Utilizing Energy Storage to Improve Distribution Reliability

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Background

• Traditional distribution system reliability improvement techniques classified as:
  A. Grid hardening
  B. Adding system intelligence

• Microgrids and energy storage have emerged as an alternative in the past few years

• Lack of understanding about how and when system intelligence and microgrids are to be applied

• Lack of common framework that helps utilities apply these reliability methods in a scientific and economically justifiable way

• Lack of understanding as to how Microgrids can be located, sized and operated for a distribution reliability improvement objective
Objective

- Apply reliability improvement techniques on an actual utility distribution feeder with poor reliability numbers.

- Demonstrate effectiveness of distribution automation and Distributed Energy Resources (DERs) in meeting reliability objective.

- Contrast reliability techniques by calculating cost per unit reliability improvement.

- Develop a scientific method to locate, size and operate microgrids using utility reliability targets as a benchmark.

- Collate all reliability methods into a common framework that utilities can use effectively (and easily) to meet their reliability objective.
Step 1 – Data Gathering: Gather historical fault data to calculate feeder baseline SAIDI and SAIFI and component failure rates (FR).

Step 2 – Optimal Switch Placement: Use a switch placement algorithm to optimally place distribution automation (DA) switches to minimize customer interruptions.

Step 3 – Load Transfer schemes: Explore option of load transfer using neighboring feeders.

Step 4 – Optimal ESS Placement: Identify section(s) of the feeder to be restored using storage enabled microgrids based upon reliability objective.

Step 5 – Microgrid Analysis: Compute size of the energy storage system (ESS) based upon the load size of the feeder section to be restored.
Demonstration case study: Feeder Overview

- Distribution feeder at 44 kV voltage level
- Total length = 60 km
- Total customers ~ 10,000
- Peak Load ~25 MW
- Feeder has substation breaker, two tie points to neighboring feeders and a protective switch on a lateral (near “DS5” on the diagram)
- Grid hardening using vegetation trimming not possible on feeder due to customer preferences
Feeder Single Line Diagram

DS6: 2200 customers

DS5: 1400 customers

DS3: 2600 customers

DS2: 1700 customers

DS1: 1000 customers

DS4: 1300 customers

Tie Point with feeder #1

Tie Point with feeder #2

Legend

Substation

Load

Generator

Tie-Point

Protective switch
Application of Framework: Step 1

 Due to dense vegetation, 70% faults occur within first 30% of feeder length.

 Three years’ worth of fault data used to calculate feeder baseline SAIFI and SAIDI (upon which improvement is sought).

 Feeder SAIFI = 3.34 interruptions/customer.

 Feeder SAIDI = 17.6 hrs/customer.

 CAIDI = 5.3 hrs/interruption (used as ‘average repair time’ in reliability analysis).

 Utility reliability targets: SAIFI = 2 interruptions/customer and SAIDI = 5.5 hrs/customer.
Step 1 (contd.)

- Failure rate assigned to each line section of the feeder:

\[
\lambda = \frac{\text{Total faults on line section}}{\text{Total length of line section}} \times (\% \text{ perm. faults}),
\]

Where ‘% perm. Faults’ indicates percentage of line section faults that were permanent.
Step 2: Optimal Switch Placement

Switches on Feeder: 1
SAIFI : 3.34
SAIDI : 17.6

Switches on Feeder: 2
SAIFI : 3.09

Switches on Feeder: 3
SAIFI : 3.07
SAIDI : 16.3

Legend
- Load
- Switch
- Substation
- ESS
- Breaker
- FR Failure Rate

ZONE 1
DS 1
1000 customers

ZONE 2
DS5 + DS6
3600 customers
FR=0.075
FR=0.075

ZONE 3
DS 2
1700 customers
FR=0.055
FR=0.01

ZONE 4
DS 3
2600 customers
DS 4
1300 customers
FR=0.01
FR=0.01
FR=0.01
FR=0.01

Feeder 1 Tie
Feeder 2 Tie

Mid_min
FR=0.68
FR=0.02
FR=0.055
FR=0.01
Step 3: Load Transfer

- 2 additional switches effectively bifurcate feeder into 4 zones.
- Currently no provision to operate zones independently.
- Load transfer switches currently not automated.
- Load transfer option explored as benefits from DA switch placement become marginal.
- Load transfer more expensive (changes to protection coordination, additional infrastructure costs etc) but capable of energizing all of zone 4 (and hence, large improvement in reliability).
Step 3: Load transfer

Switches on Feeder: 3
SAIFI : 3.07
SAIDI : 16.2

Switches on Feeder: 3 + Load Transfer
SAIFI : 1.9
SAIDI : 10.03

Legend
- Load
- Switch
- Substation
- ESS
- Breaker
- FR Failure Rate

ZONE 1
DS 1
1000 customers
FR = 0.68
FR = 0.02
FR = 0.055

ZONE 2
DS5 + DS6
3600 customers
FR = 0.075
FR = 0.075

ZONE 3
DS 2
1700 customers
FR = 0.055
FR = 0.01

ZONE 4
DS3
2600 customers
FR = 0.01

DS4
1300 customers
FR = 0.01

Feeder 1 Tie
Feeder 2 Tie
Mid_min1
Step 4: ESS Placement

- SAIFI target met during Step 3. SAIDI still unacceptably high.

- Zone 1 connected to substation. However, zones 2 and 3 can be restored using energy storage systems (ESS).

- SAIFI and SAIDI improvements achieved by operating zone 2 / zone 3 as microgrid in islanded mode were calculated. Operating zone 2 as an islanded microgrid was found to meet reliability objective.

<table>
<thead>
<tr>
<th>BESS Location</th>
<th>SAIFI</th>
<th>SAIDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 3</td>
<td>1.48</td>
<td>7.81</td>
</tr>
<tr>
<td>Zone 2</td>
<td>0.98</td>
<td>5.22</td>
</tr>
<tr>
<td>Zone 2 and Zone 3</td>
<td>0.56</td>
<td>2.98</td>
</tr>
</tbody>
</table>
Step 5: Sizing the battery for Microgrid operation

- System average load determined from load duration curve (see figure).
- Load in Zone 2 calculated from spot load data and system average load.
- Battery support duration set equal to average repair time (5.3 hrs).
- Size of battery needed calculated to be 34.5 (28.5) MWh for Zone 2 (Zone 3).

Figure: System Load data over 3 years. Load remains below 25 MW ~90% of the time.
Cost Analysis

- Cost of distribution automation switch ~ $100k per switch.

- Installed cost of battery storage assumed to be ~$500/kWh.

- Cost of load transfer assumed to be equal to cost of DA switch for analysis. Infrastructure changes not considered/specified.

- Benefits calculated as ‘dollar amount’ per unit SAIFI/SAIDI improvement.

- Results presented as a unified solution to the utility to decide order of priority of implementation based upon capital available/reliability improvement sought.
Cost-Benefit Analysis outcomes

Figure: Benefits from the reliability improvement study plotted as a function of cost. Inset: benefits from switch placement alone.
Conclusions

- Due to feeder topology, recloser placement alone yields marginal benefits.

- Maximum benefits derived from fault isolation AND partial feeder restoration.

- Restoring parts of the feeder that do not have access to generation sources, yields high benefits.

- High cost of Battery Storage leads to prohibitively high Microgrid costs.

- Load needs to be separated as ‘high priority’ or ‘low priority’ to bring down the size of the Storage system and hence, cost.
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