LESSON

Energy Storage

BIG IDEA(S)

Understanding the capabilities of batteries is extremely important and is emerging globally as a critical technology for energy efficiency. Batteries are not a source of energy, but store energy and release energy stored within. A rechargeable battery, or a ban of multiple batteries, stores the daily PV production.

OBJECTIVES

Students will be able to:

- Design and install an off grid solar and energy storage system.
- Prepare a battery sizing calculator with all house loads.
- Explain the difference between power and energy as it pertains to battery systems.
- Choose the proper inverter and batteries for a given situation.

BRIGHT SOLAR FUTURES

SOLAR

TOPIC OF STUDY

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Year 1:
3 SESSIONS
(90 MINUTES EACH)
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TASK LIST SUBCATEGORY

401	Identify solar mechanical and electrical components
402	Select appropriate components to design a solar system
405	Identify factors related to system sizing and production
406	Differentiate the design of grid-tied, storage and off grid systems
416	Use solar industry vocabulary
507	Install energy storage equipment

OVERVIEW

There are three types of battery-based PV Systems and several types of batteries. One is a stand-alone (off grid) system with batteries providing energy storage. Students will design and install an off grid solar and energy storage system. This will include battery sizing and choosing the appropriate inverter for a specific system.

KEY TERMS

flooded lead acid battery (FLA)
valve regulated lead acid battery (VRLA)
lithium cobalt
lithium iron phosphate
depth of discharge
state of charge
deep-cycle batteries
shallow-cycle batteries
battery bank
stand-alone DC load-only systems
stand-alone system (off-grid)
inverter/charger
grid-tied battery back-up systems

STANDARDS

PA/SDP

3.4.10.A1. Illustrate how the development of **technologies** is often driven by profit and an economic market.

3.4.10.A2. Interpret how **systems** thinking applies logic and creativity appropriately in complex real-life problems.

3.4.10.B2. Demonstrate how humans devise **technologies** to reduce the negative consequences of other **technologies**.

3.4.12.B2. Illustrate how, with the aid of **technology**, various aspects of the environment can be monitored to provide information for decision making.

3.4.12.C2. Apply the concept that engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and the ability to visualize and think abstractly.

ETS1.B: Developing Possible Solutions: When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (secondary to HS-ESS3-2),(secondary HS-ESS3-4)

INSTRUCTIONAL

TEXTS/REFERENCES

Solar Electric Handbook, SEI, pp. 377-383

Solar Photovoltaic Basics, White: Chapter 6 System Components: Pages 88-90.

MATERIALS NEEDED

Teacher Prep: New Enphase Battery Installation

Content:

- New Enphase Battery Installation
- https://www.tesla.com/support/energy/more/installers/installing-powerwall
- Tesla Electrical Time-lapse
- Enphase Ensemble first install
- Simple Solar Power System for an off grid Cabin

MATERIALS

- Multimeter for measuring battery voltage
- Materials assembled for small groups to design and assemble a miniature off-grid system

IMPLEMENTATION (LESSON PLAN)

SESSION 1

ENGAGE

- You probably use batteries to power different devices every day, ranging from toys to TV remotes, without giving it much thought. Eventually the batteries will die and you have to replace them with new ones (or recharge them if they are rechargeable batteries). How much do you actually know about how batteries work?
  a. Batteries are not really a source of energy. They provide storage. Batteries used in PV systems are rechargeable, household batteries may or may not be.
  b. Batteries lose power at different rates when they are used. Rechargeable batteries last longer if they are recharged regularly and brought up to 100% capacity.

EXPLORE

1. Battery Experiment #1 (10th Grade)
   a. Demonstrated household rechargeable appliances: electric shaver, remote, flashlight (non or rechargeable)
   b. Test the voltage in a flashlight battery. Turn on a flashlight at the beginning of class and test it periodically to assess how the load is lowering the voltage. Graph.
2. Battery experiment #2: Measure battery voltage accounting for internal resistance. Testing household batteries for voltage taking into account internal resistance

   How To Test Standard AA, AAA, D, C, and 9V Batteries with a Multimeter

EXPLAIN

Understanding Batteries in System Design:

a. Understanding the capabilities of batteries is extremely important. The word battery is much like the word car in that there is a wide variety available with lots of different, and sometimes highly focused, capabilities. For example, some batteries can provide

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IMPLEMENTATION (LESSON PLAN) - CONTINUED

very high power (shallow cycle), but for a short period of time (think car battery). Other batteries are better at delivering smaller amounts of power, but over a long period of time (these are sometimes referred to as deep cycle batteries). Most home/business owners use deep cycle batteries. It used to be, with older battery chemistries, that draining a battery too far, past about 50% state of charge, could damage the battery and shorten its life. These older chemistries include flooded lead acid, absorbed glass mat, and gel batteries. New battery chemistries allow for almost 100% depth of discharge and they often carry warranties into the thousands of battery cycles (1 cycle = 1 complete discharge and recharge of the battery). Most modern batteries have warranties that go above 5,000 cycles (some even go to 10,000 cycles). These modern batteries use, almost exclusively, Lithium chemistry.

b. There are two main lithium chemistry batteries types on the market today: lithium cobalt and lithium iron phosphate.

   i. **Lithium cobalt** is cheaper and has better power density (so it is typically lighter/smaller than the other chemistry batteries). However, lithium cobalt is flammable and the fire creates a chain reaction that is extremely difficult to put out (maybe impossible).

   ii. **Lithium iron phosphate** is a bit more expensive and less power dense than Cobalt, but it does not have the same fire safety issues as cobalt. All lithium batteries are much more expensive, but last longer and store more energy, than lead acid batteries. Additionally Lithium batteries can be recharged faster than lead acid batteries.

   iii. Batteries are typically a low voltage, high current storage medium. Because there is no motion, instead of motion there is a chemical reaction involved with the storage of energy in batteries, they receive and will release DC current. Typical battery voltages are 12V, 24V, or 48V. Like solar panels, batteries can be strung together in series and/or parallel. When wired in series voltage is additive but current stays constant. When wired in parallel, current is additive but voltage stays constant. Batteries store energy chemically.

   iv. Show video: Different types of batteries and their properties. Best Batteries for Solar: Choose the Best for Your System

SESSION 2: PREPARE A BATTERY SIZING CALCULATOR

1. Prepare a Solar Battery Sizing Calculator Solar Battery Bank Sizing Calculator for Off-Grid
2. How do you know the state of charge of a battery? Review the battery specifications/data sheet. State of charge will be determined by the voltage of the battery.
3. How do you wire Batteries to a solar system? There are two solutions:

   a. **AC coupled** - In this scenario the solar will have an inverter that inverts the solar's DC current into AC current and the battery will have a separate inverter that inverts the battery current from DC to AC and the two systems will be coupled in a AC combiner panel. Some batteries come with inverters prewired to them so they must be AC coupled (Tesla and Enphase batteries come with inverters so they can only be AC coupled). The advantage of AC coupled batteries is that they can be retro-fit to almost any solar system. The disadvantage is that AC coupled batteries tend to cost more money and are less efficient.

   b. **DC coupled** - This is the most efficient form of battery integration. A single inverter inverts both the battery and solar power. The solar is coupled directly to the batteries however, a charge controller may be needed to match the solar voltage to the battery voltage. Additionally, the charge controller can monitor the battery state of charge to

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ensure it is not over charging or depleting the battery to a harmful state. The downside of DC coupled batteries is it can be very difficult to retrofit DC coupled batteries to an existing solar system. See DC Coupled battery.pdf

4. Use cases for energy storage:
    a. Hybrid system: A Hybrid system has multiple power sources. Typically the power sources are the electrical grid, solar, and a gas generator. Solar is a variable power, meaning it goes up and down during the day based on the amount of sunshine available and it does not produce energy at night. In order to smooth out the variability of solar energy either another power source is required or storage is needed. This is where batteries come in. Batteries can store excess energy that is produced by a solar system and can release that energy when the solar system is functioning at less than needed capacity for the home or if the solar is completely off. Hybrid systems require a transfer switch if a house is going to have power when the grid is off.
        i. Activities:
            1. Review the DocSet_Hybrid-Solar.pdf for how Hybrid systems are designed. Discuss the various components (Enphase Envoy Combiner, Enpower smart switch [transfer switch], Enphase Storage System [Encharge batteries], AC disconnect, etc.
            2. Review the spec sheets for the Enpower and Encharge devices. What is the peak current output of the Encharge batteries? What is the rated current output? Why does this matter? Peak and rated current relate to the amount of current that can be used at a single point in time. Understanding not only the energy devices use but also the power is critical.
            3. Have students use the Energy Use calculator to figure out how much energy their home uses. This will help students understand how to size batteries. Additionally you can discuss the smart Load-and-Solar-Circuit-Control-Technical-Brief.pdf document to talk about the need for load control so as to not overwhelm the batteries.
    b. There are a number of use cases for hybrid solar
        i. **Time-of-use rates**: Hybrid solar can help homeowners save money on their electricity bills where time-of-use rates are in place. Typically time-of-use rates have on peak and off peak rates. For example, in the PECO service area the highest rate is from 4PM - 6PM during weekdays. The kWh rate is about $.19 - $.21 per kWH. However, off peak rates are typically $.10 - $.12 per kWh. Then there is a third rate class named Late Night Rates that drops all the way down to $.06 per kWh. As one might guess, homeowners will want to use as little electricity as possible during the peak hours. However, that is a very hard time to avoid using electricity. It's around the time that people come home from work or school and need to start doing things around the house. This is where a Hybrid solar system can help people save money. The inverter can be programmed to allow the house to run off of solar energy and stored battery power during peak (and even off peak hours). If for some reason the solar is not able to fully recharge the battery because of high energy use during the day the inverter can be programmed to charge the battery during the very inexpensive Late Night Rate hours. By using electricity when it is cheap and not using it when it is expensive the homeowner can live their normal lifestyle while saving money because the solar and storage energy is offsetting the expensive peak electrical rates.
        ii. **Peak shaving**: Certain industrial users of electricity are billed based on their electrical demand (aka power, kW not kWh) as well as their energy use (kWh). The demand charges can be quite high. If they can stay below a certain demand level

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then they can save a significant about of money. For ex. If the utility charges Acme Co. $1,000 for 50 - 99 kW of demand but will charge $2,000 if Acme goes up to and over 100 kW of demand then Acme can save $1,000 per month by staying under 100 kW of demand. Acme might find it financially prudent to install a smart building system that can signal a hybrid solar system to release battery power when the building hits 90 kW of demand. This will allow Acme to never go past the 99kW threshold and save them $1,000 per month.

iii. **Power grid issues**: Some areas of the United States (Hawaii for example) have high voltage issues with their power grid. This means it is illegal to backfeed solar into the grid. To be clear, a house can still use power from the grid to operate (or to charge batteries) but it is not allowed to feed any solar or battery stored power back into the grid. For this type of scenario hybrid solar systems with battery storage make a lot of sense. During the day, when the solar is over producing, power can be stored in batteries and then at night that power can be released as the house needs it (but no more than the house needs!). This way a homeowner can still use solar power without ever feeding it back into the grid.

iv. **Resilience**: There are businesses that require power 24/7/365 in order to function, such as hospitals. If a hospital goes without power it can lead to life and death issues. Additionally there are materials in hospitals that can be very costly to replace. Such as vaccines. If a hospital were to have a power outage and its vaccine refrigerators go off there could be many thousands of dollars of lost medicine. A hybrid solar power system with battery back-up can help to resolve this issue. The hospital could isolate the vaccine refrigerator circuit on a critical loads panel and have that panel fed by solar and batteries. If designed properly, should there be a power outage the solar and batteries will isolate themselves from the grid (through the use of an automatic transfer switch) and continue to power the vaccine fridges until the gird comes back. The same general idea is true for homeowners. Imagine there is a terrible storm and power is knocked out for many days (actually not so hard to imagine these days). Consider that the person living in the home may have life saving medicine in their refrigerator (such as insulin for diabetics). Having a hybrid system would allow the refrigerator to remain cold and some circuits in the house to function until the utility was able to restore power to the area. Resilience is a huge reason people opt for hybrid solar and battery systems.

c. Batteries in place of a generator

SESSION 3

1. Off grid systems
   a. **Gardens or outdoor structures** - Sometimes gardens or other small outdoor structures need small amounts of power. It is not financially feasible to ask the electric company to hook up power for such a small site so a small off grid system may provide the perfect solution. ACTIVITY: Have students pick a small water pump and some LED lights for a garden and design a small off grid system to power them. The system should have at least 3 days of autonomy.
   b. **Construction signage** - One of the most common uses for off-grid solar. You may see these types of setups when driving down the highway and seeing a digital construction sign. Often these signs need power so they can be seen. They are in remote locations and only need to be in place for a temporary time period. It is easier to set up a few solar panels, batteries, and inverter (if needed) than it is to get any sort of power hookup to the location.

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c. **Off Grid homes**

i. **Houses** - ***Electrically Designing an offgrid house will be the class's Capstone project. Students will need to use a load calculator to ensure all loads are considered. Students will need to understand the orientation of the house so that you can maximize the solar gain. Additionally, students will need to consider how to make the house itself as energy efficient as possible. While the students will be able to design with any solar and battery system they choose, Students will be able to use the battery system in the classroom to get hands-on experience building a DC coupled battery system.***

ii. **Tiny houses** - The tiny house movement is a new trend, but growing fast. Some tiny houses are completely off grid. Powering such a small space presents some challenges as there is not much room for solar panels or battery storage. Off-The-Grid Tiny House Is Pure Design Genius

iii. **Buses or RVs** - Another new trend is converting old school busses (sometimes called Skoolie's) into living spaces or adding solar panels and batteries to RV's. This allows for mobile, off grid living. The Most Cleverly Designed School Bus Conversion - A True Apartment On Wheels

iv. **Earthships** - Earthships are intentionally designed off grid houses that try to use as little energy and resources as possible. They are often built using old tires for walls and as much recycled material as possible. They can be built into the ground so that they use the natural temperature of the earth to stay warm in the winter and cool in the summer. Since Earthships are so energy efficient they do not need much in terms of solar power and battery storage to operate. Some Eathships need as little as 5 solar panels and 4 batteries to operate off grid.

- Incredible Small Off-Grid Earthship Home
- New Earthships capture more energy, water & food at lower cost

2. Design and Assemble a Small Off-Grid System in the Lab

HOMEWORK

1. Find your home electrical bill and examine it. What are the charges on it? Will solar offset all of the charges on your bill? Are there any demand charges? When you add up all of the kWh rates on the bill what is your effective electrical rate? When you add up every single charge on your bill (you will need to spread non-kWh charges over the total number of kWh charges) what is your electricity kWh rate?
2. What materials could you recycle locally if you were going to build an earthship where you live. How many solar panels would you need?

MEETING INDIVIDUAL NEEDS

The Capstone project will involve hands-on wiring and assembling of batteries, inverters and solar panels. There are also lots of video resources available for visual learners.

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RESOURCES/LINKS

Different types of batteries and their properties.

Best Batteries for Solar: Choose the Best for Your System

What is a hybrid solar system? — Clean Energy Reviews

Making Sense of Demand Charges: What Are They and How Do They Work?

We build Earthships and retrofit houses — Earthship Biotecture michael reynolds

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