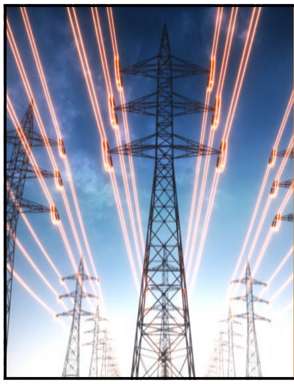

APPA Utilities

ELECTRIC PRODUCTION & DISTRIBUTION

January 2024

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Course Objectives

- Basic understanding of how electricity is produced and distributed
- Basic understanding of production and distribution options
- Overview of common approaches in higher education
- Class exercises - APPA University

APPA Utilities

Electric Production & Distribution

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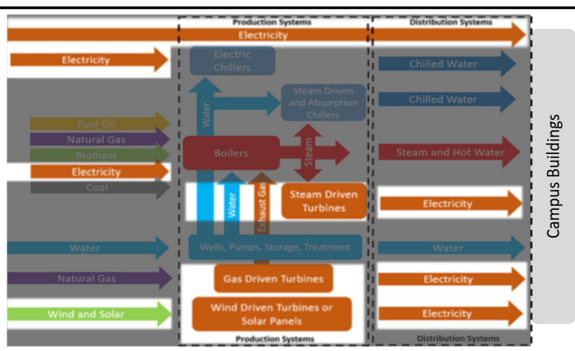
ELECTRICTY



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PHYSICAL PLANT

"Everything" Needs Electricity

- Drinking water
- Chilled water
- Heating hot water
- Steam
- Building lighting and power
- Geothermal
- Sanitary sewer
- Storm sewer

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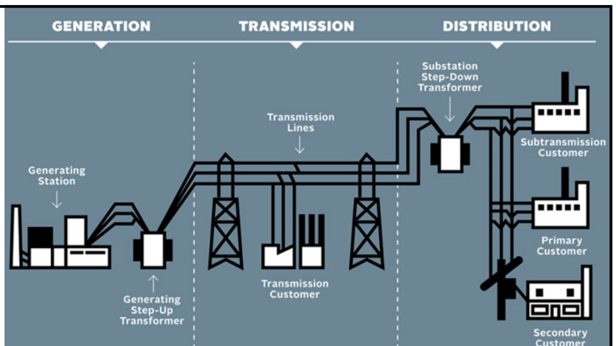
ELECTRICTY



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ELECTRIC PRODUCTION

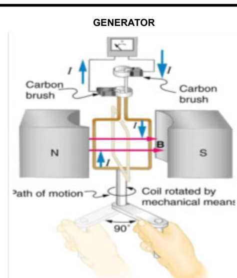
It's "simple"

Turn copper inside a magnet*

- Copper turning speed determines frequency

How it is turned is up to you…

- Resource availability
- Economics
- Sustainability goals



Electricity = Flow of Electrons

* Exceptions (fuel cell & PV solar)

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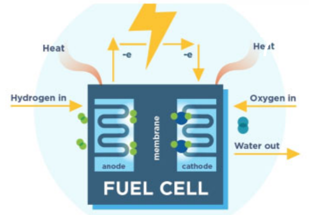

ELECTRIC PRODUCTION EXCEPTIONS

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TURNING THE GENERATOR

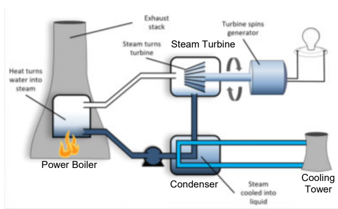
Steam (~80% of power production)
- Coal, natural gas, fuel oil, bio-fuel
- Nuclear

Combustion Turbine
- Natural gas
- Fuel oil
- Heat can be recovered to generate steam for use in a steam turbine

Engine
- Natural Gas
- Fuel oil (diesel)

Water
- River/dam
- Waves
- Pumped hydro

Wind



CONVENTIONAL THERMAL POWER PLANT

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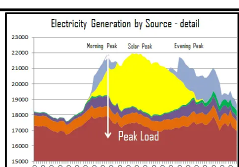
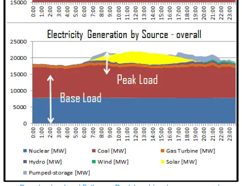
GENERATING PLANTS





Base load vs Load Follow vs Peak Load (nuclear-power.com)

Base Load Power Plant:
- Runs 24/7/365
- Only turned off for service & maintenance, overhaul, & upgrades
- Demand Response is SLOW for most base load plants
- Examples: nuclear, conventional thermal, hydro-electric, geothermal

Load Following (Peak Load) Power Plant:
- Runs only during hours of peak load demand
- Demand Response is FAST for most peaking plants
- Examples: gas turbines, engines, and pumped storage

Non-Load Following Power Generation:
- Produces only as much as the energy resource is available
- NO Demand Response – it produces what it can when it can
- Examples: solar PV and wind turbines

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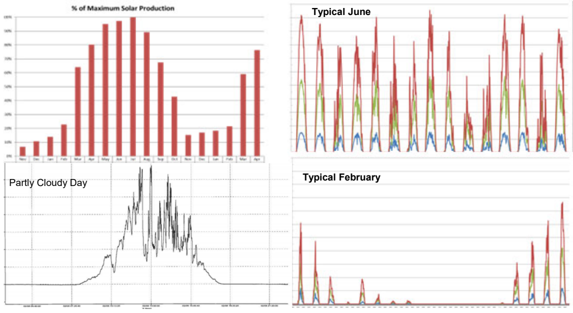
SOLAR PV PERFORMANCE



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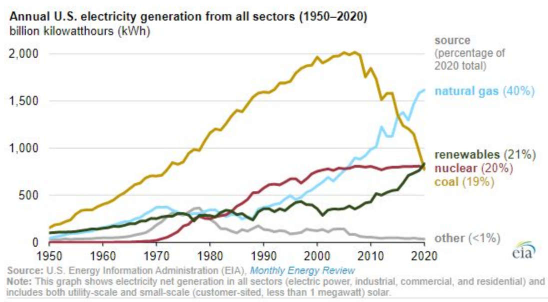
ANNUAL GENERATION



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RESIDENTIAL TIME-OF-USE RATE EXAMPLES

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What Is The Best Plan For Your Business? | Consumers Energy

DEMAND BASED RATES:
- Energy charge – same all the time
- Delivery charge
- Demand charge – monthly surcharge based on highest energy use over a 15-minute period
- Other fees

TIME-OF-USE BASED RATES:
- Energy charge - peak and off-peak rates
- Delivery charge
- Other fees

HIGH ENERGY USE:
- May included peak and off-peak energy charges PLUS demand AND capacity charges

BUSINESS RATE EXAMPLES

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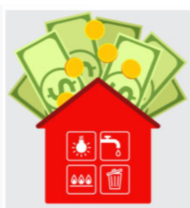
ELECTRIC UTILITY RATES

Cost for power consumed (consumption)

Power is measured in Watts
1,000 Watts (W) = 1 kiloWatt (kW)

Energy Used = Power x Time
kiloWatt hours (kWh) = Power (kW) x Time (hours)



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ELECTRIC DRYER EXAMPLE

- Power consumption = 2.5 kW
- Run time = 3 hours/day
- Rate = $0.12 per kWh

Energy Used = 2.5 kW x 3 hours = 7.5 kWh

Cost = 7.5 kWh x $0.12/kWh = $0.90

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POWER PURCHASE OPTION

Power Purchase Agreement (PPA)

- Developer investment (DBOOM) on university property
- University purchases net power produced a fixed rate ($/kWh) and receives Renewable Energy Credits (REC)
- Agreement durations 20 – 35 years (typ)
- Additional things to consider:
  - Climate
  - Parking lot usage cases
  - Production & microgrid stability risk
  - Interconnection cost and risk
  - FERC registration and “sale for resale” prohibition
  - Buy-out clauses
  - End of agreement clauses

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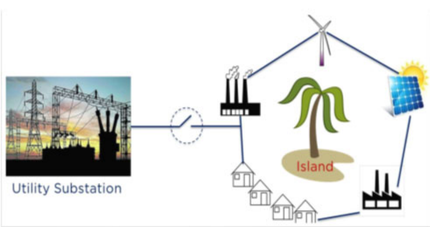
SELF-GENERATION – INCREASED RELIABILITY & RESILIENCY



- Generation capacity vs. campus demand
- N+1 redundancy
- Black-start capability
- Ability to “island” from local utility grid

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CAMPUS UTILITY RATES

Not just one way…

- Cost based accounting
- Enterprise model or not…
- Fees or not…
- Capital depreciation or not…
- Debt interest or not…
- Where does the distribution system stop?
- Special rates…grants may dictate…
- Rates for energy conservation projects…

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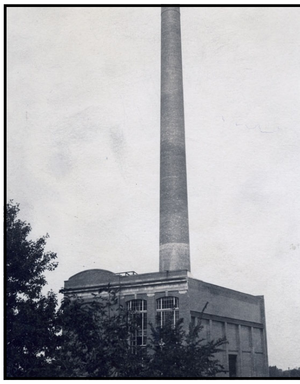

APPA University Plant

Things to Consider

- University Values & Expectations
  - Sustainability
  - Academic vs. Research
  - Reliability vs. Resiliency
- Location
  - Heating and cooling needs
  - Energy resource availability
- Generation
  - Technology
  - Fuel/energy resource availability & cost
- Return On Investment (ROI)

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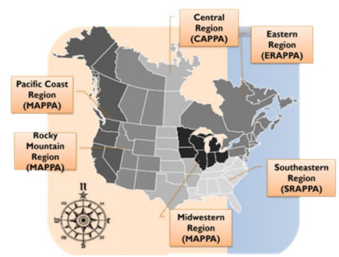
CLASS EXERCISE

Assumptions:

- New university/site
- Self- generate
- In/adjacent to major city
- Positive ROI

10-minute discussion → report out:

- Fuel / energy resource to be used
- Generation type and capacity
- Why



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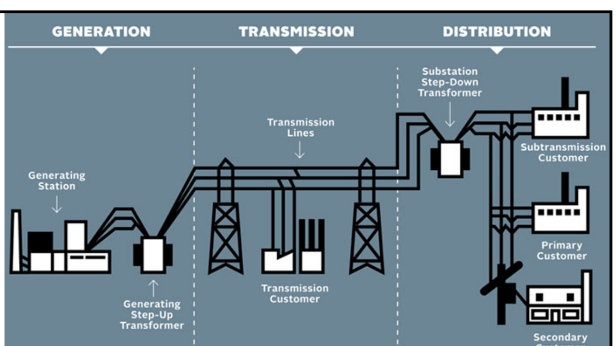
ELECTRICTY



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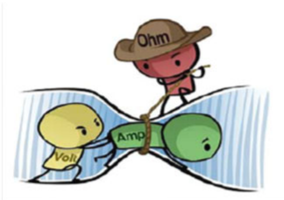
ELECTRICITY EXPLAINED



Voltage (Volts)
Difference in charge between two points (pressure in the circuit)

Current (Amps)
Rate at which the charge is flowing (like flow rate)

Resistance (Ohms)
The material's tendance to resist the flow of charge (like pipe size or friction)

Power (Watts) = Voltage (V) x Current (Amps)

Voltage (V) = Current (Amps) x Resistance (Ohm)

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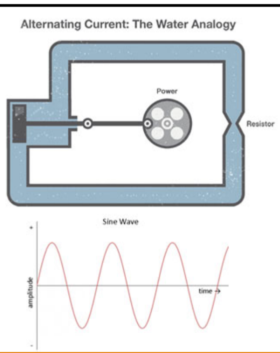
AC CURRENT EXPLAINED



AC = Alternating Current

- Current reaches a peak and changes direction (sine wave)
- Transmits electric efficiently over long distances
- AC voltage can be easily stepped up for longer distance transmission, then stepped down for building use
- Examples: turbine generators, inverters, transmission & distribution, buildings, industrial

Alternating Current (AC) vs. Direct Current (DC) - SparkFun Learn

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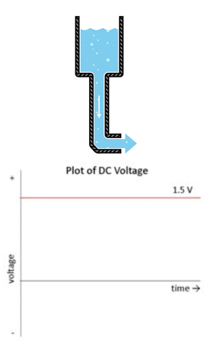
DC CURRENT EXPLAINED



DC = Direct Current

- DC is constant and flows in one direction, from negative to positive
- Transmits electric over short distances
- DC is more stable and reliable for sensitive devices and power storage
- Examples: batteries, DC generators. Solar PV cells, telecom, electronics

Alternating Current (AC) vs. Direct Current (DC) - SparkFun Learn

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AC / DC CONVERSION

Inverter – converts DC to AC

Rectifier – converts AC to DC

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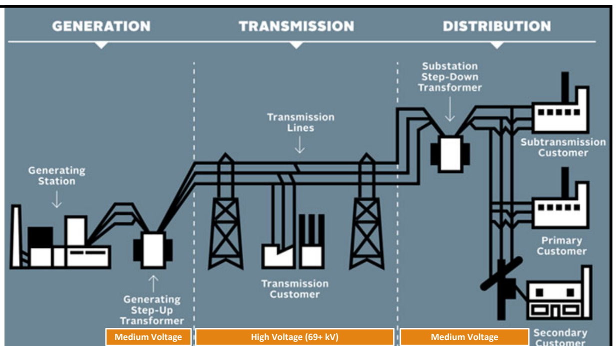
SYSTEM VOLTAGES



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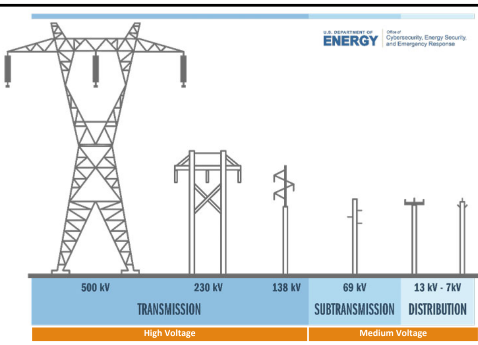
TRANSMISSION & DISTRIBTUTION



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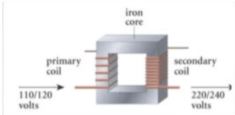
TRANSFORMERS

- Changes voltage and current
- Step-up Transformer increases voltage, but lowers current
- Step-down Transformer decreases voltage, but raises current
- *Why is this necessary?*
  Current produces heat (losses)

  Stepping up voltage (138kV+) for long distance transmission greatly improves efficiency by minimizing heat losses and therefore cost

  Voltage can then be stepped down to safe usage levels (120/240V) close to the point of use



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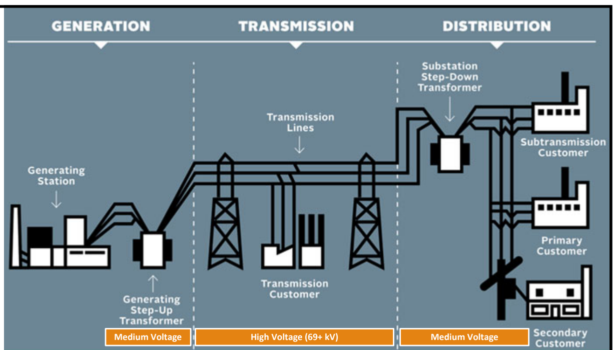
SYSTEM DESIGN



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ELECTRICAL CONDUCTION

Aluminum

- 60% as conductive as copper
- Less expensive (more abundant)
- 33% lighter than copper
- Thermally reactive (cold creep)

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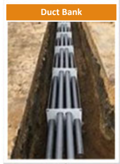
Overhead Transmission & Distribution

- Significant cost advantage over underground installations
- Longer life
- Faster fault finding and repair
- More readily withstand overloads

Underground Distribution



- Aesthetics
- Safety – less chance for public contact
- Significantly fewer service interruptions
- No tree trimming needed
- Less voltage drop

OVERHEAD VS. UNDERGROUND CABLES

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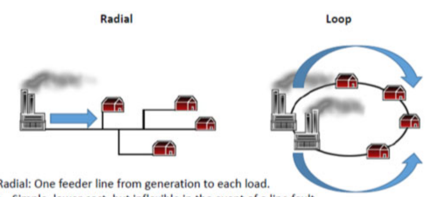
CAMPUS DISTRIBUTION

Distribution: Radial vs. Loop Topology



Radial: One feeder line from generation to each load.
- Simple, lower cost, but inflexible in the event of a line fault
- No way to divert power through other feeders to keep power on

Loop: Multiple feeder lines, allowing power to flow to load from either direction
- Managed via switchgear (breakers, switches, etc) to allow or block the flow

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ELECTRIC RELIABILITY

Service Interruption –
- An event that results in zero voltage at the customer load
- Also known as power outage

Power Quality –
- Power delivered to the customer within a specified voltage range above required minimum current

Power Quality events are not considered to be Service Interruptions as defined by IEEE

How do you know if you have experienced a power quality event?

What are the potential impacts of a power quality event?

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BUILDING ELECTRICITY

Emergency generators supply power for Building Code life safety systems such as:

- Egress lighting
- Fire alarm systems
- Smoke evacuation
- Elevators
- Broadband Utility and Telephone Utility Rooms
- Communication and Fiber rooms
- Central Control system cabinets

Standby generators supply power for user defined needs beyond building code life safety. For example:

- Critical lab equipment such as ultra-lows/freezers
- Critical lab exhaust fans

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BUILDING ELECTRIC OUTAGES

- Outage identified
- Isolate circuits (using loop or redundancy to maintain power)
- Communicate if power lost
- Diagnose issue
- Repair and test
- Restore power
- After-action review
- Communicate / notify

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APPA University Electric Distribution

Things to Consider

- University Values & Expectations
  - Reliability vs. Resiliency
  - Aesthetics
- Return On Investment (ROI)

APPA

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APPA University Electric Distribution

Things to Consider

- University Values & Expectations
  - Reliability vs. Resiliency
  - Aesthetics
- Return On Investment (ROI)

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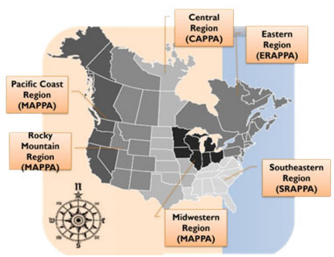
CLASS EXERCISE

Assumptions:

- New university/site
- Academic and research
- Self- generate
- In/adjacent to major city
- Positive ROI

10-minute discussion → report out:

- Major features of electrical distribution system design
- Reliability and resiliency design features
- Why



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- Sign-in sheet
- Evaluation form

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