EE580 – Solar Cells
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- Lecture 09
- Photovoltaic Systems

Several types of operating modes

- Centralized power plant
  - Large PV system located in an optimum location, feeding into the grid
- Distributed Grid tied
  - Small residential type systems
- Stand Alone systems
  - No grid connection needed or wanted

Residential Side Mounted

You loose as much as 50% of the power if one cell is shadowed

Could have future issues when the tree matures and shadows PV system

Residential Stand Alone

Roof Mounted System

- National Center for Appropriate Technology Headquarters (Butte, MT)
- 60 Shell SP75 modules each rated at 75 Watts
- Peak electrical output of system is 4.5 kilowatts
- 48 volt system connected to utility grid with inverter
- Provides 15% of building electrical consumption

Hybrid System

Mobile Systems

Simple Stationary

Emergency

Temperature Dependence ?

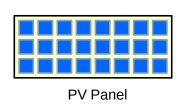
Solar Cells loose efficiency with the increase in temperature
Colder is better

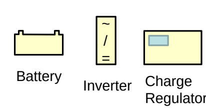
Solar Heating

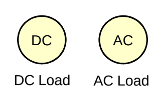
Solar heating (70-90%) is more efficient than photovoltaic (15%-20%) but electricity generally is more useful than heat.

Solar Cell Basics

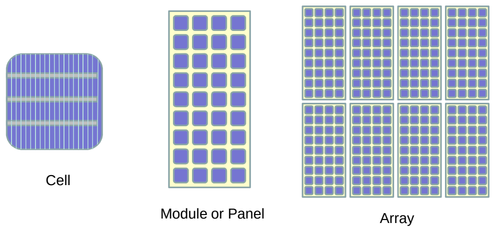
- Photovoltaic Systems
  - Cell → Panel → Array
  - Balance of System (BOS)
    - Mounting Structures
    - Storage Devices
    - Power Conditioners
  - Load
    - DC
    - AC







Modularity: Solar Cell to Array



- **Cell (c-Si 10×10 cm² η=15% P=1.5Wp V=0.5V I=3A)**
- **Solar panel (36 c-Si cells P=54Wp I=3A V=18V)**
- **Solar array**

Specifications of PV Modules

- Type
  - c:Si, a-Si:H, CdTe
- Rated Power Max: P_{max} (W_p)
- Rated Current: I_{MPP} (A)
- Rated Voltage: V_{MPP} (V)
- Short Circuit Current: I_{SC} (A)
- Open Circuit Voltage: V_{OC} (V)
- Configuration (V)
- Cells per Module (#)
- Dimensions (cm x cm)
- Warranty (years)

Storage Devices (Batteries)

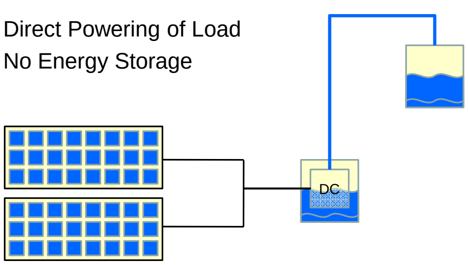
- Advantages
  - Back up for night and cloudy days
- Disadvantages
  - Decreases the efficiency of PV system
  - Only 80% of energy stored retainable
  - Adds to the expense of system
  - Finite Lifetime ~ 5 - 10 years
  - Added floor space, maintenance, safety concerns

Power Conditioners (Inverters)

- Limit Current and Voltage to Maximize Power
- Convert DC Power to AC Power
- Match AC Power to Utilities Network
- Protect Utility Workers during Repairs

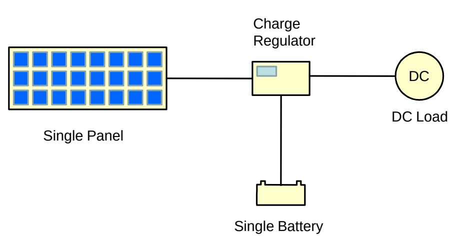
Simple DC

- Direct Powering of Load
- No Energy Storage



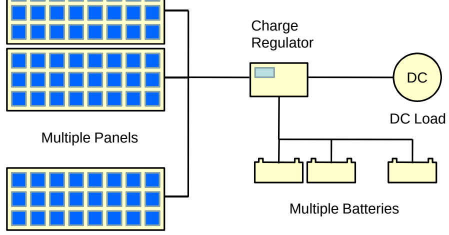
Small DC

- Home and Recreational Use



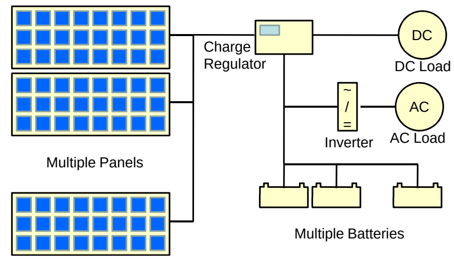
Large DC

- Home and Recreational Use
- Industrial Use



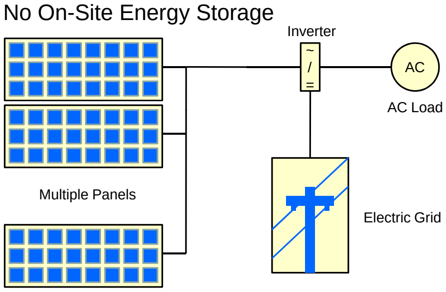
Large AC/DC

- Both AC and DC loads



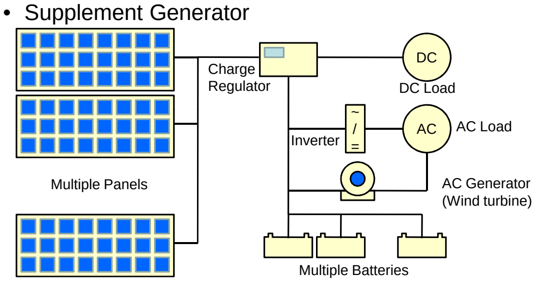
Utility Grid Connected

- No On-Site Energy Storage



Hybrid System

- Supplement Generator



PV System Design Rules

- 1. Determine the total load current and operational time
- 2. Add system losses
- 3. Determine the solar irradiation in daily equivalent sun hours (EHS)
- 4. Determine total solar array current requirements
- 5. Determine optimum module arrangement for solar array
- 6. Determine battery size for recommended reserve time

Determining Your Load

- The appliances and devices (TV's, computers, lights, water pumps etc.) that consume electrical power are called loads.
- **Important** : examine your power consumption and reduce your power needs as much as possible.
- Make a list of the appliances and/or loads you are going to run from your solar electric system.
- Find out how much power each item consumes while operating.
  - Most appliances have a label on the back which lists the Wattage.
  - Specification sheets, local appliance dealers, and the product manufacturers are other sources of information.

Power Consumption (DC)

- **DC [W]**
  - Television 60
  - Refrigerator 60
  - Fan 15-30
  - Radio/tape 35
  - **Lighting**
    - Bathroom 25-50
    - Bedroom 25-50
    - Dining room 70
    - Kitchen 75
    - Living room 75

Power Consumption (AC)

- **AC [W]**
  - Television 175
  - Radio 15-80
  - **Lighting**
    - Bathroom 75
    - Bedroom 75
    - Dining room 100
    - Kitchen 100
    - Living room 75
  - **Tools**
    - Saw circular 800-1200
    - Saw table 800-950
    - Drill 240
- **AC [W]**
  - **Appliances**
    - Refrigerator 350
    - Freezer 350-600
    - Microwave oven 300-1450
    - Toaster 1100-1250
    - Washing machine 375-550
    - Coffee maker 850-1500
    - Air conditioner 3000-4000

Determining your Loads II

- Calculate your AC loads (and DC if necessary)
- List all AC loads, wattage and hours of use per week (Hrs/Wk).
- Multiply Watts by Hrs/Wk to get Watt-hours per week (WH/Wk).
- Add all the watt hours per week to determine AC Watt Hours Per Week.
- Divide by 1000 to get kW-hrs/week

Determining the Batteries

- Decide how much storage you would like your battery bank to provide (you may need 0 if grid tied)
  - expressed as "days of autonomy" because it is based on the number of days you expect your system to provide power without receiving an input charge from the solar panels or the grid.
- Also consider usage pattern and critical nature of your application.
- If you are installing a system for a weekend home, you might want to consider a larger battery bank because your system will have all week to charge and store energy.
- Alternatively, if you are adding a solar panel array as a supplement to a generator based system, your battery bank can be slightly undersized since the generator can be operated in needed for recharging.

Batteries II

- Once you have determined your storage capacity, you are ready to consider the following key parameters:
  - Amp hours, temperature multiplier, battery size and number
- To get Amp hours you need:
  1. daily Amp hours
  2. number of days of storage capacity (typically 5 days no input)
  - 1 x 2 = A-hrs needed
  - Note: For grid tied – inverter losses

Temperature Multiplier

Temp °F	Temp °C	Multiplier
80 F	26.7 C	1.00
70 F	21.2 C	1.04
60 F	15.6 C	1.11
50 F	10.0 C	1.19
40 F	4.4 C	1.30
30 F	-1.1 C	1.40
20 F	-6.7 C	1.59

Select the closest multiplier for the average ambient winter temperature your batteries will experience.

Determining Battery Size

- Determine the discharge limit for the batteries (between 0.2 - 0.8)
  - Deep-cycle lead acid batteries should never be completely discharged, an acceptable discharge average is 50% or a discharge limit of 0.5
- Divide A-hrs/week by discharge limit and multiply by "temperature multiplier"
- Then determine A-hrs of battery and # of batteries needed - Round off to the next highest number.
  - This is the number of batteries wired in parallel needed.

Total Number of Batteries Wired in Series

- Divide system voltage (typically 12, 24 or 48) by battery voltage.
  - This is the number of batteries wired in series needed.
- Multiply the number of batteries in parallel by the number in series –
- This is the total number of batteries needed.

Determining the Number of PV Modules

- First find the Solar Irradiance in your area
- **Irradiance** is the amount of solar power striking a given area and is a measure of the intensity of the sunshine.
- PV engineers use units of Watts (or kiloWatts) per square meter (W/m^2) for irradiance.
- For detailed Solar Radiation data available for your area in the US: http://rredc.nrel.gov/solar/old_data/nsrdb/

How Much Solar Irradiance Do You Get?

Calculating Energy Output of a PV Array

- Determine total A-hrs/day and increase by 20% for battery losses then divide by "1 sun hours" to get total Amps needed for array
- Then divide your Amps by the Peak Amps produced by your solar module
  - You can determine peak amperage if you divide the module's wattage by the peak power point voltage
- Determine the number of modules in each series string needed to supply necessary DC battery Voltage
- Then multiply the number (for A and for V) together to get the amount of power you need
  - P=IV [W]=[A]x[V]

Charge Controller

- Charge controllers are included in most PV systems to protect the batteries from overcharge and/or excessive discharge.
- The minimum function of the controller is to disconnect the array when the battery is fully charged and keep the battery fully charged without damage.
- The charging routine is not the same for all batteries: a charge controller designed for lead-acid batteries should not be used to control NiCd batteries.
- Size by determining total Amp max for your array

Wiring

- Selecting the correct size and type of wire will enhance the performance and reliability of your PV system.
- The size of the wire must be large enough to carry the maximum current expected without undue voltage losses.
- All wire has a certain amount of resistance to the flow of current.
- This resistance causes a drop in the voltage from the source to the load. Voltage drops cause inefficiencies, especially in low voltage systems (12V or less).
- See wire size charts here: www.solarexpert.com/Photowiring.html

V=IR

or

R = V/I

Inverters

- For AC grid-tied systems you do not need a battery or charge controller if you do not need back up power –just the inverter.
- The Inverter changes the DC current stored in the batteries or directly from your PV into usable AC current.
  - To size increase the Watts expected to be used by your AC loads running simultaneously by 20%

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Books for the DIYer

- If you want to do everything yourself also consider these resources:
  - Richard J. Komp, and John Perlin, *Practical Photovoltaics: Electricity from Solar Cells,* Aatec Pub., 3.1 edition, 2002. (A layman's treatment).
  - Roger Messenger and Jerry Ventre, *Photovoltaic Systems Engineering,* CRC Press, 1999. (Comprehensive specialized engineering of PV systems).

Photovoltaics Design and Installation Manual

- Photovoltaics: Design & Installation Manual by SEI Solar Energy International, 2004
- A manual on how to design, install and maintain a photovoltaic (PV) system.
- This manual offers an overview of photovoltaic electricity, and a detailed description of PV system components, including PV modules, batteries, controllers and inverters. Electrical loads are also addressed, including lighting systems, refrigeration, water pumping, tools and appliances.