Field Testing Smart Inverters as Grid Assets

Panel Session

Moderated by: Fathalla Eldali (NRECA)
Distribution Optimization Engineer
Share Comments & Questions in Chat
**Demonstration**

**Testing Smart Inverters as Grid Assets**

**Panelists**
- John Becker
- James Moye
- JC Hernandez

**With**
- Central Electric Power, SC
- Black River Electric Cooperative, SC
- Georgia Tech-NEETRAC
Smart Inverter Demonstration Objectives

• Interconnect and test smart inverter-based DER using parameters of IEEE 1547-2018
  • Address problems
  • Find challenges and limitations
• Simulation studies to determine potential alternative settings
• Field tests and analyses on inverter performance
## Scope

<table>
<thead>
<tr>
<th>Perform</th>
<th>Conduct</th>
<th>Analyze</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation studies of alternative settings</td>
<td>Field tests at 2 co-ops</td>
<td>Analyze inverter performance</td>
</tr>
</tbody>
</table>
Central Electric Power Cooperative, Inc.

- 20 member cooperatives
- 800,000+ meters
- No baseload generation
- 2 long-term power purchase agreements
  - Santee Cooper & Duke Energy
Solar Capacity

• Community Solar
  • 18 member cooperatives have installed 4.2 MW to date
  • 5 MW planned for completion
  • Berkeley Electric Cooperative first integrated solar + battery system

• Residential and Commercial Solar Systems
  • 4,200+ installations
  • 3.3 MW
Solar Initiatives

• 2018 – Horry County Schools 1.2 MW
• 2019 – Announced 2 x 75 MW PPAs
• 2020 – Volvo manufacturing site 6.5 MW PPA
• 2020 – RFP for 363 MW of solar PPAs

“This will give us great long-term flexibility as well as lower pricing of renewable resources for the benefit of our member cooperatives.”

-- Robert C. Hochstetler, President & CEO of Central
Black River Electric Cooperative, Inc.

- James Moye – VP of Engineering
- Located in Sumter, SC
- Serving parts of 4 counties
  - Sumter, Clarendon, Lee and Kershaw Counties
- 35,000 meters
- Black River is one of the member co-ops with Central Electric that installed a 240 KW community solar farm
- All our energy needs are purchased through Central Electric
Solar Initiatives & Goals

- **Experience**
  - Be on the front end of knowing what to expect, how to handle and get the most from solar farms on our system

- **Partnership**
  - We were very open to partnering with NRECA and NEETRAC in utilizing our solar farm to conduct these tests
The Solar Site

- The site was commissioned 1\textsuperscript{st} of 2017
  - So, we’ve had it now in operation for 4 years
- This site is feeder connected to our Industrial Park Substation which is 12.47 kV
- The max load on this circuit is approximately 2.7 MW
- This circuits feeds mostly commercial and some residential members
  - Serves Walmart and Lowes
The Solar Site

• Black River owns a 4-acre open field right near the office, which was perfect for this solar project
  • We cut off 2 acres for this site, which left some room for expansion

• The distance to the substation is approximately 3500 feet

• The Solar site transformer is only 70 feet from the point of connection to the overhead circuit
Simulation Studies
Key Differences in IEEE 1547-2018

- 10 MVA Limit is removed
- Voltage Regulation via Reactive Power Control
- Interoperability Capability Required for All DER
- Clause on Intentional Islands
- Disturbance Performance
- Abnormal Operating Performance **Categories**

Source : A New Template for the Integrated Grid (EPRI)
Smart Inverter – Planned Tests

Test 1: Interoperability

Test 2: Voltage Regulation
Simulation Studies – Voltage Regulation

• The goal of conducting simulations to determine alternative settings

• Study the impact of changing the settings on the operations of the inverters and distribution feeder

• We use actual datasets from both sites

• We use circuit models to run dynamic simulations in GridLAB-D
Simulation Studies – Voltage Regulation

• Base Case (Default Settings)
  • Unity PF/Set and forget
  • No Voltage Regulation required (older versions IEEE 1547)

• Case-I
  • Fixed PF Inductive/Capacitive

• Case-II
  • Volt-Var Curve (with and without dead-band)
  • Considering CAT-I & CAT-II
Smart Inverter Demo Project
Voltage Regulation

Case-I: Fixed PF

Considering fixed step fixed PF

Case-II: Volt-Var Curves

Considering with and w/o dead-band curves
Smart Inverter Demo Project
Voltage Regulation

- Simulation Studies Outputs
  - Voltage profile along the feeder and its distance from PV system and the substation
  - Impact on losses
  - Power Factor at the substation
  - Impact on voltage regulating devices operations
## Voltage Regulation- Summary of the results

**Case-I: Fixed PF**

<table>
<thead>
<tr>
<th>Output (Unit)</th>
<th>Unity (1)</th>
<th>(0.9) Ind</th>
<th>(0.8) Ind</th>
<th>(0.9) Cap</th>
<th>(0.8) Cap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Energy (Active) (kWh)</td>
<td>306.8 MWh</td>
<td>276 MWh</td>
<td><strong>245.5 MWh</strong></td>
<td>276 MWh</td>
<td>245.4MWh</td>
</tr>
<tr>
<td>Average Sub PF</td>
<td>0.92</td>
<td>0.924</td>
<td>0.9327</td>
<td>0.917</td>
<td>0.917</td>
</tr>
<tr>
<td>Average line losses (%)</td>
<td>1.87%</td>
<td>1.87%</td>
<td>1.86%</td>
<td>1.87%</td>
<td>1.87%</td>
</tr>
<tr>
<td>No. of violations of ANSI for all meters</td>
<td>13273</td>
<td>13273</td>
<td>13265</td>
<td>13276</td>
<td>13277</td>
</tr>
<tr>
<td>No. of violations of ANSI for surrounding sub/solar meters</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Regulator changes</td>
<td>1170</td>
<td>1170</td>
<td>1162</td>
<td>1188</td>
<td>1204</td>
</tr>
</tbody>
</table>
# Voltage Regulation - Summary of the results

## Case-II: Volt-Var Curve

<table>
<thead>
<tr>
<th>Output (Unit)</th>
<th>Unity (1)</th>
<th>CAT-I NDB</th>
<th>CAT-II NDB</th>
<th>CAT-I WDB</th>
<th>CAT-II WDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Energy (Active) (kWh)</td>
<td>306.8 MWh</td>
<td>306.6 MWh</td>
<td>306.4 MWh</td>
<td>305.88 MWh</td>
<td>305.7 MWh</td>
</tr>
<tr>
<td>Average Sub PF</td>
<td>0.92</td>
<td>0.926</td>
<td>0.925</td>
<td>0.923</td>
<td>0.923</td>
</tr>
<tr>
<td>Average line losses (%)</td>
<td>1.87%</td>
<td>1.87%</td>
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<td>1.87%</td>
</tr>
<tr>
<td>No. of violations of ANSI for all meters</td>
<td>13273</td>
<td>13270</td>
<td>13271</td>
<td>13273</td>
<td>13271</td>
</tr>
<tr>
<td>No. of violations of ANSI for surrounding sub/solar meters</td>
<td>20</td>
<td>10</td>
<td>13</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Regulator changes</td>
<td>1170</td>
<td>1136</td>
<td>1146</td>
<td>1170</td>
<td>1156</td>
</tr>
</tbody>
</table>

WDB: with dead-band  
NDW: No dead-band
Discussion of the Simulation Results

• Not a significant impact of the setting changes on the outputs
  • Stiff distribution system that is very well regulated
  • PV system is not big enough to make a significant impact in the voltage of the system
  • Solar Farm location near the substation
  • Simulations limitation (low resolution data)

• But, what if:
  • PV system is bigger
  • Weaker distribution system (higher source impedance)
Field Testing Initial Results
About NEETRAC

• National
• Electric
• Energy
• Testing
• Research
• Application
• Center

In Electrical & Computer Engineering at Georgia Tech

Scope: Electric Energy Delivery
Approach: Self-supporting Membership Consortium
Expertise: Asset Management, Condition Evaluation, Diagnostics, High & Medium voltage, Utility Analytics
NEETRAC & NRECA

831 Co-op’s

88 million US Electric Customers
> 60% of US Customer Base
EIA 2017
Approach

- Locate potential sites – NRECA members
- Discuss project details and assess feasibility with local utility and related parties
- Obtained and digest site technical information
- NRECA conducts simulations
- Develop test program - specific conditions for each case
- Conduct field test program
- Analyze data
- Report on findings
Identified PV-Sites

Black River - Sumter, SC – 240 kW

White River - Meeker, CO – 4 MW
Central Black River PV Station

Community Solar Site Size: 240 kW AC / 338 kW DC
Location: Sumter, SC
Inverters: (4) 60 kW

Locally Controlled
PV- Station Production for 2019

- Production for a week in Nov. 2019
- Same dates for planned field test in 2020
- Need to consider the random nature of variables – station & others
- Solid test program
- Design of Experiments (DoE)
- Relevant data
Design of Experiment (DoE)

• **Applied statistics** - plan, conduct, analyze, and interpret controlled tests
• **Evaluate variables** that influence a parameter or group of parameters
• **Be bold** - explore the full variable range when possible
• Variables are classified as follows:
  - **Factors**: Variables that can be controlled, i.e. inverter settings
  - **Covariates**: Variables that cannot be controlled but known to have an effect on the responses
  - **Responses**: Measurable outputs that are directly related to the issues under analysis
DoE and Test Program

Factors:
- P (kW)
- Q (kVAR)
- PF (Cap or Ind)
- Control Mode Q(P) or Q(U)

Station Response:
- Power Quality Meter
- LOCUS DAQ system

Covariates:
- Feeder Load
- Irradiance
- Season
- AMI Meter Location
- EPS Voltage
- Temperature

Feeder

Circuit Response:
- Voltage at PCC
- Profile from AMI meters

• Full factorial design with two factors and three levels each
• The factors take on all possible combinations of their levels
• A series of replicate and repeat measurements are needed for the experiment design to be robust
• Factor combinations are set and tested in random order in three sets per day
## Test Program

<table>
<thead>
<tr>
<th>Factors</th>
<th>No. Levels</th>
<th>Covariates</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Active Power (P)</td>
<td>3 (33-67-100%)</td>
<td>• Load</td>
<td>Station Response:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Irradiance</td>
<td>• Active Power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AMI Meter’s location</td>
<td>• Reactive Power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• EPS Voltage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Temperature</td>
<td></td>
</tr>
<tr>
<td>Output Reactive Power (PF)</td>
<td>3 (-0.8 cap, 1, 0.8 ind)</td>
<td></td>
<td>Circuit Response:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Voltage at PCC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Voltage Profile from AMI meters</td>
</tr>
</tbody>
</table>

Repeats: 3 – Parameter changes every 15 min in 6.75 hour period  
Replicates: 3 days of testing
Field Test
Prelim Results – Irradiance

Three sunny almost identical days!
Prelim Results – Active Power & PF

Active Power

Power Factor - PF

Irradiance Limit
Prelim Results – PCC Voltage

Voltage variability up to ~3%

Point of Common Coupling (PCC)
Main Takeaways

• Planning intensive – several iterations required
• Focus on safety – (PES) personnel – equipment – system
• Experience is imperative
• Need for understanding/modelling coupled with firm analytics and test deployment in the field
• Robust test program - random nature of variables
• Supported by theoretical and experimental work
• Novel method to assess dynamic voltage support
Summary and Acknowledgements

• Helping NRECA’s members to use smart inverters to provide grid services such as voltage regulations

• Helping NRECA’s members understand the implications of the issues and standards related to DER interconnection

• Acknowledgements
  • Joshua Perkel, & Nigel Hampton  NEETRAC
  • Robert Harris, David Pinney, & Venkat Banunarayanan  NRECA
  • Scott Hammond  Central Electric Coop
  • Matthew Compton  Black River Electric Coop
Thank You!

Questions?

John Becker  
Member Services Analyst  
Central Electric Power, SC  
JBecker@CEPCI.ORG

JC Hernandez  
Research Engineer  
Georgia Tech-NEETRAC  
jh480@gatech.edu

James Moye  
VP of Engineering  
Black River Electric Cooperative, SC  
james.moye@blackriver.coop

Fathalla Eldali  
Distribution Optimization Engineer  
Business and Technology Strategies, NRECA  
Fathalla.Eldali@nreca.coop