Unit J: Energy Storage

Overview

Lead acid batteries were invented in 1859 by Gaston Plante. Lead acid battery technology was the first rechargeable battery created for commercial use. Lead acid batteries are made up of an odd number of plates of lead inside a container with one more negative plate than positive. These combinations of plates are called cells. In lead acid technology each cell is usually 2 volts. The flow of current in lead acid batteries is reversible, this allows them to be recharged a number of times (cycle lives) before they are used up.

Higher voltage increases the amount of available horsepower. A motor rated at 20 hp at 72 volts would have almost 40 hp at 144 volts. RPMs increase as voltage increases, and RPMs are an important part of power.

Like gas vehicles, when we drive an EV faster we get less miles of range. This is because it takes more power to go faster. Instead of burning gas, we are using amps, or current. It takes 4x the amount of current to go 70 mph as it does to go 35 mph.

Storing electric power

It takes about 20 lbs of lead to get 1 mile in range on level ground for a 2500 lb electric vehicle. To go 50 miles on lead acid batteries you would need about 1000 lbs of batteries.

About 1/3 of the weight of a lead acid EV will be its batteries.

Most on-road EVs require at least 96 volts of battery service to operate effectively on city streets.

New battery technologies, such as Nickel Metal Hydride and Lithium Ion, can cost ten times as much as lead acid, but have better range than lead acid.

Battery Configuration

Parallel wiring = current is added together, voltage remains the same

Series wiring = voltage is added together, current remains the same

Watt Hour

A Watt Hour is a unit of energy. Most energy bills are defined by kilowatt hours, or the amount of energy multiplied by the number of hours it is used.

kg = kilogram, a unit of weight equal to 1000 grams.

L = liter, a unit of volume. One liter is equal to 0.001 cubic meter.

Energy-to-Weight Capacity

Lead Acid **energy-to-weight -**The capacity of Lead Acid batteries is measured in ampere hours. When multiplied by the average voltage over their discharge cycle we get watt-hours. Lead Acid batteries have a low **energy-to-weight** ratio. This means Lead

Acid batteries are heavy compared to the energy they can delivery. They typically feature 30-40 Wh/kg.

Energy-to-Volume

Lead Acid **energy-to-volume -**Lead Acid batteries also have a low **energy-to-volume** ratio, which means they deliver relatively low energy for their size. They typically feature 60-75 Wh/L.

Power-to-Weight

Lead Acid **power-to-weight -**A good feature of lead acid is they can deliver a lot of power quickly; this gives them a high **power-to-weight** ratio. They can deliver 180W/kg.

Self-Discharge

Lead acid batteries will self discharge, they can lose up to 25% of their power within one month, depending upon temperature.

Cost Comparisons

Lead acid batteries also have a relatively low cost, which make them a good economical choice for EV conversions.

Pack Voltage Determination

Our vehicle is designed for local city and highway use. For this reason, we will use a configuration of 144 volts. This voltage configuration will give us good range and acceptable acceleration to drive on the highway. This voltage is also best suited for our controllers, which will manage the power in the battery pack.

The main battery pack, where all batteries get wired together to power the vehicle, is called the "traction battery". We will also use another battery system to power the accessories.

Battery Ventilation and Cooling

Closed battery containers must maintain forced-air ventilation to remove gases and vapors. This is necessary regardless of which types of batteries are used, and operate any time the vehicle is operating or charging. Our battery system uses have both insulation and ventilation to keep it properly maintained.

Battery Isolation

To prevent the possibility of shock, the battery pack should never be grounded to the chassis. We test for 100% isolation by measuring voltage to the chassis from the battery pack. This voltage must = zero.

Pack Location and Rack Design

Batteries must be kept isolated from the passenger compartment. To maximize stability we use the lowest profile possible within a central location with good ground clearance. In the front of the S-10, our batteries are located right behind the grill; in the rear of the truck our batteries are located between the frame rails. This location reduces the chances of vehicle rollover and allows us to keep the usefulness of the truck bed.

We will install a tilt bed so we can easily access the batteries for their normal maintenance. The battery enclosures are padded and insulated to further protect the batteries from temperature extremes, bumps, and other outside weather elements. These enclosures are non-conductive to help isolate current from reaching the frame of the vehicle.

Disconnect Switch

A system disconnect switch must be manually operable within the driver's reach. The switch must be capable of disrupting full battery current.

Fusing

A 400 amp, current-limiting battery fuse must be used within the battery string to protect the power circuit. If excessive amperage goes through the system, the fuse will interrupt the current and protect the wiring and components in the circuit. It will also protect the driver and passengers from any excess voltage reaching the interior of the vehicle.

Battery Storage Technologies

Other battery technologies include Nickel Cadmium (NiCd), Nickel metal hydride (NiMH), and Lithium-ion (LiIon) used in many computers.

The most economic battery option for electric vehicles is still lead acid. They do not work as well, and are heavier than other types, but they are much less expensive. It is hoped that an increase in electric vehicles, and therefore an increase in the need for batteries, will allow for the newer technologies to come down in cost.

Battery Equalization

Batteries have a unique characteristic in that they can be added together to get bigger, but they still act as individual parts. An example of this is how they act during the charging process. Batteries get charged together, but the chemistry inside of them makes them unique individuals.

Most EVs have a main battery "traction pack" made up of multiple individual batteries wired in series to produce more voltage. These batteries each have multiple cells. The batteries are almost exactly the same, but they are not perfectly equal. Whether from construction, or inconsistencies in their original raw material they have slight differences in capacity and internal resistance. These compromised, "imperfect" batteries will act a little differently when they get charged and discharged over time.

Physics tells us, and It is true, that all batteries in series put out the same current , but the weaker batteries have to "work harder" to produce the current, so they're at a slightly lower state of charge than the others as the power in the battery pack gets used. Then as they charge, the weaker batteries need more recharge to get back to full charge.

The same law of physics tells us that when batteries are in series they all get exactly the same amount of recharge. This leaves the weaker battery a little undercharged, making it even weaker than it was before. It will keep getting weaker until eventually it fails. This hurts the rest of the pack because one bad battery will compromise the others wired to it. The EV battery pack is really only ever as good as its weakest link.

A solution to this problem is "equalization charge." This type of charge will slightly overcharge the batteries to make sure that the weakest cells are brought up to full charge. This must be done without damaging the strongest batteries by overcharging. Some sophisticated (expensive) chargers can actually read the voltage of each cell in each battery and adjust the charge to make sure that they are all equal.

Gassing or Boiling

Gassing occurs mostly at the end of the charge cycle. When lead-acid batteries are run down to a low level of charge, nearly all the charging current is readily accepted by the battery. Just like when you pour a glass of water to the very top, you can pour quickly at first, a rush of water goes in with no problem. As the glass fills, though, you need to pour more slowly and carefully to get the glass full to the brim.

Once the state of charge becomes more full, at about 80 percent of capacity, the batteries become more resistant to the current coming in. As a result the energy from the charger goes into heat and electrolysis of the water in the cells. This resulting bubbling of electrolyte is called "boiling" or "gassing". To compensate for this the charging current must cut back for the last 20 percent of the charging process. This tops off the batteries more slowly and prevents excessive boiling and gassing.

Recycling

Lead acid batteries are one of the most recycled commodities in the world. At most US locations you cannot even buy new batteries with retuning the old battery for recycling. Seller will charge a core-charge of the old battery is not brought in. Both the lead and plastics are recovered and used again for manufacturing new batteries.

Other Types of Batteries

Carbon battery is the very common AA, C and D dry-cell batteries. The electrodes are zinc and carbon, with an acidic paste between them that acts as the electrolyte.

Alkaline battery is used in common Duracell and Energizer batteries, the electrodes are zinc and manganese-oxide, with an alkaline electrolyte.

Lithium-iodide batteries are used in more specialized applications such as pacemakers and hearing aides because of their reliability and long life.

Nickel-cadmium batteries are made with nickel-hydroxide and cadmium electrodes, with potassium-hydroxide as the electrolyte (rechargeable).

Nickel-metal hydride batteries are rapidly replacing nickel-cadmium because it is not limited by the memory effect that nickel-cadmium has (rechargeable).

Lithium-ion batteries can be found in mobile electronics such as laptop computers and cell phones because they are very light and reliable (rechargeable).

Zinc-air batteries have a possibility for future use in EVs if a suitable zinc replacement system can be perfected.

Zinc-mercury oxide batteries have a somewhat limited use due to its mercury content.

Silver-zinc batteries are only used in specialized applications due to very high costs related to silver content.

Unit J Lesson Plans

Students will

- understand the basic design and function or lead acid battery technology;
- understand the physical nature of a lead acid battery;
- understand the economics of using lead acid vs. other technologies;
- understand battery systems and subcomponents;
- recognize battery changes under different conditions; and
- offer projections of future battery use and technology

Materials

- Computer with Internet access (optional)
- Unit J text
- Appendix D MSDS Sheets

Procedures

1. Lead acid batteries were invented a long time ago, yet we still use virtually the same design today. What features of the lead acid battery keep them valuable today? Why are batteries made the same way today as they were 150 years ago? What could manufacturers do to improve the design of lead acid batteries? Students may use correlation to existing news stories and events of modern companies for comparison.

2. The following has been said of battery technology for EVs: "Great range, fast acceleration, low price – you can have two but not all three." What two features would you select? On what factors would you base this decision? Will we some day be able to have all three?

3. Have students consider these questions:

   - ✓ What motivates battery manufacturers?
   - ✓ What happens to batteries when they wear out and need to be replaced?
   - ✓ How often to lead acid batteries need to be charged?
   - ✓ When is the lead acid battery "empty"?
   - ✓ What happens during the final stages (last 20%) of the charge?

4. Ask students to explain the processes of battery equalization and boiling/gassing. What do we use to resolve these issues?

5. Break the class into two groups and ask them to determine which factors will bring down the price of batteries. Have them give price projections and justify the timelines. What cars available on the market today will benefit from these changes? How large will EVs get if we can find the right battery management for them?

Evaluation

Use the following ten-point metric to evaluate students' work during this lesson.

- **Ten points:** Students understand all battery characteristics; students were able to answer all performance questions; their projections were creative and plausible.
- **Five points:** Students understand most battery characteristics; students were able to answer general performance questions; their projections were creative and plausible.
- **One point:** Students have difficult understanding battery features and characteristics; students were not able to answer performance questions; projections and ideas were limited.

Extensions

- Have the class select other technologies that were expensive initially but are now very inexpensive (or free). Have them justify their choices.
- Ask students to predict EV driving range capabilities in the next 10 years.
- What battery options could make EVs more popular? (ex. Quick-exchange, fast charging, disposables, fuel cells)
- Name three other battery technologies. Which other batteries technologies might work with EVs? Why?

Vocabulary

energy to weight
Definition: a sequential process of adding individual components in organized production facility
Context: Early automobiles were built by hand, they became much more economical and efficient when they were built in plants that used organized assembly lines.

energy to volume
Definition: the process of building many copies of a single item
Context: When the Ford Motor Company introduced automobile mass production in 1913 it changed the entire economics and quality of automobiles.

series wiring
Definition: batteries wired pos > neg > pos > neg > pos > neg to increase voltage
Context: Eighteen 8volt batteries are wired in series to make the 144volt system.

parallel wiring
Definition: batteries wired in groups of pos > pos > pos and neg > neg > neg to increase current
Context: A solar system might have eighteen 12volt batteries wired in parallel in its 12volt system.