Electricity Generation & Transmission
GEOS 24705/ ENST 24705

Generator power grew very quickly

- exponential growth in several stages, topping-out ca. 1960
- Requires growth not just in generators but in devices that power them

From Vaclav Smil,
"Energy at the Crossroads"

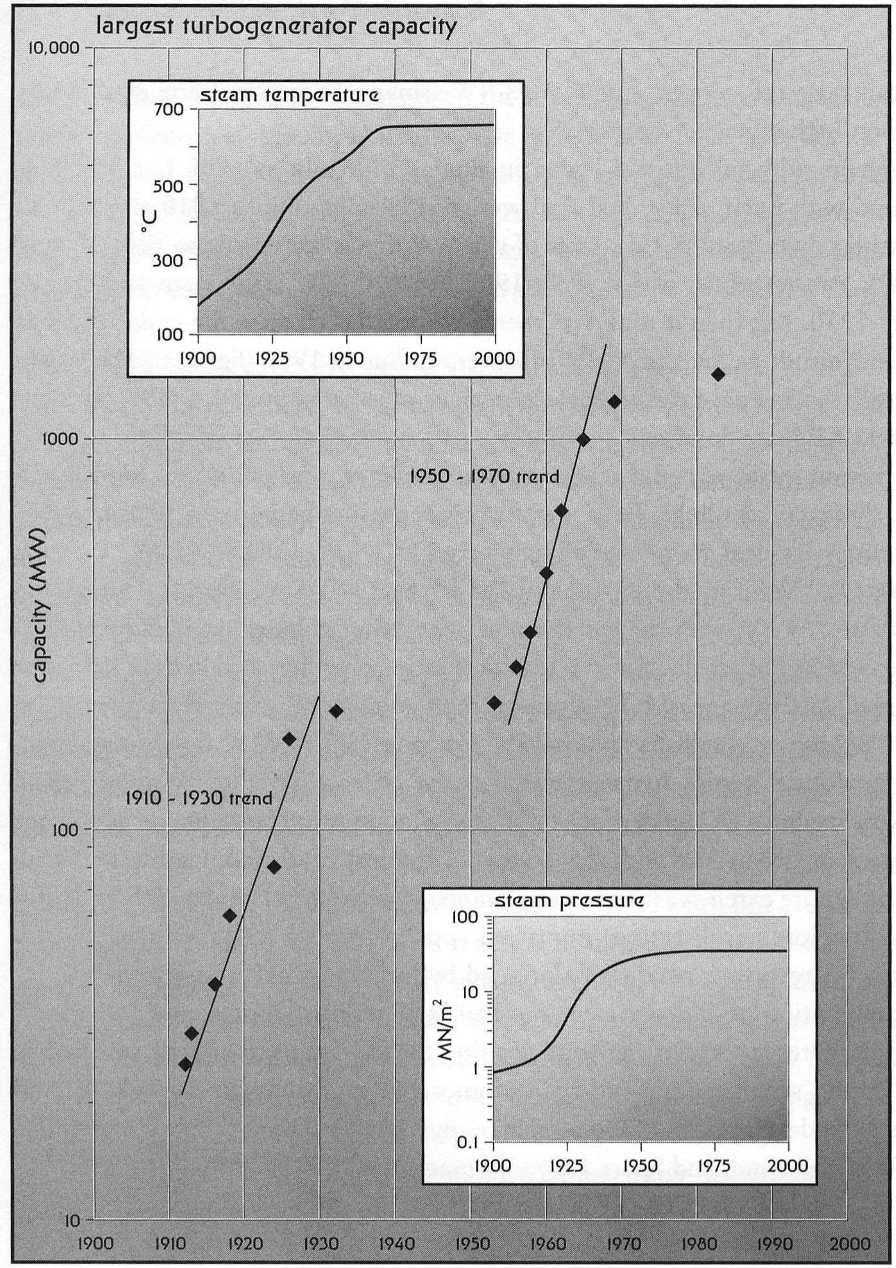


Figure 1.9
Record ratings of the U.S. turbogenerators during the twentieth century. Growth of the highest capacities was interrupted by the economic crisis, WWII, and the postwar recovery; afterward

Industrial generation design considerations

Avoiding overheating

- High voltage to minimize resistive heating
- Large size for heat dissipation
- Circulating coolant

Scale issues for large power

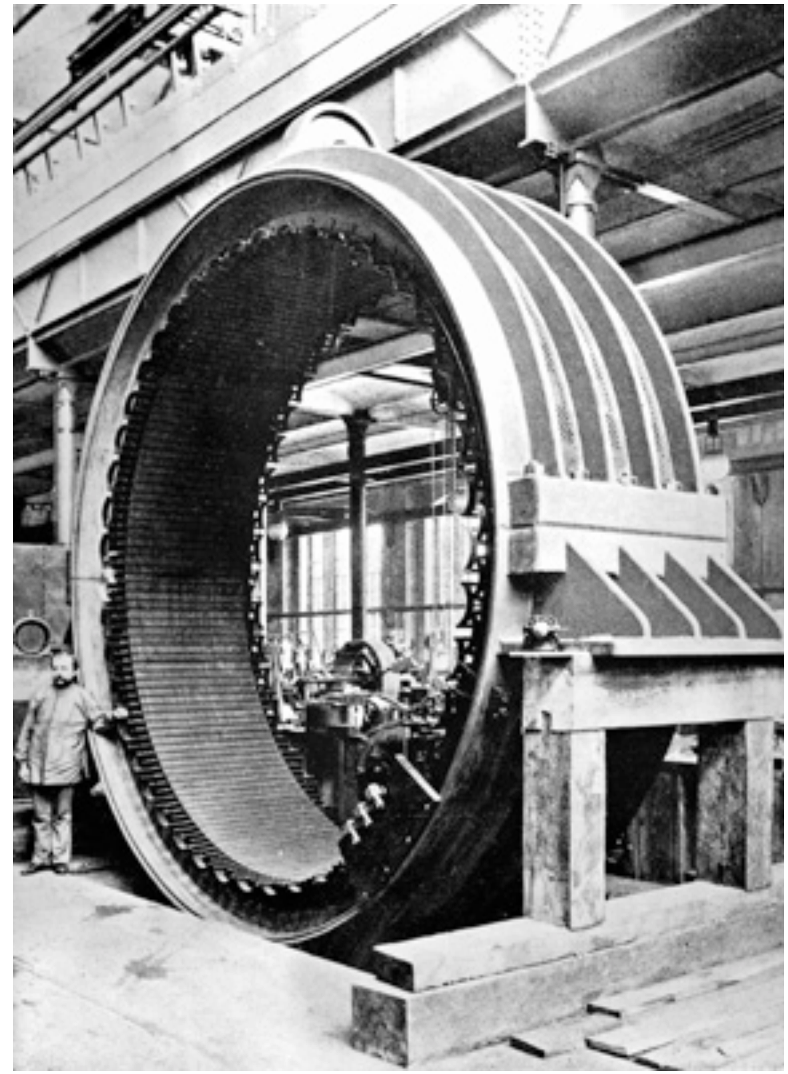
- Make workaround to let generator rotate slower than 60 Hz
- Many loops to increase voltage and power output
- Use electromagnet for bigger B-field

Safety issues for large power

- Organize so that no net current flows
- No sliding mechanisms that carry big current & could spark

Generators are virtually unchanged in 100 yrs

Stator, 3-phase generator, Wellluck Co., China, 12.5 MW, 2010



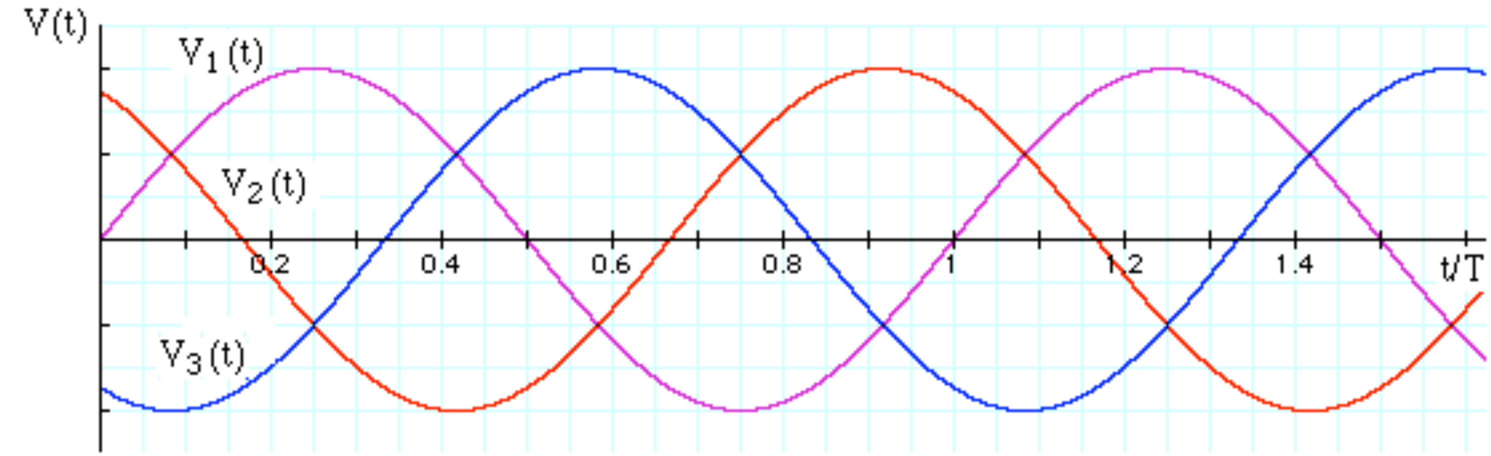
Stator, 3-phase generator, Brakpan, South Africa, 1897. *Photo: Siemens*

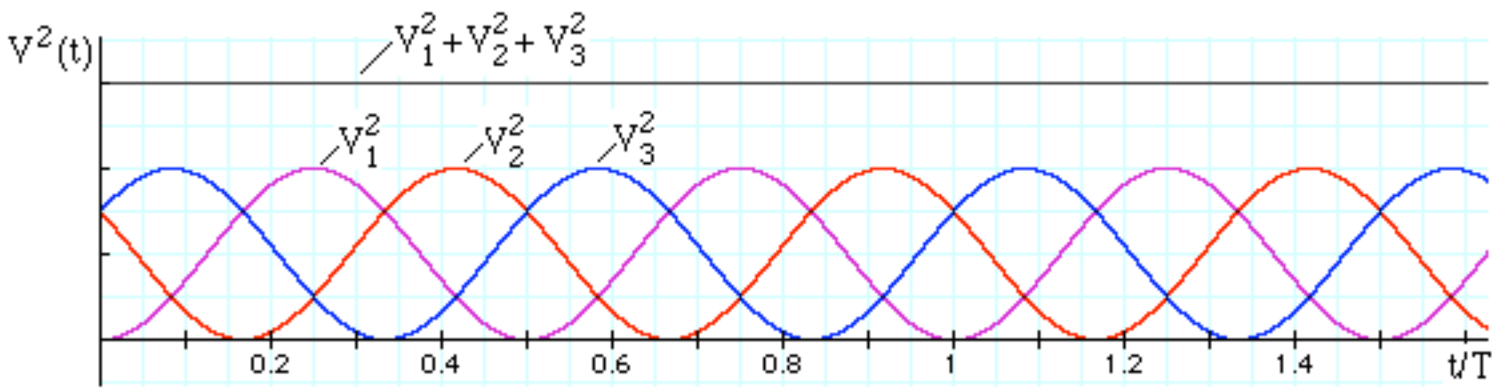
Rotor carries electromagnet

Old mill rotor (source unknown)

Small Hydro Generator rotor - Rotor Assembly Area - Alstom Hydro Manufacturing site in Galindo (Spain) copyright © 2010 M. Monteaux for Alstom

Electrical power transmitted as 3-phase power



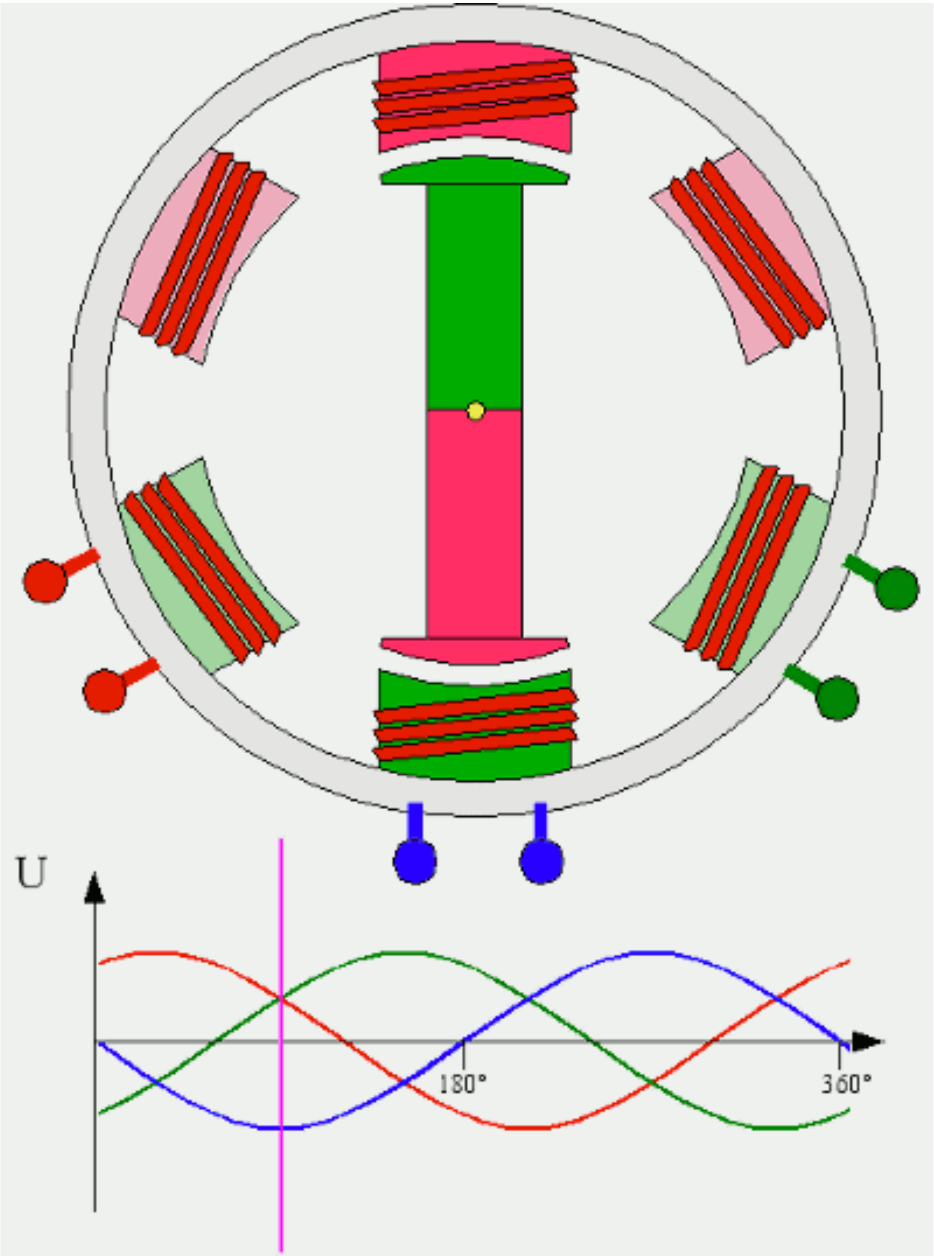


Voltages (and current) sum to 0 if perfectly balanced

Power (prop. to V^2) sums to a constant – no fluctuations in power transmitted

There is no need for a return wire, which saves costs.

Modern AC generation is "three-phase"



The electrical grid: link between generation and consumption

carries 1/3 of U.S. power usage

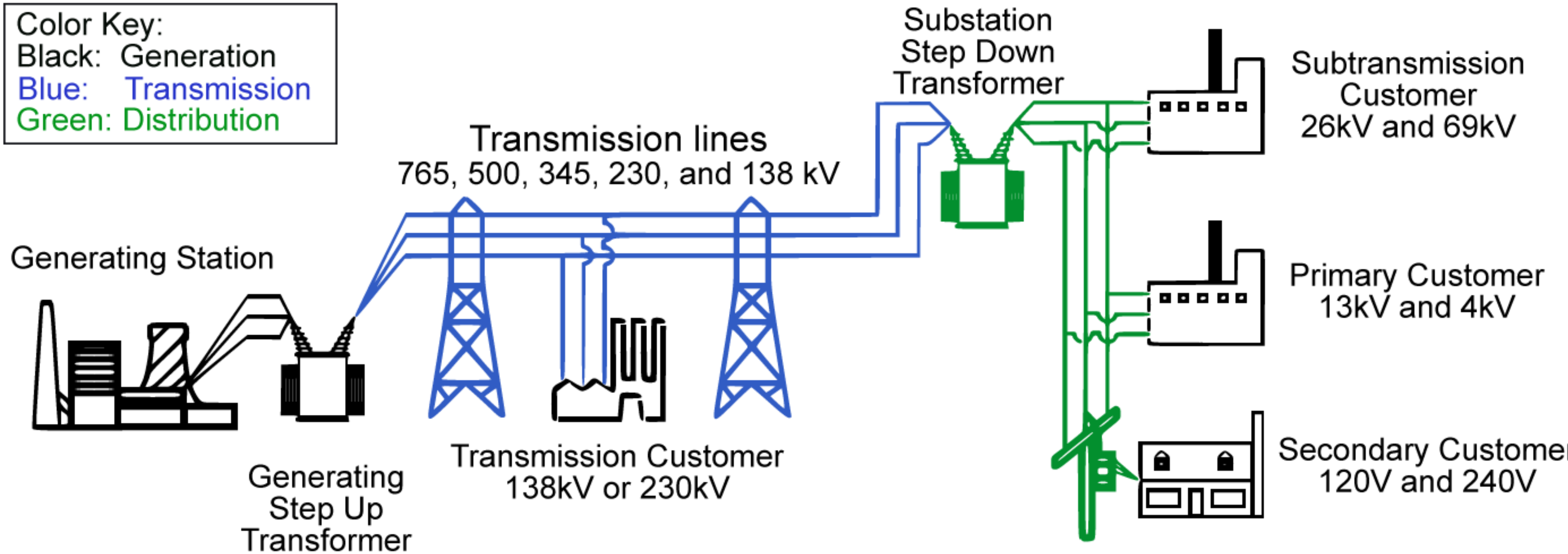
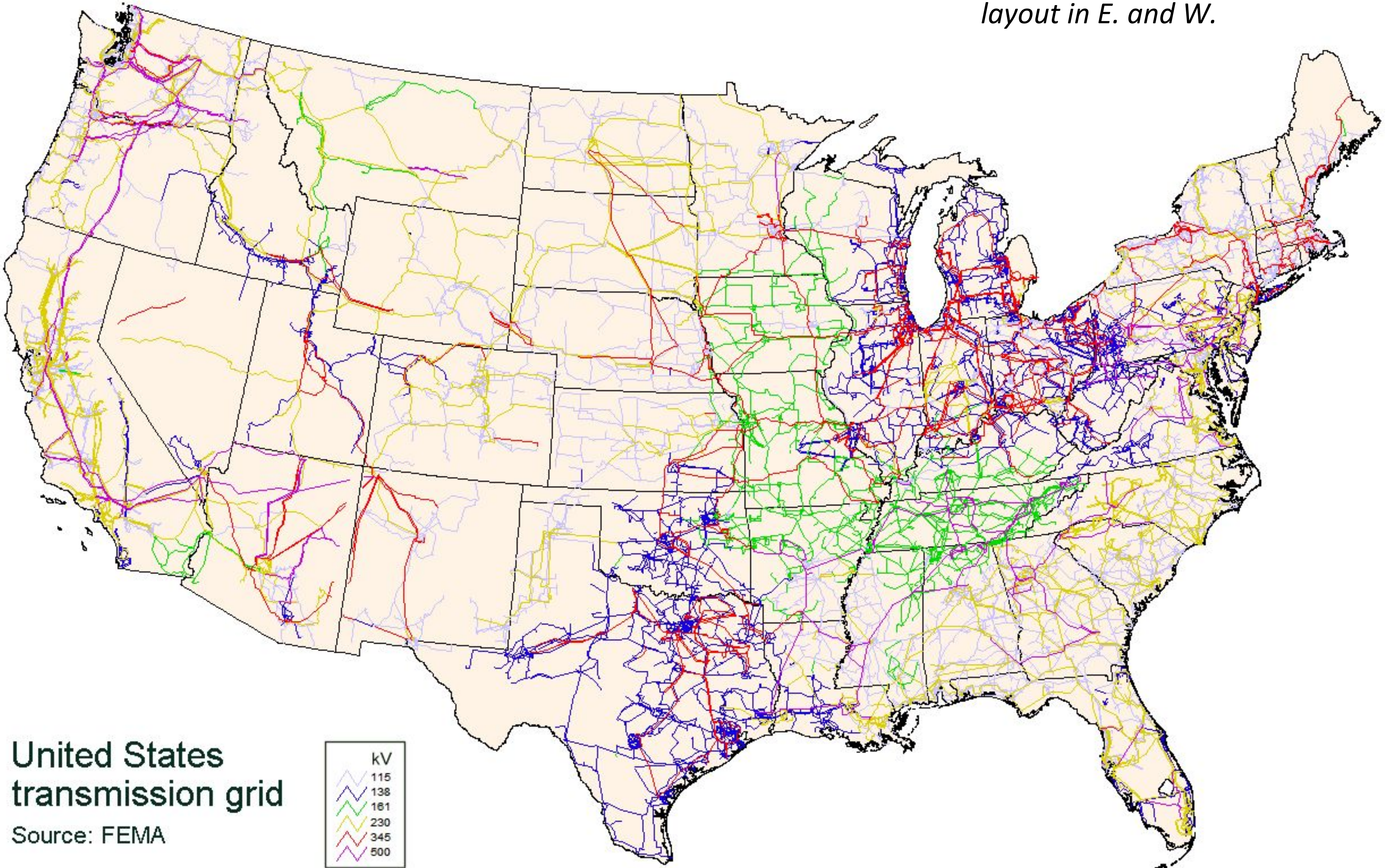


Image: Wikipedia

Why so many different voltages?

Note also different layout in E. and W.



Why so many different voltages?

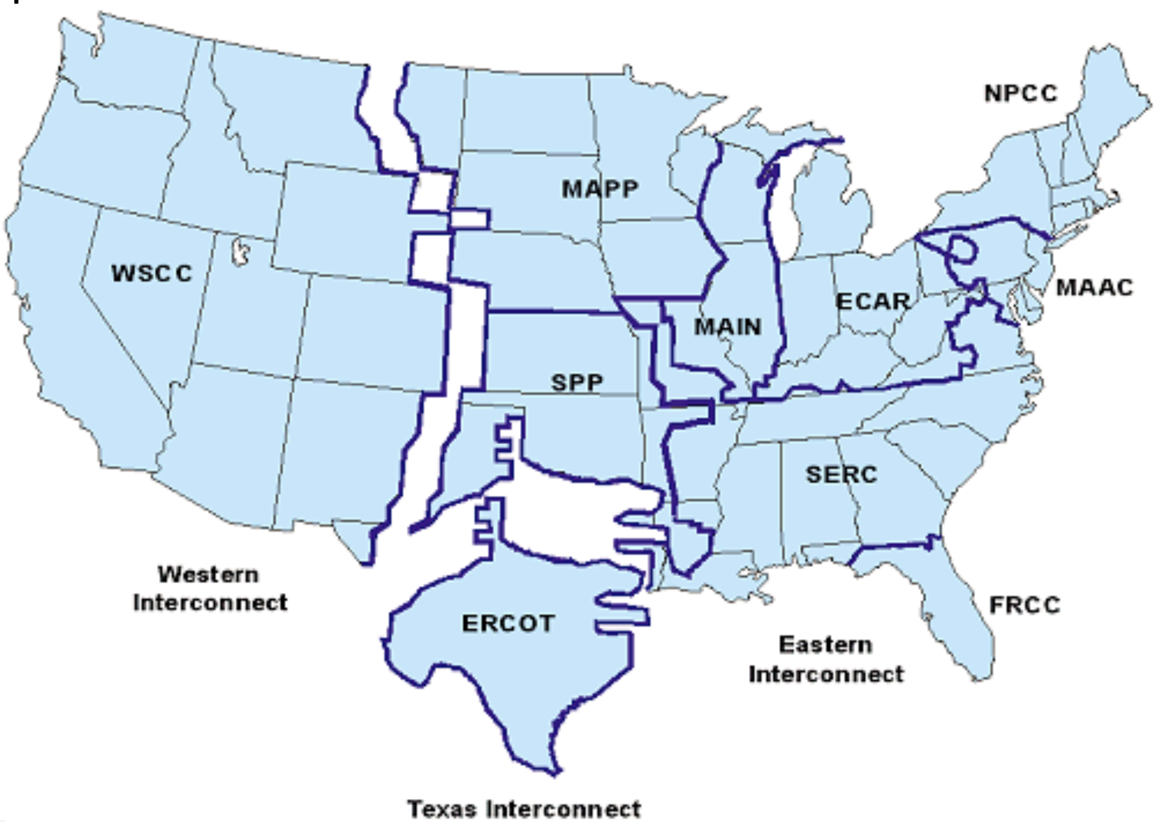
To some extent is logical – don't want to waste $ building big transformers for lines running a short distance, if can get away with lower voltage

Lots of diversity is historical circumstance – grid arose from many independent companies and regions, all of which picked their own voltage standards.

For historical reasons, typical voltages are different in Eastern and Western U.S.

What controls how much power flows, and where?

Nothing except the balance of generation and demand – an entire interconnected grid is a single complex circuit. Imagine a plumbing system with interconnected pipes but no "valves" that control the flow of current. You can't control what power flows where except by tinkering with inputs and outputs



The U.S. grid is broken into 3 weakly connected regions, and not much power flows in between. But the regions are connected to Canada (strongly) & Mexico (weakly).

Texas is its own grid! And its own regulatory entity.

From the Energy Information Agency, U.S. Dept. of Energy.

Why are lines in multiples of 3?

Image: PennLive.com

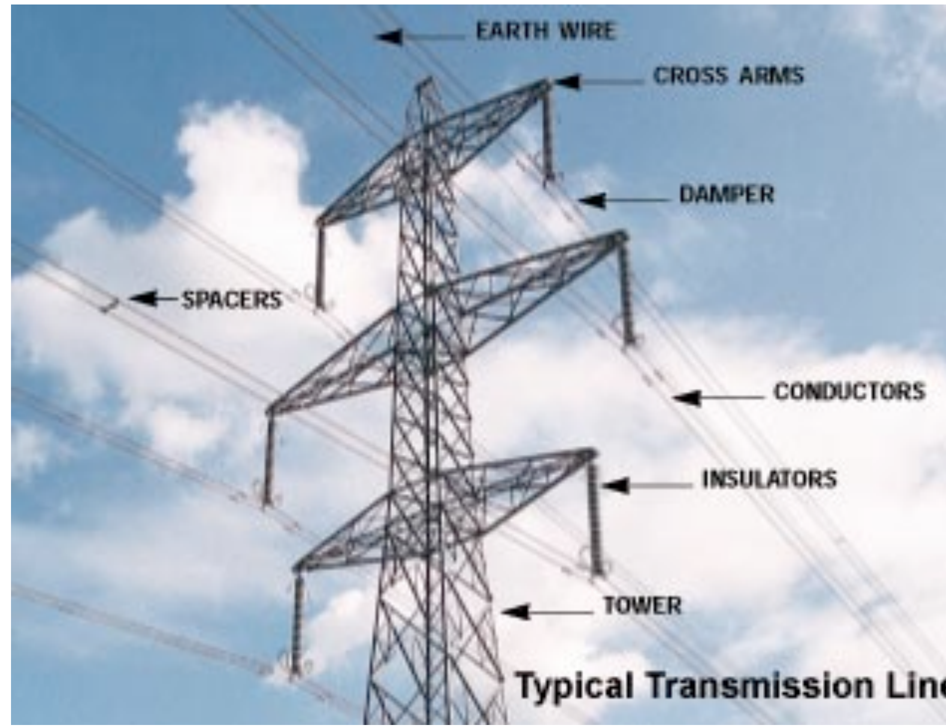


Image: NationalGrid

Distribution: why 4 wires now?

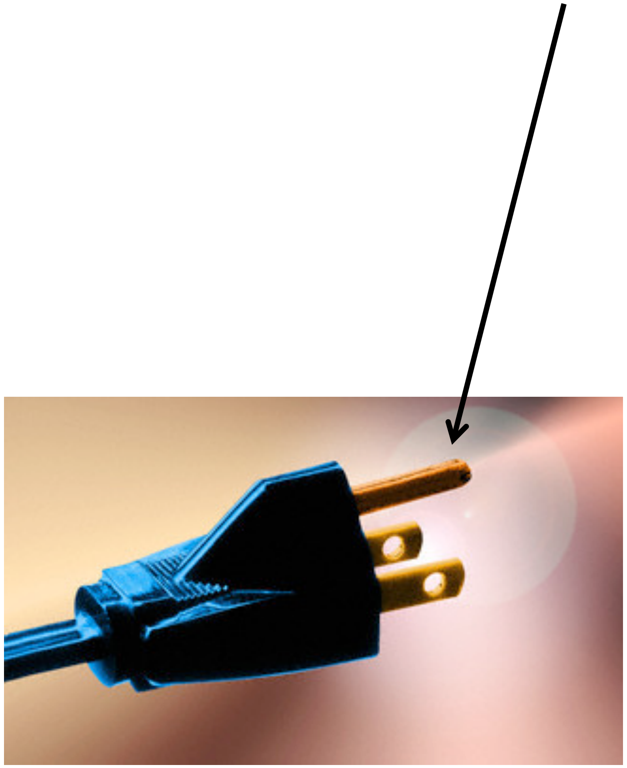
Distribution: neutral wire is added

Each household circuit uses only ONE of the three AC phases transmitted. That means that three different phases could see different loads (could have different power demand).

If demand becomes unbalanced, the three-phase transmission won't cancel the current - a net flow of current would occur. A neutral (return) wire is therefore added at some point.

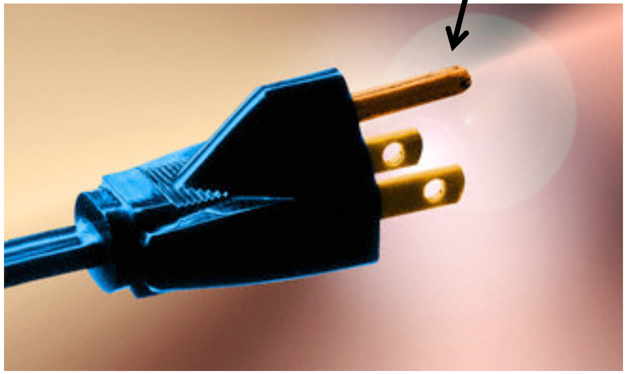
The return loop of current is not all the way back to the generator but (usually) just to the substation, or sometimes even just to the local transformer.

Distribution: what is the 3rd prong on a 3-prong plug?



If each household circuit uses only ONE of the three AC phases transmitted, why does it need three prongs?

Distribution: what is the 3rd prong on a 3-prong plug?



Third prong is neutral grounding wire to to "earth ground" – separate connection to ground – never carries current except in emergencies. Ensures that the electrical device itself can't carry a voltage.

Physical grid infrastructure: what's unusual about this picture?

Long-distance transmission line, Western U.S.

DC lines carry 4% of U.S. electricity (identifiable by only 2 conductors)

http://en.wikipedia.org/wiki/Pacific_DC_Intertie

Pacific DC intertie (WA to S. California):

1362 km, ±500 kV, carries 3.1GW (3100 A)

This is longer and higher-power than is normal in the U.S. The average U.S. AC line is ~400 km at 400 kV, 1600 A -> 650 MW)

Each wire is uninsulated, 3.9-cm (1.5")diameter, mostly copper with a steel core

Losses in DC transmission are lower than those in AC since no inductive reactance – only direct I^2R Joule heating.

Losses on this line = 8% *(that's ~ U.S. average even if line is longer)*

Most DC is very long, very high-voltage lines. Why? Because rectifying/inverting is expensive and inefficient. DC only offers net benefit for long-distance transmission.

Longest HVDC in world is from Inga Dam in D.R.C. to Shaba copper mine (1700 km)