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R&D Needs in Resilient Distribution Systems

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Resiliency

- Resiliency: “..ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions..”*
- For distribution systems, resiliency means the ability to withstand major disturbances.
  - Natural disasters: Earthquake, tsunami, hurricane, flood, forest fire, ice storm, etc.
  - Major events:
    - Superstorm Sandy, US, 2012
    - East Japan earthquake, March 11, 2011
    - Ice storm in Québec, Canada, 1998

Blackout in Manhattan caused by Sandy

Source: Beth Buczynski, “What Hurricane Sandy Taught Us About America's Crumbling Infrastructure”, http://inhabitat.com/what-hurricane-sandy-taught-us-about-americas-crumbling-infrastructure/

* Office of the Press Secretary of the White House, Presidential Policy Directive 21 – Critical Infrastructure Security and Resilience [Online]. Available: http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

Enhancing Resiliency in Distribution Systems

- Nearly 90% of power outrages occur in distribution systems.*
- Natural disasters cause large-area and extended outages for electricity services, resulting in unsafety and huge losses.

Downed utility poles and wires after hurricane

Source: Rebecca Smith, "Getting 'Smart' on Outages", http://online.wsj.com/news/articles/SB10001424052970204755404578101591971017814

Power poles pulled down by ice storms

Source: "Thousands in the dark after ice storms cut power lines in US, Canada", http://eyebuster.com/thousands-in-the-dark-after-ice-storms-cut-power-lines-in-us-canada/

* H. Farhangi, "The path of the smart grid," *IEEE Power & Energy Magazine*, vol. 8, no. 1, pp. 18-28, Jan. 2010.

Damages to Distribution Grids by Superstorm Sandy

Downed power lines and other debris litter the streets of Seaside Heights, N.J., on 31 October 2012, two days after Superstorm Sandy made landfall in the US.*

The storm surge that accompanied Superstorm Sandy sent water rushing through the streets near a substation in Brooklyn, N.Y. Restoring a flooded substation takes much longer than restoring a downed power line because of the large amounts of water, rust, and mud left trapped in the structure.*

* Source: Nicholas C. Abi-Samra, “One Year Later: Superstorm Sandy Underscores Need for a Resilient Grid”, IEEE Spectrum, http://spectrum.ieee.org/energy/the-smarter-grid/one-year-later-superstorm-sandy-underscores-need-for-a-resilient-grid

Differences Between Typical Outages and Catastrophic Outages Due to Extreme Events

Typical Outages	Catastrophic Outages
• **Single faults**: In most cases, there is only one faulted components.	• **Multiple faults**: Multiple electrical facilities are damaged.
• **Small amount of load and a small number of customers are involved.**	• **Large amount of load and a large number of customers are out of services.**
• **Power is available**: Most power sources are working and stay connected.	• **Lack of power**: Power sources can not access the load or are out of service.
• **T&D network remains intact**: Outage loads are easily connected to sources.	• **T&D network damaged**: Overhead lines, transformers, substations damaged.
• **Easy to repair and restore**	• **Difficult to repair and restore**

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Approaches to Resilient Distribution Systems*

- Construction
  - Improving design and construction standards, overhead distribution reinforcement, undergrounding, etc.
- Maintenance
  - Online temperature monitoring, power system assessment, thermal imaging, vegetation management, etc.
- Design and Operation – Smart Grid Techniques
  - Fault Location, Isolation, and Service Restoration (FLISR)
  - Integrated Distribution Management System (IDMS)
  - Advanced Metering Infrastructure (AMI)
  - Advanced Control and Communication System
  - Distribution Operation Training Simulator
  - Microgrid

* G. Davis, A. F. Snyder, and J. Mader, "The future of Distribution System Resiliency," *2014 Clemson University Power Systems Conference (PSC)*, pp. 1-8, Mar. 2014.

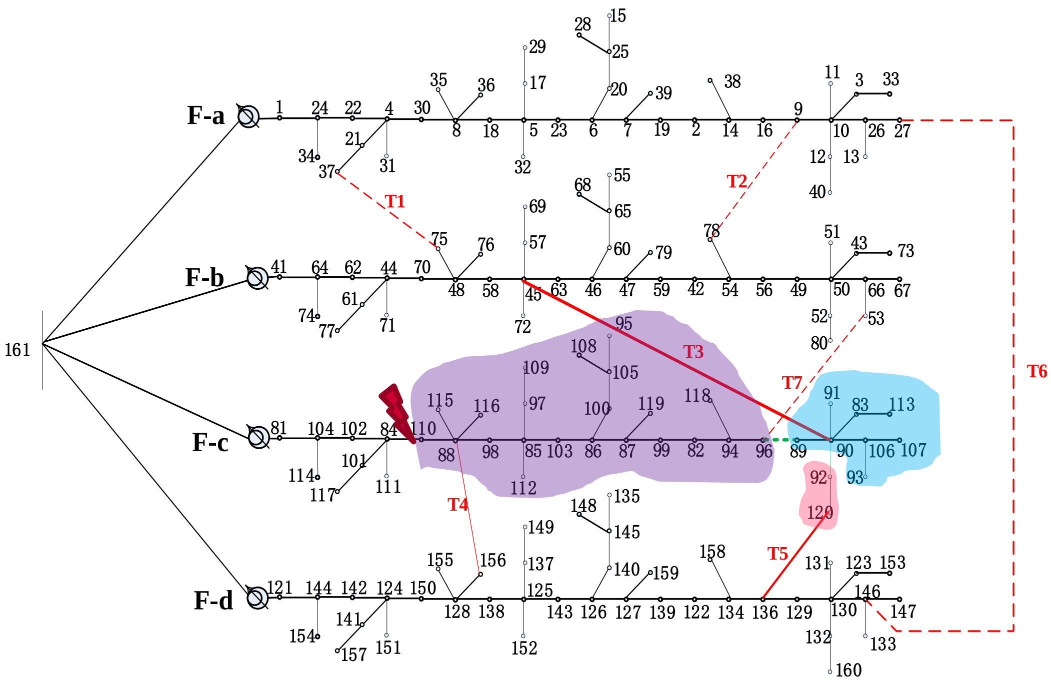
Smart Grid Technique (1) Distribution System Restoration

- Distribution system restoration (DSR) is aimed at restoring load after a fault by altering the topological structure of the distribution network while meeting electrical and operational constraints. *
- Self-healing capability
- Effective restoration algorithms
- Implementation: remote vs manual operations

* J. Li, X.-Y. Ma, C.-C. Liu, and K. P. Schneider, "Distribution system restoration with microgrids using spanning tree search," IEEE Trans. Power Syst., Aaccepted.

Example

Taxonomy “R3-12.47-2” is a prototypical distribution feeder model for moderate urban areas. *



- Without DSR, outage load on feeder **F-c** can only be restored after the repair of the faulted component.
- With DSR, outage loads are restored by the neighboring feeders, i.e., **F-b** and **F-d**, after the faulted section is isolated.
- ***Outage time reduces with DSR*.**

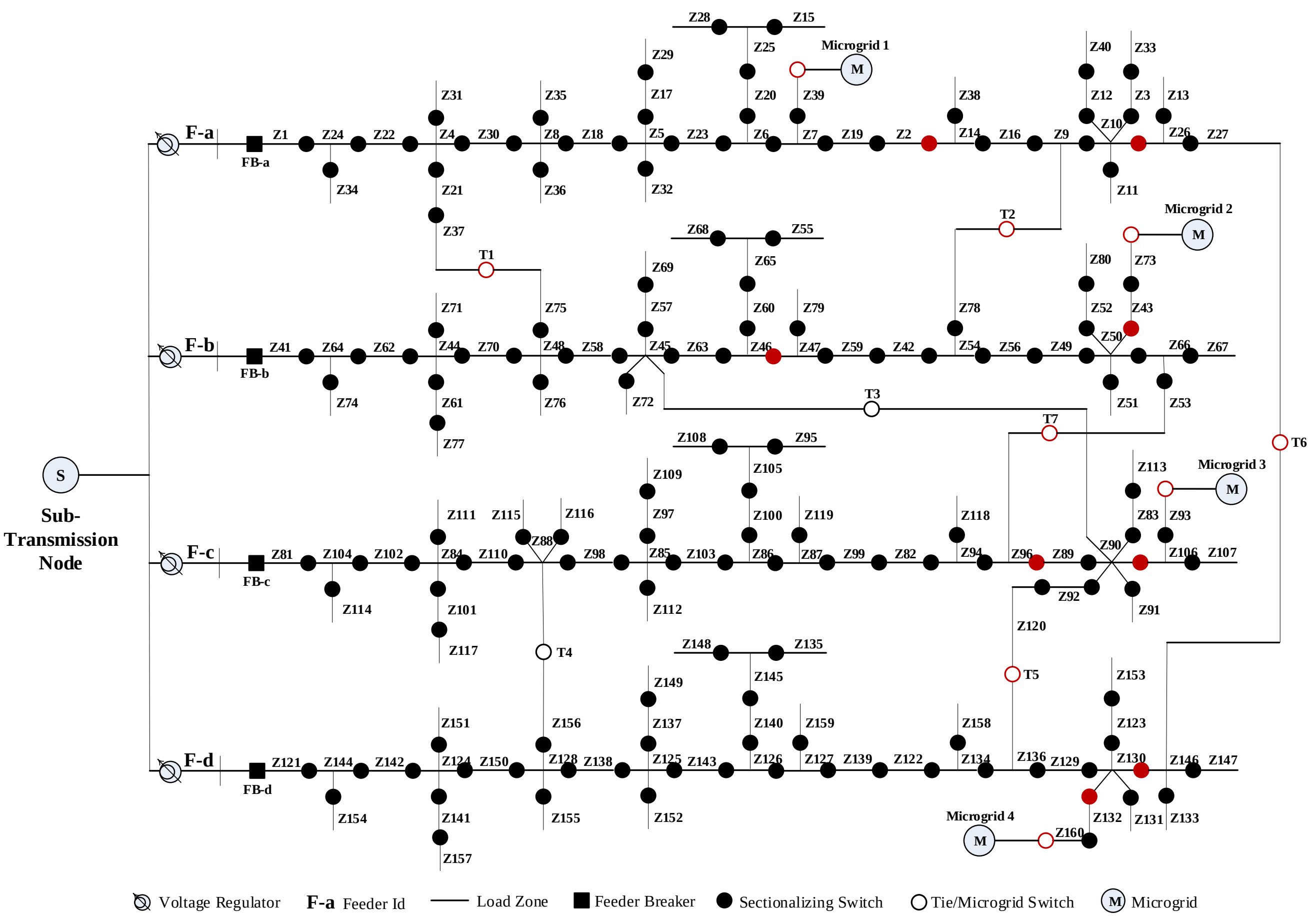
Restoration Scheme
Open: 90-92, 96-89
Close: 88-156(T4), 136-120(T5), 45-90(T3)

* K. P. Schneider, Y. Chen, D. Engle, and D. Chassin, "A Taxonomy of North American Radial Distribution Feeders,“ *Proc. IEEE PES Gen. Meet.*, 2009, pp. 1-6.

Smart Grid Technique (2) Fast Recovery with Remote Control Ability

- Upgrading existing manual switches in a distribution system to remote-controlled switches (RCSs) enables faster response to disturbances.
- RCSs are costly
- For implementation, the optimal number and locations of RCSs should be determined
- Objectives:
  - Improve reliability indices
  - Minimize the sum of outage cost and RCS investment cost
  - Maximize restoration capability

Example



- It can be shown that upgrading of 17 out of 167 switches will achieve ***maximal restoration capability*** – restoration can always be performed by RCSs after the faulted section is isolated.

Smart Grid Technique (3) Microgrids

- Consisting of DERs, storage, and controllable load
- Grid-connected and islanded modes
- Microgrids enhance resiliency of distribution systems in two ways:
  - Providing reliable electricity supply for critical loads within microgrids.*
  - Supporting outage load recovery of distribution systems.**

* C. Abbey, D. Cornforth, N. Hatziargyriou, K. Hirose, A. Kwasinski, E. Kyriakides, G. Platt, L. Reyes, and S. Suryanarayanan, "Powering through the storm," *IEEE Power & Energy Magazine*, vol. 12, no. 3, pp. 67-76, May 2014.
** J. Li, X.-Y. Ma, C.-C. Liu, and K. P. Schneider, "Distribution system restoration with microgrids using spanning tree search," *IEEE Trans. Power Syst.*, to be published.

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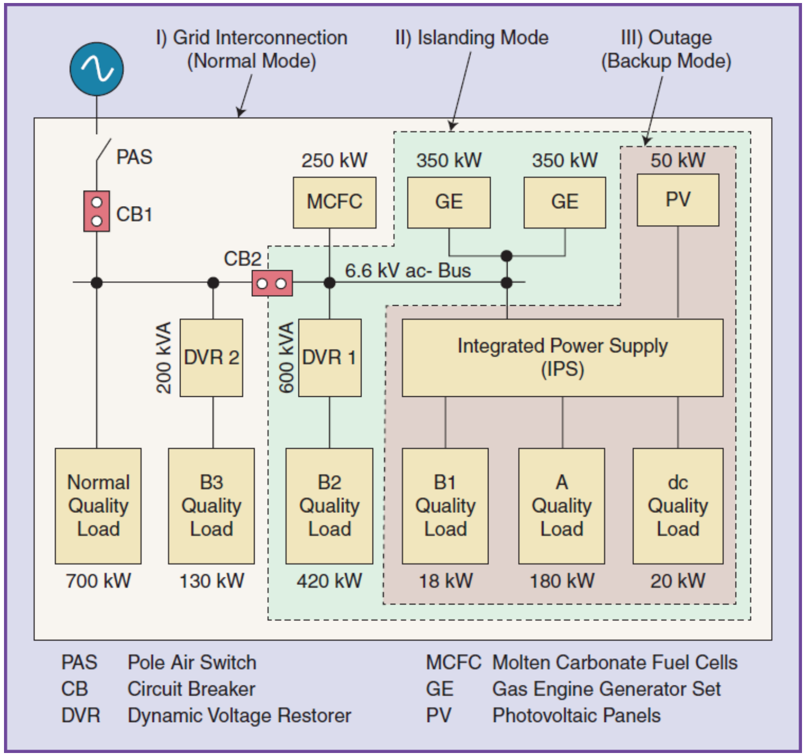
Example – Microgrid Provides Reliable Electrical Supply to Critical Loads

- A microgrid installed in Sendai, Japan*



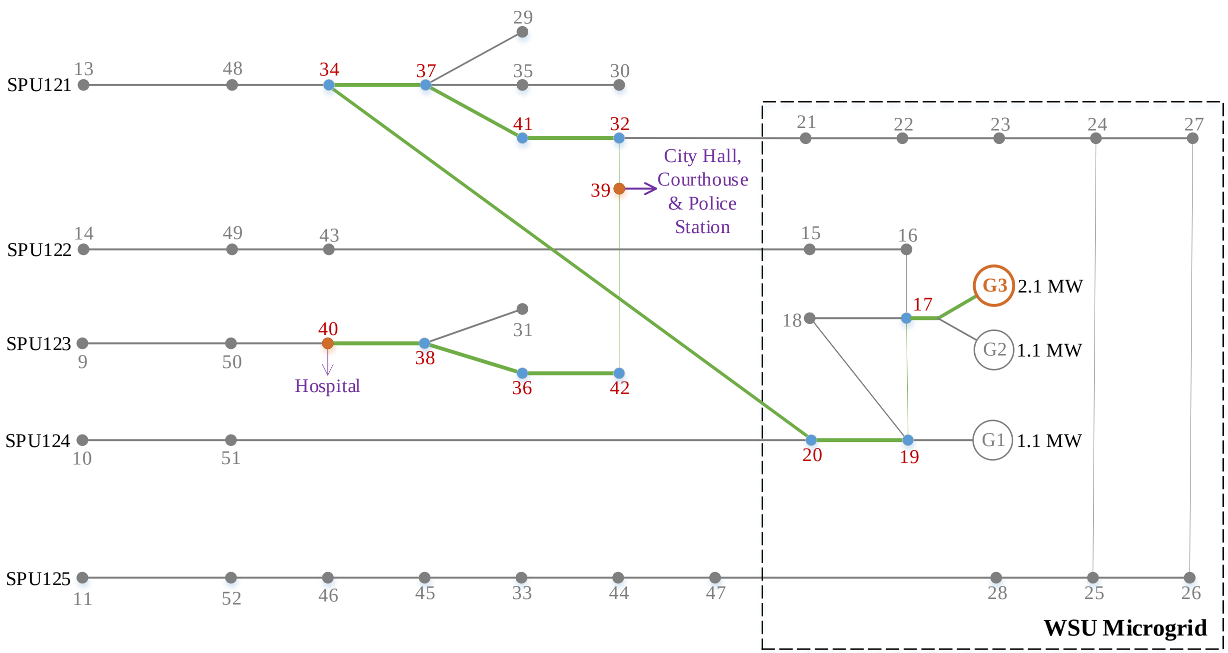
- East Japan earthquake, March 11, 2011
- Accident at the Fukushima #1 nuclear power plant
- Power generators used to power university hospitals and welfare facilities.
- The supply of high-quality power such as dc and uninterruptible ac to load continued without interruption even immediately after power was lost to the rest of Sendai.

Source: Marianne Lavelle, "Japan Battles to Avert Nuclear Power Plant Disaster", http://news.nationalgeographic.com/news/energy/2011/03/110314-japan-nuclear-power-plant-disaster/

* C. Abbey, D. Cornforth, N. Hatziargyriou, K. Hirose, A. Kwasinski, E. Kyriakides, G. Platt, L. Reyes, and S. Suryanarayanan, "Powering through the storm," *IEEE Power & Energy Magazine*, vol. 12, no. 3, pp. 67-76, May 2014.

Example (2) – Microgrid Supports Fast Recovery of Distribution Systems

- WSU microgrid supports Pullman distribution system



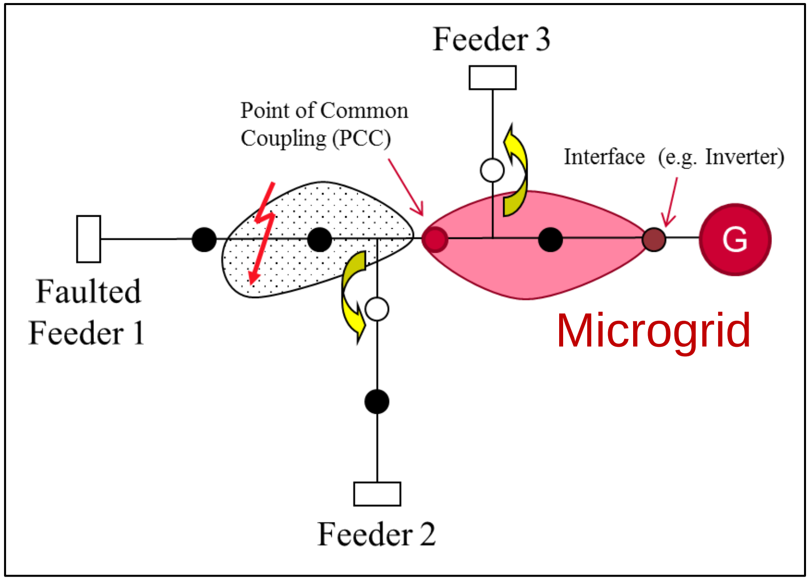
- Assume that all five feeders in the SPU substation out of services.
- DERs in the WSU Microgrid pick up critical loads in the Pullman system, i.e., Hospital, City Hall, etc.
- Restoration scheme is validated by GridLAB-D power flow.

- Five feeders are served by the South Pullman (SPU) Substations.
- There are 3 generators on the WSU east campus.

R&D Needs: Microgrids Increase Resiliency

- Smart grid applications enhance resiliency of distribution systems
  - DG/DER, Microgrid resources survivability must be high
  - Access through distribution to critical loads must be maintained

Source: Jesse Jenkins, "The Smart Grid and Natural Disasters", http://theenergycollective.com/dickdeblasio/155946/smart-grid-and-natural-disasters



Restoration schemes considering DERs and Microgrids

R&D Needs: Vulnerability wrt Extreme Events

- Critical load needs to be identified
- Access of generation and distribution facilities to critical load must be resilient
- System study to determine the vulnerability or survivability of critical load incorporating all generation and distribution facilities

Source: Peter Bronski, "Sandy One Year Later", http://blog.rmi.org/blog_2013_10_30_Sandy_One_Year_Later

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R&D Needs: Automation Increases Resiliency

- Further advancement in distribution automation - planning and operation
  - Enable efficient implementation of smart grid applications through remote monitoring and control
  - Restoration can be performed by remote-controlled switches
  - Infrastructure development:
    - Advanced metering infrastructure (AMI)
    - Remote-controlled switches/transformers/voltage regulators
    - Telecommunication infrastructure, such as WAN and LAN.
    - IT infrastructure, such as data management, GIS, and so on.
    - DMS, OMS, and microgrid EMS
  - Functional and cost-benefit requirements should be considered

R&D Needs: Realistic Test Beds Accelerates Technology Deployment

- Development of realistic test beds
  - One of the major difficulties for utilities to adopt new technologies is the absence of near-real world R&D capability.*
  - New architectures, components, and applications need to be evaluated in near-real world environment before they are applied to the real systems.
    - Design of Microgrids
    - Advanced metering, communication, protection, and control
    - Smart grid applications, such as service restoration, control strategies for microgrids, coordinated protection schemes, etc.

* H. Farhangi, "The path of the smart grid," *IEEE Power & Energy Magazine*, vol. 8, no. 1, pp. 18-28, Jan. 2010.

R&D Needs: Evolution of Technology

- Coordination between traditional and new technologies
  - Traditional distribution systems cannot become resilient and smart distribution systems in one step
  - Traditional and new technologies will coexist for decades.
  - Coordination is necessary:
    - Coordination between different levels of control systems, e.g., DMS and microgrid EMS
    - Coordinated protection/restoration schemes for distribution systems with DERs and microgrids
    - New market mechanisms considering traditional and new participants

* H. Farhangi, "The path of the smart grid," *IEEE Power & Energy Magazine*, vol. 8, no. 1, pp. 18-28, Jan. 2010.