Resilient Planning and Design of Information and Communications Technology (ICT) Systems through Microgrids

Alexis Kwasinski, Ph.D.

R. K. Mellon Faculty Fellow in Energy

University of Pittsburgh, Swanson School of Engineering

Overview

- Introduction – motivation
- Resilience
- Microgrid planning
- Application to ICT
- Conclusions

Introduction

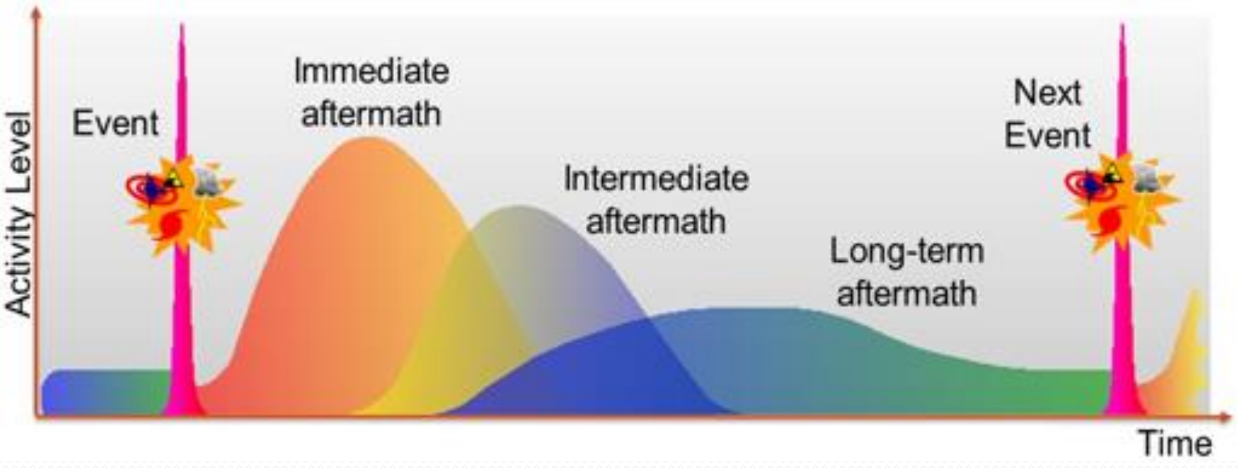
Motivation

- There is considerable recent talk about resilience, but….. What is resilience? How can it be measured?
- Why measuring resilience?
  - To support planning and design.
  - Metrics allow to determine how much more or less resilient a given system is and help to objectively determine technological options.
- Previously used ideas:
  - Resilience has been confused with resistance
  - Traditional use of resilience in civil engineering was associated with recovery speed.

Resilience

Chosen definition

- Based on U.S. Presidential Policy Directive (PPD) #21
- **PPD-21 defines resilience "as the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."**



Resilience

Energy Security Definition Highlights

- Broader Resilience Definition from U.S. PPD-21
- Four components of resilience:
  - Ability to prepare for changing conditions
  - Ability to adapt to changing conditions
  - Ability to withstand disruptions
  - Ability to recover rapidly from disruptions.
- Various temporal scales:
  - Short term
  - Medium term
  - Long term

Resilience

Why the focus on Information and Communications Technology (ICT) Systems?

- The Presidential Policy Directive 21 identifies "energy and communications systems as uniquely critical due to the enabling functions they provide across all critical infrastructure sectors." I.e., importance of **dependencies** is identified in the PPD-21.

Resilience

Performance of ICT systems in recent natural disasters

- Significant disruptions were observed in recent events, particularly in the 2011 and 2010 earthquake and tsunami in Japan and Chile, respectively, and after hurricanes Katrina, Ike and Sandy.
  - For more than a week wireless communication networks experienced between 50% and 100% loss of coverage in large areas.
  - Many central offices and data centers lost service.

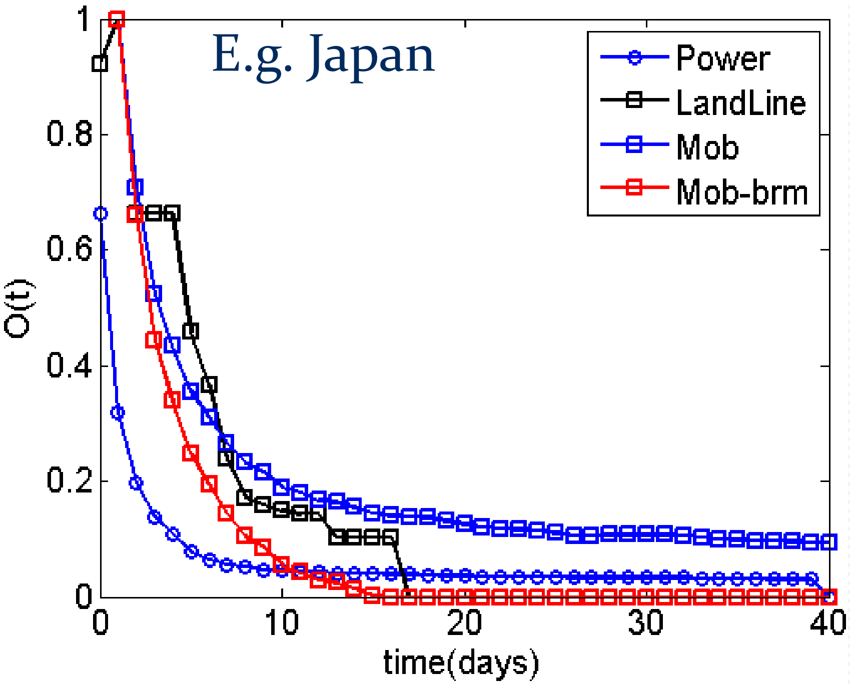
- Power issues were a main cause of service disruptions during these events.

LEAdERS

Resilience

Lessons from past events: Power supply

- Correlation between power outages and communication outages is stronger in cases where there are insufficient number of onsite and deployable gensets.
- Due to energy storage at communication sites, communication outages lags power outages.


E.g. Japan

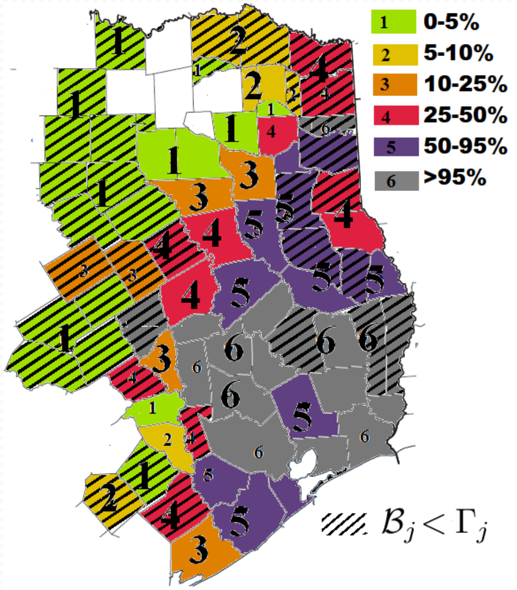
Miyako, Japan, 4/2011

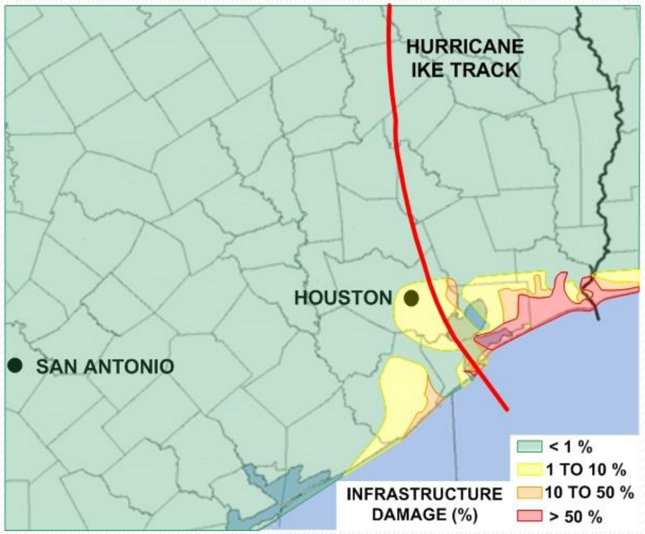
Resilience

Performance of power systems in recent natural disasters

•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.

- Intense damage is limited to relatively small areas.
- Most of the area affected by a large disaster show little damage to the power grid, yet, power outages are extensive and last a long time.

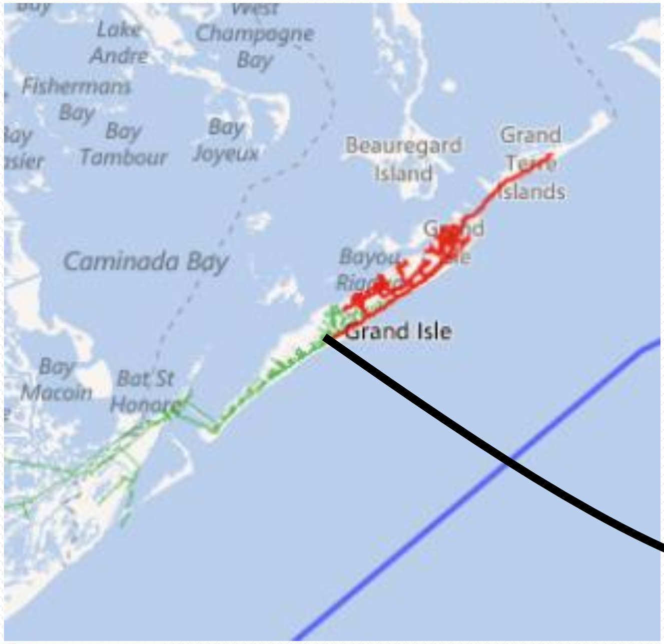




Resilience

Performance of power systems in recent natural disasters - Vulnerabilities

- Sub-transmission and distribution portions of the grid lack redundancy
- E.g. after Hurricane Isaac: Only one damaged pole among many undamaged causing most of Grand Isle to lose power.



Entergy Louisiana

Grand Isle, about 1 week after the hurricane

Resiliency Metrics

Resiliency (from PPD21):

- The ability to **prepare** for and **adapt** to changing conditions and **withstand** and **recover rapidly** from disruptions.

- "Withstand" refers to an "up" time
- Rapid recovery refers to a "down" time

- Inclusion of an up and a down time points towards an analogy between the concept of base resiliency and that of availability.

- Preparation and adaptation relates to the influence of processes through the down time.

LEAdERS

Resilience Metrics

- Base resiliency:

$$R_B = \frac{\sum_{i=1}^{N} T_{U,i}}{NT} = \frac{\sum_{i=1}^{N} T_{U,i}}{\sum_{i=1}^{N} (T_{U,i} + T_{D,i})}$$

- N is the total number of customers in a given area, $T_{U,i}$ is the time when customer i receives electric power during the total measured time T (no "mean" behavior here).

- $T_{U,i}$ (withstanding characteristic) is mostly related with hardware issues.

- $T_{D,i}$ (recovery speed) is the down time, which is influenced by human processes and aspects, such as logistical management, as well as hardware-related issues.

- Base resiliency is analogous to the average service availability index (ASAI) or, more generally, to availability. However, resilience does not consider a long-term steady state performance.

Resilience Metrics

- Accounting for dependencies….. Local resilience:

$$R_L = 1 - (1 - R_C)e^{-\mu T_S}$$

where T_S is the energy storage autonomy, μ is the combined repair rates from the minimal cut states (for a simple grid tie it is just the inverse of the down time for that grid tie).

- R_C is the resilience at the point of common coupling as seen by an individual load, such as an ICT facility. It is measured as

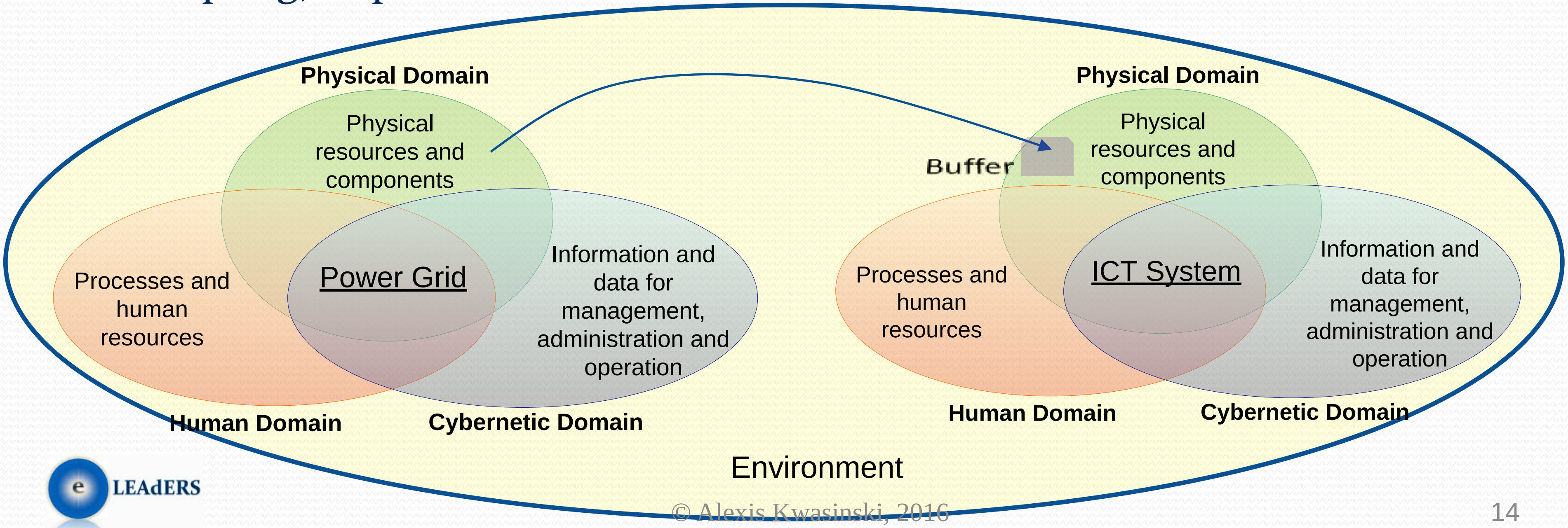
$$R_C = \frac{T_U}{T} = \frac{T_U}{(T_U + T_D)}$$

- Notice that resistance is different from resilience. A system that recovers quickly from disruptions may still be resilient even when it is not resistant. Likewise, a system, such as underground cables, may be resistant to an event, yet, it may not be resilient because repairs may take a long time when a failure happens.

$$R_I = \frac{T_U}{T} = \frac{T_U}{(T_U + T_D)}$$

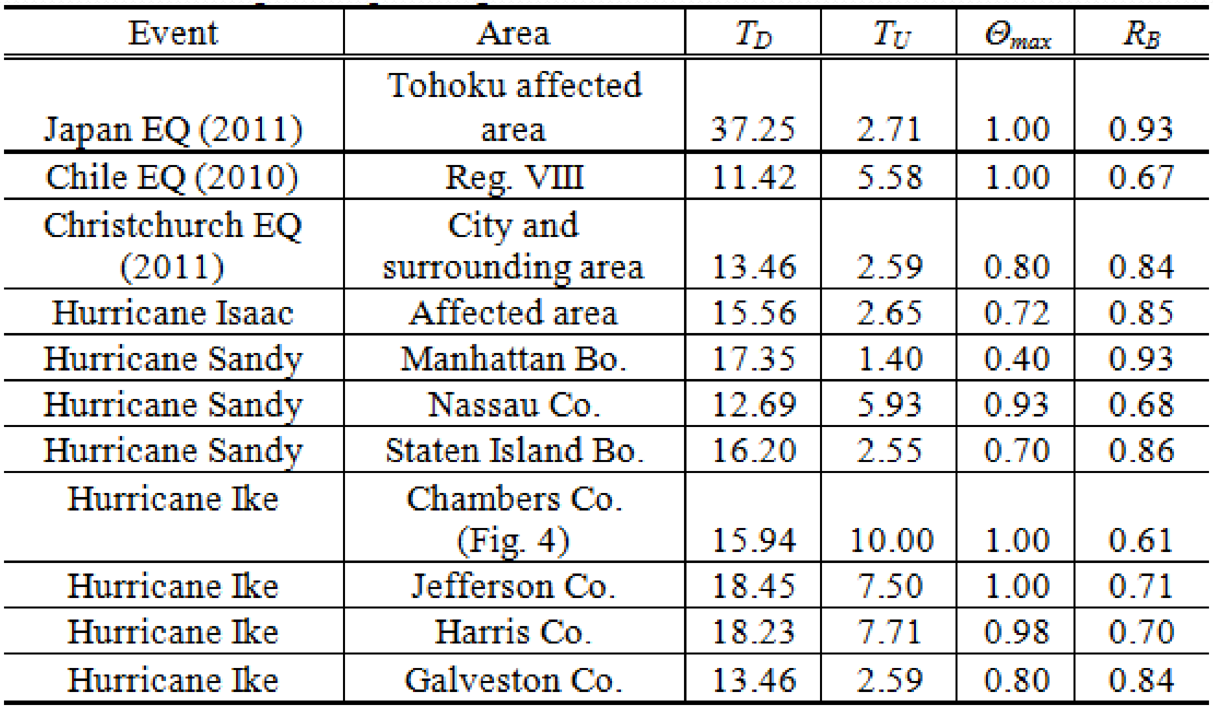
Resilience Metrics

- Key observations
  - Degree of dependence could be measured based on energy storage requirements.
  - Dependencies add vulnerabilities potentially reducing resilience.
  - Degree of dependence could be managed through local energy storage. I.e. local energy storage are buffers regulating (and in an extreme case decoupling) dependencies.



Application

Examples of power grid resilience in recent events



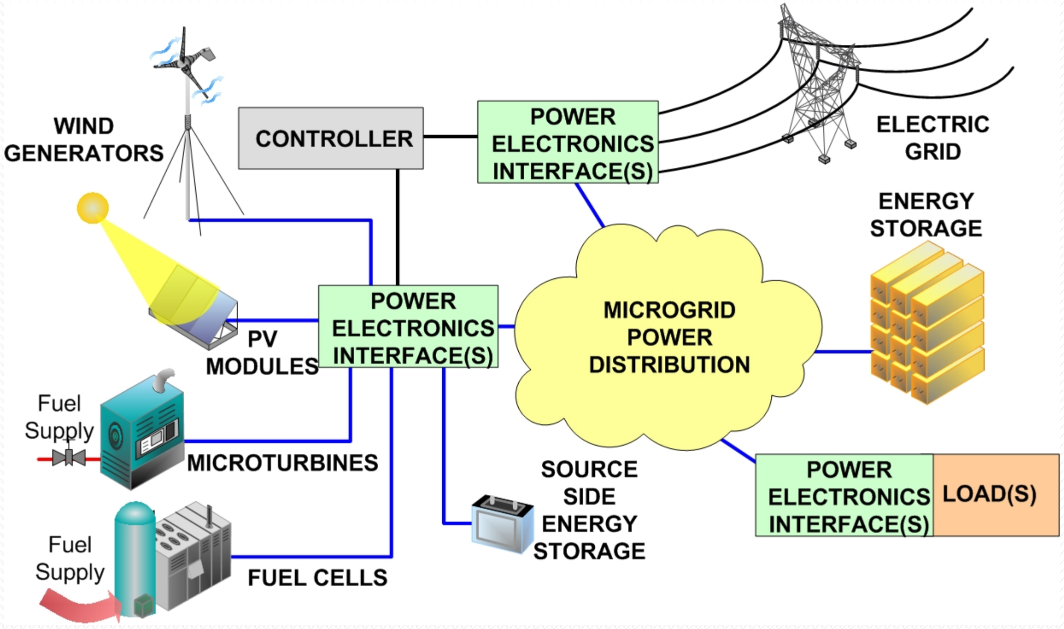
Event	Area	T_D	T_U	Θ_{max}	R_B
Japan EQ (2011)	Tohoku affected area	37.25	2.71	1.00	0.93
Chile EQ (2010)	Reg. VIII	11.42	5.58	1.00	0.67
Christchurch EQ (2011)	City and surrounding area	13.46	2.59	0.80	0.84
Hurricane Isaac	Affected area	15.56	2.65	0.72	0.85
Hurricane Sandy	Manhattan Bo.	17.35	1.40	0.40	0.93
Hurricane Sandy	Nassau Co.	12.69	5.93	0.93	0.68
Hurricane Sandy	Staten Island Bo.	16.20	2.55	0.70	0.86
Hurricane Ike	Chambers Co. (Fig. 4)	15.94	10.00	1.00	0.61
Hurricane Ike	Jefferson Co.	18.45	7.50	1.00	0.71
Hurricane Ike	Harris Co.	18.23	7.71	0.98	0.70
Hurricane Ike	Galveston Co.	13.46	2.59	0.80	0.84

- Typical power grids performance yield a low resilience floor.
- Compensating for the low resilience floor requires very large investments.
- Microgrids may be a suitable option for improved resilience.

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

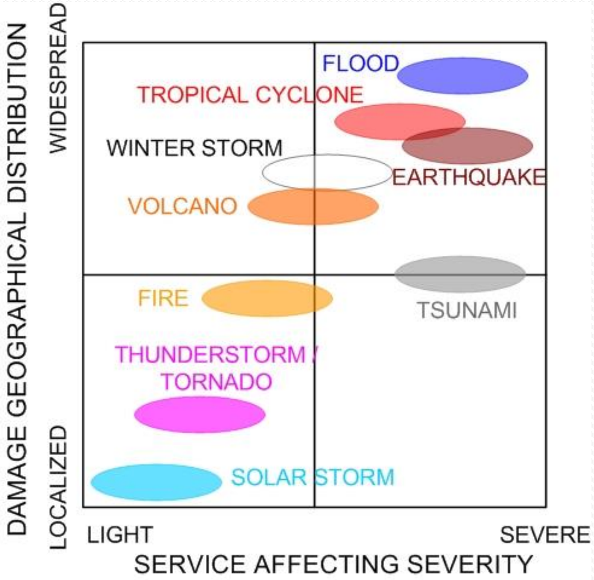


Microgrid Planning

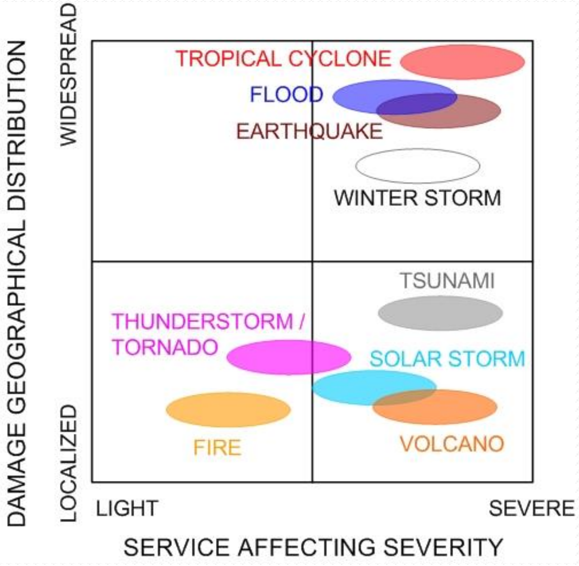
Power sources dependent on a lifeline

- There are two types of sources: those that depend on a lifeline and those that do not depend on lifelines (e.g. renewable energy sources).

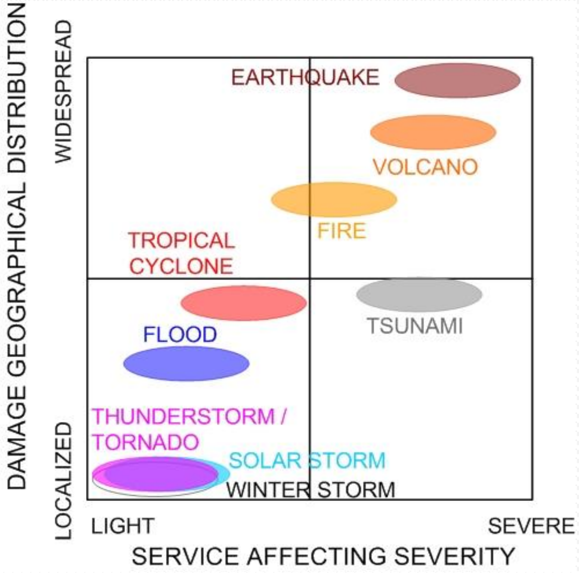
- Lifelines are infrastructures used by generation units in microgrids to receive energy. Lifelines are affected differently by various natural disasters.



Transportation and fuel delivery



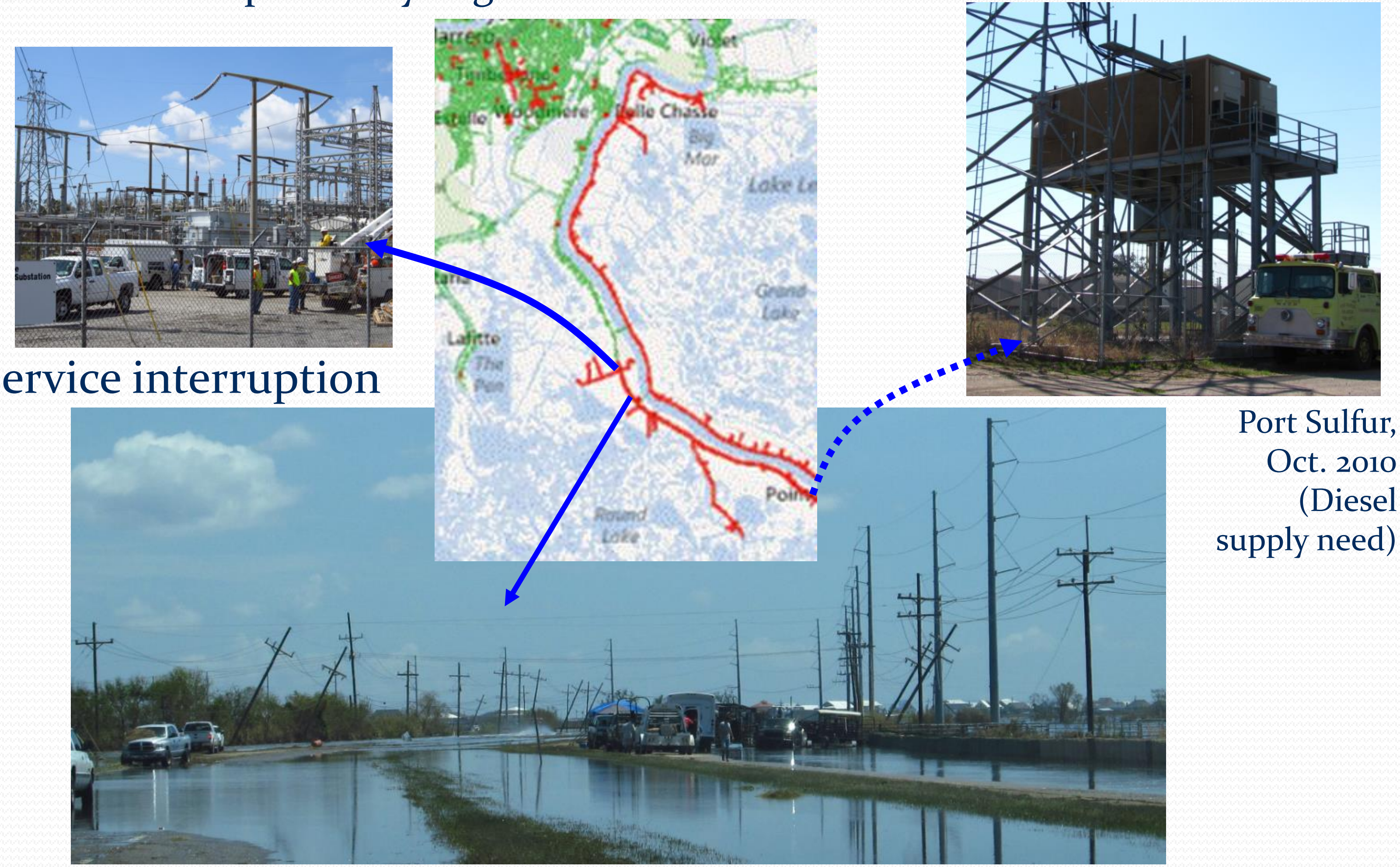
Electric grid



Natural gas

Microgrid Planning

- Lifeline dependency. E.g. Hurricane Isaac



- Electric service interruption

Port Sulfur, Oct. 2010 (Diesel supply need)

- Flooded roads made impossible to deliver fuel for permanent diesel gensets

Microgrid Planning

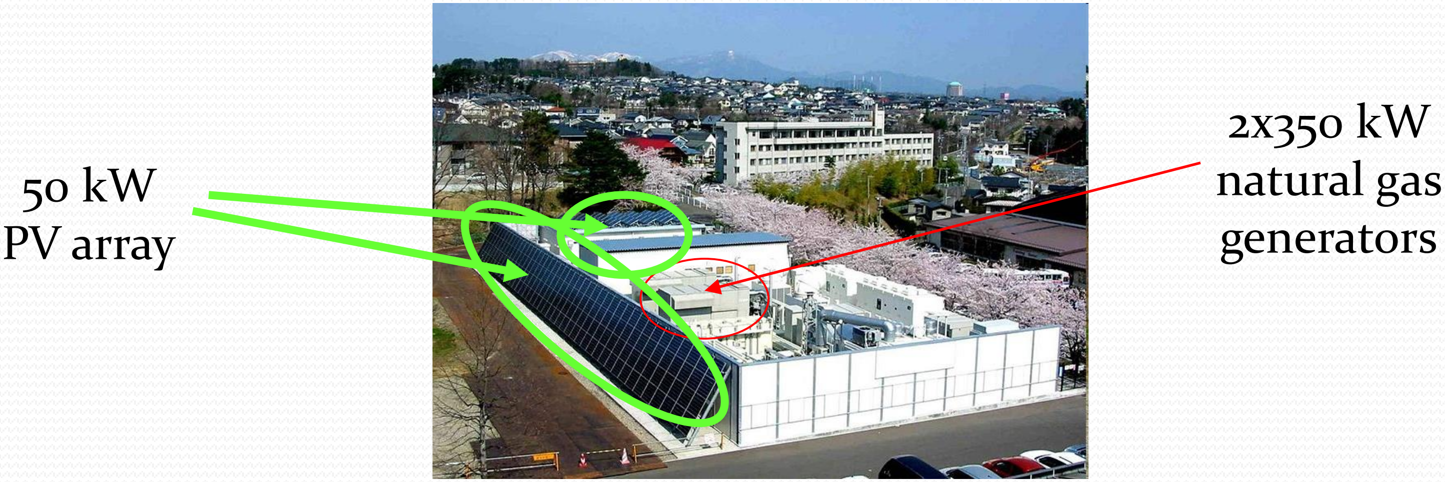
Power sources dependent on a lifeline

- Approaches to limit the negative impact of lifeline dependencies on microgrid availability:
  - Use of **diverse power source technologies** (e.g. combine natural gas and diesel, or natural gas and renewable energy sources)
  - **Local energy storage**

Microgrid Planning

Renewable energy sources

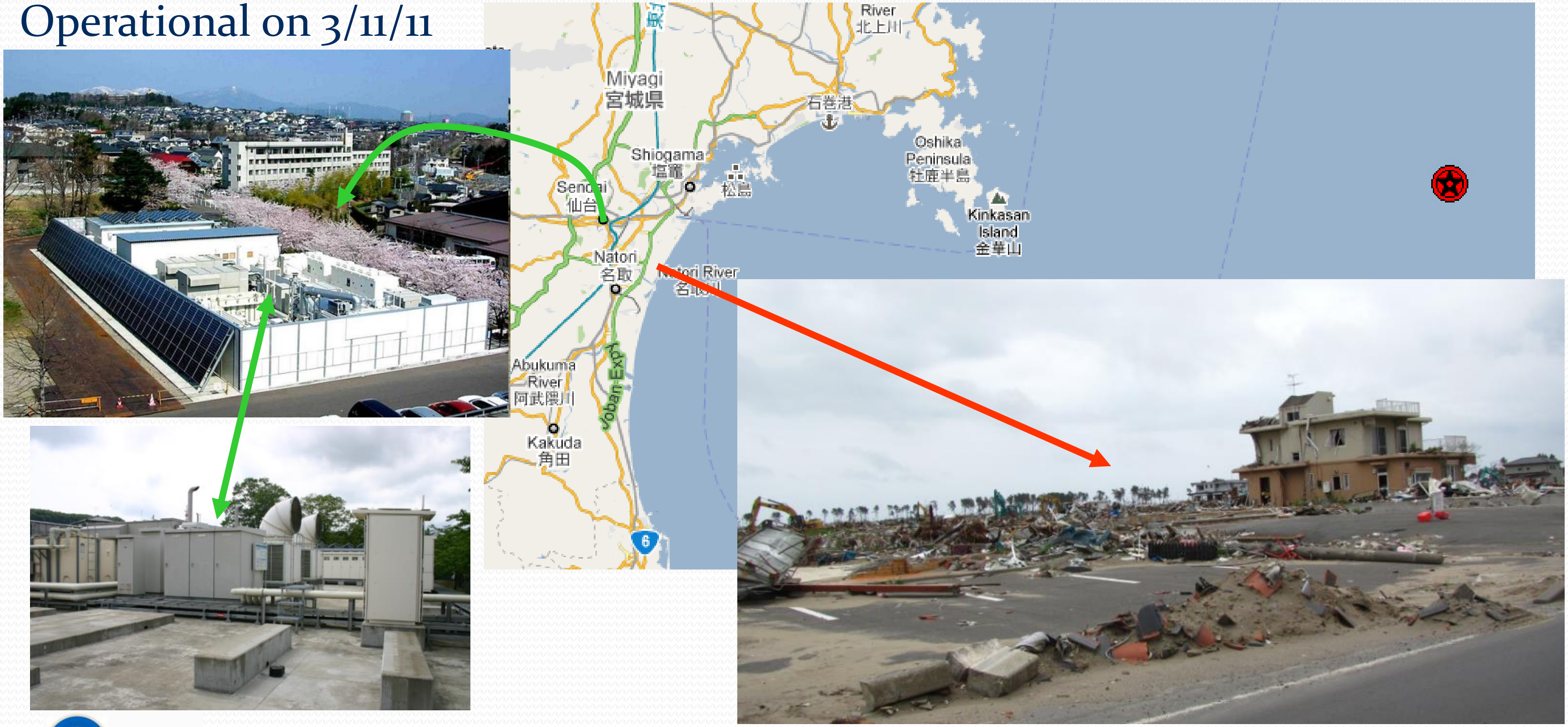
- Most renewable energy sources do not require lifelines, but…..
- Issues with PV systems: large footprints. Solution:
  - Size PV arrays for less than the required load and use it to support another power source rated at full capacity.
- Renewable energy sources have, typically, variable output. Solutions: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



Application

Microgrids in 2011 Japan’s earthquake and tsunami

- NTT/NEDO Microgrid in Sendai: This microgrid was designed to provide different power quality levels to part of an university campus, including a clinic. Operational on 3/11/11

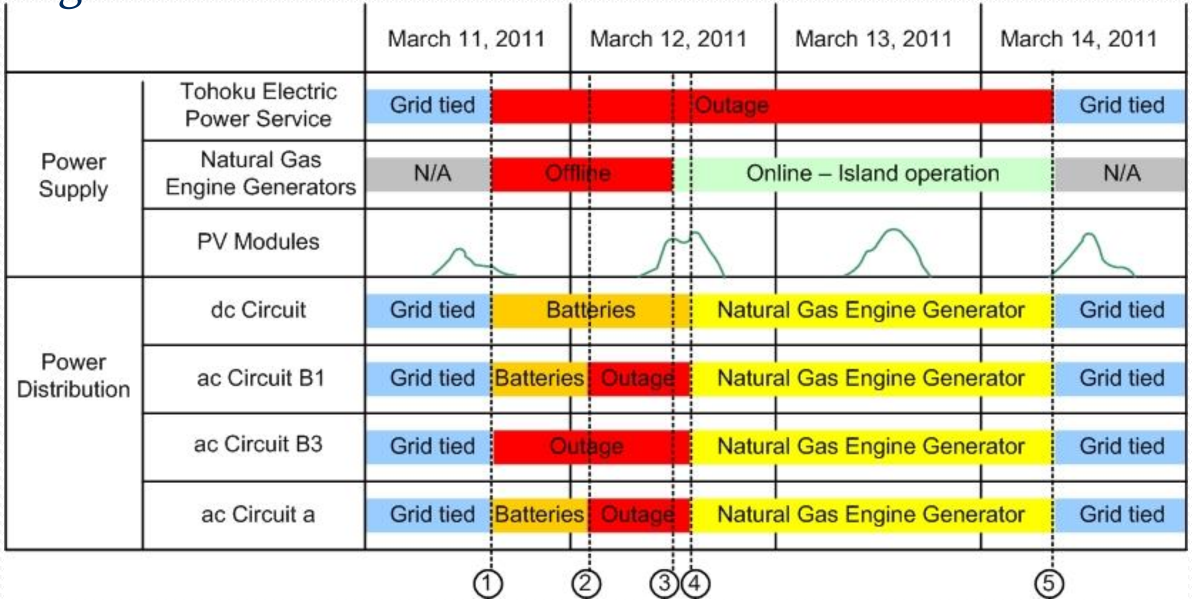


LEAdERS

Application

Microgrids in 2011 Japan’s earthquake and tsunami

NTT/NEDO Microgrid in Sendai



		March 11, 2011	March 12, 2011	March 13, 2011	March 14, 2011
Power Supply	Tohoku Electric Power Service	Grid tied	Outage		Grid tied
	Natural Gas Engine Generators	N/A Offline		Online – Island operation	N/A
	PV Modules				
Power Distribution	dc Circuit	Grid tied	Batteries	Natural Gas Engine Generator	Grid tied
	ac Circuit B1	Grid tied Batteries	Outage	Natural Gas Engine Generator	Grid tied
	ac Circuit B3	Grid tied	Outage	Natural Gas Engine Generator	Grid tied
	ac Circuit a	Grid tied Batteries	Outage	Natural Gas Engine Generator	Grid tied

2x350 kW

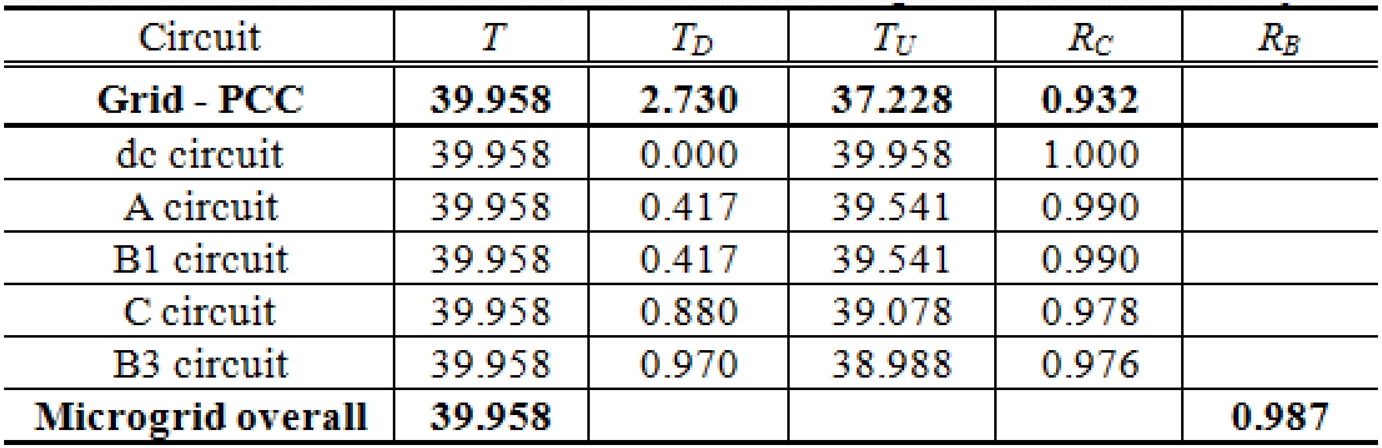
50 kW

- 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.

Application

Micrograms in 2011 Japan's earthquake and tsunami

Resilience metrics applied to the NTT/NEDO Microgrid in Sendai



Circuit	T	T_D	T_U	R_C	R_B
Grid - PCC	**39.958**	**2.730**	**37.228**	**0.932**	
dc circuit	39.958	0.000	39.958	1.000	
A circuit	39.958	0.417	39.541	0.990	
B1 circuit	39.958	0.417	39.541	0.990	
C circuit	39.958	0.880	39.078	0.978	
B3 circuit	39.958	0.970	38.988	0.976	
Microgrid overall	**39.958**				**0.987**

- The dc circuit showed better resilience that the other circuits
- Local energy storage in batteries were a key asset to keep at least the most critical circuit operating serve to distinguish local resilience among circuits.
- PV power played a complementary role.
- Natural gas supply did not fail thanks to an almost exclusive design for the distribution pipelines for this site.
- Source diversification is important.

Application

Micrograms in 2011 Japan’s earthquake and tsunami

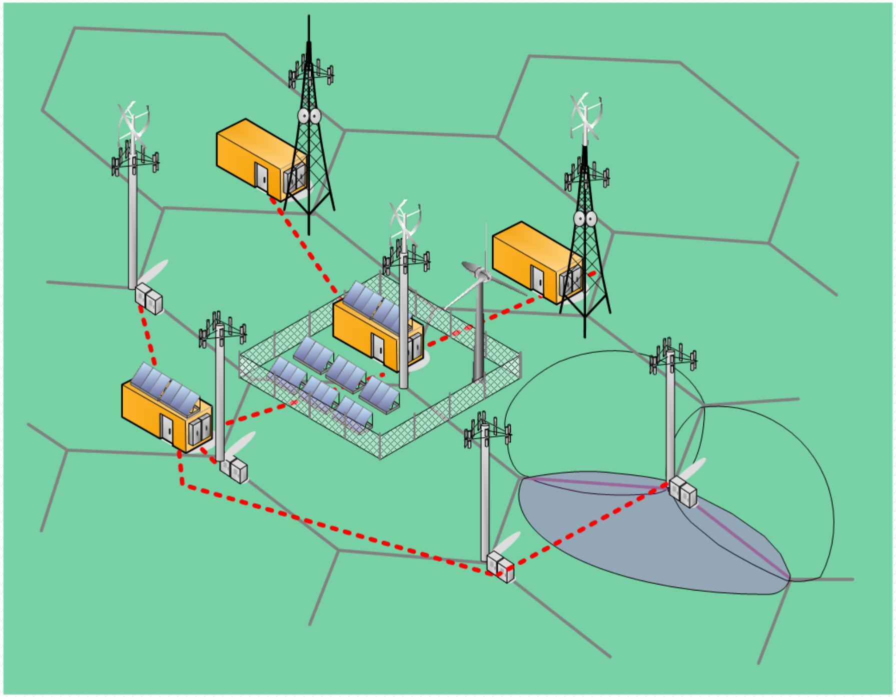
NTT/NEDO Microgrid in Sendai

- 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.

Application Example

Goal

- Increase resilience in wireless communication networks by using renewable energy sources



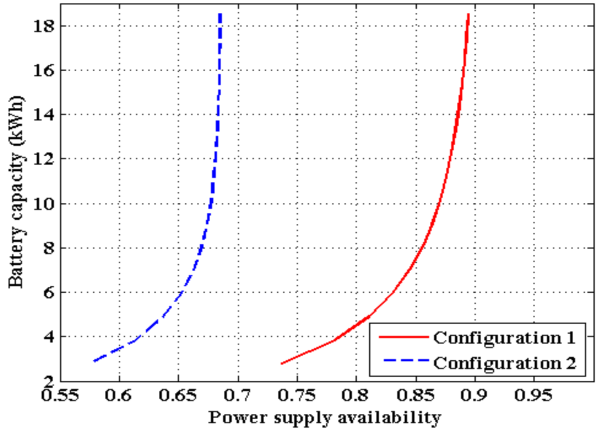
- **Approach:**
  Integrated management of power generation, energy storage and load within acceptable users quality of experience levels.
- **Type of system:**
  DC microgrid with power electronic circuits controlling power flows.

LEAdERS

Application Example

Issues addressed with the proposed solution in which load is controlled in an integrated fashion:

- Issues with PV systems:
  - Large footprints (PV: 250 W/m2 vs. base station: 1.5 kW/m2)
  - Variable output (part stochastic, part deterministic)
- Issues with wind generators in cities:
  - Wind profiles and aesthetics
- Charging limitations affecting energy storage effectiveness

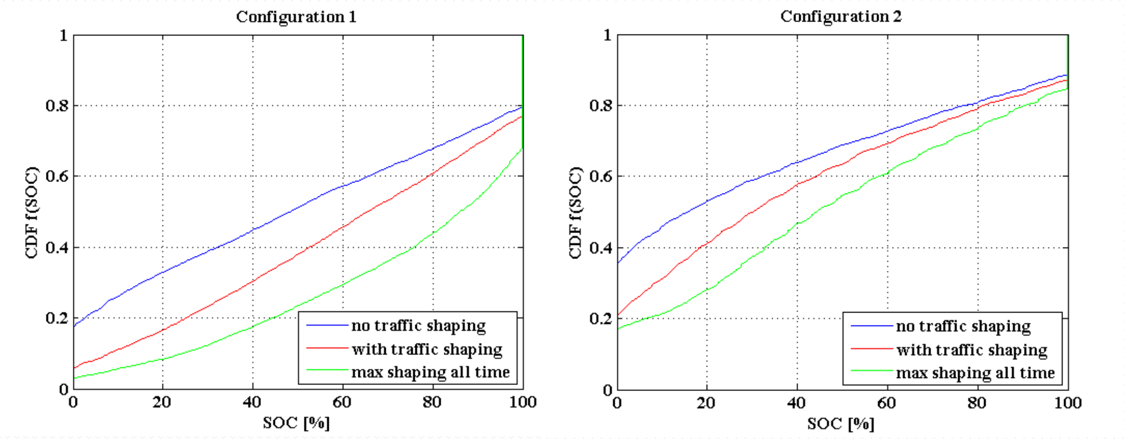


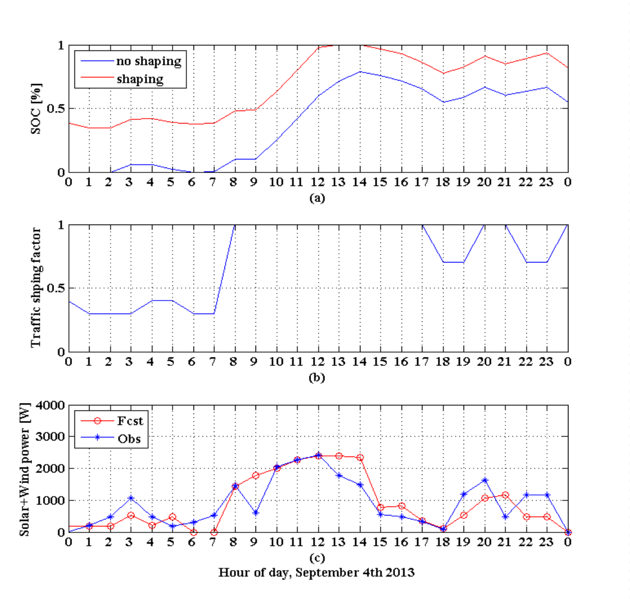
- Configuration 1: 6 x MX60-240 PV modules + 1 x Excel 10 kW wind turbine,
- Configuration #2 : 20 x MX60-240 PV modules

Application Example

Results

- VPP-based control allows for better resource utilization yielding:
  - 25 % improvement in availability.
  - 10 % improvement in battery life
  - 25 % reduction in battery bank capacity for a same availability
  - 40 % reduction in PV array size for same performance.





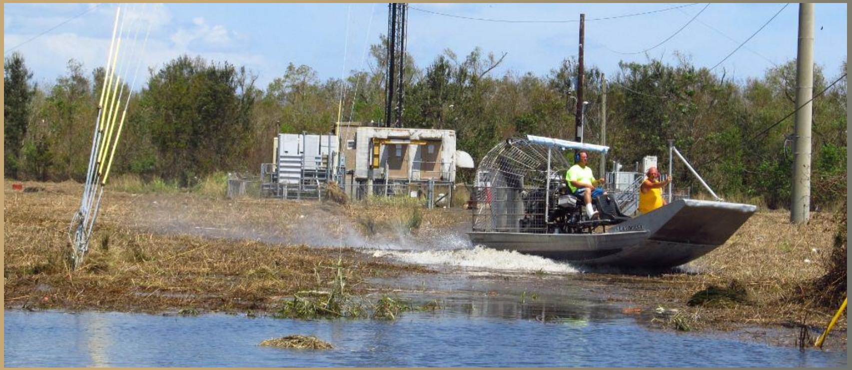
Conclusion

- Dependencies on power grids is a critical resilience vulnerability for ICT systems.
- Varying energy storage capacity allows regulating the degree of dependency on a power grid.
- Microgrids and possibly dc power distribution architectures may provide improved resilience than traditional grid technological approaches.
- Effective microgrid planning approaches:
  - Inclusion of energy storage (e.g. batteries)
  - Diversifying power sources
  - Manage load, local power generation and energy storage levels in an integrated way.
  - Use DC power distribution

Thank you very much

Questions?

Alexis Kwasinski (akwasins@pitt.edu)



University of Pittsburgh

PITT SWANSON ENGINEERING ELECTRICAL & COMPUTER

e LEAdERS @PITT