WHAT IS A MICRO-GRID?

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Historical Perspective

Competing technologies for electrification in 1880s:

- Edison:
  - dc.
  - Relatively small power plants (e.g. Pearl Street Station).
  - No voltage transformation.
  - Short distribution loops – No transmission
  - Loads were incandescent lamps and possibly dc motors (traction).

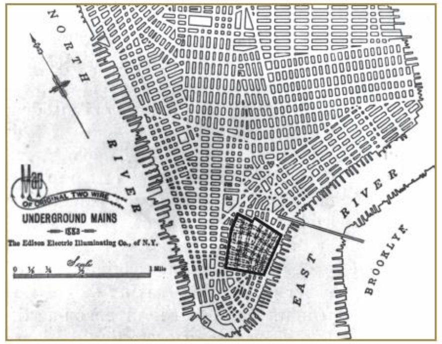


figure 1. Map of lower Manhattan showing the original area served by the Pearl Street station and its distribution system (courtesy of the Consolidated Edison Company of New York).

Pearl Street Station:
6 "Jumbo" 100 kW, 110 V generators

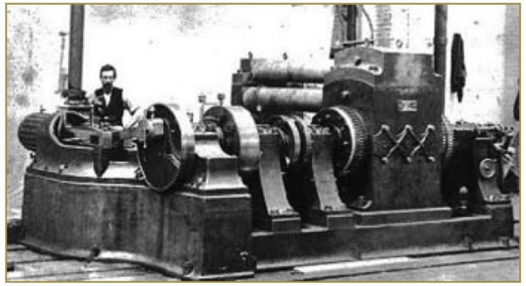
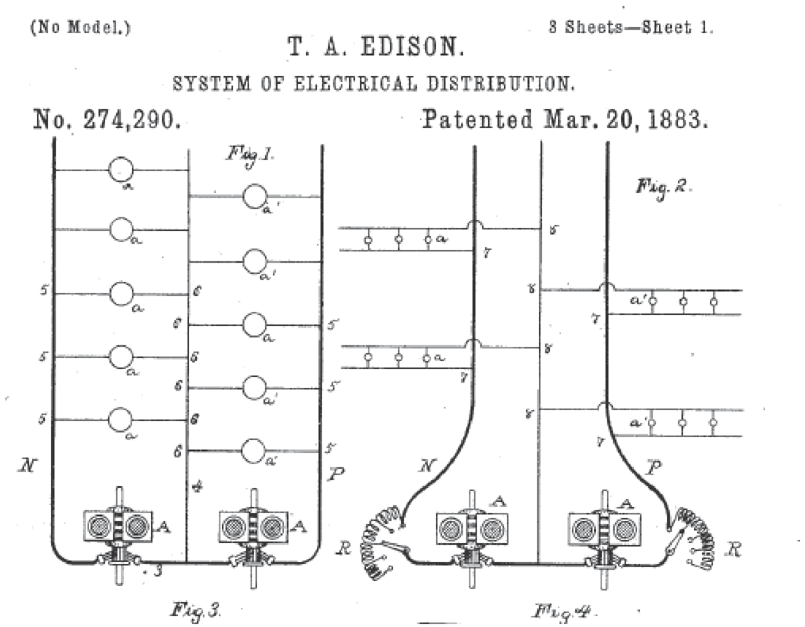


figure 3. Edison's 100-kW engine-driven "Jumbo" dynamo of the type installed at the Pearl Street station (photo courtesy of the Edison National Historical Site, U.S. Department of the Interior, National Park Service).



"Eyewitness to dc history" Lobenstein, R.W. Sulzberger, C.

History

Competing technologies for electrification in 1880s:

•Tesla:

- ac
- Large power plants (e.g. Niagara Falls)
- Voltage transformation.
- Transmission of electricity over long distances
- Loads were incandescent lamps and induction motors.

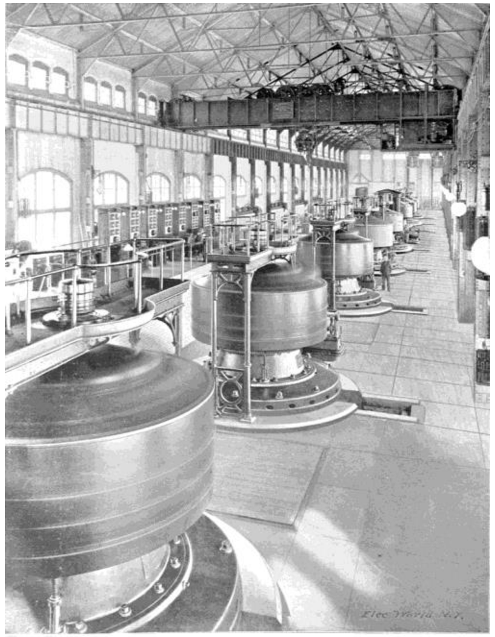
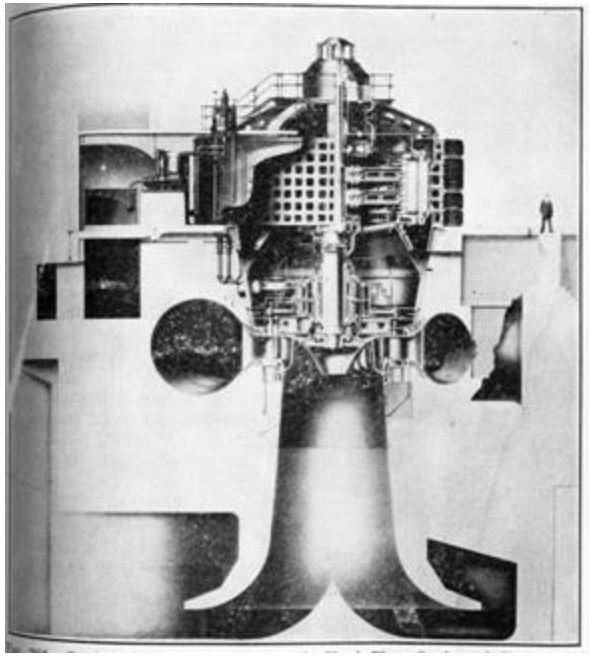


Fig. 11.—A View of the Dynamo Room, Looking South from the Visitors' Gallery.



Niagara Falls historic power plant:
38 x 65,000 kVA, 23 kV, 3-phase
generatods

http://spiff.rit.edu/classes/phys213/lectures/niagara/niagara.html

History

Edison's distribution system characteristics: 1880 – 2000 perspective

• Power can only be supplied to nearby loads (< 1mile).

• Many small power stations needed (distributed concept).

• Suitable for incandescent lamps and traction motors only.

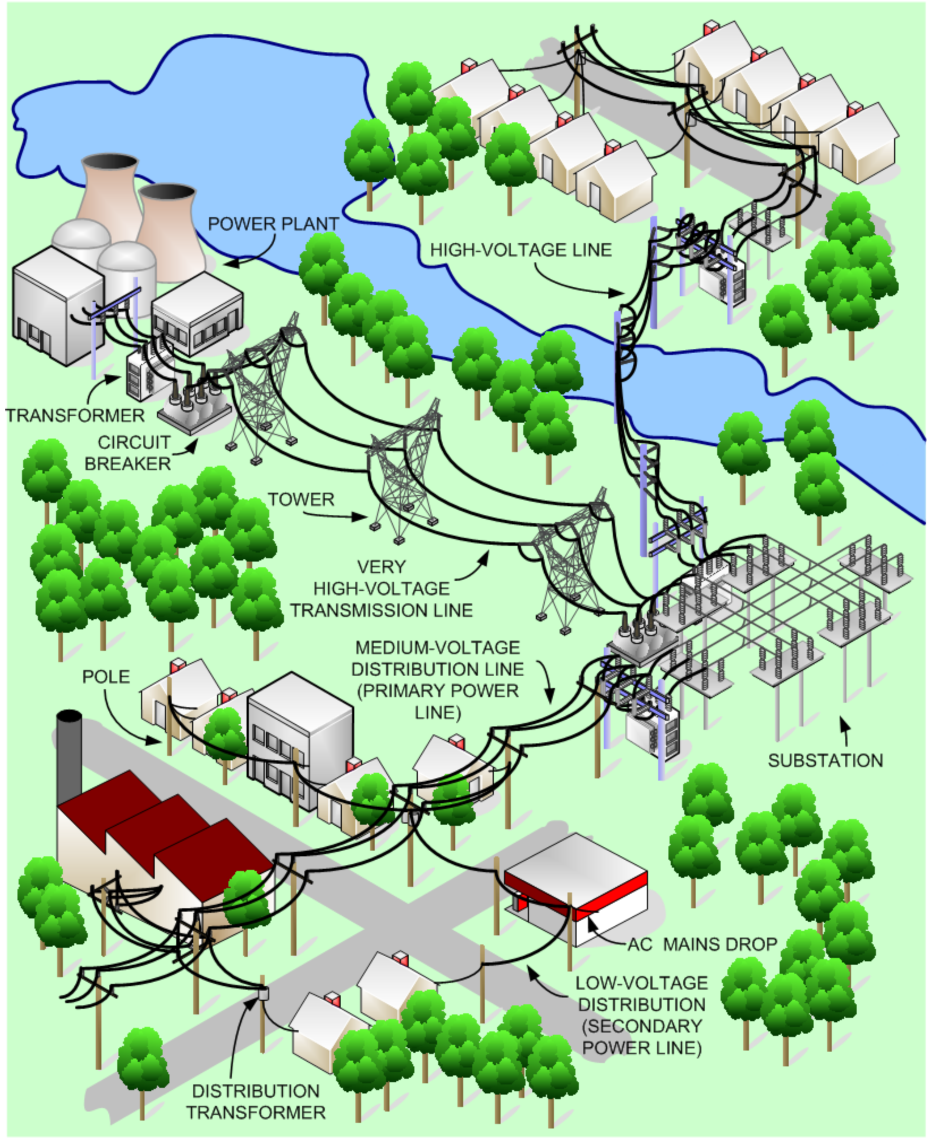
• Cannot be transformed into other voltages (lack of flexibility).

• Higher cost than centralized ac system.

• Used inefficient and complicated coal – steam actuated generators (as oppose to hydroelectric power used by ac centralized systems).

• Not suitable for induction motors.

History



Traditional technology: the electric grid:

- Generation, transmission, and distribution.
- Centralized and passive architecture.
- Extensive and very complex system.
- Complicated control.
- Not reliable enough for some applications.
- Stability issues.
- Vulnerable/fragile.
- Need to balance generation and demand
- Lack of flexibility.

History

Conventional grids operation:

- In order to keep frequency within a tight stable operating range generated power needs to be balanced at all time with consumed power.

- A century working around the need for adding electric energy storage through grid stiffness by:
    - Interconnecting many large power generation units (high inertia = mechanical energy storage).
    - Individual loads power ratings are much smaller than system's capacity

- Conventional grid "stiffness" make them lack flexibility.

- Lack of flexibility is observed by difficulties in dealing with high penetration of renewable energy sources (with a variable power output).

- Electric energy storage can be added to conventional grids but in order to make their effect noticeable at a system level, the necessary energy storage level needs to be too high to make it economically feasible.

History

Edison’s distribution system characteristics: 2000 – future perspective

• Power supplied to nearby loads is more efficient, reliable and secure than long power paths involving transmission lines and substations.

• Many small power stations needed (distributed concept).

• Existing grid presents issues with dc loads (e.g., computers) or to operate induction motors at different speeds. Edison’s system suitable for these loads.

• Power electronics allows for voltages to be transformed (flexibility).

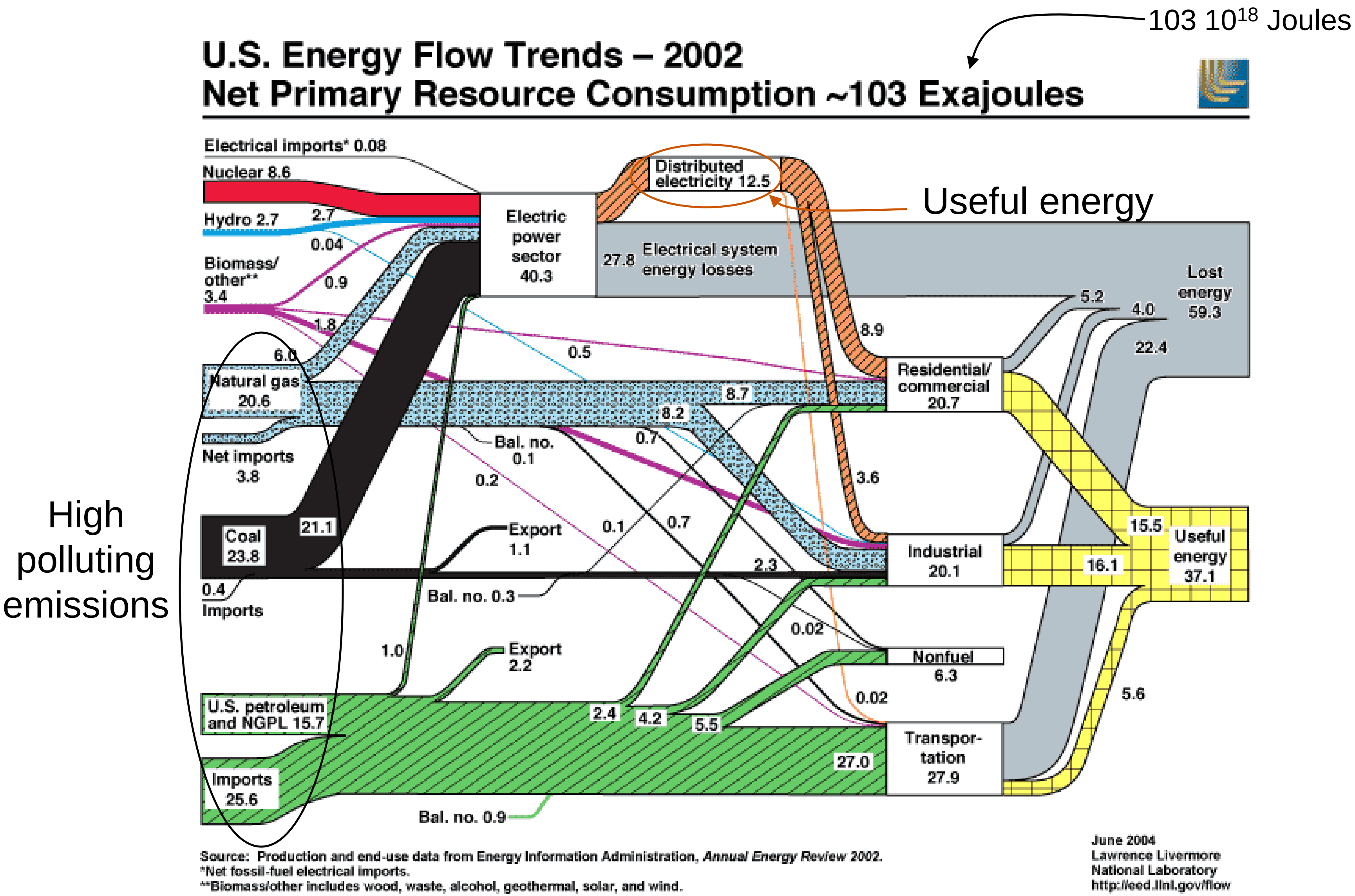
• Cost competitive with centralized ac system.

• Can use renewable and alternative power sources.

• Can integrate energy storage.

• Can combine heat and power generation.

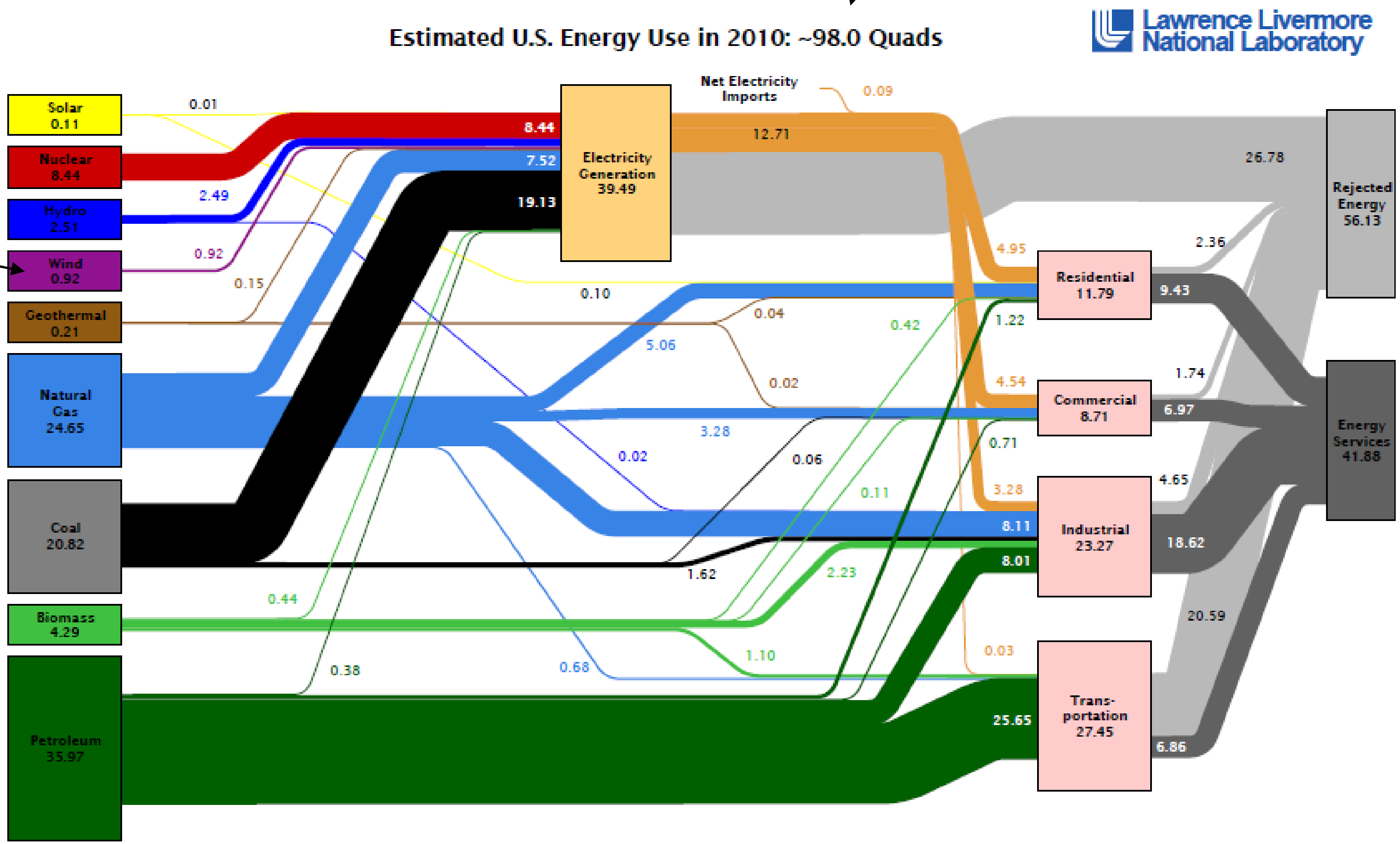
Sustainability



https://eed.llnl.gov/flow/02flow.php

Sustainability

103.4 Exajoules



“New” renewable sources

Source: LLNL 2011. Data is based on DOE/EIA-0384(2010), October 2011. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for hydro, wind, solar and geothermal in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." (see EIA report for explanation of change to geothermal in 2010). The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

https://flowcharts.llnl.gov/

Sustainability

Issues with integration of "new" renewable sources into large conventional power grids

• Variable output (part stochastic) may lead to potential stability and power quality issues.

• Large footprint.

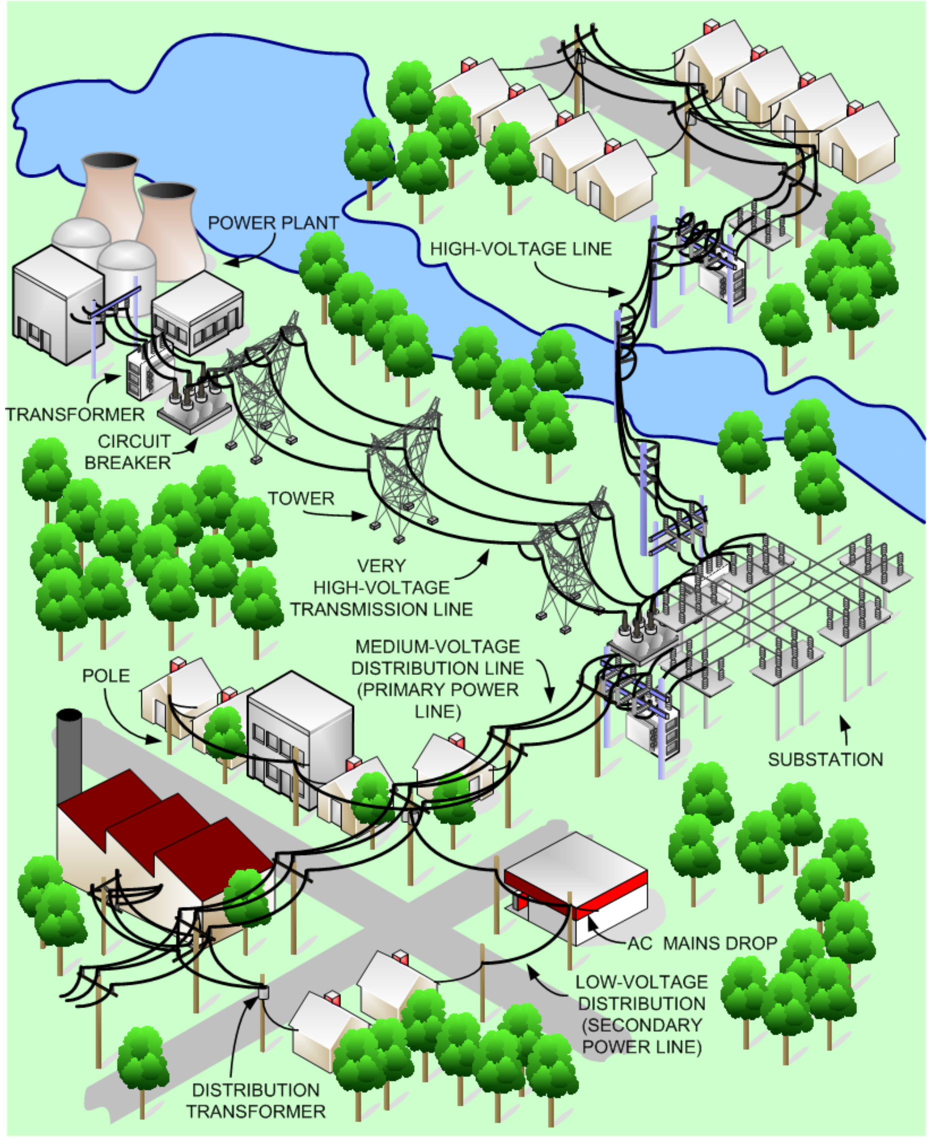
• No (or very little) "inertia"

Other issues with renewable sources in general (inc. hydroelectric plants)

• Not usually sufficiently available near load centers (so cost evaluation need to add construction of transmission lines)

• Ecological issues.

Reliability/Resilience

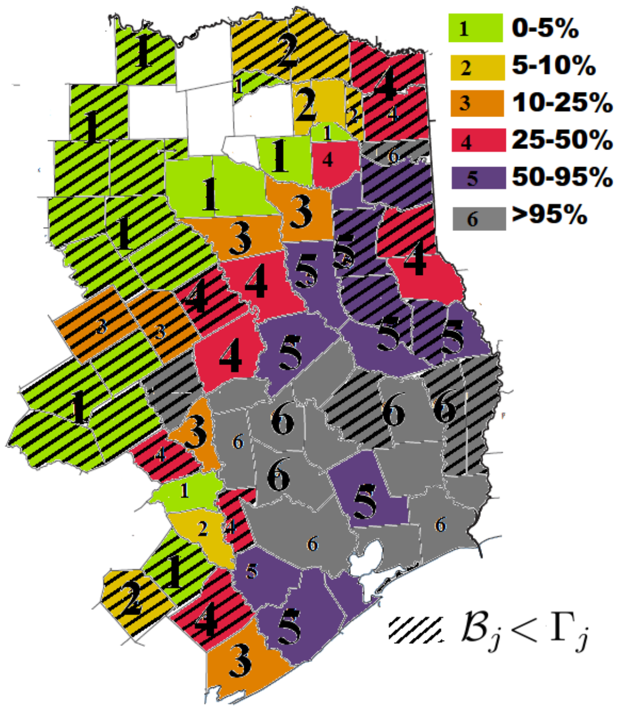


Conventional U.S. grid availability in normal conditions:
Approximately 99.9 %

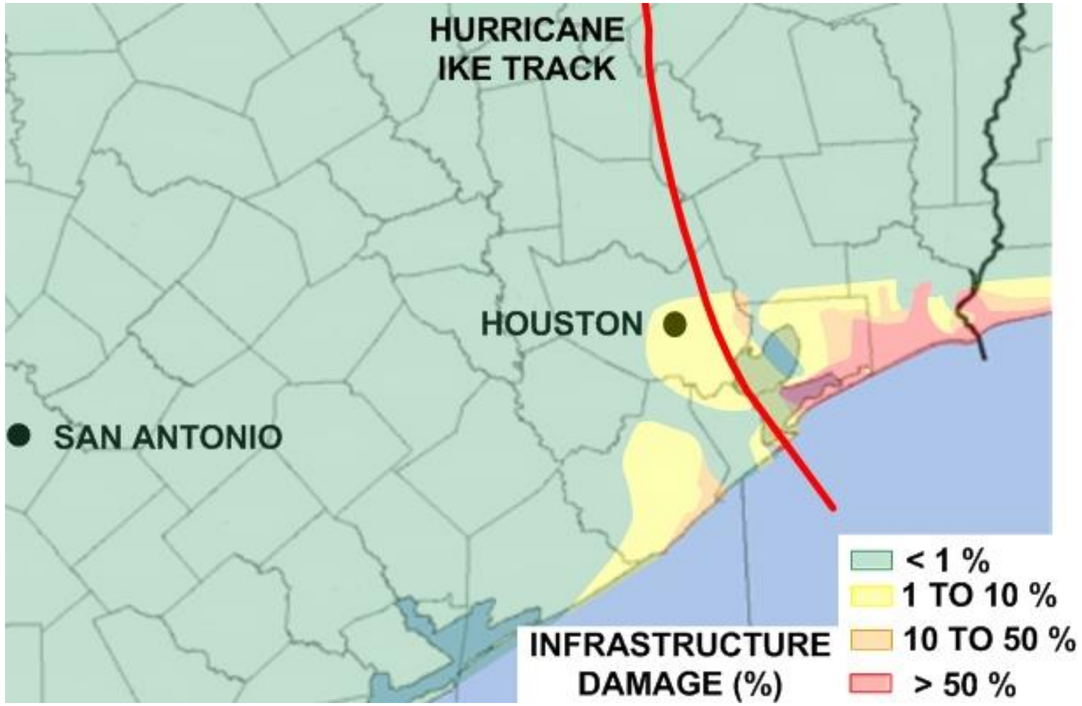
Availability required in critical applications:
Approximately 99.999%

Reliability/Resilience

• Due to their predominately centralized control and power generation architectures, power grids are very fragile systems in which little damage may lead to extensive outages.



Maximum power outage incidence ($O\%_{max}$) after Ike



Percentage of power grid damage after Ike

- Information obtained from field damage assessments

Reliability/Resilience

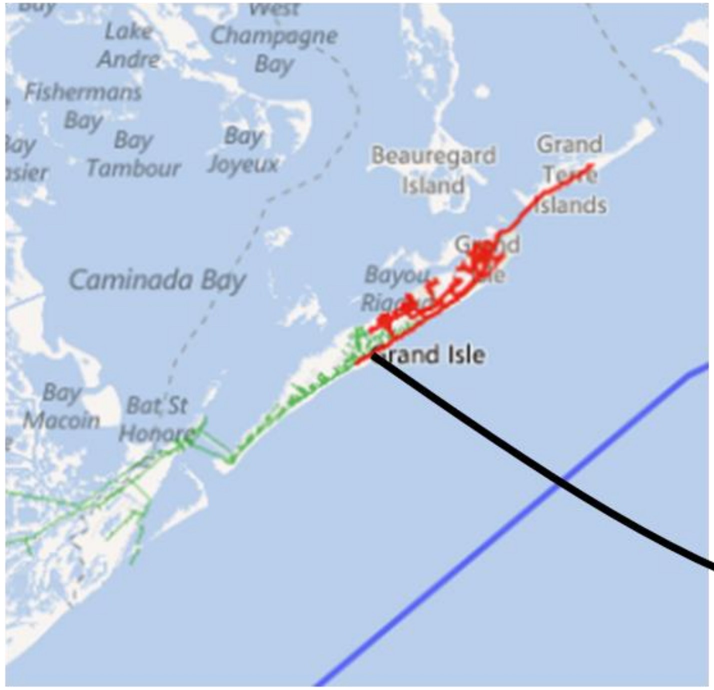
- **Other weaknesses of power grids observed during natural disasters**
  - Very extensive network (long paths and many components).
  - Typically, sub-transmission and distribution portions of the grid lack redundancy. As a result, long restoration times usually originate at the distribution level of power grids.
  - Need for continuous balance of generation and demand.
  - Difficulties in integrating meaningful levels of electric energy storage
  - Aging infrastructure
  - Aging workforce (people is an essential part of infrastructure systems)

Reliability/Resilience

• **Example of lack of redundancy at sub-transmission/distribution**

• Vulnerability: Sub-transmission and distribution portions of the grid lack redundancy. Most outages originate in distribution-level issues.

• E.g., Only one damaged pole among many undamaged causing most of Grand Isle to lose power.

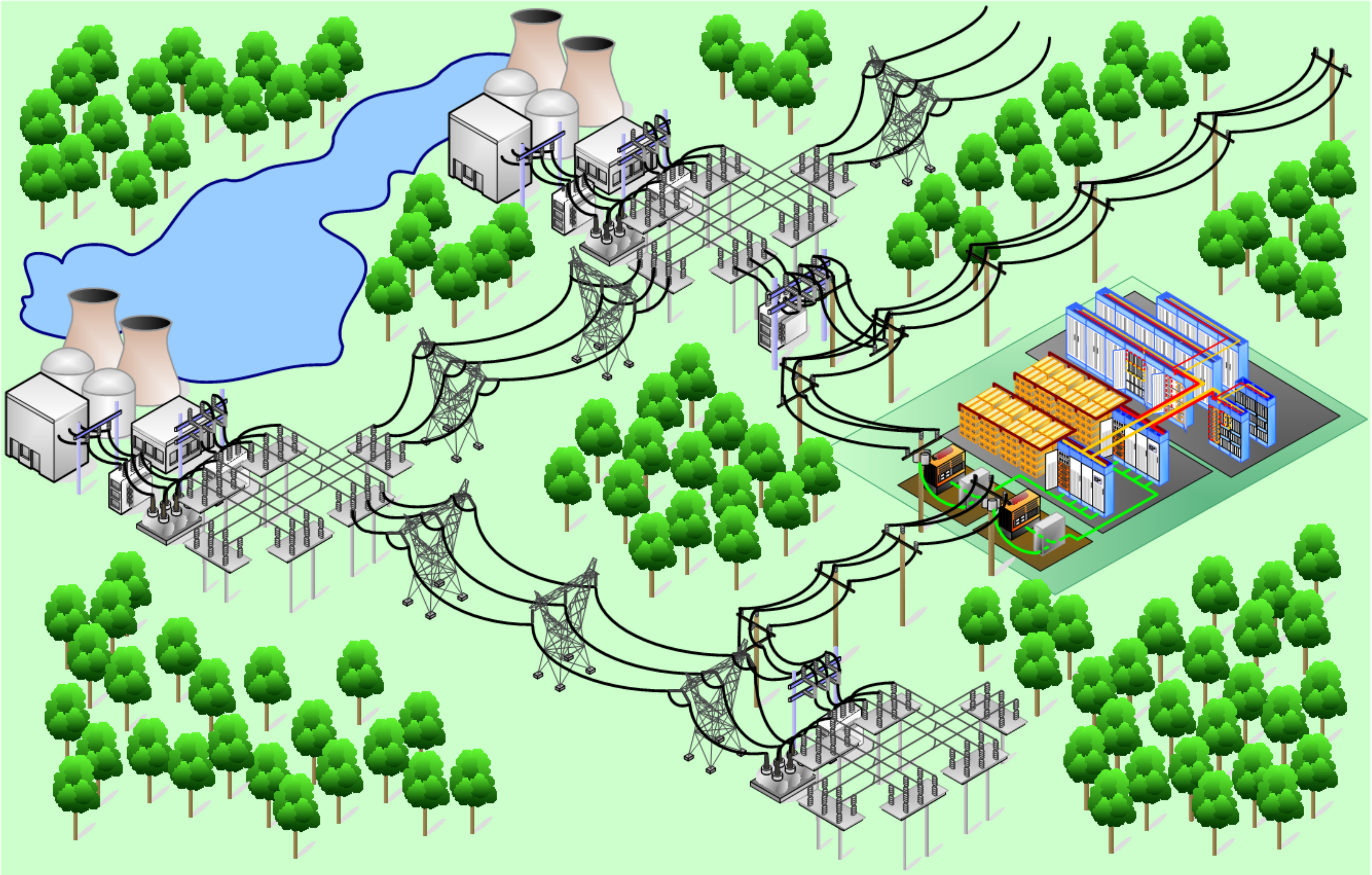


Grand Isle, about 1 week after the hurricane

Entergy Louisiana

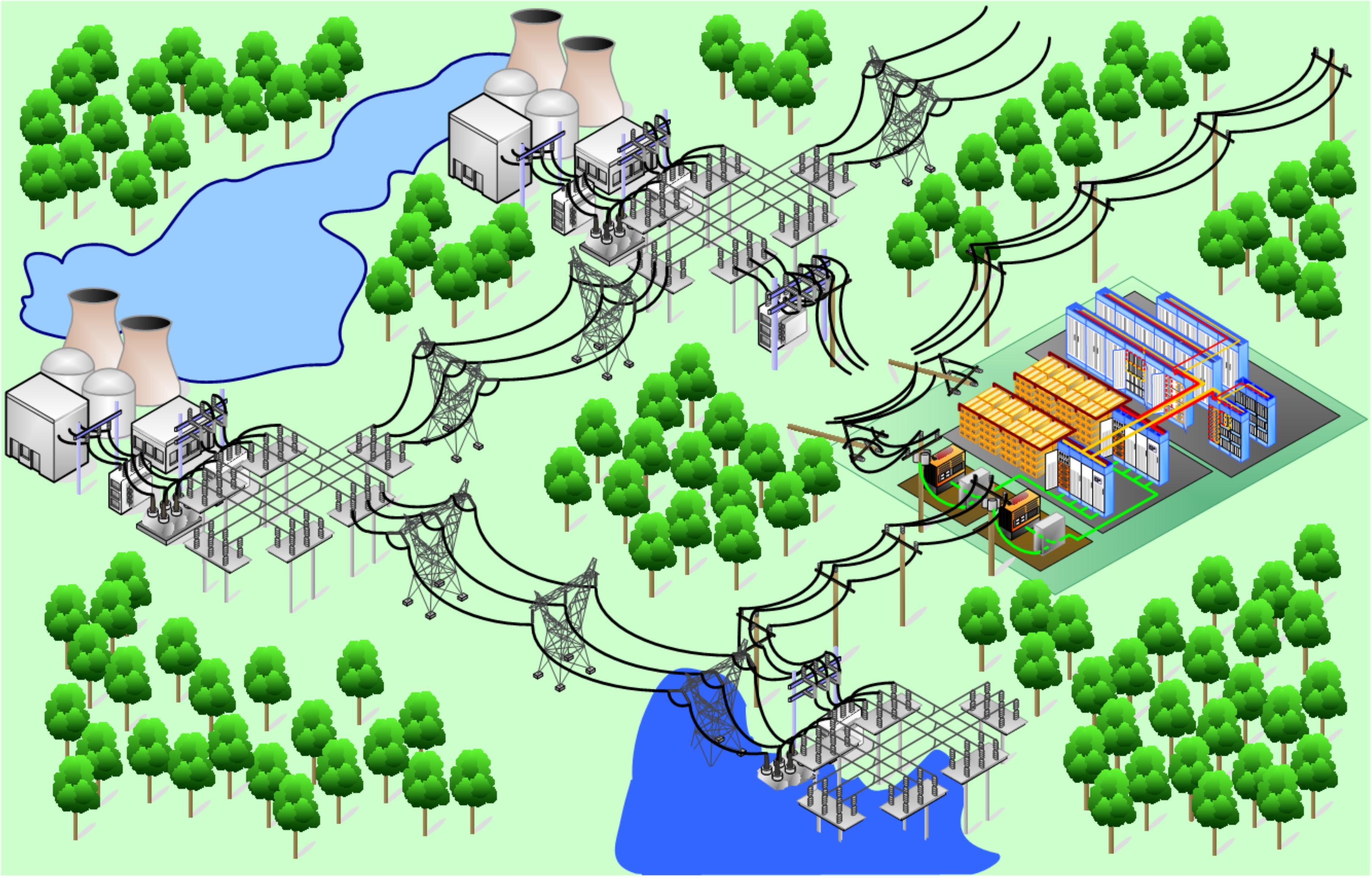
Reliability/Resilience

Example of lack of diversity



Reliability/Resilience

Example of lack of diversity



Reliability/Resilience

- Power grids performance during natural disasters
- Case study: Superstorm Sandy
- Often, damage to power grids is less severe than for residences.
- Storm surge damaged some substations in coastal areas




Other issues in conventional grids

• Centralized integration of renewable energy issue: generation profile unbalances.

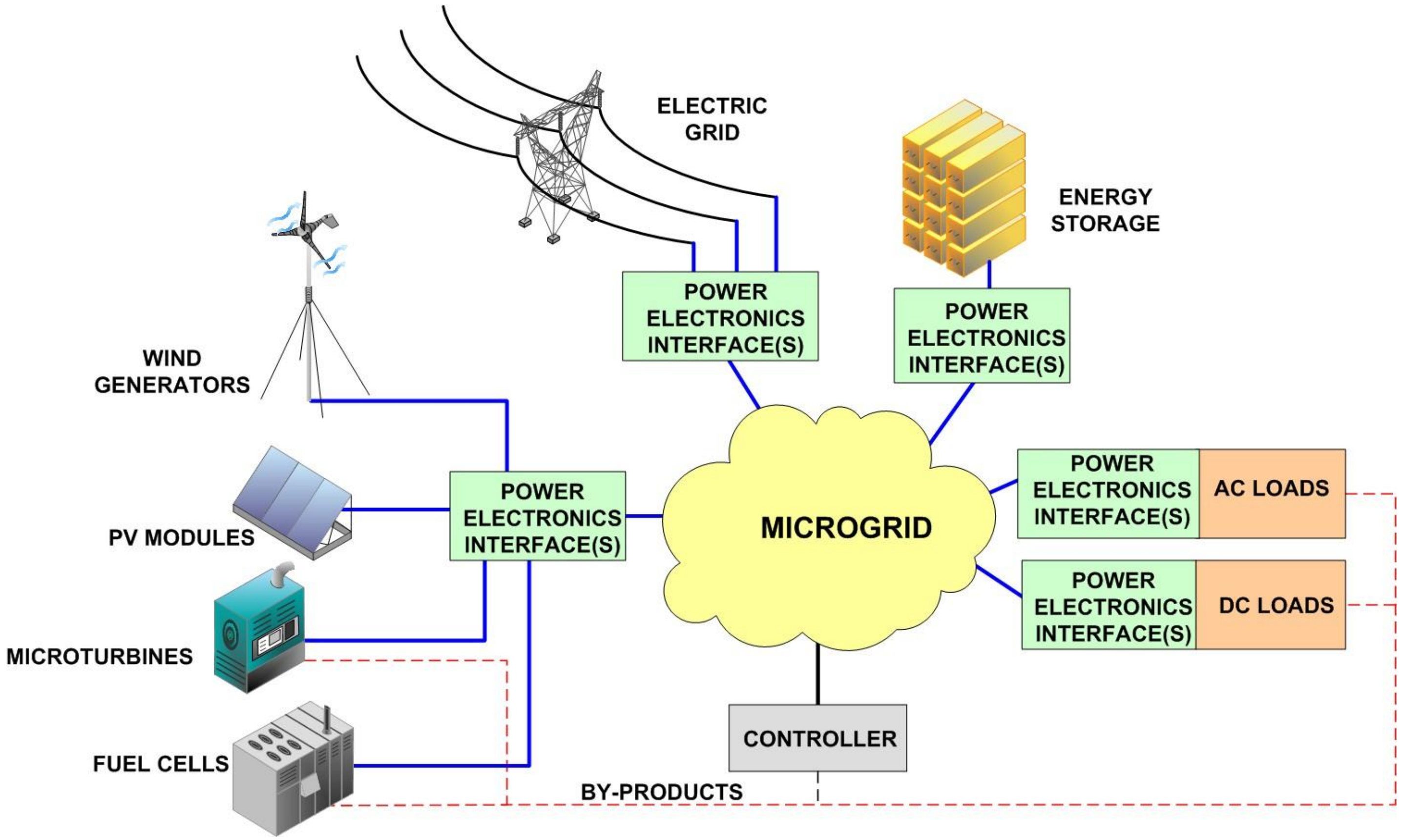
• Complicated stability control

• The grid lacks operational flexibility because it is a passive network.

•The grid is old: it has the same 1880s structure. Power plants average age is > 30 years.

Microgrids: Concept (a first approach)

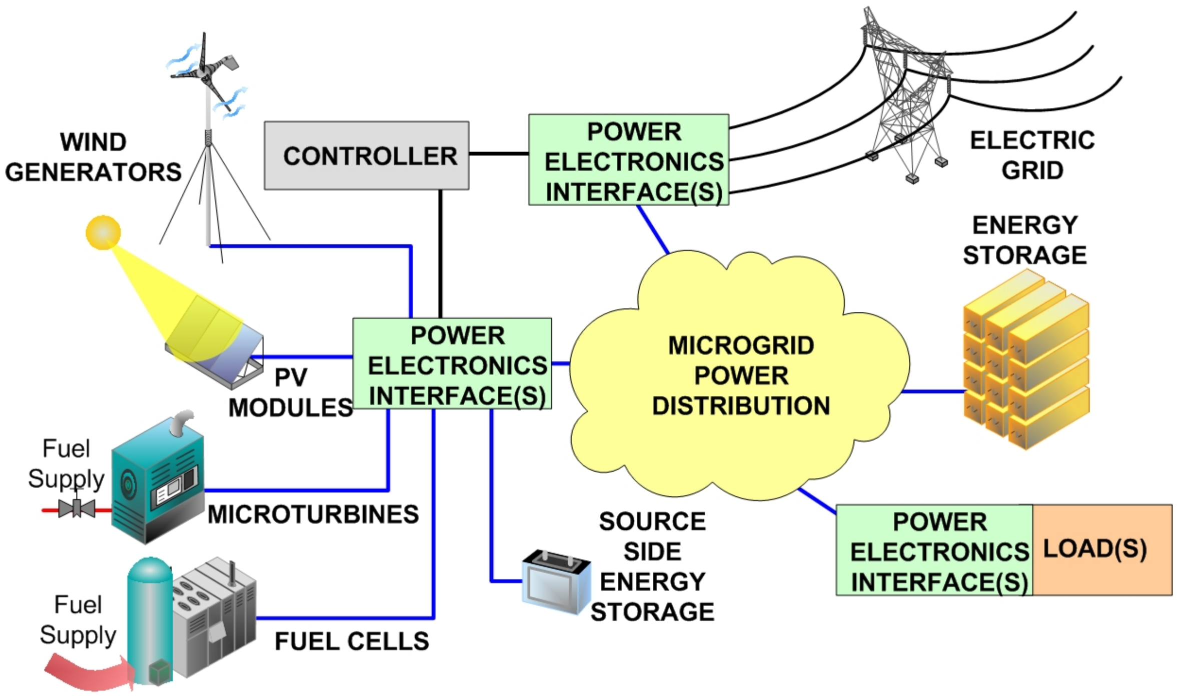
- Microgrids are independently controlled (small) electric networks, powered by local units (distributed generation).



Microgrid: Concept (newest DOE def.)

• What is a microgrid?

• Microgrids are considered to be locally confined and independently controlled electric power grids in which a distribution architecture integrates loads and distributed energy resources—i.e. local distributed generators and energy storage devices—which allows the microgrid to operate connected or isolated to a main grid



Distributed Generation: Concept

- Key concept for microgrids: independent control.

• This key concept implies that the microgrid has its own power generation sources (active control vs. passive grid).

• A microgrid may or may not be connected to the main grid.

• DG can be defined as “a subset of distributed resources (DR)” [T. Ackermann, G. Andersson, and L. Söder, “Distributed generation: A definition.” Electric Power Systems Research, vol. 57, issue 3, pp. 195-204, April 2001].

• DR are “sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies” [T. Ackermann, G. Andersson, and L. Söder, “Distributed generation: A definition.” Electric Power Systems Research, vol. 57, issue 3, pp. 195-204, April 2001]

• DG “involves the technology of using small-scale power generation technologies located in close proximity to the load being served” [J. Hall, “The new distributed generation,” Telephony Online, Oct. 1, 2001 http://telephonyonline.com/mag/telecom_new_distributed_generation/.]

• Thus, microgrids are electric networks utilizing DR to achieve independent control from a large widespread power grid.

Microgrids

• Distributed Generation: Advantages

With respect to the traditional grid, well designed microgrids can be:

• More resilient (with diverse power inputs and in most cases with energy storage).
• More efficient
• More environmentally friendly
• More flexible
• Less vulnerable
• More modular
• Easier to control
• Immune to issues occurring elsewhere

• Microgrids can be integrated into existing systems without having to interrupt the load.

• Microgrids allow for combined heat and power (CHP) generation.

Microgrids: System Components

Generation units = microsources (approximately below than 100 kW each)
- PV Modules.
- Small wind generators
- Fuel Cells
- Microturbines

Energy Storage (power profile)
- Batteries
- Ultracapacitors
- Flywheels

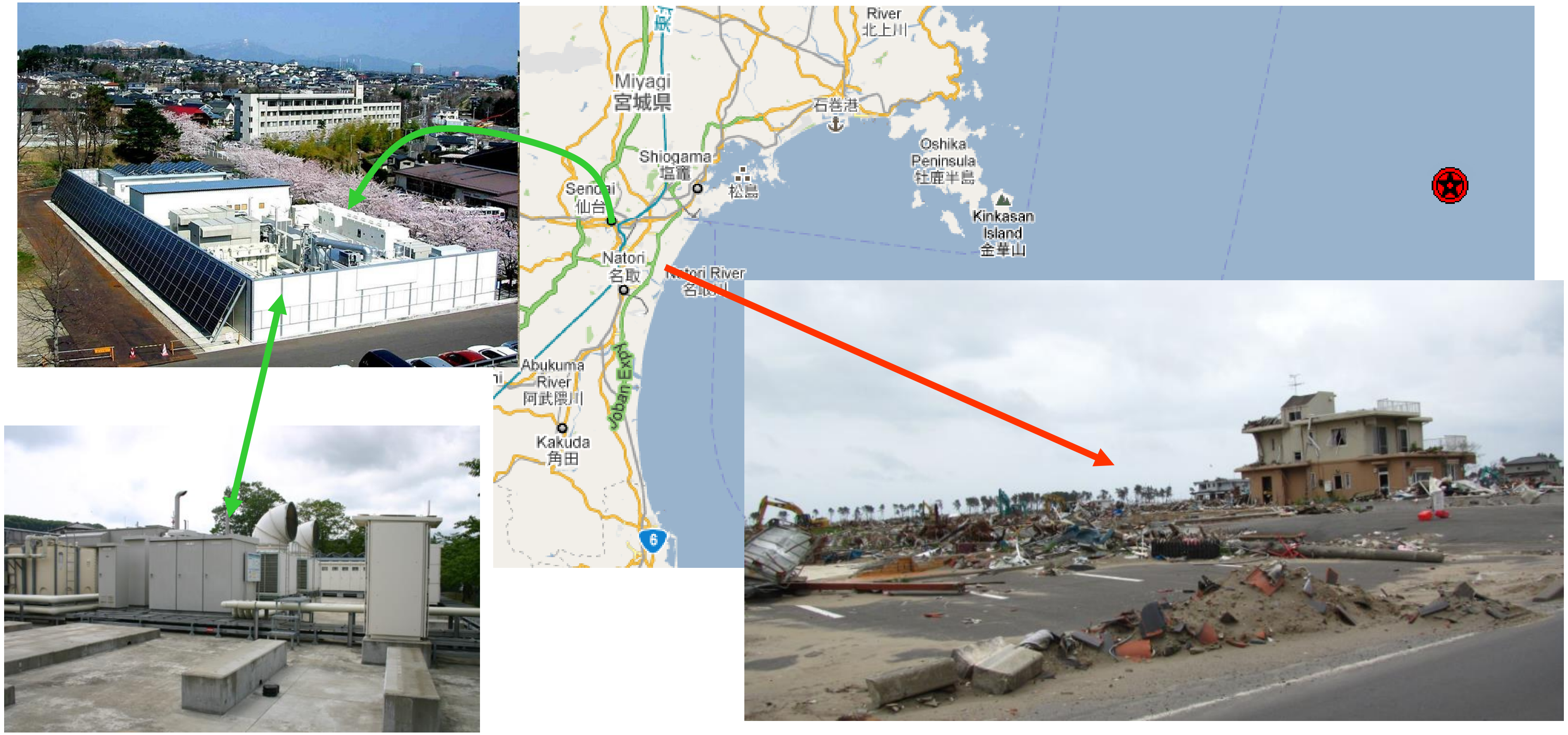
Loads
- Electronic loads.
- Plug-in hybrids.
- The main grid.

Power electronics interfaces
- dc-dc converters
- inverters
- rectifiers

Microgrid Examples

• Resilient power supply during disasters

• Power electronics-enabled microgrids may be the solution that achieves resilient power during disasters (e.g. NTT's microgrid in Sendai, Japan)



Microgrid Examples

• Isolated microgrids for villages in Alaska.
• Wind is used to supplement diesel generators (diesel is difficult and expensive to transport in Alaska

http://avec.securesites.net/images/communities/Toksook%20Wind%20Tower%20Bulk%20Fuel%20and%20Power%20Plant.JPG

- **Toksook Bay**
- Current Population: 590
- # of Consumers: 175
- Incorporation Type: 2nd Class City
- Total Generating Capacity (kw): 2,018
  - 1,618 kW diesel
  - 400 kW wind
  - (tieline to Tununak and Nightmute)

Information from "Alaska Village Electric Cooperative"

Microgrid Examples

- Other examples in Alaska

Selawik

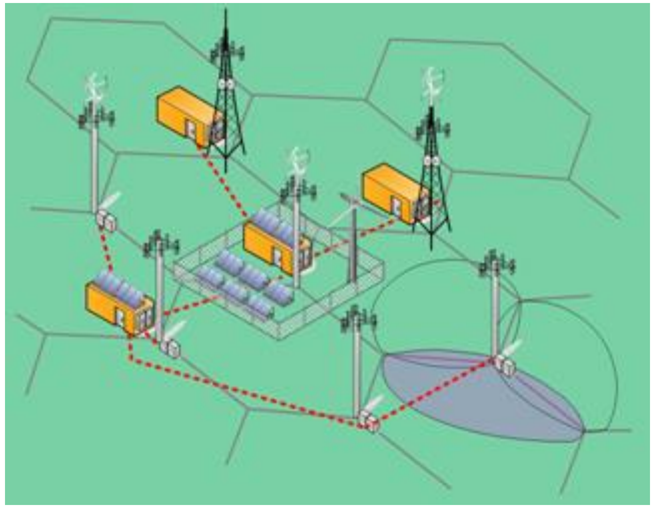
http://www.alaskapublic.org/2012/01/18/wind-power-in-alaska/

Kasigluk

http://www.akenergyauthority.org/programwindsystem.html

Microgrid Examples

• This is a proposed microgrid concept in order to use more renewable sources in wireless communication networks by creating so-called sustainable wireless areas.
• SWAs are dc (e.g. 380V) microgrids created by interconnecting a few (e.g. 7) base stations with, possibly, an advanced power distribution architecture.
• Renewable energy sources are placed in base stations or nearby locations where there is sufficient space.
• Resources (power generation and energy storage) are shared among all base stations within the SWA.
• Communications traffic and electric energy management is integrated. I.e., traffic is regulated (or shaped) based on local energy resources availability and forecast.



Microgrid Examples

- Kitakyushu smart community (Japan)
- The area has a few 3 kW wind generators.


Microgrid Examples

- Kitakyushu smart community (Japan)
- Hydrogen produced in the industrial area is distributed with a 1.2 km pipeline for
    - 7 x 3 kW Toshiba residential fuel cells,
    - 3 kW hydrogen station
    - 100 kW fuel cell at a museum.

Microgrid Examples

- Kitakyushu smart community (Japan)

- Residential fuel cells

Deodorant and flow meter

Fuel Cell

Hot water storage

Microgrid Examples

- Kitakyushu smart community (Japan)
- EV fast charging (and discharging) station + 50 kWh Li-ion batteries.

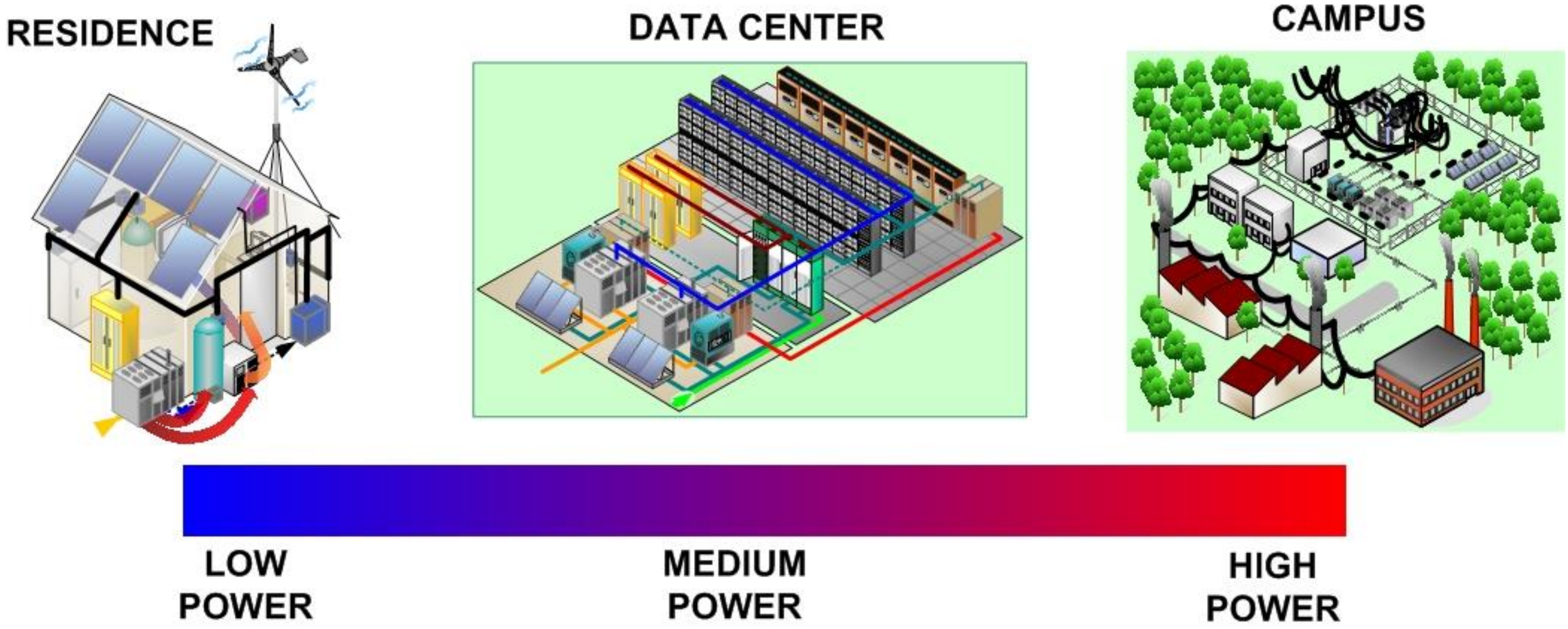
Microgrid Examples

- Kitakyushu smart community (Japan)

- 300 kWh Lead-acid batteries

Microgrids

- Application range:
  - From a few kW to MW



- Other applications: hospitals, military facilities, buildings, industrial complex.

Smart grids

Smart grids definition:

• Besides being the new buzz word is not a concept but rather many technologies.

Smart grid focus:

• Reliability.

• Integration of environmentally friendly generation and loads.

Concept evolution:

• “Smart grid 1.0”: Smart meters, limited advanced communications, limited intelligent loads and operation (e.g. demand response).

• “Smart grid 2.0” or “Energy Internet”: Distributed generation and storage, intelligent loads, advanced controls and monitoring.

Smart Grids

• A customer-centric view of a power grid includes microgrids as one of several smart grids technologies.