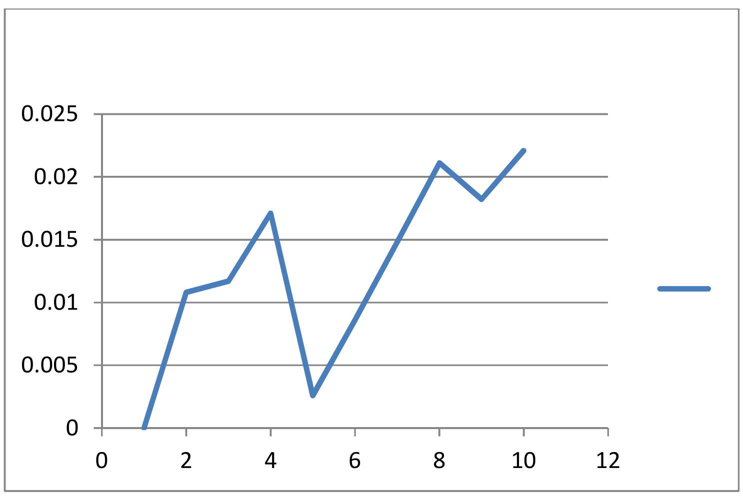


Fig.4. The relative error chart by polynomial mathematic model.

Conclusion: For the actual circuit design to do charge and discharge test obtained the battery pack voltage, resistance and other perameters and to determine which each other dependency.

And deduce the battery internal dynamic resistance and in order to other applications before the load operations. In the charging mode, when the charging voltage is fixed that result of the battery voltage, current and internal resistance is closely related to each other.

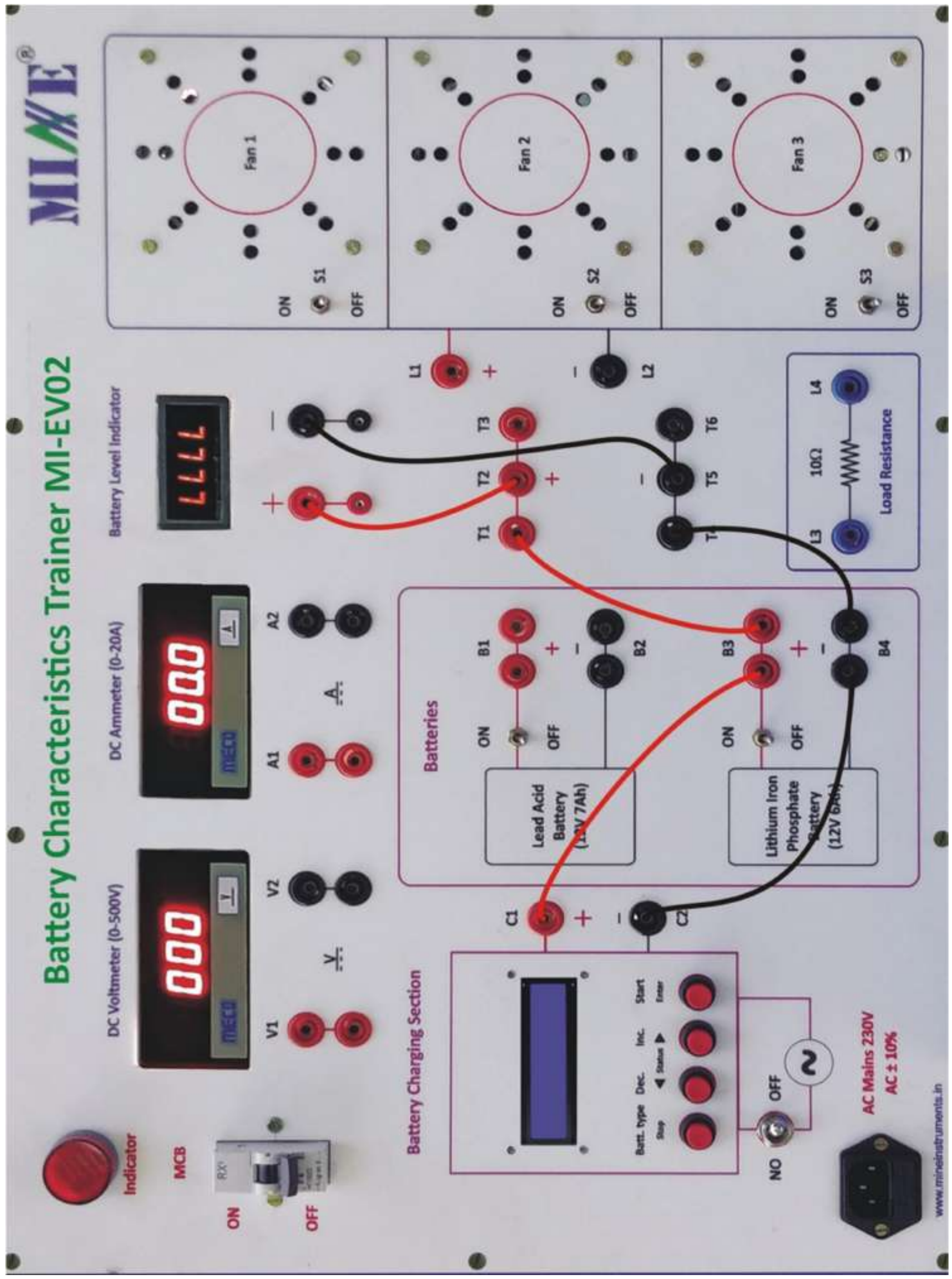
Similarly, in the discharge mode is also the same. In the discharge mode , the battery internal resistance and the battery potential can be approximated by the mathematical model of the third order polynomial to the internal resistance of the battery pack and obtain its value.

Through the every voltage level to statistics the total relative error is 1.41%.In this experiment, through the relevant simple circuit can be accurate and quickly know the dynamic resistance of the battery pack and the relevant internal resistance and electricity residue of battery pack.

Safety Precautions:

- Make all the connection before power ON the trainer.
- All connection should be tight.
- The circuit should be OFF while changing the connection.
- Switch OFF the supply of trainer and remove all connections after completing the experiments.

Connection Diagram:



Procedure:

Charging of battery

- First of all, connect the Battery Charging Section C1 +V & C2 -V to the Lithium Iron Phosphate LiFePO4 Battery B3 +V & B4 -V terminal via patch cords.
- Connect B3 to T1 +V & B4 to T4 –V.
- Connect T2 & T5 to +V & -V of Battery level indicator terminal.
- Connect AC mains to EV02 Trainer board.
- Make sure all toggle fault switches are in OFF condition.
- After connecting Battery terminals and mains AC plug put toggle and MCB switch ON for supply.
- Now both Toggle switches ON in LiFePO4 Battery section and Battery Charger section.
- You can see the battery charger section is enabling to read data.
- After enabling of Battery charger section press the Battery type (Stop) key then Battery Program is shown on display.

- First set the BATT PROGRAM select System setting. And set the Bal. Connection in OFF condition.

- In BATT/PROGRAM have many options so first select BATT METER using by Inc. & Dec. status key and then press Enter.

- After that you can see the appropriate Battery voltage value of charger shown on display.

- Next select resistance from BATT PROGRAM for find the internal resistance value shown on display.

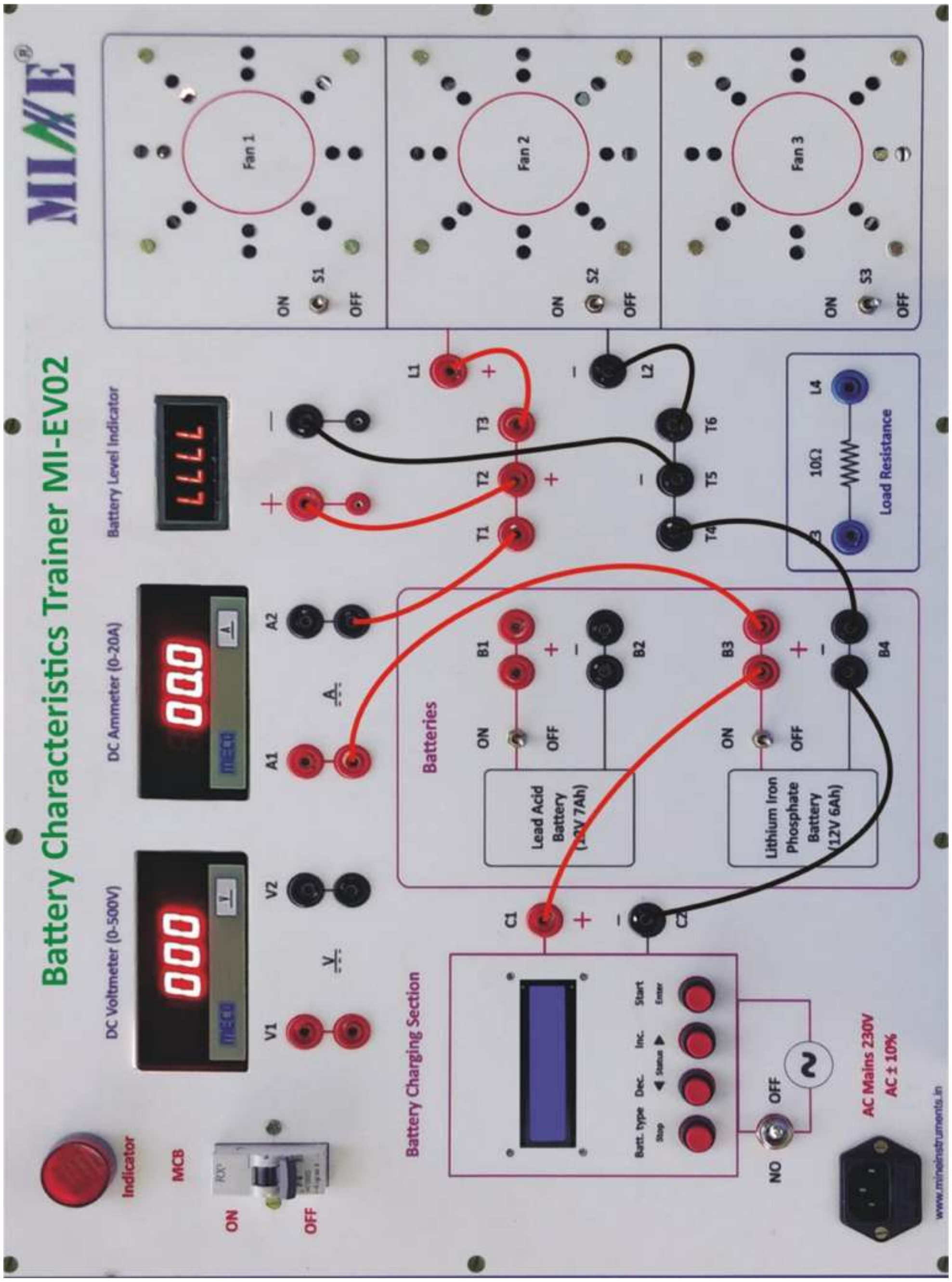
- Now select the LiFePO4 from BATT PROGRAM for charging process.

- Select LiFePO4 charge & set the current 0.5A & voltage 12V by using of Inc. Dec. key.

- Long press of Enter key for charging of LiFePO4.
- Now charging voltage is shown on display.
- The voltage values are same of charger display and battery level indicator.

Conclusion: As per above process charging is enable for LiFePO4.

Discharging of battery



Procedure:

- Follow the previous connections.
- Connect DC Ammeter A1 to B3 and A2 to the any of (T1, T2 & T3) terminal.
- Additionally now connect the T3 (+V) & T6 (–V) to the load L1 & L2 for Fan.
- All Toggle switch ON to the S1, S2 & S3 so all Fan are in running condition.
- Now select the LiFePO4 from BATT PROGRAM for discharging process.

- Also Ammeter show the current value.(If single Fan is run current value is shown 1.5A, when 2 Fan are run 2.5A and 3Fan are running the value are approx 3.5A.If load L3 & L4 connected the total current shown on meter is 5A).
- Select LiFePO4 discharge and set the current 0.5A & voltage 12V by using of Inc. Dec. key.
- Long press of Enter key for discharging of LiFePO4.
- Now discharging Battery voltage is shown on display and Battery level indicator.
- The voltage values are same of charger display and battery level indicator.

Conclusion: As per above process Discharging is enable for LiFePO4.

Experiment 6

AIM: Comparative study of Lead-Acid and Lithium Iron Phosphate battery.

Apparatus Required:

- **Battery Characteristics Trainer (MI-EV02).**
- Patch Cords
- Power cable

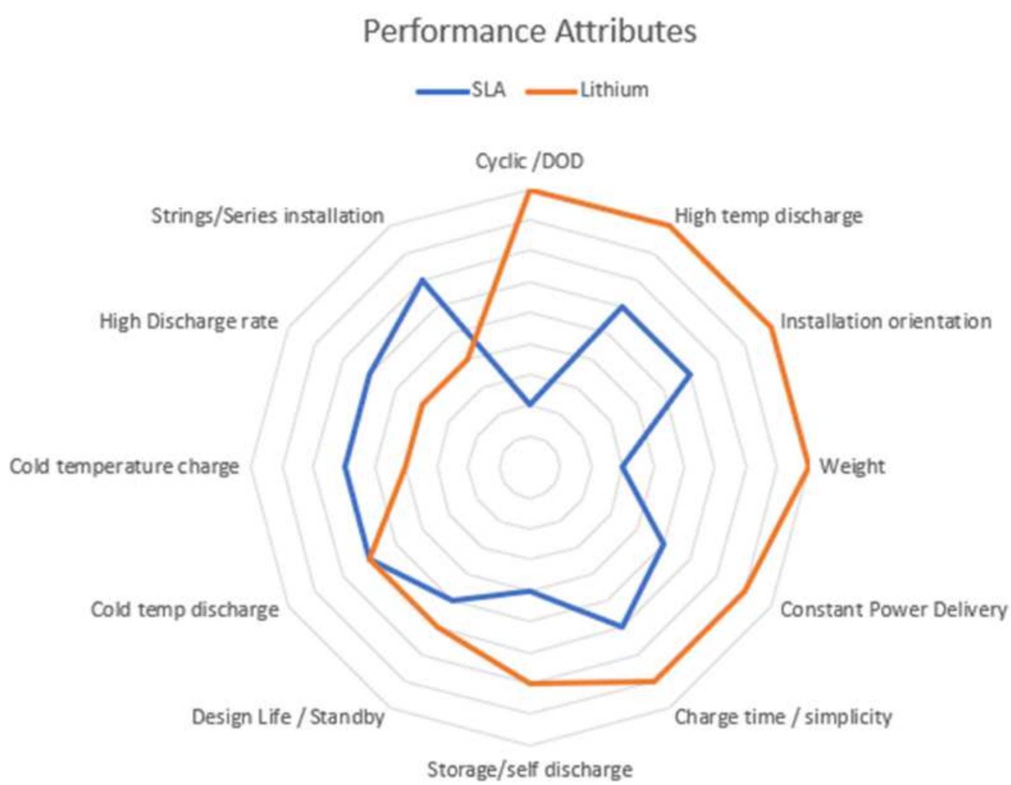
Theory:

When it comes to choosing the right battery for your application, you likely have a list of conditions you need to fulfill. How much voltage is needed, what is the capacity requirement, cyclic or standby etc.

So, here we describe the difference between Lithium and sealed lead acid battery.

There are several factors to consider before choosing battery chemistry, as both have strength and weakness.

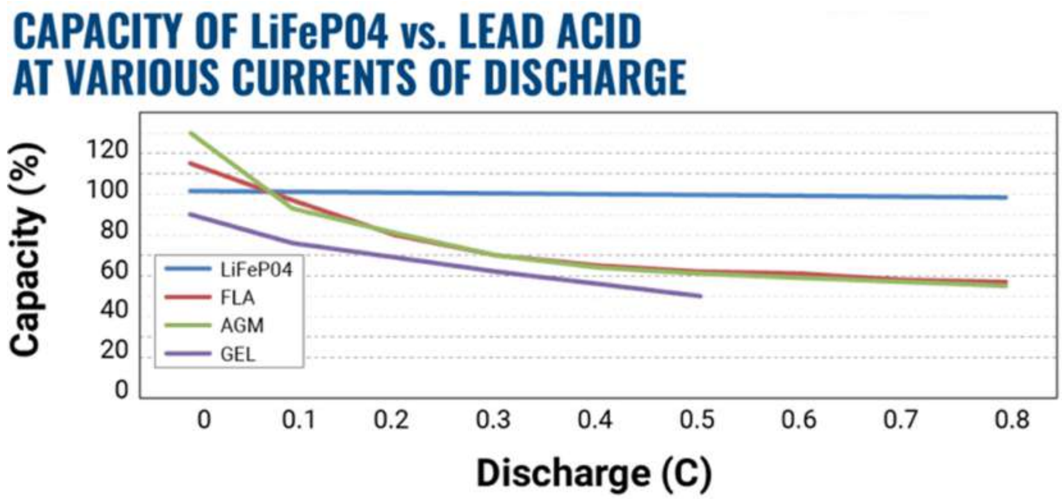
Note: Lithium refers to Lithium iron Phosphate (LiFePO4) battery only and SLA refers to Lead Acid/Sealed lead acid batteries.



Performance difference between Lithium & Lead acid battery

Cyclic performance Lithium Vs SLA

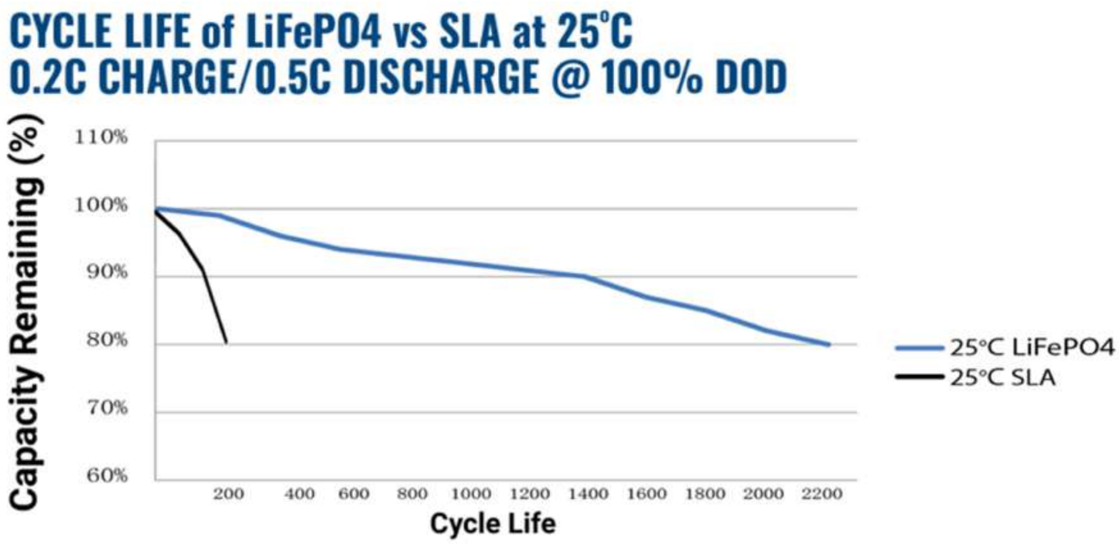
The most notable difference between lithium iron phosphate and lead acid is the fact that the lithium battery capacity is independent of the discharge rate. The figure below compares the actual capacity as a percentage of the rated capacity of the battery versus the discharge rate as expressed by C (C equals the discharge current divided by the capacity rating). With very high discharge rates, for instance .8C, the capacity of the lead acid battery is only 60% of the rated capacity. Find out more about C rates of batteries.



Capacity of lithium battery vs different types of lead acid batteries at various discharge currents.

Therefore, in cyclic applications where the discharge rate is often greater than 0.1C, a lower rated lithium battery will often have a higher actual capacity than the comparable lead acid battery. This means that at the same capacity rating, the lithium will cost more, but you can use lower capacity lithium for the same application at a lower price. The cost of ownership when you consider the cycle further increases the value of the lithium battery when compared to a lead acid battery.

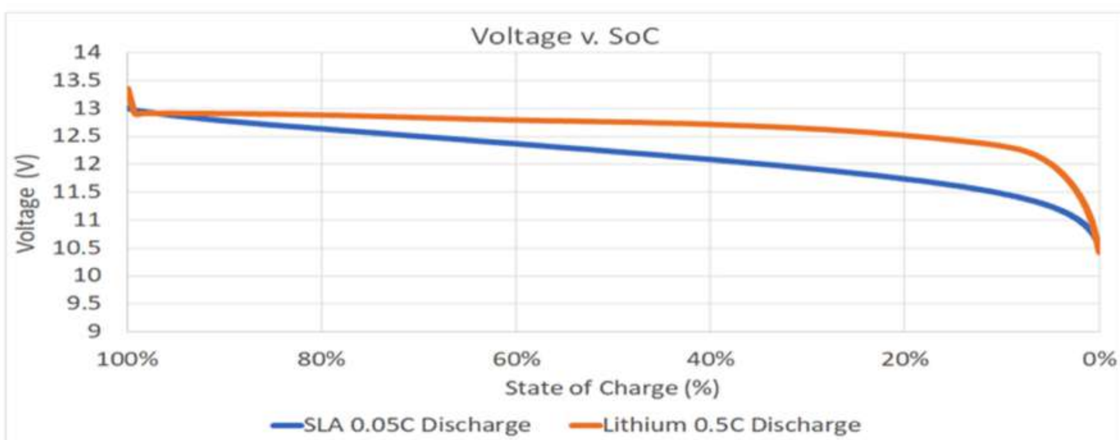
The second most notable difference between SLA and Lithium is the cyclic performance of lithium. Lithium has ten times the cycle life of SLA under most conditions. This brings the cost per cycle of lithium lower than SLA, meaning you will have to replace a lithium battery less often than SLA in a cyclic application.



Comparing LiFePO4 vs SLA battery cycle life

Constant Power delivery Lithium Vs Lead Acid

Lithium delivers the same amount of power throughout the entire discharge cycle, whereas an SLA's power delivery starts out strong, but dissipates. The constant power advantage of lithium is shown in the graph below which shows voltage versus the state of charge.



Constant power advantage of lithium against lead acid

A lithium battery as shown in the orange has a constant voltage as it discharges throughout the entire discharge. Power is a function of voltage times current. The current demand will be constant and thus the power delivered, power times current, will be constant. So, let's put this in a real-life example.

Have you ever turned on a flashlight and noticed it's dimmer than the last time you turned it on? This is because the battery inside the flashlight is dying, but not yet completely dead. It is giving off a little power, but not enough to fully illuminate the bulb.

If this were a lithium battery, the bulb would be just as bright from the beginning of its life to the end. Instead of waning, the bulb would just not turn on at all if the battery were dead.

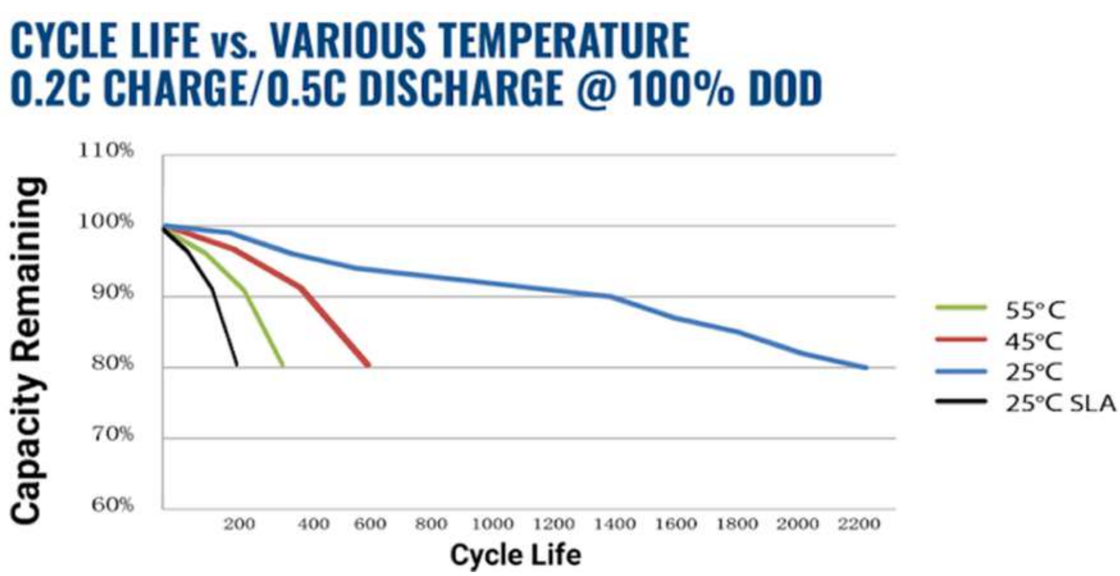
Charging Times of Lithium & SLA

Charging SLA batteries is notoriously slow. In most cyclic applications, you need to have extra SLA batteries available so you can still use your application while the other battery is charging. In standby applications, an SLA battery must be kept on a float charge.

With lithium batteries, charging is four times faster than SLA. The faster charging means there is more time the battery is in use, and therefore requires less battery. They also recover quickly after an event (like in a backup or standby application). As a bonus, there is no need to keep lithium on a float charge for storage. For more information on how to charge a lithium battery, please view our Lithium Charging Guide.

High Temperature Battery Performance

Lithium's performance is far superior to SLA in high temperature applications. In fact, lithium at 55°C still has twice the cycle life as SLA does at room temperature. Lithium will outperform lead under most conditions but is especially strong at elevated temperatures.



Cycle life vs various temperatures for LiFePO4 batteries

Cold Temperature Battery Performance

Cold temperatures can cause significant capacity reduction for all battery chemistries. Knowing this, there are two things to consider when evaluating a battery for cold temperature use: charging and discharging. A lithium battery will not accept a charge at a low temperature (below 32° F). However, an SLA can accept low current charges at a low temperature.

Conversely, a lithium battery has a higher discharge capacity at cold temperatures than SLA. This means that lithium batteries do not have to be over designed for cold temperatures, but charging could be a limiting factor. At 0°F, lithium is discharged at 70% of its rated capacity, but SLA is at 45%.

One thing to consider in cold temperature is the state of the lithium battery when you want to charge it. If the battery has just finished discharging, the battery will have generated enough heat to accept a charge. If the battery has had a chance to cool down, it may not accept a charge if the temperature is below 32°F.

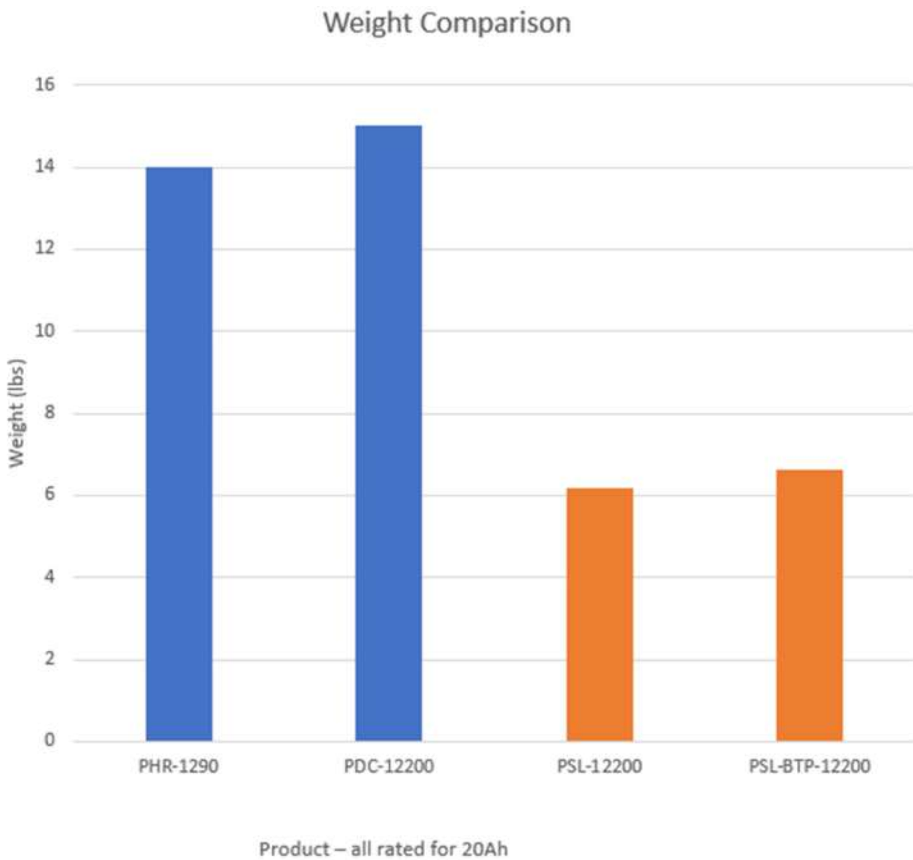
Battery Installation

If you have ever tried to install a lead acid battery, you know how important it is to not install it in an invert position to prevent any potential issues with venting. While an SLA is designed to not leak, the vents allow for some residual release of the gasses.

In a lithium battery design, the cells are all individually sealed and cannot leak. This means there is no restriction in the installation orientation of a lithium battery. It can be installed on its side, upside down, or standing up with no issues.

Battery weight comparison

Lithium, on average, is 55% lighter than SLA. In cycling applications, this is especially important when the battery is being installed in a mobile application (batteries for motorcycles, scooters or electric vehicles), or where weight may impact the performance (like in robotics). For standby use, weight is an important consideration in remote applications (solar fields) and where installation is difficult (up high in emergency lighting systems, for example).



A comparison of lithium and lead acid battery weights

SLA Vs Lithium battery storage

Lithium should not be stored at 100% State of Charge (SOC), whereas SLA needs to be stored at 100%. This is because the self-discharge rate of an SLA battery is 5 times or greater than that of a lithium battery. In fact, many customers will maintain a lead acid battery in storage with a trickle charger to continuously keep the battery at 100% so that the battery life does not decrease due to storage.

Series & Parallel battery installation

A quick and important note: When installing batteries in series and parallel, it is important that they are matched across all factors including capacity, voltage, resistance, state of charge, and chemistry. SLA and lithium batteries cannot be used together in the same string.

Since an SLA battery is considered a “dumb” battery in comparison to lithium (which has a circuit board that monitors and protects the battery), it can handle many more batteries in a string than lithium.

The string length of lithium is limited by the components on the circuit board. Circuit board components can have current and voltage limitations that long series strings will exceed. For example, a series string of four lithium batteries will have a max voltage of 51.2 volts. A second factor is the protection of the batteries. One battery that exceeds the protection limits can disrupt the charging and discharging of the entire string of batteries. Most lithium strings are limited to 6 or less (model dependent), but higher string lengths can be reached with additional engineering.

There are many differences between SLA and lithium battery performance. In most instances, lithium is the stronger battery. However, SLA should not be discounted as it still has an edge over lithium in some applications, like long strings, extremely high rate of discharge, and cold temperature charging.

Experiment 1

Aim: Study of Battery Management System (BMS) Operation and Display Setting.

Apparatus Required:

- **Electric Vehicle Trainer-(MI-EV05)**
- **Patch Cords.**
- **Power Cable.**

Theory: - BMS (Battery Management System) -Lithium-ion batteries have a lot of advantages over their lead-acid counterparts. They're lighter, more efficient, charge faster, and have a longer lifespan. However, they're susceptible to conditions that can damage the battery pack. Tapping into all of this potential requires lithium-ion batteries to be more complex and include components to help avoid these damaging conditions. In fact, this is the primary purpose of the BMS, which means a battery management system.

A battery management system (BMS) is said to be the brain of a battery pack. The BMS is a set of electronics that monitors and manages all of the battery's performance. Most importantly, it keeps the battery from operating outside of its safety margins.

The battery management system is critical to the battery's safe operation, overall performance, and longevity. Moreover, it protects whatever the lithium battery is installed in (boat, RV, etc.) and the people who are using it.

What is the Function of a Battery Management System?

The primary function of the BMS is to protect the battery cells from damage caused by being overcharged or over-discharged. Additionally, the BMS calculates the remaining charge, monitors the battery's temperature, and monitors the battery's health and safety by checking for loose connections and internal shorts. The BMS also balances the charge across the cells to keep each cell functioning at maximum capacity.

If it detects any unsafe conditions, the BMS shuts the battery down to protect the lithium-ion cells and the user.

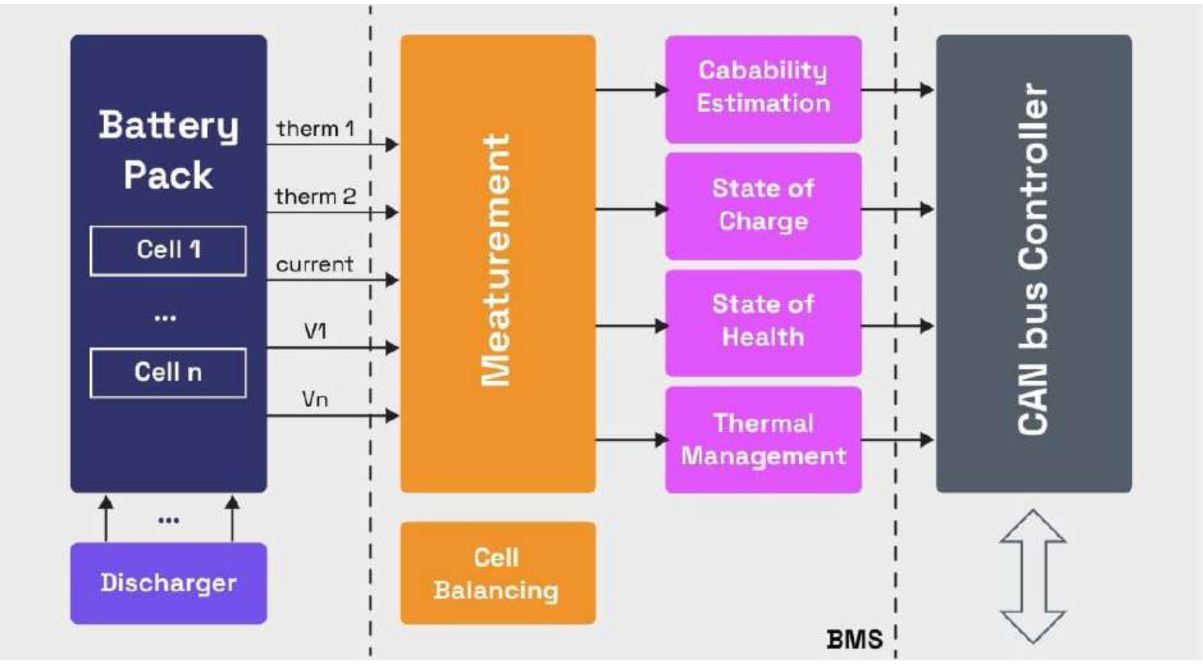
The Importance of Battery Management System

Battery Management System is the chief in command for performing critical operations in a battery pack and provides the following functionality:

- Voltage, Current, and Temperature control and measurement
- SOC and SOH assessment
- Detection of fault

- Passive cell balancing
- Data storage

Analyzing the Components of Battery Management System for EV



Mainly, there are 6 components of battery management system.

1. Battery cell monitor
2. Cut off FETs
3. Monitoring of Temperature
4. Cell voltage balance
5. BMS Algorithms
6. Real-Time Clock (RTC)

Let's look at the significance and the application of each components of battery management system:

1. Battery cell monitor

A battery cell monitor primarily monitors the voltages for battery systems. It is a high-speed system that offers a low overall cost for high voltage measurements.

- The easiest way to determine the battery pack's charge is to monitor individual cell voltage with reference to the set voltage level.
- When the voltage of the first cell reaches the voltage limit, the charging automatically trips. It indicates that the battery charging limit has been reached.
- If the battery pack has a lesser charge than the average cell, then the least charged cell will reach the limit first, and the rest of the cells will be left partially charged.

2. Cutoff FETs

FET driver is accountable for connection and isolation between load and charger of the battery pack. The behavior prediction is done through voltage, current measurements, and real-time detection circuitry.

- They can be connected to a battery pack's low or high side.
- NMOS FETs activation is needed for enabling high-side connection and requires a charge pump driver. A reference for the solid ground is set using a high-side driver for the rest of the circuitry.
- We use a low-side FET driver to reduce costs in integrated solutions since a charge pump is not needed. High voltage devices are not required in such cases.
- The ground connection of the battery pack floats using low-side cut-off FETs. This can affect the IC performance, making it more sensitive to insinuated noise measurement.

3. Monitoring of Temperature

With the increase in product requirements, the batteries have been on a constant surge in delivering currents at fixed voltages. The continuous operation processes may cause a catastrophic event such as fire or explosion.

- We can identify whether battery charging or discharging is desirable using temperature measurements.
- Temperature sensors monitor the energy storage system or cell grouping for compact portable applications.

- The circuit temperature is monitored by the internal ADC voltage-powered thermistor. Employing the internal voltage reference helps reduce the temperature inaccuracies and improves the overall measurement system.

4. Cell voltage balance

It is crucial to determine the health of the battery pack. That is why cell voltage monitoring is done to ensure that the cells are in a proper running condition for attaining a long battery life.

- The operating voltage ranges from 2.5V to 4.2V in a lithium-ion battery.
- The battery life is significantly affected while performing battery operations beyond the voltage range. This reduces the life of a cell, which may even make it unfit for use.
- Connecting the battery pack in parallel increases the overall drive current, whereas series connection adds the overall voltage.

5. BMS Algorithms

To make quick and effective decisions in real-time based on the information received. For this purpose, a microcontroller for battery management system is needed to collect, organize and assess the information from the sensing circuitry.

- Renesas' ISL94203 is the most famous example of employing a battery management system algorithm. It is a standalone digital solution embedded in a single chip with programmable capabilities.
- The memory space and microcontroller for battery management system clock cycles can be cleared using these standalone solutions.

6. Real-Time Clock

Allowing the user to know the battery pack's behavior before any alarming event, the real-time clock acts as a black box system for time-stamping and memory storage.

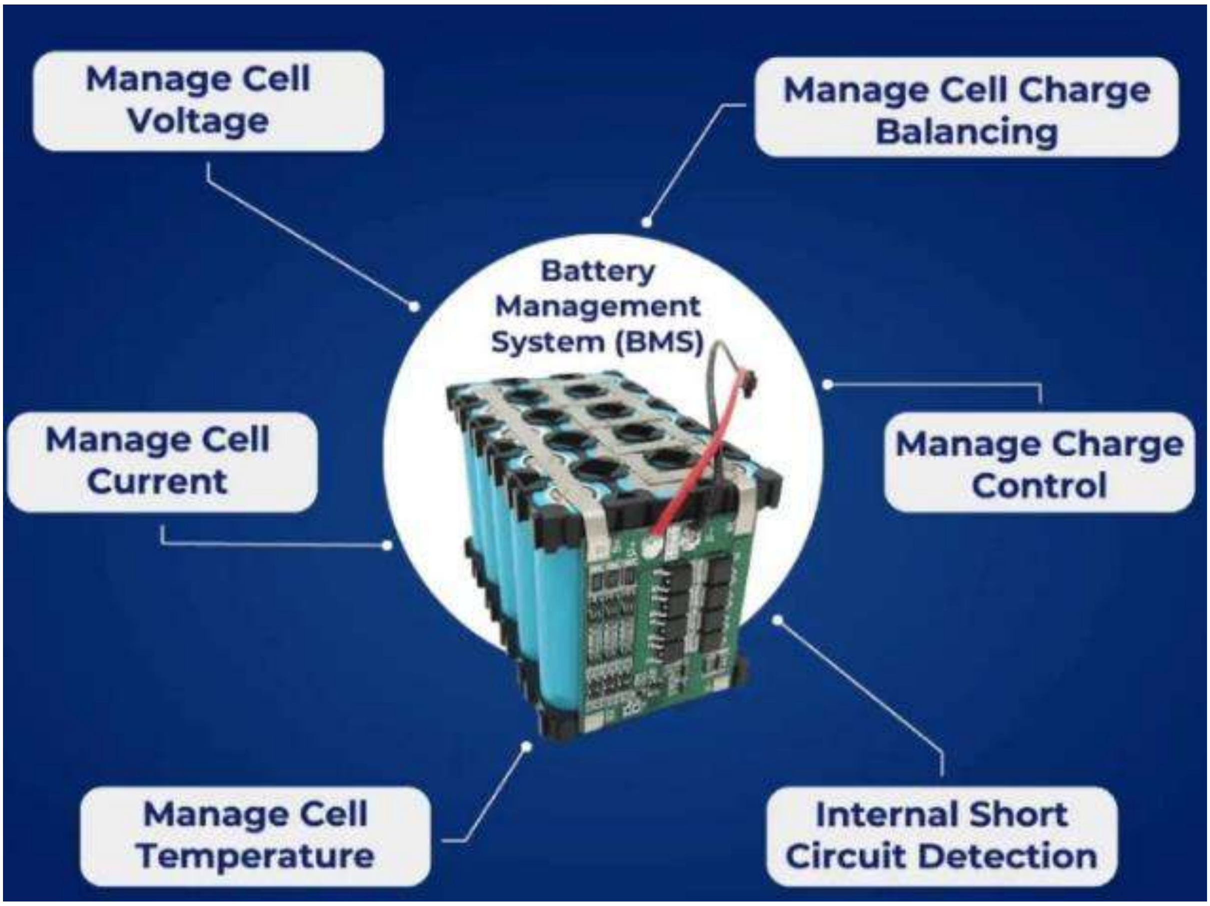
- The BMS electronics is kept away from synchronizing with a third-party battery pack through battery authentication.
- The peripheral power circuitry is used around the components of battery management system through voltage reference/regulator.

How Does a Battery Management System Work?

The battery management system monitors individual cells in the battery pack. It then calculates how much current can safely go in (charge) and come out (discharge) without damaging the battery.

The current limits prevent the source (usually a battery charger) and the load (such as an inverter) from overdrawing or overcharging the battery. This protects the battery pack from cell voltages getting too high or low, which helps increase the battery's longevity.

The BMS also monitors the remaining charge in the battery. It continually tracks the amount of energy entering and exiting the battery pack and monitors cell voltages. It uses this data to know when the battery is drained and shut the battery down. This is why lithium-ion batteries don't show signs of dying like a lead-acid, but just shut off.



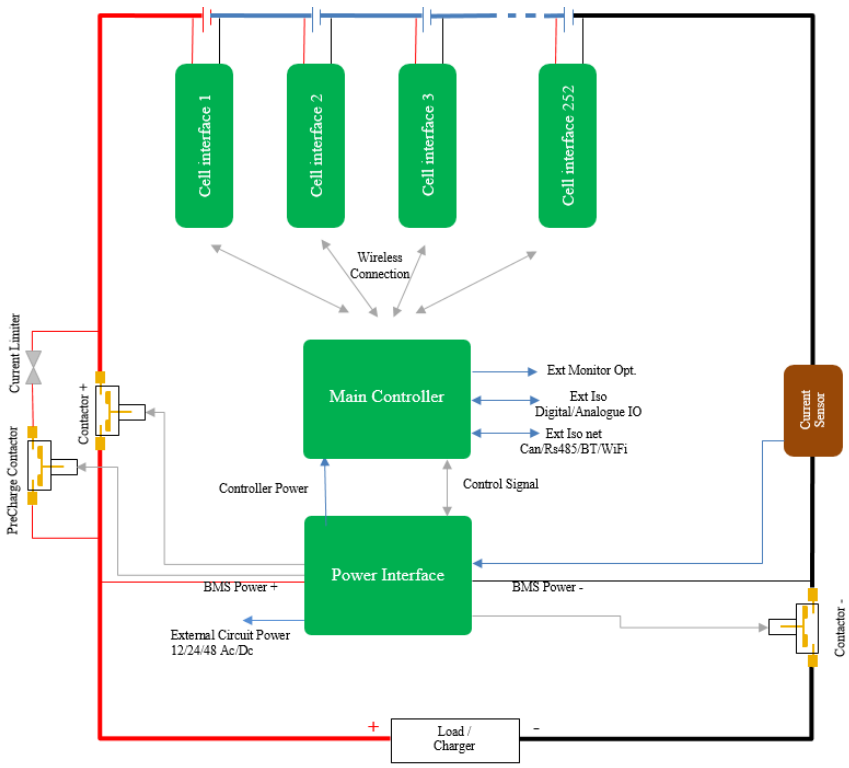
The battery management system tracks the status of each cell in the battery pack. Determining the SOC (State of Charge) and SOH (State of Health) helps estimate the amount of current needed for a safe charge and discharge operation without harming the battery.

The current limits act as a cut-off and prevent the battery from overcharging. This safeguard the cell voltages of the battery pack from high or low fluctuations, which immunes the battery life.

The BMS consistently tracks the charge and discharge activities for the battery pack and monitors cell voltages. This data is useful in deciding if the battery is drained, sustaining passive cell balancing.

The CAN (Controller Area Network) bus is the reliable unit for internal communications, driving most of the messaging protocols. The IEM (Intelligent Electric Meter) estimates the state parameters of the battery pack, total current, and battery pack voltage. It transfers the information to the CMU (Central Monitoring Unit) or the sub-controller unit.

The sub-controller unit quickly checks the temperature and voltage signals and sends data to the CAN bus. The BCU (Battery Control Unit) obtains the signals from the CAN bus and responds by transmitting back the control signals required in battery pack managing and modeling.



Why a BMS is Important

Battery management systems are critical in protecting the battery's health and longevity but even more important from a safety perspective. The liquid electrolyte in lithium-ion batteries is highly flammable.

So, these batteries need to be operating optimally and within safety limits at all times to prevent a fire.

Protections Offered By a Battery Management System

Briefly reviewing the most important protections offered by a BMS, we can summarize them as protection from under-or-over-voltage, extreme temperatures and shorts that can occure for many number of reasons.

Under and Over-Voltage

Damage occurs if you overcharge (cell voltage getting too high) or over-discharge (cell voltage gets too low) a lithium-ion battery cell. The BMS helps protect from under and over-voltage situations so that damage to the battery's cells does not occur.

Temperature Extremes

The safety and stability of lithium-ion battery cells depend on temperature maintenance within certain limits. If the temperature exceeds the critical level on either end, thermal runaway can occur. Consequently, this can lead to an inextinguishable fire.

The BMS monitors the temperature and sometimes controls cooling fans (in the case of an electric vehicle) to help maintain proper conditions. It will even shut down cells if needed to protect the battery.

Protection from Shorts

Internal and external shorts can also lead to thermal runaway. For this reason, protection from shorts is another critical component of a battery management system.

Types of Battery Management Systems:

Based on the topology of the battery packs, there are 4 types of battery management systems. They are:

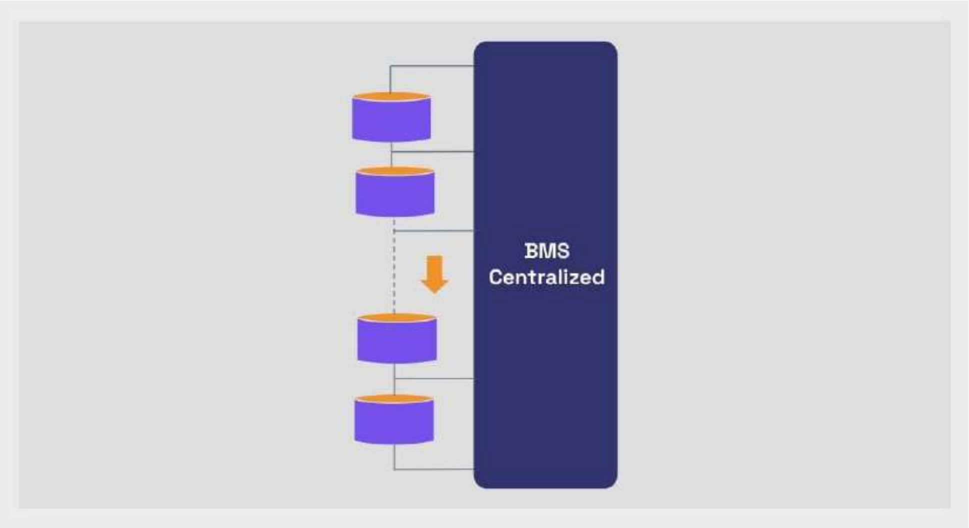
1. Centralized Battery Management System Architecture:

It is clear in the figure below, that all the battery packages are connected directly with the central BMS.

- **Advantages of Centralized BMS**
  1. Compactness
  2. Feasibility

- **Disadvantages of a Centralized BMS**

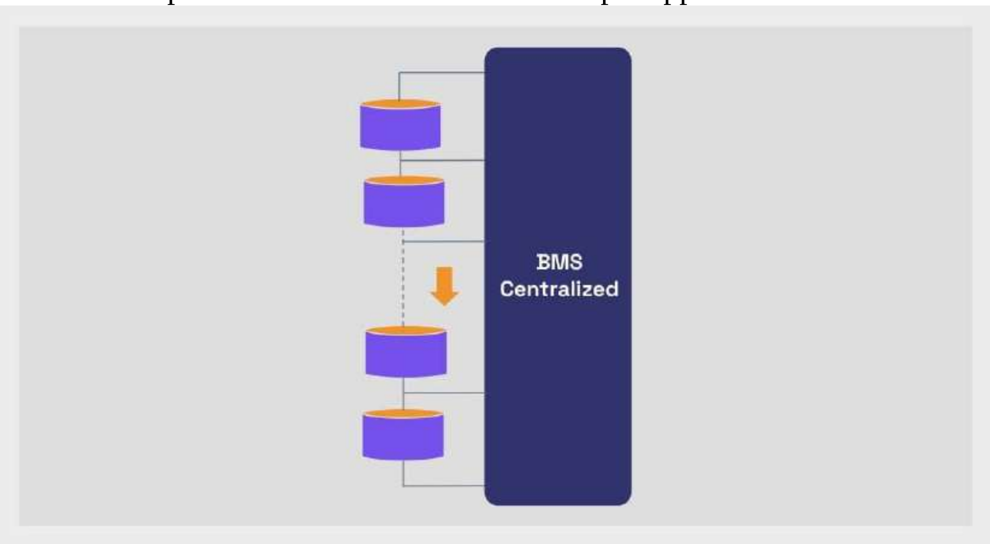
  The more the number of batteries, the more the number of ports required to support the same, leading to many wiring, cabling, and connectors. It can cause complications while troubleshooting and maintenance.



2. **Modular Battery Management System:**

The BMS is grouped into various duplicate modules, just like the centralized implementation wherein every module is associated with a separate wire bundle and connect to the battery pack's adjacent assigned portion.

- **Advantages of Modular BMS**
  1. Reduces computational efforts
  2. Increases the room for adding more functionalities
- **Disadvantages of a Modular BMS**
  1. Higher overall costs
  2. Duplicated unused functionalities as per application

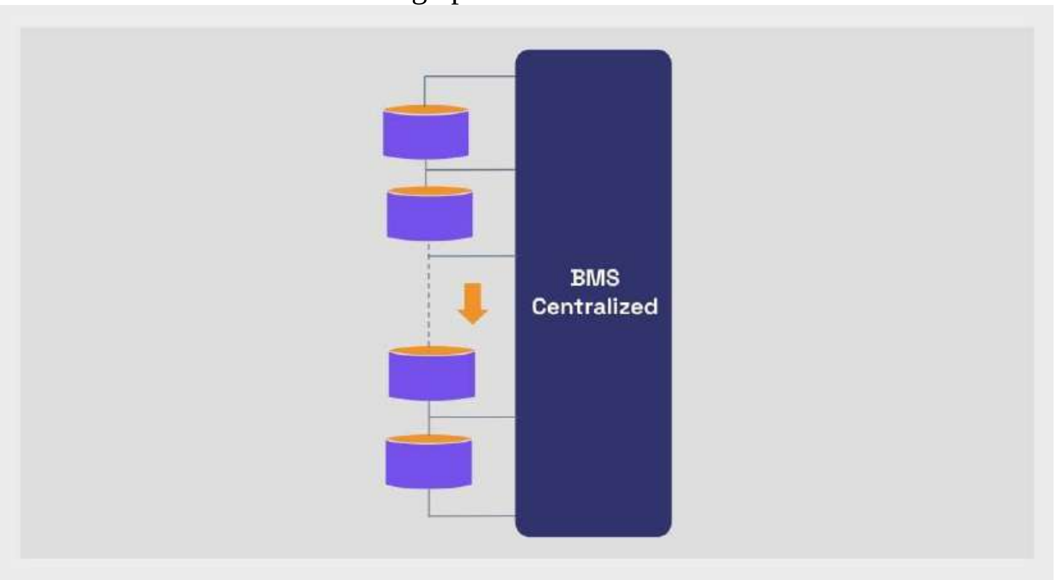


3. Primary Battery Management System:

The concept is almost similar to the modular topology, but here, slaves are more confined to just transferring measurement information and the master is assigned for computation, control, and external communication.

- **Advantages of Primary Battery Management System**
  1. Lower costs
  2. Simpler functionalities

- **Disadvantages of Primary Battery Management System**
  1. Less feature options
  2. Not suitable for scaling operations

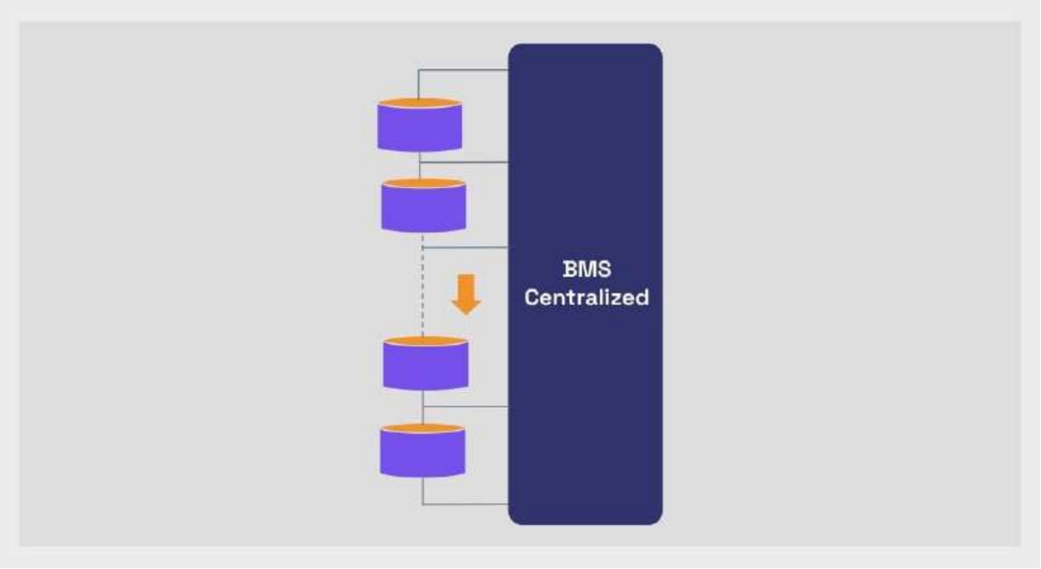


4. Distributed Battery Management System Architecture:

The architecture of distributed battery management system comprises of modules wherein the software and hardware is embedded in the form of modules attached through wiring. All the electronic hardware is synchronized with the cell or module under monitoring on a control board.

- **Advantages of Distributed Battery Management System**
  1. Reduces cable bundling
  2. Autonomously handles communications and processing

- **Disadvantages of Distributed Battery Management System**
  1. High maintenance
  2. Higher cost
  3. Difficult to troubleshoot because of its deep routing



IoT based Battery Management System

The advent of cloud computing and the Internet of Things (IoT) has assured the EV industry that testing and product development have a long way to go. Through an IoT based battery management system, having high data storage capabilities, computation time, and efforts decrease exponentially. All the data captured during the battery operations can be analyzed and seamlessly transmitted to the cloud platform.

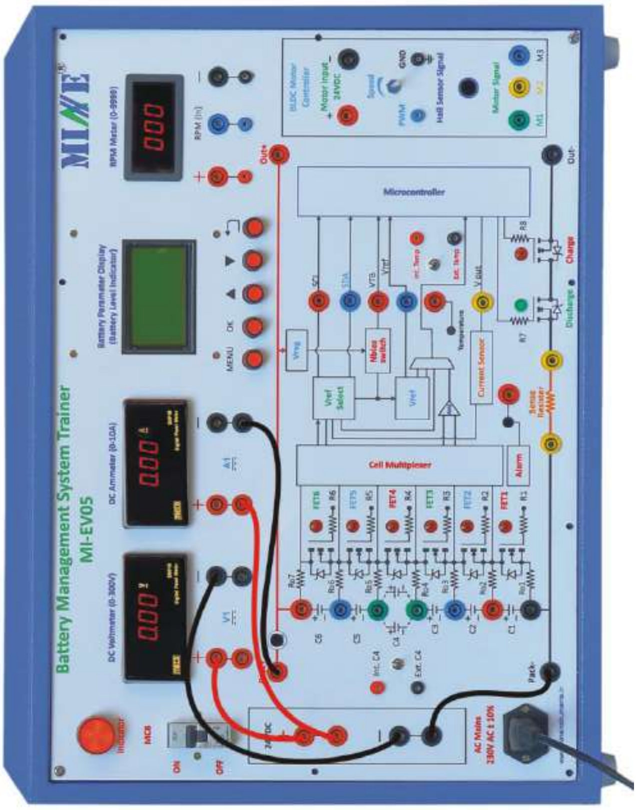
Through advanced diagnostic algorithms, the data is measured by battery pack sensors, analyzing the state of each battery cell. With big data collection in a single base, the battery management system algorithms for machine learning can attain system prediction and optimizations, revolutionizing our approach towards battery life cycle and performance.

Additionally, the BMS’s reliability increases by substituting wired communication with wireless IoT communication.

Safety Precaution:

- Please make sure your power cable is connected properly to the trainer.
- Please make connections properly as mentioned.
- Do not apply any external high voltage or current source by which trainer get damaged.
- Do not touch motor pulley when motor is running condition.
- Make sure the loading arrangement is on no load condition when motor will start.

Connection Diagram:



Procedure:

- First of all, Connect the +24VDC (Red) to the DC Voltmeter +V1 (Red) via patch cord.
- Connect the -24VDC (Black) to the DC Voltmeter -V1 (Black) via patch cord.
- Connect the +24VDC (Red) to the DC Ammeter +A1 (Red) via patch cord.
- Connect DC Ammeter -A1 (Black) to the Battery Pack+ terminal via patch cord.
- Connect the -24VDC (Black) to the Battery Pack- terminal via patch cord.
- Always toggle switch of battery pack+Ve is in on condition when battery is charging.
- Make sure Internal toggle switch is in ON condition.
- After connecting the above connections, connect the mains AC plug ON and MCB switch ON for supply.
- Then we are able to see the appropriate Trainer Voltage on DC Voltmeter.
- For setting of BMS go to the section of Battery Perameter Display, and press the MENU key. After that Display shows Name of Company.

- Now display section is on and shown Battery Management system.
- It takes few seconds to show the Cell voltage on Display.

- Now Click on MENU key, all functions are shown on Display.

- Select "Normal Charging" using by updown key. Then after select "OFF" from Normal Charging.

- Now go to the Balance Charging using by updown key and select "OFF" option.

- Then after go to the option of "Under Voltage Limit" using by updown key, select it & set on 18.8V, if BMS voltage is below this value alarm is ON for alert. Otherwise it is charge or discharge as per need.

- Next select "Over Voltage Limit" using by updown key & set the voltage on 22.0V, if BMS Voltage is above this value alarm is ON for alert. Otherwise it is charge or discharge as per need.

- Next select "Current Limit" & set the Current on 1Amp, if BMS current is above this value alarm is ON for alert. (It is just for example set on current from1-5 Amp). Otherwise it is charge or discharge as per need.

- Next set the Temperature on 29^0 C, if BMS temperature is above this value alarm is ON for alert. (It is just for example set Temperature on as per need).If temperature is more than given value it is automatic cutt off the trainer, on that time charging & discharging is “OFF”.

- Last option is Alarm, so set is “ON” condition. It is help to alert from above options for over voltage, current & Temperature.(So always it is in “ON” condition)

- Above procedures describe the functions of BMS Display Setting.

Conclusion: As per result now display setting is done for next experiments.

Experiment 2

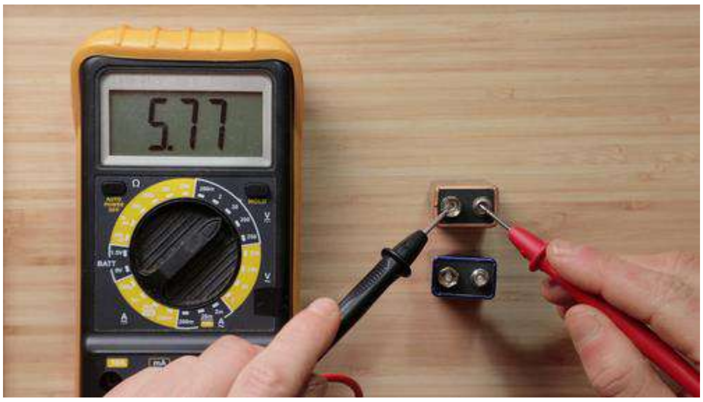
Aim: Study of Cell Voltage test by Multimeter.

Apparatus Required:

- **Electric Vehicle Trainer-(MI-EV05)**
- Patch Cords.
- Power Cable.
- Digital Multimeter

Theory: - To measure the voltage, we simply need to select the DC function on our multimeter, and then we connect the red lead to the positive terminal and the black lead to the negative. This will give us a voltage reading. You can see that this battery is rated at 1.5 volts, but when we test it, we get 1.593 volts. The two values are close, but usually not the same.

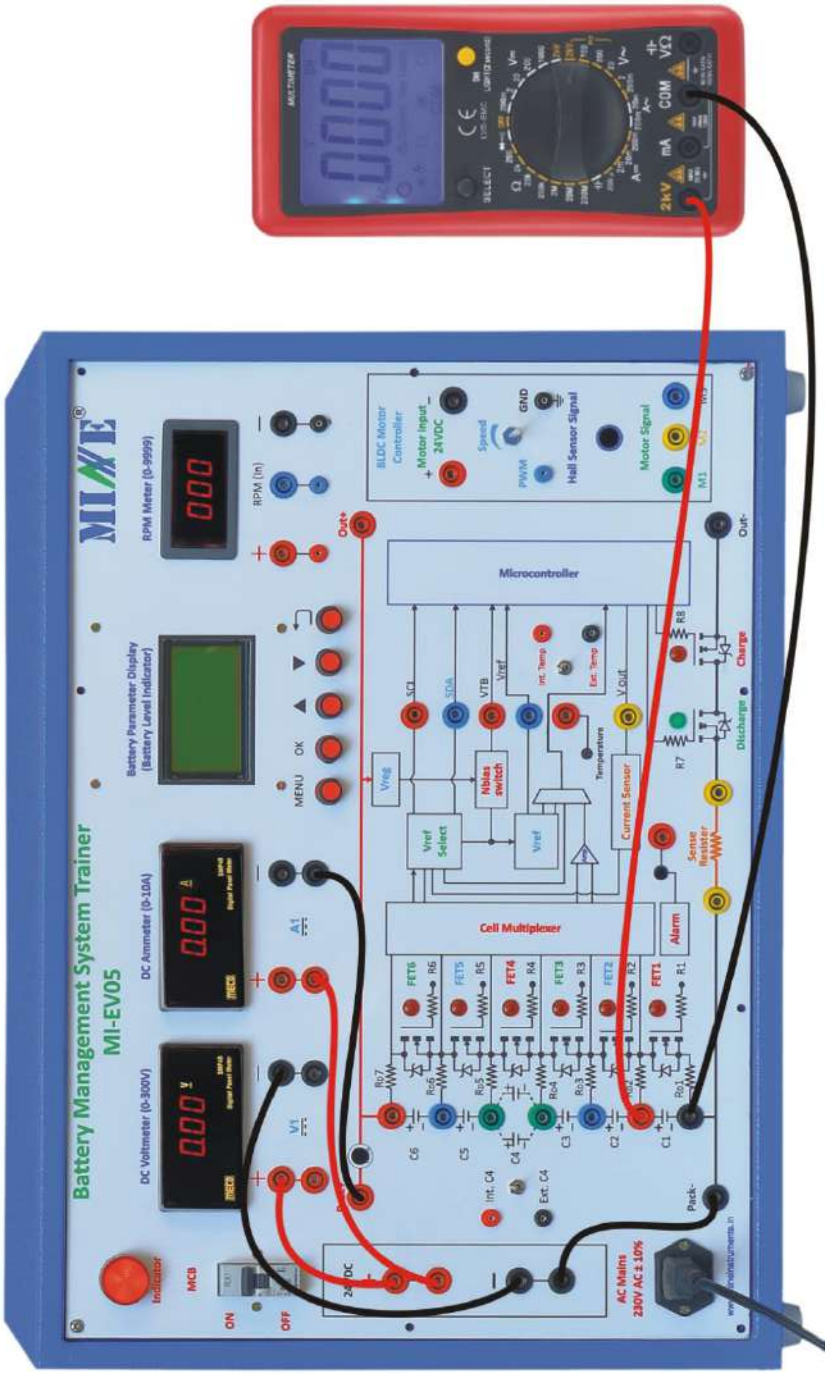
A multimeter can be used to check the voltage and current produced by a cell which helps to recognize a battery voltage.



Safety Precaution:

- Please make sure your power cable is connected properly to the trainer.
- Please make connections properly as mentioned.
- Do not apply any external high voltage or current source by which trainer get damaged.
- Do not touch motor pulley when motor is running condition.
- Make sure the loading arrangement is on no load condition when motor will start.

Connection Diagram:



Procedure:

- First of all, Connect the +24VDC (Red) to the DC Voltmeter +V1 (Red) via patch cord.
- Connect the -24VDC (Black) to the DC Voltmeter -V1 (Black) via patch cord.
- Connect the +24VDC (Red) to the DC Ammeter +A1 (Red) via patch cord.
- Connect DC Ammeter -A1 (Black) to the Battery Pack**+** terminal via patch cord.
- Connect the -24VDC (Black) to the Battery Pack- terminal via patch cord.
- Always toggle switch of battery pack+Ve is in on condition when battery is charging.
- Make sure Internal toggle switch is in ON condition.
- After connecting the above connections, connect the mains AC plug ON and MCB switch ON for supply.
- Then we are able to see the appropriate Trainer Voltage on DC Voltmeter.
- For test of each Cell voltage so set multimeter on DC Voltage & connect multimeter +Ve (Red) –Ve (Black) to the any cell of +ve & -ve terminal and see the appropriate voltage of each cell on Multimeter.

Conclusion: Now we able to test the cell voltage using by Multimeter.

Experiment 3

Aim: Study of Normal Battery Charging.

Apparatus Required:

- **Electric Vehicle Trainer-(MI-EV05)**
- Patch Cords.
- Power Cable.

Theory: - Three Stage of Battery Charging

- **Bulk**
- **Absorption**
- **Float**

BULK -The BULK stage involves about 80% of the recharge, wherein the charger current is held constant (in a constant current charger), and voltage increases. The properly sized charger will give the battery as much current as it will accept up to charger capacity (25% of battery capacity in amp hours), and not raise a wet battery over 125 ° F or an AGM or GEL (valve regulated) battery over 100° F.

ABSORPTION-The ABSORPTION stage (the remaining 20%, approximately) has the charger holding the voltage at the charger's absorption voltage (between 14.1 VDC and 14.8 VDC, depending on charger set points) and decreasing the current until the battery is fully charged. Some charger manufacturers call this absorption stage an equalization stage. We don't agree with this use of the term. If the battery won't hold a charge, or the current does not drop after the expected recharge time, the battery may have some permanent sulphation.

FLOAT-The FLOAT stage is where the charge voltage is reduced to between 13.0 VDC and 13.8 VDC and held constant, while the current is reduced to less than 1% of battery capacity. This mode can be used to maintain a fully charged battery indefinitely.

Recharge time can be approximated by dividing the amp hours to be replaced by 90% of the rated output of the charger. For example, a 100 amp hour battery with a 10 % discharge would need 10 amps replaced. Using a 5 amp charger, we have 10 amp hours divided by 90% of 5 amps (.9x5) amps = 2.22 hour recharge time estimate. A deeply discharged battery deviates from this formula, requiring more time per amp to be replaced.

Recharge frequency recommendations vary from expert to expert. It appears that depth of discharge affects battery life more than frequency of recharge. For example, recharging when the equipment is not going to be used for a while (meal break or whatever), may keep the average depth of discharge above 50% for a service day. This basically applies to battery applications where the average depth of discharge falls below 50% in a day, and the battery can be fully recharged once during a 24 hour period.

Equalization

Equalization is essentially a controlled over charge. Some charger manufacturers call the peak voltage the charger attains at the end of the BULK mode (absorption voltage) an equalization voltage, but technically it's not. Higher capacity wet (flooded) batteries sometimes benefit from this procedure, particularly the physically tall batteries. The electrolyte in a wet battery can stratify over time, if not cycled occasionally. In equalization, the voltage is brought up above typical peak charging voltage (to 15 to 16 volts in a 12 volt system) well into the gassing stage, and held for a fixed (but limited) period. This stirs up the chemistry in the entire battery, "equalizing" the strength of the electrolyte, and knocking off any loose sulphation that may be on the battery plates.

The construction of AGM and Gel batteries all but eliminates any stratification, and most all manufacturers of this type do not recommend it (advising against it). Some manufacturers (notably Concorde) list a procedure, but voltage and time are critical to avoid battery damage.

Battery Testing

Battery testing can be done in several ways. The most popular includes measurement of specific gravity, and battery voltage. Specific gravity applies to wet cells with removable caps, giving access to the electrolyte. To measure specific gravity, buy a temperature compensating hydrometer at an auto parts store or tool supply. To measure voltage, use a digital voltmeter in the DC voltage setting. The surface charge must be removed from a freshly charged battery before testing. A 12 hour lapse after charging qualifies, or you may remove the surface charge with a load (20 amps for 3 plus minutes).

State of Charge	**Voltage**		**Specific Gravity**
	12V	**6V**	
100%	12.7	6.3	1.265
75%	12.4	6.2	1.225
50%	12.2	6.1	1.190
25%	12.0	6.0	1.155
Discharged	11.9	6.0	1.120

Load testing is another method of testing a battery. Load testing removes amps from a battery (similar to starting an engine). Some battery companies label their battery with the amp load for testing. This number is usually 1/2 of the CCA rating. For instance, a 500 CCA battery would load test at 250 amps for 15 seconds. A load test can only be performed if the battery is at or near a full charge. Some electronic load testers apply a 100 amp load for 10 seconds, and then display battery voltage. This number is compared to a chart on the tester, based on CCA rating to determine battery condition.

Sulphation of batteries starts when specific gravity falls below 1.225 or voltage measures less than 12.4 (12v Battery) or 6.2 (6 volt battery). Sulphation can harden on the battery plates if left long enough, reducing and eventually destroying the ability of the battery to generate rated volts and amps. There are devices for removing hard sulphation, but the best practice is preventing formation by proper battery care and recharging after a discharge cycle. Sulphation is the main reason a significant portion of lead acid batteries doesn't attain their chemical life span.

Charging Parallel Connected Batteries

Batteries connected in parallel (positive to positive, negative to negative) are seen by the charger as one large battery of the combined amp hour capacity of all the batteries. Thus, three 12 volt 100 amp hour (ah) batteries in parallel are seen as one 12 volt 300 ah battery. They can be charged with one positive and negative connection from one charger of the recommended amp output. They also can be charged with a multiple output charger, like a three bank unit in this case, with each battery getting its own connection at battery voltage. The charging amperage would be the sum of the individual output amps.

Charging Series Connected Batteries

Batteries connected in series are a different story. Three 12 volt 100 amp hour batteries connected in a series string (positive to negative, positive to negative, positive to negative) would make a 36 volt 100 ah battery pack. This can be charged across the pack with a 36 volt output charger of the appropriate amp output. They also can be charged with a multiple output charger, like a three bank unit in this case, with each battery getting its own connection at battery voltage (12 volts in this case). Either method is fine, **UNLESS** one or more of the batteries are tapped at lower than system voltage. An example would be tapping one of the batteries in this 36 volt string at 12 volts for a radio or some lights, etc. This imbalances the pack, and charging at system voltage (36V) doesn't correct the imbalance. The multiple bank charger connecting to each battery is the correct way to deal with this series battery string, as it corrects the imbalance with every charge cycle.

EOD

End of discharge voltage is the level to which the battery string voltage or cell voltage is allowed to fall to before affecting the load i.e. 1.75V or 21V nominal 24V system.

Temperature Compensation

As previously detailed, the energy stored within a battery cell is the result of an electrochemical reaction, so any change in the electrolyte temperature has an effect on the rate of reaction provided all other factors (charge voltage and current) relating to the reaction remain constant.

The simplest way of maintaining the rate of reaction within design parameters is to alter the charge voltage at a rate proportional to the change in temperature, i.e. decrease the charge voltage with an increase in temperature above 20-25°C and increase the charge voltage with a decrease in temperature below 20-25°C.The typical change in charge voltage is 3mV/°C. Contact our engineers for further information our battery chargers have temperature compensation options.

Boost Charge

Charge given to a battery to correct voltage imbalance between individual cells and to restore the battery to fully charged state.

Terms Associated with standby Batteries

Ah

The Ah or Ampere/hour capacity is the current a battery can provide over a specified period of time, e.g. 100Ah @ C10 rate to EOD of 1.75V/cell. This means the battery can provide 10 Amps for 10 hours to an end of discharge voltage of 1.75V per cell. Different battery manufacturers will use different Cxx rates depending on the market or application at which their batteries are targeted. Typical rates used are C3, C5, C8, C10 and C20. Because of this it is important, when comparing batteries from different manufacturers having the same Ah rate, to confirm on what Cxx rate this figure is based.

Cell

A cell comprises a number of positive and negative charged plates immersed in an electrolyte that produces an electrical charge by means of an electrochemical reaction. Lead acid cells generally produce an electrical potential of 2V while Nickel-cadmium cells generally produce an electrical potential of 1.2V.

Battery

A battery is a number of cells connected together. Check Out our complete range of batteries.

DOD (Depth of discharge)

Fraction of total capacity used in discharge.0-100%.

String/Bank

A battery string or bank comprises a number of cells/batteries connected in series to produce a battery or battery string with the required usable voltage/potential e.g. 6V, 12V, 24V, 48V, 110V.

SOC (State of Charge)

Fraction of total capacity that is still available for discharge. 0-100%.100%-DOD

End of Life Factor

This is a factor included within the battery sizing calculation to ensure the battery is able to support the full load at the end of the battery design life, calculated by multiplying Ah by 1.25.

VPC (Volts per Cell)

Volts per cell i.e. for a lead acid battery the VPC is 2V so 6 cells in a 12V.

Charging Methods-There are three common methods of charging a battery; constant voltage, constant current and a combination of constant voltage/constant current with or without a smart charging circuit.

Constant voltage allows the full current of the charger to flow into the battery until the power supply reaches its pre-set voltage. The current will then taper down to a minimum value once that voltage level is reached. The battery can be left connected to the charger until ready for use and will remain at that "float voltage", trickle charging to compensate for normal battery self-discharge.

Constant current is a simple form of charging batteries, with the current level set at approximately 10% of the maximum battery rating. Charge times are relatively long with the disadvantage that the battery may overheat if it is over-charged, leading to premature battery replacement. This method is suitable for Ni-MH type of batteries. The battery must be disconnected, or a timer function used once charged.

Constant voltage / constant current (CVCC) is a combination of the above two methods. The charger limits the amount of current to a pre-set level until the battery reaches a pre-set voltage level. The current then reduces as the battery becomes fully charged. The lead acid battery uses the constant current constant voltage (CC/CV) charge method. A regulated current raises the terminal voltage until the upper charge voltage limit is reached, at which point the current drops due to saturation.

Check the voltage

The voltage which your battery is kept at plays a major role in determining the overall service life you'll get out of it. For example - a battery which is kept fully charged at all times will last much longer than one which has been undercharged or kept at a reduced voltage.

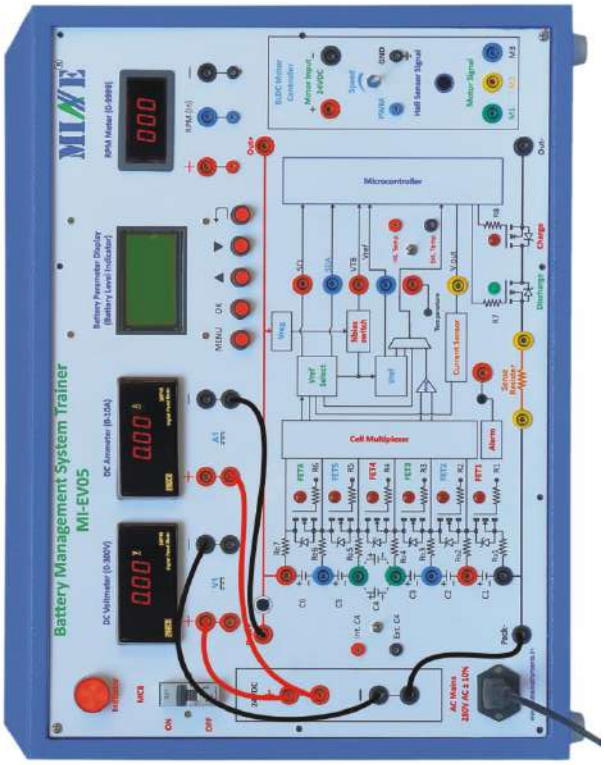
To check the voltage you'll need a voltmeter, which can be purchased cheaply from most major automotive parts stores. Check the voltage of your battery using the voltmeter to help determine your next course of action.

- **12.6V volts or above** - Your battery is healthy and fully charged. No further action is required.
- **12.5 volts** - Your battery is at a healthy state of charge, but we'd recommend re-checking it within a few days to ensure the voltage hasn't dropped any further.
- **12.1 - 12.4 volts** - Your battery is partially discharged and should be recharged as soon as possible, using a suitable battery charger. The lifespan of your battery will be moderately affected if it remains within this voltage range for extended periods of time.
- **12.0 volts or below** - At 12.0 volts your battery is considered to be fully discharged or 'flat' and should be recharged as soon as possible. The lifespan of your battery will be severely affected if it remains within this voltage range for extended periods of time.

Safety Precaution:

- Please make sure your power cable is connected properly to the trainer.
- Please make connections properly as mentioned.
- Do not apply any external high voltage or current source by which trainer get damaged.
- Do not touch motor pulley when motor is running condition.
- Make sure the loading arrangement is on no load condition when motor will start.

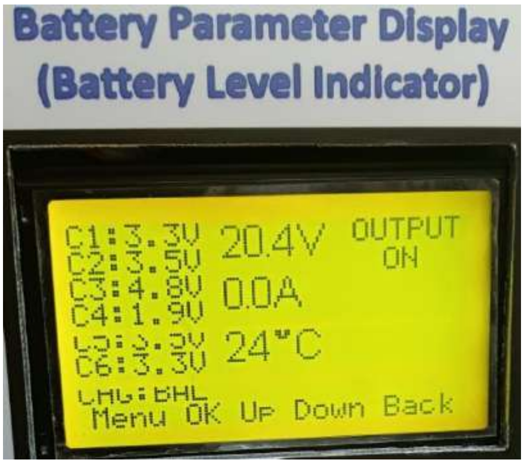
Connection Diagram:



Procedure:

- First of all, Connect the +24VDC (Red) to the DC Voltmeter +V1 (Red) via patch cord.
- Connect the -24VDC (Black) to the DC Voltmeter -V1 (Black) via patch cord.
- Connect the +24VDC (Red) to the DC Ammeter +A1 (Red) via patch cord.
- Connect DC Ammeter -A1 (Black) to the Battery Pack+ terminal via patch cord.
- Connect the -24VDC (Black) to the Battery Pack- terminal via patch cord.
- Always toggle switch of battery pack+Ve is in on condition when battery is charging.
- Make sure Internal toggle switch is in ON condition.
- After connecting the above connections, connect the mains AC plug ON and MCB switch ON for supply.
- Then we are able to see the appropriate Trainer Voltage on DC Voltmeter.
- For setting of BMS go to the section of Battery Perameter Display, and press the MENU key. After that Display shows Name of Company.

- Now display section is on and shown Battery Management system.
- It takes few seconds to show the Cell voltage on Display.



- Now Click on MENU key, all functions are shown on Display.

- Select "Normal Charging" using by updown key. Then after select "ON" from Normal Charging.

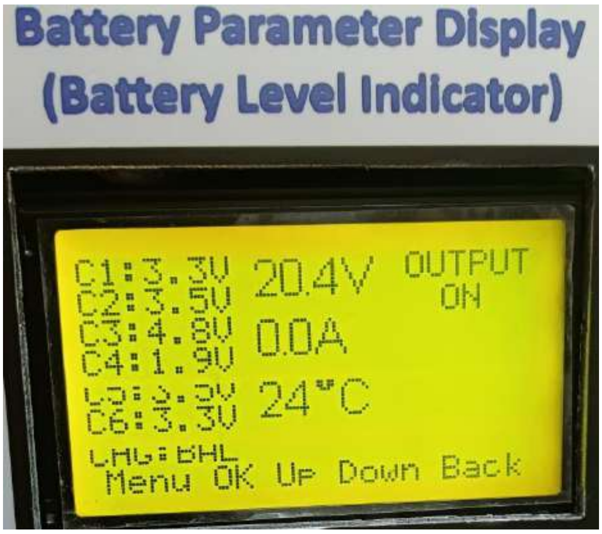
- Now go to the Balance Charging using by updown key and select "OFF" option.

- Then after go to the option of "Under Voltage Limit" using by updown key, select it & set on 18.8V, if BMS voltage is below this value alarm is ON for alert. Otherwise it is charge or discharge as per need.

- Next select "Over Voltage Limit" using by updown key & set the voltage on 22.0V, if BMS Voltage is above this value alarm is ON for alert. Otherwise it is charge or discharge as per need.

- If voltage is below the over voltage so charge the cell as per need & charging will start.

  In below diagram we can easily see the individual cell voltage.



- Now charging LED blink until the voltage value reach to over voltage.(Then after Discharging LED blink)
- Same procedure for normal voltage discharge until the voltage value reach to under voltage.

Conclusion: As per result now normal charging and discharging experiment done.

Experiment 4

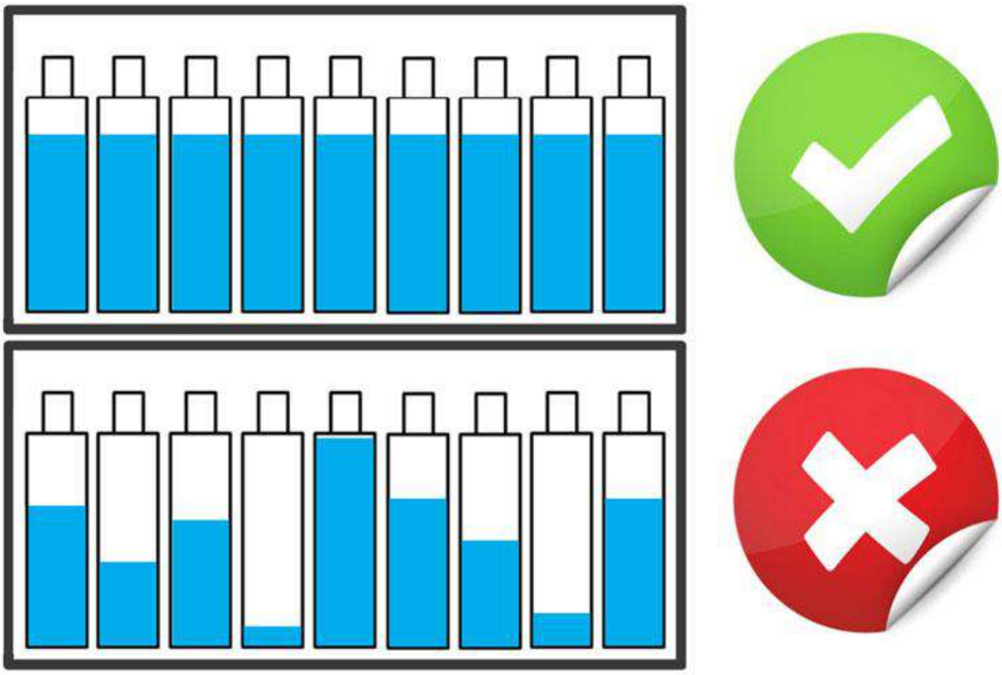
Aim: Study of Balanced Battery charging and its types.

Apparatus Required:

- **Electric Vehicle Trainer-(MI-EV05)**
- **Patch Cords.**
- **Power Cable.**

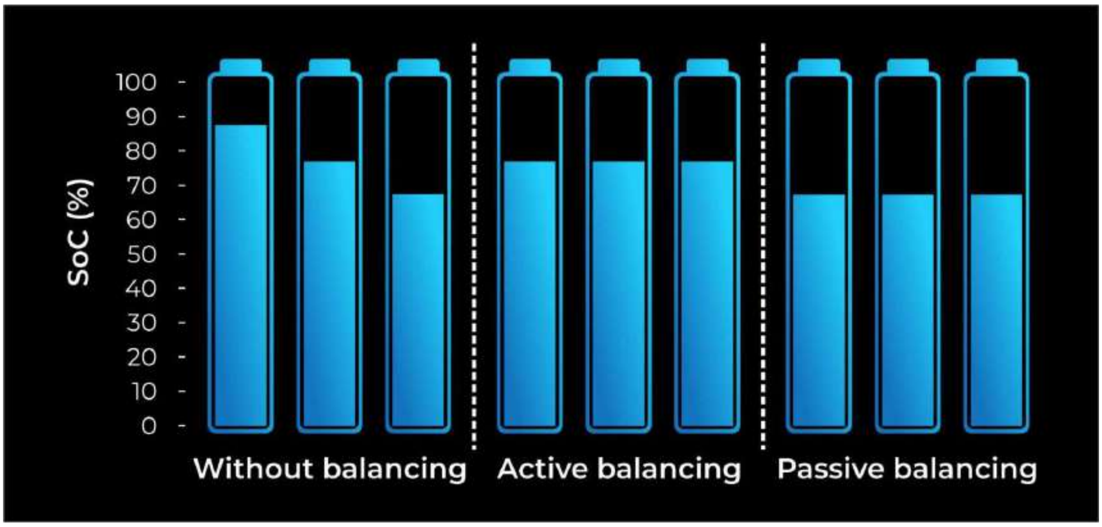
Theory: - A nominal lithium cell is rated for around 4.2V only, but in its applications like EV, portable electronics, laptops, power banks etc we require a lot higher voltage than its nominal voltage. This is the reason why designers combine more than one cell in series to form a battery pack of higher voltage values. As we know from our previous Electric Vehicle battery article, when batteries are combined in series the voltage value gets added up. For example when four lithium cells of 4.2V is connected in series the effective output voltage of the resulting battery pack will be 16.8V.

But you can imagine connecting many cells in series is like mounting many horses to a chariot. Only if all the horses run at the same speed the chariot will be driven with maximum efficiency. Out of four horses if one horse runs slowly, then the other three also has to reduce thier speed thus reducing the efficiency and if one horse runs faster it would eventually hurt itself by pulling the load of the other three horses. Similarly, when four cells are connected in series the voltage values of all the four cells should be equal to derive the battery pack with maximum efficiency. The method of maintaining all the cell voltages to be equal is called as cell balancing. In this article we will learn more about cell balancing and also briefly about how to use them on the hardware and software level.



Why do we need Cell Balancing?

Cell balancing is a technique in which voltage levels of every individual cell connected in series to form a **battery pack** is maintained to be equal to achieve the maximum efficiency of the battery pack. When different cells are combined together to form a battery pack it is always made sure that they are of the same chemistry and voltage value. But once the pack is installed and subjected to charging and discharging the voltage values of the individual cells tends to vary due some reasons which we will discuss later. This variation in voltage levels causes cell unbalancing which will lead to one of the following problems.



Thermal Runaway

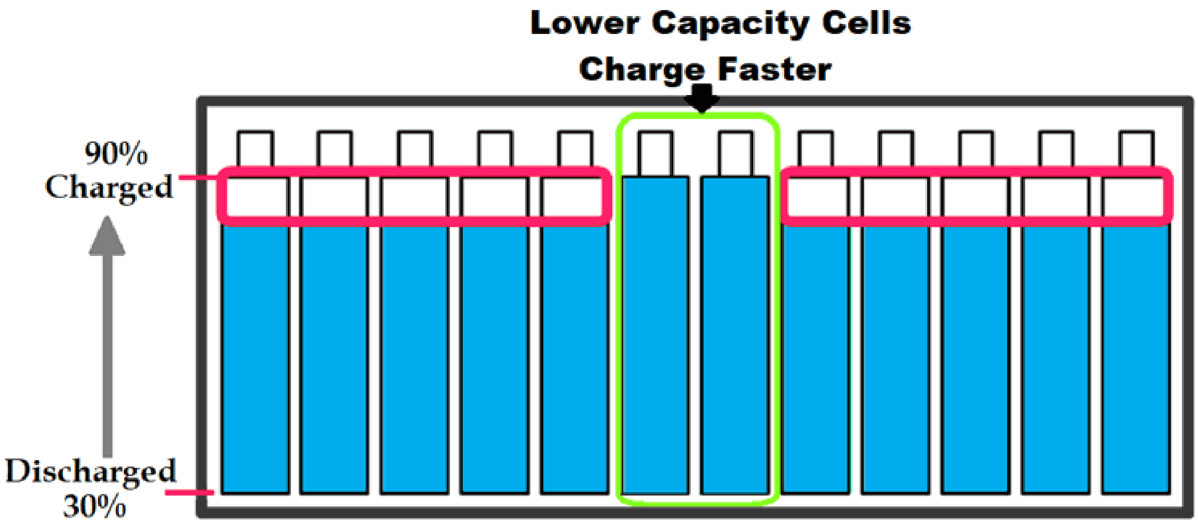
The worst thing that can happen is thermal runaway. As we know lithium cells are very sensitive to overcharging and over discharging. In a pack of four cells if one cell is 3.5V while the other are 3.2V the charge will charging all the cells together since they are in series and it will charge the 3.5V cell to more than recommended voltage since the other batteries are still require charging.

Cell Degradation

When a lithium cell is overcharged even slightly above its recommended value the efficiency and life cycle of the cell gets reduced. For example a slight increase in charging voltage from 4.2V to 4.25V will degrade the battery faster by 30%. So if cell balancing is not accurate even slight overcharging will reduce the battery life time.

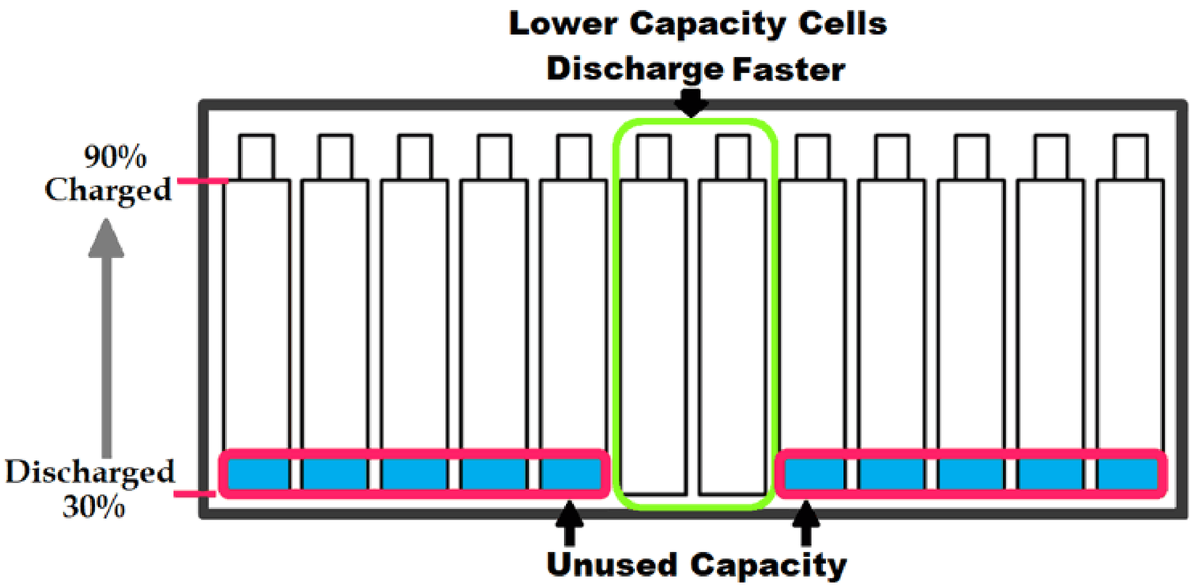
Incomplete charging of Pack

As the batteries in a pack get older few cells might be weaker than its neighboring cells. These week cells will be huge problem since they will charge and discharge faster than a normal healthy cell. While charging a battery pack with series cells the charging process should be stopped even if one cell reaches the maximum voltage. This way the if two cells in a battery pack get week they will charger faster and thus the remaining cells will not be charged to it maximum as shown below.



Incomplete use of Pack energy

Similarly in the same case when the battery pack is being discharged, the weaker cells will discharge faster than the healthy cell and they will reach the minimum voltage faster than other cells. As we learnt in our BMS article the pack will be disconnected from load even if one cell reaches the minimum voltage. This leads to the unused capacity of the pack energy as shown below.



Accounting all the above possible disadvantages in consideration, we can conclude that a cell balancing would be mandatory to utilize the battery pack to its maximum efficiency**.** Still there are few applications where initial cost should be very low and battery replacement is not a problem in those applications cell balancing could be avoided. But in majority of applications including electric vehicles, cell balancing is mandatory to get the maximum juice from the battery pack.

What causes Cell unbalancing in battery packs?

Now we know why keeping all the cells balanced in a battery pack is important. But to address the problem properly we should know why the cells get unbalanced in the first hand. As told earlier when a battery pack is formed by placing the cells in series it is made sure that all the cells are in same voltage levels. So a fresh battery pack will always have balanced cells. But as the pack is put into use the cells get unbalanced due to the following reasons**.**

SOC Imbalance

Measuring the SOC of a cell is complicated; hence it is very complex to measure the SOC of individual cells in a battery. An ideal cell balancing technique should match the cells of same SOC instead of the same voltage (OCV) levels. But since it is practically not possible cells are matched only on voltage terms when making a pack, the variation in SOC might lead to change in OCV in due course.

Internal resistance variation

It is very hard to find cells of the same Internal resistance (IR) and as the battery age the IR of the cell also get changed and thus in a battery pack not all cells will have the same IR. As we know the IR contributes to the internal impedance of the cell which determines the current flowing though a cell. Since the IR is varied the current through cell and its voltage also gets varied.

Temperature

The charging and discharging capacity of the cell also depends on the temperature around it. In a huge battery pack like in EVs or solar arrays the cells are distributed over a waste areas and there might be temperature difference among the pack itself causing one cell to charge or discharge faster than the remaining cells causing an imbalance.

From the above reasons it is clear that we cannot prevent cell from getting imbalanced during the operation. So, the only solution is to use an external system that forces the cells to get balanced again after they get unbalanced. This system is called the Battery Balancing System**.** There many different types of hardware and software techniques used for battery cell balancing. Let is discuss the types and widely used techniques.

Cell balancing

Cell balancing is considered when multiple cells in a battery pack are connected in series. Cell balancing is not needed in parallel connected Li-Ion cells since this configuration is self-balancing. In a battery pack, cells are balanced when all the cells in the pack have the same voltage per cell whilst in a fully charged or discharged state. If one or more of the cells in a pack are not matched then the battery pack is not balanced. In an unbalanced stack, the usable capacity is significantly lower compared to the nominal capacity.

The impact of cell imbalance on run-time performance and battery life in applications using series connected cells is certainly undesirable. The fundamental solution of cell balancing equalizes the voltage and SOC among the cells.

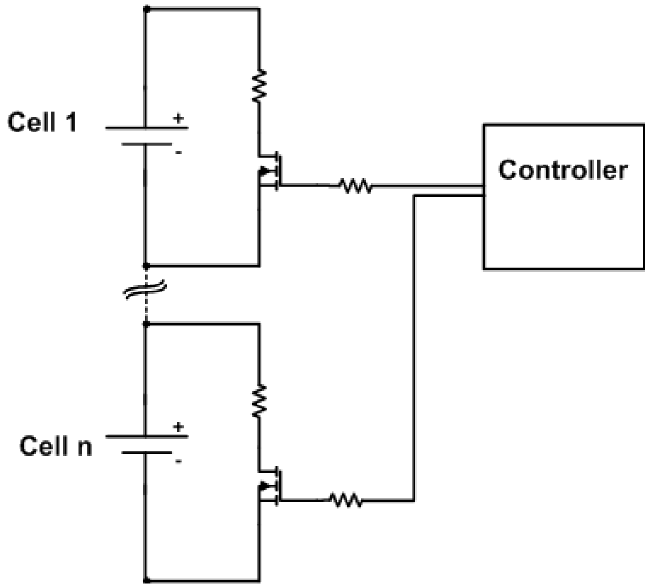


Figure1: Simplified cell balancing set up

A simple implementation of cell balancing is using a MOSFET and a resistor placed in parallel with each cell to discharge it or bypass a part of the charging current of the cells that are needed to be balanced. This method is also called “resistor bleeding balancing”. These circuits are controlled by a comparator for simple voltage based algorithms. Figure1 above illustrates a simplified cell balancing set up using bypass MOSFETs. The main task here is to select a MOSFET. The MOSFET should have as small a footprint as possible so that it occupies minimum space on the PCB. And it should have as low power dissipation as possible so that it bypasses sufficient current to balance the cell in reasonable time without heating up.

Implementation of cell balancing

Individual cell voltage must be monitored to allow cell balancing. When the cell-to-cell voltage variation is greater than a specific value, the cell balancing circuitry is enabled that gradually matches the voltages of the individual cells. As stated above, the MOSFET along with a series resistance bypasses a part of the current around the cell.

During charging of the battery pack when the MOSFET is turned on, it bypasses the current around the cell. This forces the cell to charge at a slower rate than the other cells in the pack. During discharge of the battery pack when the MOSFET is turned on, it acts as an extra load to the cell which forces the cell to discharge faster than the other cells in the pack. Figure2 illustrates an example of a cell balancing circuit for a single cell in the battery pack.

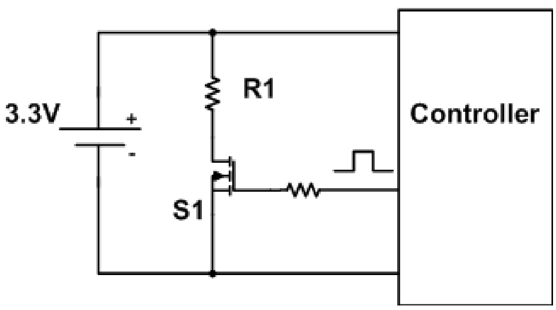


Figure2: Example of cell balancing module

There are three considerations which determine the bypass current used to balance the cell: the amount of cell imbalance, balance time and cell capacity. A reasonable amount of cell balancing is 10 % to 20% of capacity and a minimum time available for cell balance is one charge/discharge period and can be extended over multiple charge/discharge cycles.

For example, consider a cell of 2.3Ah capacity has an imbalance of 20% and has to be balanced in 1 hour then the bypass current can be calculated by:

$$I_{bypass} = \frac{Imbalance\ X\ Capacity}{Balancingtime} = \frac{0.2X2.3Ah}{1.0h} = 0.46A$$

To bypass this current at a nominal cell voltage of 3.3V, the loss in bypass path is around 1.5W. Even if the RDS(on) of the MOSFET (S1) is considered as negligible, the series resistance (R1) has to dissipate all of the energy. Thus the size of the resistor will be very big. So there is a trade-off between balancing time and the resistor size. Figure3 illustrates the relationship between R1, balancing time and bypass current of a 2.3Ah, 3.3V Li-Ion cell.

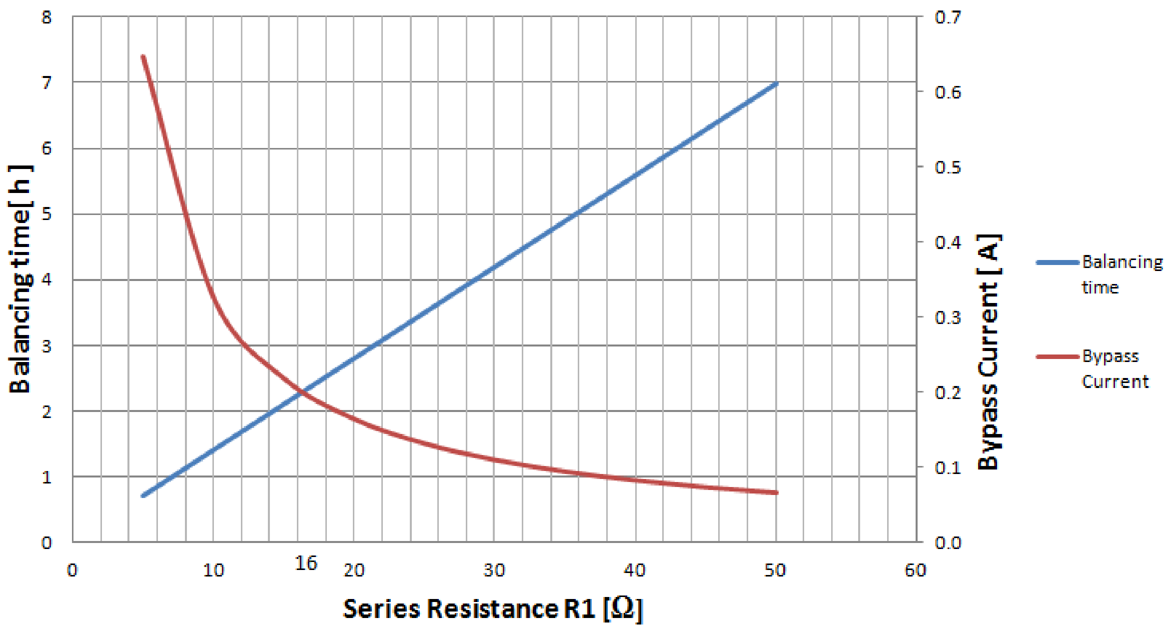
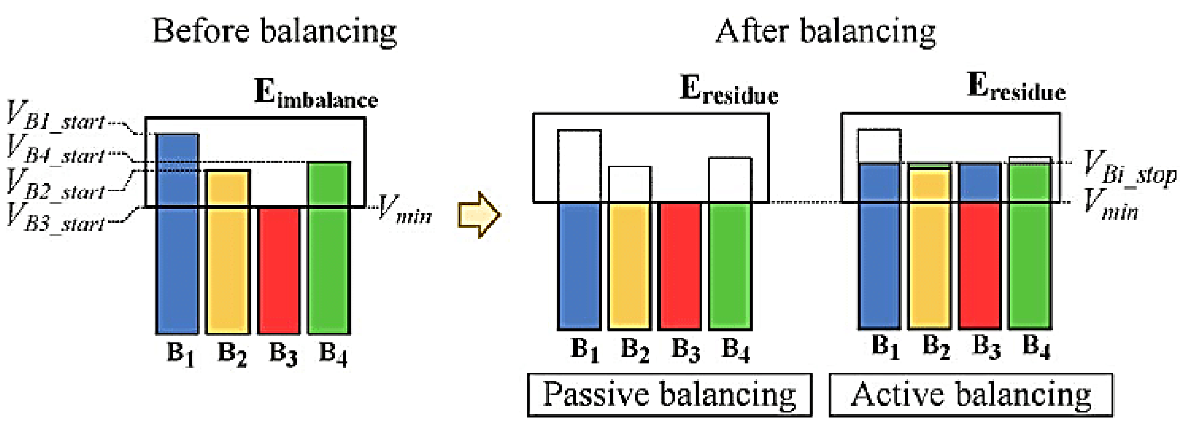
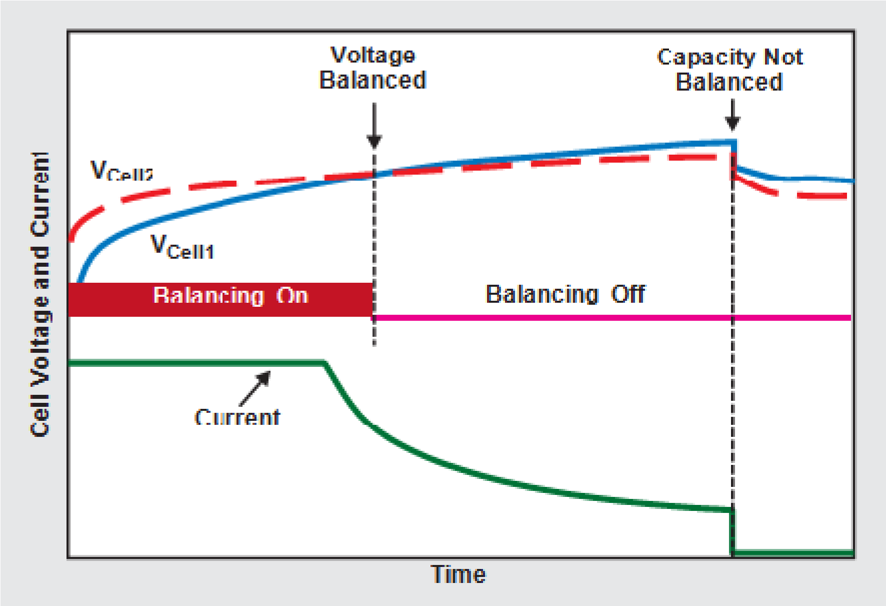


Figure3: Series resistance vs. balancing time of a 2.3Ah, 3.3V Li-Ion cell





Simple voltage based cell balancing may not effectively balance capacity

Cell-balancing algorithms that use only voltage diver- gence as a balancing criterion have the disadvantage of overbalancing or underbalancing because of the different impedance between cells (see above Fig). The problem is that cell impedance also contributes to voltage divergence during charging. The pack protector using simple voltage- based cell balancing cannot tell if the voltage difference is caused by the capacity or the impedance imbalance. Therefore, this type of balancing cannot guarantee that all cells will reach 100% capacity at full charge.

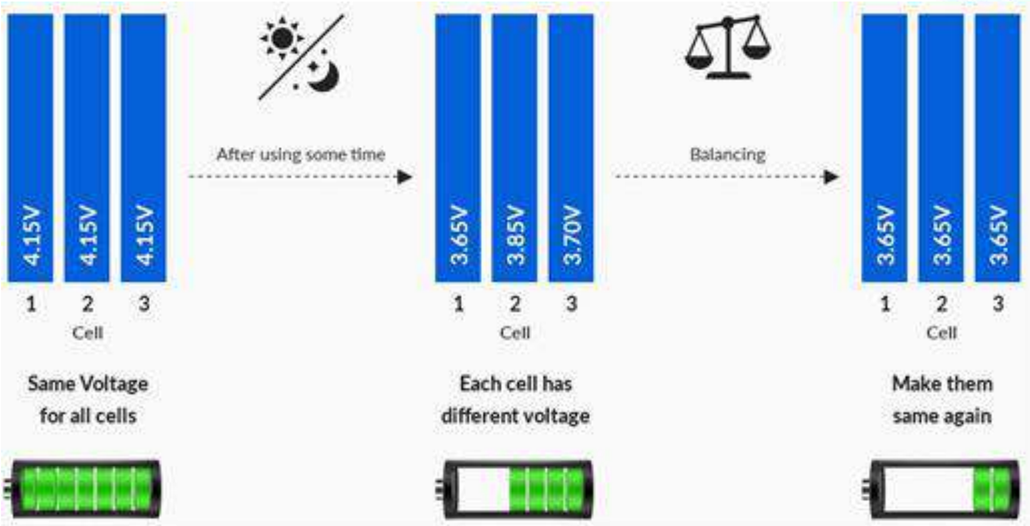
Types of Battery Cell Balancing

Cell balancing techniques can be broadly classified into the following the four categories which are listed below. We will discuss about each category.

1. Passive Cell Balancing
2. Active Cell Balancing
3. Lossless Cell Balancing
4. Redox Shuttle

1. Passive Cell Balancing

In the Passive Cell Balancing technique, there is a burn-off of excess energy from the higher energy cells till it matches or equals the lower voltage cell. There can be either fixed shunting or switching shunting resistor method for passive cell balancers.



Advantages of Passive Cell Balancing

- No need to balance a smooth working battery pack.
- There is no unnecessary wasting of energy when it is balanced.
- It maintains all cells at the same State of Charge.
- One of the low-cost methods for cell balancing.
- Offers self-discharging current and corrects long-term mismatch.

Disadvantages of Passive Cell Balancing

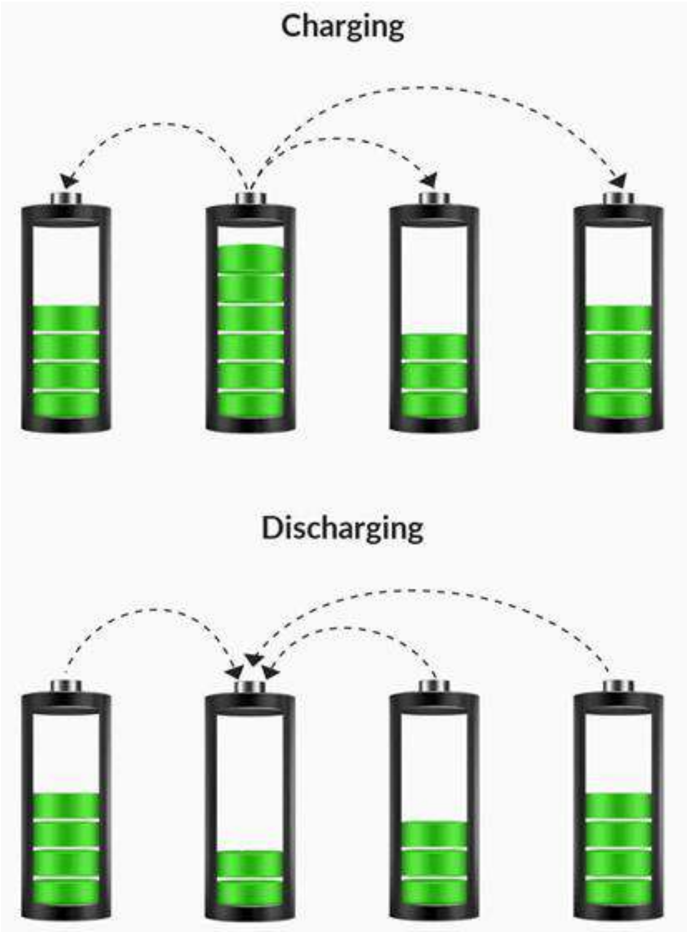
- It has low thermal management.
- There is zero balancings when SoC is full.
- This technique only balances the top 95% of each cell because it burns off excess energy.
- There is a massive amount of energy loss which results in low transmission efficiency.
- No improvements with battery run time.

2. Active Cell Balancing

In an active cell balancer, energy transfers from a higher voltage to a lower voltage cell within the battery. In other words, the cell with higher SoC transfers energy to a lower SoC cell. Thus, the active cell balancing technique avoids dissipating heat energy and rather uses shuttling or converters to balance out the energy levels of the highest voltage cell and the lowest.

The charge shuttling method transfers charges to reach an equal cell voltage. Whereas, energy converts transfer energy via transformers and conductors.

Instead of wasting all that energy as heat, an active cell balancer efficiently balances cells with tiny converter circuits that pass energy from the highest voltage cells to the lowest voltage cells. There are two different categories of active cell balancing methods: charge shuttling and energy converters. Charge shuttling is used to actively transport charges from one cell to another to achieve equal cell voltage. Energy converters use transformers and inductors to move energy among the cells of a battery pack.



Other active cell balancing circuits are typically based on capacitors, inductors or transformers, and power electronics interface. These entail:

Based on capacitors

- **Single capacitors –** this method is simple because it uses a single capacitor regardless of the number of cells connected in the battery. However, this method requires a large number of switches and intelligent control of the switches.
- **Multiple capacitors –** this method with multiple capacitors connected to each battery transfers unequal cell energy by multiple capacitors. It does not require a voltage sensor or closed-loop control.

Based on inductors or transformers

- **Single/ multiple inductors** – a cell balancing circuit with a single inductor has a small volume and low cost while multiple inductors have fast balancing speed and decent cell balancing efficiency.
- **Single transformer** – this method has a fast balancing speed with low magnetic losses.
- **Multiple transformers** – this cell balancer has a fast equalizing speed. However, it requires an expensive and complex circuit that prevents the transformer from being flooded.

Based on Power Electronics Interface

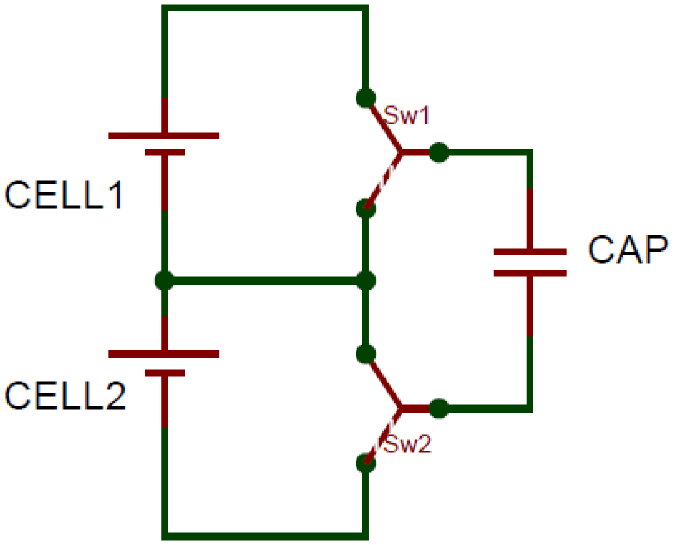
- **Flyback/ forward converter** – the energy of a high voltage cell is stored in the transformer. This cell balancer has high reliability.
- **Full-bridge converter** – this cell balancer has fast equalization speed and high efficiency.

Active balancers are capable of pushing a lot of current from one cell to another.

In Passive cell balancing the excess charge was not made used of, hence it is deemed to be inefficient. Whereas in active balancing the excess charge form one cell is transferred to another cell of low charge to equalize them. This is achieved by utilizing charge storing elements like Capacitors and Inductors. There are many methods to perform Active cell balancing lets discuss the commonly used ones.

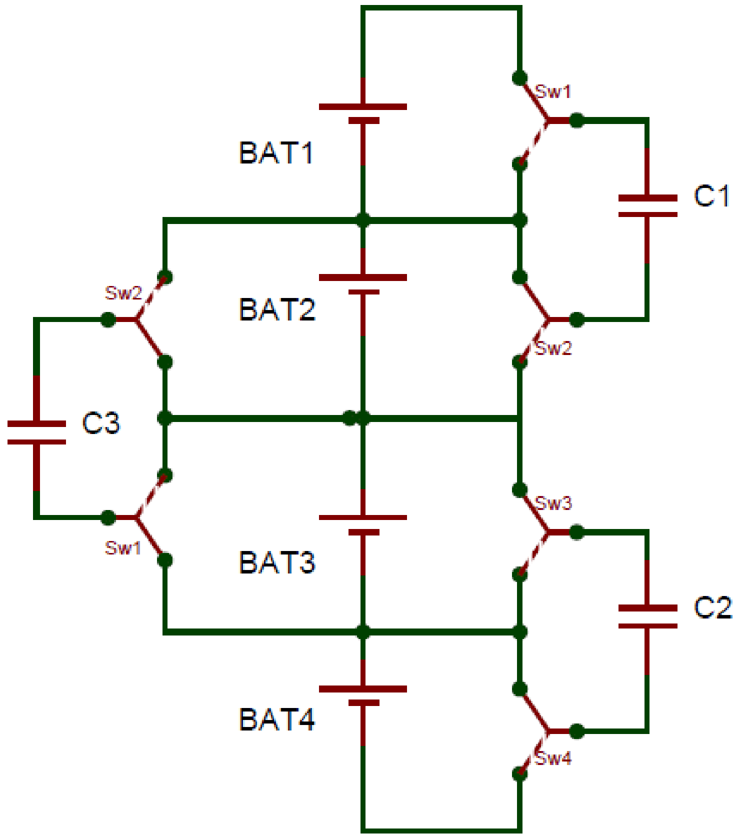
Charge Shuttles (Flying Capacitors)

This method utilizes capacitors to transfer charge from high voltage cell to low voltage cell. The capacitor is connected through SPDT switches initially the switch connects the capacitor to the high voltage cell and once the capacitor is charged the switch connects it to the low voltage cell where the charge from the capacitor flows into the cell. Since the charge is shuttling between the cells this method is called as charge shuttles. The below figure should help you understand better.



Charge Shuttles - flying capacitor illustration

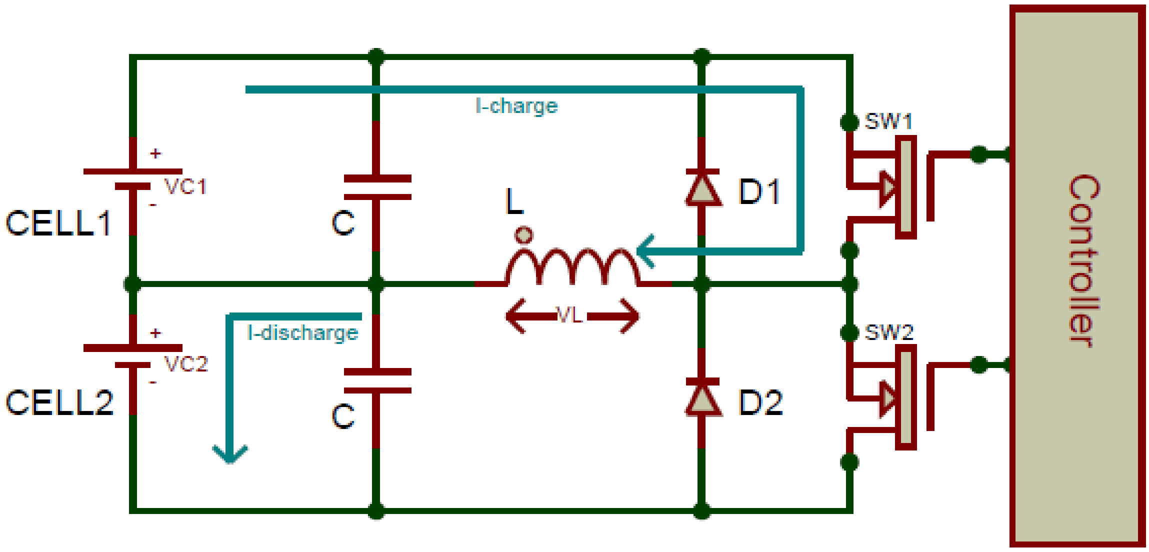
These capacitors are called the flying capacitors since the fly between the low voltage and high voltage cells carrying chargers. The drawback with this method is that charge can be transferred only between adjacent cells. Also it takes more time since the capacitor has to be charged and then discharged to transfer the charges. It is also very less efficient since there will be loss in energy during the charging and discharging of the capacitor and the switching losses also have to be accounted. The below image shows how the flying capacitor will be connected in a battery pack



Charge Shuttles - flying capacitor illustration

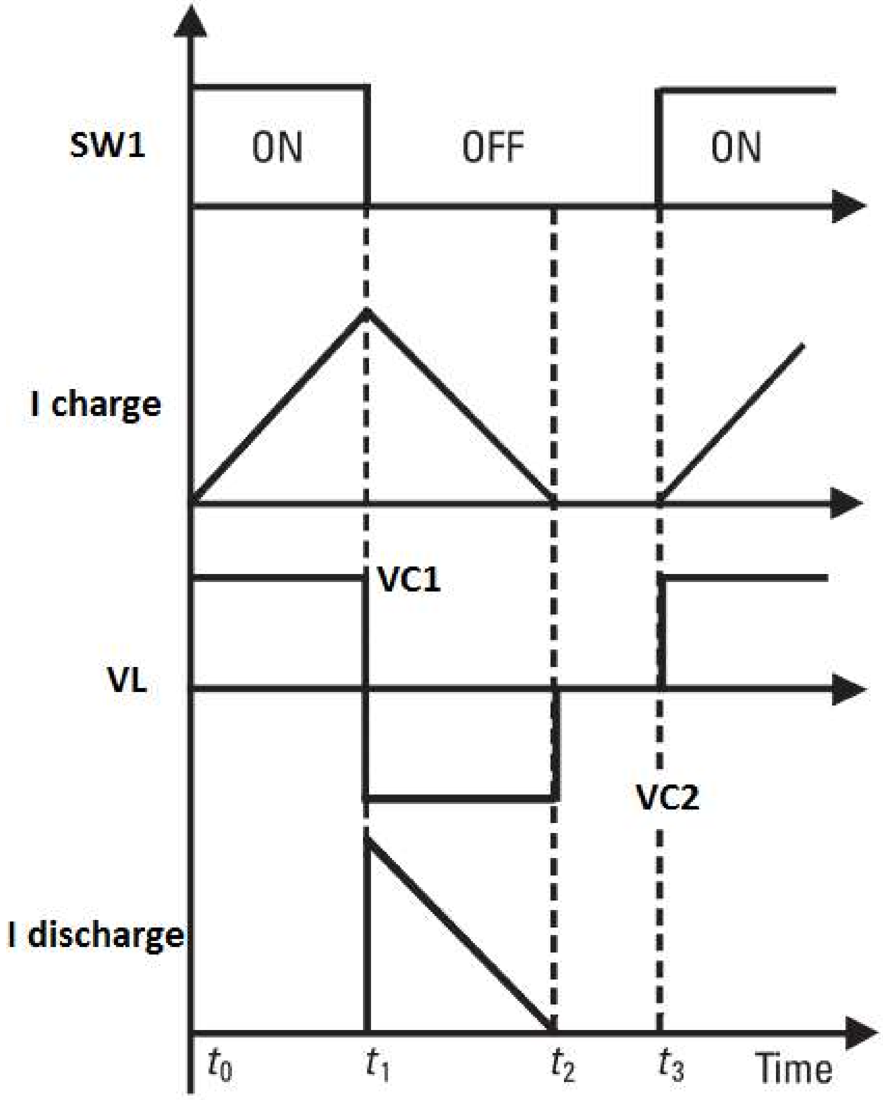
Inductive converter (Buck Boost method)

Another method of Active cell balancing is by using inductors and switching circuits. In this method the switching circuit consists of a buck boost converter. The charge from the high voltage cell is pumped in the inductor and then discharged into the low voltage cell by using the buck boost converter. The below figure represents an Inductive converter with only two cells and single buck boost converter.



In the above circuit charge can be transferred from cell 1 to cell 2 by switching the MOSFETS sw1 and sw2 in the following manner. First the switch SW1 is closed this will make the charge from cell 1 to flow into the inductor with current I-charge. Once the inductor is fully charged the switch SW1 is opened and the switch sw2 is closed.

Now, the inductor which is fully charged will reverse its polarity and begin to discharge. This time the charge form the inductor flows into the cell2 with current I-discharge. Once the inductor is fully discharged the switch sw2 is opened and the switch sw1 is closed to repeat the process. The below waveforms will help you get a clear picture.

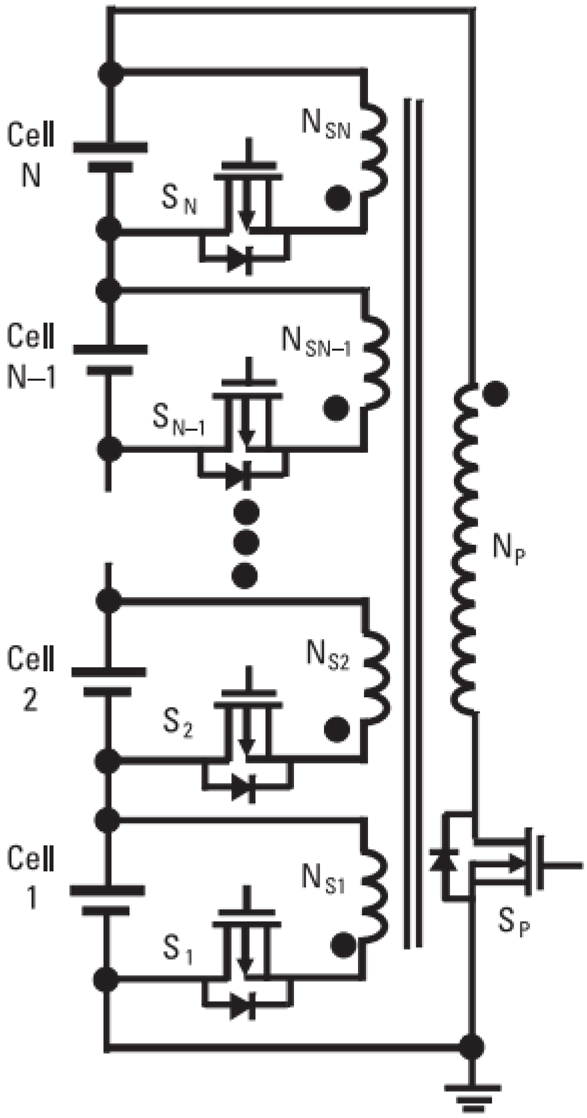


During the time t0 the switch sw1 is closed (turned on) which leads to the current I charge to increase and the voltage across inductor (VL) to increase. Then once the inductor is fully charged at time t1 the switch sw1 is opened (turned off) which makes the inductor to discharge the charge that it accumulated in previous step. When a inductor discharges it changes its polarity hence the voltage VL is shown in negative. When discharging the discharge current (I discharge) decrease from its maximum value. All this current enters the cell 2 to charge it up. A small interval is allowed from time t2 to t3 and then at t3 the whole cycle repeats again.

This method also suffers from a major disadvantage that charge could be transferred only from higher cell to lower cell. Also the loss in switching and diode voltage drop should be considered. But it is faster and efficient than the capacitor method.

Inductive converter (Fly back based)

As we discussed the buck boost converter method could only transfer charges form the higher cell to the lower cell. This problem can be avoided by using a Fly back converter and a transformer. In a flyback type converter the primary side of the winding is connected to the battery pack and the secondary side is connected to each individual cell of the battery pack as shown below



As we know the battery operates with DC and the transformer will have no effect until the voltage is switched. So to begin the charging process the switch on the primary coil side Sp is switched. This converts DC to pulsed DC and the transformer primary side is activated.

Now on the secondary side each cell has its own switch and the secondary coil. By switching the mosfet of the low voltage cell we can make that particular coil to act as a secondary for the transformer. This way the charge form the primary coil is transferred to the secondary coil. This causes the overall battery pack voltage to discharge into the weak cell.

The biggest advantage of this method is that any weak cell in the pack can be easily charged from the pack voltage and not particular cell is discharges. But since in involves a transformer, it occupies a large space and the complexity of the circuit is high.

Advantages of Active Cell Balancing

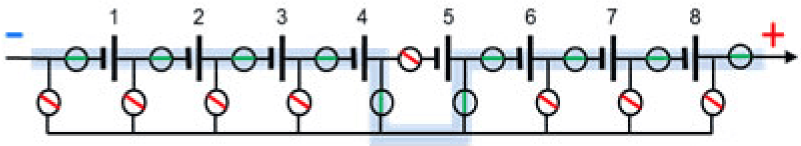
- Offers great performance when you have various cells in your battery having varying capacities.
- Improves efficiency of battery energies by reserving and retaining their excess energy.
- Active cell balancing enhances the cell's life expectancy.
- It is a speedy cell balancing technique.

Disadvantages of Active Cell Balancing

- There is a loss of energy (10-20%) while transferring energy amongst cells.
- Only one-way flow of energy from higher to lower.
- It has a complex control algorithm and expensive production cost as it needs a power electronics interface.

3. Lossless balancing

Lossless balancing is a recently developed method that reduces losses by reducing the hardware components and providing more software control. This also makes the system simpler and more easier to design. This method uses a matrix switching circuit which provides the capability to add or remove a cell from a pack during charging and discharging. A simple matrix switching circuit for eight cells is shown below.



During charging process the cell which is of high voltage will be removed from the pack using the switch arrangements. In the above figure the cell 5 is removed from the pack by using the switches. Consider the red line circles to be open switches and the blue line circle to be closed switches. Thus the rest time of the weaker cells are increased during the charging process so as to balance them during charging. But the charging voltage has to be adjusted accordingly. The same technique can be followed during discharging also.

4. Redox Shuttle

The final method is not for hardware designers but for chemical engineers. In lead acid battery we do not have the problem of cell balancing because when a lead acid battery is overcharged it causes gassing which prevents it from getting over charged. The idea behind Redox shuttle is to try achieving the same effect on lithium cells by altering the chemistry of the electrolyte of the lithium cell. This modified electrolyte should prevent the cell from getting overcharged.

Cell balancing algorithms

An effective cell balancing technique should combine the hardware to a proper algorithm. There are many algorithms for cell balancing and it depends on the hardware design. But the types can be boiled down to two different sections.

Measuring the Open circuit voltage (OCV)

This is the easy and most commonly followed method. Here the open cell voltages are measured for each cell and cell balancing circuit works to equalize the voltage values of all the cells connected in series. It is simple to measure OCV (Open circuit voltage) and hence the complexity of this algorithm is less.

Measuring Sate of charge (SOC)

In this method the SOC of the cells are balanced. As we already know measuring the SOC of a cell is a complex task since we have to account in the voltage and current value of the cell over a period of time to calculate the value of SOC. This algorithm is complex and used in places where high efficiency and safety is required like in aerospace and space industries.

Experiment 5

Aim: Study of Passive cell balancing.

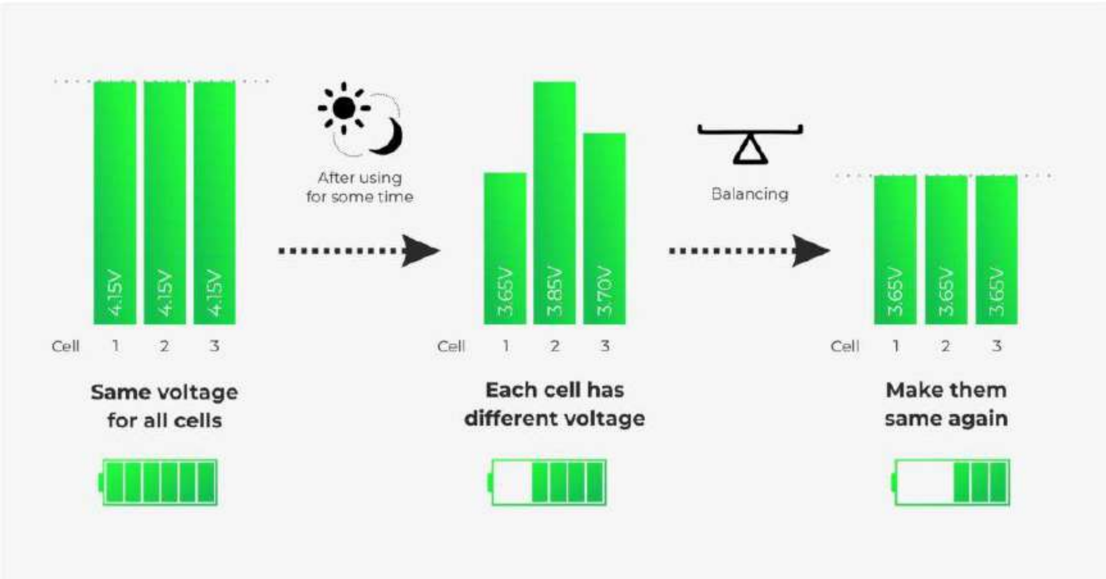
Apparatus Required:

- **Battery Management System Trainer -(MI-EV05)**
- **Patch Cords.**
- **Power Cable.**

Theory:-

Passive cell balancing method is the simplest method of all. It can be used in places where cost and size are major constraints. The following are the two types of passive cell balancing.

In the automotive and transportation marketplace, large battery stacks provide high output power without producing harmful emissions (that is, carbon monoxide and hydrocarbons) associated with gasoline-powered combustion engines. Ideally, each individual battery in the stack equally contributes to the system. However, when it comes to batteries, all batteries are not created equally. Even batteries of the same chemistry with the same physical size and shape can have different total capacities, different internal resistances, different self-discharge rates, etc. In addition, they can age differently, adding another variable in the battery life equation.



A battery stack is limited in performance by the lowest capacity cell in the stack; once the weakest cell is depleted, the entire stack is effectively depleted. The health of each individual battery cell in the stack is determined based on its state of charge (SoC) measurement, which measures the ratio of its remaining charge to its cell capacity. SoC uses battery measurements such as voltage, integrated charge and discharge currents, and temperature to determine the charge remaining in the battery. Precision single-chip and multichip battery management systems (BMS) combine battery monitoring (including SoC measurements) with passive or active cell balancing to improve battery stack performance. These measurements result in:

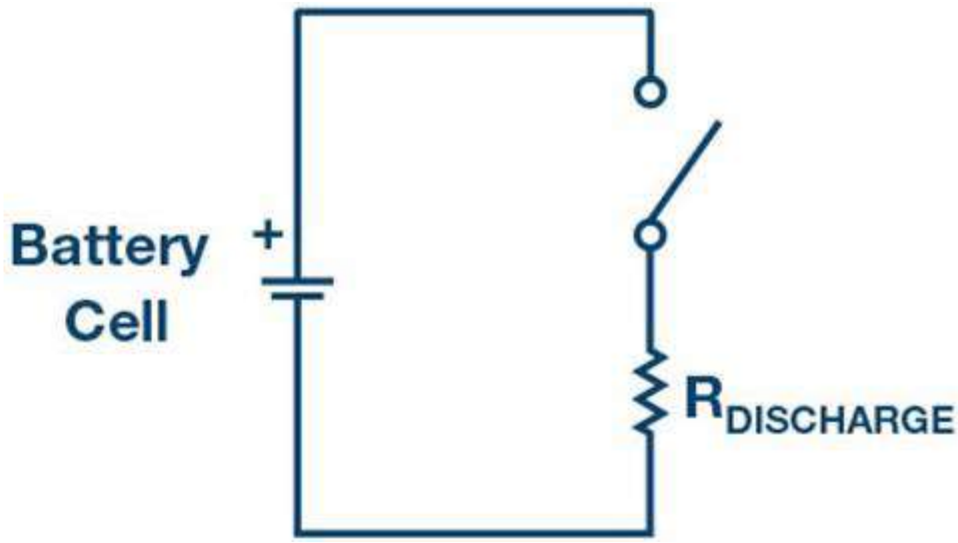
- Healthy battery state of charge independent of the cell capacity

- Minimized cell-to-cell state of charge mismatch
- Minimized effects of cell aging (aging results in lost capacity

Passive and active cell balancing offer different advantages to the battery stack and Analog Devices offers solutions in our battery management product portfolio for both methods. Let's first examine passive balancing.

Passive Balancing Allows All Cells to Appear to Have the Same Capacity

Initially, a battery stack may have fairly well matched cells. But over time, the cell matching degrades due to charge/discharge cycles, elevated temperature, and general aging. A weak battery cell will charge and discharge faster than stronger or higher capacity cells and thus it becomes the limiting factor in the run-time of a system. Passive balancing allows the stack to look like every cell has the same capacity as the weakest cell. Using a relatively low current, it drains a small amount of energy from high SoC cells during the charging cycle so that all cells charge to their maximum SoC. This is accomplished by using a switch and bleed resistor in parallel with each battery cell.



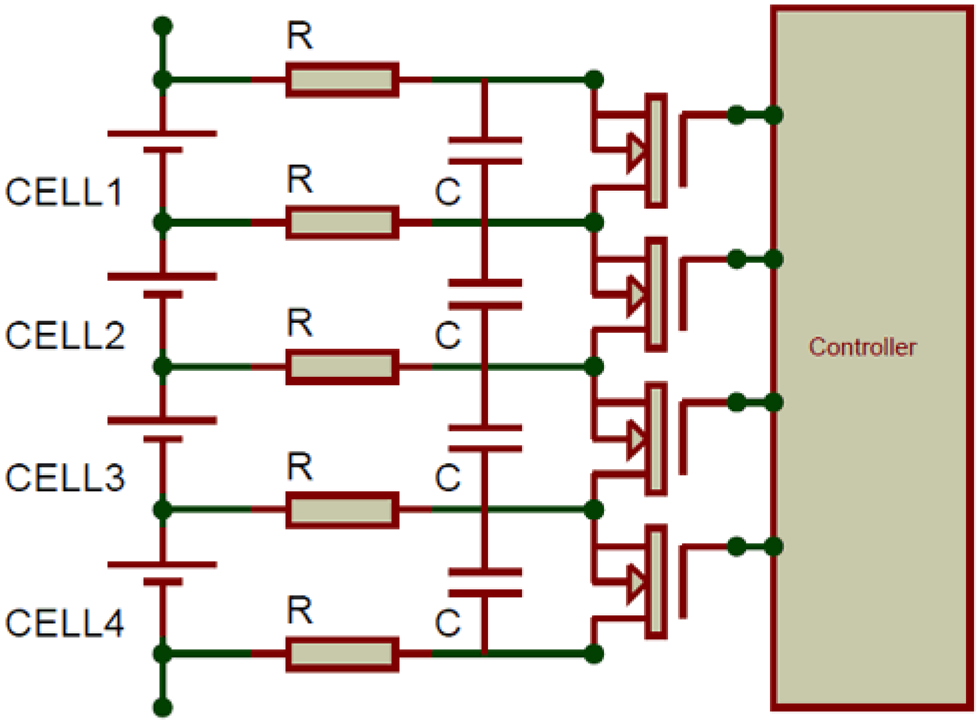
Passive cell balancer with bleed resistor

The high SoC cell is bled off (power is dissipated in the resistor) so that charging can continue until all cells are fully charged.

Passive balancing allows all batteries to have the same SoC, but it does not improve the run-time of a battery-powered system. It provides a fairly low cost method for balancing the cells, but it wastes energy in the process due to the discharge resistor. Passive balancing can also correct for long-term mismatch in self discharge current from cell to cell.

Charge Shunting

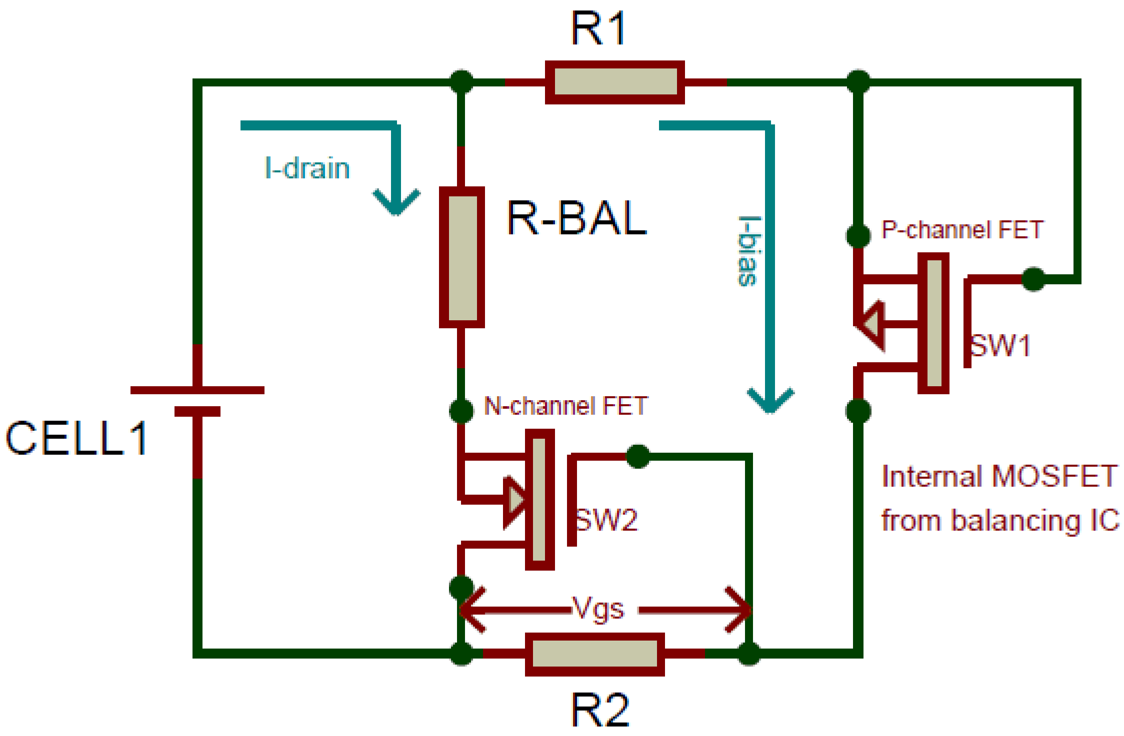
In this method a dummy load like a resistor is used to discharge the excess voltage and equalize it with other cells. These resistors are called as bypass resistors or bleeding resistors. Each cell connected in series in a pack will have its own bypass resistor connected through a switch as shown below.



Passive Cell Balancing using bypass resistors - charge shunting

The sample circuit above shows four cells each of which is connected to two bypass resistors through a switch like MOSFET. The Controllers measures the voltage of all the four cells and turns on the MOSFET for the cell whose voltage is higher than the other cells**.** When MOSFET is turned on that particular cell begins to discharge through the resistors. Since we know the value of resistors we can predict how much charge is being dissipated by the cell. The capacitor connected in parallel with the cell is used to filter voltage spikes during switching.

This method is not very efficient because electrical energy is dissipated as heat in the resistors and the circuit also accounts of switching losses. Another drawback is that the entire discharge current flows through the MOSFET which is mostly build into the controller IC and hence the discharge current has to be limited to low values which increases the discharging time. One way to overcome the drawback is **to** use an external switch to increase the discharge current as shown below.



External FET connection for high discharging current

The internal P-channel MOSFET will be triggered by the controller which causes the cell to discharge (I-bias) through the resistors R1 and R2. The value of R2 is selected in such a way that the voltage drop occurring across it due to the flow of discharge current (I-bias) is enough to trigger the second N-channel MOSFET. This voltage is called the gate source voltage (Vgs) and the current required to bias the MOSFET is called as biasing current (I-bias).

Once the N-channel MOSFET is turned on the current now flows through the balancing resistor *R-Bal*. The value of this resistor can be low allowing more current to pass though it and thus discharging the battery faster. This current is called as drain current (I-drain). In this circuit the total discharge current is the sum of drain current and bias current. When the P-channel MOSFET is turned off by the controller the biasing current is zero and thus the voltage Vgs also gets zero. This turns off the N-channel MOSFET leaving the battery to get ideal again.

Passive cell balancing ICs

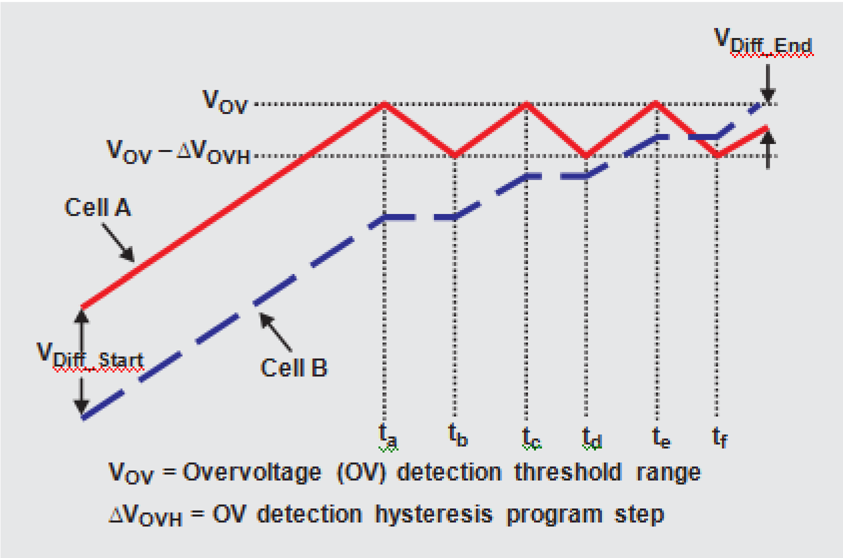
Even though the passive balancing technique is not efficient it is more commonly used because of this simplicity and low cost. Instead of designing the hardware you can also use few readily available IC's like LTC6804 and BQ77PL900 from renowned manufacturers like Linear and Texas instruments respectively. These ICs can be cascaded to monitor multiple cells and saves development time and cost.

Charge Limiting

The charge Limiting method is the most inefficient method of all. Here only the safety and life time of the battery is considered while giving up on the efficiency. In this method the individual cell voltages are monitored continuously.

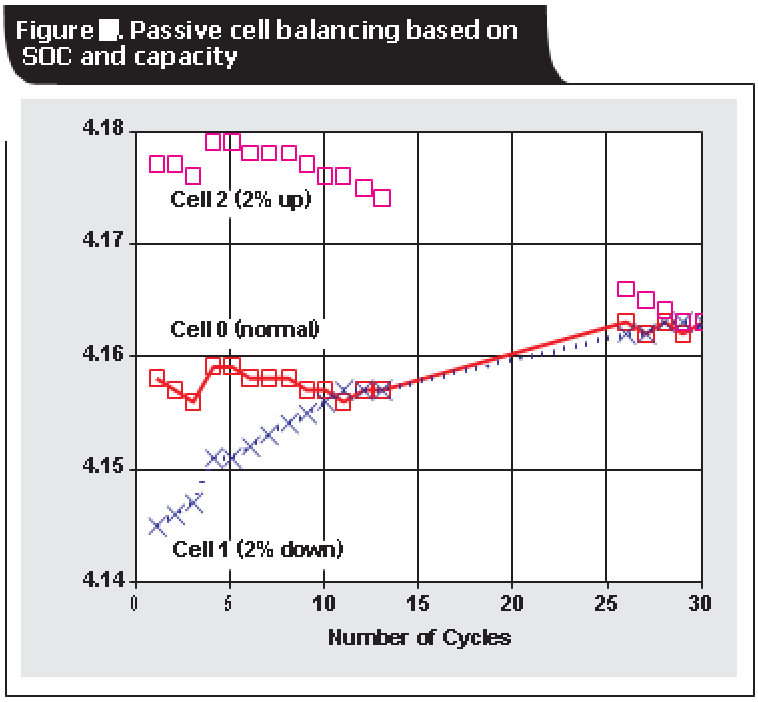
During the charging process even if one cell reaches the full charge voltage the charging is stopped leaving the other cells half the way. Similarly during discharging even if one cell reaches the minimum cut-off voltage the battery pack is disconnected from the load until the pack the charged again.

Although this method is inefficient it reduces the cost and size requirements. Hence it is used in an application where batteries could be often charged.



Passive cell balancing based on voltage

Above Fig. shows the operation principle. If any particular cell hits the threshold, charging is halted and an internal bypass is enabled. The charging is halted until the high-voltage cell hits the recovery limit, when the cell balancing will stop.



Passive cell balancing based on SOC & capacity

The bq20zxx family of Impedance Track™ fuel gauges uses a different balancing strategy based on cell SOC and capacity. Instead of balancing voltage divergence, the bq20zxx gauges calculate the charge,Q_{need}, that each cell needs to reach a full-charge state, then find the difference, ΔQ, between the Q_{need} of each cell. The balancing algorithm turns on the cell-balancing FETs during charging to zero out ΔQ.

The Impedance Track fuel gauges implement these tasks with ease because the total capacity, Q_{max}, and the SOC are readily available from the gauging function. Furthermore, since this method of cell balancing is not compromised by cell impedance (it actually monitors cell impedance), it can be per- formed at any time, during charge or discharge or even at idle. More important, it achieves the best passive-balancing accuracy (see above Fig.).

Advantages of Passive Cell Balancing:

- You should never have to balance a pack that is working perfectly.
- A cell cannot waste energy that it does not have. As soon as the energy bank is full, that is only when the cell has enough energy to balance.
- It allows all cells to have the same SoC.
- It provides a fairly low-cost method for balancing the cells.
- It can correct for long-term mismatch in self-discharge current from cell to cell.

Disadvantages of Passive Cell Balancing:

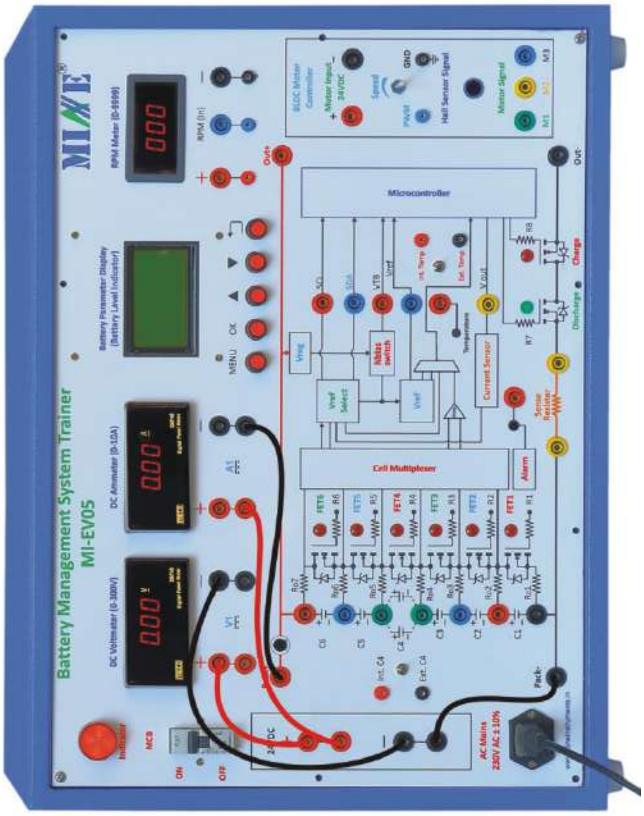
- Poor thermal management.
- They do not balance during the full SoC. They only balance through the top of each cell at around 95%. This is because if you have different cell capacities, you are forced to burn off the excess energy.

- Its energy transmission efficiency is usually low. Electrical energy is dissipated as heat in the resistors and the circuit also accounts for switching losses. In other words, it results in a high amount of energy loss.
- It does not improve the run-time of a battery-powered system.

Safety Precaution:

- Please make sure your power cable is connected properly to the trainer.
- Please make connections properly as mentioned.
- Do not apply any external high voltage or current source by which trainer get damaged.
- Do not touch motor pulley when motor is running condition.
- Make sure the loading arrangement is on no load condition when motor will start.

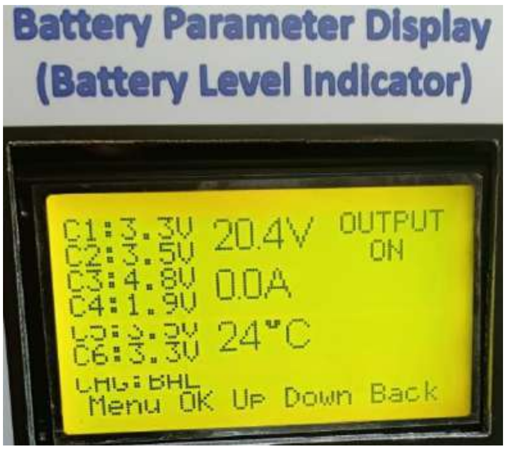
Connection Diagram:



Procedure:

- First of all, Connect the +24VDC (Red) to the DC Voltmeter +V1 (Red) via patch cord.
- Connect the -24VDC (Black) to the DC Voltmeter -V1 (Black) via patch cord.
- Connect the +24VDC (Red) to the DC Ammeter +A1 (Red) via patch cord.
- Connect DC Ammeter -A1 (Black) to the Battery Pack+ terminal via patch cord.
- Connect the -24VDC (Black) to the Battery Pack- terminal via patch cord.
- Always toggle switch of battery pack +Ve is in on condition when battery is charging.
- Make sure Internal toggle switch is in ON condition.
- After connecting the above connections, connect the mains AC plug ON and MCB switch ON for supply.
- Then we are able to see the appropriate Trainer Voltage on DC Voltmeter.
- For setting of BMS go to the section of Battery Perameter Display, and press the MENU key. After that Display shows Name of Company.

- Now display section is on and shown Battery Management system.
- It takes few seconds to show the Cell voltage on Display.



- Now Click on MENU key, all functions are shown on Display.

- Select "Normal Charging" using by updown key. Then after select "OFF" from Normal Charging.

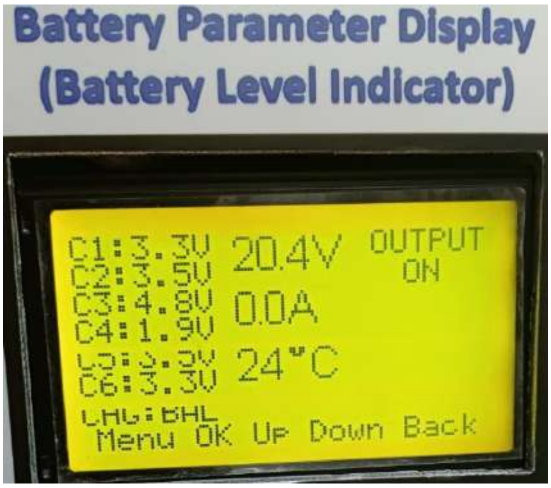
- Now go to the Balance Charging using by updown key and select "ON" option.

- Then after go to the option of “Under Voltage Limit” using by updown key, select it & set on 18.8V, if BMS voltage is below this value alarm is ON for alert. Otherwise it is charge or discharge as per need.

- Next select “Over Voltage Limit” using by updown key & set the voltage on 22.0V, if BMS Voltage is above this value alarm is ON for alert. Otherwise it is charge or discharge as per need.

- Next select “Current Limit” & set the Current on 1Amp, if BMS current is above this value alarm is ON for alert. (It is just for example set on current from1-5 Amp). Otherwise it is charge or discharge as per need.

- If Balance Charge is in ON condition, and the battery voltage is below the over voltage so each cell is charge as per appropriate cell voltage value, simultaneously another cell also want to reach the appropriate cell voltage value. (Each cell voltage shown on Display.)



- Every time each cell is charge on that time ammeter shows the value and charging LED is blink.

- If the battery voltage is above the under voltage so each cell is discharge as per appropriate cell voltage value, simultaneously another cell also want to reach the appropriate cell voltage value. (Each cell voltage shown on Display.)

- If all the cell voltage is not balance charging or discharging continue until the all cell voltage equal.
- When cell 1 is charge on that time ammeter shows the value of cell 1 & Charging LED is blink and also if cell 1 is discharge on that time FET 1 LED is blink.
- Same procedure for another cell balancing.

Conclusion: As per result Passive cell balance is done.

Experiment 6

Aim: Study of Battery discharge using Load (BLDC Motor).

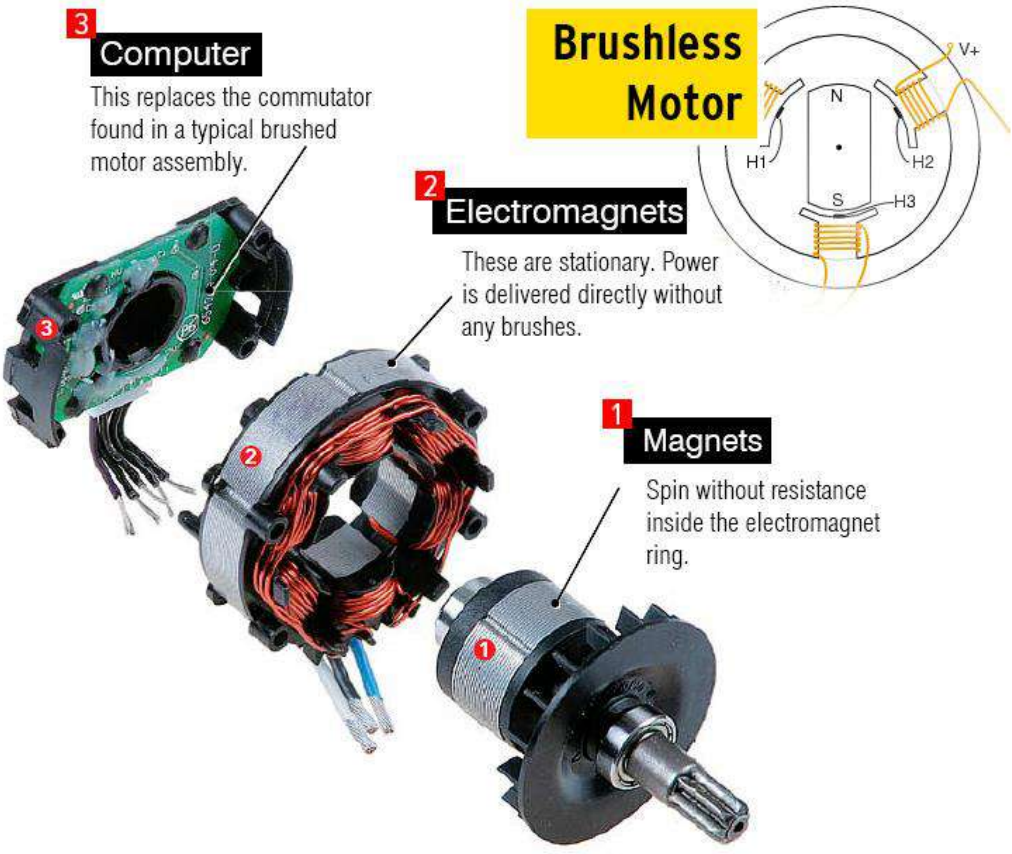
Apparatus Required:

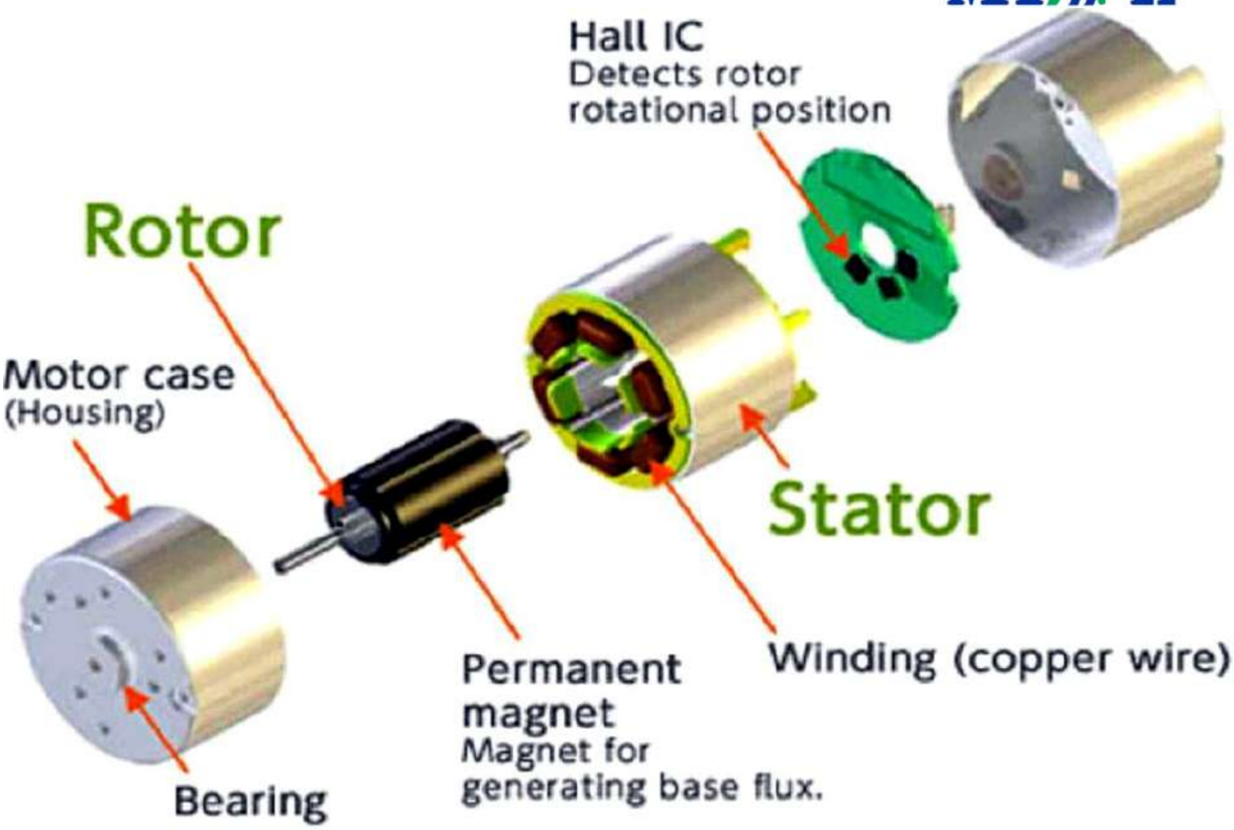
- **Electric Vehicle Trainer-(MI-EV05)**
- **Patch Cords.**
- **Power Cable.**

Theory:-

BLDC Motor:-

As their name implies, brushless DC motors do not use brushes. With brushed motors, the brushes deliver current through the commutator into the coils on the rotor. So how does a brushless motor pass current to the rotor coils? It doesn't—because the coils are not located on the rotor. Instead, the rotor is a permanent magnet; the coils do not rotate, but are instead fixed in place on the stator. Because the coils do not move, there is no need for brushes and a commutator.





Brushless DC motor structure

Electric Motor

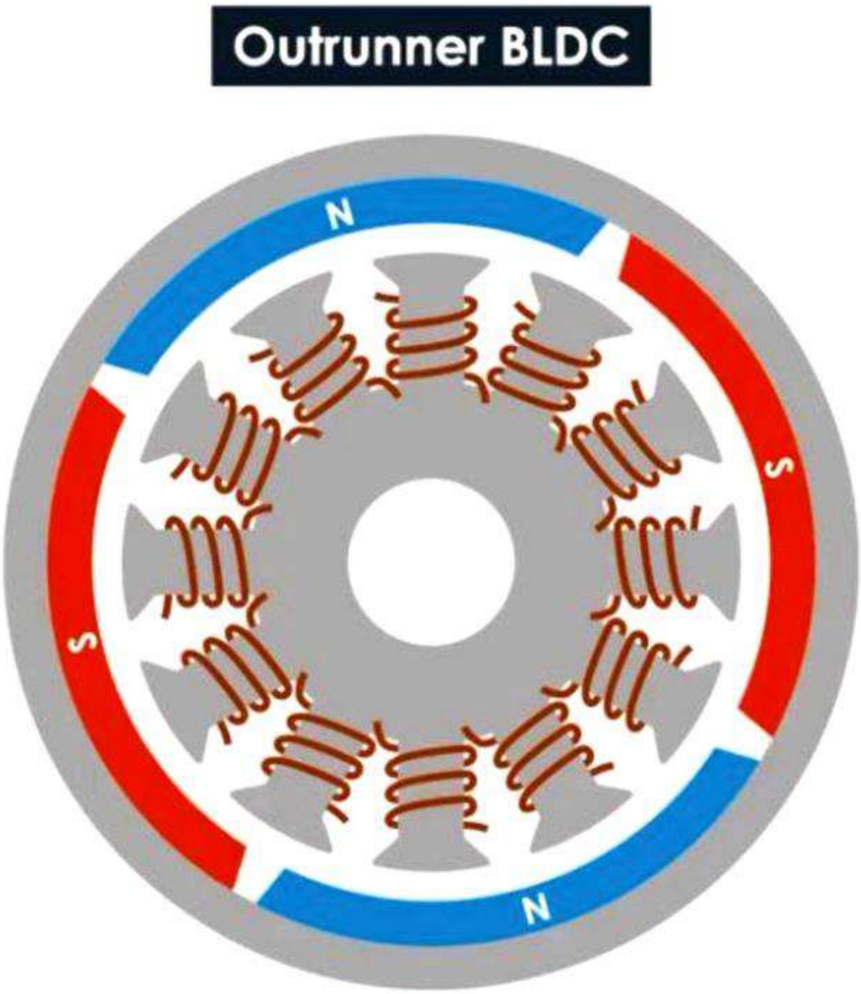
BLDC motors based on the physical design are two types, with different benefits and drawbacks

- **Outer rotor design**
- **Inner rotor design**

Any BLDC motor has two primary parts; the rotor, the rotating part, and the stator, the stationary part. Other important parts of the motor are the stator windings and the rotor magnets.

Outer rotor design:- the windings are located in the core of the motor. The rotor magnets surround the stator windings as shown here. The rotor magnets act as an insulator, thereby reducing the rate of heat dissipation from the motor. Due to the location of the stator windings, outer rotor designs typically operate at lower duty cycles or at a lower rated current. The primary advantage of an outer rotor BLDC motor is relatively low cogging torque.

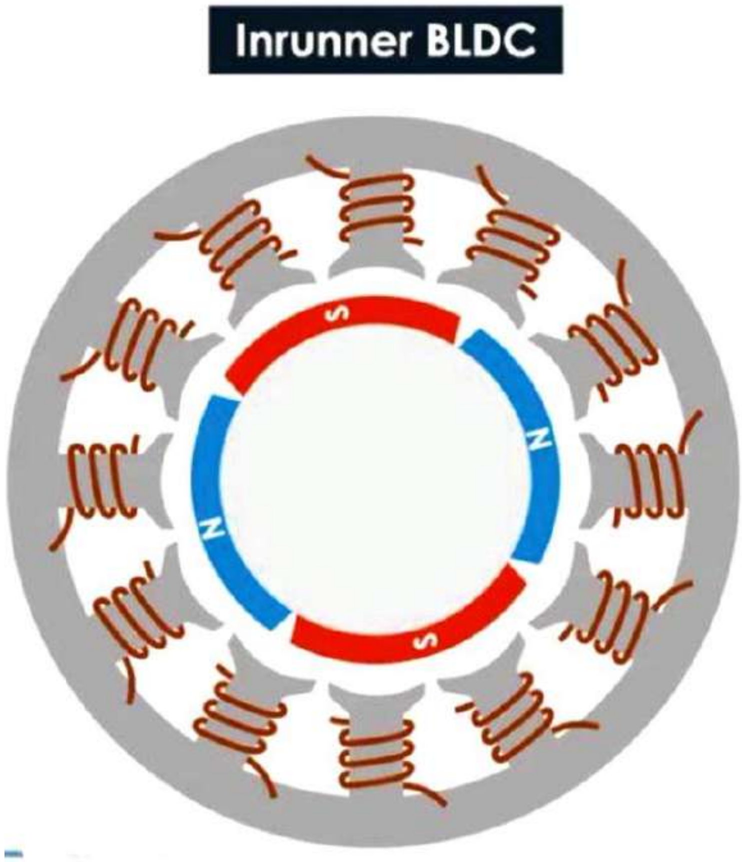
Application: - Two Wheeler hub motor and drone motors



BLDC motor designs- Outer rotor design

Inner rotor design:- the stator windings surround the rotor and are affixed to the motor's housing as shown here. The primary advantage of an inner rotor construction is its ability to dissipate heat. A motor's ability to dissipate heat directly impacts its ability to produce torque. For this reason, the overwhelming majority of BLDC motors use an inner rotor design. Another advantage of an inner rotor design is lower rotor inertia.

Application: - Rickshaw motor.



BLDC motor designs- Inner rotor design

Again, there are two types of BLDC based on the sensors

- **Sensorless BLDC Motor**
- **Sensor-based BLDC Motor**

Sensor less BLDC motor control - sometimes called sensorless trapezoidal control of BLDC motors—uses back EMF (BEMF) for determining the location of the motor's rotor (the motor's rotating part) with respect to the motor's stator (the stationary part).

Sensorless BLDC, A sensor based BLDC motor is more accurate but costly and is used for a specific application.

Sensor-based BLDC Motor BLDC motors use Hall-effect sensors for detecting the position of the motor's rotor with respect to the motor's stator.

Brushless DC or BLDC Motor -A Brushless DC Motor, BLDC accomplishes commutation electronically using rotor position feedback to determine when to switch the current. The BLDC motor is electrically commutated by power switches instead of brushes. The structure of Brushless DC Motor, BLDC is shown in figure below.

In simple words, a BLDC has no brushes and commutator for having unidirectional torque rather integrated inverter / switching circuit is used to achieve unidirectional torque. That is why these motors are, sometimes, also referred as **Electronically Commutated Motors.**

Construction of a BLDC Motor:

Electric motor, a BLDC motor also has a stator and a rotor. Here we will consider Stator and Rotor each separately from construction point of view.

BLDC Stator:

There are three types of the BLDC motor:

- Single-phase
- Two-phase
- Three-phase

Stator for each type has the same number of windings. The single-phase and three-phase motors are the most widely used. The simplified cross section of a single-phase and a three-phase BLDC motor is shown in figure below. The rotor has permanent magnets to form two magnetic pole pairs, and surrounds the stator, which has the windings.

A single-phase motor has one stator winding wound either clockwise or counter-clockwise along each arm of the stator to produce four magnetic poles as shown in above figure.

A three phase BLDC motor has three windings. Each phase turns on sequentially to make the rotor revolve.

Rotor:

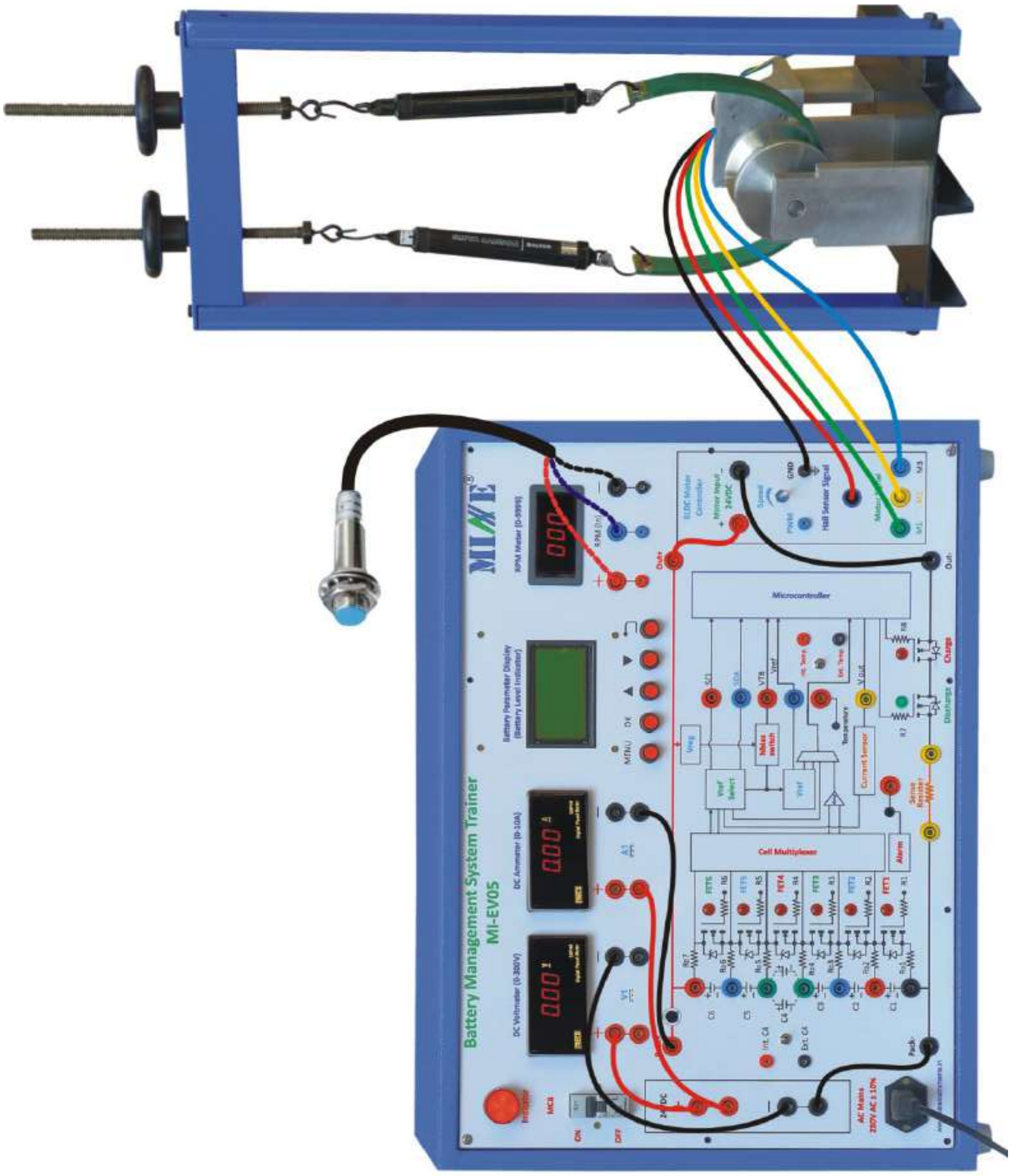
A rotor consists of a shaft and a hub with permanent magnets arranged to form between two to eight pole pairs that alternate between north and south poles. Figure below shows cross sections of three kinds of magnets arrangements in a rotor.

The magnetic equivalent circuit of BLDC machine was derived. Each parameter in the given circuit should be expressed analytically to calculate the motor performance

Safety Precaution:

- Please make sure your power cable is connected properly to the trainer.
- Please make connections properly as mentioned.
- Do not apply any external high voltage or current source by which trainer get damaged.
- Do not touch motor pulley when motor is running condition.
- Make sure the loading arrangement is on no load condition when motor will start.

Connection Diagram:



Procedure:

- First of all, Connect the +24VDC (Red) to the DC Voltmeter +V1 (Red) via patch cord.
- Connect the -24VDC (Black) to the DC Voltmeter -V1 (Black) via patch cord.
- Connect the +24VDC (Red) to the DC Ammeter +A1 (Red) via patch cord.
- Connect DC Ammeter -A1 (Black) to the Battery Pack+ terminal via patch cord.
- Connect the -24VDC (Black) to the Battery Pack- terminal via patch cord.
- Always toggle switch of battery pack+Ve is in on condition when battery is charging.
- Make sure Internal toggle switch is in ON condition.
- Connect Battery Out +Ve to the BLDC Motor Controller +Ve (Red) 24VDC Motor input.
- Also connect Battery Out–Ve to the BLDC Motor Controller -Ve (Black) 24VDC Motor input.
- Connect BLDC Motor to the Motor Signal M1 (Green), M2 (Yellow) & M3(Blue) and also connect hall sensor signal (Blue) via patch cord.
- Connect RPM Sensor meter to the RED, BLUE & Black of the RPM Meter.
- After connecting the above connections, connect the mains AC plug ON and MCB switch ON for supply.
- Then we are able to see the appropriate Trainer Voltage on DC Voltmeter.
- Firstly set the Current limit value is 1Amp on BMS Display.

- When load apply motor will start to discharge.
- Now motor is run and current value is increase as per speed of motor, shown on display of ammeter and RPM meter.
- When current value is achieve the 1Amp value on that time Alarm is ON and motor will stop & Discharging is also OFF.

Conclusion: BMS discharge using of BLDC Motor.

Experiment 7

Aim: Study of Thermal Cell cut-off.

Apparatus Required:

- **Electric Vehicle Trainer-(MI-EV05)**
- **Patch Cords.**
- **Power Cable.**

Theory:- BMS thermal runaway protection (TRP)
BMS thermal runaway protection is a condition that can occur in lithium-ion batteries when the battery cells get too hot. A thermal runaway event can cause the battery to overheat, leading to a fire or an explosion. To prevent this from happening, most lithium-ion batteries have a BMS thermal runaway protection feature.

The TRP will shut down the battery if it gets too hot, preventing it from going into thermal runaway. Most BMS thermal runaway protection features are set to activate at around 65 degrees Celsius, but you should check your battery's specific specifications to be sure.

If you are using a lithium-ion battery in a device that has a TRP feature, it is important to make sure that the TRP is enabled. If the BMS thermal runaway protection is not enabled, the battery may overheat and cause a fire or an explosion. To enable the TRP, check your battery's specifications or consult with the battery manufacturers.

Discover more about the main causes of thermal runaway and techniques for thermal runaway prevention in lithium-ion batteries.

Most lithium-ion batteries also have a thermal cutoff temperature (TCT). The TCT is the temperature at which the battery will shut down to prevent it from overheating.

The thermal cutoff temperature is typically set to around 80 degrees Celsius, but you should check your battery's specific specifications to be sure. If your battery does not have a TCT, it is important to keep it away from heat sources and use caution when charging it.

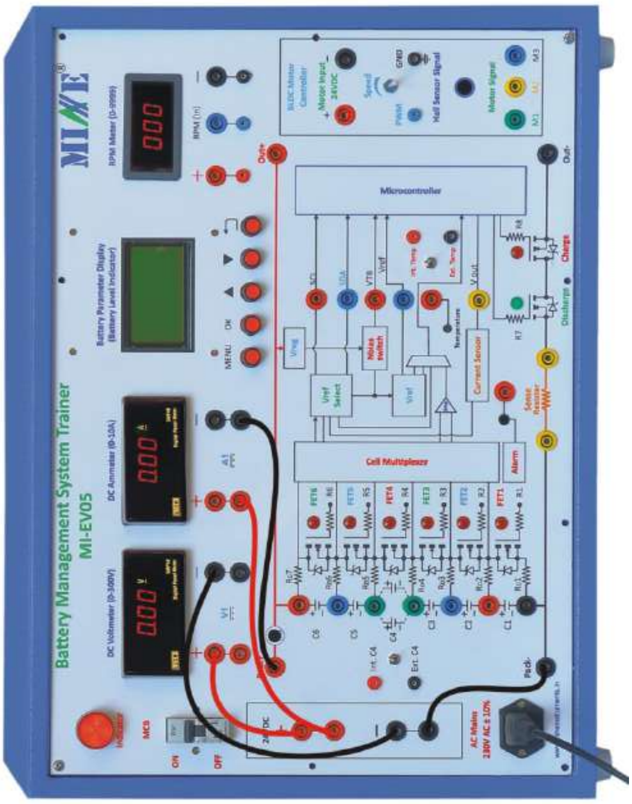
It is also important to note that the BMS thermal runaway protection (TRP) and thermal cutoff temperature are not the same things.

The TRP is a safety feature that will shut down the battery if it gets too hot, preventing it from going into thermal runaway. The TCT is the temperature at which the battery will shut down to prevent it from overheating. Both of these features are important for preventing fires and explosions in lithium-ion batteries.

Safety Precaution:

- Please make sure your power cable is connected properly to the trainer.
- Please make connections properly as mentioned.
- Do not apply any external high voltage or current source by which trainer get damaged.
- Do not touch motor pulley when motor is running condition.
- Make sure the loading arrangement is on no load condition when motor will start.

Connection Diagram:



Procedure:

- First of all, Connect the +24VDC (Red) to the DC Voltmeter +V1 (Red) via patch cord.
- Connect the -24VDC (Black) to the DC Voltmeter -V1 (Black) via patch cord.
- Connect the +24VDC (Red) to the DC Ammeter +A1 (Red) via patch cord.
- Connect DC Ammeter -A1 (Black) to the Battery Pack**+** terminal via patch cord.
- Connect the -24VDC (Black) to the Battery Pack- terminal via patch cord.
- Always toggle switch of battery pack +Ve is in on condition when battery is charging.
- Make sure Internal toggle switch is in ON condition.
- After connecting the above connections, connect the mains AC plug ON and MCB switch ON for supply.
- Then we are able to see the appropriate Trainer Voltage on DC Voltmeter.
- For setting of BMS go to the section of Battery Perameter Display, and press the MENU key. After that Display shows Name of Company.

- Now display section is on and shown Battery Management system.
- It takes few seconds to show the Cell voltage on Display.

- Now Click on MENU key, all functions are shown on Display.

- Next set the Temperature on 29^0 C, if BMS temperature is above this value alarm is ON for alert. (It is just for example set Temperature on as per need).If temperature is more than given value it is automatic cutt off the trainer, on that time charging & discharging is “OFF”.

- Also we can test temperature of external device so “ON” the ext. toggle switch of temperature section and connect the thermocouple +Ve (Red) & -Ve (Black) to the temperature section and see the temperature of thermocouple on BMS Display.

Conclusion: Able to see the internal and external temperature value and also see the Thermal cut-off is done using by above procedure.