Microgrid's Impact on Power Grid Resilience

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Damages to Distribution Grids by Nature Disasters

- Natural disasters cause large-area and extended outages for electricity services, resulting in unsafety and huge losses.


Resilience in Distribution Systems

• Resilience: “..ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions..”*

• For distribution systems, resilience means the ability to withstand major disturbances. *Fast recovery* is essential for a resilient system.

• 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.

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Microgrids Enhance Restoration Capability

- Generation resources and control capabilities of microgrids enhance fast recovery of distribution systems.
- When a blackout occurs, microgrids can be controlled to provide an efficient DSR strategy to restore critical loads in the distribution system and hence improve the resilience.

Restoration schemes considering DERs and Microgrids
PNNL Test System with Microgrids
Restoration with/without Microgrids

• Microgrid Enhance Restoration Capability
  – Using the capability of microgrids to pick up more interrupted load (Scenario 1 & 2)
  – Microgrids reduce the number of switching operations during restoration (Scenario 3)

<table>
<thead>
<tr>
<th>Scenario #</th>
<th>Fault Location</th>
<th>Switching Operations without Microgrids</th>
<th>Switching Operations with Microgrids</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Zone Z43</td>
<td>---</td>
<td>Close: 73-Microgrid2</td>
</tr>
</tbody>
</table>
Reliability Enhancement by Microgrids

- SAIDI, SAIFI and Outage Cost are calculated. *

<table>
<thead>
<tr>
<th>Index</th>
<th>Without Microgrids</th>
<th>With Microgrids</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIDI (minute/year)</td>
<td>196.54</td>
<td>182.64</td>
<td>7.07%</td>
</tr>
<tr>
<td>SAIFI (/year)</td>
<td>0.7800</td>
<td>0.7800</td>
<td>0 % **</td>
</tr>
<tr>
<td>Outage Cost (k$/year)</td>
<td>3729.8</td>
<td>3426.5</td>
<td>8.13%</td>
</tr>
</tbody>
</table>

* Assume that the permanent failure rate for each zone is 0.02, the mean time to operate a (manual) switch is 90 minutes, and the cost for outage load is $1 per kW per minute, respectively.

** In order to improve SAIFI, remote-controlled ability should be added.
Evaluation of Resilience

• System Performance and Resilience

The resilience is evaluated by the integration of system performance over the period of interest:

\[ R = \int_{t_r}^{t_{ir}} F(t) \, dt \]

In our study, the periods of service restoration process and post-restoration state are considered.

Objective of Critical Load Restoration

• The contribution of serving a critical load (indexed by $i$) to the system performance $F(t)$ is assumed to be in proportion to its priority level, denoted by $c_i$.

• Resilience: cumulative service time to critical loads weighted by their priority

\[
\text{Resilience: } R = \int_{t_r}^{t_i} F(t) \, dt
\]

\[
\max \sum_{i \in Z_{uni}} t_i c_i
\]
Using Microgrids for Service Restoration to Critical Loads: Challenges

• Dynamic Features of DGs
  – DGs in microgrids have relatively small capacity
  – Abilities to absorb shocks and maintain stability
  – In-rush
  – Protection actions may lead to fail in restoration

• Scarcity of Generation Resources
  – Fuels for generators
  – Electric energy in storage devices
  – Hard to get supplemented after an extreme event
Constraints of Critical Load Restoration

• Dynamic constraints
  – Stability and limits on steady-state frequency
  – Limits on transient frequency
  – Limits on terminal voltages and currents of DGs

• Generation resource constraints
  – Limits on the amount of energy that a microgrid can provide to external critical loads

• Operational Constraints
  – Unbalanced three-phase power flow
  – Limits on steady-state bus voltages and line currents
  – Limits on steady-state output power of DGs

• Topological Constraints
  – Maintain a radial network structure
A heuristic to determine restoration strategy

- Three feeders
- Two local sources
- Three critical loads
- Four faulted zones

Examples of load groups

<table>
<thead>
<tr>
<th>Source</th>
<th>Load Zones</th>
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<tbody>
<tr>
<td>1</td>
<td>Z3, Z2, Z1 (CL1)</td>
</tr>
<tr>
<td>1</td>
<td>Z3, Z7 (CL2)</td>
</tr>
<tr>
<td>2</td>
<td>Z8, Z9 (CL3)</td>
</tr>
</tbody>
</table>

Identify Candidate Restoration Paths

Form Load Groups

Solving a Maximum Coverage Problem

Examples of Restoration Paths starting from Source 1

Examples of Load Zones

Source 1

CL1

Z3, Z2, Z1

CL2

Z3, Z7

CL3

Z8, Z9

Source 2

Interrupted Island 1

Interrupted Island 2

Interrupted Island 3

Interrupted Island 4

Source 1

Z1 Z2 Z3 Z4 Z5 Z6

Z8 Z7

S2 S3 S4 S5 S6

S10 S9

S7 S8

DG

M

S1

S13

Z9

Source 1
Case Study: PNNL Test System

- Utility power unavailable
- 7 faults
- 4 microgrids
- 5 critical loads
- Restoration path identified (green paths)
- Switching operations determined
Dynamic Simulation using GridLAB-D

- Transient Frequency of Microgrids 1 and 3

Microgrid 1 restores critical loads CL1, CL2, and CL3 in five switching operations.

Microgrid 3 restores critical loads CL4 in one switching operation.
Application: Using WSU Generators to Serve Critical Loads in Pullman Distribution Systems

- WSU DGs: one diesel and two natural-gas generators
- Critical loads in Pullman distribution systems
  - Pullman Regional Hospital and Pullman City Hall

Critical loads within and outside WSU microgrid are restored by WSU generators with seven switching actions.
Validation by GridLAB-D Dynamic Simulation

System Frequency

Generator Terminal Voltage
Fuel Supply for WSU Generators

• Natural Gas:
  – Pipeline from British Columbia, Canada, with a back up.

• Diesel:
  – 250,000-gallon fuel tank
  – 10,000 gallons per delivery, 8 deliveries per year

• Sufficient generation resources to supply critical loads on and off campus if one of the pipeline is functional

• Worst Case:
  – Two pipelines are damaged and no supplement of diesel
  – Diesel generator supplies WSU critical loads with fuel in tank
  – A full tank of diesel can last for 5-7 days
A Computational Tool for Reliability Assessment Considering Service Restoration

- Evaluate impact of service restoration strategies and distribution automation
- Determine optimal switching sequence to minimize target reliability index

Distribution System Information → Distribution System Restoration (DSR) Program → Switching Operations → Reliability Analysis Program → Set Target Index → Switching Sequence → Values of Reliability Indices

Reliability Indices considered in the program include:
- SAIDI, SAIFI, CAIDI, ASAI, ASIFI, and ASIDI
The Proposed Methodology

- A set of scenarios
- States
- Transition arches
- Levels
- Optimal path
- SAIDI per event
- Calculate Indices

The contribution to reliability indices are calculated once the shortest path is identified.
Further Information

Optimizations for PJM System Restoration Strategy

Jianzhong Tong
Sr. Strategist
Applied Solutions
PJM Interconnection
July, 2016
PJM as Part of the Eastern Interconnection

- 26% of generation in Eastern Interconnection
- 28% of load in Eastern Interconnection
- 19% of transmission assets in Eastern Interconnection

**KEY STATISTICS**

- PJM member companies: 800+
- Millions of people served: 60
- Peak load in megawatts: 163,848
- MWs of generating capacity: 185,600
- Miles of transmission lines: 59,750
- GWh of annual energy: 832,331
- Generation sources: 1,365
- Square miles of territory: 214,000
- Area served: 13 states + DC
- Externally facing tie lines: 142

21% of U.S. GDP produced in PJM

As of 9/7/2012
PJM – Focus on Just 3 Things

1. Reliability
   - Grid Operations
   - Supply/Demand Balance
   - Transmission monitoring

2. Market Operation
   - Energy
   - Capacity
   - Ancillary Services

3. Regional Planning
   - 15-Year Outlook
Background

• Facts affect on PJM’s approach to Black Start generation and System Restoration:
  – EPA Cross-State Air Pollution Rule (CSAPR) inspired retirements across RTO
  – The need for PJM to look across TO restoration plans to identify external Black Start units (external to Transmission zone)
  – Increasing costs of Black Start units
  – NERC CIP standards
Objectives of New System Restoration Strategy

• More efficient utilization of Black Start resources from a system perspective
• Equal or faster overall System Restoration time than current strategy
• Maintain priority of restoring offsite power to nuclear stations
• Establish a priority of restoring integrity to the Interconnection
• Maintain compliance with NERC Standards
• Maintain existing TO contractual and regulatory restoration obligations
Optimization Tools for System Restoration Strategy

• Understanding PJM System Restoration Strategy and Procedures

• Development of Optimization based Decision Tools
  – Maximized black start capability and Locations of new black start units placement
  – Evaluation of system restoration strategy options
  – System restoration training
  – On-line black start and system restoration
Phase 1: Blackstart Capability Assessment Study
Objectives

• Optimal blackstart capability assessment study focuses on the optimal installation strategy and provides the start-up sequence

• Critical for developing new restoration plan

• Evaluate the blackstart capability requirement to achieve the economic efficiency.
• In this study, considering the restoration process of both generation and transmission system, the value of additional BS capability was evaluated in terms of total restoration time and system generation capability.

• PJM system used as a test system
PJM Test System

• PJM Planning case (2015/2016)
  – Including Retirement of BS generators
PJM Test Case

• Provide Generator Characteristics
  – List of BS and NBS generators
  – $T_{c\text{tp}}$, the cranking time for NBS generators to begin to ramp up and parallel with system;
  – $R_r$, the generator ramping rate;
  – $P_{\text{start}}$, the generator start-up power requirement;
  – $P_{\text{max}}$, the maximum generator active power output;
  – $T_{\text{cmin}}$, the critical minimum time interval, which after a blackout happened, a NBS unit cannot receive any cranking power to be restarted until this time interval ends;
  – $T_{\text{cmax}}$, the critical maximum time interval, during which if a NBS unit was not started, the unit will become unavailable for a considerable time delay.
Review of the Results

• PSEG Zone
  – 1029 buses
  – 155 generators
  – 3 Blackstart units (one is not included in the study due to the large minimum down time)
Review of the Results

Optimal Blackstart Capability

Generation Capability Curve

All PS generation online in about 9 hours
Fully loaded in about 16-17 hours
### Review of the Results

**Generator cranking sequence**

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<th>216901</th>
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Next Steps

• PJM-EPRI Pilot Project
  – Prototype decision-support tool for blackstart and system restoration strategy