FLORIDA SOLAR ENERGY CENTER

Creating Energy Independence Since 1975

Introduction to Electricity

A Research Institute of the University of Central Florida

Objectives

- Become familiar with some fundamentals laws of electricity

Objectives

- Become familiar with some fundamentals laws of electricity
- Become familiar with basic theory, principles, and technology associated with common electrical power systems

Objectives

- Become familiar with some fundamentals laws of electricity
- Become familiar with basic theory, principles, and technology associated with common electrical power systems
- Identify equipment and tools used in common electrical work

Objectives

- Become familiar with some fundamentals laws of electricity
- Become familiar with basic theory, principles, and technology associated with common electrical power systems
- Identify equipment and tools used in common electrical work
- Identify sources of information pertaining safety and electrical work

Basic Electrical Theory

- Electric charge
- Voltage
- Current
- Resistance
- Power
- Energy
- Direct Current (DC)
- Alternating Current (AC)

Electric Charge

- Atoms have protons (positively charged), electrons (negatively charged), and neutrons (no charge)

Electric Charge

- Atoms have protons (positively charged), electrons (negatively charged), and neutrons (no charge)

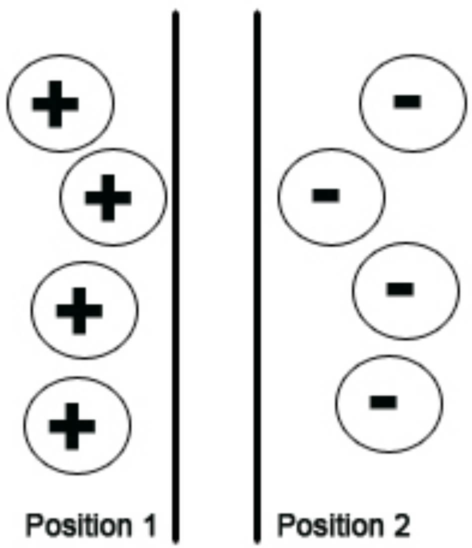
- Similar charges repel, while opposite charges attract

Electric Charge

- Atoms have protons (positively charged), electrons (negatively charged), and neutrons (no charge)
- Similar charges repel, while opposite charges attract
- Scientists and engineers exploit this principle to make electrons “do work”

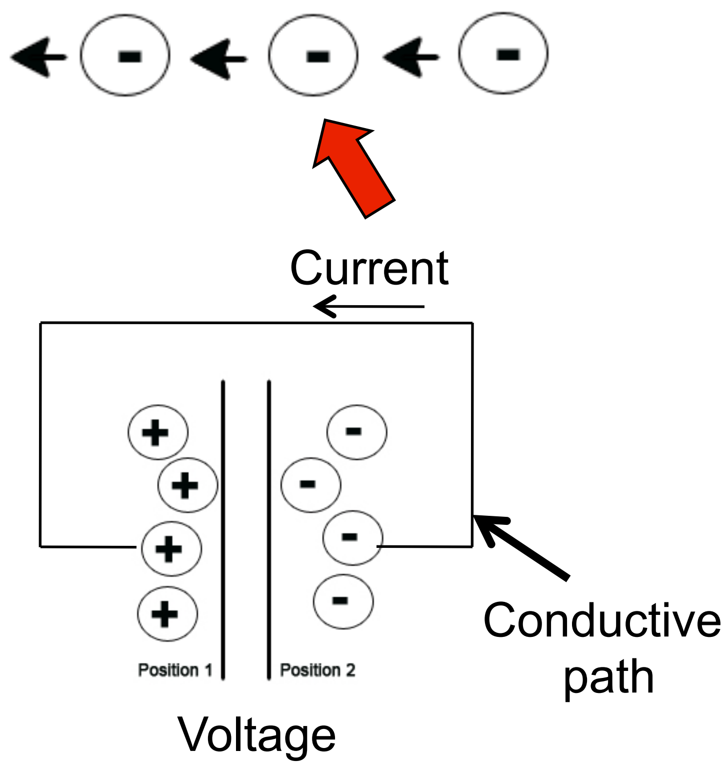
Voltage

- Voltage – electrical "potential difference" between two positions



Current

- Current – flow rate of electric charge



Credit: msn.com

Resistance and Conductance

- For current flow to occur, we need:
  - A voltage to “push” the electrons

Resistance and Conductance

- For current flow to occur, we need:
  - A voltage to “push” the electrons
  - A conductive path from the positive terminal to the negative terminal of the power source

Resistance and Conductance

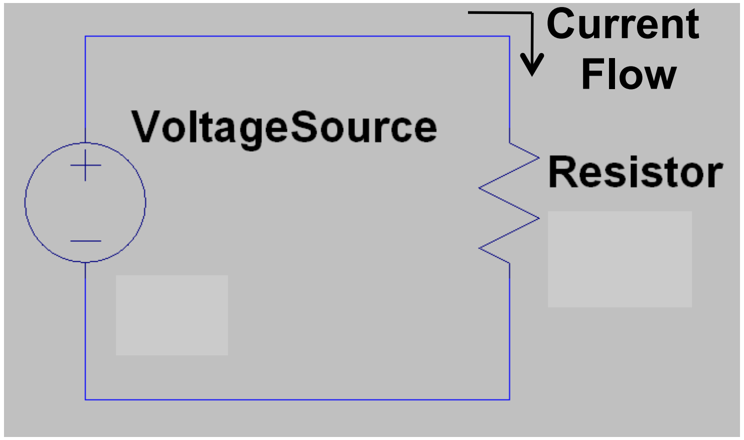
- For current flow to occur, we need:
  - A voltage to “push” the electrons
  - A conductive path from the positive terminal to the negative terminal of the power source
- Resistance is the inverse of conductance:
  - R = 1/G, where G is conductance

Resistance and Conductance

- For current flow to occur, we need:
  - A voltage to “push” the electrons
  - A conductive path from the positive terminal to the negative terminal of the power source
- Resistance is the inverse of conductance:
  - R = 1/G, where G is conductance
  - This means that if something is REALLY conductive, its resistance can be approximated as zero (e.g. metals like copper, aluminum)

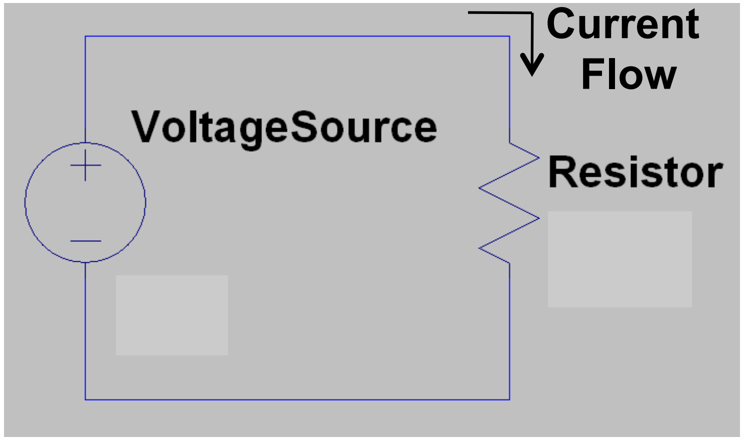
Ohm's Law

- Ohm's Law states the voltage (V) is equal to the current (I) passing through a component times the resistance (R) of that component.



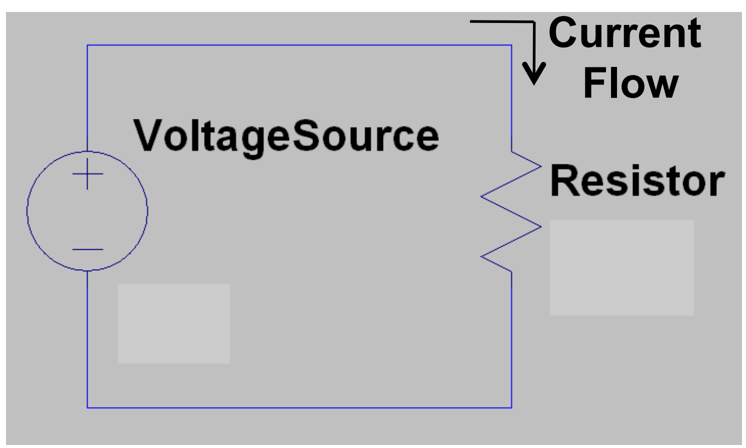
Ohm's Law

- Ohm's Law states the voltage (V) is equal to the current (I) passing through a component times the resistance (R) of that component.
- Equation: V = IR



Ohm's Law

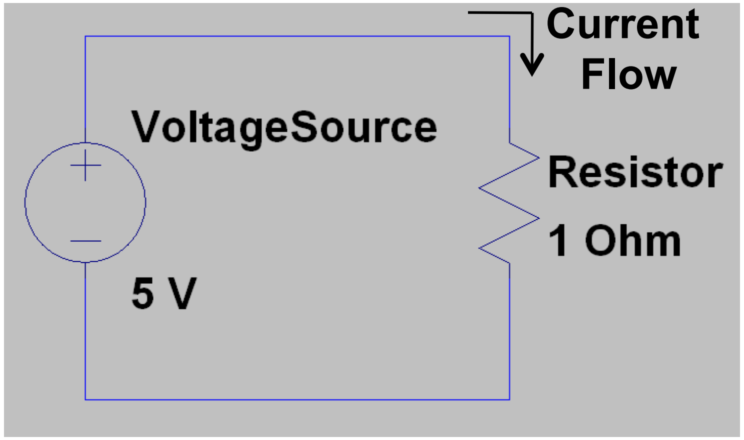
- Ohm's Law states the voltage (V) is equal to the current (I) passing through a component times the resistance (R) of that component.
- Equation: $V = IR$
- Here the wire's resistance is neglected



Resistor, R

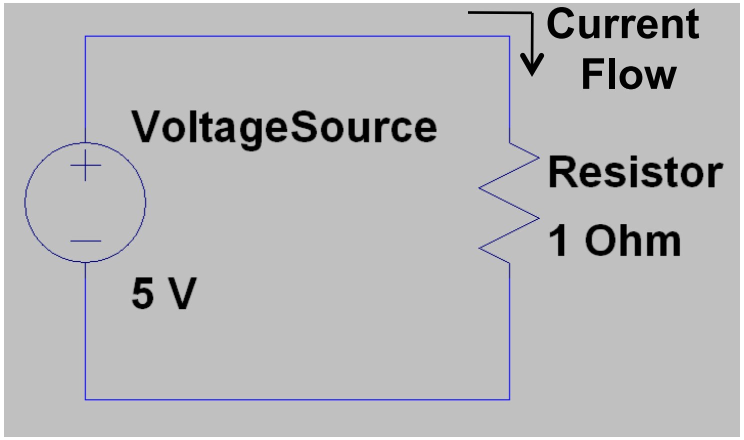
Example of Ohm's Law

- What would the current be in this circuit configuration?



Example of Ohm's Law

- What would the current be in this circuit configuration?
- V = IR, or I = V/R = 5 Volts / 1 Ohm = 5 Amps



Energy and Power

- Energy is the capacity to do work

Energy and Power

- Energy is the capacity to do work
- There are many forms of energy, including mechanical, electrical, chemical, nuclear, etc.

Energy and Power

- Energy is the capacity to do work
- There are many forms of energy, including mechanical, electrical, chemical, nuclear, etc.
- Power is the rate at which energy is transferred, produced, or consumed

Energy and Power

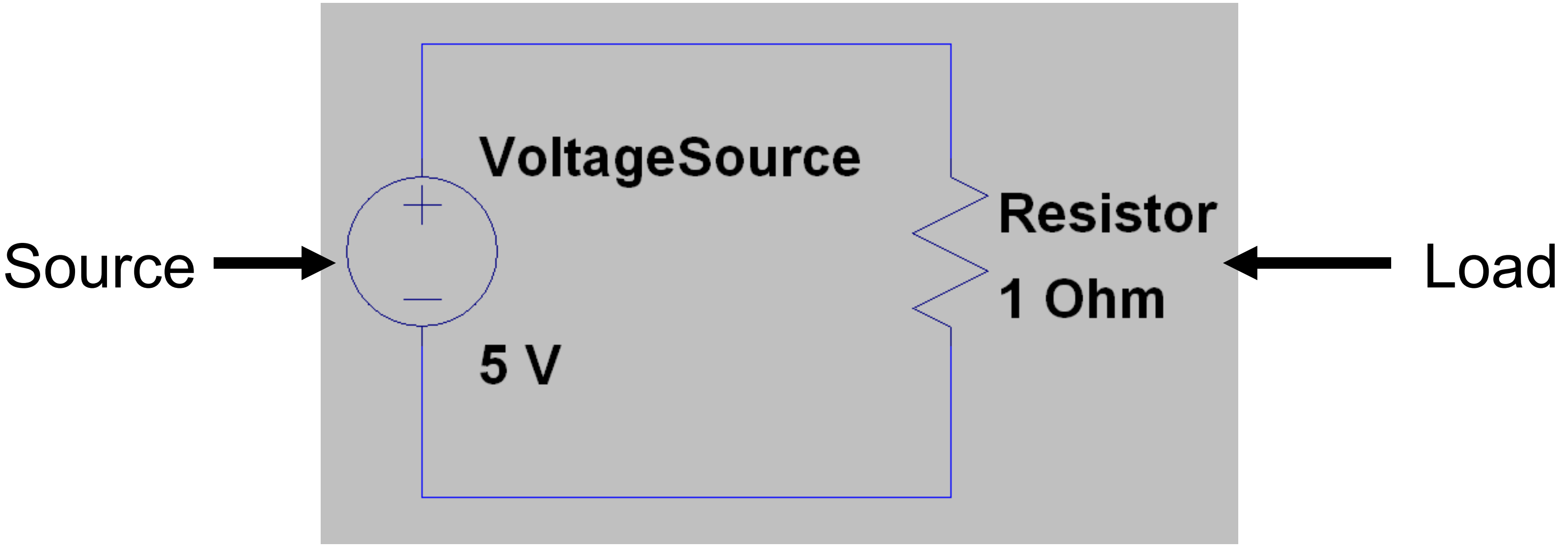
- Energy is the capacity to do work
- There are many forms of energy, including mechanical, electrical, chemical, nuclear, etc.
- Power is the rate at which energy is transferred, produced, or consumed
- Electrical power is equal to voltage times current

Energy and Power

- Energy is the capacity to do work
- There are many forms of energy, including mechanical, electrical, chemical, nuclear, etc.
- Power is the rate at which energy is transferred, produced, or consumed
- Electrical power is equal to voltage times current
- Equation: $P = VI$

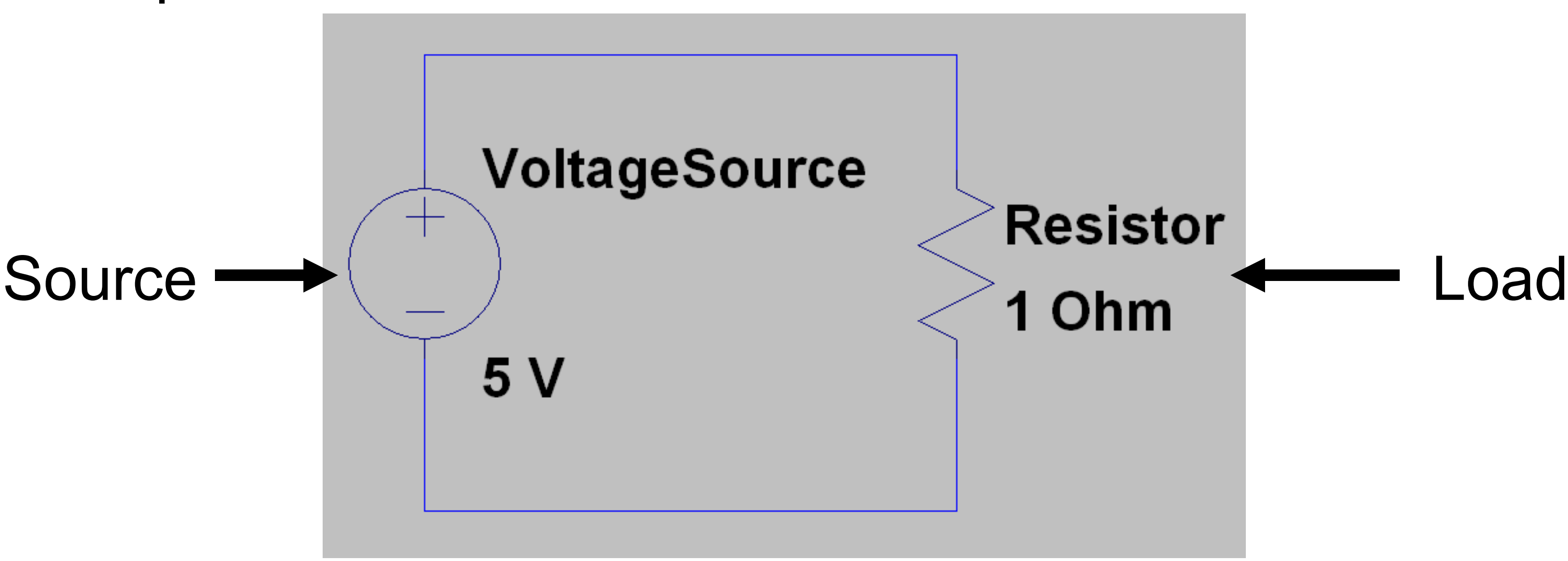
Power Sources and Loads

- In a circuit, some components act as sources of power, while others act as sinks, or loads



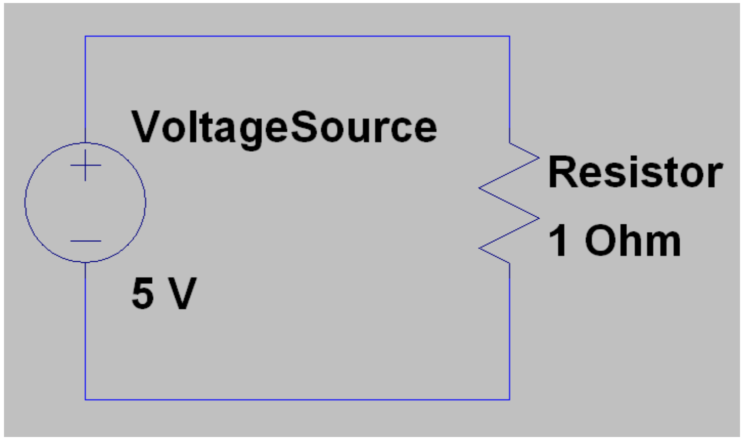
Power Sources and Loads

- In a circuit, some components act as <u>sources</u> of power, while others act as sinks, or <u>loads</u>
- The electrical power (P) delivered to a load is equal to the delivered voltage (V) times the delivered current (I).
- Equation: $P = VI$



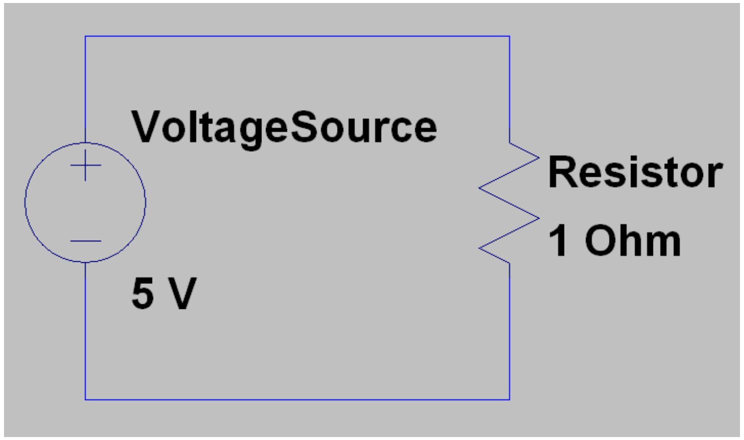
Example

- What would be the electrical power delivered to the resistor?



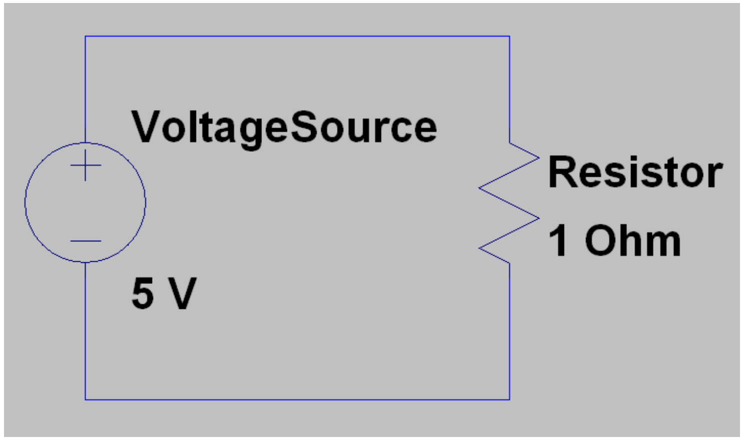
Example

- What would be the electrical power delivered to the resistor?
- First, current must be calculated using Ohm's Law



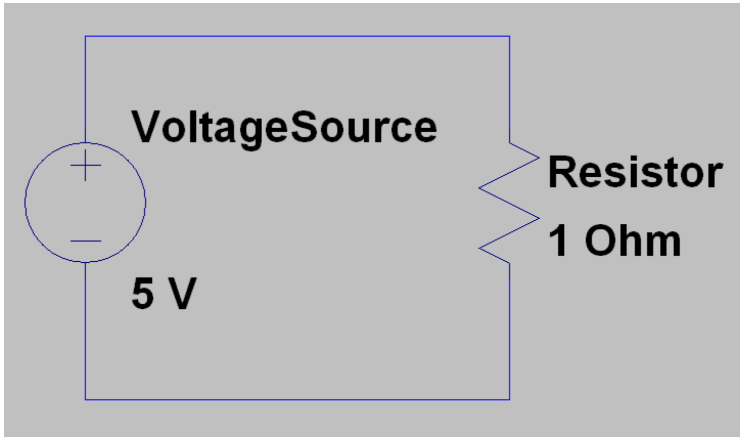
Example

- What would be the electrical power delivered to the resistor?
- First, current must be calculated using Ohm's Law
- V = IR, which is I = V/R = 5 Volts / 1 Ohm = 5 Amps



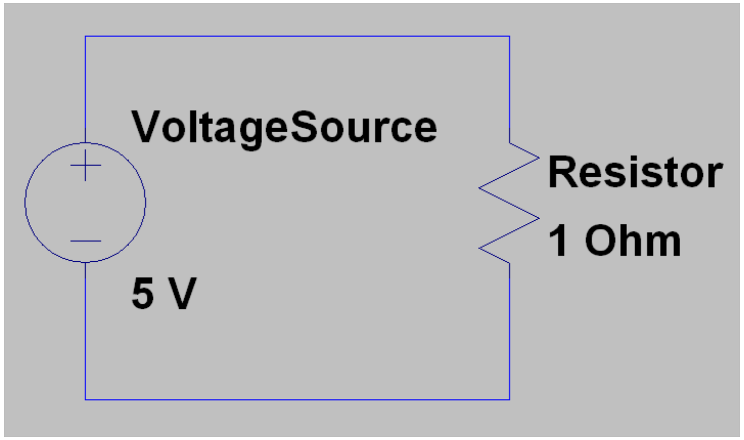
Example

- What would be the electrical power delivered to the resistor?
- First, current must be calculated using Ohm's Law
- V = IR, which is I = V/R = 5 Volts / 1 Ohm = 5 Amps
- Knowing that current equals 5 Amps, we can use the power equation, P = IV

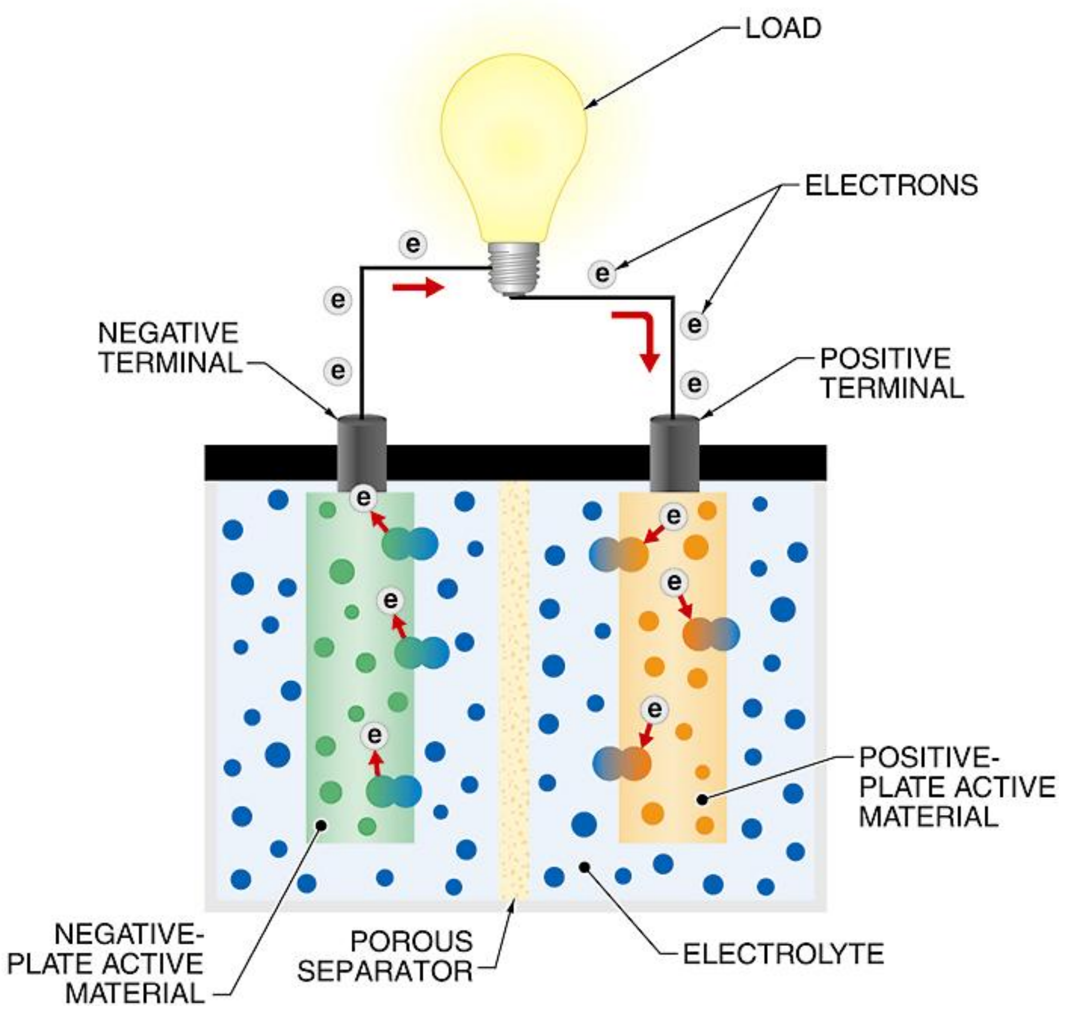


Example

- What would be the electrical power delivered to the resistor?
- First, current must be calculated using Ohm's Law
- V = IR, which is I = V/R = 5 Volts / 1 Ohm = 5 Amps
- Knowing that current equals 5 Amps, we can use the power equation, P = IV
- P = IV = 5 Amps * 5 Volts = 25 Watts

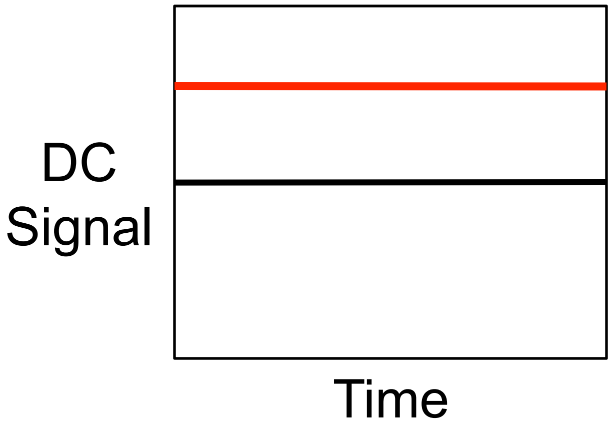


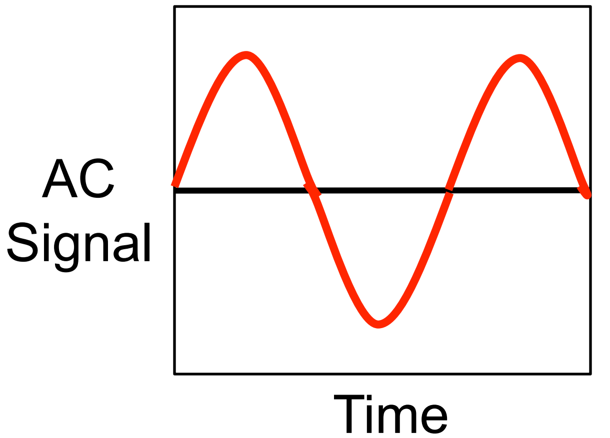
Example: Battery and a Light Bulb



Direct Current (DC) vs. Alternating Current (AC)

- If voltage and current signals are either always positive or always negative, they are DC waveforms.
- If the signals switch between positive and negative, they are AC waveforms.

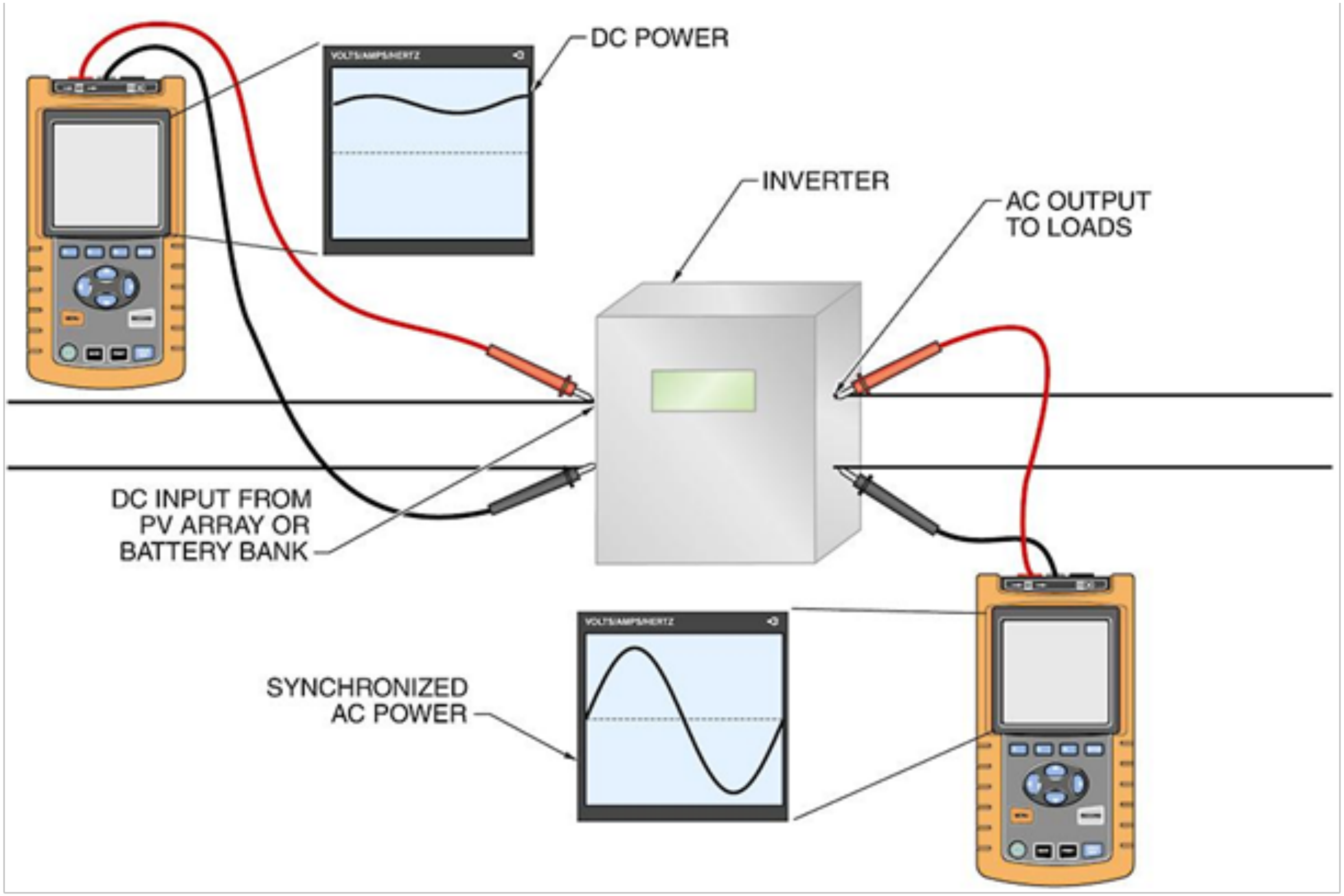




Types of Power Sources

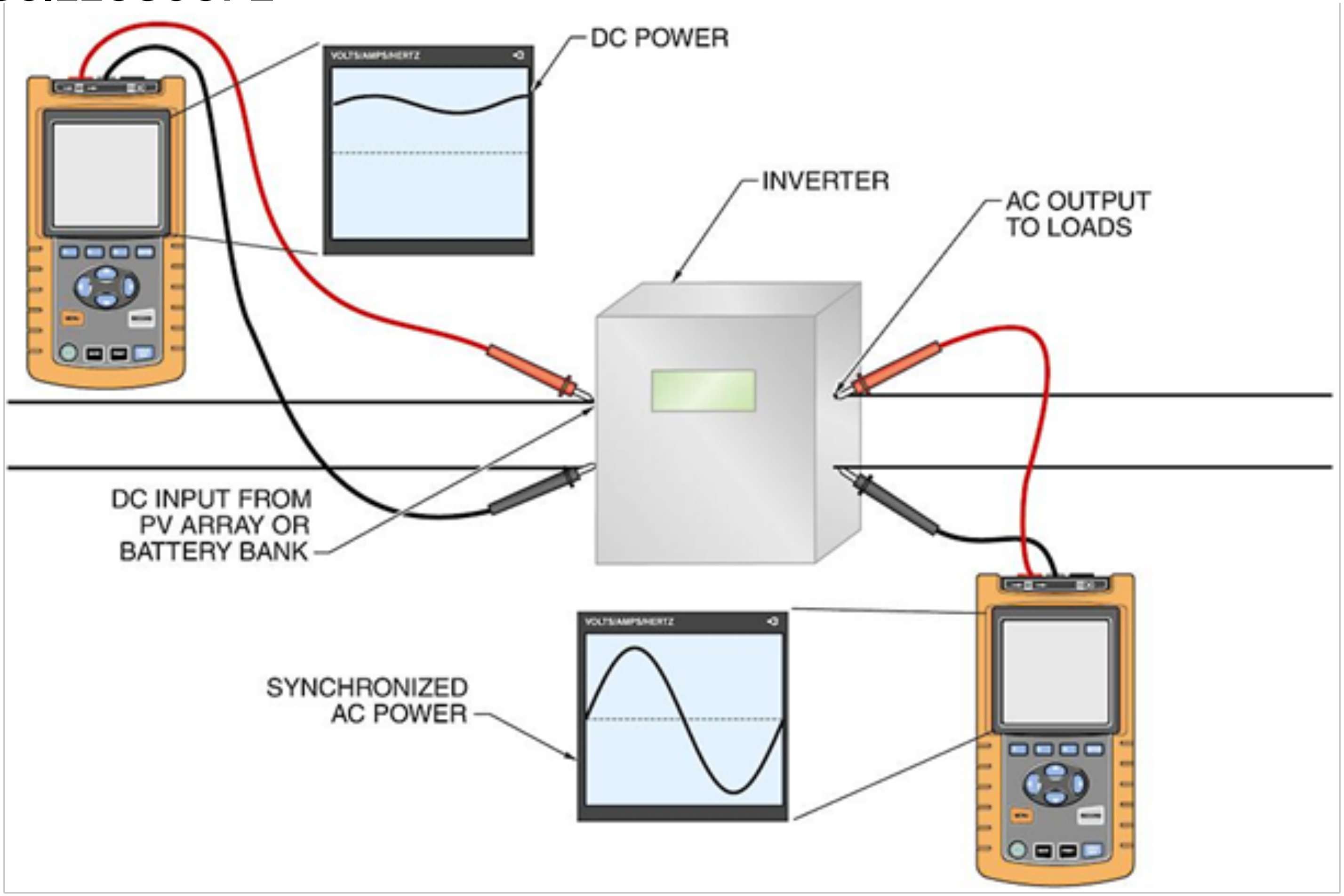
- DC sources
  - Batteries
  - Capacitors
  - Fuel cells
  - Photovoltaic cells (i.e. solar cells)
- AC sources
  - Rotating machines (e.g. fossil fuel generators, wind turbines, hydro-powered turbines)
  - Inverters (e.g. solid-state electronics)

Types of Power Sources



Types of Power Sources

OSCILLOSCOPE

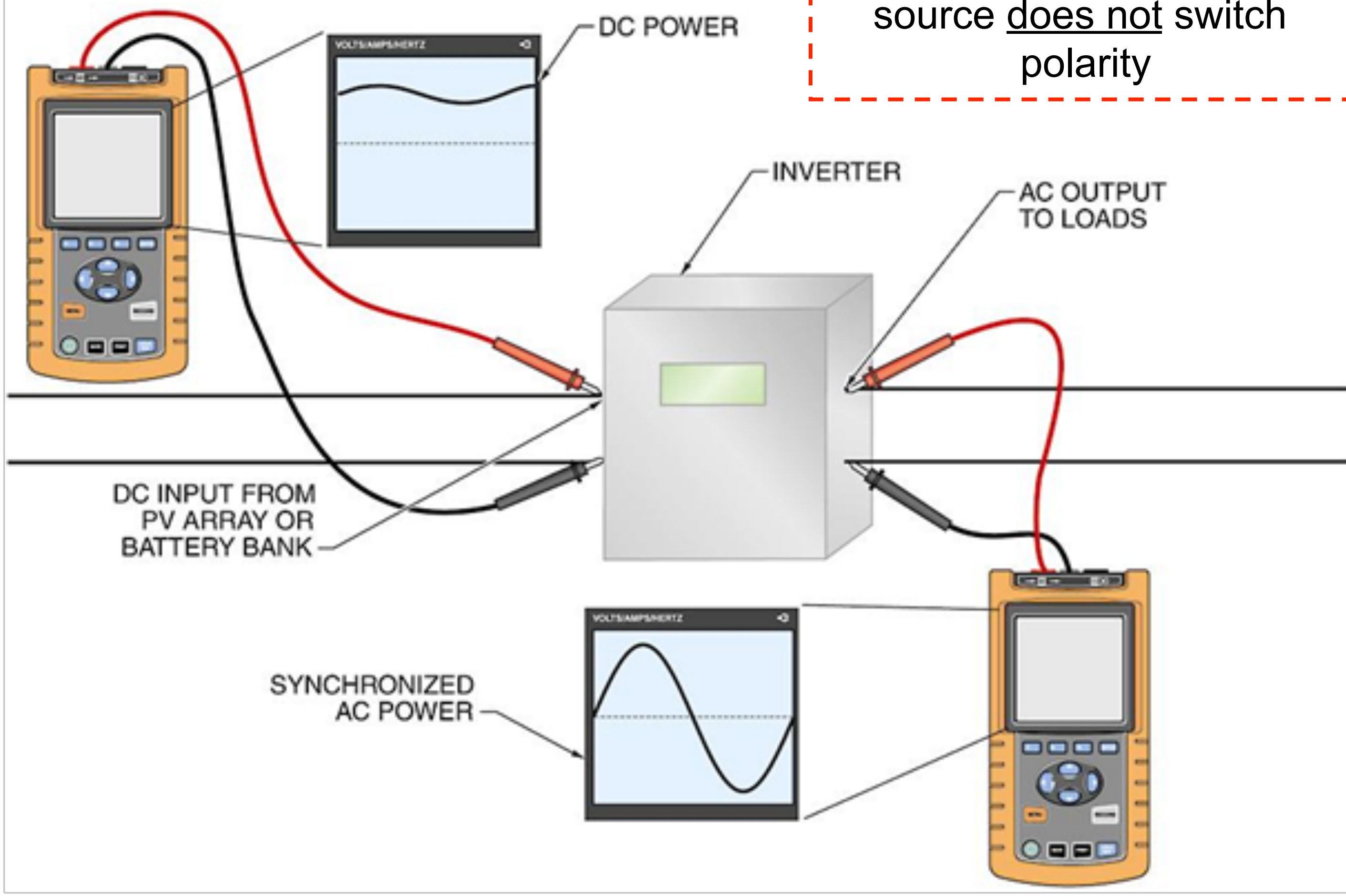


OSCILLOSCOPE

Types of Power Sources

OSCILLOSCOPE

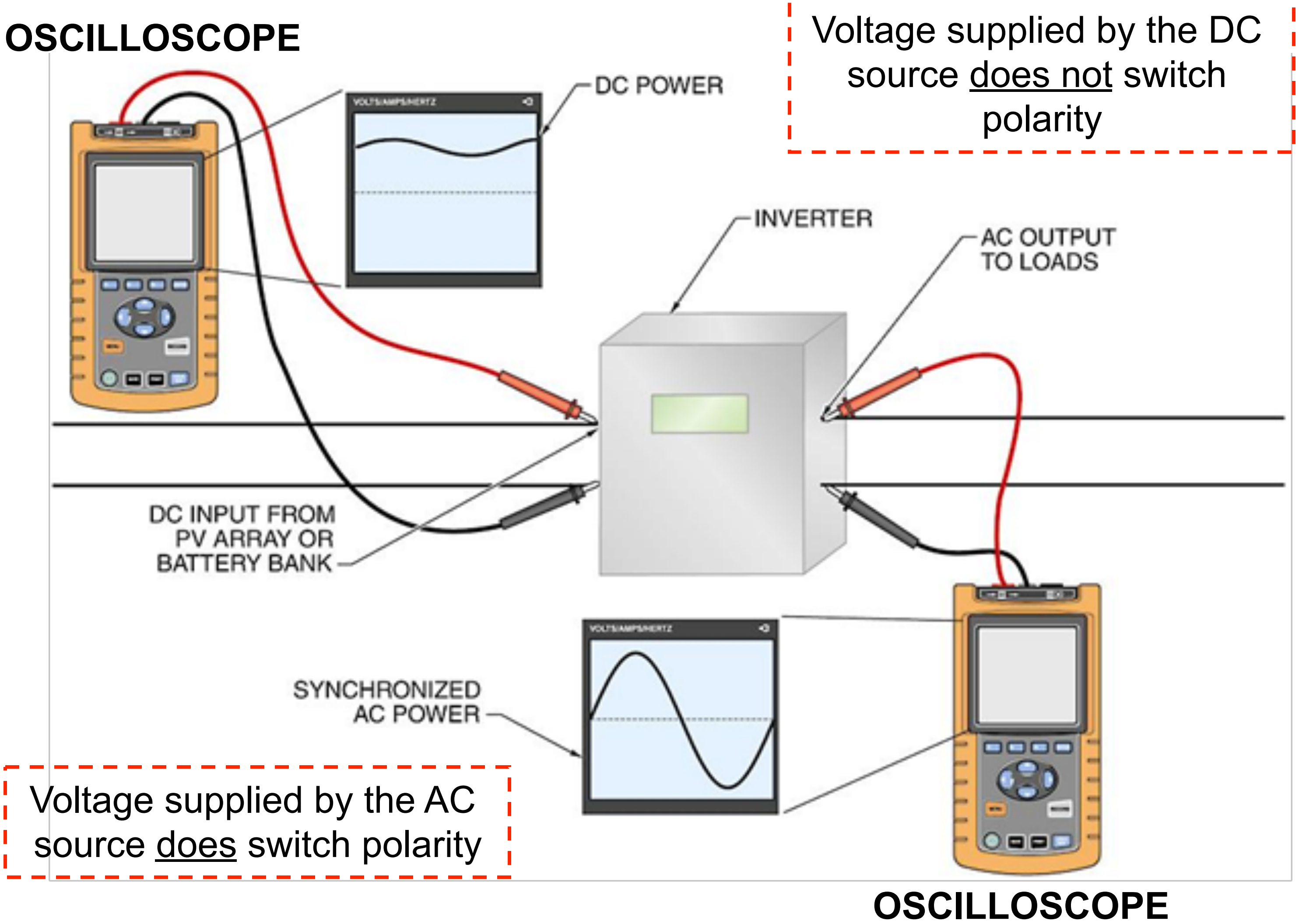
Voltage supplied by the DC source does not switch polarity



OSCILLOSCOPE

Types of Power Sources

Voltage supplied by the DC source does not switch polarity

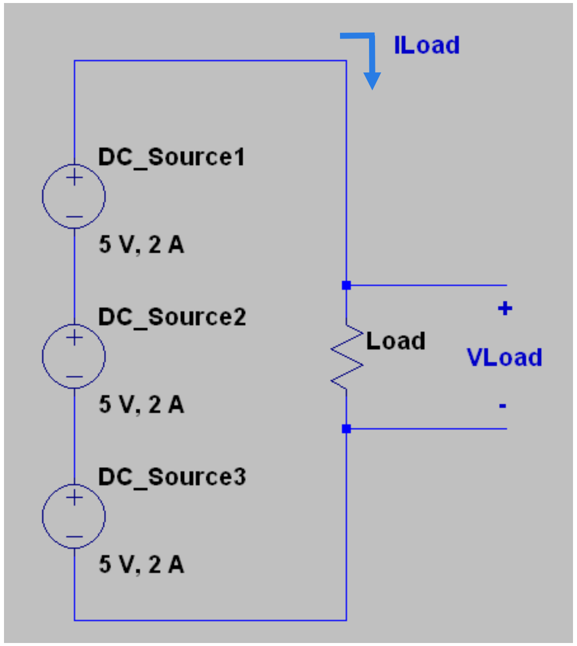


Voltage supplied by the AC source does switch polarity

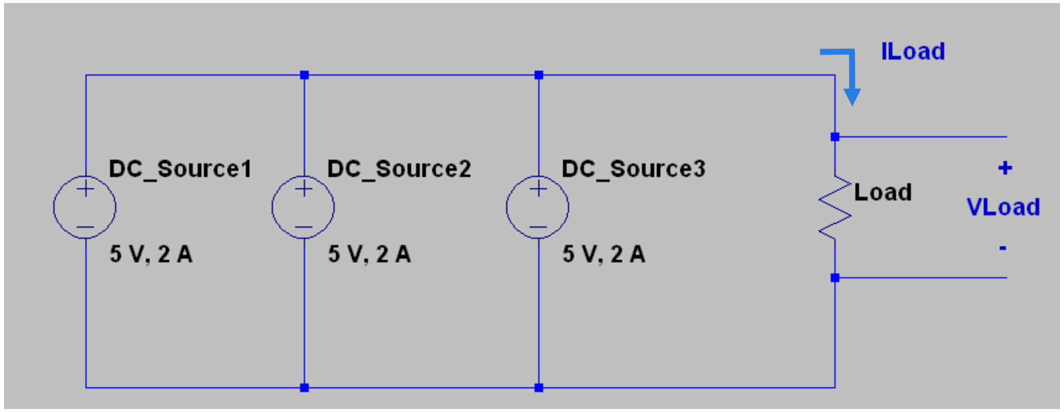
DC Circuits

- Circuit components can be connected in <u>series</u> or <u>parallel,</u> or some combination

Series connection

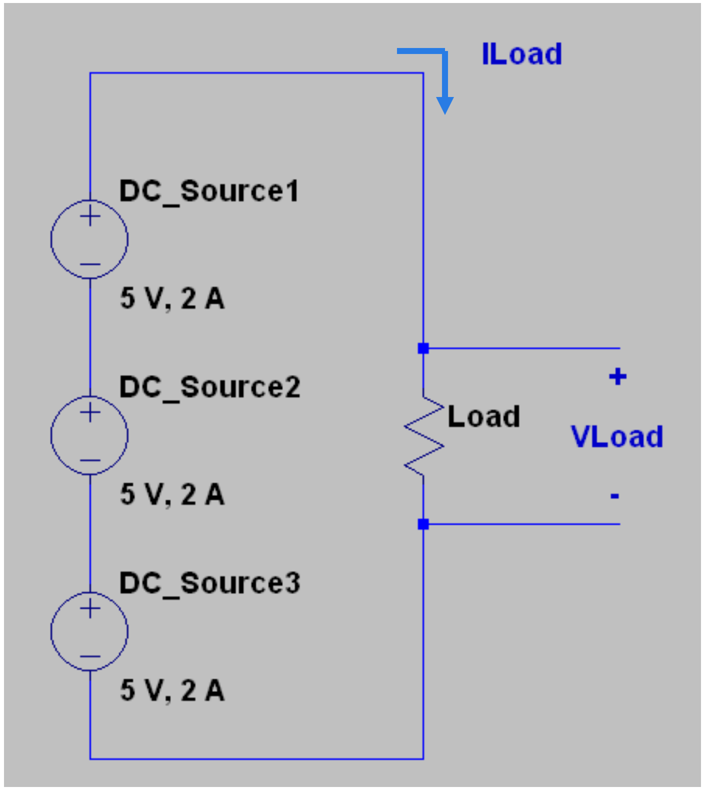


Parallel connection



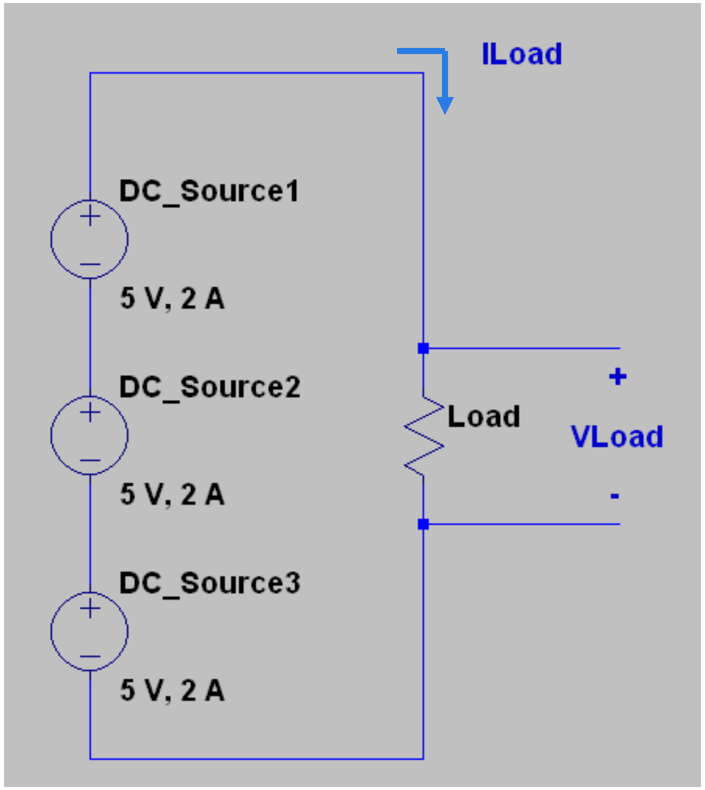
DC Circuits – Series Connections

- With series connected DC sources, the voltage delivered to the load adds and current delivered remains the same.



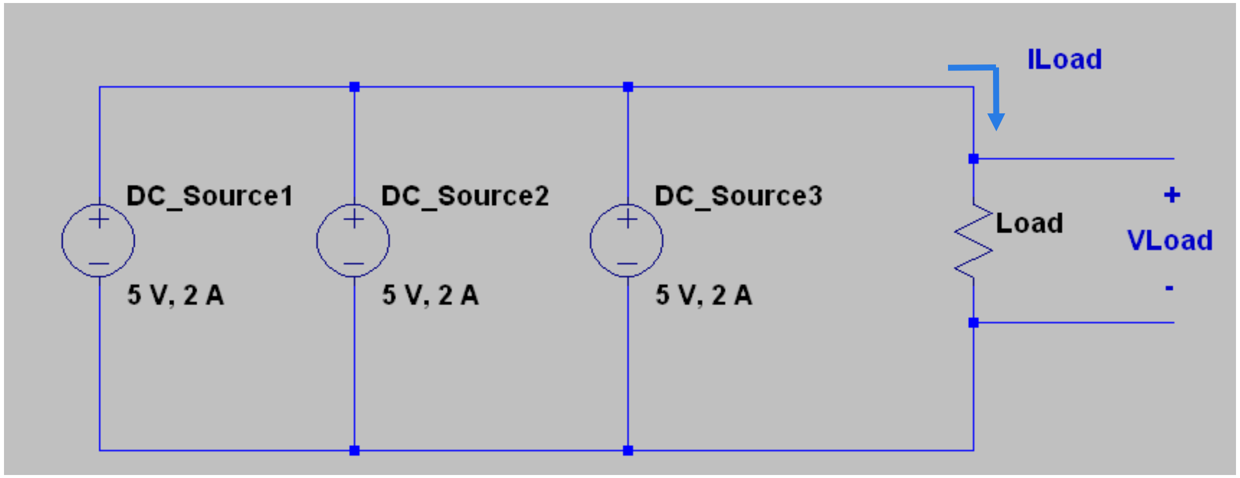
DC Circuits – Series Connections

- With series connected DC sources, the voltage delivered to the load adds and current delivered remains the same.
- $V_{Load} = 5 + 5 + 5 = 15$ V
- $I_{Load} = 2$ A
- $P_{Load} = V_{Load} * I_{Load} = 30$ Watts



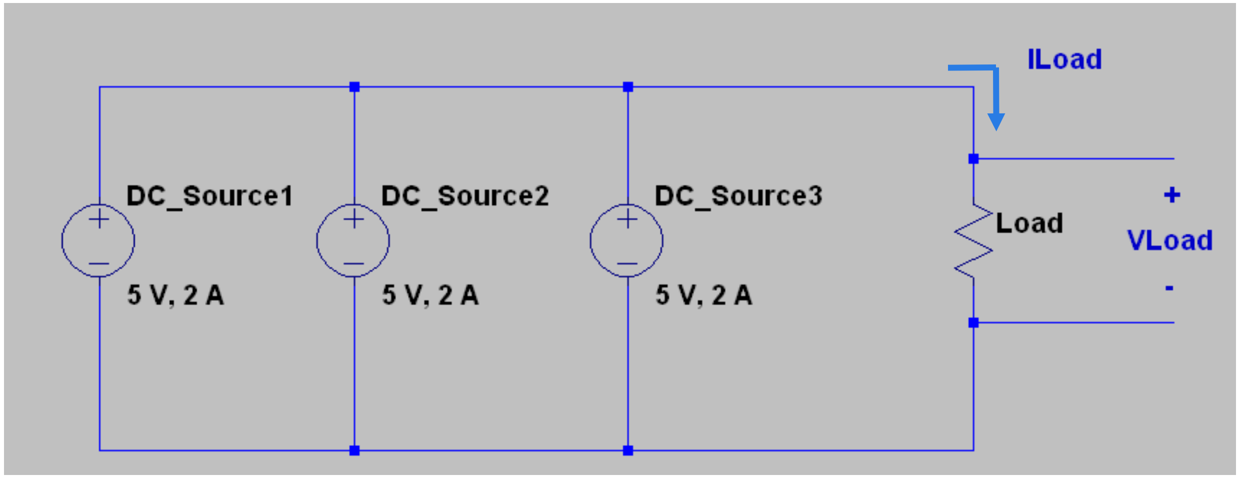
DC Circuits – Parallel Connections

- With parallel connected DC sources, the voltage delivered to the load remains the same and the delivered current adds.

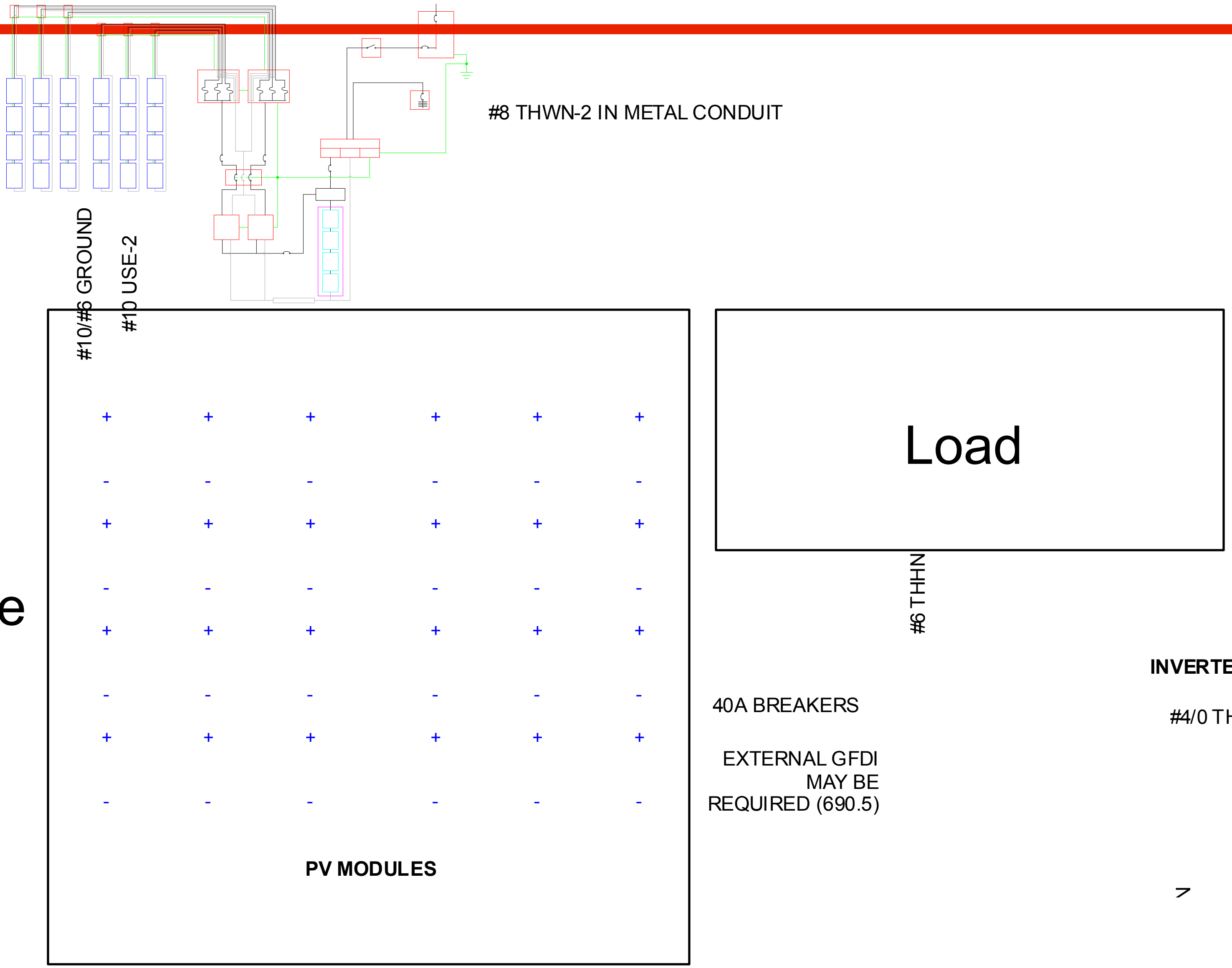


DC Circuits – Parallel Connections

- With parallel connected DC sources, the voltage delivered to the load remains the same and the delivered current adds.
- $V_{Load} = 5$ V
- $I_{Load} = 2 + 2 + 2 = 6$ A
- $P_{Load} = V_{Load} * I_{Load} = 30$ Watts (Same value as before!)



How many modules in series? Parallel?



Source

Electrical Power Systems

- Power generation
- Transmission & Distribution
- Common electrical equipment
- Electrical tools to be familiar with
- Electrical safety

Power Generation

- Energy conversion
  - Mechanical to Electrical
  - Nuclear to Electrical
  - Chemical to Electrical
  - Solar Energy to Electrical

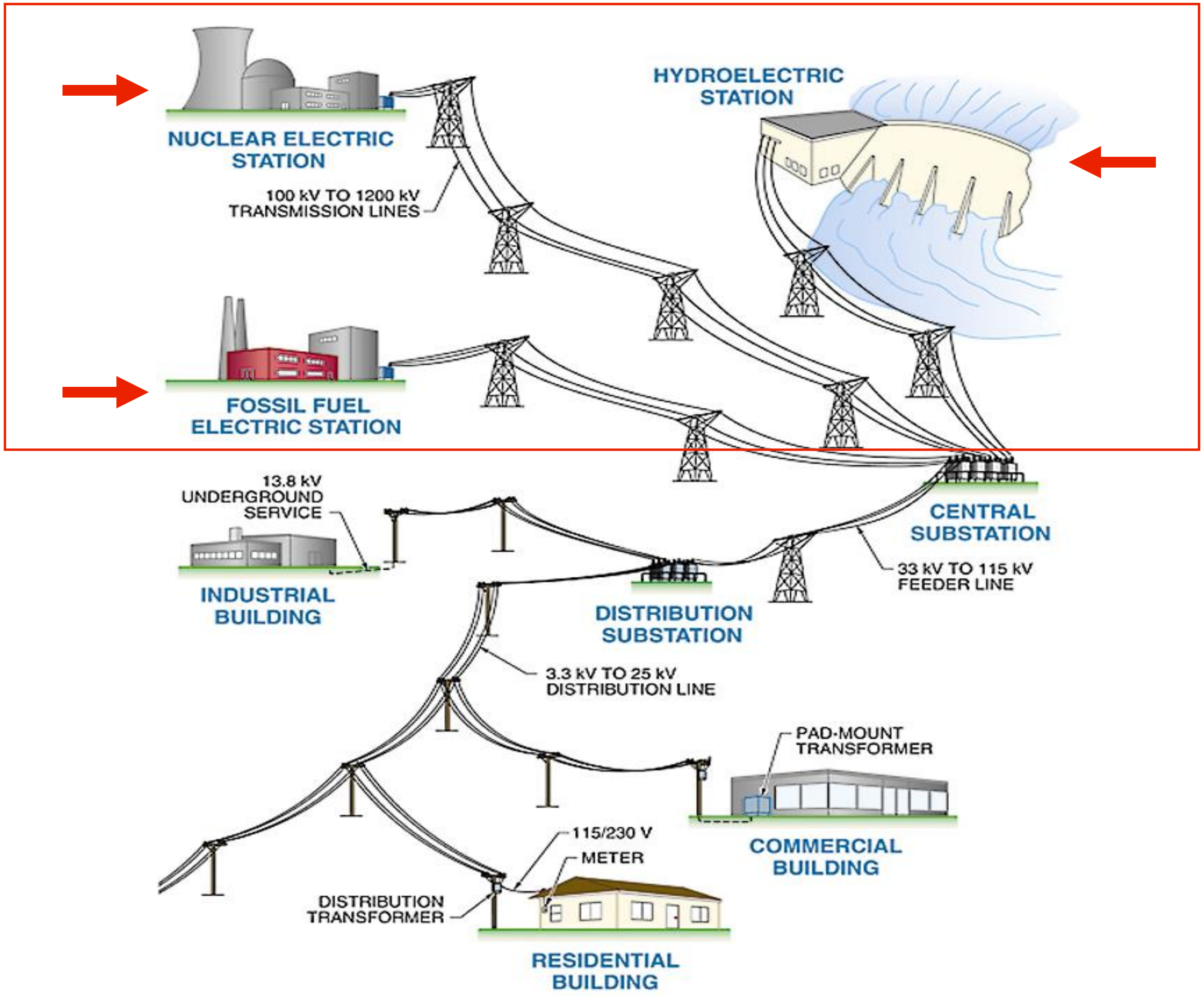
Power Generation

- Energy conversion
  - Mechanical to Electrical
  - Nuclear to Electrical
  - Chemical to Electrical
  - Solar Energy to Electrical
- Centralized Generation with Transmission and Distribution (T&D) infrastructure

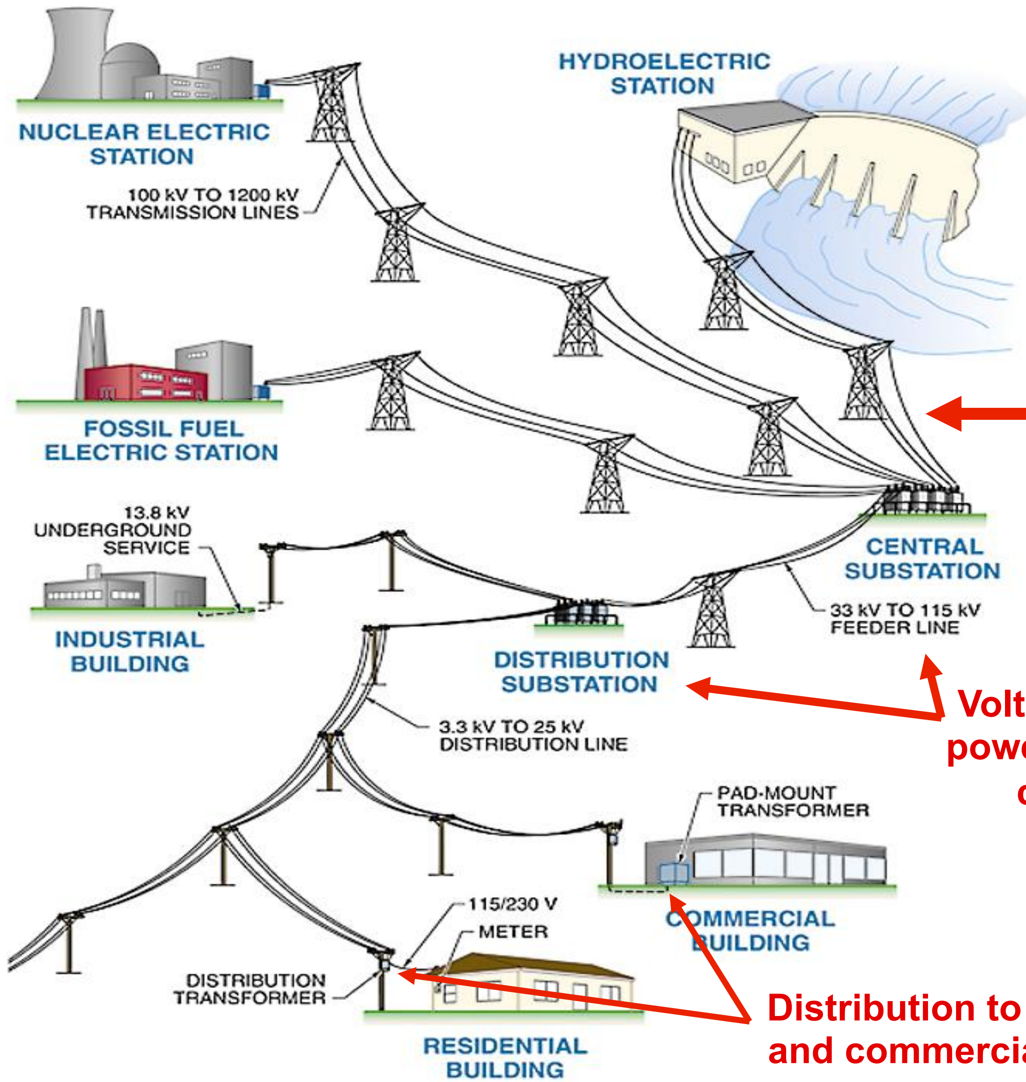
Power Generation

- Energy conversion
  - Mechanical to Electrical
  - Nuclear to Electrical
  - Chemical to Electrical
  - Solar Energy to Electrical
- Centralized Generation with Transmission and Distribution (T&D) infrastructure
- Distributed Generation (DG)

Centralized Generation



Transmission & Distribution

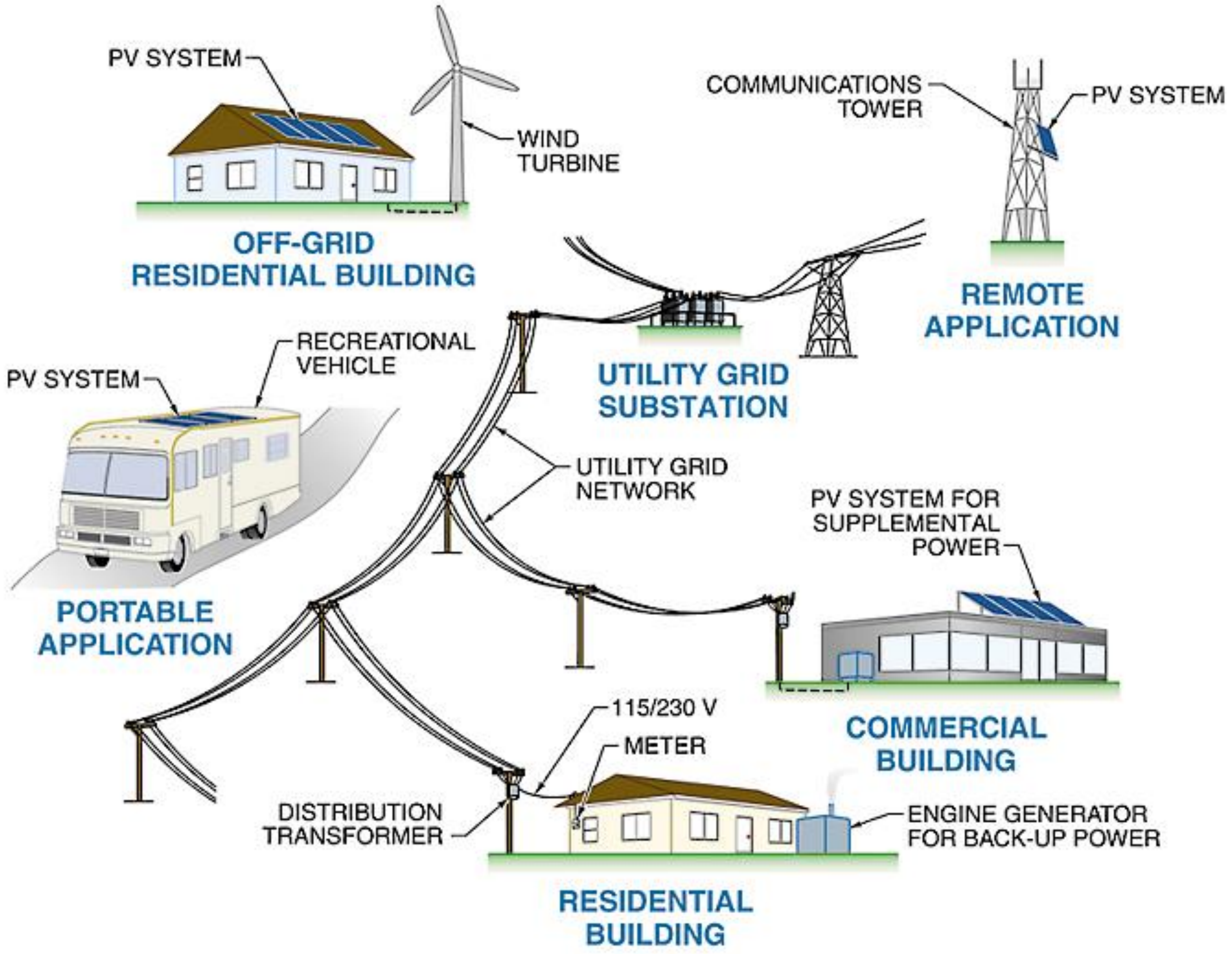


HV transmission lines (to minimize resistive losses)

Voltages are lowered as power approaches cities, communities, etc.

Distribution to residential and commercial buildings

Distributed Generation



Common Electrical Equipment

- Conductors
- Conduit
- Combiner boxes
- Overcurrent protection
- Disconnects
- Grounding
- Surge arrestors
- Transformers
- Panelboards

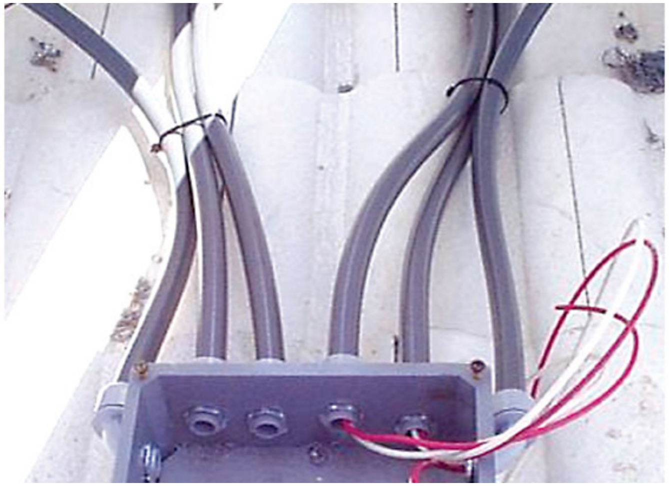
<u>Important: Make sure equipment is rated for the environment in which it will operate!</u>

Conductors

- Typically copper, but can be aluminum
- Can be solid or stranded
- Insulation jacket dictates a conductor’s operating temperature and its ability to act as a barrier to the environmental (UV light, moisture, etc.)
- Ampacity determines the amount of current a conductor can safely carry, which is to say how much current can be carried without overheating the insulation

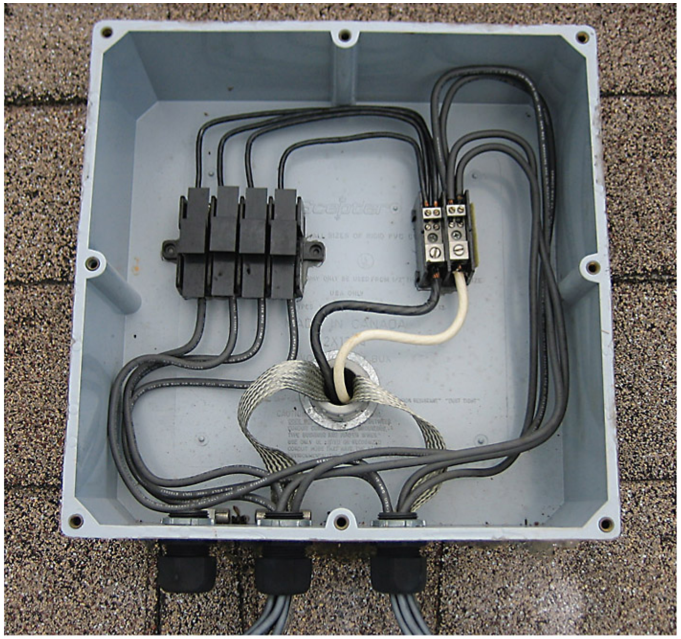
Conduit

- Conduit is a type of electrical piping used for protecting and routing conductors
- It is typically made out of metal or plastic and is rated for use in certain environments (i.e. conduit exposed to sunlight must be UV rated)
- It is also rated to carry only a certain volume of wire (number of individual conductors and conductor size)



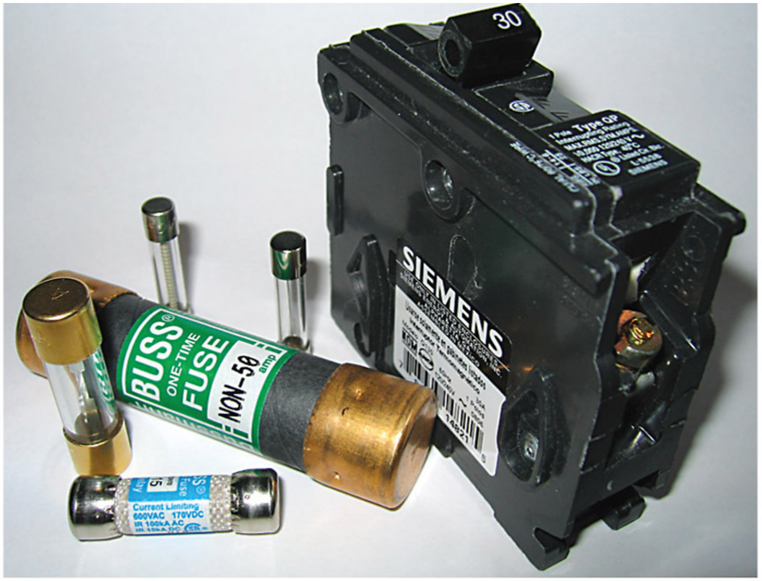
Combiner boxes

- Combiner boxes are enclosures used to connect multiple circuits
- They are often used to combine parallel strings of modules in PV systems



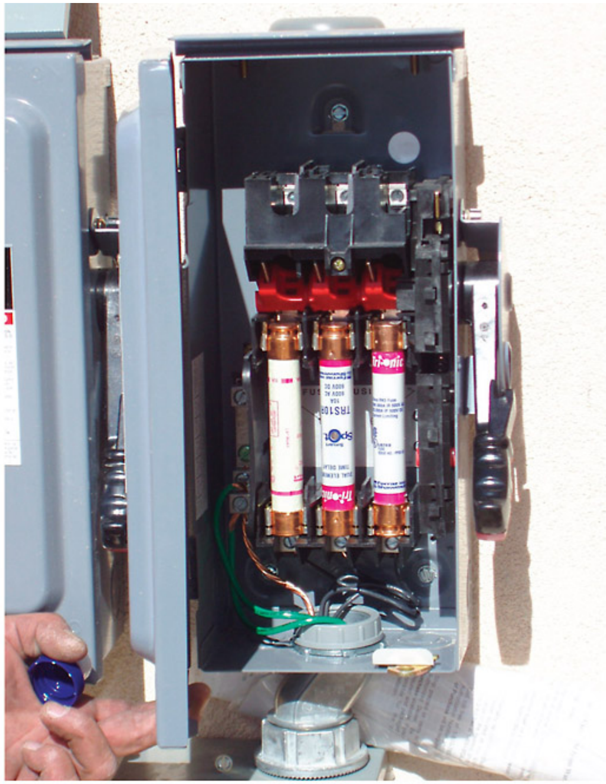
Overcurrent Protection

- Overcurrent protection devices prevent conductors and electrical equipment from experiencing excessively high temperatures which can occur under high currents



Disconnects

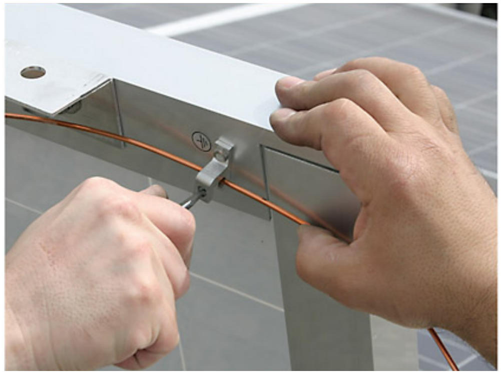
- Disconnects are used to isolate conductors and electrical equipment from power sources during installation, maintenance, and servicing



Direct Power and Water Corporation

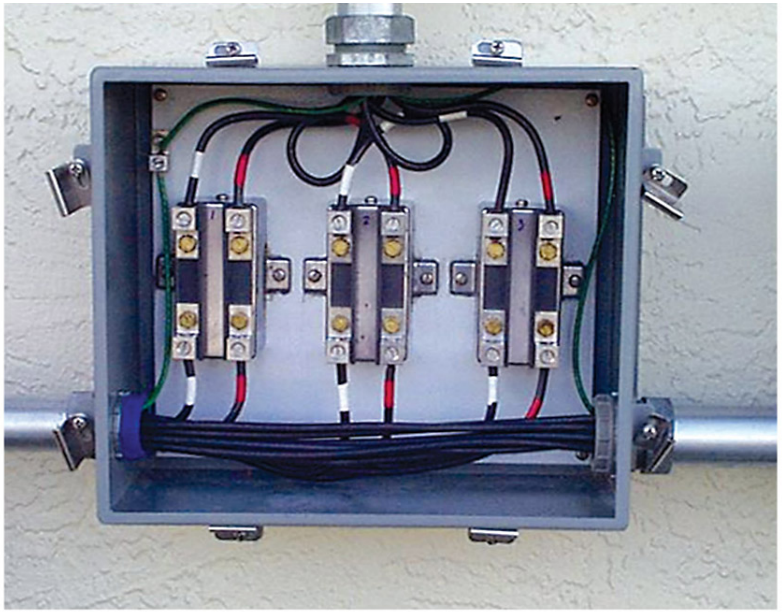
Groundings

- Grounding refers to connecting exposed electrical equipment to earth to prevent shock due to excessive voltage
- It is used in common AC systems (mains electricity) as well as in PV systems to provide a “path to ground” when faults occur (i.e. electrical insulation fails)



Surge Arrestors

- Surge arrestors protect electrical equipment from large voltage spikes, known as transients

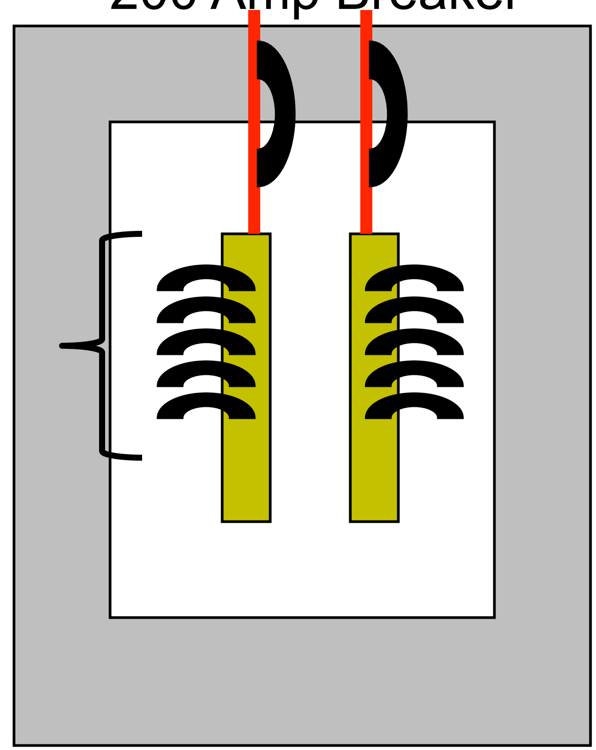


Transformers

- Transformers are devices that transfer electrical energy in one part of the circuit to another via magnetic coupling
- In power systems, its purpose is to “step up” or “step down” AC voltages to interconnect different parts of an electrical network

Panelboards

- Main “hub” of an electrical system
- Divides the electrical power from the sources (utility, PV system) into subsidiary circuits (loads)
- Incorporates overcurrent protection into those circuits to ensure safe operation



National Electric Code

- US standard that deals with the safe installation of electrical equipment and wiring
- Provides the minimum standards required for safe electrical installations
- "Authority Having Jurisdiction", or AHJ, will use this code to inspect electrical installations (though they might modify or add requirements)
- The code is updated every 3 years
- Many articles in the code directly apply to PV systems

Selected Applicable NEC® Articles

110*	Requirements for Electrical Installations
200	Use and Identification of Grounded Conductors
210*	Branch Circuits
220	Branch-Circuit, Feeder, and Service Calculations
230*	Services
240*	Overcurrent Protection
250*	Grounding and Bonding
280	Surge Arrestors
285	Transient Voltage Surge Suppressors: TVSSs
300	Wiring Methods
310*	Conductors for General Wiring
334	Nonmetallic-Sheathed Cable: Types NM, NMC, and NMS
338	Service-Entrance Cable: Types SE and USE
340*	Underground Feeder and Branch Circuit Cable: Type UF
400*	Flexible Cords and Cables
422	Appliances
445	Generators
450*	Transformers and Transformer Vaults
480*	Storage Batteries
490*	Equipment, Over 600 Volts, Nominal
690	Solar Photovoltaic Systems
702	Optional Standby Systems
705*	Interconnected Electric Power Production Sources
720	Circuits and Equipment Operating at Less Than 50 Volts

* Articles directly referenced in Article 690

Electrical Tools

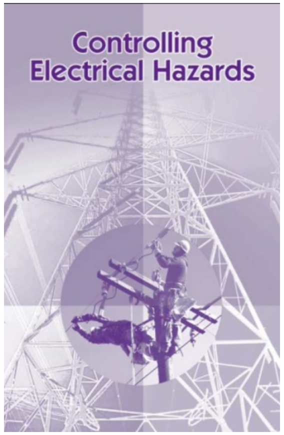
- Hand tools (screw drivers, pliers, etc.)
- Digital Multimeter (DMM)
- “Clamp-on” meter (Hall-effect)
- Wire strippers
- Fish tape
- Personal Protective Equipment (PPE)

Electrical Safety

- Electrical work can be dangerous!
- Check out the Occupational Safety & Health Administration (OSHA) website for information:

  http://www.osha.gov/SLTC/electrical/index.html
- Free OSHA publication in PDF format:

  http://www.osha.gov/Publications/osha3075.pdf



Summary

- Fundamental laws of electricity
  - Ohm's Law: $V = IR$
  - Power Equation: $P = IV$
- Basic principles of circuits
  - DC, AC
  - Sources, loads
  - Series, parallel connections
- Electrical power systems
  - Centralized generation, distributed generation
  - Transmission and distribution
  - Common equipment
  - Safety first!

References

J. Dunlop, "Photovoltaic Systems", American Technical Publishers (2007)