Electric Power Systems – An Overview

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Overview

- **Power Generation**
  - Conventional and renewable power generation

- **Power transmission & Distribution**
  - Cables and other transmission & distribution system equipment

- **Power Utilization**
  - Demand curves, load characteristics

- **Power System Analysis**
  - Power flow, fault currents, economic dispatch, unit commitment, state estimation,....
North American Electrical Grid

- Four Islands: Western, Texas, Eastern, Quebec.

- There are over 3,000 electric utilities:
  - Some provide service in multiple states.
  - Over 1,700 non-utility power producers.
  - Utilities are either investor-owned, publicly-owned, or Federal utilities.
  - Electric utilities are regulated by local, State, and Federal authorities.
Basic Power System Layout

Conventional (non-renewable) primary energy source
World Electricity Generation by Source (2014)

- Fossil fuel: 15714.5 TWh, 66.8%
- Hydro: 3884.6 TWh, 16.5%
- Nuclear: 2536.8 TWh, 10.8%
- Other renewable: 508.5 TWh, 2.2%
- Solar: 185.9 TWh, 0.8%
- Wind: 706.2 TWh, 3.0%

Source: US Energy Information Administration (EIA)
USA Electricity Generation by Source

April 2010, 2015 US net generation by fuel source (%)

- Gas: 22% (2010), 31% (2015)
- Coal: 5% (2010), 9% (2015)
- Nuclear: 20% (2010), 20% (2015)
- Renewables: 7% (2010), 8% (2015)
- Conventional hydro: 1% (2010), 1% (2015)
- Pet products: 1% (2010), 1% (2015)
- Other: 1% (2010), 1% (2015)

As of July 1, 2015. 
Source: Energy Information Administration
US Sources of Electricity Generation, 2017

Total = 4.01 trillion kilowatthours

- hydro: 7.5%
- wind: 6.3%
- biomass: 1.6%
- solar: 1.3%
- geothermal: 0.4%

renewables 17%

- nuclear: 20%
- coal: 30%
- natural gas: 32%

petroleum 1%

Note: Electricity generation from utility-scale facilities.

Natural Gas Plants

- Share of Total: 32%
- 8,100 Generators (2016)

https://www.eia.gov/state/maps.php
Open cycle gas turbine: Typical efficiency: 30-35%

Air-breathing jet engines are gas turbines optimized to produce thrust from the exhaust gases. In our case, the system is optimized to produce maximum shaft power.
Combined cycle power plant: Typical efficiency: 60-65%

Efficiencies are even higher when the steam is used for district heating or industrial processes.
Coal Plants (shrinking)

- Share of Total: 30%
- 1,300 plants (2012)
Diagram of a modern coal power plant

Steam Turbines and their Governors

- Steam turbines can have non-reheat, single-reheat or double-reheat.
- The steam flow is controlled by the governor.
- Main and reheat stop valves are normally fully open - they are used only during generator start-up and shut down.
The electric generator

- **Governor** controls turbine torque and power
- **Exciter** controls voltage and reactive power
Nuclear Plants

- Share of Total: 20%
- 61 Plants (2017)
Diagram of a nuclear power plant

- Types of nuclear reactors:
  - Pressurized Water Reactor (PWR)
  - Boiling Water Reactor (BWR)
Hydro Plants

- Share of Total: 7.5%
- 50 Large plants (>100 MW)
Hydro power plants

- Low and medium head plants use Francis turbines
- High head plants use Pelton wheel turbines
Wind Plants

- Share of Total: 6.5%
- Over 50,000 wind turbines (2017)
US Wind Resource Map

Diagram of a wind turbine generator
Solar Plants

- Share of Total: 2%
Solar Resource

Global Horizontal Irradiation (GHI)
Sun-tracking mirrors (heliostats) focus sunlight onto a receiver at the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which in turn is used by turbine generator to produce electricity.

Some power towers use water/steam as the heat transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer capabilities.
World’s Largest - Ivanpah Solar, CA: 400 MW
Power Tower CSP in Nevada: Tonopah – 110 MW
Linear CSP Systems

- Linear CSP collectors capture the sun’s energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube.
- The receiver contains a fluid that is heated by the sunlight and then used to create steam that spins a turbine driving a generator to produce electricity.
Linear CSP Plant, Belridge, CA – 850 MW
Linear CSP in Nevada: NV Solar I (65 MW)
Linear CSP in Arizona: Gila Bend (280 MW)
Drought Issue!

Average annual precipitation in desert southwest: 10 cm!
Largest PV Systems in CA – several over 500 MW
Large Solar PV plants in Nevada
Large Solar PV plants in Arizona
Biomass Plants

- Share of Total: 1.5%
Biomass Resources of the United States
Forest Residues

Forest residues include logging residues and other removable material left after carrying out silviculture operations and site conversions. Logging residue comprises unused portions of trees, cut or killed by logging and left in the woods. Other removable materials are the unutilized volume of trees cut or killed during logging operations. Source: USDA, Forest Service’s Timber Product Output database, 2007.

For more information on the data development, please refer to http://www.nrel.gov/docs/fy06osti/39181.pdf Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.

Author: Billy Roberts - September 23, 2009
Diagram of a biomass power plant

Types of Biomass

- Wood
- Crops
- Garbage
- Landfill Gas
- Alcohol Fuels

(not to scale)
Geothermal Plants

- Share of Total: 0.5%
Geothermal Resource of the United States
Locations of Identified Hydrothermal Sites and Favorability of Deep Enhanced Geothermal Systems (EGS)

Favorability of Deep EGS
- Most Favorable
- Least Favorable
- N/A*
- No Data**
- Identified Hydrothermal Site (≥ 90°C)

* Map does not include shallow EGS resources located near hydrothermal sites or USGS assessment of undiscovered hydrothermal resources.
* Source data for deep EGS includes temperature at depth from 3 to 10 km provided by Southern Methodist University Geothermal Laboratory (Blackwell & Richards, 2009) and analyses for regions with temperatures ≥ 150°C performed by NREL (2009).
* Source data for identified hydrothermal sites from USGS Assessment of Moderate- and High-Temperature Geothermal Resources of the United States (2008).
* “N/A” regions have temperatures less than 150°C at 10 km depth and were not assessed for deep EGS potential.
* “Temperature at depth” data for deep EGS in Alaska and Hawaii not available.

This map was produced by the National Renewable Energy Laboratory for the US Department of Energy. October 13, 2009 Author: Billy J. Roberts
Diagram of a flash steam geothermal power plant
Geothermal plants in NV & CA
Nevada Power Generation by Source

- **NATURAL GAS**
  Owned and contracted

- **RENEWABLE ENERGY**
  Nameplate megawatts of capacity that is owned or under long-term contracts

- **COAL**

**MARCH 2017**
- Natural Gas: 76%
- Renewable Energy: 18%
- Coal: 6%

**YEAR END 2019**
- Natural Gas: 78%
- Renewable Energy: 19%
- Coal: 3%
Nevada Renewables

2015 RENEWABLE PORTFOLIO CREDITS BY TECHNOLOGY

Geothermal: 69.2%
Solar: 16.4%
Wind: 7.4%
Private Generation: 5.1%
Biomass/Biogas & Waste: 1.5%
Hydro: 0.4%

*Private Generation includes solar, wind, and hydro systems installed at a customer locations.
List of Nevada Renewable Plants

Geothermal: 550 MW
Solar: 1000 MW
Solar rooftops: 250 MW
Hydro: 250 MW
Wind: 150 MW
Other: 20 MW

Total: 2.22 GW
Peak Load: 7.3 GW
Nevada Net Electricity Generation by Source, Jan. 2018

Source: Energy Information Administration, Electric Power Monthly
Basic Conventional Power System Layout

Color Key:
Black: Generation
Blue: Transmission
Green: Distribution

Generating Station
Generating Step Up Transformer
Transmission Customer 138kV or 230kV
Transmission lines 765, 500, 345, 230, and 138 kV
Substation Step Down Transformer
Subtransmission Customer 26kV and 69kV
Primary Customer 13kV and 4kV
Secondary Customer 120V and 240V
Step-up (Station) transformers:

- Size up to 1000 MVA
- Generator voltage up to 25 kV
- Transmission voltage up to 765 kV
- Forced Air and Forced Oil Cooling.
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Electric Transmission Lines

- Voltages: 115 kV, 138 kV, 161 kV, 230 kV, 345kV, 500kV, 765kV
- Over 180,000 miles of high-voltage lines, connecting to about 7,300 power plants.

https://www.eia.gov/state/maps.php
High Voltage Power Lines (overhead)

- Common voltages in north America: 138, 230, 345, 500, 765 kV
- Bundled conductors are used in extra-high voltage lines
- Stranded instead of solid conductors are used.
Construction of “One Nevada” Power Line


11,000 kV Line in China

- [https://www.youtube.com/watch?v=SpVR3pySq-U](https://www.youtube.com/watch?v=SpVR3pySq-U)
- [https://www.youtube.com/watch?v=WiHzvkB2jdk](https://www.youtube.com/watch?v=WiHzvkB2jdk)
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Generating Station
- Generating Step Up Transformer

Transmission lines
- 765, 500, 345, 230, and 138 kV

Transmission Customer
- 138 kV or 230 kV

Substation
- Step Down Transformer

Subtransmission
- Customer 26 kV and 69 kV

Primary Customer
- 13 kV and 4 kV

Secondary Customer
- 120 V and 240 V
Substation Transformers

- Typical size: 20 MVA
- Primary voltage down to 69 kV
- Secondary voltage down to 4.16 kV
Distribution Substation Layout

- Incoming Subtransmission Lines
- Electric power path through substation
- Lightning Arresters
- Air-break Switches
- Outgoing Distribution Lines
- Step-down Transformer
- Distribution Bus
- Cutout Switches
- Oil Circuit Breakers
- Voltage Regulators
- Metal-clad Switchgear
- Control House
- 34KV in
- 7.2KV out
Electric Substations

- Over 55,000 Substations
Power distribution lines
(placed underground in new urban areas)

- Primary Distribution voltages: 4.16, 12.47, 13.2, 13.8, 25, 34.5 kV
Power distribution transformers

- The distribution circuits may be overhead or underground. This will depend on the load density and the physical conditions of the particular area to be served.

*Overhead Transformer Bank & Service*

*Padmount Transformer for Underground System*
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Electrical Power Utilization (electric load)

- Utilization voltage: 120V, 208V*, 240V, 277V, 480V*, 600V*

2/3 to 3/4 of electricity is consumed by motors
Changes in demand of individual customers is fast and frequent due to load switching.
The aggregated demand at the substation is smoother, and total load fluctuations are usually small.
MW and MVAR loading on a distribution feeder over 4 month period
The aggregated demand on the system is even smoother, and total load fluctuations are very small. The overall daily profile of load can be predicted reasonably well using forecasting tools.
The local (southern Nevada) load is dominated by winter and summer patterns, with May and October as shoulder months.
Nevada typical demand curve: June 12-14
Nevada Power Interchange

Balancing authority in-flow (-) and out-flow (+) 06/06/2018 – 06/13/2018, EDT

Source: U.S. Energy Information Administration

Balancing authority Interchange (BA-to-BA interchange data available up to two days prior to current day.)

Balancing authority electricity flow 06/06/2018 – 06/13/2018, EDT
Typical US Demand Curve
Peak demand in 2017: 770 GW

U.S. electricity demand

U.S. hourly actual and forecast demand 06/04/2018 – 06/11/2018, EDT

megawatthours
North American Balancing Authorities

- The actual operation of the interconnections is handled by over 100 Balancing Authorities (BA’s). The BA’s dispatch generators in order to meet their individual needs.
Status Map

487,582 U.S. electricity demand (Lower 48 states) megawatthours

Jun 13, 2018

Hour 13 EDT

Midcontinent Independent System Operator, Inc. (MISO)
Region: MIDW
95,161 MW actual demand
95,078 MW forecasted demand
0.09 % over forecast

AC-DC-AC tie
Generation only, no demand
Data missing or