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# BATTERIES USED IN ELECTRIC VEHICLES

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***Abstract: This paper presents a detailed comparison of different types of batteries used in electric vehicle (EV). In this paper, battery equivalent circuit and basic types of batteries used in EV have also been looked in to. Battery parameters like State of Charge (SoC), charge rate, discharge rate, specific energy, specific power are discussed in this paper to juxtapose different types of batteries. Batteries discussed in this paper are Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lead acid (Pb-acid) and Lithium ion (Li-ion). Working of battery is also discussed in this paper.***

***Index Terms: Battery, Electric vehicle (EV), Cell***

## I. INTRODUCTION

There are many different types and sizes of EV available in the market. In all of them, battery is the principle component. In both electrical and hybrid-electrical vehicle, battery is the most significant element, of highest cost, weight and volume. For detailed understanding of EV, a good knowledge about working of battery, it's parameters, it's types and selection criteria is needed. A battery is basically an electrical energy source. It is a combination of electric cells. In the cell, a positive electrode and a negative electrode is connected by an electrolyte, which converts chemical energy in to electrical energy and thus DC electricity is generated. A very wide range of batteries are available in the market like chargeable and rechargeable types. Still after so many years of research and development, a good fit of battery in an EV is not found. However, in the current scenario, if the working of battery, it's technical requirements and maintenance knowledge is known then a suitable design for EV can be made. After designing, the main thing comes is choosing a battery appropriately. A battery can be of small size and long runtime but the battery pack will wear out soon, another battery can be used for a long runtime but it is heavy. The third battery can be a combination of all these but it can be too expensive for a common purpose use. In this paper, we will examine the advantages and disadvantages of Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lead acid (Pb-acid) and Lithium ion (Li-ion) batteries. Also, the analysis will not only be based on battery's longevity and reliability but also on energy density, load characteristics, running costs, maintenance costs. A suitable battery for an equally suitable application will be suggested.

## II. BATTERY BASICS

A series combination of electrolytic cells gives rise to one battery. These cells are grouped in many casings to form a battery module. These battery modules are further combined in series or parallel way to give specified voltage and current to an EV drive. This combination forms a battery pack. A battery pack of an EV can consist of many hundreds of electric cells.

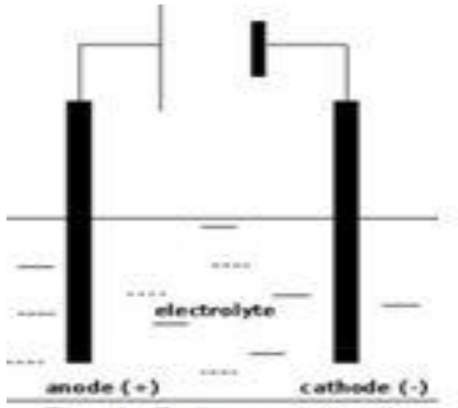

Fig. 1. Cell cross section

The basic components of electric cell are positive electrode, negative electrode, separator and an electrolyte. Chemical reactions like oxidation and reduction takes place at electrodes. In figure 1, the electrodes are shown. Electrons flow from one terminal to another during the charging of battery.
Description of battery components:

A. Positive electrode
Electrons get consumed at this electrode during cell discharge. It is made of sulfide or oxide or some other compound.

B. Negative electrode
Electrons are generated at this electrode during cell discharge. It is made up of a metal or an alloy.

C. Electrolyte
It permits conduction between positive and negative electrode in a cell. The electrolyte can be in the form of gel, liquid, resin, alkaline, acidic or solid material.

D. Separator
It acts as the insulating medium between two electrodes of the opposite sign. It should be permeable to the ions present in the electrolyte.

The equivalent circuit of battery is shown in figure 2. The battery has a fixed voltage E, terminal voltage V and internal resistance R. A current I flow in the circuit. By basic KVL,

$$V = E - IR \quad (1)$$

The internal resistance should be low as possible in the EV.

  

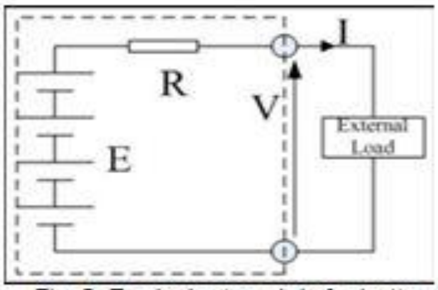


Fig. 2. Equivalent model of a battery

Two types of batteries are there. They are primary batteries and secondary batteries. Battery which can be used for a single use is called a primary battery. It is non-rechargeable. Battery that can be recharged is called a secondary battery. EVs need secondary battery for a long time run. Since the battery needs to get recharge for the EV to operate.

## III. BATTERY PARAMETERS

A. Battery Capacity

It is the charge produced at the negative electrode and expended at the positive electrode. It is measured in Amp-hours (Ah). One Ah is equivalent to 3600 Coulomb. Say, if the battery capacity is 100 Ah, that means, the battery can provide 100 Amps for one hour.

In a practical scenario, because of unnecessary cell reactions, the capacity of battery is affected if the entire charge is removed from it. It can be seen in figure 3.

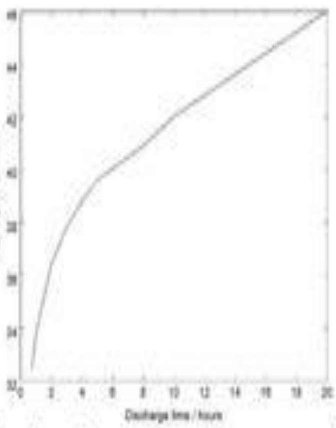

Fig. 3. Graph showing change in battery capacity with disch time

B. Energy Stored

The energy stored in a battery is the charge stored and it depends on its voltage. It is measured in Watthours (Wh). One Watthour is equivalent to 3600 Joules.

Energy (Wh) = Voltage * Amphours (2)

C. Discharge Rate

It is the rate at which the battery is discharged. It is the ratio of rated battery capacity to discharge time. It is expressed as Q/h rate.

D. State Of Charge (SoC)

It is the amount of charge which remained after discharge. Basically, it represents the present capacity of a battery. It is given by the expression,

SoCT(t) = QT – integral (i(t)) dt (3)

E. State Of Discharge(SoD)

It is the amount of charge which is withdrawn from a battery. It is given by the expression,

SoDT(t) = 1 – SoCT(t) (4)

F. Depth Of Discharge (DoD)

It is the ratio of battery capacity to which a battery is discharged.

$$DoD(t) = \frac{Q_T - SoC(t)}{Q_T} * 100\% \quad (5)$$

G. Specific Energy

It is the amount of energy stored per kilogram of battery mass. It is expressed in Wh/kg. Battery mass approximately can be found by specific energy and energy stored values.

H. Energy Density

It is the amount of energy stored for every cubic meter of battery volume. It is expressed as Wh/m3. Battery volume and further how much electrical energy can be made available can be found using energy stored and energy density values.

I. Specific Power

It is the amount of power acquired for every kilogram of battery. It is expressed as W/kg. Batteries with good specific energy and low specific power means the battery can store ample amount of energy but releases it slowly.

J. Battery temperature, heating and cooling needs

Batteries should run at ambient temperature ideally. But sometimes, it heats at start and cools at run. This kind of behavior is undesirable. So always the battery temperature, its heating and cooling requirements should be met.

K. Energy Efficiency

It is a variable quantity. Since it depends on voltage and Amphours ratings.

It is the ratio of amount of energy provided by a battery to the amount of energy returned before discharge state.

## IV. TYPES OF BATTERIES

A. Lead Acid Battery

This battery is in use since a long time due to its low cost, and easy availability.

1) Cell discharge operation

Here, the battery supplies energy to the motor to produce propulsion power. Following figure 4 shows the cell discharge operation. Negative electrode supplies the electrons while positive electrode consumes the electrons. Hydrogen, oxygen and sulfur is emitted, which are harmless if proper ventilation is available.

  

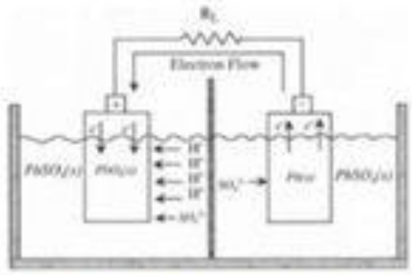

Fig. 4. Cell discharge operation

2) Cell charge operation

It's the reversal of cell discharge. Here, the electrons are supplied by positive electrode whereas the negative electrode consumes it. The current flows in such a way to deliver electrical energy. Following figure 5 shows the cell charge operation. Multi step charging method is used.

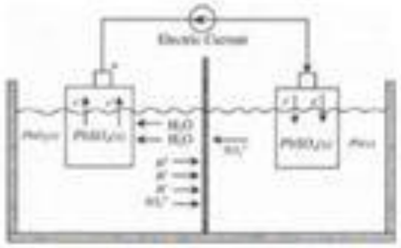

Fig. 5. Cell charge operation

Advantages

Cheap and easy to manufacture

Since it is a well-known technology, so it is reliable Self-discharge rate is low.

It is the lowest amongst all rechargeable batteries High discharge rate

Good range of specific power Used for short range Less requirement of maintenance

Limitations

Low energy density

Suited only for standby applications due to limited number of discharge cycles

Lead content can cause harmful effects

Chances of thermal runaway because of improper charging

Cannot be used for long range

Limited amount of energy can be stored

B. Nickel Cadmium (NiCd) Battery

This battery is an example of alkaline batteries. A chemical reaction between metal and an alkaline electrolyte takes place to produce electrical energy.

1) Cell charge - discharge operation

NiCd battery has a nickel oxide positive electrode and a metal cadmium negative electrode. Potassium Hydroxide (KOH) is the electrolyte. With the cell reactions, it is observed that cadmium hydroxide production rate is exactly equal to conversion rate to cadmium. This ensures that there will be full charge at positive electrode always. Such overcharging condition is waste of energy but it is not harmful to battery. This battery works well under strenuous condition. NiCd may lose its performance if not allowed to fully discharge periodically.

Advantages

Quick and easy to charge Long life

Excellent reliability

Good low temperature and load performances. It allows torecharge the battery even under low temperatures

Wide range of size and performance available

Most efficient in portable applications since storage and transportation is easier

Good number of charge/discharge cycles available Flat discharge voltage

Limitations

Low energy density High self-discharge

Contains toxic elements. Hence, harmful to use Expensive

Power delivered is insufficient sometimes

C. Nickel Metal Hydride (NiMH) Battery

It is like NiCd battery except the negative electrode in NiMH battery uses hydrogen which is being absorbed in the metal hydride. This makes the battery free from cadmium, which is a major advantage. Here, an additional energy source is available in the form of fuel cell. Since negative electrode acts as fuel cell. Among all the batteries, NiMH batteries is the most advanced one and it has been used in Toyota Prius. These batteries improved steadily and is considered as the most promising one in the future. It is also considered as a temporary option for lithium battery technology. They are mainly used for satellite applications.

1) Cell charge – discharge operation

During discharge, nickel oxyhydroxide becomes nickel hydroxide, at the positive electrode. Water and electrons are produced at the negative electrode, because of hydrogen being released from the metal. For charging, multi-step charging method is used. The cell voltage is changed from minimum to maximum values.

Advantages

High energy density

Less requirement of periodic discharge cycles Easy to store and transport

Not toxic to environment

Limitations

Very high self-discharge rate. About 50% greate than NiCd

Poor load performance under high temperature. Needs to be stored at low temperature Very high maintenance requirements Only 200-300 cycles. Limited life

20% cost is high than NiCd

D. Lithium ion Battery

Lithium metal is one of the metals which has high electrochemical reduction capacity and is the lightest. It provides high energy density.

1) Cell charge – discharge operation

  

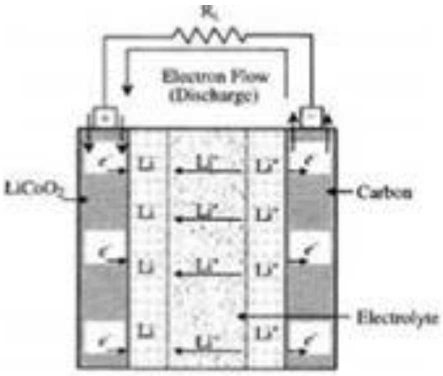


Fig. 6. Li ion Cell

During cell discharge operation, lithium ions travel from negative electrode to positive electrode through an electrolyte as shown in figure 6. Whereas at the positive electrode, these lithium ions are combined with the lithium compound material.
During cell charge operation, movement of lithium ions takes place from positive to negative electrode.

Advantages
High specific energy High specific power High energy density
High energy efficiency
High temperature performance Low self-discharge
Low maintenance required

Limitations
Expensive
Not easily portable
Requires protective circuit to maintain safe operation Life span reduces with storing at cool temperature
Low discharge current flow

## V. COMPARATIVE BATTERY CHARACTERISTICS

Table 1. Characteristics comparison of different batteries

| | Lead Acid Battery | NiCd Battery | NiMH Battery | Li Ion Battery |
|---|---|---|---|---|
| Specific Energy (Wh/kg) | 35-50 | 30-50 | 60-80 | 80-130 |
| Specific Power (W/kg) | 150-400 | 100-150 | 200-300 | 200-300 |
| Energy efficiency (%) | 80 | 75 | 70>90 | |
| Cycle life | 500-1000 | 1000-2000 | 1000-2000 | 1000 |
| Estimated cost US $/KWh | 100-150 | 250-350 | 200-350 | 200 |
| Nominal cell voltage(Volts) | 2 | 1.25 | 1.2 | 3.6 |
| Operating temp (degree C)(discharge) | (-20) to 60 | (-40) to 60 | (-20) to 60 | (-20) to 60 |
| Maintenance requirement | 3 to 6 months | 30 to 60 days | 60 to 90 days | Not required |
| Self-discharge/month (%) | 5 | 20 | 30 | 10 |
| Overcharge tolerance | High | Moderate | Low | Very low |

The NiCd battery has low energy density but can be used where long life span, good discharge rate and moderate price are required. Although it contains toxic element and is environment unfriendly. Applications in which NiCd batteries can be used are power tools, video cameras, radios and biomedical equipment. Compared to NiCd, NiMH battery has more energy density but the life span is less. Also, they don't possess any toxic element. They are widely used in laptops and mobile phones. Lead acid battery can be used where large power is required but weight of the battery is of not that significant. Such applications are UPS systems, emergency lighting, hospital equipment. Applications where high energy density but light weight is required, Li ion batteries are used. Such applications are tablets and mobile phones.

## VI. CONCLUSION

Many research and developments are observed in batteries. These developments surely suggest an appropriate battery which can be used widely in EV. Till then, approximations are to be made about the fair use of batteries. Lead acid batteries remain the cheapest one and is used for short range. Batteries like NiMH, Li ion, Sodium nickel chloride are used for medium range since they have sufficient energy density. Li ion and NiMH batteries are expensive but are the promising ones. Since they can be recharged at a faster rate. To enable EV in a wide range, no suitable battery is available. For this, we need help of hybrid EVs and that is totally a different prospective to look in to.

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