HISTORY AND CURRENT STATUS OF THE ELECTRICITY INFRASTRUCTURE IN THE PACIFIC NORTHWEST

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OVERVIEW

Part 1: The Current Status of the Electricity Infrastructure in the Pacific Northwest

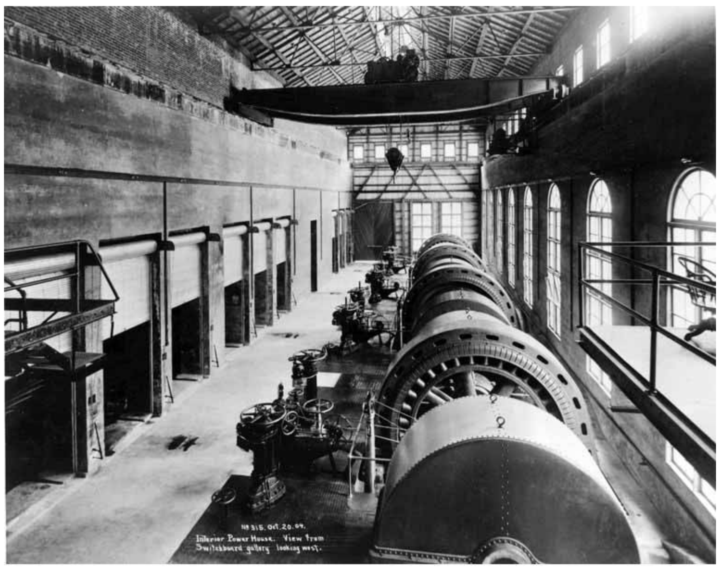
Part 2: How the Current System Evolved Over Time

Part 3: Current Challenges and the Path Forward

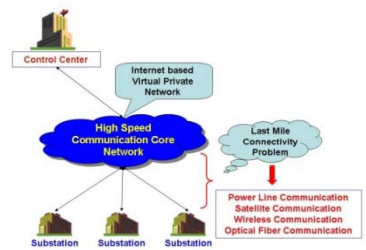
Part 4: Concluding Comments

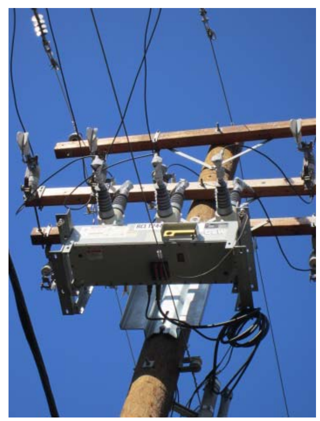
Part 1: The Current Status of the Electricity Infrastructure in the Pacific Northwest

COMMON PERCEPTION OF THE ELECTRICITY INDUSTRY

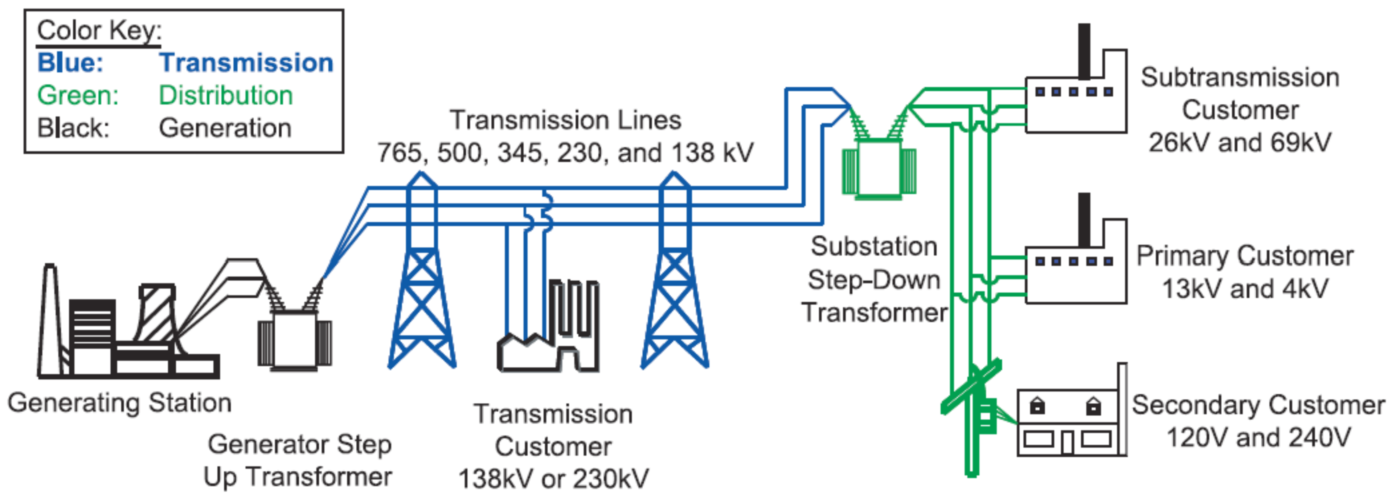


What the Electricity Industry Really Looks Like





Fundamental Overview of the North American Power System



Scale Of Electricity in the Nation, and the Northwest

Power	
Peak U.S. capacity	1,039,062 MW
Peak PNW capacity	**61,300 MW**
Largest plant by capacity: Grand Coulee Dam	7,079 MW
Average nuclear plant	1,000 MW
Average coal plant	300 MW
Utility-scale wind turbine	0.5-3 MW
Solar PV (residential)	1-5 kW / rooftop

Energy	
U.S. Production in 2011	4,105,734,000 MWh
PNW Production in 2010	**214,795,200 MWh**
Average residential monthly use	958 kWh
heat water for a 15 minute shower	10 kWh
a single cycle on an electric dryer	2.5 kWh
watch a 1 hour program on a big-screen plasma TV	200 Wh
charge a smartphone	10 Wh

THE GENERATION OF ELECTRICITY

- Regardless of what drives the prime mover, all electrons are created equally.
- Large central units generate electricity at up to 33kV.
- In the PNW 60%-70% of electric energy is from hydroelectric generators.
- There is still one operating nuclear power plant, the Columbia Generating Station.
- Most new construction projects are natural gas generators or wind turbines.
- There are no large, >500MW, generators planned to be built.





The Transmission of Electricity

- Transmission lines are the interstate highways of power systems.
- Transmission lines operate at 69 kV-500 kV in the Pacific Northwest.
- There is a single +/- 500 kV Direct Current line connecting to California.
- There is a strong north-south transfer path between Washington and California.
- Similar to the interstate highways, congestion is problem.

The Distribution of Electricity

- Distribution systems are the local systems that distribute power within a small area such as a city.

- Distribution lines operate at 4 kV-35 kV, with 12.47 kV being the most common.

- 4 Types of Distribution companies:
  - Municipal
  - Investor Owned
  - Rural Cooperative
  - Public Utility District

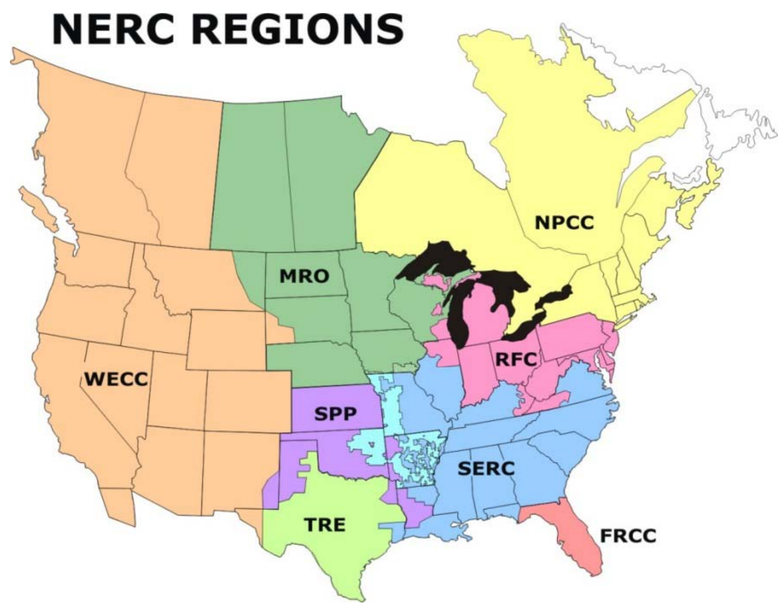
- This is the portion of the infrastructure where many of the new technologies are being deployed, but historically it is where the least work has been done.

HIGH LEVEL ORGANIZING ENTITIES

- Federal Energy Regulatory Committee (**FERC**)
  - regulates interstate transmission of natural gas, oil, and electricity, as well as natural gas and hydropower projects
  - independent federal entity

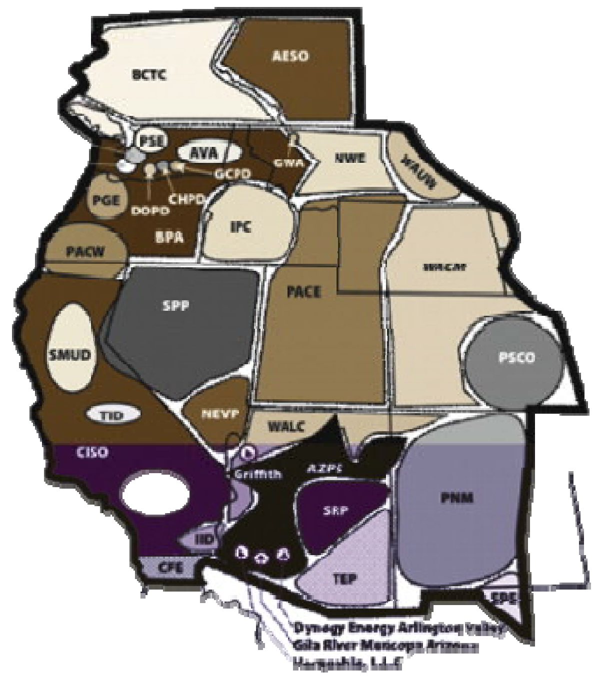
- North American Electric Reliability Corporation (**NERC**)
  - non-governmental organization, granted legal authority to enforce reliability standards

- Western Electricity Coordinating Council **(WECC)**
  - Regional entity responsible for coordinating bulk electric system reliability, day-to-day operation and long-range planning

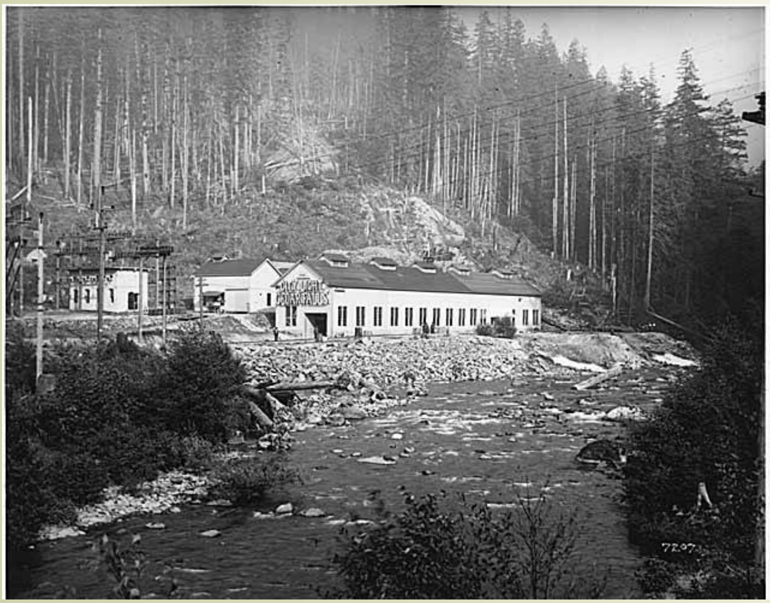


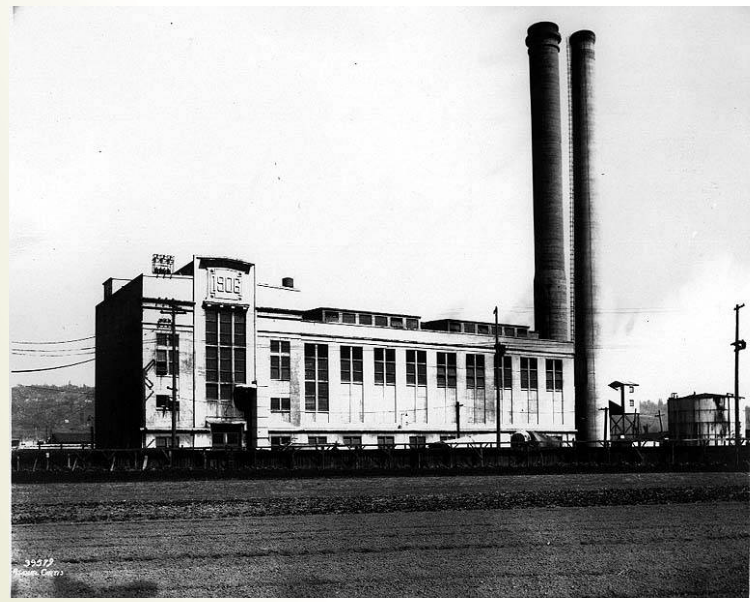
WESTERN INTERCONNECTION BALANCING AUTHORITIES

- The Western Interconnect is one of three synchronous systems in North America.
- The Balancing Authorities (BA), is the first level of operational control.
  - Are responsible for ensuring that generation and load match at all times
  - Support interconnection frequency in real-time
  - Control all transmission operations
  - Are responsible for long term planning and capacity expansion
- There are many operating companies that are not balancing authorities



Part 2: How the Current System Evolved Over Time





THE FIRST ELECTRICITY IN THE NORTHWEST

- The first form of electric lighting to reach the Northwest was in the summer of 1879 when the S.S. California docked in Portland, OR.

- The S.S. California had six arc lights that were powered by the ships dynamos. Dynamo was the name given to direct current generators.

- Incandescent light would not arrive for another year, aboard the S.S. Columbia.

- At this time Portland had a population of 40,000, Seattle only 10,000, and the total Northwest was less than 500,000.

- Seattle did not see electricity for 2 more years (1881) when the S.S. Willamette anchored in Elliot Bay.

Electrification of Industrial Hydraulic Systems

- In 1882 the Tacoma Mill Company built a small plant on Galliher's Gulch that included a dynamo to power a string of arc lamps, in addition to the existing mechanical load, so that workers could put in longer hours.
- This was the first generator in the Washington Territory and the first example of using hydro for industrial, as well as electrical, purposes.
- The power was only used at the mill, it was not transmitted any further.

- For industrial locations that were already using hydraulic and/or steam, the addition of a dynamo was a relatively easy, and cost effective, upgrade.

The First Standalone Hydroelectric System

- The first hydroelectric plant, without a corresponding industrial facility, in the northwest was built at Spokane Falls, WA in 1885.
- A water wheel provided the motive force for a single dynamo that powered 12 arc lamps.
- This type of hydroelectric plant only used a water wheel, it did not span the river like modern facilities.
- The generated electricity only supplied local loads (e.g. within the same building).

The First Urban "Central System" in the Northwest

- Hydroelectric plants were useful, but they were rarely near large cities.
- In 1885 Sidney Z. Mitchell and F. H. Sparling formed the Seattle Electric Light (SEL) Company with a 25-year franchise, financed by the sale of 250 bulbs for a flat monthly fee per bulb.
- The first full SEL generation station was built on Jackson street with:
  - 2 steam Dynamos
  - 600 DC amp capacity

- On March 22, 1886 they demonstrated the first incandescent light bulb to be energized west of the Rocky Mountains by a fixed terrestrial system.
- This demonstration consisted of eleven 16 candlepower lights in the SEL headquarters and occurred 5 months before Edison began operation of his famous Pearl Street Station in New York.
- These early companies tended to be small and inefficient.

THE RISE OF LARGER GENERATION STATIONS

- Initially each individual company provided enough generation to meet "load plus losses". This resulted in a significant amount of duplication, and machines running at inefficient levels, especially steam units.
- A financial panic in 1893 resulted in many of the smaller utilities going out of business. Once the many failed smaller companies were consolidated, it was necessary to develop larger and more efficient generators to supply the load.
- One of the first large generation stations to supply multiple companies was the Snoqualmie Falls Power Plant in WA state.

- Originally envisioned by Charles Baker in the 1880's, Snoqualmie Falls began operation in 1898 with four 1,500 kW turbines. Each unit was 10 times larger than the Jumbo dynamos that Edison used at Pearl Street Station 15 years earlier.
- 32,000V AC lines ran from the power house to Seattle (32 miles), Tacoma (44 miles), Everett (36 miles), and locations in between. This was an improvement as compared with DC power, where 100V systems were limited to transmitting over distances of about a mile.

Private Companies and Municipal Power

- Despite the lowering electricity rates provided by private utilities, there were people who felt that the companies were still making larger than appropriate profits.

- In 1902, the voters of Seattle approved a $590,000 bond for the construction of a municipal dam on the Cedar Creek that would operate to provide electricity in direct competition with private utilities.

- In 1905, Cedar Falls began operation and was the first municipally-owned hydroelectric plant in the nation. It produced 2,400 kW for Seattle street lights and was run by the water department

- The Seattle Electric Company had been supplying power for 20 ₵/kWh. Within a year of Cedar Falls beginning operation, SEC cut their rates in half to compete with Cedar Falls which charged 8.5 ₵/kWh.

- 1910 saw the formal formation of Seattle City Light, which took control of Cedar Falls from the Water Department.

- The competition between the new municipal system in Seattle and the existing private systems, reflected the question being asked on a national level “which is better public or private power?”.

Regional Consolidation of Private Utilities

- Shortly after the establishment of Seattle City Light in 1910, further consolidation of private power in Washington occurred with the incorporation of Puget Sound Traction Light & Power Company in 1912.
- Consolidation in 1912 was at a regional level and was made possible by large new generators and their interconnecting 55,000V AC lines.
- 4 Hydro plants
  - Snoqualmie falls (6 MW, 44MW by 1954)
  - White River (20MW, 65MW by 1914)
  - Electron (Currently 22MW)
  - Nooksack
- Steam plants
  - Georgetown - Seattle
  - Post street - Seattle
  - York Street – Bellingham
- Regional consolidation was something that the municipal utilities did not have the authority to do, since municipal authority was limited to within city boundaries. Thus regional consolidation was generally the province of private utilities.

DEVELOPMENT OF THE COLUMBIA RIVER SYSTEM

- Early dams for the production of electricity were across relatively small rivers.
- In 1933, Puget Sound Power & Light Company, a holding of Stone & Webster Engineering Corporation, completed Rock Island Dam. It was the first dam to span the mainstem Columbia River; its sole purpose was to generate electricity
- In 1934 construction began on the first two federal dams on the Columbia:
  - Bonneville (first power house 1938:526.7 MW second power house 1983 (558.2 MW)
  - Grand Coulee dam (first and second power house 1941: 2,280 MW third power house 1974: 3,900 MW later upgraded+ 315 MW) Also 600MW of pumped hydro capacity.

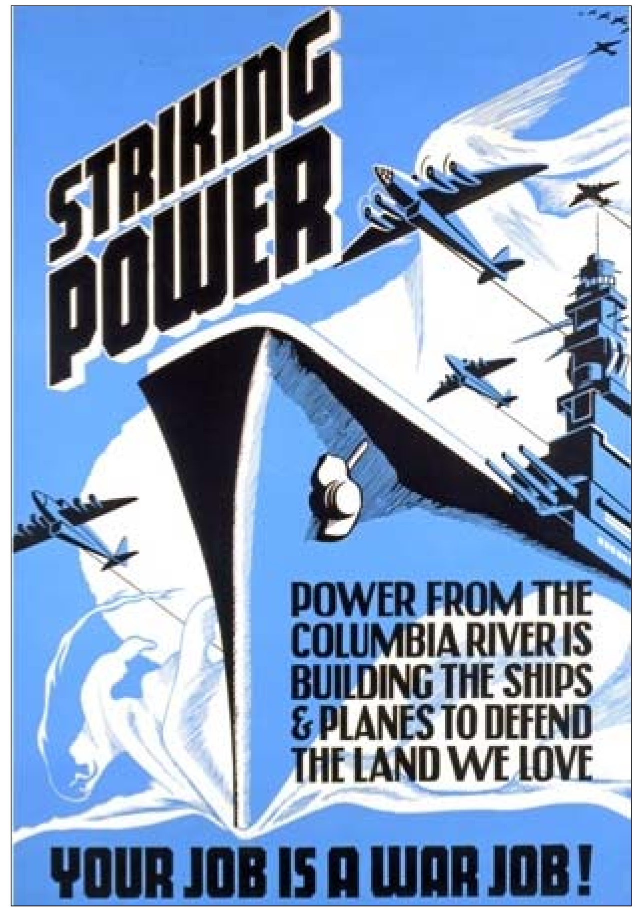
- As part of the National Resource Planning Board, established in 1933 to investigate comprehensive river basin planning, the Pacific Northwest Regional Planning Commission was composed of one representative each from Washington, Oregon, Idaho and Montana.
- The commission’s report, dated Dec. 28, 1935, suggested an independent federal agency be created to market the power from Bonneville and Grand Coulee dams. The agency would be modeled after the Panama Canal Company. It would both operate the generators and build and operate the regional transmission lines. The commission recommended that power be sold for its cost of generation, not at a market rate, and that preference be given to public utilities for the federal power.
- The Bonneville Project Act was passed by Congress in 1937.

Why the Federal Government Because Involved

- While utilities were consolidating across large areas, they often ignored rural areas. This was less true in the Pacific northwest, but there was still a discrepancy.
- Municipal utilities often formed in response to private utilities. Because of concerns regarding the franchise system, the regulation of utilities had moved from a municipal to a state level. Utilities were regulated based on the state that they were located in.
- Large holding companies were used to circumvent the power of state level regulation, while at the same time state level regulation was used to guarantee a favorable business environment.
- In response to the actions of large holding companies, and the Great Depression, the federal government became involved in the electricity industry; for the Northwest the most visible form of this intervention was the Bonneville Power Administration.
- It was through the Work Progress Administration (WPA) that many of the larger dams were constructed.

Federal Power and WWII

- Through the 1930's, federal hydroelectric projects developed a massive generation surplus, far in excess of what was needed during the depression.
  - Bonneville power house 1 was over 500 MW
  - Grand Coulee left and right power combined were over 2,200 MW (from 1941-1950)
- The increased load due to war time production justified, after the fact, the construction of massive projects such as Grand Coulee Dam.
- Energy intensive industries such as aircraft manufacturing and ship building were located in the Pacific Northwest because of the abundance of low cost electricity.
- These industries contributed to the war effort, and laid the foundation for many key industries that currently exist in the Pacific Northwest.
  - Aluminum production
  - Aircraft manufacturing

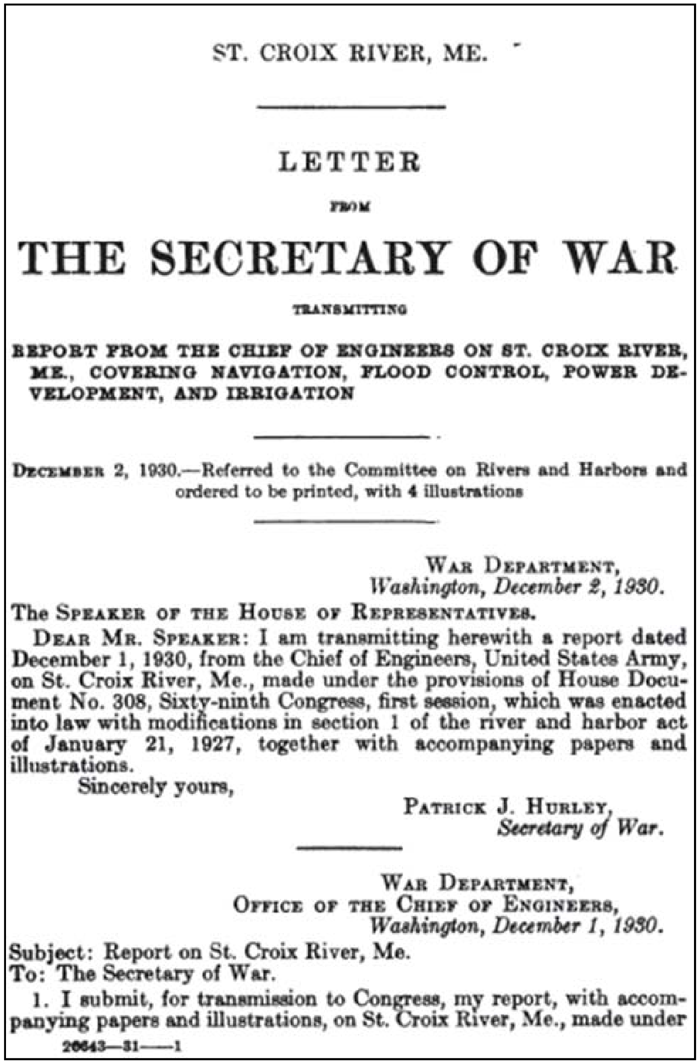


The Interconnected Power System

- Initially, transmission lines were constructed by individual companies to connect remote dams with population centers, Snoqualmie, WA and Willamette Falls, OR being the earliest examples.
- On July 9th, 1938, BPA had energized its first line between the Bonneville dam and the city of Cascade Locks. Later that year on December 1st, BPA energized its first 230 kV line between Bonneville Dam and Portland. By 1957, BPA had a significant 230 kV transmission system interconnecting the major dams on the Columbia River. On August 26th, legislation was signed that allowed BPA to "wheel" power across its system for a fee.
- "Wheeling" made it possible for a large number of organizations to access the high-capital-cost transmission system. The demand for the service lead to expansion of the 230 kV system, and to its first 345 kV line from McNary Dam to Portland, OR and Vancouver, WA.

- October 20th, 1953 BPA signed it first 20-year contract with an Investor Owned Utility (IOU).
- September 20th, 1968, BPA energized the first of three AC lines of the Pacific Northwest-Southwest Pacific Intertie, now the California Oregon Intertie (COI). This enabled sharing of resources with California.
- On May 21st, 1970, BPA energized the 500 kV High-Voltage DC (HVDC) line that stretched 845 miles.
- On October 9th 1970, BPA held a region wide meeting on environmental impacts. The National Environmental Policy Act had been passed the year before.

THE HYDRO-THERMAL POWER PLAN


ST. CROIX RIVER, ME.

LETTER

FROM

THE SECRETARY OF WAR

TRANSMITTING

REPORT FROM THE CHIEF OF ENGINEERS ON ST. CROIX RIVER, ME., COVERING NAVIGATION, FLOOD CONTROL, POWER DEVELOPMENT, AND IRRIGATION

DECEMBER 2, 1930.—Referred to the Committee on Rivers and Harbors and ordered to be printed, with 4 illustrations

WAR DEPARTMENT,
Washington, December 2, 1930.

The SPEAKER OF THE HOUSE OF REPRESENTATIVES.

DEAR MR. SPEAKER: I am transmitting herewith a report dated December 1, 1930, from the Chief of Engineers, United States Army, on St. Croix River, Me., made under the provisions of House Document No. 308, Sixty-ninth Congress, first session, which was enacted into law with modifications in section 1 of the river and harbor act of January 21, 1927, together with accompanying papers and illustrations.

Sincerely yours,

PATRICK J. HURLEY,
Secretary of War.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, December 1, 1930.

Subject: Report on St. Croix River, Me.
To: The Secretary of War.

1. I submit, for transmission to Congress, my report, with accompanying papers and illustrations, on St. Croix River, Me., made under

26643—31——1

In 1957, the Army Corps of Engineers updated its 1929 308 report and determined that at the current rate of load growth, all economically feasible hydroelectric resources would be subscribed by 1975. This revised 308 report detailed three distinct phases for power in the Northwest:

- Phase 1: A system predominantly supplied by hydroelectric resources. This phase was estimated to end in 1975.
- Phase 2: A system served by a combination of existing hydroelectric resources and soon-to-be-built thermal plants. These thermal plants would be a combination of coal and nuclear.
- Phase 3: A system served primary by thermal plants, with the continued operation of legacy hydroelectric resources.

In October 1968, BPA unveiled its vision of the future, “The Hydro-Thermal Power Plan”. This plan required the construction of 21,400 megawatts of thermal power (2 coal-fired plants and 20 nuclear plants) , as well as 20,000 megawatts of new hydroelectric capacity between 1971 and 1990. The cost was estimated at just $15 billion.

The problem was that by federal law, BPA could not build its own power plants.

WPPSS TURNS TO "WHOOPS"

- In 1972 the Internal Revenue Service determined that the tax exempt status of net billing was illegal. Without the tax exempt status, the cost of issuing bonds increased significantly.

- One of the major problems with the Phase 1 projects was that none of the participating members had any experience with capital projects of this size. As a result, cost quickly began to skyrocket.
- In January 1982, the WPPSS board stopped construction on Plants 4 and 5 when total cost for all the plants was projected to exceed $24 billion.
- Since plants 4 and 5 generated no power, and generated no revenue, the system was forced to default on $2.25 billion in bonds. This meant that the member utilities, and ultimately the rate payers, were obligated to pay back the borrowed money. Numerous lawsuits began.
- Plants 1 and 3 were never finished either, but their costs were backed by the Bonneville Power Administration and the power it generated from the Columbia River Dams, cost that were eventual passes on to the customers as well. It was not until December 24, 1988, the parties in the various lawsuits reached a settlement of $753 million.
- The WPPSS was at the center of the largest municipal bond default in the history of the country.

PART 3: CURRENT CHALLENGES AND THE PATH FORWARD

Challenges To the Existing Grid

Generation

- Siting and permitting of new units
- Impact of emissions
- Cost of fuel
- Impact of supplying ancillary services

Transmission

- Intermittent renewables
- Significant investments for peak periods
- Transmission congestion
- Stability
- Losses due to Reactive Power flows
- Aging workforce

Distribution

- Distributed generation
- Losses due to Reactive Power flows
- Aging workforce

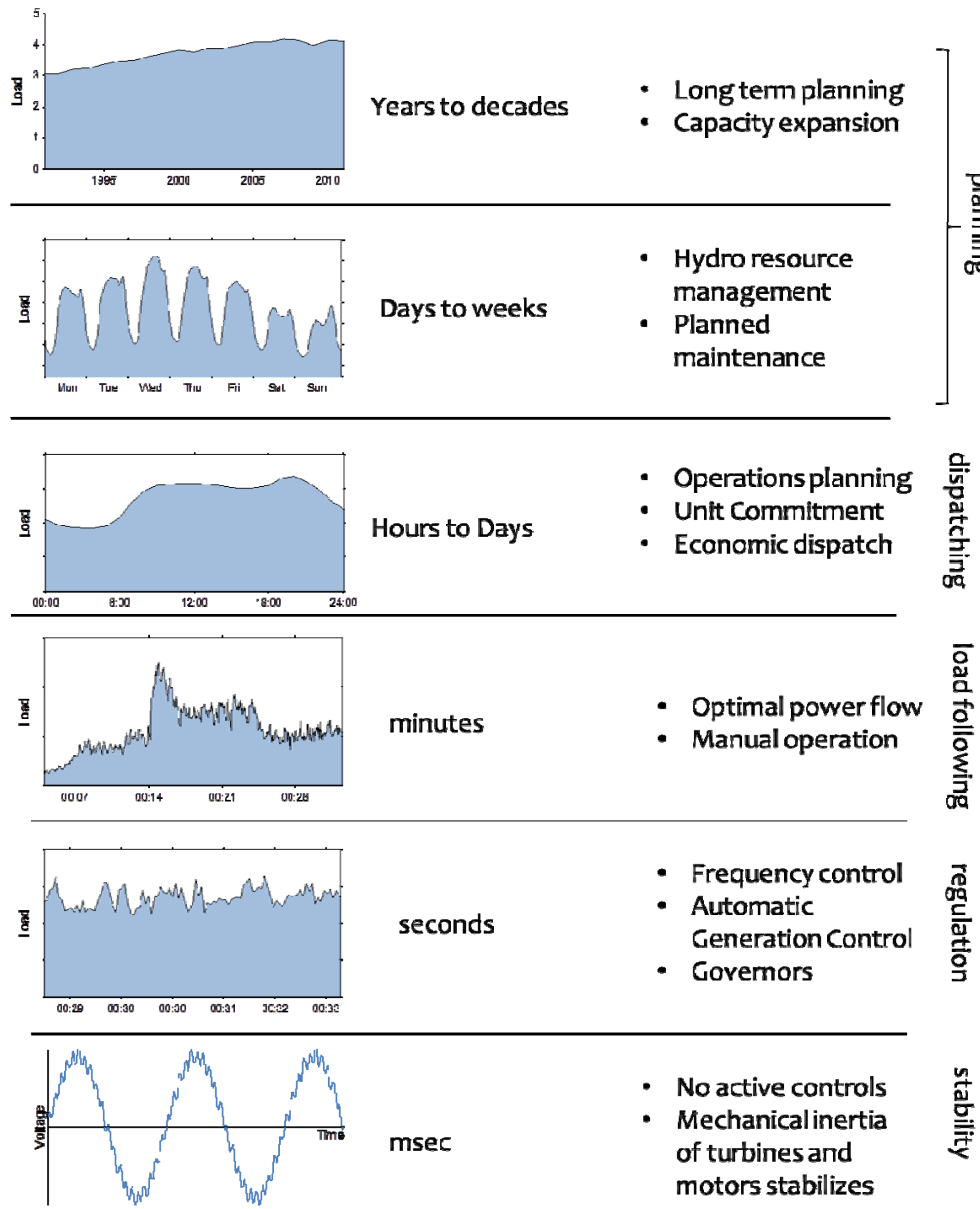
VARIABILITY OF LOAD

- Changes in the load must be accounted for by generation immediately. There is no bulk energy storage.

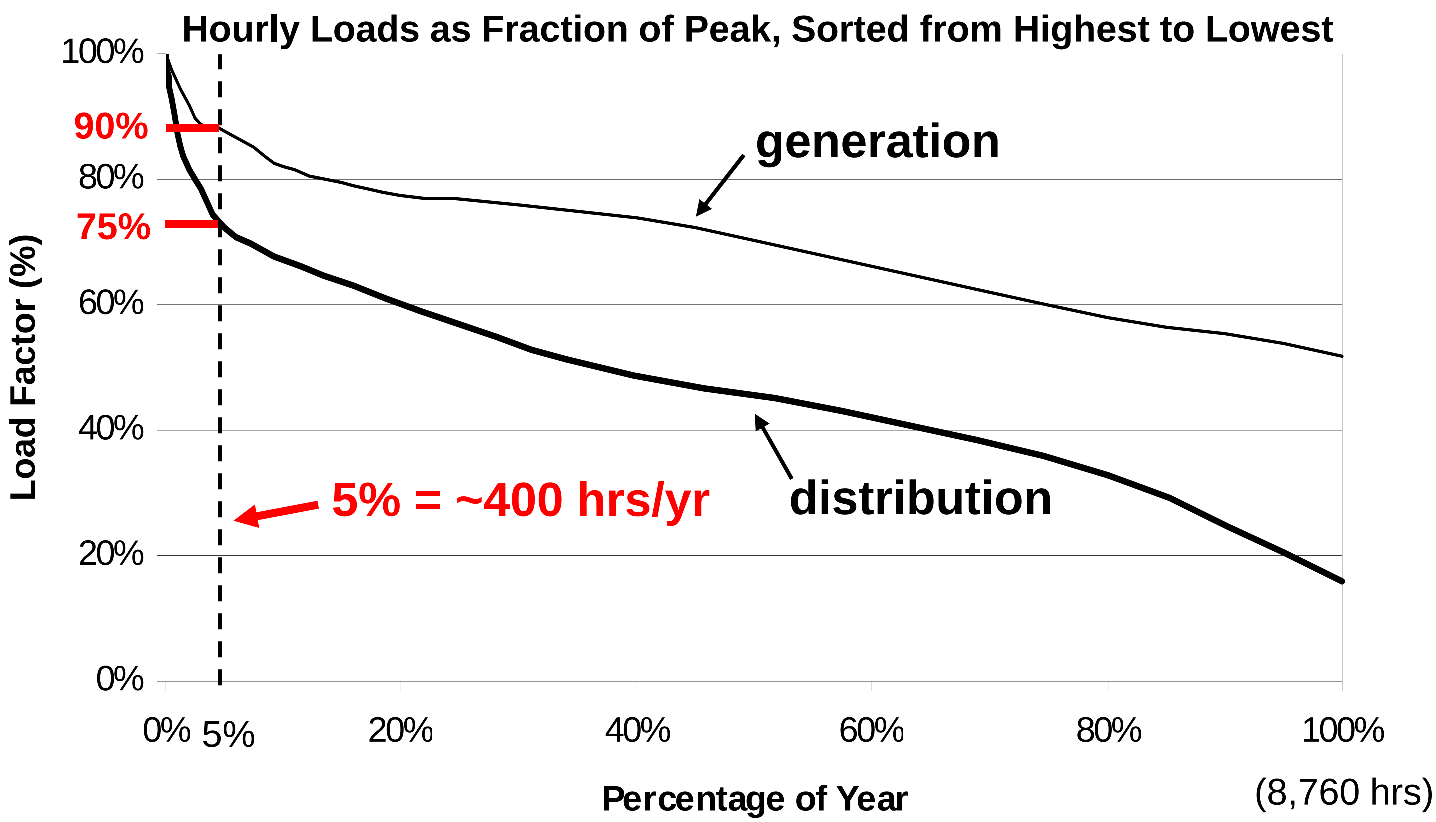
- Variations in load occur at multiple time scales:
  - Millisecond
  - Seconds
  - Minutes
  - Hours
  - Days
  - Weeks
  - Years
  - Decades

- Historically the hydroelectric generators in the northwest have provided many of the necessary ancillary services.

- There are no new dams planned, and system variability is increasing.



PEAK LOAD



25% of distribution & 10% of generation assets (transmission is similar), worth of 100s of billions of dollars, are needed less than 400 hrs/year!

SYSTEM COMPLEXITY

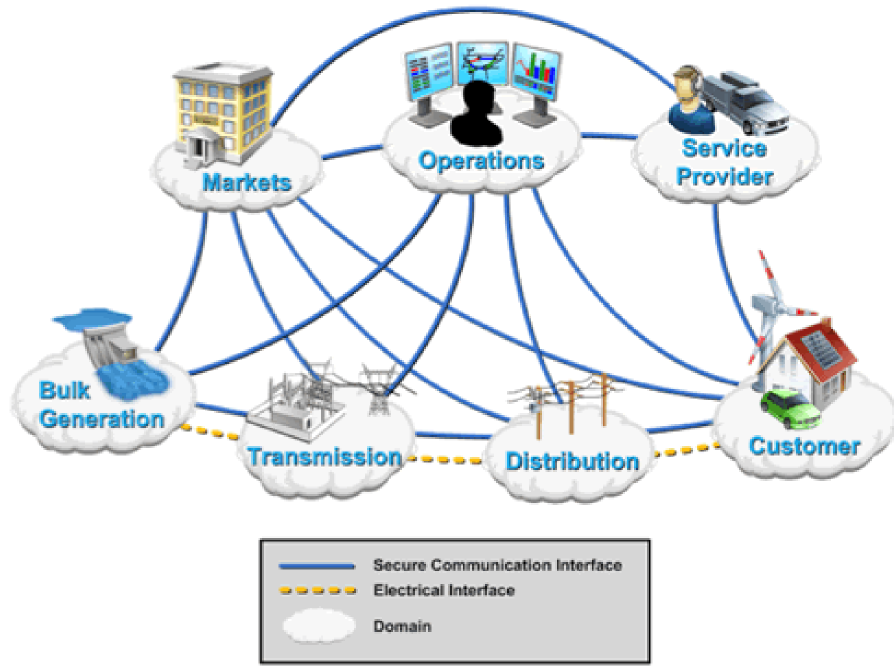
- Prior to 1965 it was widely believed that the "modern" interconnected power systems were modern marvels that were too robust to fail. That misconception was corrected on the evening of November 9th, 1965.
- One of five parallel 230 kV lines supplying power from New York into Ontario tripped due to a incorrectly set over-current relay. The power from this line was forced onto the 4 parallel lines, over loading all 4 remaining lines.
- This interrupted 1,800 MW of power flowing into Canada and caused instabilities on the northeastern portion of the Eastern Interconnect. The Eastern Interconnect separated into 4 islands, and 30 million people lost power.
- In addition to sparking the deployment of modern energy management systems, the 1965 blackout raised the question of whether something similar could happen in the Pacific Northwest.
- Since 1965 there have been numerous additional "cascading blackouts". The question has been asked if these can be prevented, or if that is impossible.

EMERGING TECHNOLOGIES TO ADDRESS OPERATIONAL CHALLENGES: "THE SMART GRID"

- There are numerous definition for the smart grid. Smartgrid.gov defines it as follows: "The Smart Grid is a developing network of new technologies, equipment, and controls working together to respond immediately to our 21st century demand for electricity".

- From this definition it can be seen that the smart grid is a combination of new equipment and controls all coordinated via communication networks.

- The features of the smart grid extend from the generation, through the transmission and distribution systems, and into the end-use customers. The end-use customers can be connected through operations and controls functions, as well as markets and third party service providers.



Emerging Technologies to Address Operational Challenges

- Throughout the 80's and 90's many of the power engineering programs in the U.S. were in decline, with many programs disappearing completely. This was partially due to the economic downturn of the 70's. Negative perceptions of the electricity industry also contributed to the declining number of power programs.

- This created a large 20 year gap within the workforces of many utilities. With many senior technical experts ready to retire, there are very few qualified people ready to take their place.

- There is a significant need for early to mid career personnel who are able to understand how the new technologies will fit into the existing systems.

- These will be the people who will shape what the nations electric infrastructure looks like in the future.

PART 4: CONCLUDING COMMENTS

- The Pacific Northwest has a complex electrical infrastructure that requires interactions with many aspects of society.
- The existing infrastructure, and associated regulatory and policy framework are the products of over 100 years of evolution.
- Understand where the system has come from, and why things operate the way they do, is the key to future changes.
- New technologies are also driving change in the industry.
- There has been more change in the past ten years than in the previous 50.
- There is currently a need for people in the area of electric energy, and this need will increase in the future.