PNNL-SA-103186

2014 Smart Grid R&D Program Peer Review Meeting

(Microgrids as a Resiliency Resource)

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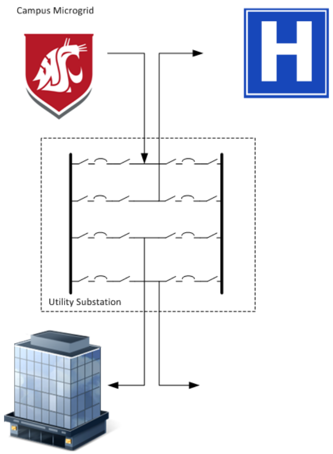
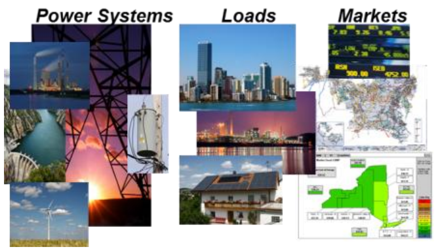
Microgrids as a Resiliency Resource

Objective

To increase the resiliency of the nation's electric infrastructure via the integration of microgrids. Increased resiliency can be achieved by using microgrids to support their own critical loads, community critical loads, and/or to act as a black start resource.





Life-cycle Funding Summary ($K)

	Prior to FY 14	FY14, authorized	FY15, requested	Out-year(s)
PNNL*	250	380	300	600
WSU	188	150	166	320

- In FY13 GridLAB-D Analysis contains three focus areas, "Micro Grids as a Resiliency Resource" is one area.

Technical Scope

To use distribution level dynamic simulations to determine the capability of microgrids to act as a resiliency resource. Simulations are conducted on the Washington State University system, as well as portions of the Avista Utilities system. Operational generator tests, and an AMI diagnostics system, are used to validate simulation results. The validated simulations are then used to determine to what extent microgrids can be used as a resiliency resource.

Problems and Needs

- Wide area outages due to extreme weather events are becoming more common in the United States, and because of their scale, building more central generators and transmission lines will not address the associated problem.

- Microgrids have proven themselves capable of supplying load when utility service is lost. Despite this benefit, the high cost of micro grid deployment, and operations, has resulted in only a modest number of deployments.

- To increase the adoption rate of microgrids, by increasing their value, it is necessary to examine the full spectrum of benefits that can be realized. This project focuses on values derived from their use as a resiliency resource.
  - Customer Resource
  - Community Resource
  - Black Start Resource

- To facilitate the utilization of microgrids as a resiliency resource, analysis capabilities are needed that will allow for designers and integrators to have greater flexibility in exercising their engineering judgment.

- This work focuses on the development of dynamic simulation capabilities to support both the design, and the development, of operational strategies.

Significance and Impact

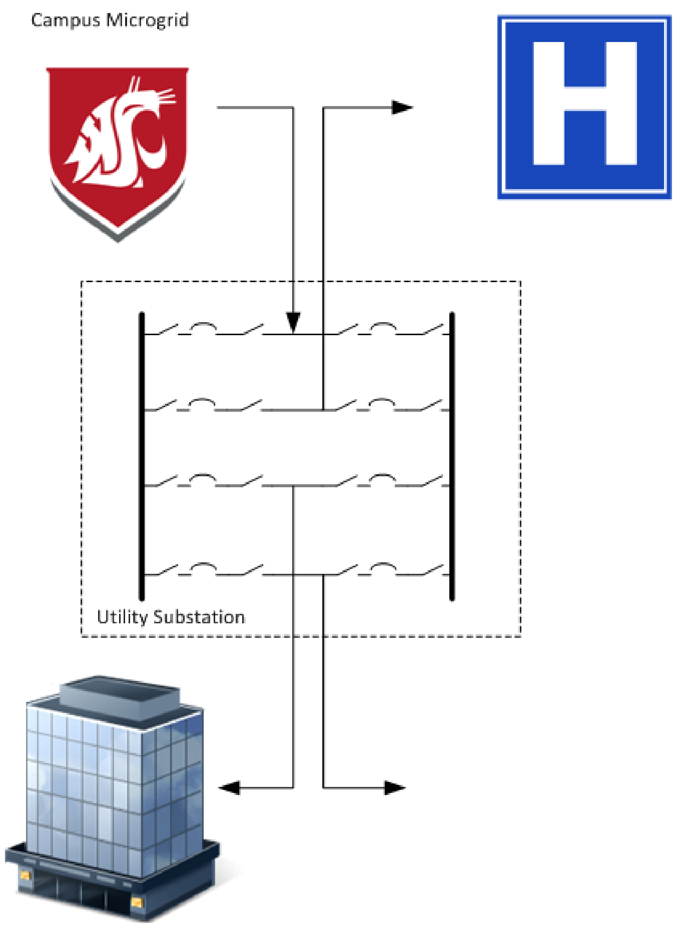
- Improved resiliency can be broken into three phases:
  - **Prevention**: best practices in advance to “harden” the system
  - **Survivability**: the ability of the system to react to real-time events
  - **Recovery**: the ability to rapidly restore end-use load after disruptive events

- Microgrids have the ability to improve the survivability of distribution systems, and to support recovery.

- Resiliency resource potential of microgrids
  - **Customer Resource**: the traditional application of microgrids where only the local loads are supplied.
  - **Community Resource**: an extended application of microgrids where critical loads outside of the normal microgrids boundaries are supplied.
  - **Black Start Resource**: a new application where microgrids are used to support the auxiliary loads of a thermal plant that does not have native black start capabilities.

Technical Accomplishments

- Developed a generalized method of conducting dynamic simulations at the distribution level.
  - **Open Source**: Implemented in the GridLAB-D simulation environment.
  - **Simplicity**: Models are easier to build than a full electromagnetic model.
  - **Detailed**: A level of detail consistent with transmission dynamic solvers.
- Developed a dynamic model of the WSU and Pullman system that has been used to examine the use of microgrids as a community resource.
  - The model contains the WSU system, and portions of four Avista feeders.
  - This model will be used to evaluate the dynamic impacts on switching, protection, and motor controllers.
- Two portions of the dynamic model must be validated:
  - **Generators**: Currently validating generator models based on operational testing on two of the three WSU generators.
  - **System**: In the process of developing an AMI-based diagnostic system to evaluate the system model. (This will be discussed in a later presentation)



FY14 Performance and Results

- Dynamic solvers have been implemented in GridLAB-D that allow for full unbalanced simulations at the distribution level.
    - **Multi-Time Scale**: Seamless integration between quasi-steady state and dynamic simulation time-scales.
    - **Multiple Devices**: Models for generators, governors, and regulators have been developed.
    - **Speed**: Significantly faster than full electromagnetic simulations.

- A completed dynamic model of the WSU and Avista feeders has been completed. (>2,200 nodes)
    - **Size**:
    - **Validation-Generator**: Validation of the generator model data is currently being conducted.
    - **Validation-System**: A validation method for the system model is being developed. (This will be discussed in a later presentation)

- By the end of FY14, it will be possible to examine the dynamic impact of transformer and line in-rush currents; which is essential for examining the use of micro grids as a resiliency resource. This will allow

Future Plans
FY15

- Verify strategies for using microgrids as a community resource
  - **Operations**: Using the existing dynamic model, the effects of transformer in-rush and line charging will be examined with respect to generator sizing and voltage deviations.
  - **Protection**: Impacts on the existing protection scheme will be examined.

- Microgrids as a black start resource
  - Using the existing dynamic model, the effects of transformer in-rush and line charging will be examined to determine the reach of this resource.
  - Evaluate the ability of microgrids to support units that are not traditionally black start.

- WSU will continue work on restoration/recovery schemes to enhance resiliency.

Microgrids to Enhance Fast Recovery of Distribution Systems

(Washington State University)

- 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. *Fast recovery* is essential for a resilient system.
- Generation resources and control capabilities of microgrids enhance *fast recovery* of distribution systems.
- ***To demonstrate feasibility for microgrids to enhance distribution systems by serving critical load and strengthening fast recovery capability following a major outage.***
- Challenge: designing a practical and efficient strategy to make full use of power sources within microgrids to support distribution system restoration.

* Office of the Press Secretary of the White House, Presidential Policy Directive – 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

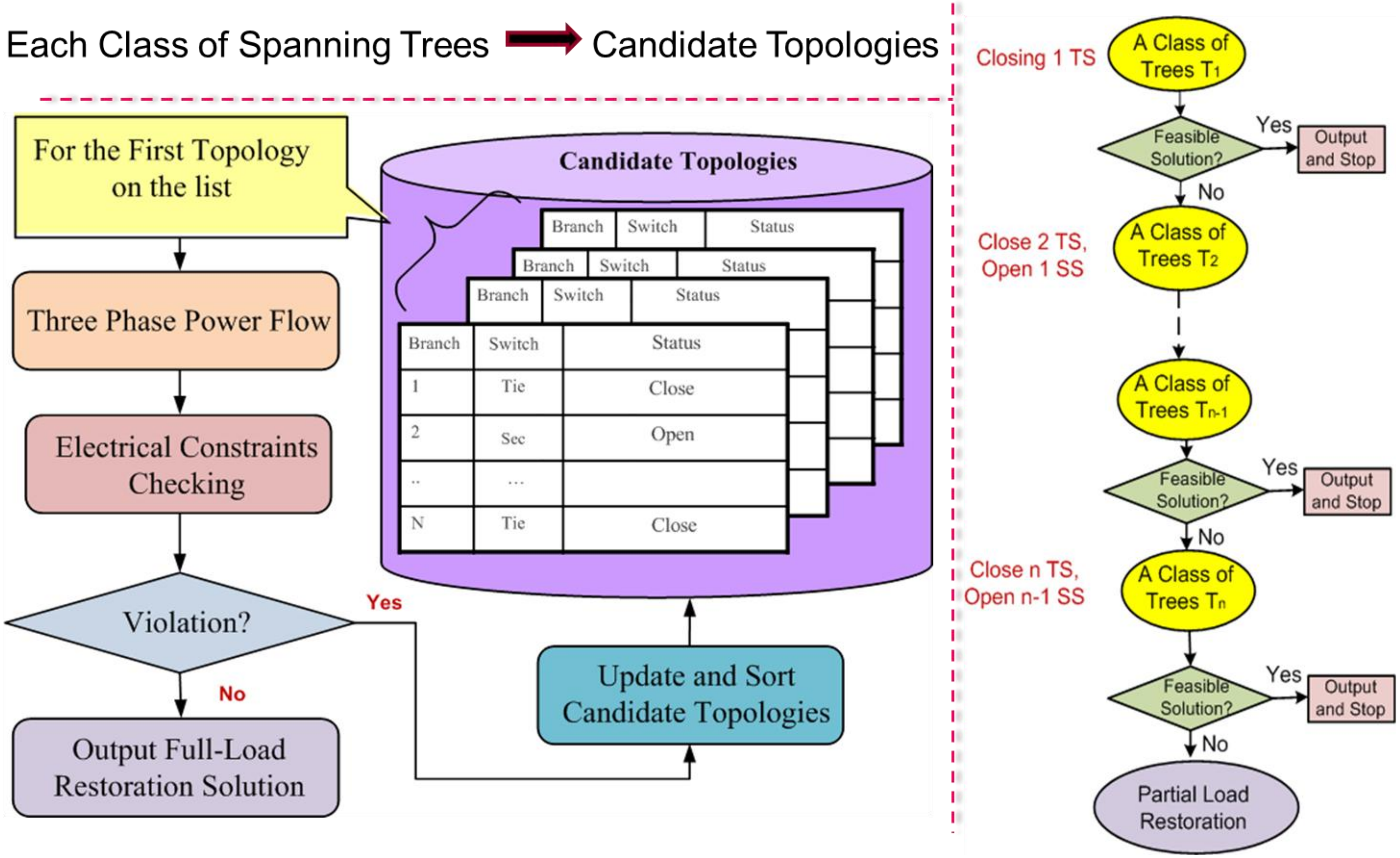
Main Results So Far

- Graph-theoretic distribution system restoration (DSR) incorporating microgrids - "*spanning tree search" algorithm*. Paper accepted by *IEEE Trans. Power Systems.**
- Restoration software tool developed based on MATLAB and GridLAB-D.
- Pullman-WSU distribution system has been simulated and analyzed.
  - A transient model for WSU Microgrid in Simulink.
  - Reliability analysis to evaluate contribution of WSU microgrid.
  - Restoration scheme under major outages.
- Algorithm designed for optimal planning to increase remote-controlled switches in a distribution system to achieve maximal restoration ability.

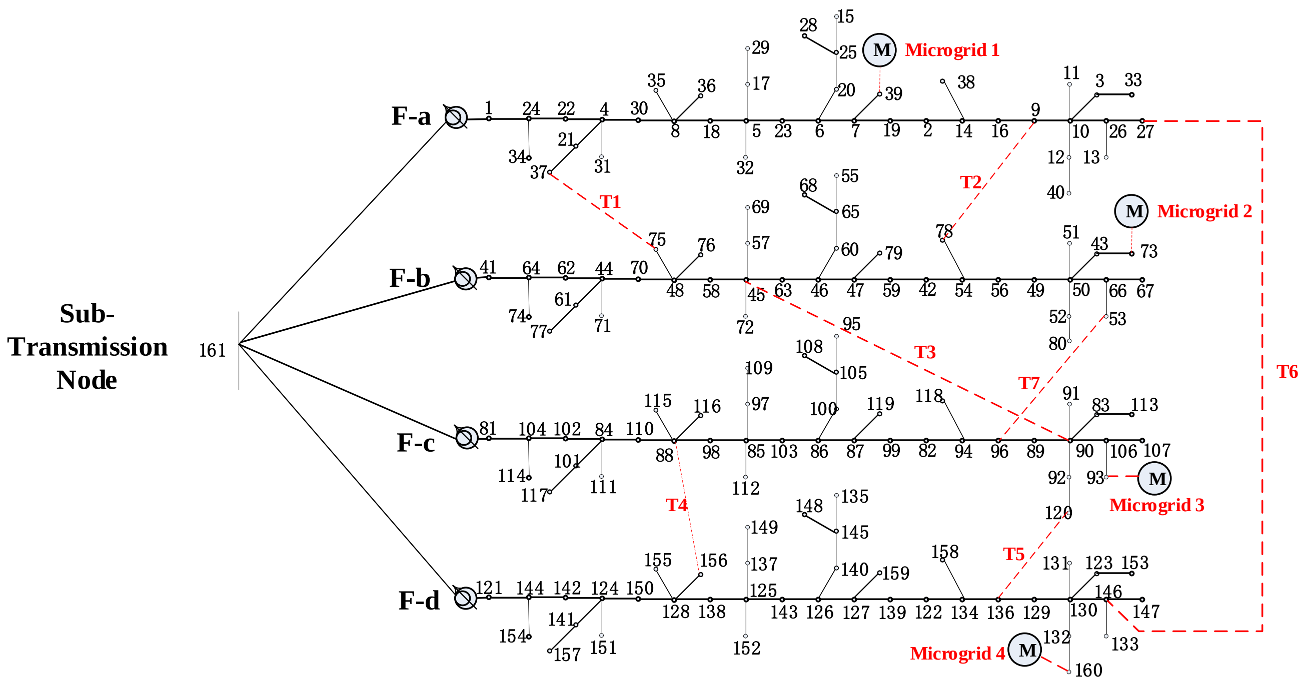
* J. Li, X.-Y. Ma, C.-C. Liu, and K. P. Schneider, "Distribution system restoration with microgrids using spanning tree search," *IEEE Trans. Power Syst.*, to be published.

DSR Algorithm Based on Spanning Tree Search

- *Spanning tree search* proposed to identify a post-outage distribution system topology that will achieve *a minimum number of switching operations* and take full advantage of the resources of microgrids.



Restoration with/without Microgrids

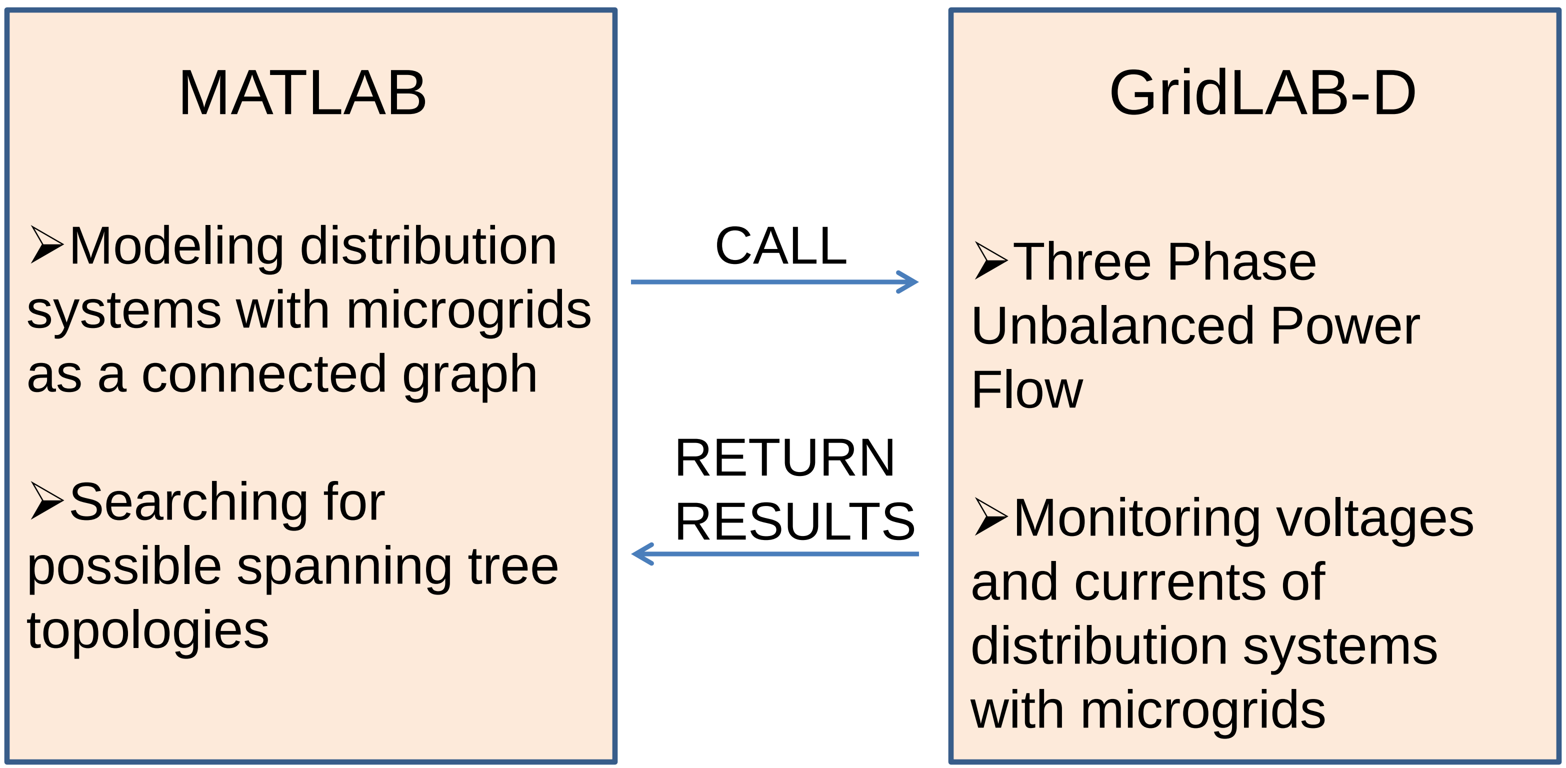


1. Microgrids reduce the number of switching operations during restoration (Scenario 1) ;
2. Using the capability of microgrids to pick up more interrupted load (Scenario 2).

Scenario	Fault Location	Switching Operations without Microgrids	Switching Operations with Microgrids
1	6-7	Open: 49-50, 90-92 Close: 78-9, 53-96, 136-120	Close: 39-Microgrid1
2	127-139	Open: 46-47, 96-89 Close: 136-120, 53-96, 45-90 Partial Restoration, 315.04 kVA load should be shed at **F-b**	Open:50-43, 90-92 Close: 45-90, 73-Microgrid2, 136-120

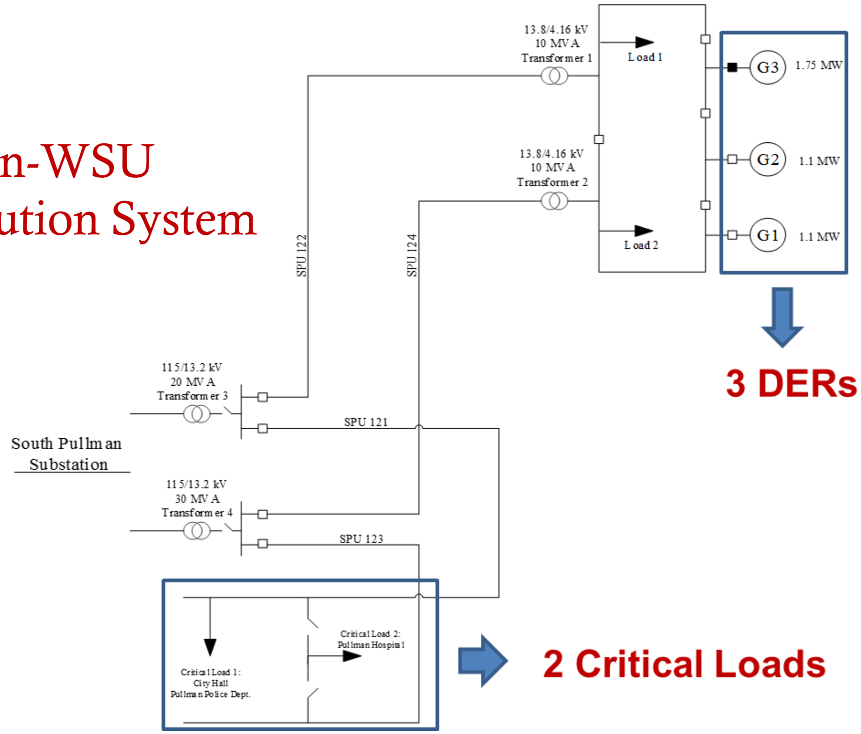
Distribution Restoration Software

- A restoration program is developed based on MATLAB and GridLAB-D



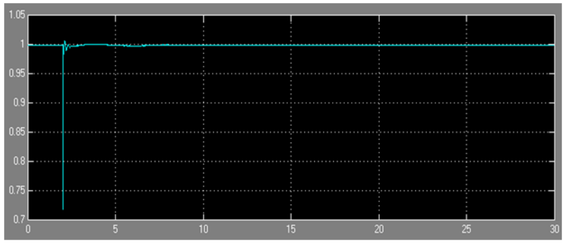
Dynamic Simulation of WSU Microgrid

Pullman-WSU Distribution System

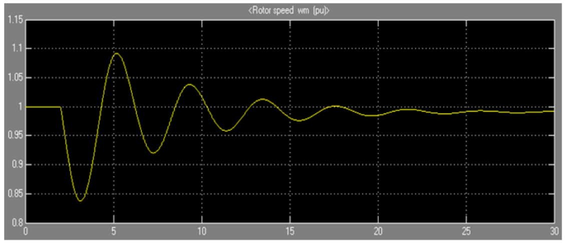


Case I: Transfer from Grid-Connected Mode to Isolated Mode

Terminal Voltage of G1

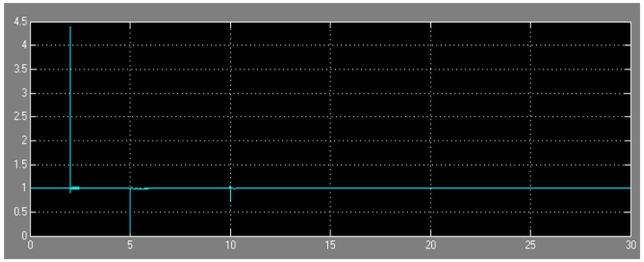


System Frequency

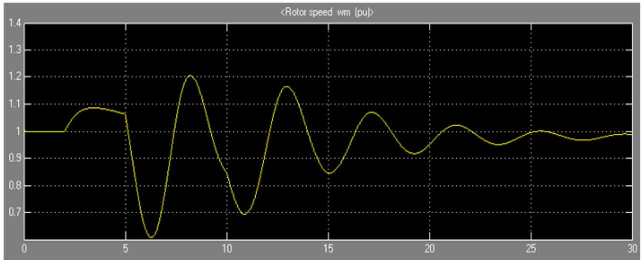


Case II: Energize Transmission Lines and Load One by One

Terminal Voltage of G1



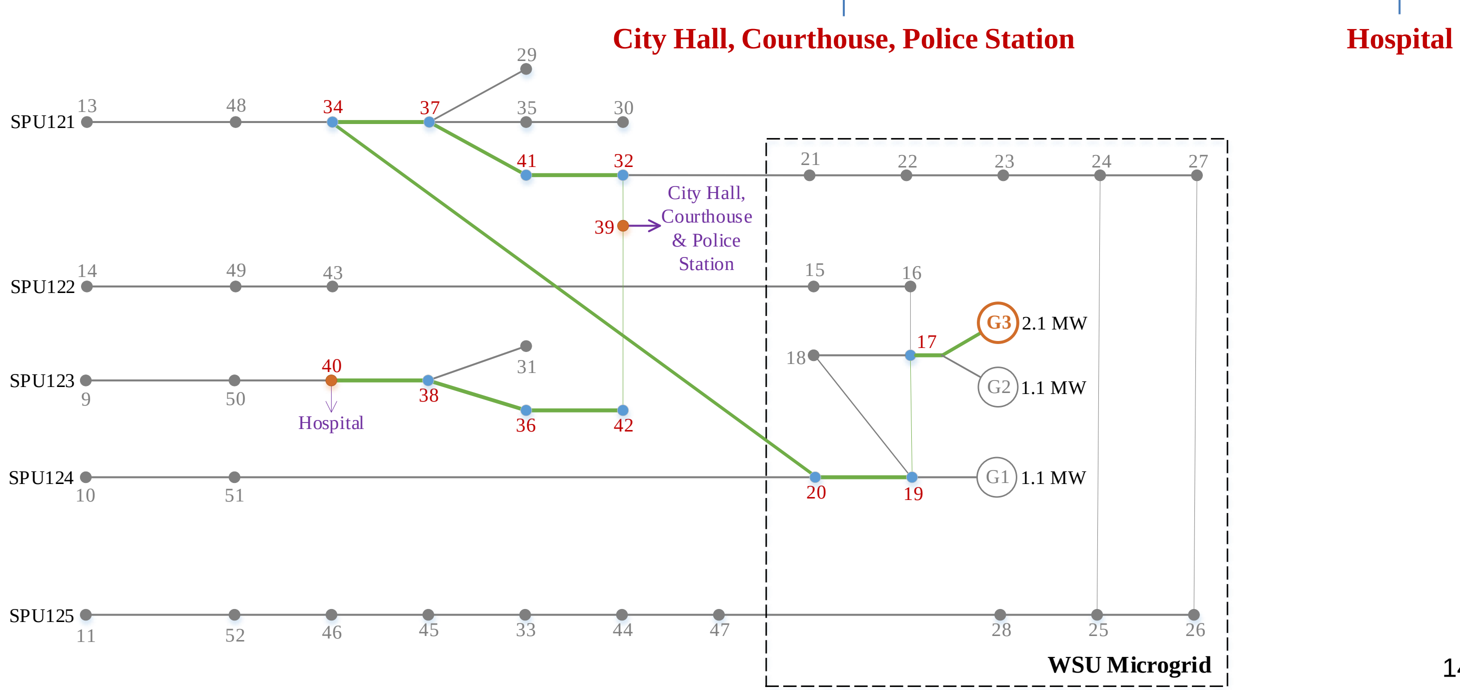
System Frequency



Restoration Actions for Pullman-WSU System Under a Major Outage

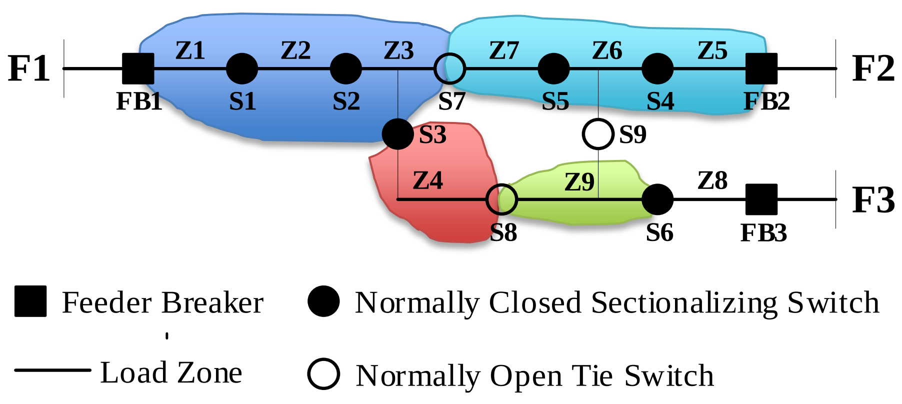
- A restoration scheme is found by spanning tree search to restore critical loads in a major outage in Pullman.
- Restoration scheme validated by *GridLAB-D power flow* step by step.
- Dynamic constraints will be considered and simulated with GridLAB-D in FY14.

G3 → 17 → 19 → 20 → 34 → 37 → 41 → 32 → 39 → 42 → 36 → 38 → 40



Enhancing Resiliency by Further Automation

- Distribution automation enhances resiliency of distribution systems through remote monitoring and control techniques.
- Upgrading existing manual switches to remote-controlled switches (RCSs) enables faster response to disturbances.
- A greedy rule-based algorithm is proposed to determine the optimal number and locations of RCSs for a distribution system.
  - *Maximum restoration ability is achieved*
  - *Minimum number of RCSs is determined*



- Load Group and Switch Group
- Weighted Set Cover
- Greedy Strategy

Reliability Analysis for Pullman-WSU Case

Assuming

- Permanent (short circuit) failure rate (λ_P) is 0.02
- Mean time to repair (MTTR) is 4 hours
- Mean time to switch (MTTS) is 90 minutes

Three restoration strategies are considered

- Strategy 1 (S1): *Restoration after repair.*
- Strategy 2 (S2): *Restoration after fault isolation*. Spanning tree search algorithm is used and DERs in WSU Microgrid are considered
- Strategy 3 (S3): *Restoration with further automation*. Three manual switches are upgraded to remote-controlled switches.

Reliability Indices (Not included if outage duration < 5 min)

- **SAIFI** (/year): 0.11197 (S1) → 0.11197 (S2) → 0.10434 (S3) ↓ 6.81%
- **SAIDI** (minute/year): 36.949 (S1) → 20.533 (S2) ↓ 44.4% → 17.774 (S3) ↓ 13.4%

Plan for FY15

- Previous work shows the feasibility for microgrids to enhance resiliency of distribution systems. For practical applications, more research need to be conducted.
- **1. Coordinated Restoration Strategies for Integrated Microgrid-Distribution Systems**
  - Coordination between DMS and Microgrid EMS
  - Consider benefits for both distribution systems and microgrids
- **2. Develop a system restoration algorithm that incorporates microgrids as a source of black start capability.**
  - Provide cranking power to other power plants that require external help to restart.
  - System stability and operational constraints must be evaluated before the sequence of actions is implemented.

Questions

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