Intro to Electricity

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What Makes Electricity Interesting

- We somehow start with a fuel (Counting wind, geothermal and sunlight in this).
- Transport it from where we found it to a generating facility.
- Turn it into electricity losing some energy as heat.
- Run it along long wires to where people want to use it, losing yet more energy.
- From there send it out to every small location (losing more), and
- Because electricity is not *easily* stored, adjust the rate at which we generate electricity moment-by-moment to make sure there is just enough.

This is a logistical miracle.

Basic Units

- $Watts = AmpsVolts$ first thing everyone learns.
  - Pro tip on units, if it is someones name, capitalize it.
  - Volt is analogous to height.
  - Amp is analogous to a weight.
  - Watt is what it happens when that weight is dropped from that height.
  - DC is easy; AC is “complex”
- AC because it is a wave, has a few more components.
  - Real Power, measured in W, it is what does the work.
  - Reactive power, measured in volt-amps (var),“r” tells you it is reactive, is what pushes the electricity around.
  - Apparent Power, is in volt-amps too (VA) is when you add the two together in a vector sense.
  - Power Factor is the Real(W)/Apparent(VA).

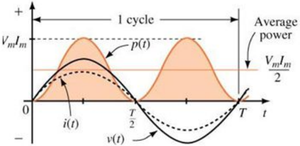
What?

Caveat IANAE and I will do thing like call current amps and the like. Also, this is the simple, single phase, view with lots of simplifications. Reality is for engineers.

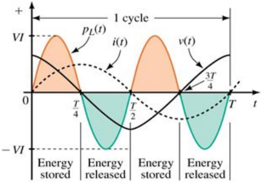
- The alternating part of AC is what causes the complication.
  - You can talk about instantaneous power but
  - Tend to talk about average power.
- With a resistive load, think light bulb, amps and volts are in sync
- Inductors and Capacitors throw amps and volts out of sync
  - Capacitors store energy in electric fields. Think a very burst battery.
    - Amps peak *before* volts
  - Inductors store energy in magnetic fields. Think about an electromagnet in a motor.
    - Amps peak *after* volts

Picture for this

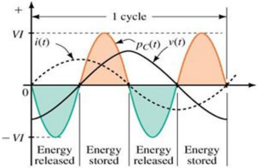
AC Power to a Resistive Load



AC Power to a Inductive Load



AC Power to a Capacitive Load



source: http://slideplayer.com/slide/5297074/

Power Factor

- Measure it
  - Henrys are the unit for inductance/capacitance and engineers use that in calculations
  - There are also power factor meters
  - You can also check out the difference between amps and volt on oscilloscope.
- Low numbers mean the utility needs to generate more power than customer uses.
  - Can happen with low load, like a motor barely moving, but you still need the electromagnet
  - Common solution is to install capacitors somewhere to cancel out the inductor

Why do we care about reactive power and power factors?

- Engineers have to design systems to accommodate not just the real, but real plus reactive, i.e., apparent power.
- Reactive power has to be generated.
- Not residential tariffs, but commercial and industrial tariffs charge for reactive power or have penalties for low power factors.

kW vs kWh

- kW is instantaneous and called power
- kWh is the integral over time and called energy.
- 100 W light bulb uses 100 Wh = 1/10 kWh per hour
- Get used to flipping between 1,000,000,000 W = 1,000,000 kW = 1,000 MW = 1 GW

Lets Generate Some Electricity

- Turbine – spin something in a magnetic field to induce a current.
- Lots of ways to spin a turbine
  - Coal, grind it up, burn it, make steam, use steam to spin the turbine.
  - Nuclear, use the heat to make steam, use steam to spin a turbine.
  - Biomass, burn stuff to ...
  - Gas, burn it to spin a turbine ...
  - Fuel Oil or Diesel
  - Solar thermal, use the sun to make steam ...
  - Water, falling water hits a turbine and spins it
  - Wind, spin a turbine
  - etc.
- Or don't spin a turbine and go for photo-voltaic, PV.

Characteristics

- Nameplate, fully loaded under ideal conditions (MW)
- Ramp rate, how fast power (MW) can change MW/min
  - Not always constant, can differ by capacity factor (fraction of nameplate)
  - Not always symmetric, up different from down.
  - Used to follow the load.
- Heat rate, BTU in/ BTU out, or BTU per kWh, only used for generation that uses a fuel.
  - It is impossible but 1 kW = 3412 BTU.
  - Not so straight forward for renewables (http://www.eia.gov/totalenergy/data/annual/pdf/sec17.pdf)
  - Recent average from EIA, https://www.eia.gov/electricity/annual/html/epa_08_01.html

Coal from the outside

Source: http://appvoices.org/images/uploads/2012/02/Asheville-coal-plant-e1432059203783.jpg

Coal on the inside

- Pulverize the coal, picture something that can do 20 Tons/hr
- Blow it into combustion chamber to burn
- Steam turns turbine, etc. https://youtu.be/IdPTuwKEfmA
- Clean up
  - NOx with ammonia common but plenty of others
  - Recover fly ash and sell it, great for concrete.
  - SOx, Mercury and other. BTW Radiation

Nuclear

Radiation to heat water and then . . . similar to coal. Just a reaction chamber

Local Reactor Columbia Generating Station

- 1,170 MW usually runs as load following. It reacts fast enough.
  - France is ~70% nuclear and they load follow.
- Most nuclear is run as base load, i.e., all the time since low variable cost and high fixed cost.
- Palo Verde (AZ) is larger 3.3GW

So, about nuclear

- So what to do with spent fuel.
- They probably produce less radiation than coal
- Can produce cheap, in the marginal cost sense, power. More on this later.

Natural Gas Conventional and Combined Cycle

- Combined cycle means
  - Taking more than one pass at extracting energy.
  - Spin the turbines first.
  - Take the heat and run a steam turbine.
  - Take the remaining heat and use a different working fluid (with different phase change properties) to extract more.
- CCNG
  - Plants are more expensive
  - Have higher heat rates
- Conventional
  - Cheap
  - Commonly run as peaking units.

Biomass

- Tend to be combined heat and power. Another way of using waste heat.
  - Cogeneration like this is common.
  - We have steam and chill water systems on campus
- While renewable, it is not, in general, clean
  - Particulates
  - Heavy metal concentration
  - etc.
- All this is improving.

Biomas One in Eugene. 30 MW and keeps catching on fire.

source: http://nationalpublicenergy.com

Geothermal

- Drill a hole down to where the temperature is high enough.
  - If it is dry, add water to make steam.
  - If wet, get steam
  - If temp is not high enough, use a few working fluids to generate electricity.
- Run through a turbine.

Neal Hot Spring in Malheur. 30 MW

Source: http://geo-energy.org

Diesel and other Fuel Oils

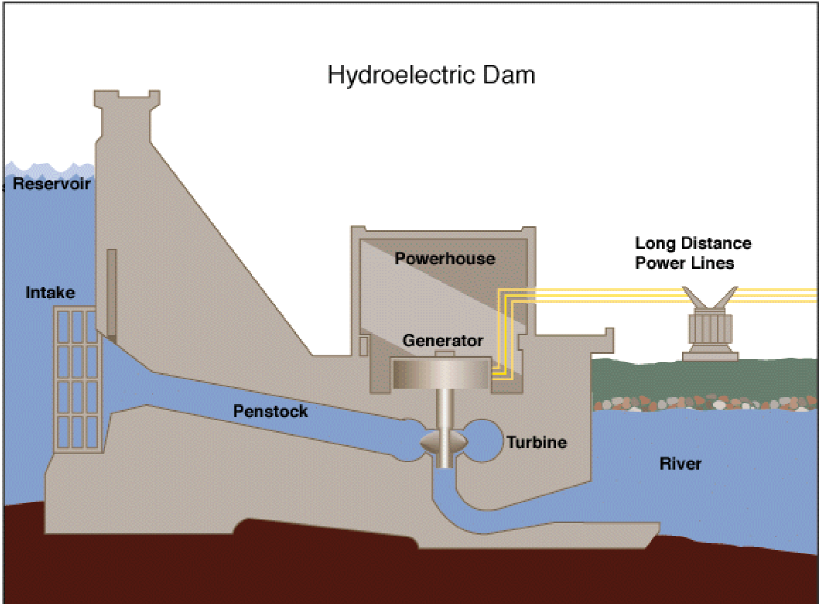
- You know the drill . . .
- Less than 1% in the US for electricity generation.
  - Still common heating fuel.
  - Backup fuel for NG generation
  - May be used in small distributed generation
- More common in less developed countries

Solar Thermal

- You have see the low and mid temperature designs for heating and cooling.
- High temperature designs are:
  - Dish
  - Tower
  - Trough
- Fluids:
  - Oil
  - Salt
  - Water steam
- Low and mid temperature are similar to roof top residential that you have seen.

Hydro

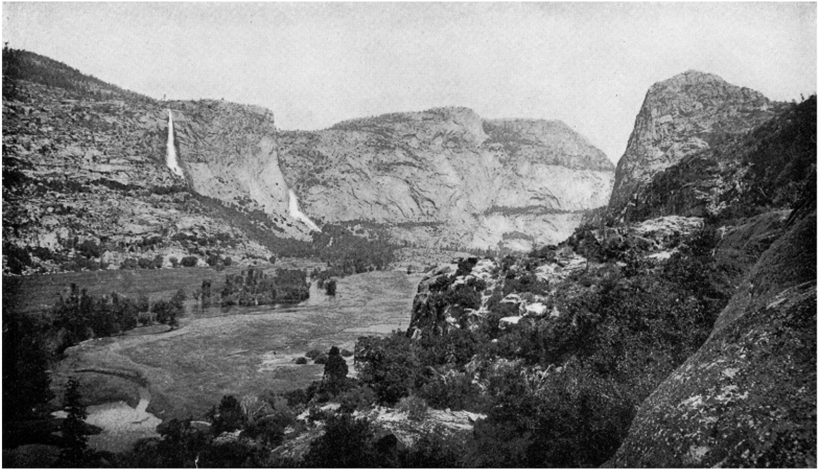
So, you spin a turbine



Hydro can be complex

- Many constraints
  - Intra and interseason storage requirements
  - Temperature and turbidity constraints
  - Treaties and contracts
  - Minimum and maximum flow constraints
  - Dredging
  - Water quality
- Can you go all hydro?
  - US ~6%
  - Norway ~95%

Everything Comes with a cost



Hetch Hetchy Valley 1908. Photo by Isaiah West Taber

Wind

- You find a good wind resource NREL Class 3 and up (https://maps.nrel.gov/wind-prospector/)
- Put up a suitably rated 1.5MW windmill. 8MW is the largest I've hear about for land based but read about a ~10MW off shore.
- Maintain them, upgrade them and if need be demo them.
- What people complain about
  - Noise – Can't hear after a mile or two
  - Raptor and bat kills – Less now with larger slower moving designs.
  - Ugly – In in the eye of the beholder.

PV

- Does not spin a turbine.
- PV effect generates DC electricity which is then converted to AC though an inverter

Levelized Cost of Electricity (LCOE) and Levelized Cost of Avoided Electricity (LACE)

- https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf Table 1
  - CC is Carbon Capture.
  - CCS is Carbon Capture and Storage

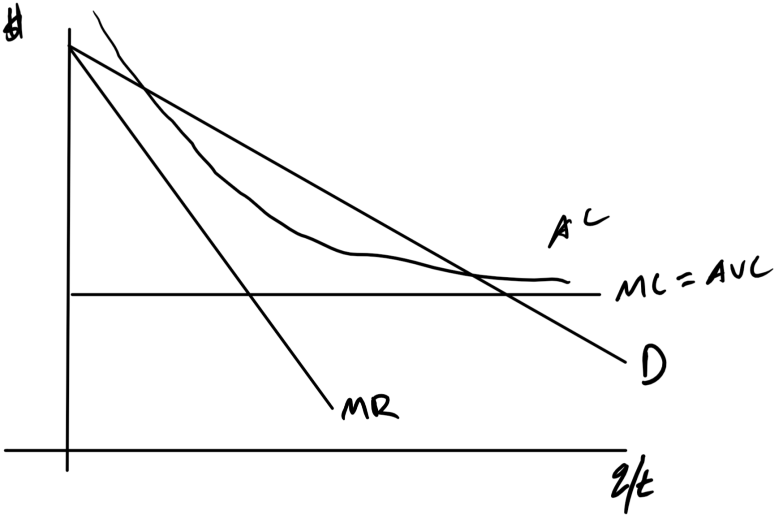
Economics and History

- Remember that material on transaction cost economics?
  - Induces firms to generate, transport (Transmission) and distribute electricity.
  - Very strong pressure to vertically integrate.
- Large economies of scale produce natural monopolies
  - Declining marginal and average cost of production.
  - Potential duplicative capital expenditures reinforce this.
    - Imagine three power companies with separate poles and connections to your house.
    - Imagine all three of them with transmission lines from UT where they generate power.
  - We tend to regulate these in some way, limiting profit.
- Warnings:
  - Very simple view.
  - With more than one price there are an infinite number of solutions to this problem.
  - Each parameter has a lot of uncertainty.
  - ROR is used in more than just energy.

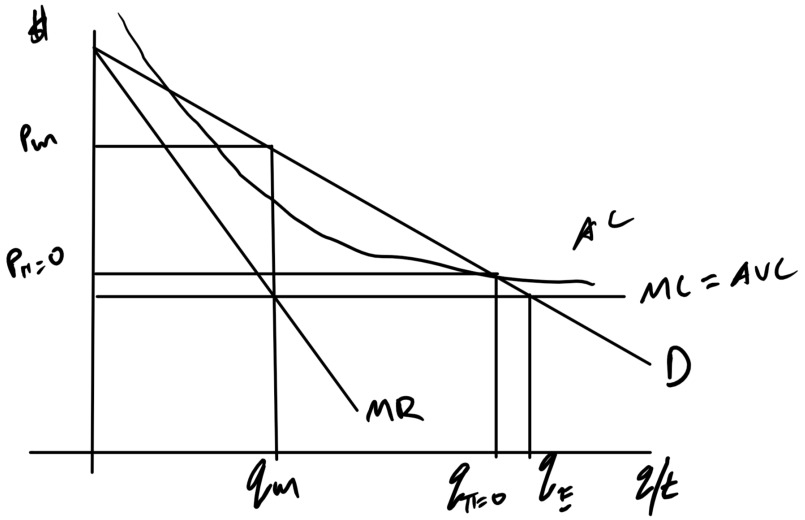
What Problems are there with Natural Monopolies

- As with all firms with monopoly power:
  - Output is reduced from socially optimal, to increase prices.
  - Dead weight loss from less than socially optimal production.
  - Transfer of surplus from buyers to sellers (Which often shows as super normal profit).
- What makes them special is:
  - Socially optimal output, $MC = D$, implies negative economic profit.

What a Natural Monopoly Looks Like in Q-Cost Space



What Rate of Return Regulation Looks like in Q-Cost Space



Sounds simple but

- How do you know those costs? They may not be known ahead of time. They could be random.
- There is more than one price for electricity and different prices for different customers.
- Rate setting is a periodic judicial process most often using retrospective cost data but also using forecasts.

The Goals of Regulation

- Profits should be normal, same as else where in the market with the same risk.
- Output should at socially optimal, MC = D, not private profit maximizing, MC = MR.
- There should be incentives to produce at lowest cost within each time period.
- There should be incentives to reduce costs from one time period to the next, through R&D, capital investments and technology improvements.

Rate of Return Regulation

ROR requires normal economic profits but is often visualized in many different ways.

- Setting P=AC
  - In a one price context this sets AR=AC and gives zero economic profit.
  - Increases output from MR=MC to AR=AC but not all the way to efficient MC=D.

ROR Math for fixed price

$$\max_{k,l} pf(k,l) - wl - rk \tag{1}$$

$$s.t. \frac{pf(k,l) - wl}{k} \leq b \tag{2}$$

- Variables:
  - k and l are capital and labor
  - f is production function
  - p is output price
  - w and r are wage and rental rate
  - b is the required rate of return

Sub in $p(f(k,l))$ for monopoly.

You probably want diagrams for this.

“Revenue Requirement”

$$RR = v(q) + bRB$$

- Note variable change from above.
- The revenue requirement (RR) must be satisfied by the pricing system.
  - Why the simple versions with a single price is P = AC.
  - No guidance on what to do when there is more than one price, except find a way to allocate costs to those prices.
- Most commonly the RR:
  - Passes variable costs, v(q), like fuel and wages though to be included in prices.
  - Has a target return on capital, b, which is known to attract capital and compensate investors for risks.
  - That rate of return is applied to the Rate Base, RB, which is analogous to capital.

“Cost” is much more complex than that

- We don’t put a price on every service to the end user.
- We often pay for one service, like transmission, by lumping it in with a different service, say energy kWh.
- We also will use average values of cost and give one price to everyone, like residential kWh.
  - The cost at peak is higher than middle of the night.
  - The cost in rural areas is higher than urban
- Other objectives that make it so cost and price don’t align.
  - Less expensive to poor
  - Incentivize conservation
  - Cognitive limitations

Pictures with lots of cost drivers

- One House (Certainty Costs):
  - Connection: Just having access is a service
  - Demand Charge kW: How much you use at most determines the fixed cost of local distribution
  - Coincident Peak kW_c: How much you consume at system peak. Your contribution to the fixed and sunk cost of transmission and generation.
  - Energy Use kW: Many choices here, do you average all the costs, integrate individually?
- System (Randomness Costs):
  - The random squiggles (high frequency noise): Regulation
    - Do you charge for individual variation or based on the incremental effect
  - Larger movements (Lower and Lower still frequency noise): Spinning and non-spinning reserve.
  - Black Start (How to start after blackout)
  - Maintenance and monitoring: SCADA, tree trimming, down lines, etc.

What do ROR incentives do?

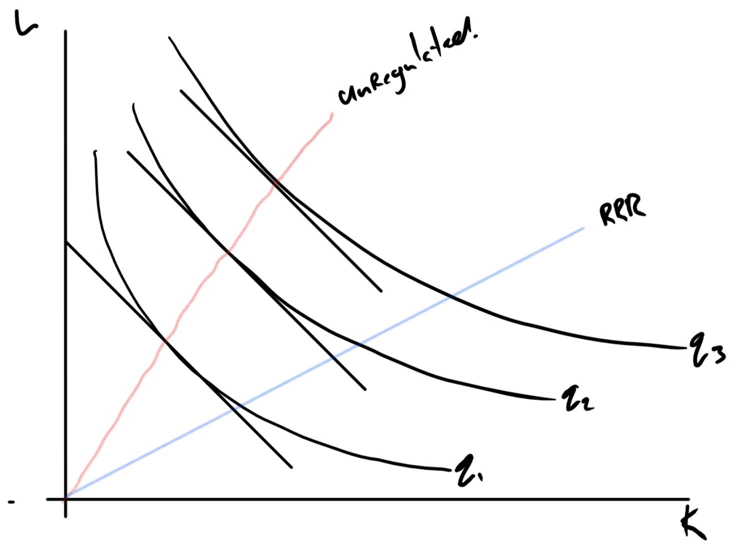
- If I can pass all variable costs on to the customer . . .
  - Regulatory Accounting Standards just like GAAP and GASB.
  - Regulators scrutinize and decide if an expenditure is allowable expenditure, in the rate base, or shareholder responsibility.
- Flip side, if I make investments or go through the effort to reduce costs, the savings don't result in more profit
  - You only see the cost and risk.
  - The customer sees only the benefits.
- Not bad if there are long periods between rate changes.
  - If you reduce costs you see the benefits between rate changes.
  - If your costs are high, you eat the costs between rate changes.

Terrible cost savings incentives.

How else can I increase profits?

- Add more things to the rate base.
- This is the A-J effect.
  - Firms prefer to deliver services by investing in capital.
  - The rate of return, b, does not increase but if you increase RB your revenue increases and your profit, i.e., net income increases.
  - Why Demand Side Management had an initial battle:
    - Rate payer advocates wanted it to pass through as expense.
    - Shareholders wanted it counted just like a power plant, in the rate base.

What ROR Regulation looks like in Input-Output Space.



What about b?

- b is actually more than one number.
- Bond rate necessary to attract lending.
- Return on common equity to attract shareholders
- There could be others.

Yardstick Regulation

Yardstick competition (Shliefer 1985) http://stats.lib.pdx.edu/proxy.php?url=http://www.jstor.org/stable/2555560. Don't use the firm's own costs, use the costs of an identical firm elsewhere.

- Creates cost competition where none previously existed.
  - If you reduce costs and your yardstick matches do not, you get higher profits.
  - If you reduce your cost of capital and your yardstick matches do not, you get higher profits.
- The usual worries
  - Benefits to colluding
  - Odd scale effects and competitor shopping
  - Mergers
    - Merging with your yardstick competitor may be a very good thing.
    - Mergers or reverse may be motivated the yardstick competitors.

CPI-X or Price Cap

CPI-X. Prices increase periodically year by CPI less some amount X. X is chosen as an average rate of cost savings.

- Incentives to reduce costs
  - If you reduce costs faster than X, you get to keep it.
  - No reference to another firm.
- But . . .
  - Where did you get X?
  - How do you know costs will on average go down?

The goals of deregulation

- The goal was not to not regulate. The goal was to only regulate what you must.
  - Control of transmission was stifling cost reductions through competition.
- Don't take the vertically integrated structure, which was dictated by transaction costs as a given.
  - FERC 888/889/2000 split the generation, transmission and distribution parts.
  - ISO/RTO, mostly non-profits set up markets and perform tasks relating to transmission.
  - If you are not in an ISO/RTO you still have to split out generation from transmission. State law does this.

What does an ISO/RTO do.

- Air traffic controllers for transmission. The direct it, plan for expansion, set open prices, pay the people that own it, set prices to avoid congestion.
- Make sure people can see the prices for transmission, Open Access Same-Time Information System (OASIS).
- Organize wholesale markets. Usually day ahead and real time, hour ahead.
- Markets for grid stability services: Regulation up/down, spinning, non-spinning, black start
- Meet NERC, and regional reliability requirements
- Make sure that no one is manipulating the markets and fix the rules so they can't