ECE 333 – GREEN ELECTRIC ENERGY

Introduction and Overview

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RENEWABLE ENERGY SYSTEMS

- We focus on the technical, economic and environmental aspects of renewable and alternative energy systems to obtain an understanding of their role in meeting society's electricity needs

- We analyze a wide range of renewable energy supply issues

RENEWABLE ENERGY SYSTEMS

- The course provides a basis to understand the distinctive scientific principles of renewable energy and the ability to provide an assessment of the economics and environmental impacts of renewable energy

RENEWABLE ENERGY SYSTEMS

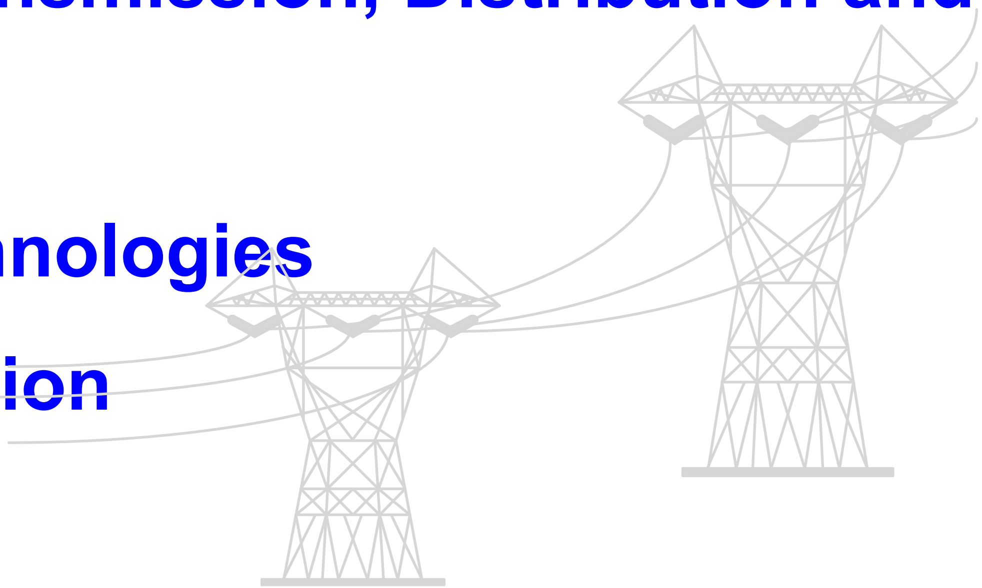
- The course covers the basics of energy generation from renewable sources, the needed thermodynamics background, the structure and nature of the electric transmission grid, the integration of renewable resources into the grid in terms of technical, environmental and economic aspects and the regulatory framework for electricity

ELECTRICITY AND ENERGY

- While the main focus of the course is on green resources, we need to also understand both the energy context and the policy context, within which such resources are planned and operated
- Energy obtained from various sources is converted into electricity; electric energy is not used in that form but is converted into other energy forms, such as light, sound and mechanical energy

Todays Topics

- Power and energy
- Energy and development: energy consumption
- Generation, Transmission, Distribution and loads
- Generation technologies
- Energy conversion



Electrification was named by the National Academy of Engineering as the top engineering achievement of the 20th century

1. Electrification
2. Automobile
3. Airplane
4. Safe and abundant water
5. Electronics

Achievements were rated by weighing the contribution to the quality of life during the past 100 years

Energy

Lifting a 100 pound mass 6 feet takes 600 foot-pounds of energy (work)

This is about 800 Joules of energy

This is the same as 800 Watt-sec

This is about .000222 KWH

Electricity costs about 10 cents per KWH

When does Energy matter?

- **Monthly utility bill**
  - We pay for energy based on KWH – typically 10 cents/KWH
- **Emissions**
  - Particulates – very fine particles suspended in the air. Bad for your lungs and heart
  - Sulfur Dioxide (SO_2) – forms sulfuric acid when it interacts with water creating acid rain
  - Nitrogen Oxides (NO_x) – forms acid rain, bad for lungs in humans, and contributes to global warming
  - Carbon Dioxide (CO_2) – contributes to global warming
  - Mercury – just bad for people in many, many ways

Power

Power = work done / time

Power = the rate at which energy is used

Lifting a 100 pound mass 6 feet in 2 sec takes a power of 300 foot-pounds/sec

This is about 400 Joules/sec

This is the same as 400 Watts

This is the same as 0.4 KW

This is about 0.5 HP (1 HP = 746 W)

Power is a measure of capacity

Power Units

- **KW – 1,000 Watt**
- **MW – 1,000,000 Watt**
- **GW – 1,000,000,000 Watt**

A large coal or nuclear plant is about 1GW

Installed U.S. generation capacity is about 1,000 GW (about 3 KW per person)

When does Power matter?

High demand at home

Too many things on one circuit breaker

High demand in the system

Everyone does the same thing at the same time (cook dinner, watch TV, turn on A/C)

Components have ratings

Operating over power ratings is destructive

Power is a measure of strength or capacity

You do pay for this, but not as a fuel charge

Power vs. Energy
Example in your home

Power

Place 5 lamps in your living room

In each lamp put a 100 Watt light bulb

That is a potential demand of 500 Watt (0.5 KW)

Energy

Turn 5 lamps on for 2 hours → 1 KWH (cost about $.10)

Turn one lamp on for 10 hours → 1 KWH

Coal to Kilo-Watt-Hours

16 charcoal briquettes weigh about 1 pound (an average heat energy content of 10,000 BTU = 10,000 KW-Sec = 2.8 KWH)

At 50% efficiency, 2.8 KWH gives 1.4 KWH, which will supply a 60 Watt bulb for about 24 hours at a cost of about 14 cents

Human power to Kilo-Watt-Hours

A person in good shape can continuously work to produce about 0.75 HP, which is about 0.5 KW

In one hour this is 0.5 KWH of energy, which will supply 5 - 100 Watt bulbs for 1 hour at a cost of 5 cents.

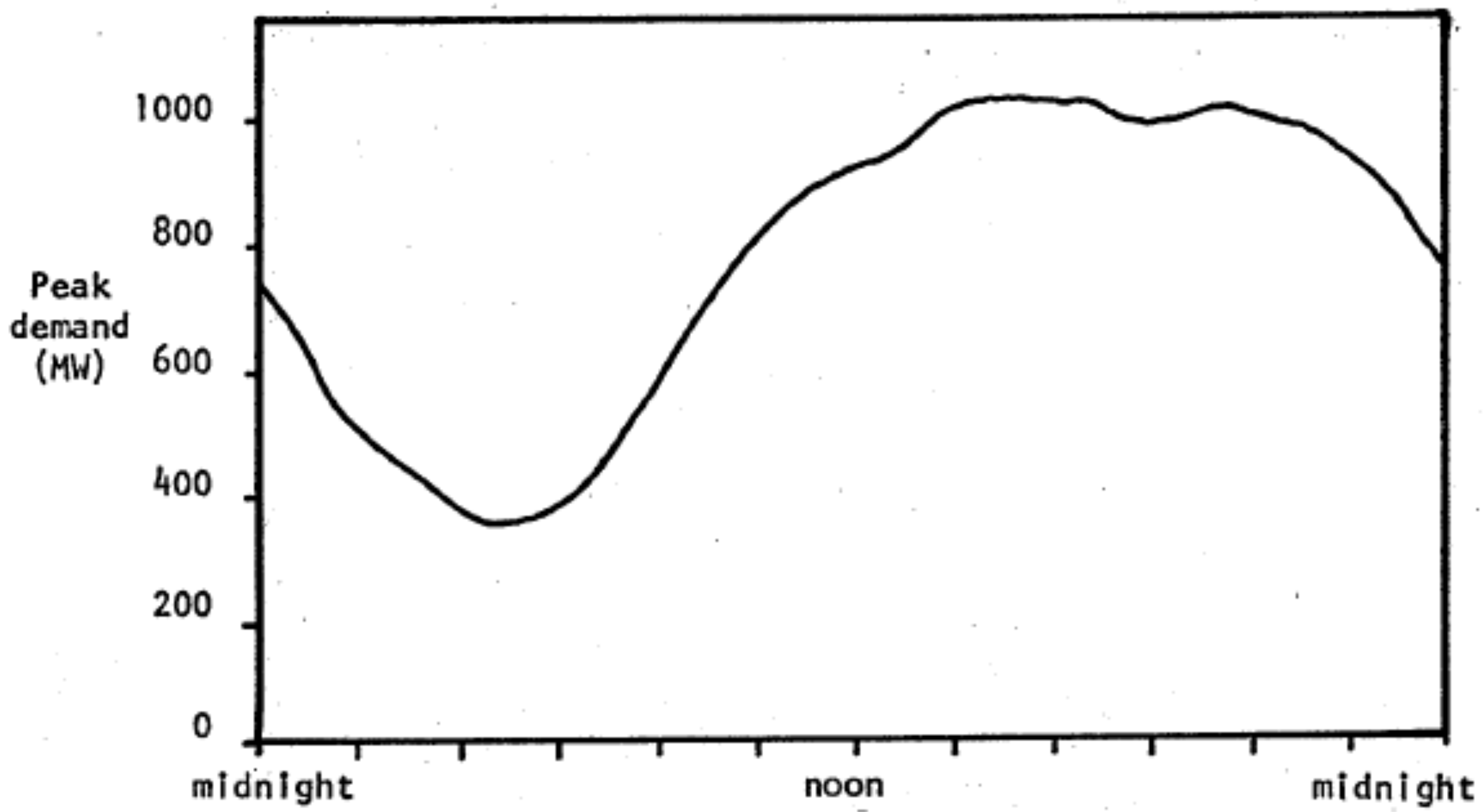
This is why electricity spread rapidly throughout the world

Loads

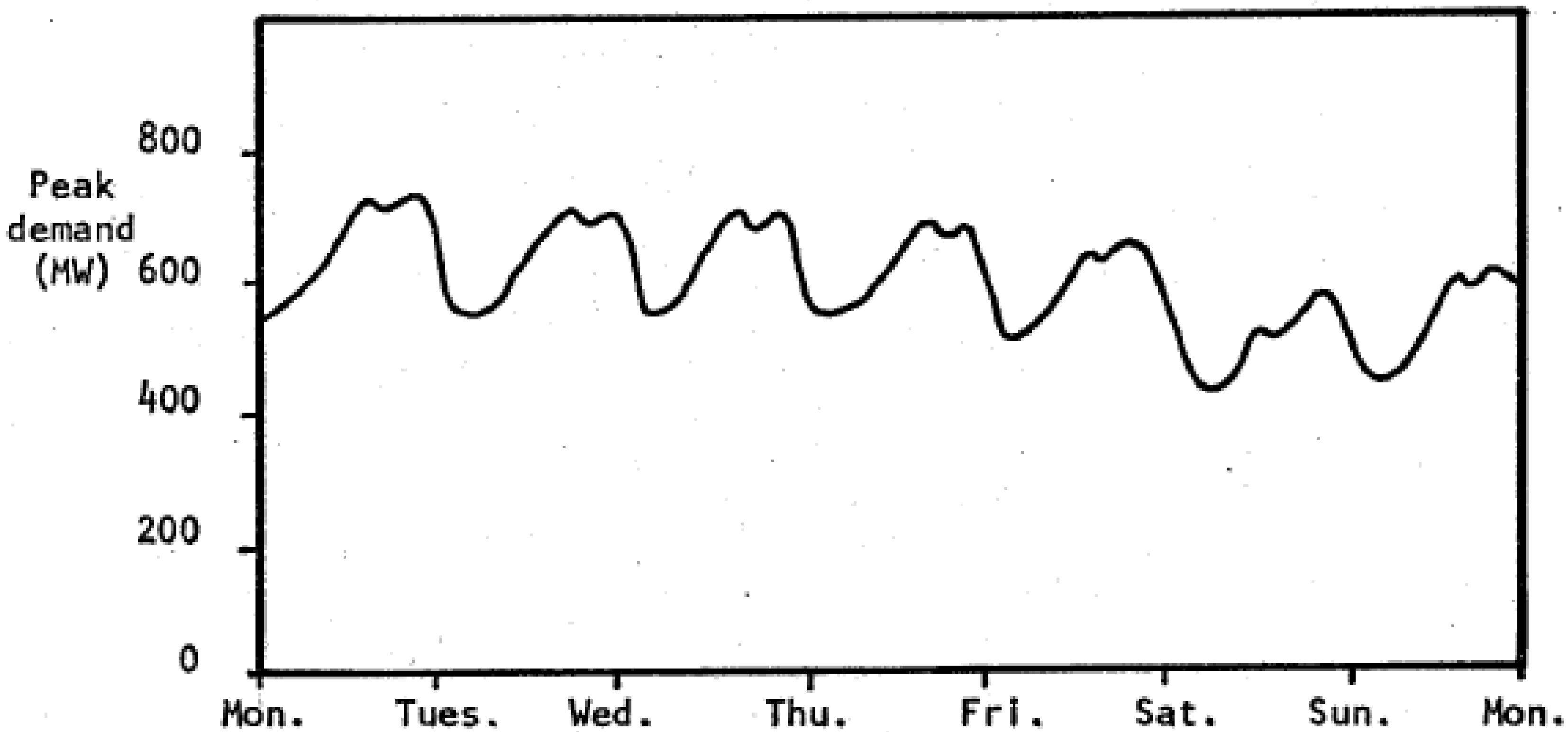
- Industrial – 30%
- Commercial – 35%
- Residential – 35%

- Lights – 20%
- Motors – 60%
- Electronics – 10%
- Heating & Other – 10%

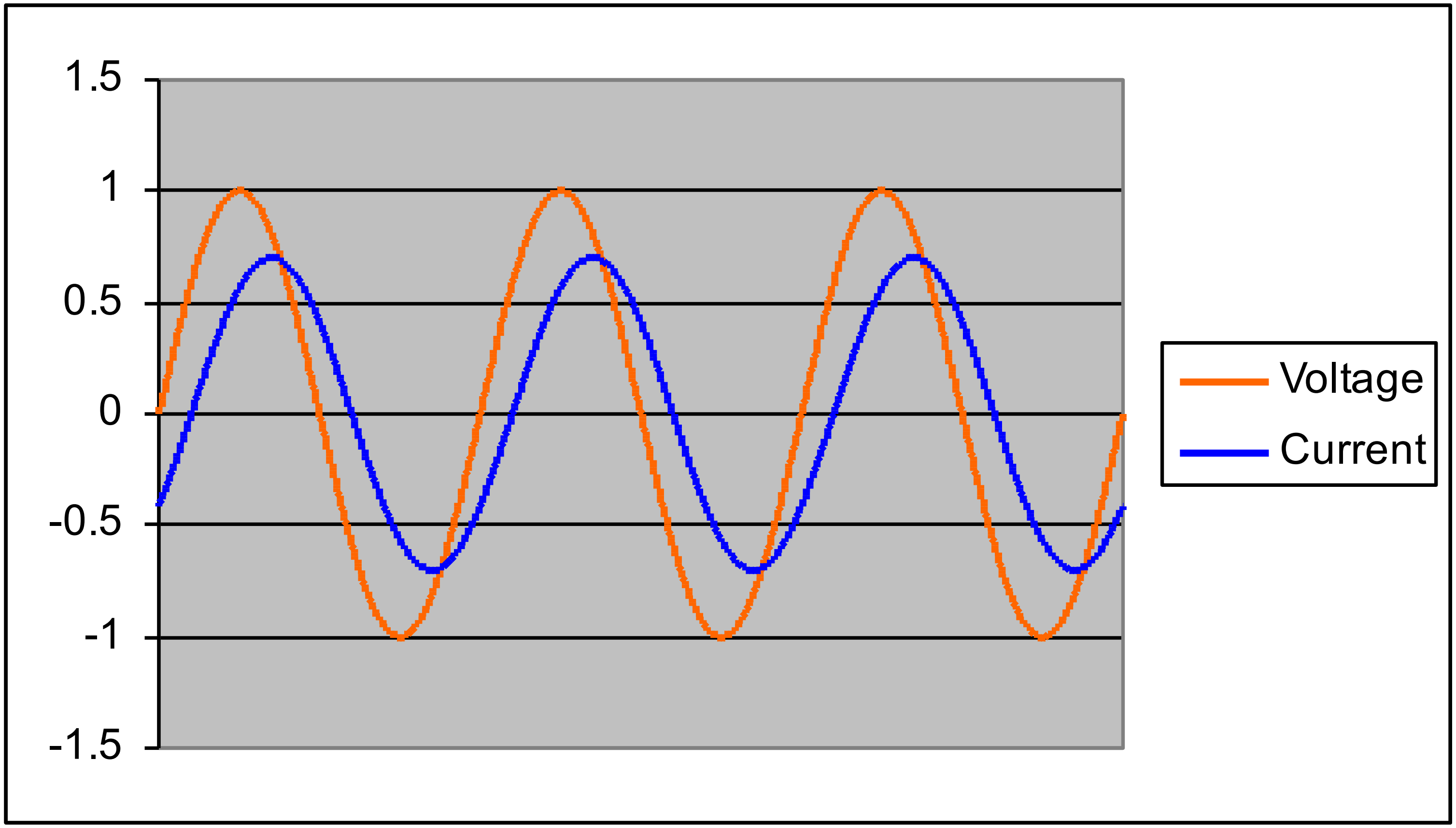
A typical daily load cycle



A typical weekly load cycle

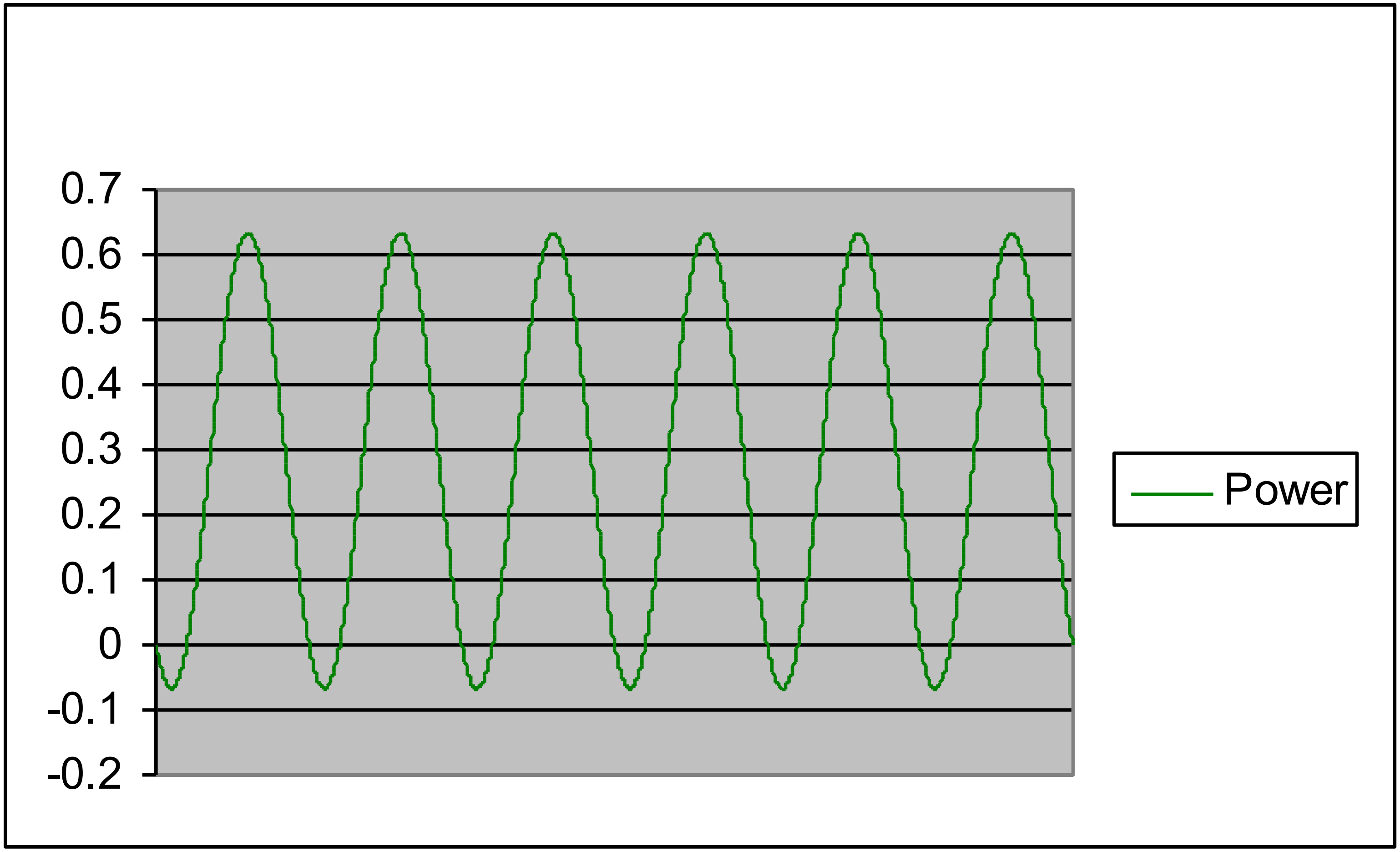


What is reactive power?

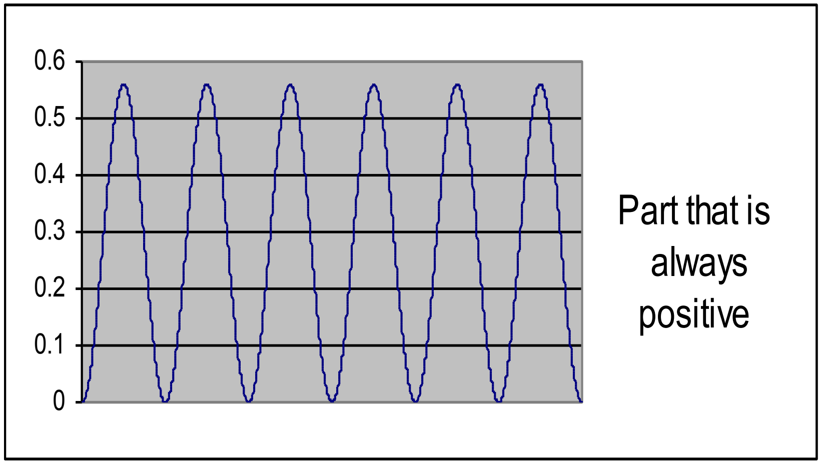


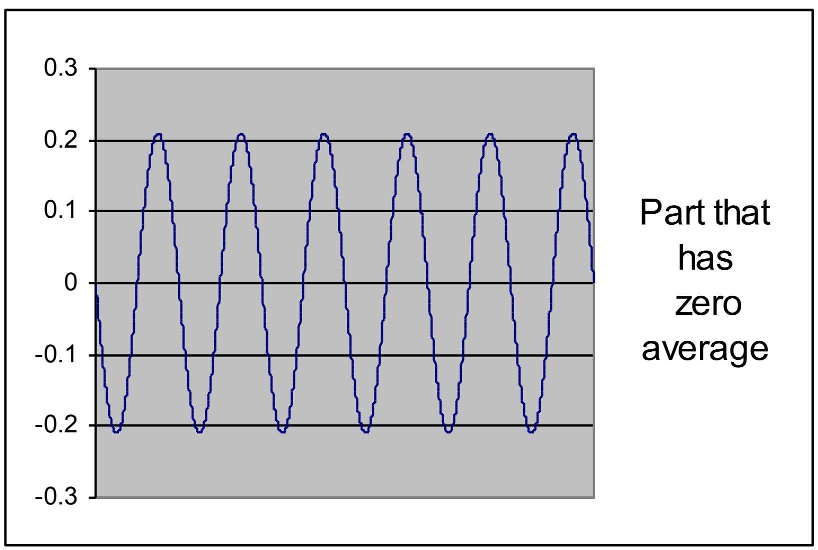
- It is all in the phase shift

Instantaneous power (one phase)



Deomposed into two terms



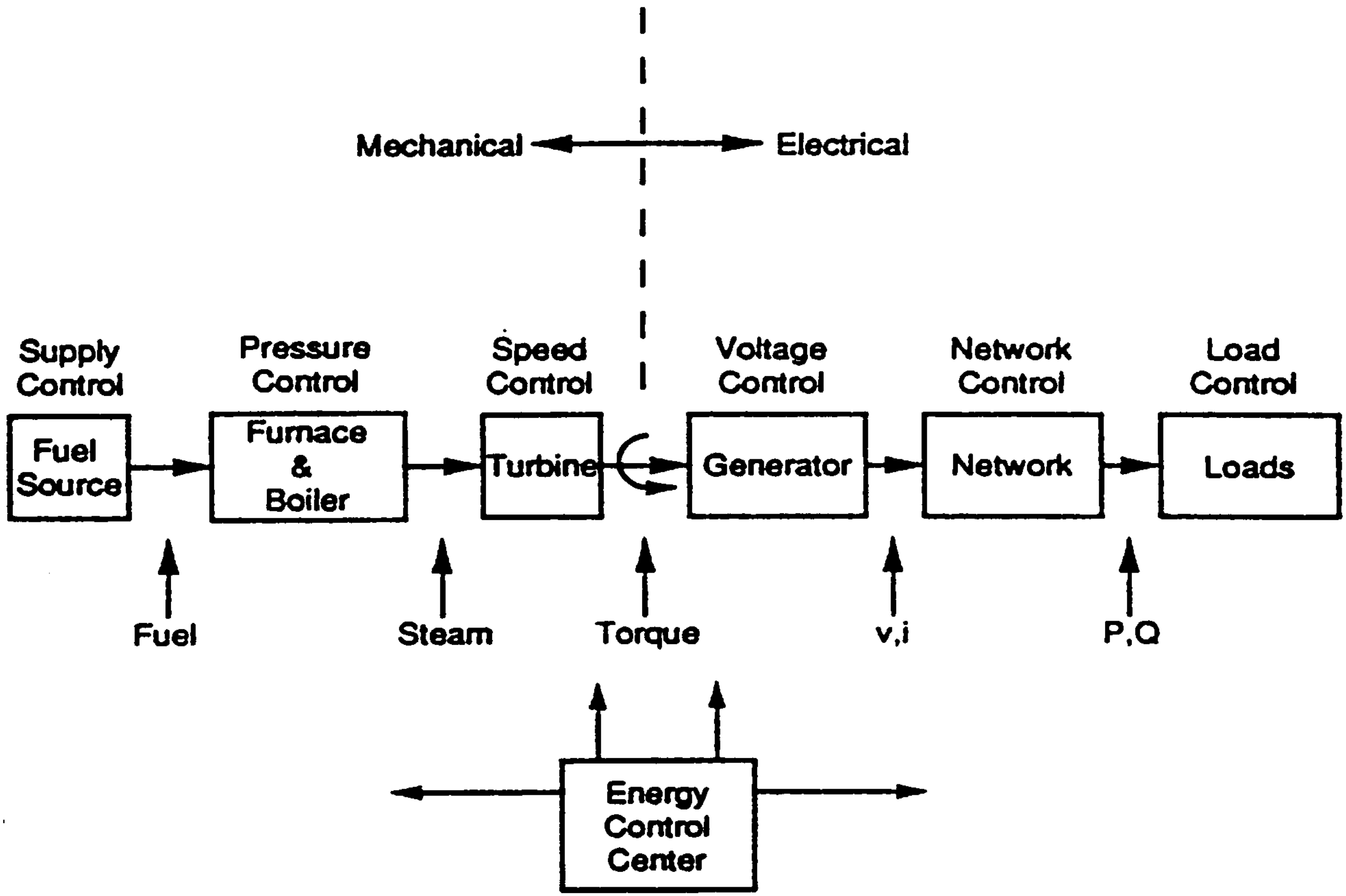


P (1-cos(2wt))

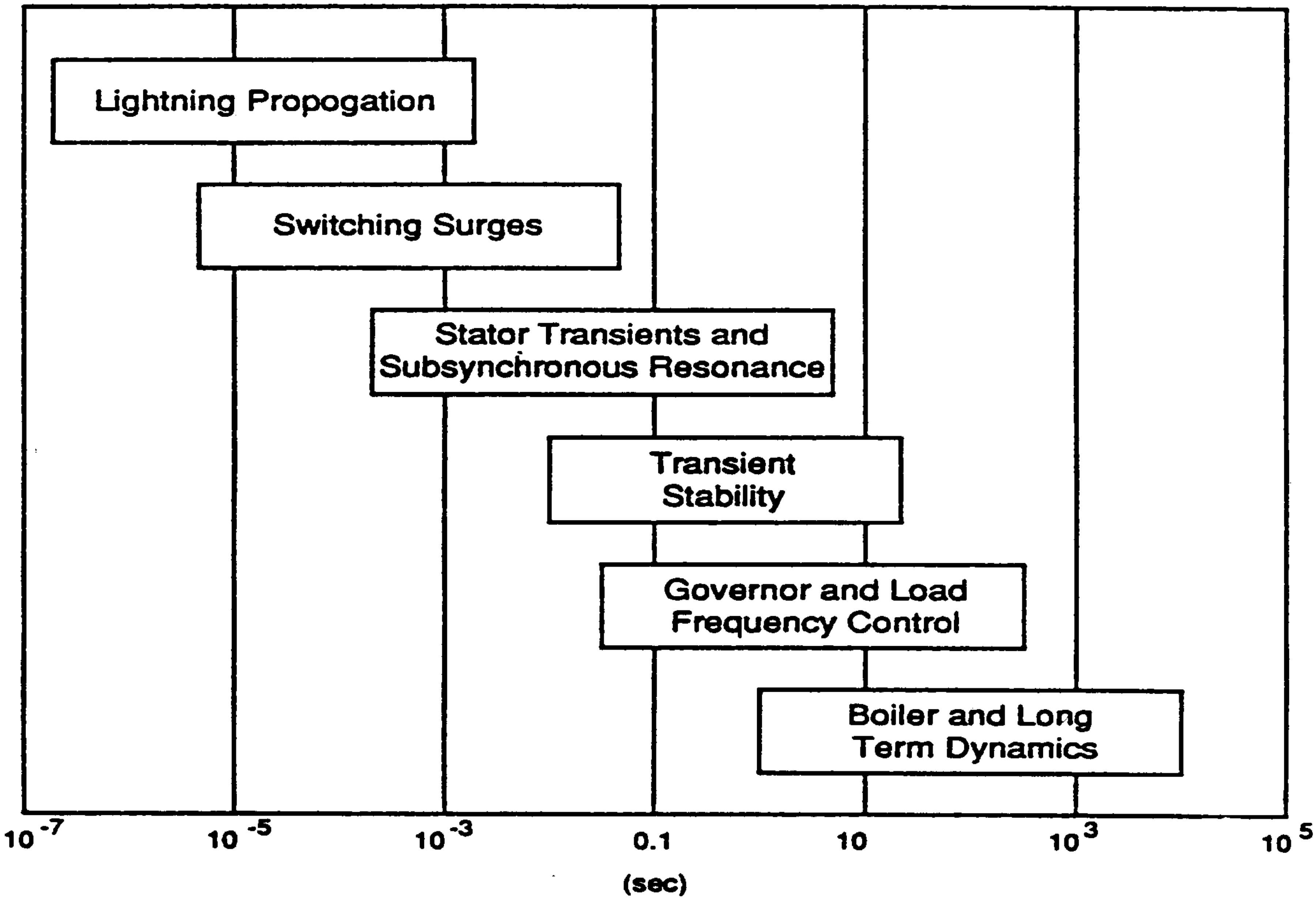
P = .275 PU Watts

- Q sin(2wt))

Q = 0.205 PU VARS



Mechanical
Electrical
Supply Control
Pressure Control
Speed Control
Voltage Control
Network Control
Load Control
Fuel Source
Furnace & Boiler
Turbine
Generator
Network
Loads
Fuel
Steam
Torque
v,i
P,Q
Energy Control Center


Lightning Propogation
Switching Surges
Stator Transients and
Subsynchronous Resonance
Transient
Stability
Governor and Load
Frequency Control
Boiler and Long
Term Dynamics
10 -7
10 -5
10 -3
0.1
10
10 3
10 5
(sec)

What happens when you turn on a light?

Five stages of response to adding load

- Stage 1: Currents redistribute almost instantaneously (could model generators as constant voltage sources – magnitude and angle)

- Stage 2: These currents create a mismatch in power/torque at every generator because the mechanical power/torque cannot change quickly. This mismatch will cause all the generators to change their speeds – energy is taken from (or supplied to) the shafts (kinetic energy based on shaft inertia). This causes their "angles" and "speeds" to change.

Five stages of response to adding load

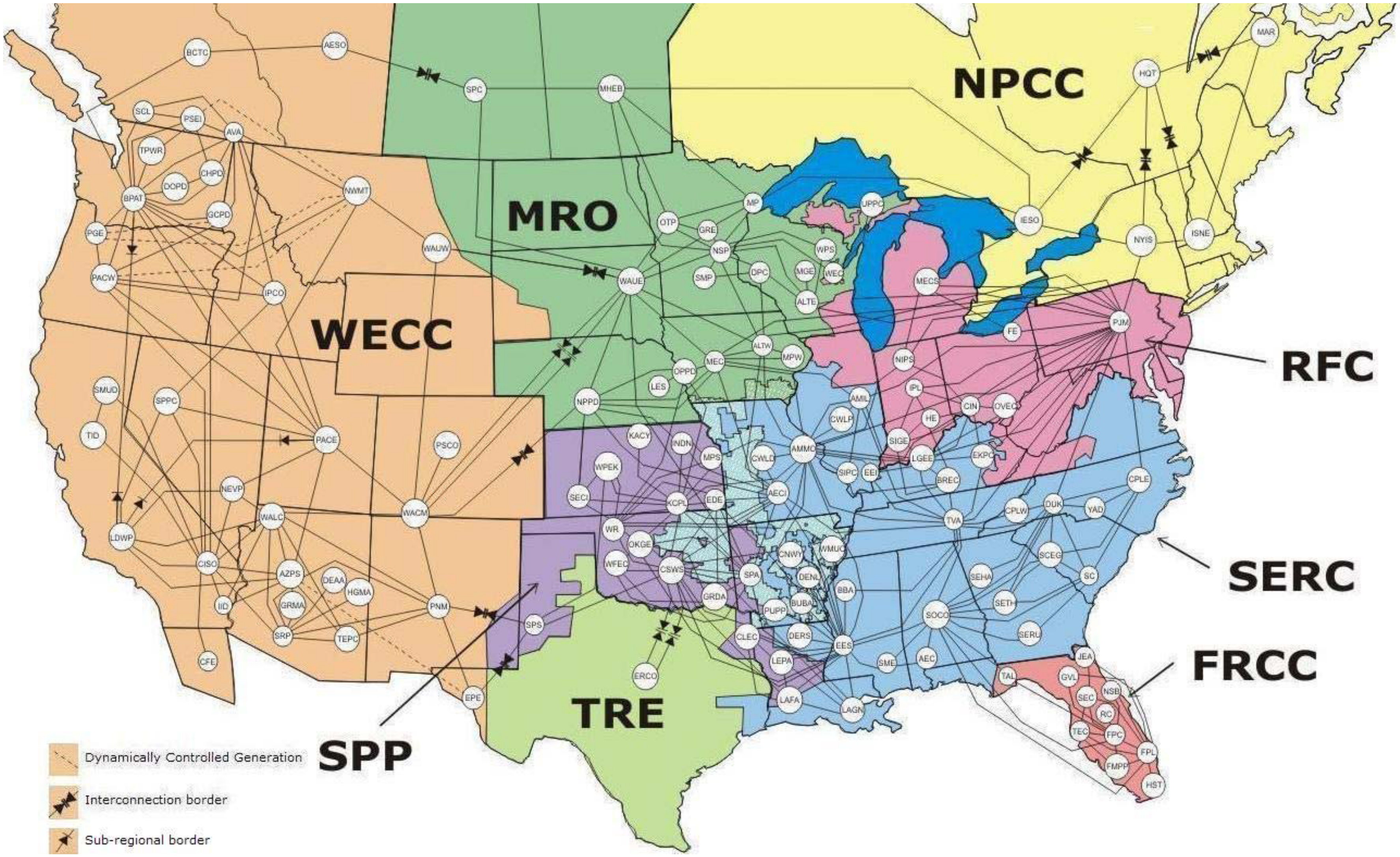
- Stage 3: The speed control governors sense the change in speed and react to return the generators to near rated speed – they typically have a 5% “droop”. They open or close a turbine valve. (This also initiates the boiler control system when the steam pressure changes).
- Stage 4: The Load Frequency Control system will detect the change in area frequency and possibly area interchange and react to change the power commands to each generator in that area.
- Stage 5: Economic dispatch and energy market activity make changes to ensure optimum production.

Control centers

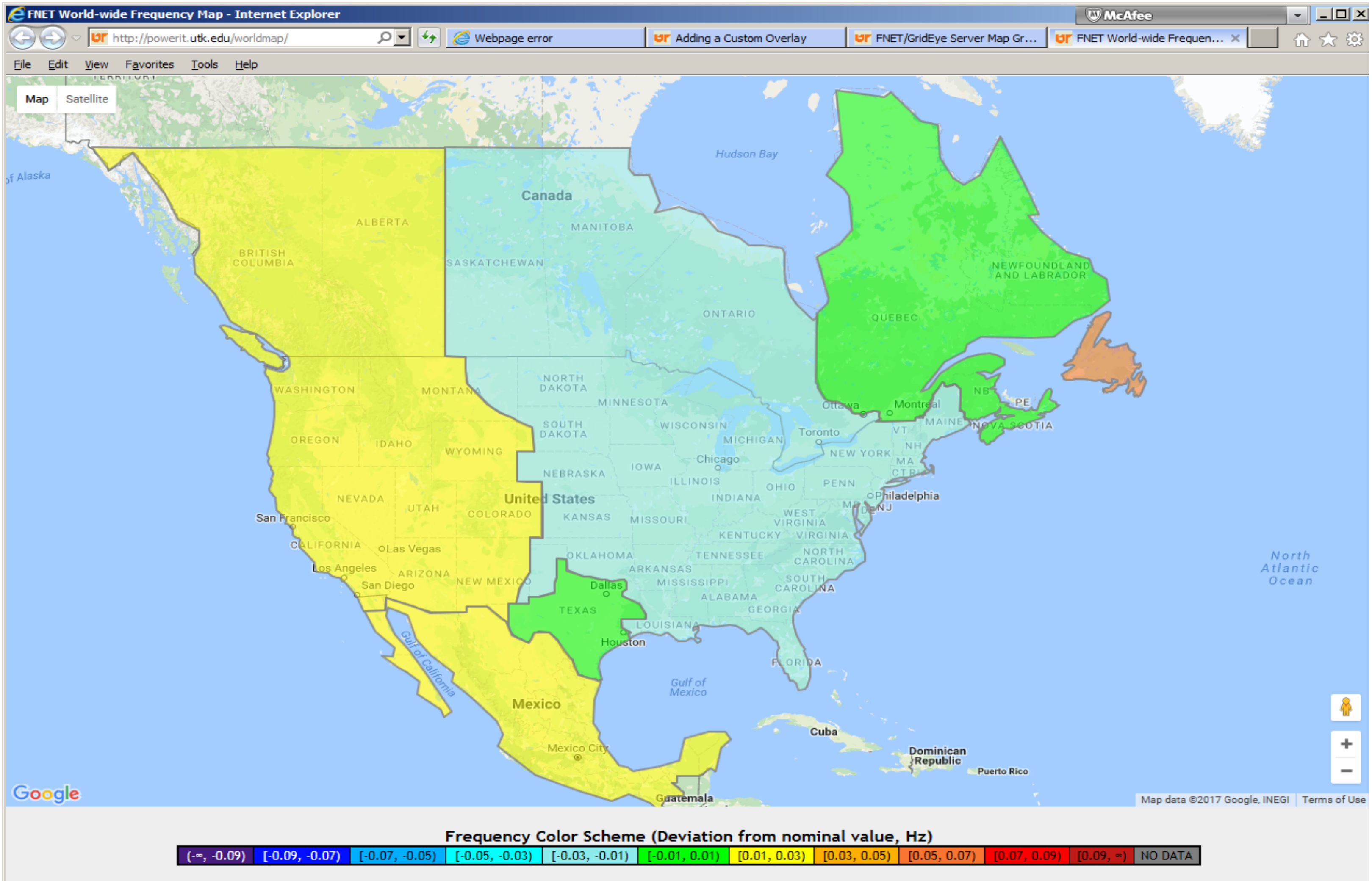
Who's in charge?

The Balancing Authority (BA) is the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within a Balancing Authority Area, and supports interconnection frequency in real time

NERC Balancing Authorities



http://fnetpublic.utk.edu/



Capacity Factor

- The ratio of the actual energy output of a power plant over a period of time and its energy output if it had operated at maximum capacity the entire time.

- Reasons why a power plant doesn't operate at its maximum output
  - Fuel isn't available, or too expensive
  - Wind isn't blowing (Wind turbine)
  - Sun isn't out (Solar panels)
  - Water Reservoir is low (hydro)
  - Ice on Mississippi so coal/oil barges can't move
  - Out of service for maintenance

Wind Farm and Nuclear Plant

- **3,000 MW wind farm**
  - A wind farm might have a capacity factor of 30%
  - In an average hour it will generate 900 MWH
- **1,000 MW nuclear plant**
  - A nuclear power plant operates 90% of the time, and when it does operate it operates at full output
  - In an average hour it will generate 900 MWH
- **They are about the same!**
  - You get 900 MWH in the average hour

Hydro

- **Pros**
  - **Renewable Energy (as long as we keep getting rain/snow)**
  - **One of the cheapest and easiest ways to make electricity**

- **Cons**
  - **Completely transforms the local environment**
  - **Can displace a large numbers of people**
  - **Issues of fish habitats and flood control**
  - **Wherever the geology permits, it has been done (none left)**

Coal

- **Pros**
  - **US has a lot and it is cheap**
  - **Few other competing uses for coal**
- **Cons**
  - **Emissions – Particulates, SO_2 , No_x , Mercury, CO_2**
  - **Mining processes can be very dangerous and messy**

Natural Gas

- **Pros**
  - Also reasonably plentiful in North America
  - Also import a lot from Canada
  - Also more liquefied natural gas (LNG) from all over world
  - Emissions are less than coal

- **Cons**
  - Many competing uses such as home heating, transportation fuel for cars/buses, ammonia production for fertilizer, plastics, etc.

Nuclear

- **Pros**
  - Proven technologies exist (France has mostly Nuclear Energy)
  - Extremely High Capacity Factor (90% or more)
  - Few competing uses for cheap fuel
  - Very little green house emissions (none from nuclear reaction)

- **Cons**
  - Waste
    - Presently all nuclear power waste ever created is stored on-site at the nuclear plant
    - A federal waste storage location has never been finished
  - Weapons proliferation
  - Fear of an accident

Biomass (Biofuels)

- **Pros**
  - Waste source is easy because it needs to be disposed of somehow
  - Less Sulfur, NO_x than coal (still some but 4-6 times less than coal)
  - Can have CO_2 reductions.
    - Growing plants consume the CO_2.
    - There is still some CO_2 impact because of transport of fuel and fuel used in farming

- **Cons**
  - Competing uses for farmland → higher food prices
  - What is the "energy balance"?
    - How much energy do you get from spending 1 unit of energy on production?
    - Corn Ethanol : 1.2 – 1.4 (this isn't very good. We spend 4 gallons to produce 5)
    - Cellulosic (grass) Ethanol : 2 – 6 (this has some potential)
    - Sugar Cane Ethanol : 8.2 – 10 (this is great, but we can't grow it most places in US) (Brazil)

Biomass fuels

Switchgrass

Corn

Sugarcane

Wood

Wind

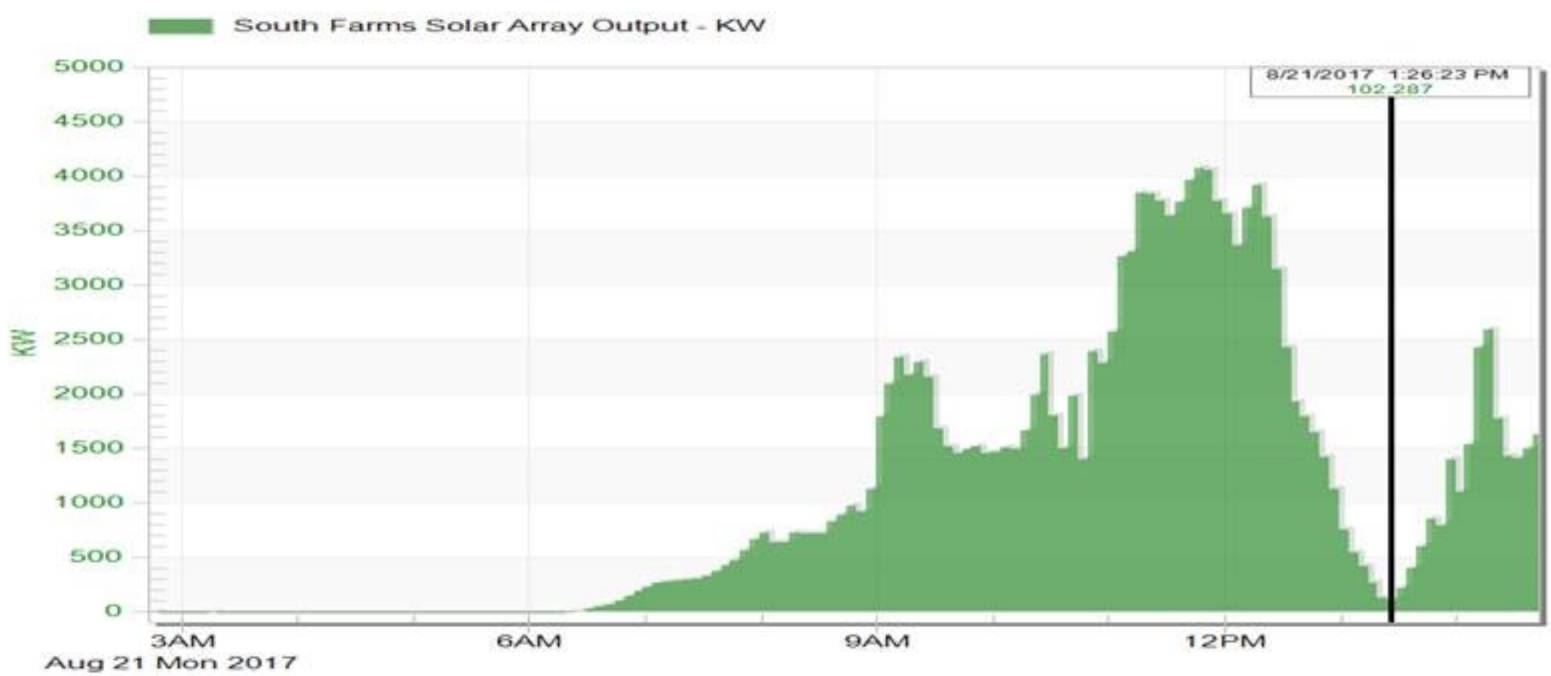
- ## Pros
  - Fuel is free
  - Many of best locations have large amounts of available land
  - Very old and proven technique, coupled with new technology

- ## Cons
  - Energy only converted when the wind blows
  - Hot summer days are highest electricity demand
  - Wind doesn’t usually blow on hot summer days
  - A good wind farm is somewhere flat where the wind blows a lot
  - Normally not where large populations like to live
  - A transportation infrastructure is needed to support large scale
  - Operation and planning of the grid is very different

Solar

- ❑ **Pros**
  - **Fuel is Free**
  - **Little maintenance**

- ❑ **Cons**
  - **Only get electricity when the sun is out**
  - **Photovoltaic cells are still expensive**



Sign up for a Solar Farm tour online

5/18/2017

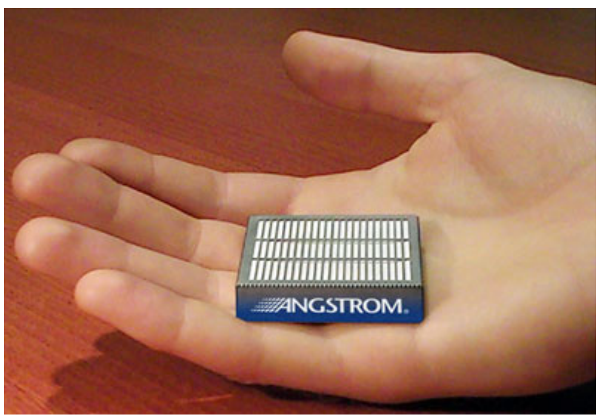
F&S will offer monthly tours of the Solar Farm on the first Friday of each month from July to December 2017, from 2 to 4 p.m. You can sign up to participate at https://illinois.edu/fb/sec/3893405

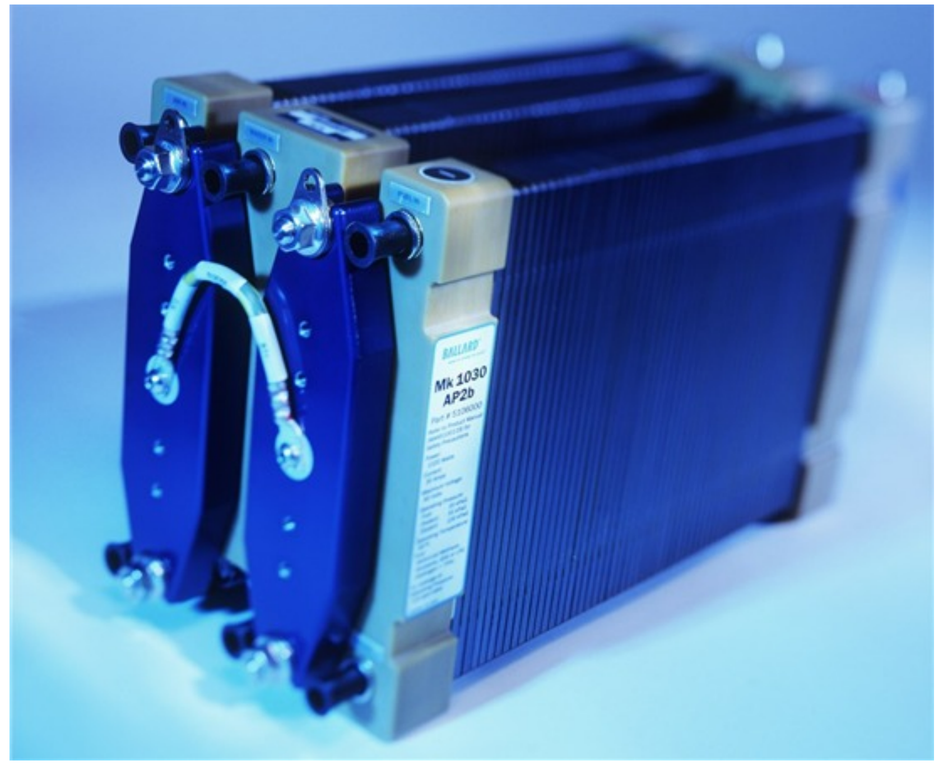
Hydrogen

- **Pros**
  - Hydrogen combustion produces mostly water as a byproduct
  - No CO_2!
  - Fuel Cell also possible (kind of like a battery)
    - Converts Chemical Hydrogen directly to electricity
    - More efficient than burning and then heating water
    - Can also run a fuel cell backwards
  - Distributed Generation (Fuel Cells in every neighborhood)
  - No transportation needed
- **Cons**
  - Hard to find lots of “free” hydrogen presently
  - Not yet commercially possible on a large scale
  - Somewhat difficult to store and transport

Hydrogen Fuel Cell Plant

- Basically they look like batteries





http://www.ecofuss.com/hydrogen-fuel-cells-the-next-generation-energy-for-cell-phones/

http://jalopnik.com/cars/industry-news/daimler-ford-teaming-up-on-fuel-cells-320383.php

Energy conversion

Steam plant (Coal, nuclear, oil)

- Fuel heats water to make steam
- High pressure steam turns steam turbine
- Steam turbine turns electromagnet
- Spinning electromagnet creates voltage
- Load connected to voltage consumes energy

Energy conversion

Hydro plant (dams and pumped hydro)

- ❑ Water turns hydro turbine
- ❑ Hydro turbine turns electromagnet
- ❑ Spinning electromagnet creates voltage
- ❑ Load connected to voltage consumes energy

Energy conversion

Gas plant (natural gas turbines)

- Gas is burned to create pressurized hot air
- Pressurized hot air turns turbine
- Turbine turns electromagnet
- Spinning electromagnet creates voltage
- Load connected to voltage consumes energy

Energy conversion

Biomass plant (includes wood and trash)

- Burn the plant to heat water and make steam (then it is like a steam power plant)
- Decomposition produces methane
- Fermentation changes biomass to alcohol

Energy conversion

Wind farm

- Wind turns blades – usually with gears
- Induction machine is connected to the grid
- Power electronics controls the power out

Energy conversion

Solar

- **Photovoltaic panels produce DC voltage**

  OR

- **Sunlight is converted to heat to make steam**

GRADING POLICY

- The course grade is based on the performance of the student in the quizzes, the two midterms and the final exam
- Students will be assigned homework but will not need to hand them in as they are not graded
- The problems in the short quizzes will be selected from the homework assignments

GRADING POLICY TABLE

component	*percentage*
homework	0
quizzes	15
midterm exams	25 x 2 = 50
final	35
total	100