ECE 5314: Power System Operation & Control

Lecture 1: Overview and Generation Units

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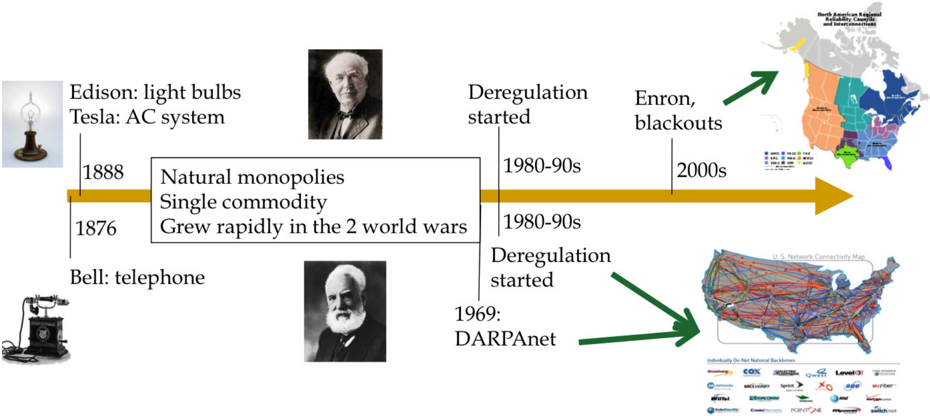
R1 Wood, Wollenberg, and Sheblé, *Power Generation, Operation, and Control*, Chapter 1.

R2 Gómez-Expósito, Conejo, and Canizares, Eds., *Electric Energy Systems, Analysis and Operation*, Chapter 1.

Some history



Power grid architecture

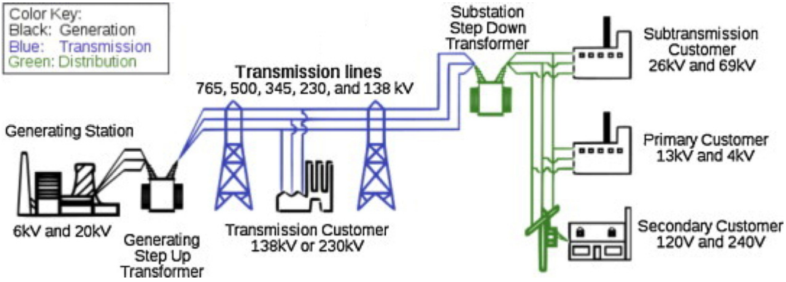
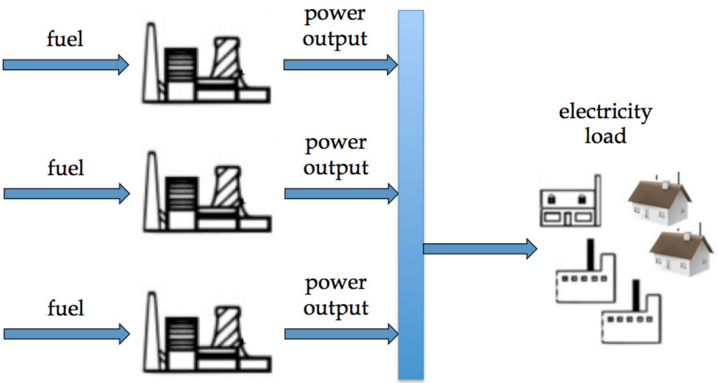


Figure: *Final report on the August 14 2003 blackout in the US and Canada*, Federal Energy Regulatory Commission (FERC), Apr. 2004.

"Most significant engineering achievement of 20th century," National Academy of Engineering report 2010.

Course overview: Thermal Units

Course overview: Economic Dispatch



- How to allocate MW outputs to generators to minimize operation cost?
- Economic dispatch is a resource allocation problem.

Course overview: Unit Commitment

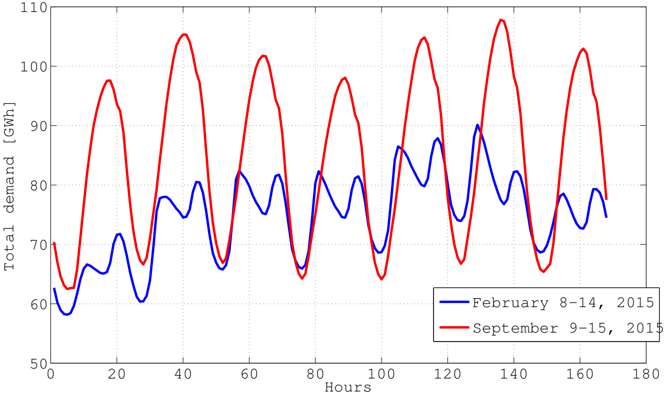


Figure: Electricity demand in Mid-continent Independent System Operator (MISO).

- Electricity load exhibits large variations across time.
- Which generators should be on/off-line at each time?

Course overview: Transmission System Effects

Network-Constrained ED:

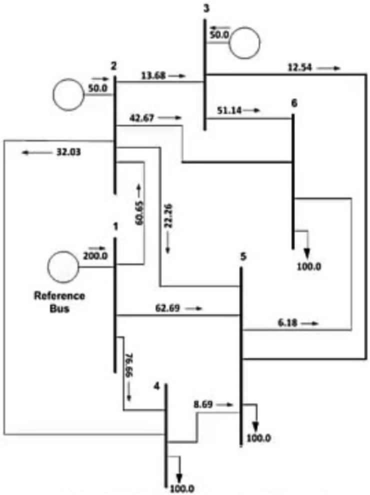
avoids transmission line overheating

Optimal Power Flow:

- enforces voltage magnitude constraints
- manages reactive power
- incorporates transmission losses

Contingency analysis:

Security-Constrained OPF (SC-OPF)



Power system operations

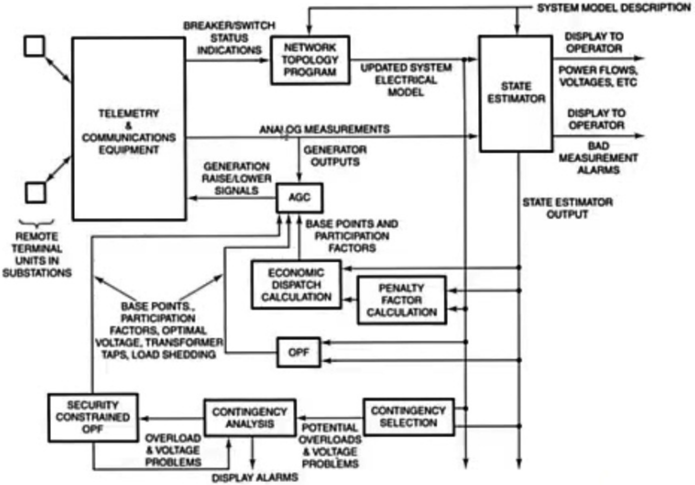


Figure: Source [R1].

Timescale of power system operations

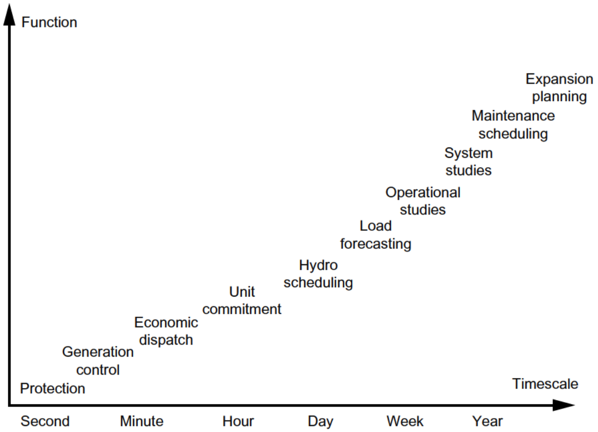


Figure: Source [R2].

Generation units

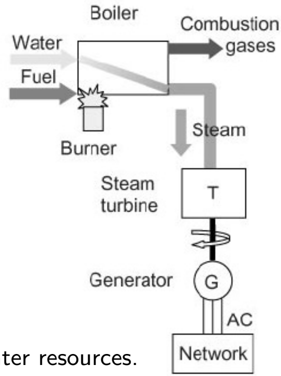
- Three-phase AC voltage system with controlled frequency and magnitude
- Broadly divided into:
  - thermal plants (coal, nuclear, natural gas, oil)
  - hydroelectric plants
  - renewables (wind farms, solar panels)
- Different technologies vary in capital, maintenance and fuel costs

  e.g., nuclear and hydro have high capital costs but low operating costs
- To see the current US electricity mix, check

  `https://www.washingtonpost.com/graphics/national/power-plants/`
- Due to load cycles and for reliability issues, there are more generators than needed. How do you pick the most economically efficient generation mix?

Thermal plants

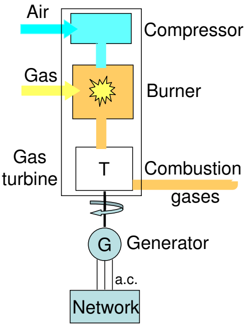
1. Burned fuel in boiler produces steam
2. Steam converted to mechanical energy in turbine
3. Generator converts mechanical to electric energy



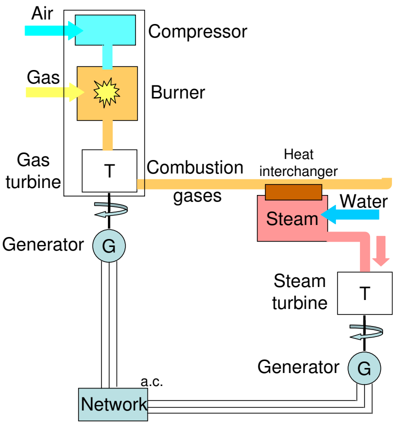
Location: away from urban centers and close to water resources.

Natural gas turbine plants

Gas turbine plant



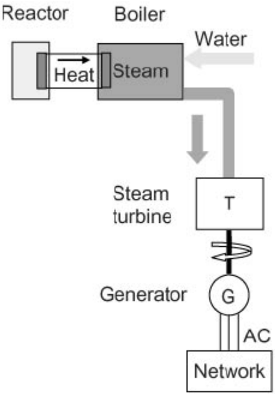
Combined Cycle Gas Turbine plant



Increased efficiency 60%; low emissions; reasonable investment costs

Peakers: fast-responding units in periods of high demand

Nuclear power plants



Baseload units: together with large coal plants operate almost always at max.

Concerns related to catastrophic events and radioactive waste.

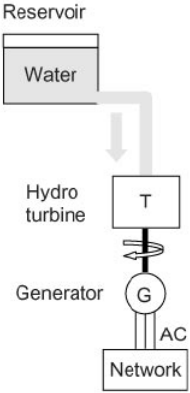
Hydroelectric plants

- Turbine converts hydraulic to mechanical energy.
- Generator converts mechanical to electric energy.
- **Types**:

  (a) Impoundment;

  (b) diversion (run-of-the-river); and

  (c) pumped storage.



First option in developing countries: avoid floods and control river navigation.

Impoundment hydroelectric plant operation

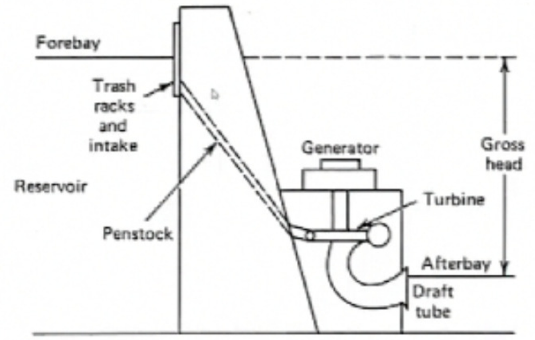


Figure: Hydroelectric plant [R1].

Pumped storage

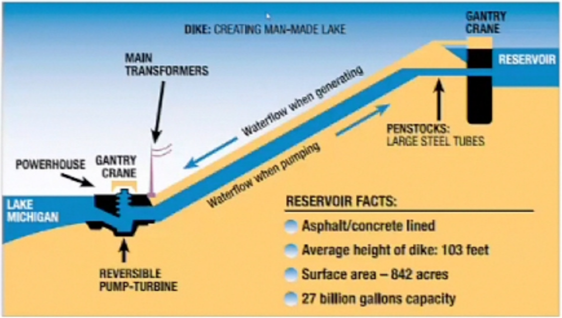


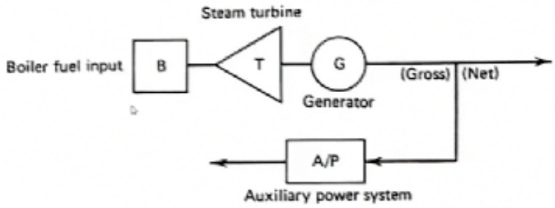
Figure: Ludington bumped storage plant.

Consume power at low-price hours (overnight) to pump water upwards.

Regular operation (downward water flow) at high-price hours.

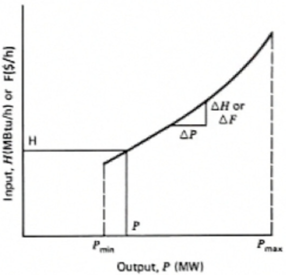
Boiler-turbine-generator units

- valve between boiler and turbine controlling steam flow
- gross vs. net power produced (2-10% for auxiliary power system)



- To optimize generation mix, need relationship between net power and cost.
- Water in hydro is free; assign cost for controlling reservoir levels.
- Hydros are typically optimized over long periods of time.
- Renewable resources can be treated like load.

Thermal unit cost curves

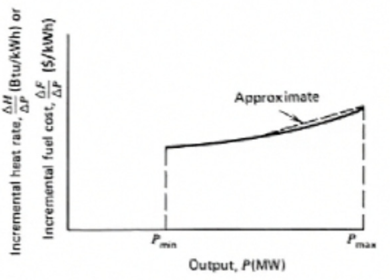


Input-output curve $H(P)$: fuel rate [MBtu/h] vs. *net* power output [MW]

Fuel-cost curve $C(P)$: multiply $H(P)$ by fuel cost [$/MBtu] to get [$/h]

- derived from calculations or test data
- approximated by piece-wise linear or quadratic curves
- maintenance and investment costs usually included

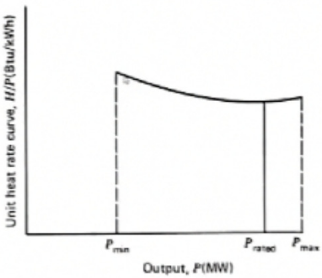
Incremental cost curve



Incremental fuel-cost curve $IC(P)$: the derivative of $C(P)$ [$/MWh]

- (incremental) fuel-cost curves routinely used in economic dispatch
- generation limits $(P_{\min}, P_{\max})$

Heat-rate curve



Heat-rate curve: the ratio $H(P)/P$ [Btu/kWh]

- curve's minimum is the most efficient operation point