THE UNIVERSITY OF TEXAS AT AUSTIN

THE UNIVERSITY OF TEXAS AT AUSTIN UT ECE ELECTRICAL & COMPUTER ENGINEERING

Electric Power Grids Performance under Extreme Weather Events

A. Kwasinski and V. Krishnamurthy

The University of Texas at Austin

Overview

- Power Grids Vulnerabilities

- Performance during hurricanes

- Adaptation: proposed technological solutions

- Conclusions

Issues in Conventional Power Grids

• **Availability**

Conventional grids weaknesses:

• Centralized architecture and control.

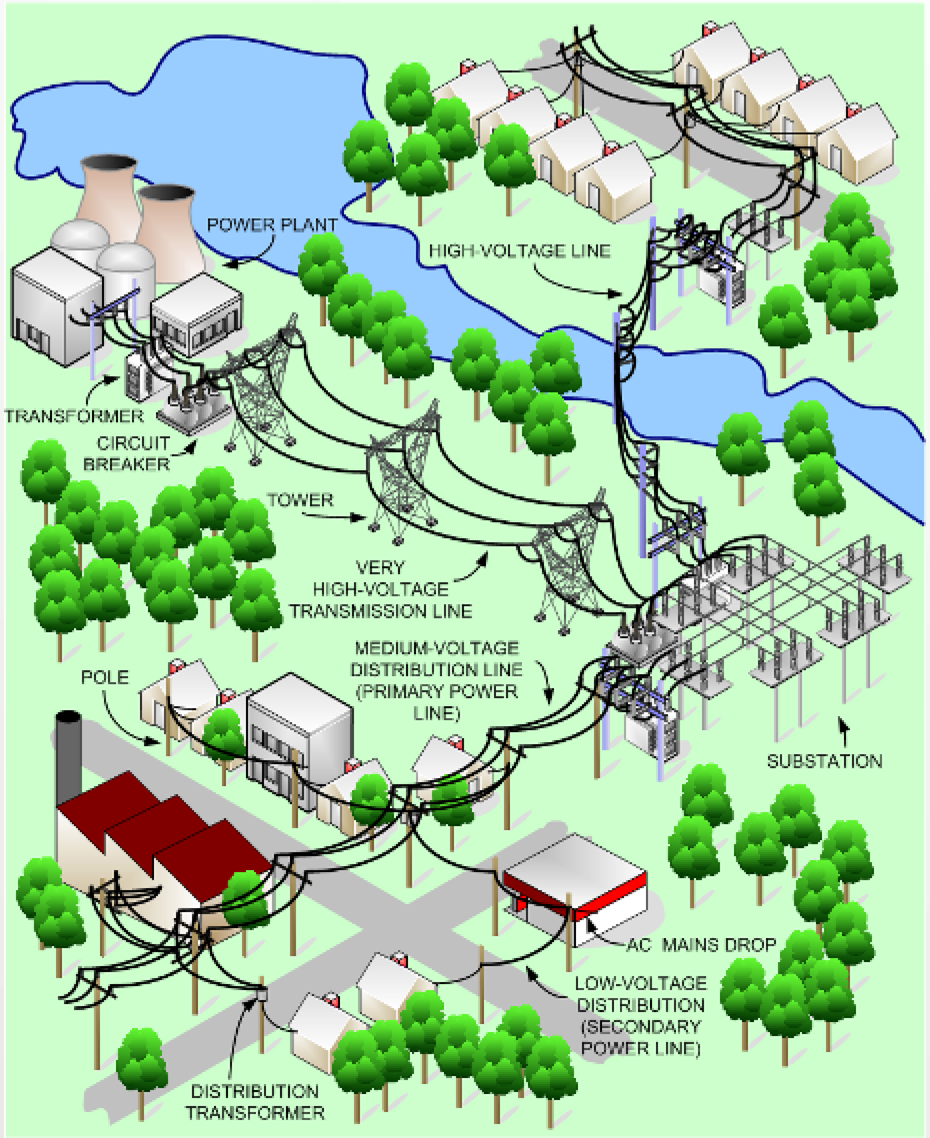
• Passive transmission and distribution.

• Very extensive network (long paths and many components).

• Lack of diversity.

• **Traditional grid availability:**
Is "up" approximately 99.9 % of the time

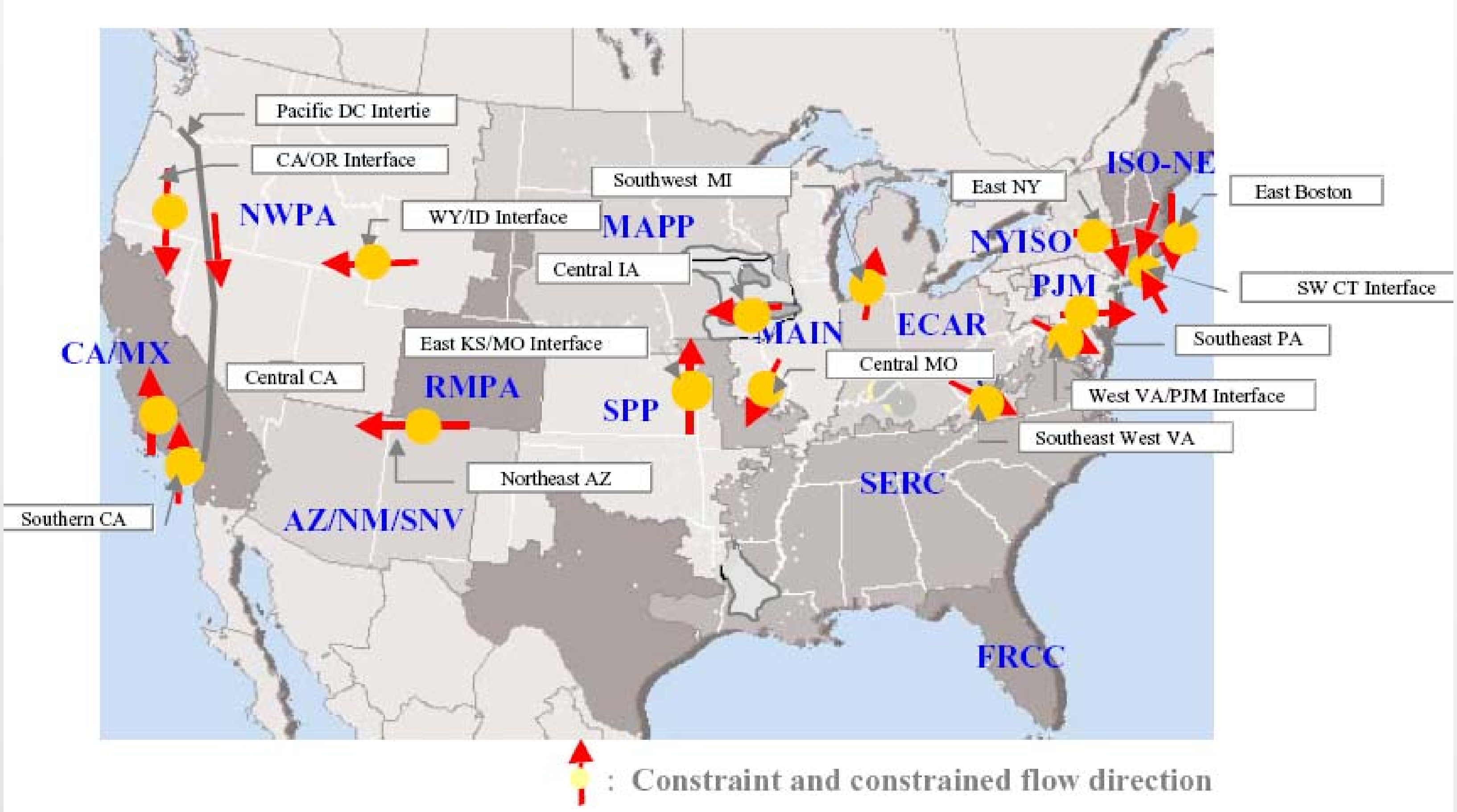
• **Availability required in critical applications:**
"Up" approximately 99.999% of the time



Issues in Conventional Power Grids

- **Availability issues**

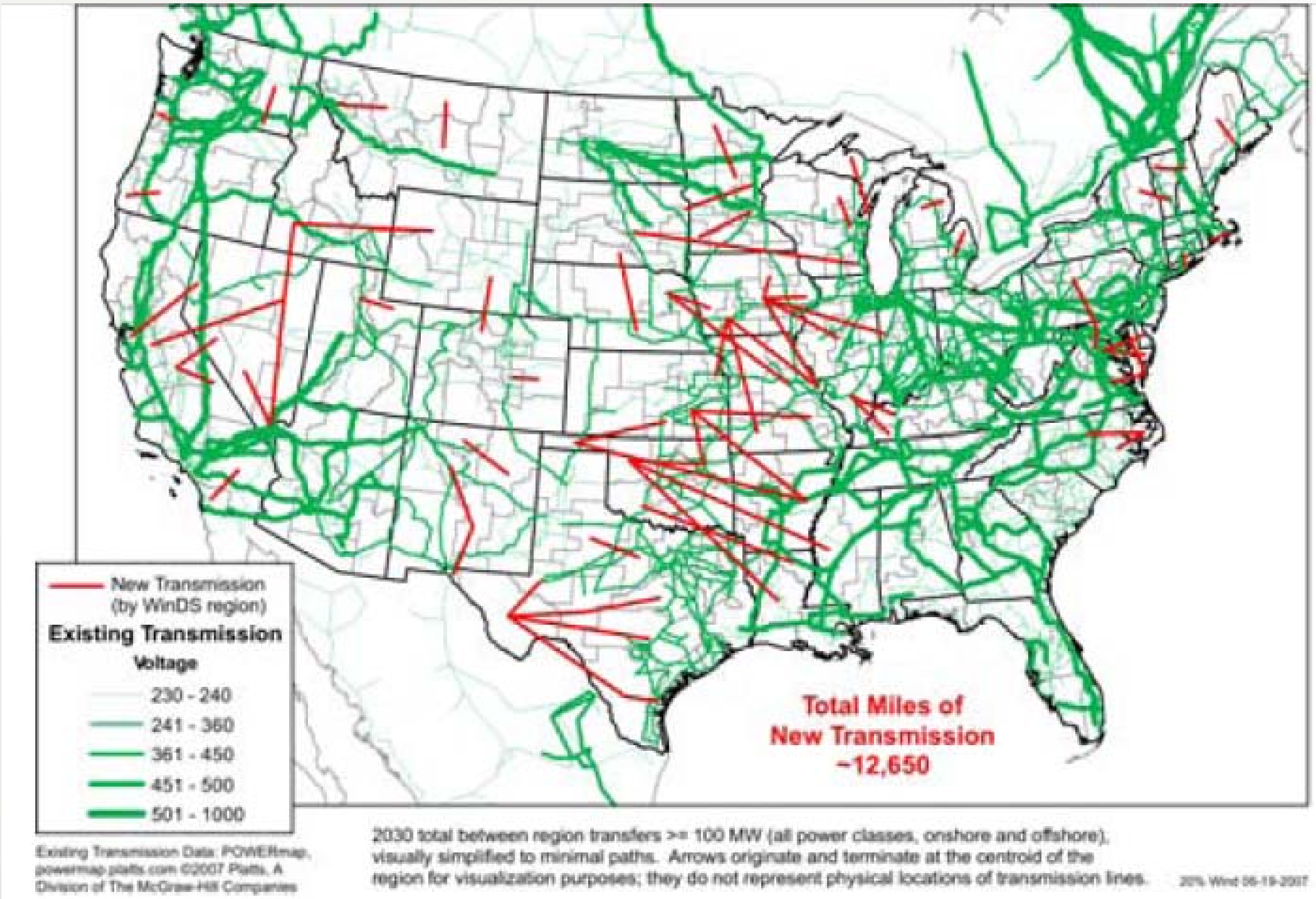
- Non-seasonal transmission congestion points.



www.ferc.gov/industries/electric/gen-info/transmission-grid.pdf

Issues in Conventional Power Grids

- **Security**
- **Long transmission lines are easy targets for both intentional and unintentional attacks.**



U.S. DOE OEERE "20% of Wind Energy by 2030."

Issues in Conventional Power Grids

• **Operation and additional issues - Flexibility**

• Centralized integration of renewable energy may create generation profile unbalances that may create stability and other issues.

• Complicated stability control as more intermittent renewable energy sources are added.

• New loads (electric vehicles, dc loads) create power quality issues.

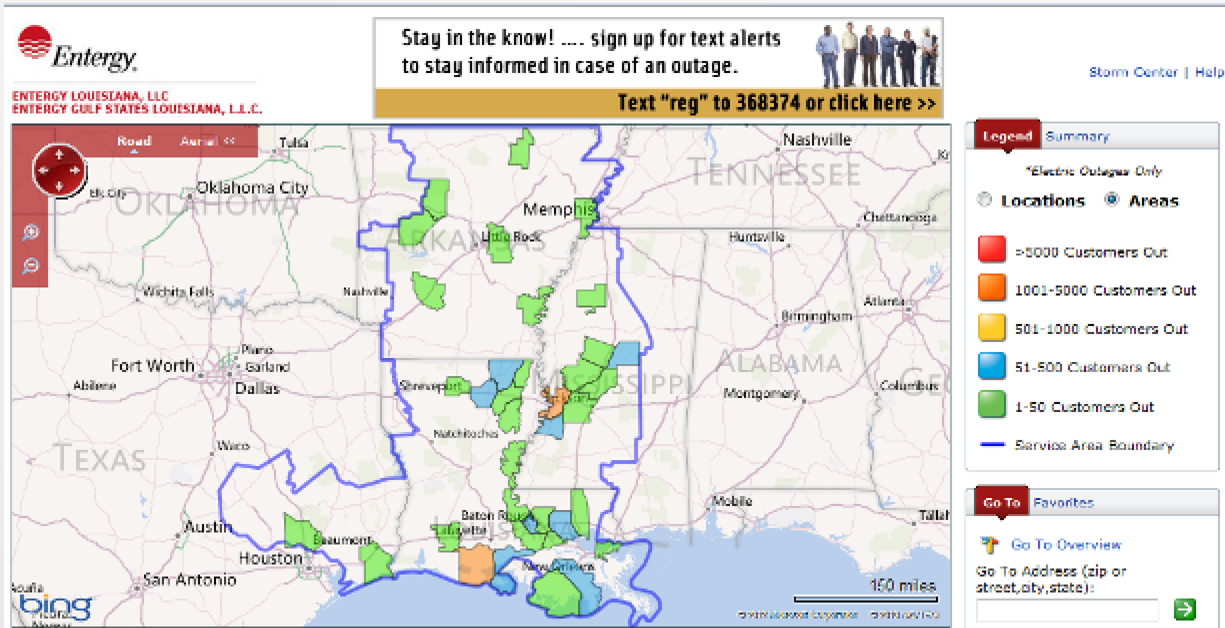
• Generation and consumption need to be continuously balanced. Energy cannot be stored in the grid, except in relatively small amounts.

• The grid's transmission and distribution portions lack operational flexibility because they are passive networks.

• The grid is old: it has the same 1880s structure. Power plants average age is > 30 years. Other components have been installed in average for over 40 years.

Issues in Conventional Power Grids

- **Power outages**



•The described weaknesses are prevalent throughout the grid. Hence, power outages are not too uncommon (they can happen even when there are no disasters).

Performance during Hurricanes

- 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.

Performance during Hurricanes

• Impact of recent hurricanes on electric power infrastructure

• 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.

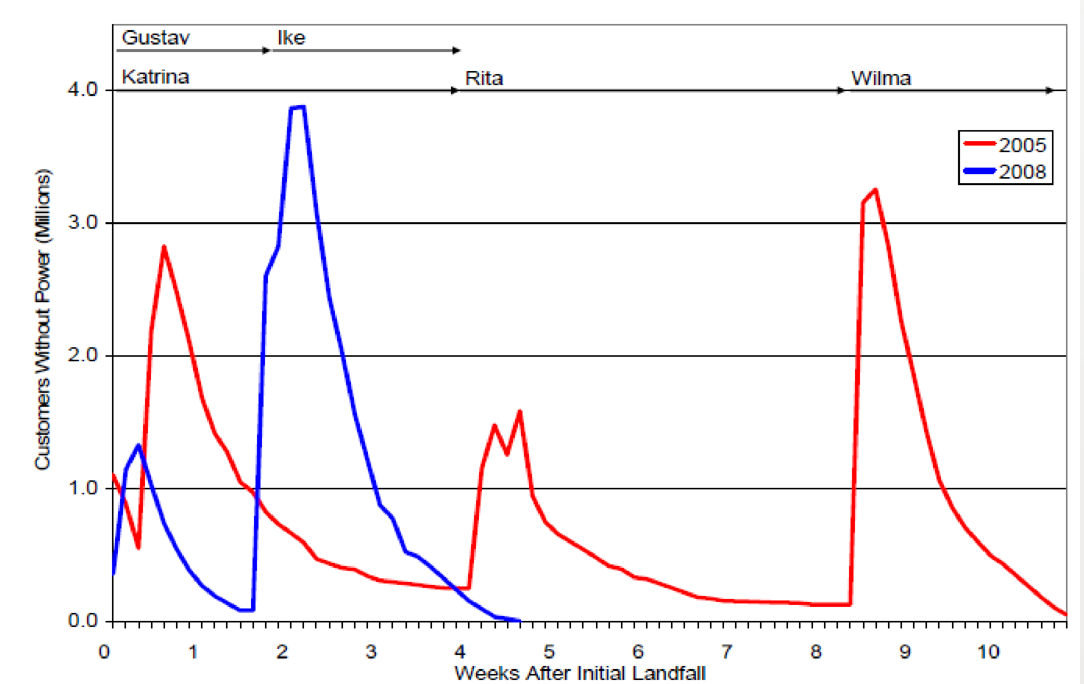
- Katrina was a cat. 3 at landfall but only cat. 1 in New Orleans.
- Gustav (cat. 2) caused more outages in Louisiana than Katrina (cat. 3). About 1,200K for Gustav vs. about 900K for Katrina.
- Ike's outages extended from Texas to the Ohio River Valley.
- Irene was mostly a tropical storm, yet it caused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

Performance during Hurricanes

• Impact of recent hurricanes on electric power infrastructure

• 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.

Performance during Hurricanes

• Impact of recent hurricanes on electric power infrastructure

• Possible causes of mismatch between hurricane intensity measured on the Saffir-Simpson scale and impact on power grids:

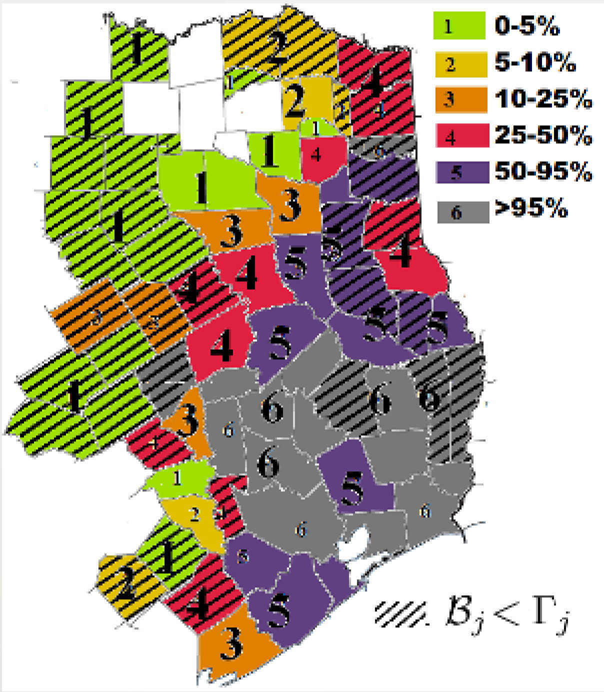
- More population
- Power grids are extended over larger areas
- More interdependent infrastructure
- Intrinsic characteristics of the storms (larger storm surges, more intense rains, larger area) that are not correlating as well as expected with respect to maximum sustained wind speeds.

Performance during Hurricanes

- **Availability during natural disasters**

Photo courtesy of NOAA

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



THE UNIVERSITY OF TEXAS AT AUSTIN

Performance during Hurricanes

- **Availability during natural disasters**

  - Severe damage is limited to relatively small areas.

< 10 % of the affected area

- Bolivar Peninsula after Hurricane Ike

> 90 % of the affected area

vs.

- Baton Rouge, Louisiana, after Hurricane Gustav

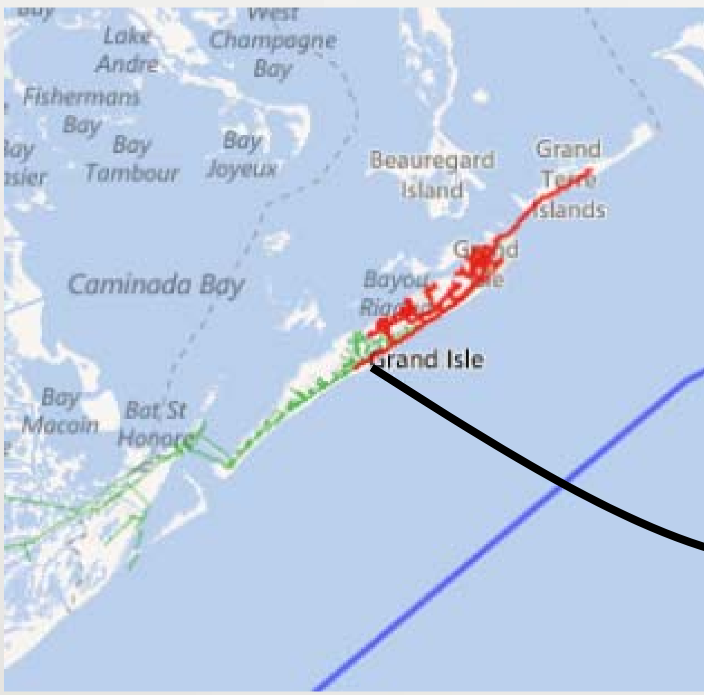
(only 1 pole damaged among many undamaged)

THE UNIVERSITY OF TEXAS AT AUSTIN UT ECE ELECTRICAL & COMPUTER ENGINEERING

Performance during Hurricanes

- **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

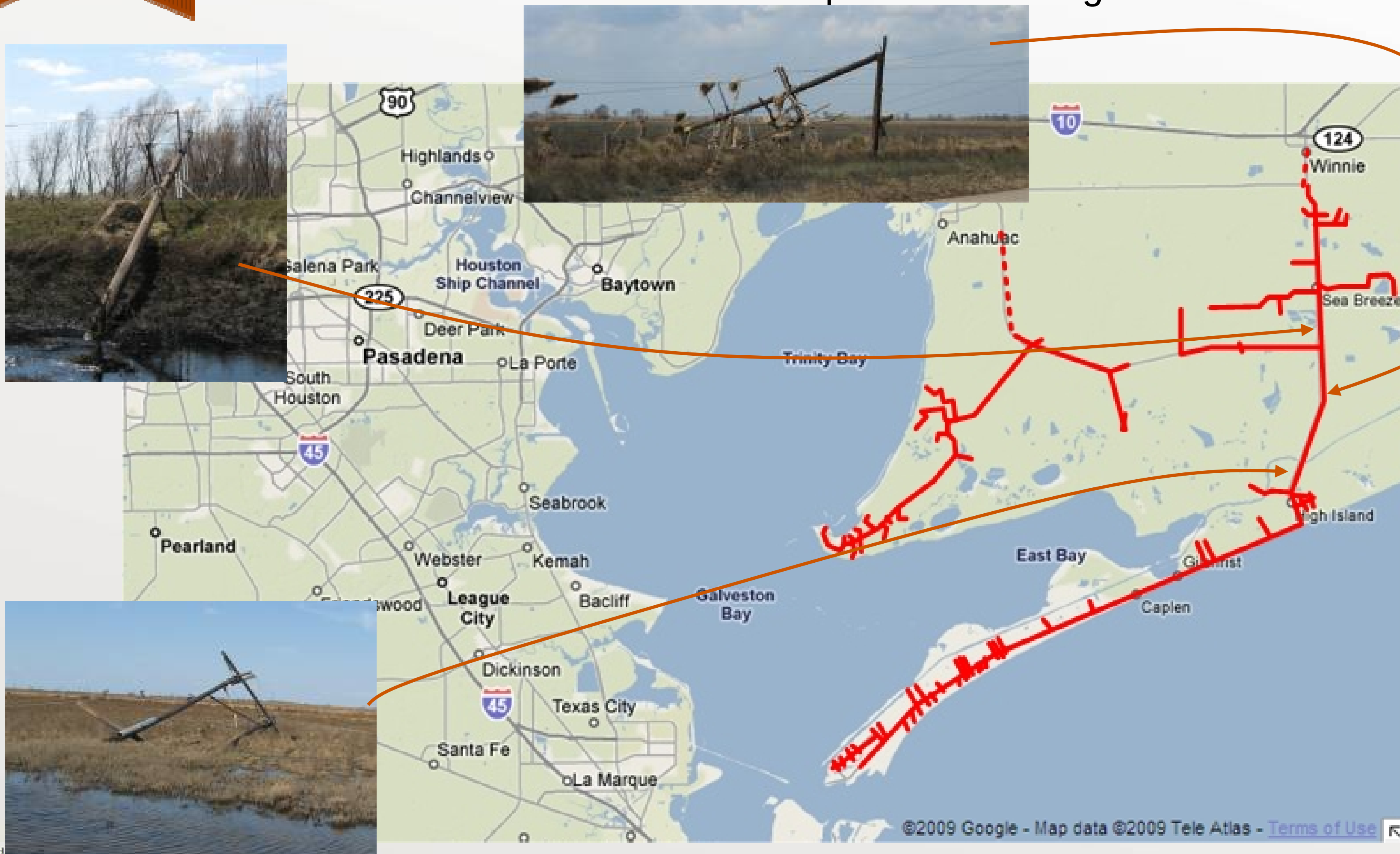
Entergy Louisiana

Performance during Hurricanes

- **Availability observations**
- During disasters damage distribution is inhomogeneous

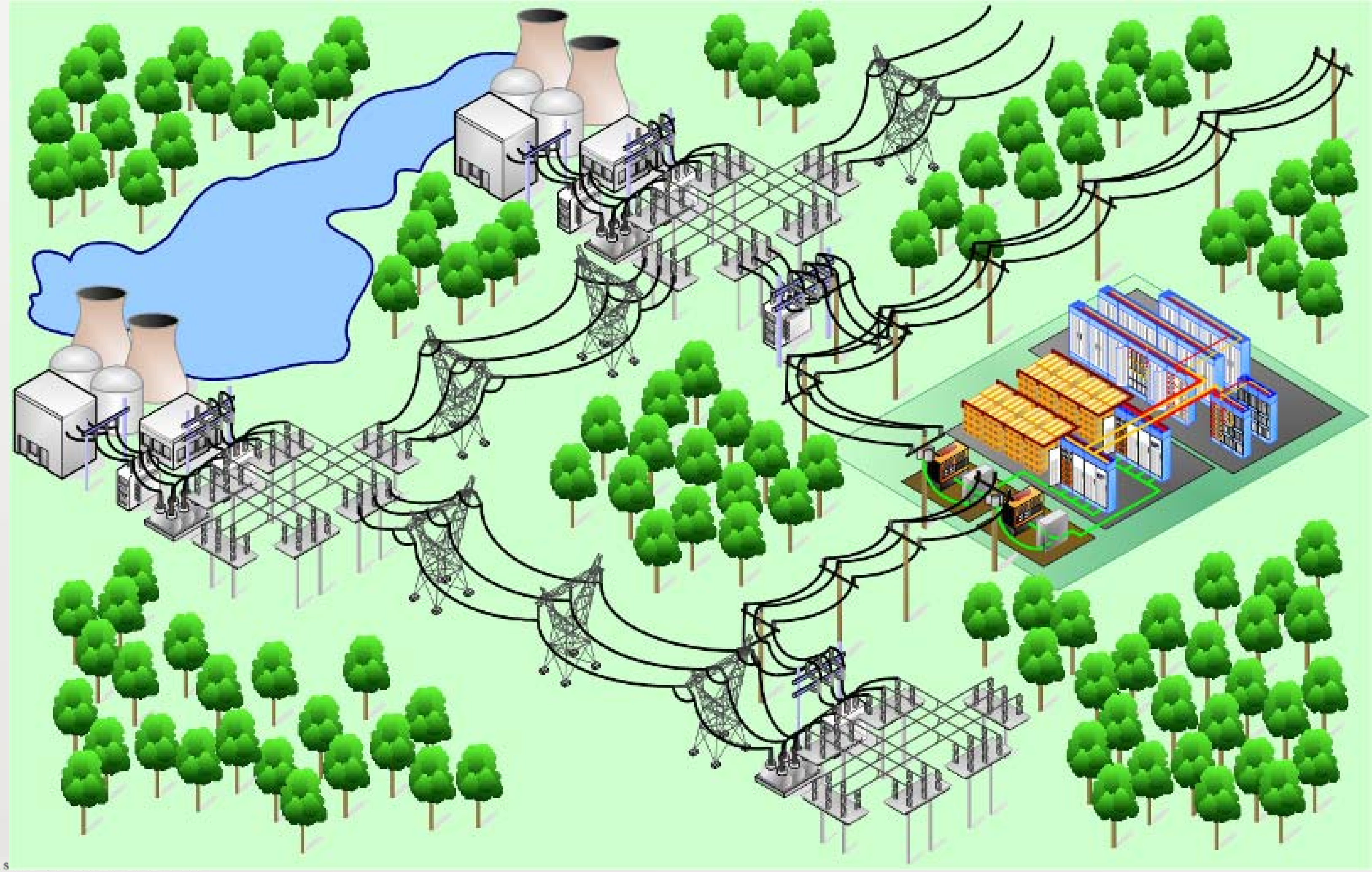
Performance during Hurricanes

- **Reliability issues**
- Sub-transmission and distribution portions of the grid lack redundancy



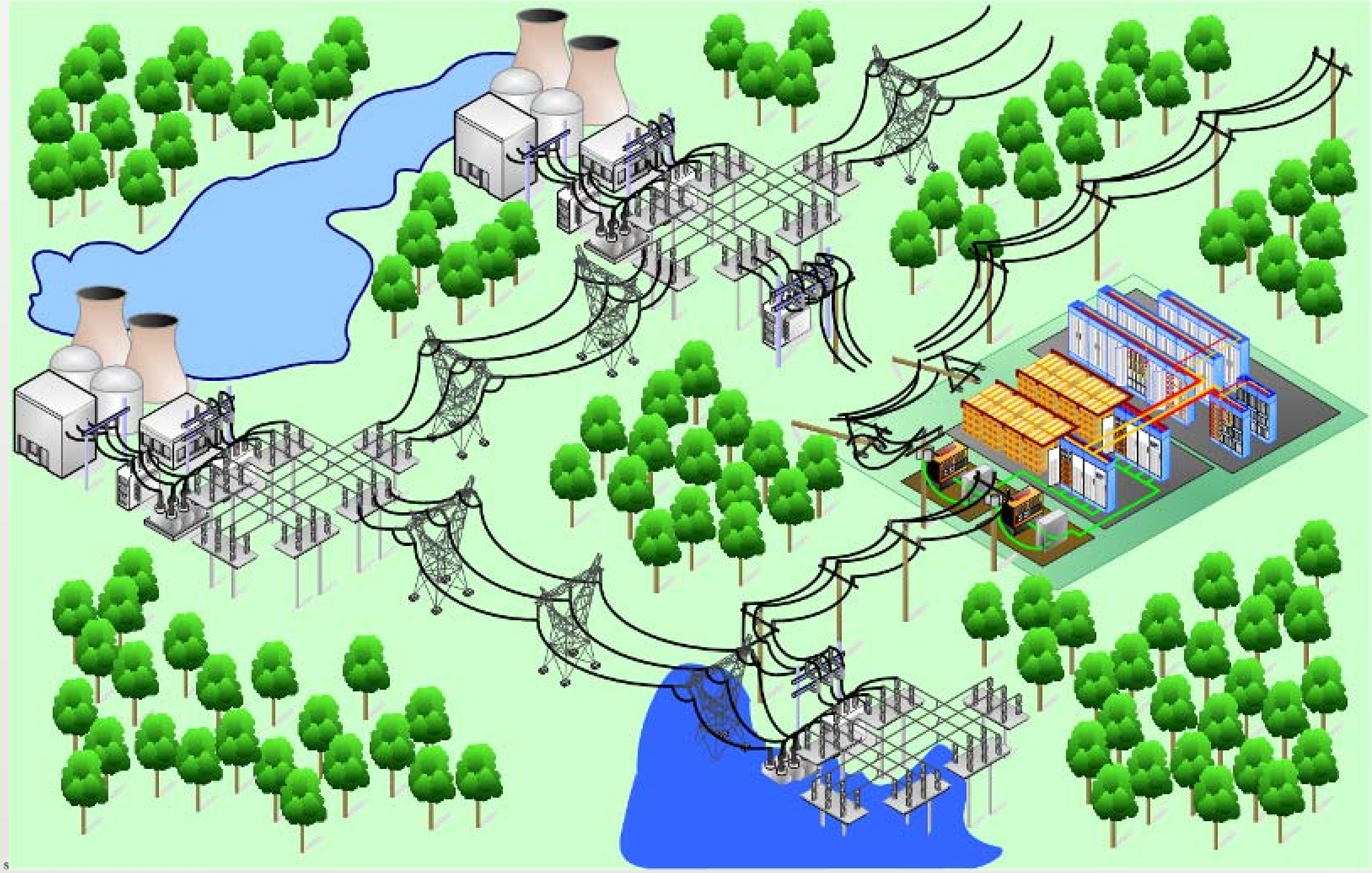
Performance during Hurricanes

- **Reliability issues**
- Lack of diverse power supply



Performance during Hurricanes

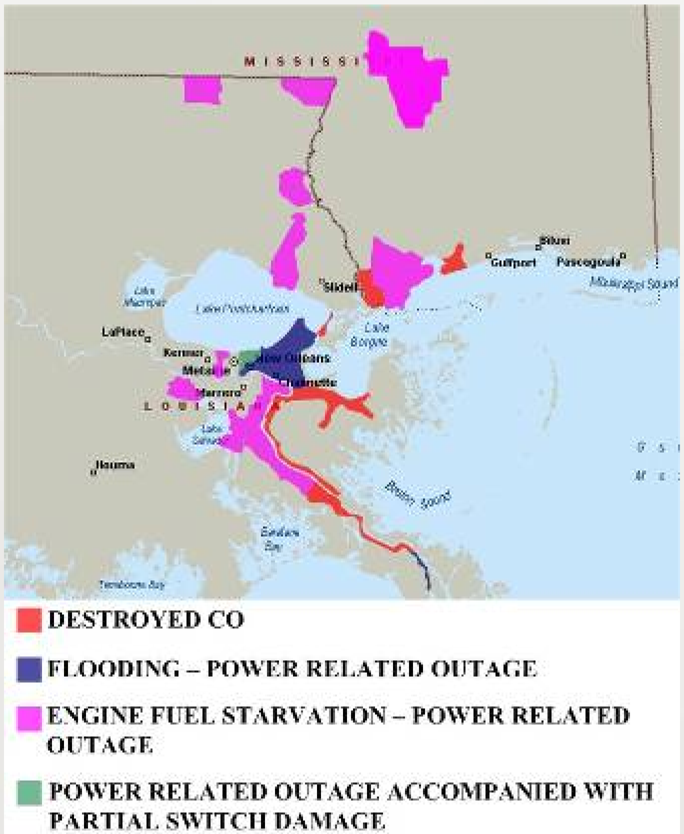
- **Reliability issues**
- Lack of diverse power supply



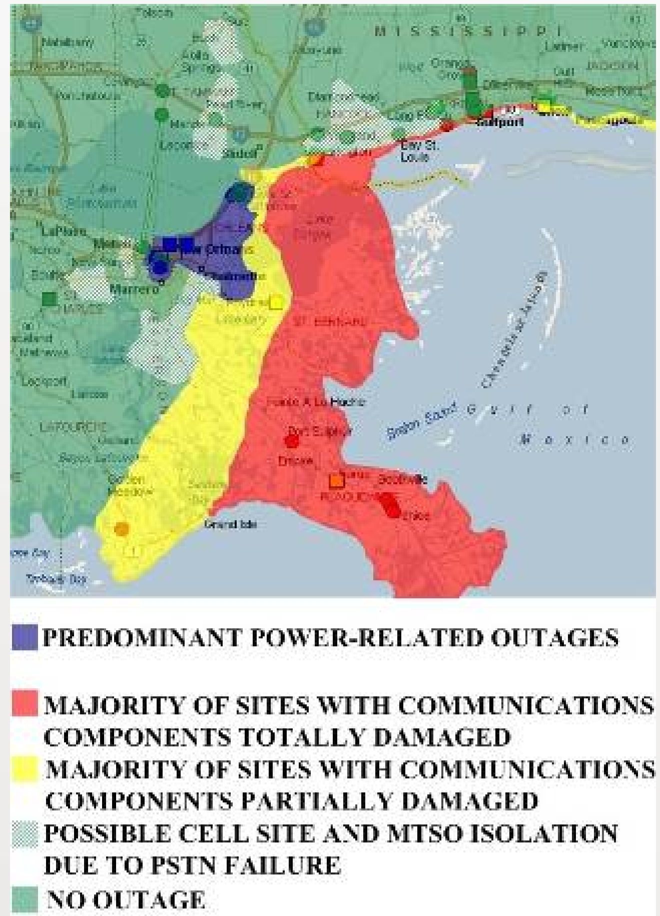
Performance during Hurricanes

- **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

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

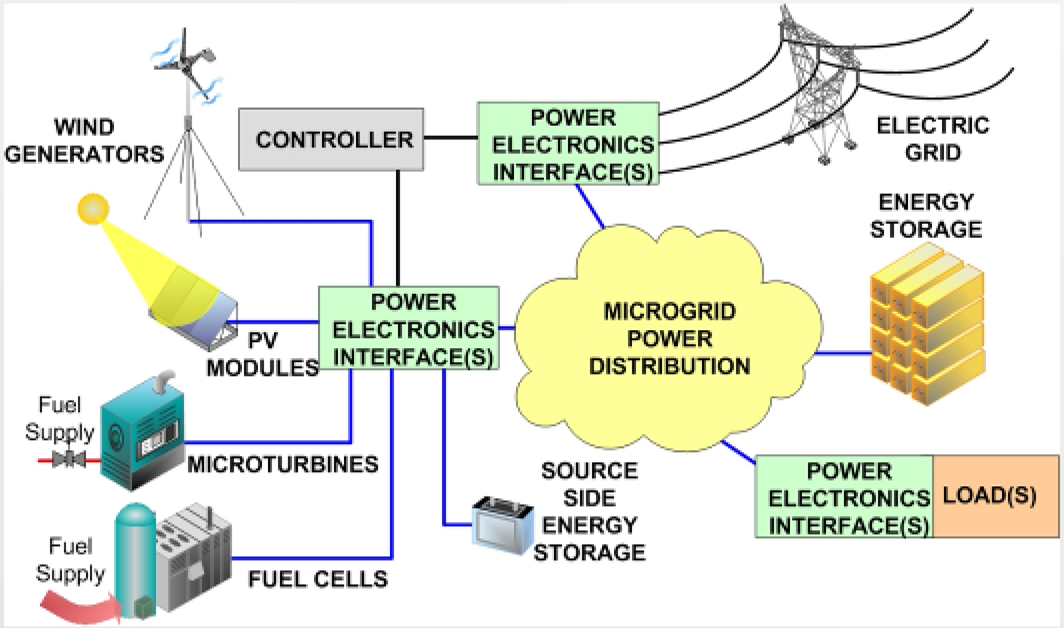
Fuel cell-based microgrid in Garden City, NY after Hurricane Irene

Cell site with a standby diesel genset after Hurricane Ike

Technical Solutions

- Solutions: microgrids
- What is a microgrid?

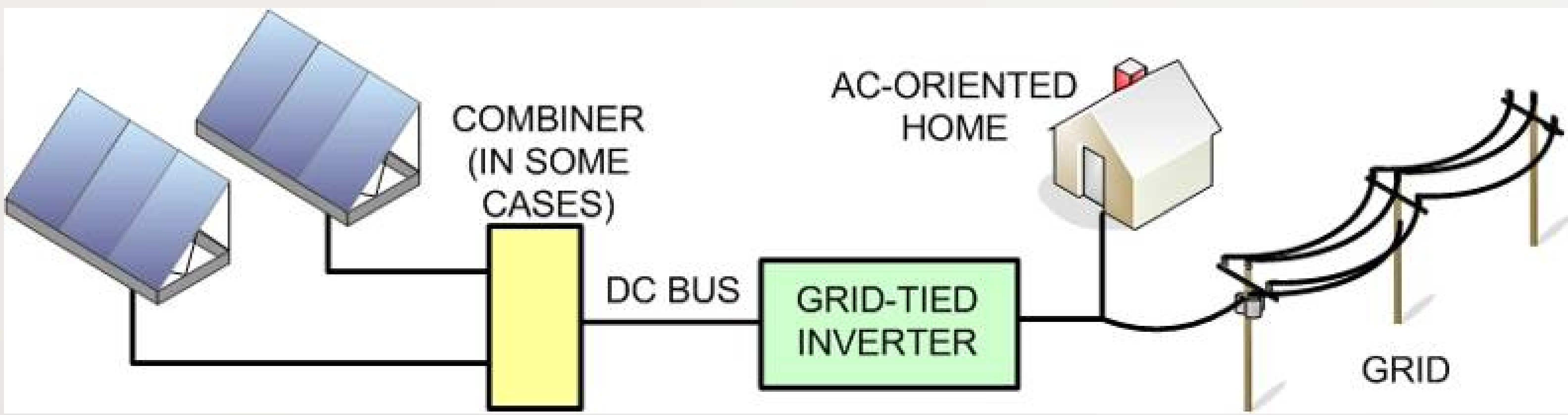
• Microgrids are considered to be locally confined and independently controlled electric power grids in which a distribution architecture integrates loads and distributed energy resources—i.e. local distributed generators and energy storage devices—which allows the microgrid to operate connected or isolated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



Technical Solutions

- Adaptation realities

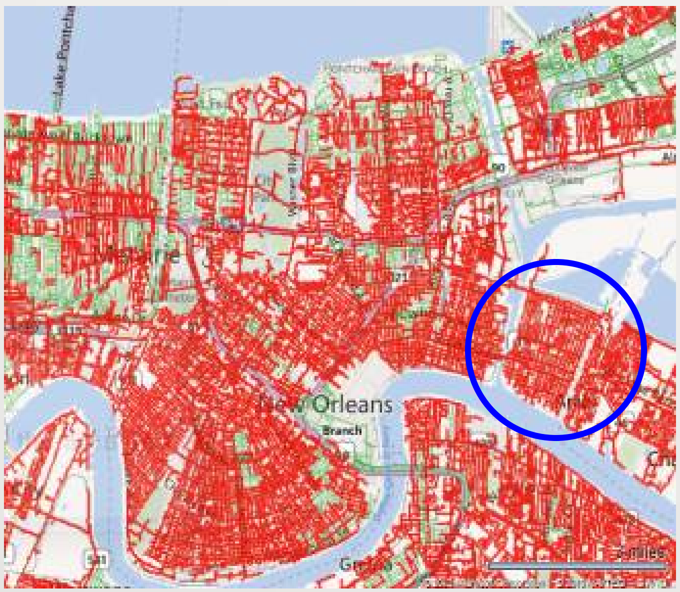
- Conventional grid-tied system (utility centered) are not a microgrid.
- Most widely used PV integration approach.
- PV and home operation subject to grid operation: Due to IEEE Standard 1547, the inverter cannot power the home when the grid is not present.



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.



Technical Solutions

- Adoption realities for microgrids and standby systems

- Except for diesel generators, all other local power solutions tend to be costly (some more expensive than others).

- Issues with PV systems: large footprints

- Renewable energy sources have, typically, variable output power.

- Most local generators depend on other infrastructures, called lifelines (e.g. natural gas distribution networks or roads)

- But lifelines can be affected by the natural disaster like conventional grids.

- Approaches to address lifeline dependencies or output variability:
  - Diverse power source technologies
  - Local Energy Storage

Technical Solutions

- Lifeline dependency. E.g. Hurricane Isaac

Port Sulfur, Oct. 2010

- Flooded loads makes impossible to deliver fuel for permanent diesel gensets

Technical Solutions

• In practice, new technologies are not yet fully adopted.

• Main issues with PV systems: large footprint and need for significant energy storage to address variable output.. Main advantage: no lifelines.

• Still, standby diesel generators (permanent or portable ones) are chosen over other options, probably because it is easier to obtain diesel than other options and because it is the best known option by restoration crews.

Site with a fuel cell powered by a diesel genset

Site with a natural gas generator powered by a diesel genset

Adaptation

- 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.
- 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

Conclusions

- Final thoughts

- Power grids has been experiencing significant power outages even with tropical storms or hurricanes of moderate intensity.

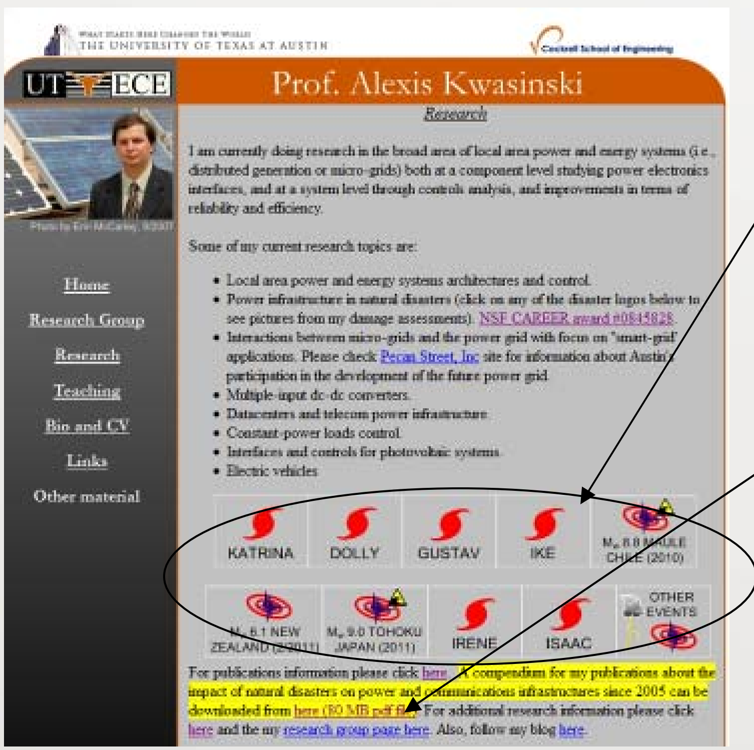
- Hurricanes show that conventional power grids—one of the basis of modern societies—are extremely fragile systems.

- Solutions have been proposed as part of so called “smart grids”. However, ***power grids may not seem to be adapting well to increased impact of weather events***:
  - Microgrids are not yet widely adopted.
  - Conventional residential PV systems do not operate during power outages.
  - In the future, electric vehicles may add challenges for operation under the effect of extreme weather events.

Supplemental material

• Resources from Prof. Kwasinski's research group.
• akwasins@mail.utexas.edu

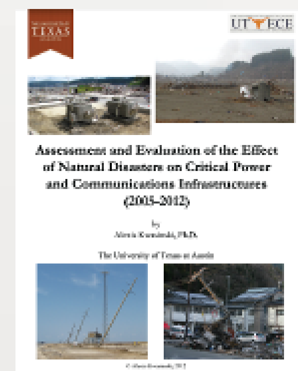
• Main website: http://users.ece.utexas.edu/~kwasinski/
• Research webpage:
http://users.ece.utexas.edu/~kwasinski/research.html



Click here to access information and photos from damage assessments after each of these events

Click here to access a compendium of publications about research related with natural disasters (80 MB file)

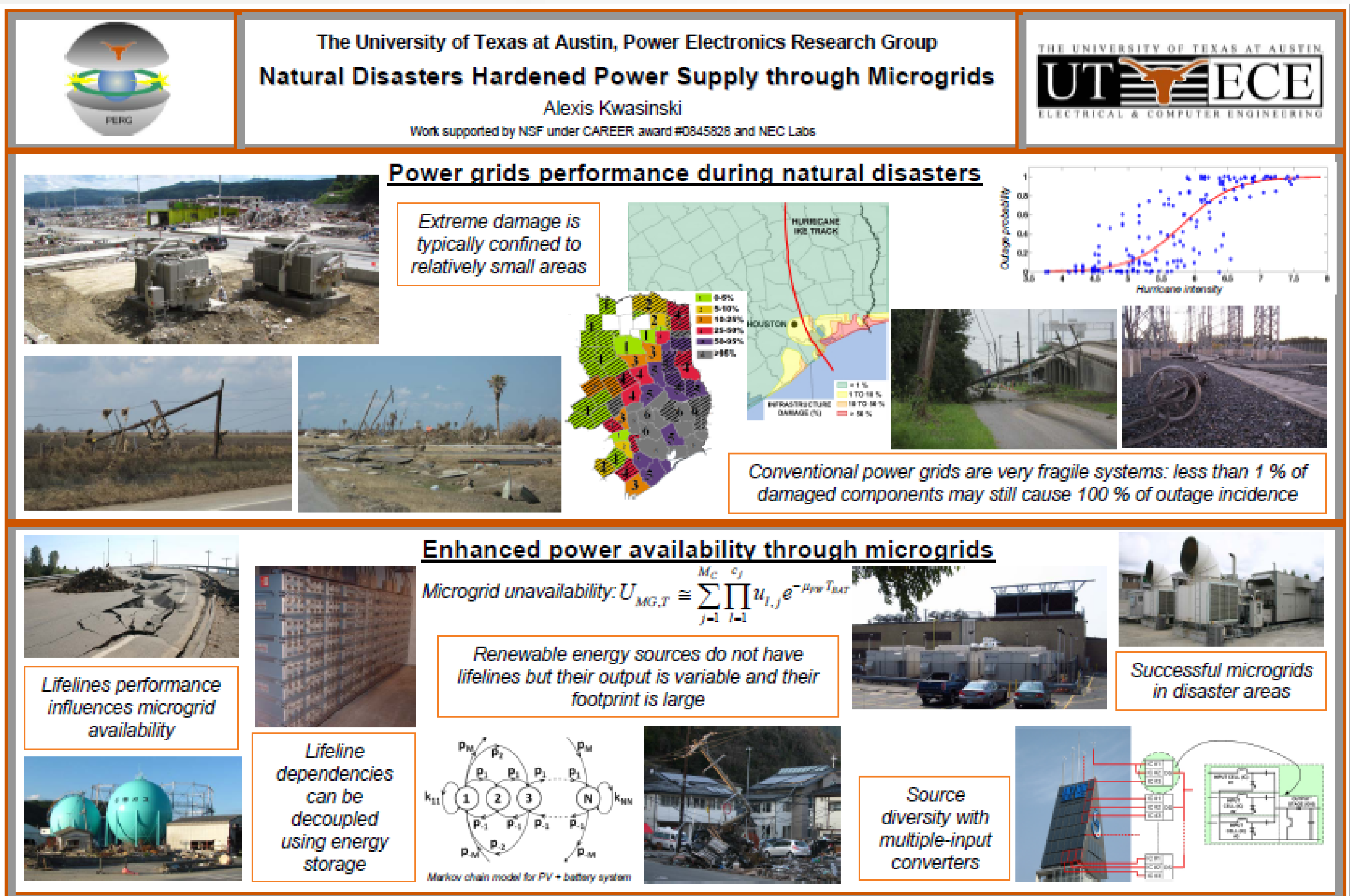
https://webspace.utexas.edu/ak9439/disasters/disasters%20comp.pdf



THE UNIVERSITY OF TEXAS AT AUSTIN
UT ECE
ELECTRICAL & COMPUTER ENGINEERING

Supplemental material

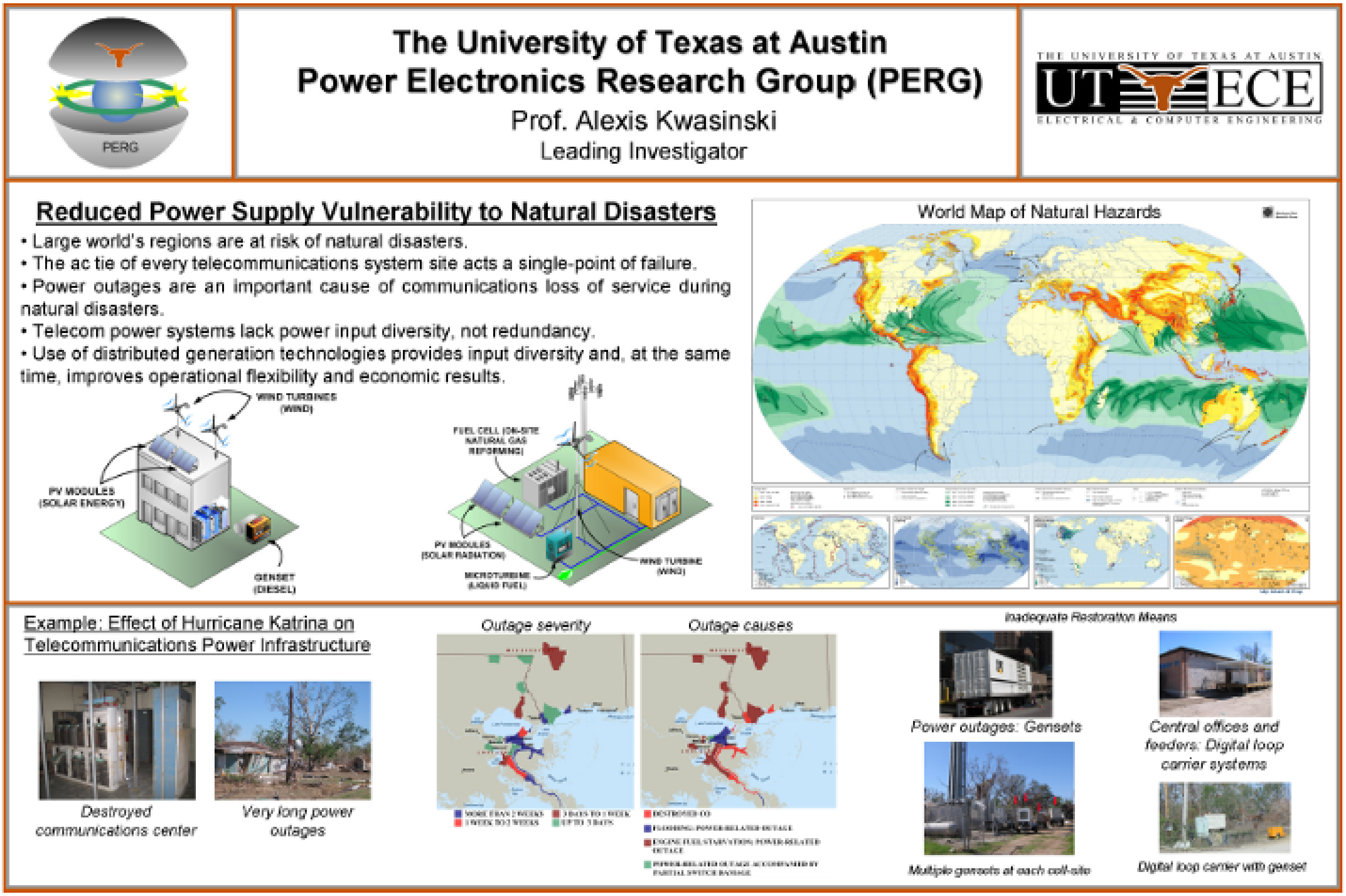
- Resources from Prof. Kwasinski's research group.
- Posters from http://users.ece.utexas.edu/~kwasinski/RG.html



Supplemental material

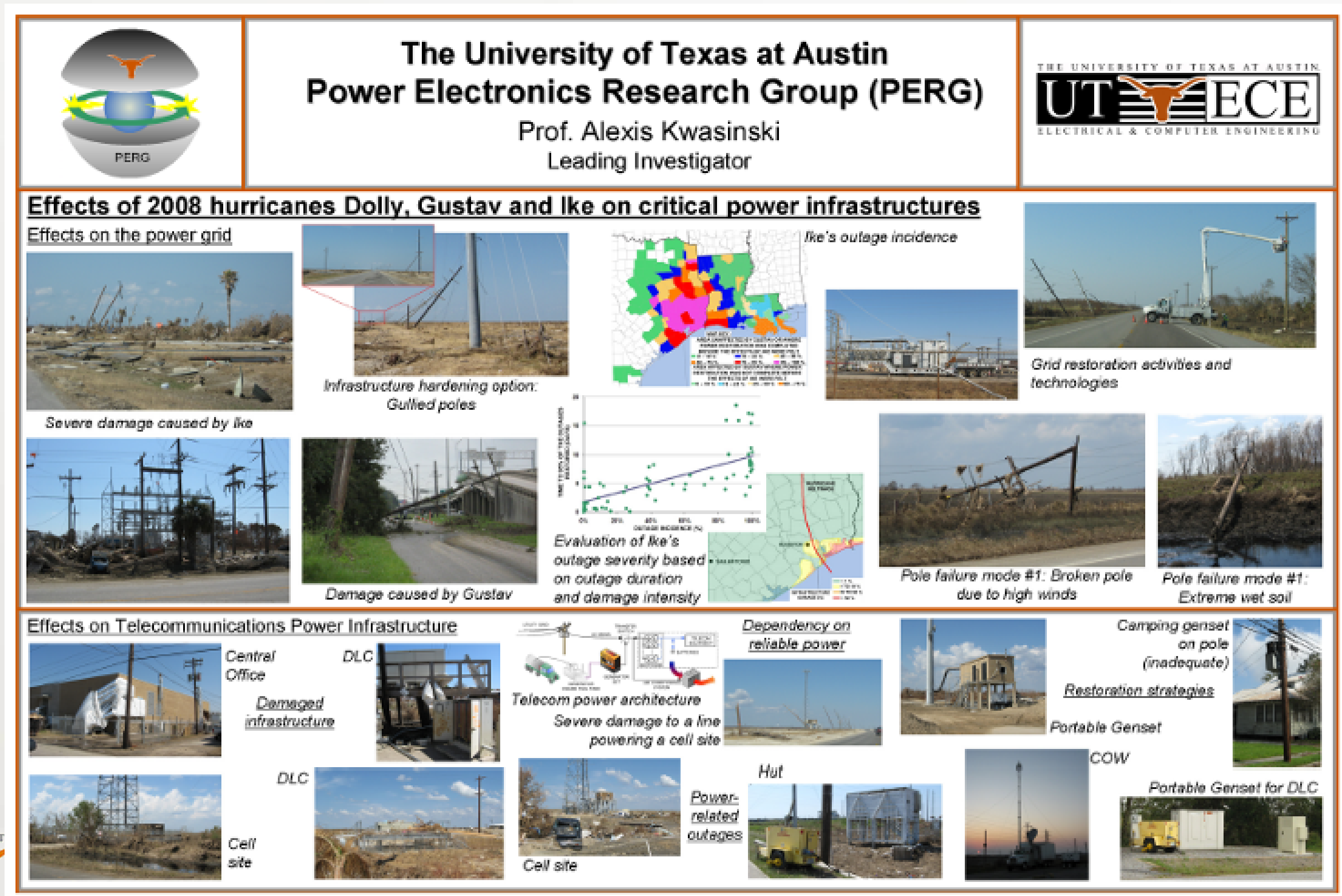
- Resources from Prof. Kwasinski's research group.

- Posters from http://users.ece.utexas.edu/~kwasinski/RG.html



Supplemental material

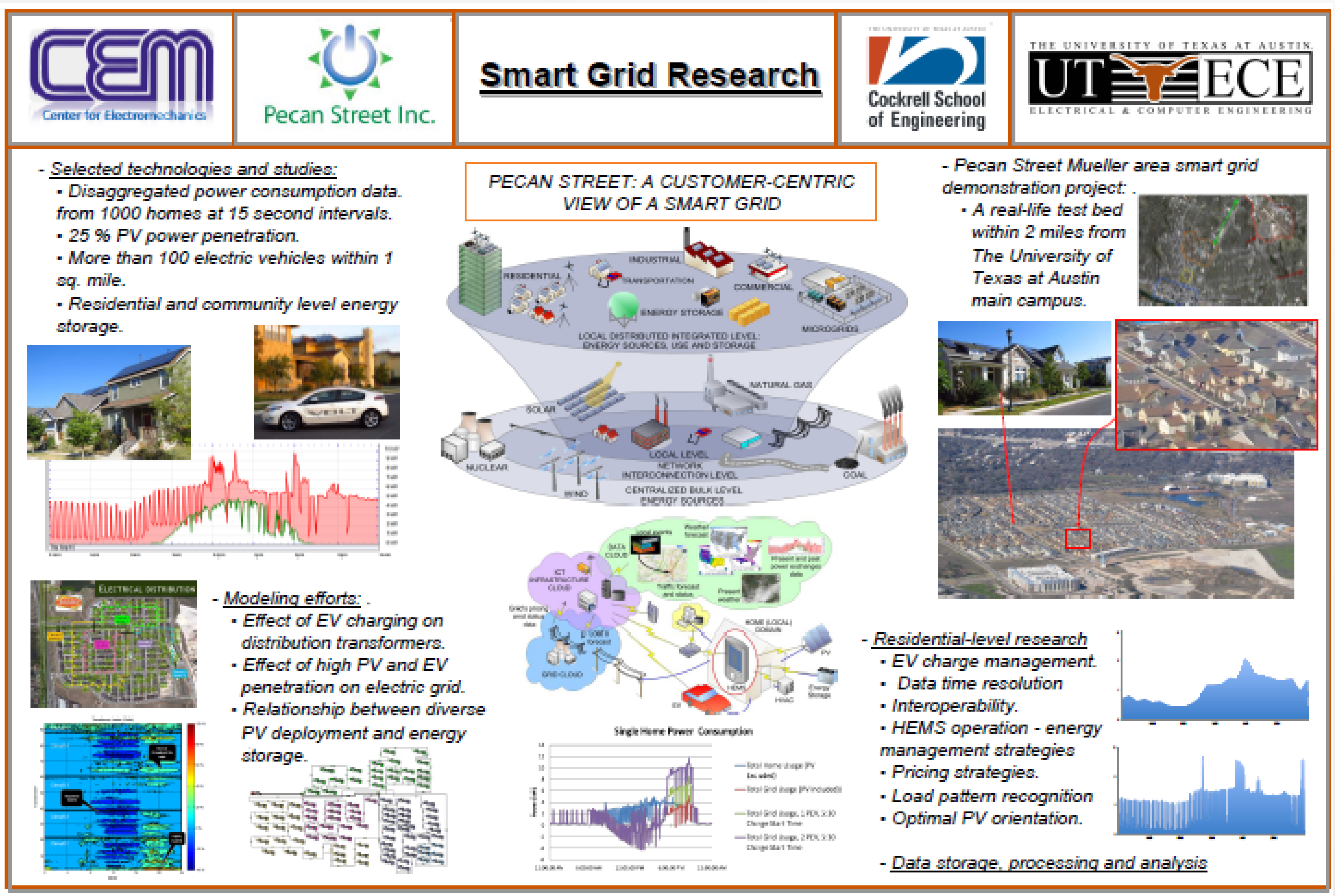
- Resources from Prof. Kwasinski's research group.
- Posters from http://users.ece.utexas.edu/~kwasinski/RG.html



Supplemental material

- Resources from Prof. Kwasinski's research group.

- Posters from http://users.ece.utexas.edu/~kwasinski/RG.html



THE UNIVERSITY OF TEXAS AT AUSTIN

UT ECE

ELECTRICAL & COMPUTER ENGINEERING