Large-scale electricity generation and transmission

Low-Power Computing
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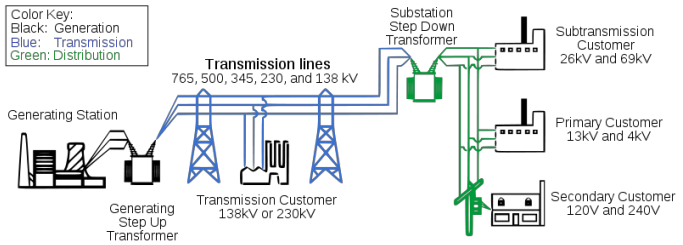
Transmission Losses

- resistance is proportional to distance, 1/diameter (for AC - skin effect)
  (nice side effect of skin: plated cables effective, cheap, less attractive for copper thieves. :)
- Joule's Law - Heat in conductor:
  - $Q = I^2 * R * t$
- Loss propto I^2, d
- Long-dist xmission costs 1/2 - 2c per kWh
  - Most efficient generation: ~1-2.5c / kWh

Resulting distribution architecture



Source: US DoE

Consequence

- Long-distance transmission at high voltage. Pretty efficient, depending on your $/kWh for generation.
- BUT: Infrastructure can be $$ and slow to build. We have 157,000 miles of HV lines, ...
  - Result: Bottlenecks.
    Power demand increased 25% 1990--2006;
    construction of transmission *decreased* 30%.

And more...

- loss proportional to I^2
- As you operate at higher %age capacity, efficiency decreases.
  - And heat increases. Rapidly, it turns out.
  - Heat causes metal to get soft - power lines sag towards the ground...

Interconnection is Hard

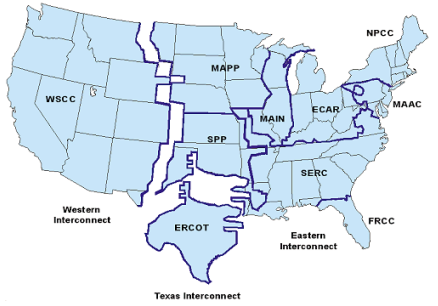
- CS types have a way simplified view of power - very battery-like: increased load causes increased current draw.
- Power folks deal with generators - increased load requires increased generation; without, it decreases the line frequency.
- Entire grid must be frequency locked - this is three-phase A/C!

And actually harder

- Reactive power (power used/returned during opposite cycles -- think capacitor plugged into wall socket) vs. Real power
- Reactive load causes the system voltage to drop. (ex: large motors... *air conditioners*...)
- Some generators can be used as voltage regulators; can add capacitors or inductors; can change transformer ratio dynamically (different taps) to boost or lower voltage.
- *Reactive power can not be efficiently supplied at long distance* - the voltage drop is distance proportional, as is the Q loss, so you get a huge whammy
- So we still need local generation...

The Power Grids

The US is three independent grids
(Isolation - good; but creates time-of-day & seasonal arbitrage opportunities!)



Source: US DoE

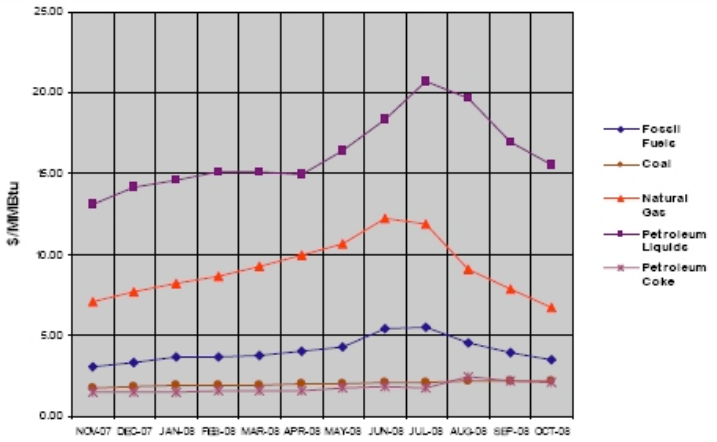
And storage is harder

- No good techniques for huge-scale storage of energy
  - Flywheels, capacitors, batteries work for small amounts -- useful for adapting to very short term (seconds) load variation
- People looking at things like compressed gas storage underground, etc., but...

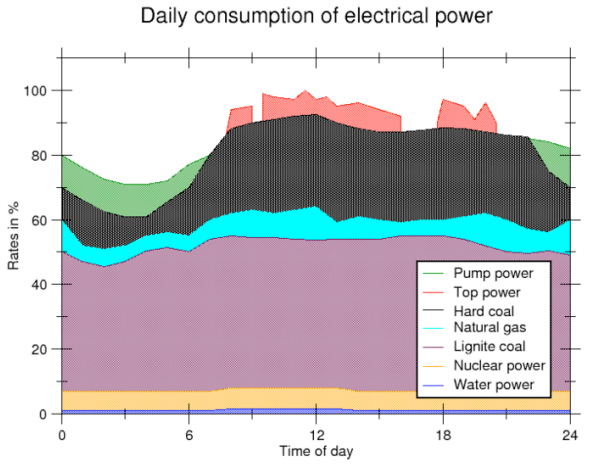
So, meeting demand...

- Baseline load is quite predictable
  - Use huge, slowly-changing, highly efficient generators for this...
  - Nuclear, hydro, etc. -> baseline
  - natural gas faster to spin up dynamically but costs more per kWh.

Cost of power sources



Sources of power (germany)

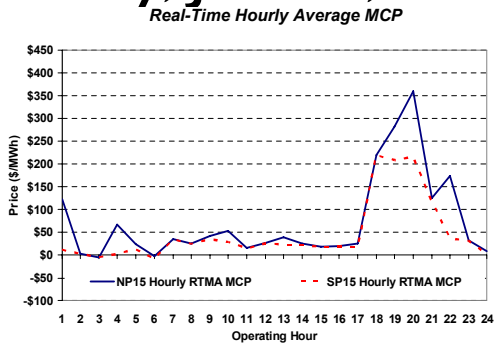


Source: Wikipedia

Electricity demand is somewhat static

- Many consumers not exposed to "spot" pricing, etc. -> demand doesn't change with price.
- But demand changes...
- so prices fluctuate wildly!

Cal ISO prices - Sunday, Jan 25, 2009



	NP15				SP15			
	Min	Max	Avg	Δ Avg.	Min	Max	Avg	Δ Avg.
	RTMA MCP							
Hours 7-22	$ (0.01)	$ 390.25	$ 68.58	$ 44.38	$ (0.01)	$ 390.25	$ 50.54	$ 40.17
Hours 1-6, 23-24	$ (15.00)	$ 390.25	$ 36.28	$ 17.16	$ (15.00)	$ 58.00	$ 9.39	$ (7.40)

Source: Cal ISO market report

Resulting in

- Demand reduction mechanisms
  - In some markets, you can sign up to let the power company shut down (or ask you to shut down) equipment during peak loads.
  - California exploring automatic signalling to home HVAC systems. :-)
- Opportunities for moving computation...