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Electric Power Grids Performance under Environmental Hazards

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Overview

- Power Grids as a critical part of nations' critical energy infrastructure supporting society's fundamental functions and services including defense
  - Vulnerabilities
  - Performance during natural disasters
  - Proposed technological solutions
  - Conclusions

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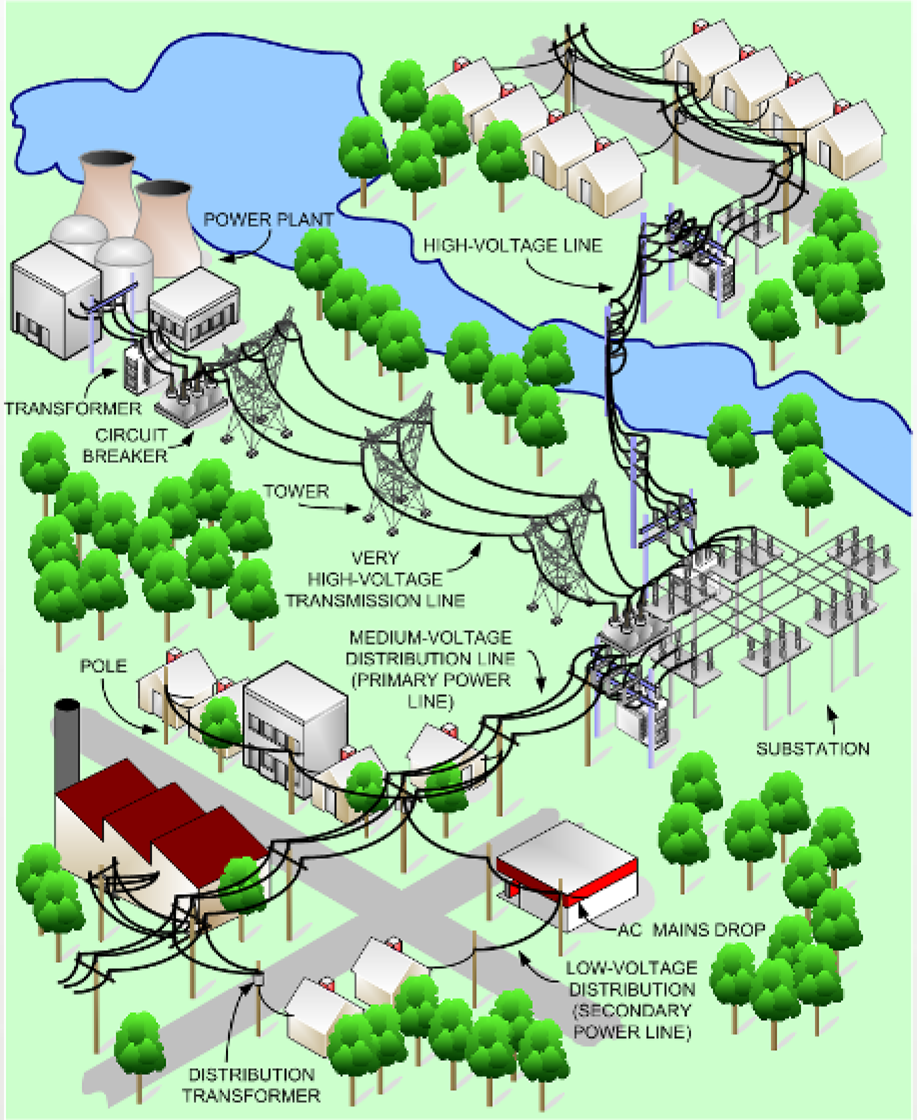
Issues in Conventional Power Grids

• **Weaknesses**

- Centralized architecture and control.
- Passive transmission and distribution.
- Very extensive network (long paths and many components).
- Lack of diversity.
- Need for continuous balance of generation and demand.
- Difficulties in integrating meaningful levels of electric energy storage.
- Stability and power quality issues when integrating renewable energy sources.
- Difficulties in integrating new loads
- "Old" components



• **Traditional grid availability:**
Is "up" approximately 99.9 % of the time (not enough for critical loads)

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Military Perspective

• Armies are more dependent on reliable power for critical electric loads

• Military bases around the world depend on conventional power grids for power. Thus, they are subject to the same power grid vulnerabilities than civilians.

• Increased worldwide use of armies for disaster relief in multinational forces. Such use may contribute to pacification of some areas (e.g. Free Aceh Movement after the 2004 tsunami) or contribute to save many lives (e.g. Haiti, 2010).

• There exist reciprocal needs and knowledge between military and civilian responses to attacks and natural disasters, respectively.

Power grids performance during natural disasters

- Natural disasters as real test-beds to evaluate power grids vulnerabilities
- Some relevant recent hurricanes: Katrina, Gustav, Ike, Irene (2011), and Isaac (2012).
- All of these hurricanes caused at least one million power outages.
- Power outages extended over large areas and lasted from several days to weeks.
- Extensive damage was mainly observed in part of the areas affected by the storm surge.
- Noticeable short and long-term drop in power demand with Katrina and Ike.

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Power grids performance during natural disasters

- Natural disasters as real test-beds to evaluate power grids vulnerabilities
- Some relevant recent earthquakes: Chile (2010), Christchurch (2/2011), and Japan (3/2011).
- Power outages extended over large areas.
- Noticeable short and long-term drop in power demand
- Except in Japan, power generation issues were minor.
- Issues in New Zealand with soil liquefaction.
- In all of these events strong shaking damaged some substation components.

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• Additional lessons from Japan's earthquake and tsunami.

• Natural disasters are not single events. They are complex events with 4 distinct phases: pre-disaster, during the disaster, immediate aftermath and long-term aftermath.

Onagawa nuclear power plant: Offline since the earthquake. Currently, almost all nuclear power plants in Japan are offline

• As a result of Fukushima #1 Nuclear Power plant event electric power utilization in Japan has been affected, particularly during the summer when rotating outages are likely. Public opinion has created pressure to discontinue the use of nuclear power in Europe, Japan and the US.

• In all these countries and regions wind power is seen as an important alternative to nuclear power.

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Planning for disaster resistance – Risk Assessments

- What is the optimum level of protection?
    - Tool: Risk Assessment… But human perception is biased towards impact, and demand drop affects risk equation.
    - Unknowns: disaster intensity vs. damage to power grids

Onagawa nuclear power plant

Otsuchi. Was it a “sufficient” level of protection?

Chubu Electric argues that 18-meter wall can beat 23-meter tsunami

September 22, 2012

By RYO TAKANO/ Staff Writer

Officials of Chubu Electric Power Co. are arguing in court that an 18-meter high breakwater wall now being constructed at its Hamaoka nuclear power plant would be sufficient to withstand even a 23-meter high tsunami.

That's even exceeding the 19-meter height experts have said a massive tsunami could reach in Omaezaki, Shizuoka Prefecture, where the plant is located.

Previous Article: Atomic engineers feel less confident about nuke safety

Next Article: Safety first, but retain nuclear power, says new watchdog chief

The Asahi Shimbun | AJW

• Natural disaster intensity vs. impact on power grids (research needs)

• There is an observed mismatch between hurricane intensity measured with the Saffir-Simpson scale and impact on power grids. Possible causes:

- More population
- Power grids are extended over larger areas
- More interdependent infrastructures
- Intrinsic characteristics of the storms (larger storm surges, more intense rains, larger area) that are not correlating as well as expected with respect to maximum sustained wind speeds. Relationship with climate change is unknown.

• Similar mismatches between intensity and damage is observed in earthquakes (see supplemental slides).

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Power grids performance during natural disasters

• Effects of natural disasters on oil and natural gas infrastructure

• Natural disasters affect oil and natural gas production, processing and distribution both directly and indirectly.

• It takes several days in order to restart a refinery after a power outage.

• Limited fuel supply after a disaster may, in turn, affect restoration process of other critical infrastructures (e.g. communications).

Direct effect

Indirect effect

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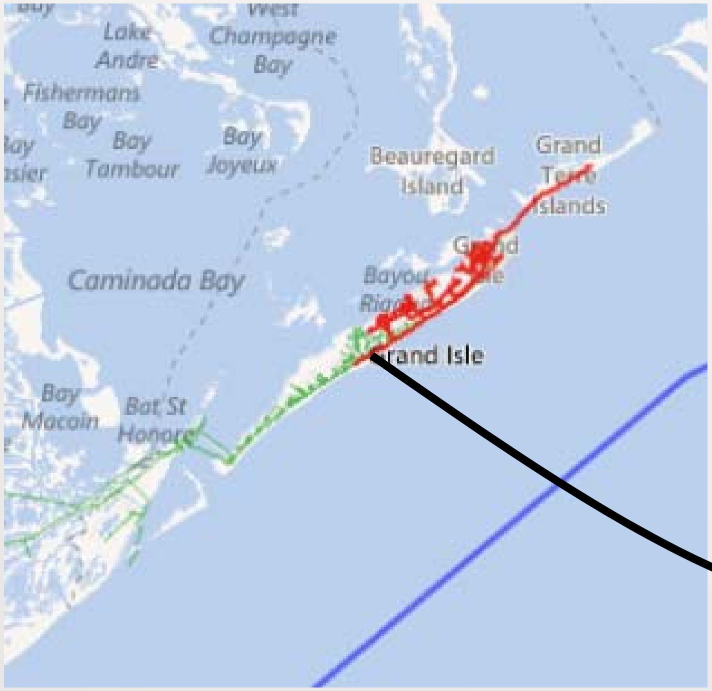
Power grids performance during natural disasters

- **Practical observations after disasters - vulnerabilities**
- Sub-transmission and distribution portions of the grid lack redundancy

- **Practical observations after disasters - Vulnerabilities**
- **E.g. Hurricane Isaac**
  - Severe damage is limited to relatively small areas.
  - Only one damaged pole among many undamaged causing most of the island to loose power.



Grand Isle, about 1 week after the hurricane

Entergy Louisiana

•I.e., an attack to a single pole miles away from a military outpost may interrupt its power supply.

Power grids performance during natural disasters

- **Key observation that leads to microgrid-based solutions:**
- During disasters damage distribution is inhomogeneous

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Technical Solutions

- Proposed solutions

- Solutions domain:
  - Utility (e.g. mobile transformers, ADA): limited effectiveness
  - Users (e.g. microgrids): may be more flexible
- Users solutions:
  - Microgrids
  - Standby systems

Fuel cell-based microgrid in Garden City, NY after Hurricane Irene

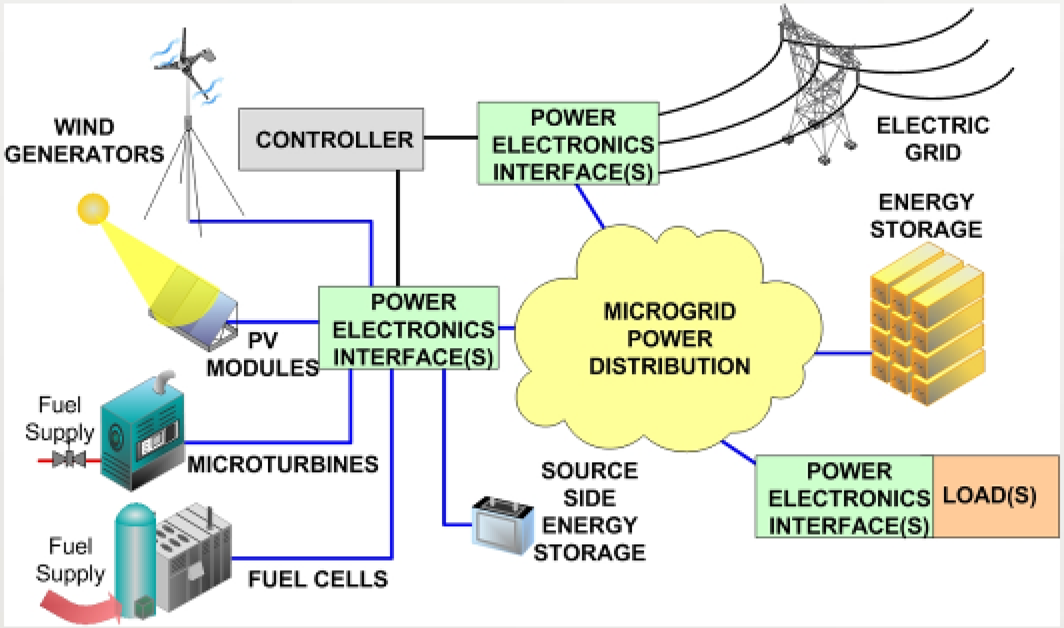
Cell site with a standby diesel genset after Hurricane Ike

Technical Solutions

• Solutions: microgrids

• 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



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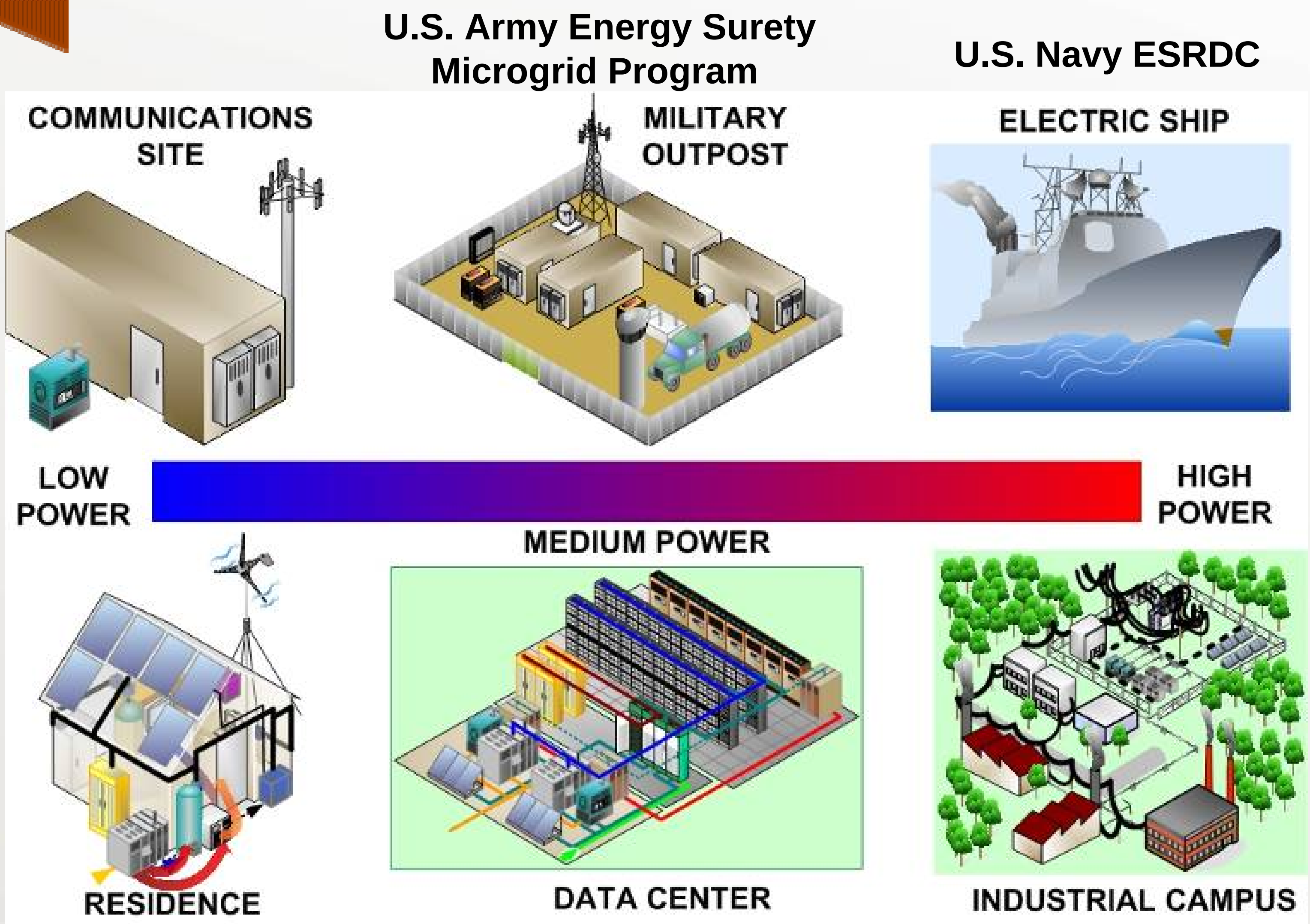
Microgrids

- Applications range for microgrids



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Technical Solutions

- Solutions: microgrids
- Lifelines and energy storage

- Most local generators depend on other infrastructures, called lifelines (e.g. natural gas distribution networks or roads) to receive energy
- But lifelines can be affected by the natural disaster like conventional grids.

- Military applications: lifelines are vulnerabilities (supply lines). Risk?
- Approaches to address lifeline dependencies:
  - Diverse power source technologies
  - Local Energy Storage

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Technical Solutions

- Lifeline dependency. E.g. Hurricane Isaac

- Electric service interruption

Port Sulfur, Oct. 2010

- Frontline: Communication roads interrupted = Flooded roads made impossible to deliver fuel for permanent diesel gensets

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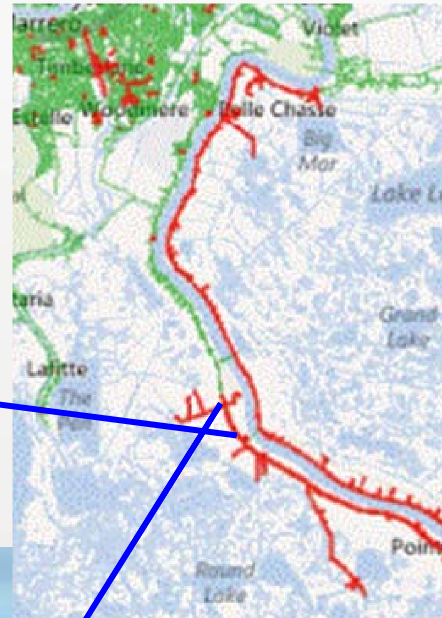
Technical Solutions

• Lifeline dependency and restoration logistics. E.g. Hurricane Isaac



• Fuel supply close to the "frontline"

Port Sulfur, Oct. 2010

• Staging area: Army of electric utilities' trucks being concentrated 1 mile behind the "frontline"

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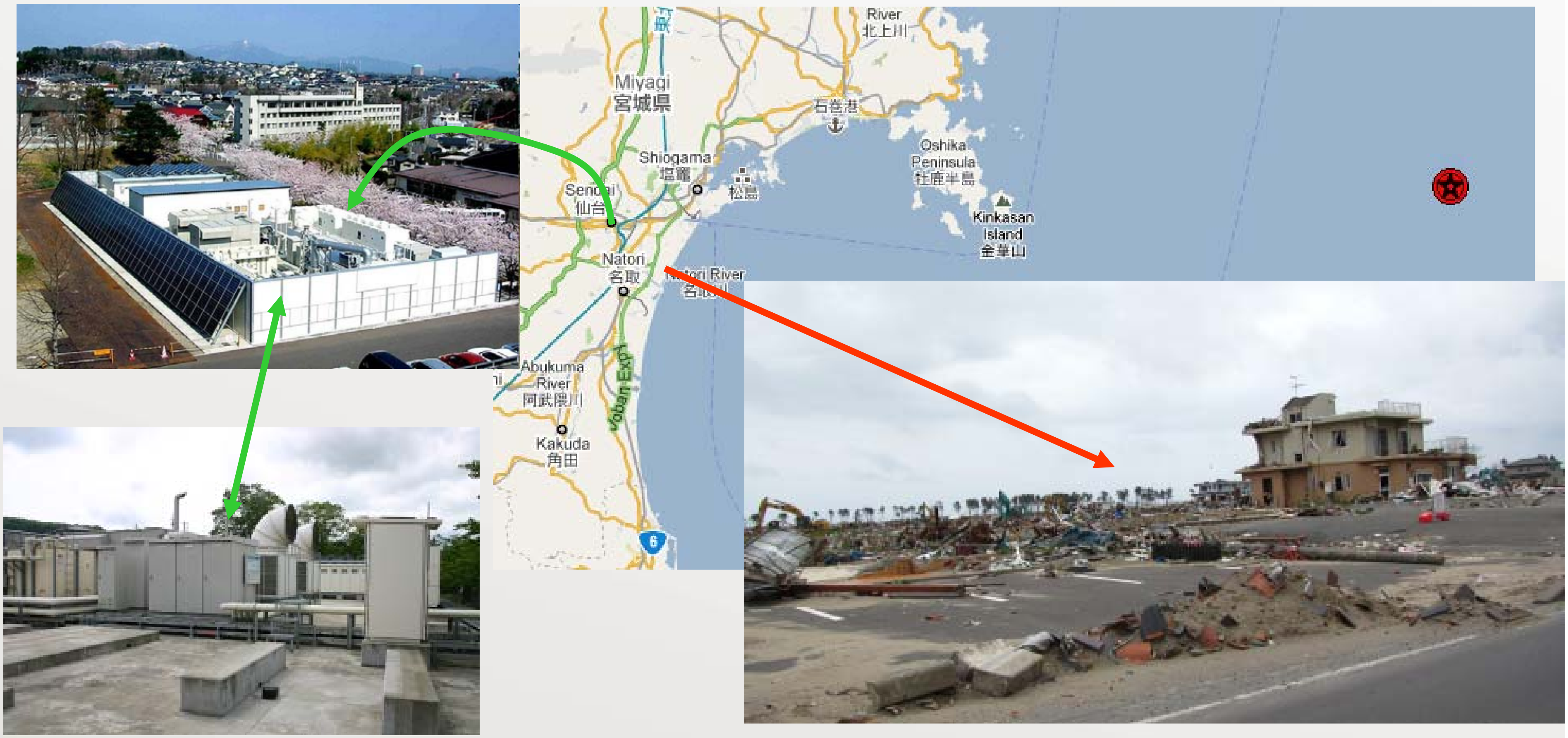
Technical Solutions

- Use of microgrids to power sites after disasters

•Power electronic-enabled micro-grids may be the solution that achieves reliable power during disasters (e.g. NTT's micro-grid in Sendai, Japan)



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Technical Solutions

• Lessons from the operation of NTT-Facilities/NEDO microgrid in Sendai.

• Local energy storage in batteries were a key asset to keep at least the most critical circuit operating.

• PV power only played a complementary role.

• Natural gas supply did not fail thanks to an almost exclusive design for the distribution pipelines for this site.

• Flexible remote operation is very important during extreme events conditions.

• Connection of generators or their components through ac buses seem to increase failure to start probability.

• Source diversification is important.

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Technical Solutions

• Photovoltaic (PV) systems

- Most renewable energy sources do not require lifelines, but…..
- Issues with PV systems: large footprints. Solution:
  - Size PV arrays for less of the required load and use it to support another power source rated at full capacity.
- Renewable energy sources have, typically, variable output. Solutions:
  - Local energy storage (e.g. batteries)
  - Source diversification

50 kW
PV array

2x350 kW
natural gas
generators

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Conclusions

- Final thoughts

- Power grids has been experiencing significant power outages in recent disasters, some of these disasters were of moderate intensity.
- Hurricanes show that conventional power grids—one of the basis of modern societies and necessary to support security and defense functions—are extremely fragile systems.
- Effects of natural disasters on power grids may last years and affect all energy infrastructures
- Planning based on risk assessment approaches present issues. Nuclear power future may be dependent on these issues.
- Local power solutions have been proposed. However, they present issues:
    - Lifelines are required to fuel non-renewable energy sources.
    - Renewable energy sources have large footprints and variable output
- International cooperation boost learning processes

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Conclusions

- Final thoughts – some NATO roles

- Research support:
  - Improved microgrids design, planning and operation.
  - Environmental risk assessment as a security threat, including disasters characterization
  - Infrastructure (computing resources, operational data).

- Disaster relief support
  - Provide experience in coordinating multinational forces
  - Provide experience in logistical operations to shorten restoration times

Thank you very much

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Supplemental slides

• Topics

• Practical observations after natural disasters

• Research needs in microgrids

• Cascade failures with interdependent infrastructures after natural disasters

• Performance of the NTT/NEDO Microgrid in Sendai after the March 11, 2011 earthquake and tsunami.

• Economic development and power grids

• Technical solutions: residential PV systems

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• **Practical observations after disasters**

• Severe damage is limited to relatively small areas.

< 10 % of the affected area

> 90 % of the affected area

• Bolivar Peninsula after Hurricane Ike

vs.

• Baton Rouge, Louisiana, after Hurricane Gustav

(only 1 pole damaged among many undamaged)

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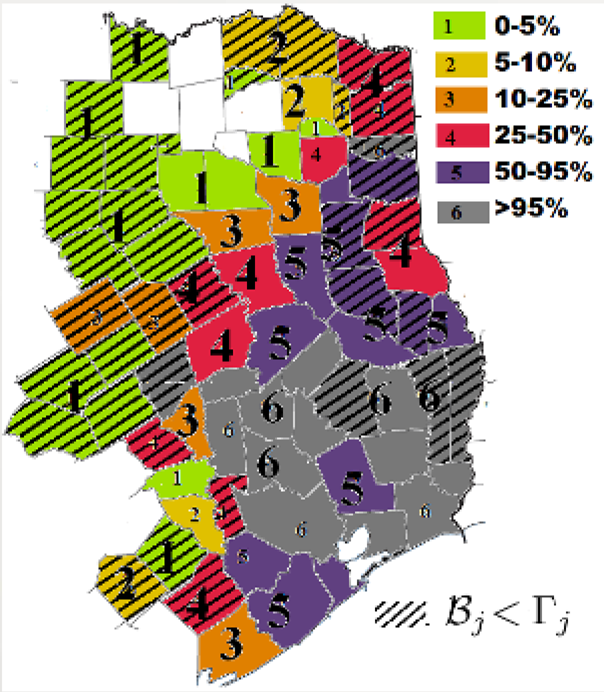
• Practical observations after disasters

• Most of the area affected by a large disaster shows little damage to the power grid, yet, power outages are significant and long.



Cat. 2 Hurricane Ike

Photo courtesy of NOAA

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• Natural disaster intensity vs. impact on power grids

• Of all discussed relevant recent hurricanes (Katrina, Dolly (2008), Gustav, Ike, Irene (2011), and Isaac (2012)) only Katrina was a major hurricane when making landfall.

- Katrina was a cat. 3 at landfall but only cat. 1 in New Orleans.
- Gustav (cat. 2) caused more outages in Louisiana than Katrina (cat. 3). About 1,200K for Gustav vs. about 900K for Katrina.
- Ike's outages extended from Texas to the Ohio River Valley.
- Irene was mostly a tropical storm, yet it caused about 6M power outages.

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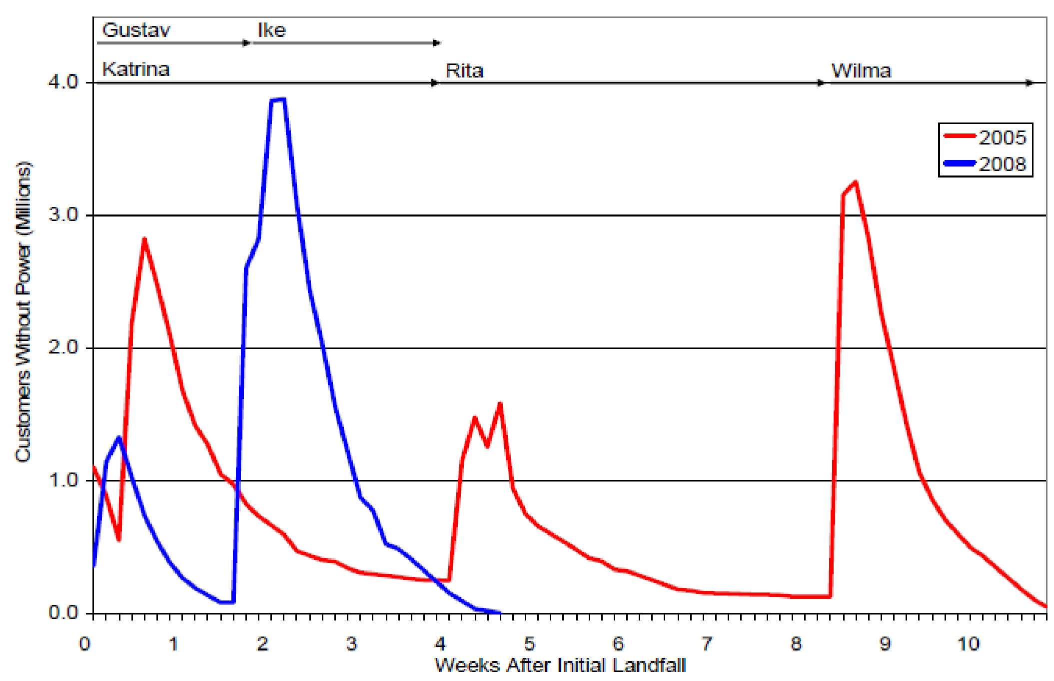
Power grids performance during natural disasters

• Natural disaster intensity vs. impact on power grids

• Of all discussed relevant recent hurricanes (Katrina, Dolly (2008), Gustav, Ike, Irene (2011), and Isaac (2012)) only Katrina was a major hurricane when making landfall.

- Ike was a cat. 2 storm, yet…..



Source: OE/ISER Situation Reports.

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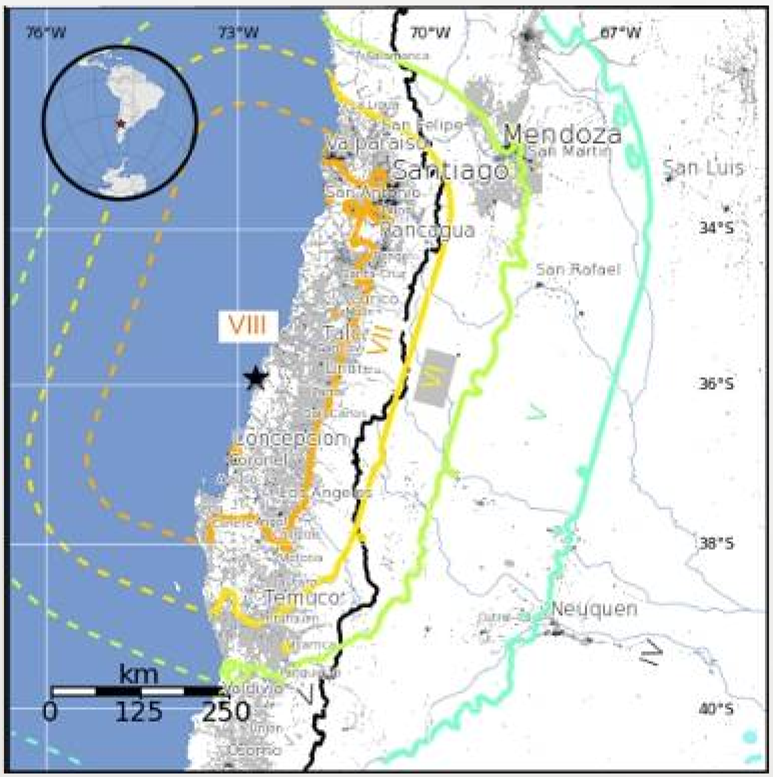
- **Mismatches between earthquake intensity and power grid damage**
- E.g. Earthquake in Chile of February 2010



Earthquake intensity (MMI)

Predominant cell sites condition after Katrina

Microgrids

- Some research topics

- Control for stable operation (contrary to conventional power grids, individual loads ratings are a significant portion of the power generation capacity).
- Power electronics for integration of diverse power sources and energy storage.
- Optimal system control.
- Autonomous controllers.
- Planning
- Grid interconnection and coordinated operation

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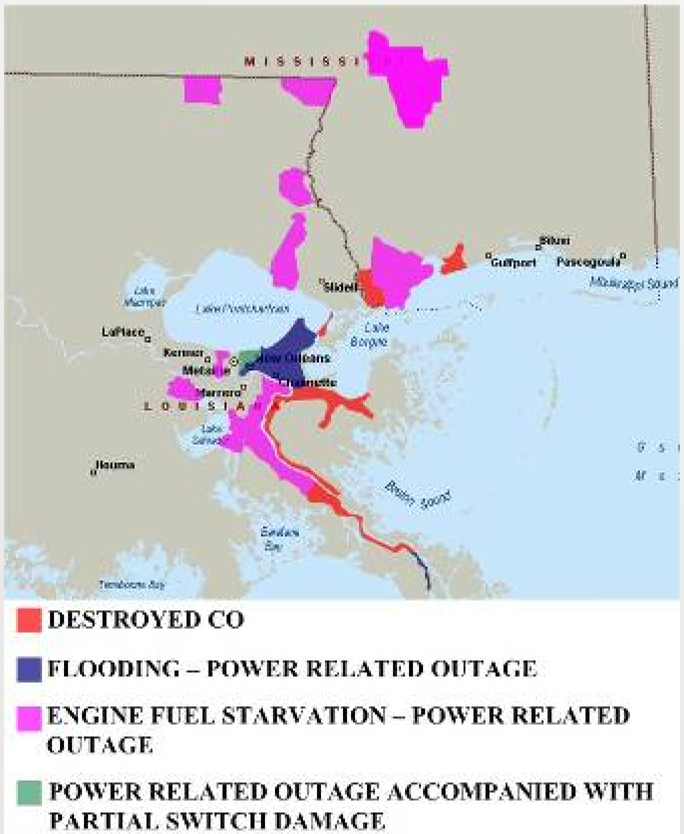
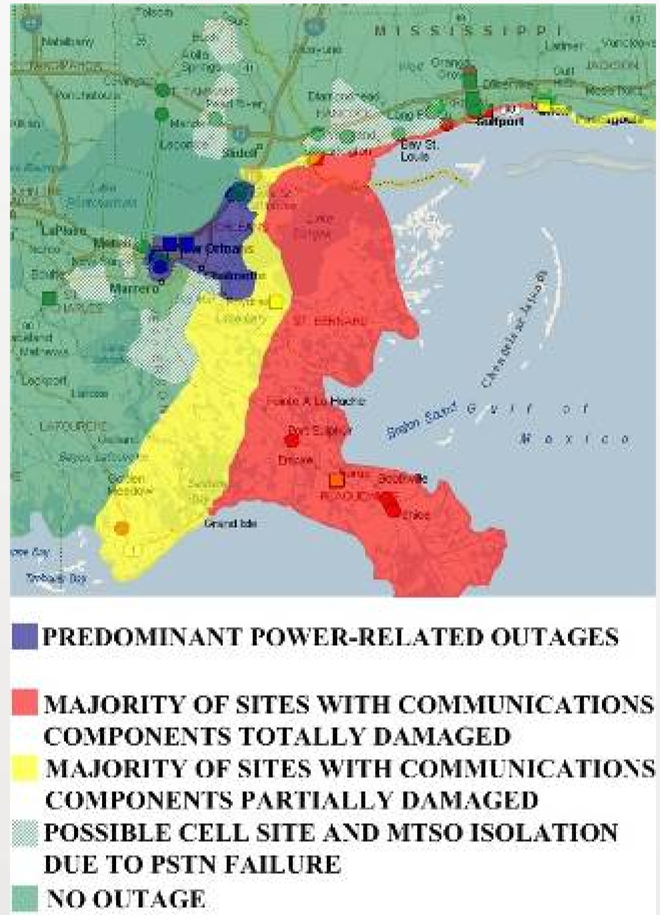
Power grids performance during natural disasters

- **Cascading failures**

- Power outages is one of the main causes of communication sites failures. E.g. Hurricane Katrina



Outage cause (PSTN)



Predominant cell sites condition after Katrina

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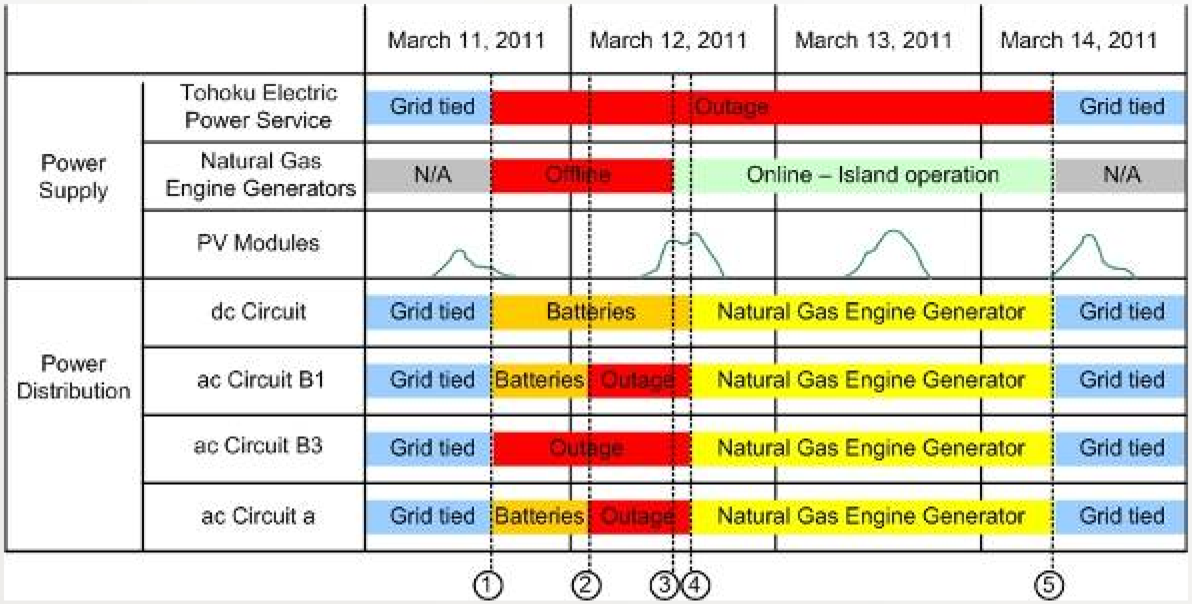
NTT/NEDO Sendai Microgrid

- **Operation of NTT-Facilities/NEDO microgrid in Sendai after the March 11, 2011 earthquake and tsunami**



2x350 kW

50 kW

- 1) Earthquake happens. Natural gas generators fail to start.
- 2) Manual disconnection of all operating circuits except the dc one
- 3) and 4) Natural gas generators are brought back into service by maintenance personnel. A few minutes later, the circuits that were intentionally disconnected are powered again.
- 5) Power supply from the main grid is restored.

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NTT/NEDO Sendai Microgrid

• **Operation of NTT-Facilities/NEDO microgrid in Sendai after the March 11, 2011 earthquake and tsunami**

• Natural gas infrastructure in Sendai: contrary to most of the city that relied on natural gas supply from a damaged facility in the port, the microgrid natural gas was stored inland and was not damaged.

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Technical Solutions

• The same solutions that are sought for improving power supply availability during disasters can be used to support economic development anywhere in the world.

• Distributed generation may support economic development.
• E.g. Isolated microgrids for villages in Alaska where wind power is used to supplement diesel generators (diesel is difficult to transport in Alaska)
• The same idea of using renewable energy sources to supplement conventional sources could be used in order to address footprint issues with PV power generation, particularly after disasters.

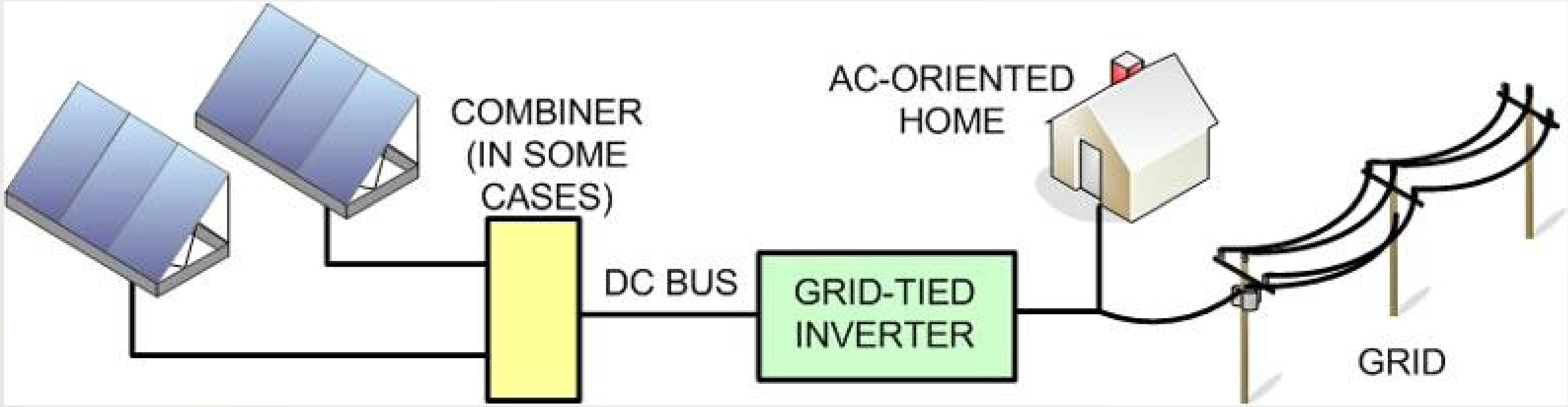
- **Toksook Bay**
- Current Population: 590
- # of Consumers: 175
- Total Generating Capacity (kw): 2,018
  - 1,618 kW diesel
  - 400 kW wind
  - (tieline to Tununak and Nightmute)

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

Technical Solutions

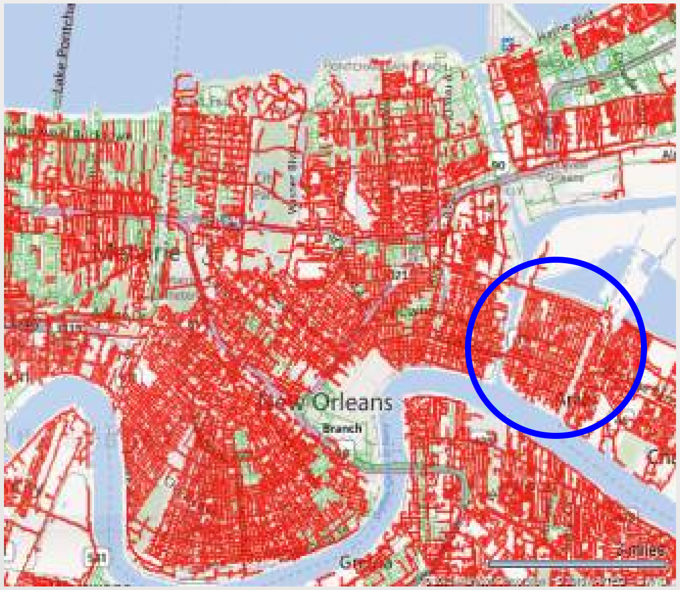
- Residential grid-tied PV systems

- Conventional grid-tied system (utility centered) are not a microgrid.
- Most widely used PV integration approach.
- PV and home operation subject to grid operation: Due to IEEE Standard 1547, the inverter cannot power the home when the grid is not present.



Technical Solutions

- Solutions: distributed generation (PV systems)
- E.g. Lower 9th Ward 4 days after Hurricane Isaac. The sun is shinning but no grid = = no power even with PV arrays.



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