PJM DER Workshop
Ride Through and DER Integration

Distributed Energy Resource (DER) Interconnection on the Electric Power System (EPS): Challenges and Opportunities

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July 30, 2019
Agenda

- Biographical Information
- About Dominion Energy
- Current DER Interconnections (Active and Pending)
- Dominion Energy’s Typical DER Interconnection Study Process
- Dominion Energy’s Typical DER Protection Packages
- Challenges during DER Interconnection Review Process
- Main Challenges associated with DERs connected to the Distribution System
  - Distribution Design Considerations
  - Grid Stability Considerations, Reliability Concerns
  - Arc Flash Considerations
  - Maintenance & other Considerations
- Field / Witness Testing or Commissioning: Challenges and Requirements
  - Visual Inspection and Verification
  - Witness Testing
- DER Technical Requirements for connecting to the EPS: associated drivers
  - IEEE 1547 Standard
  - IEEE 1547.1 Standard
  - UL 1741 standard
- Conclusion
Biographical Information

- 2 years with Renewable Energy /CHP Startup

- 10 years with Dominion Energy
  - 7 years as a System Protection Engineer
  - 3 years as DER Planning Engineer

- Involved with IEEE 1547 since May 2012
  - Member of IEEE 1547.8 Working Group (WG)
  - Member of IEEE 1547a and IEEE 1547.1a WG (i.e. “a” stands for amendment)
  - Member of IEEE 1547.1 (full revision) WG
  - Member of IEEE 1547 (full revision) WG (initiated April 2014)
  - Current Secretary for P1547.2 (Standard Guide for IEEE 1547-2018)
About Dominion Energy

- $61B market cap
- $96B assets
- 21,300 employees
- 7.5M customers (total)
- 3.4M customers (elec. utility)
- 3.3M customers (gas utility)
- 18 states of operation
- 10,200 electric trans. miles
- 84,800 electric dist. miles
- 15,900 gas trans. miles
- 92,900 gas dist. miles
- 1.1 Tcf gas storage
- 31GW generation (total capacity)
- 11GW generation (zero-carbon)
### About Dominion Energy: DER Investments

<table>
<thead>
<tr>
<th>Description</th>
<th>Coastal Virginia off-shore wind</th>
<th>Grid transformation</th>
<th>Utility solar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>2 turbine (12MW) off-shore pilot project</td>
<td>Enhanced resiliency/ security/ customer exp.</td>
<td>Regulated, utility-scale solar</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Approved</td>
<td>Approved-partial refile summer 2019</td>
<td>Approved (CPCN)</td>
</tr>
<tr>
<td><strong>Anticipated program total</strong></td>
<td>Up to 2—4GW</td>
<td>Up to $3 billion</td>
<td>Up to ~5.5GW</td>
</tr>
</tbody>
</table>

**Pumped storage**

$1.0B
2019—2023
Current DER Interconnections (Active and Pending)

Transmission:
- 900+ MW connected (Solar + Wind)
- 3500+ MW Pending / in Queue

Distribution:
- 1000+ MW connected (utility scale Solar-PV)
- 300+ MW connected (other non Solar-PV)
- 40+ MW Net Metering connected
- 2000+ MW Pending / in Queue
Dominion Energy’s Typical DER Interconnection Study Process
DER Interconnection Study Process

Inception
- DER Interconnection Process
- Grid Protection
- DER Adoption Parameters
- Operational Safety
- Grid Stability
- Distributed Energy Resources

Operation

Requirements

Connection
DER Interconnection Process (continued)
DER Interconnection Process: responsible groups within DE

- Customer Contracts
- Distribution Design
- System Metering
- Distribution Planning
- Project Management
- System Protection Engineering
- Substation Design and Engineering
- Transmission Planning
- Substation Project Management
- Complex Billing
DER Interconnection Process: typical review process

- Review of Technical Information
  - Standby/Emergency, Peak Shaving, Battery Energy Storage (if applicable):
    - Total paralleling time
    - Protection scheme
    - Sequence of operations
    - Automatic Transfer Switch

- Interconnection Equipment certification to Industry Standards and Codes
  - IEEE 1547 (inverter based interconnections)
  - PJM & other industry standards (including FAC-001)
DER Interconnection Process: Typical Review Process (continued)

• Load Review:
  – Peak Load
  – Light Load (Daylight for Solar-PV interconnection if no Battery)

• Modeling:
  – Short Circuit Model Data
  – Interface Transformer Data
  – Grounding Transformer Data
  – Up-line/down-line utility device(s)
DER Interconnection Process: Typical Review Process (continued)

• Substation Protection Review:
  – Feeder Circuit Protection
  – Substation Transformer Protection
  – Transmission line Protection

• Short Circuit Analysis
  – Relay Coordination
  – Relay Sensitivity
  – Breaker and equipment Duty
  – Arc Flash analysis (High Penetration)
DER Interconnection Process: Typical Review Process (continued)

• Temporary Overvoltage (TOV) Review
  – TOV Pre-DG
  – TOV Post DG
  – Neutral Grounding Resistor (NGR) impact
  – Grounding Transformer impact

• Other Reviews:
  – Down-line Substation
  – Future Project Changes
  – Aggregate Generation
Dominion Energy’s Typical DER Protection Package
DER Interconnection Process: Transmission Protection Packages

- **Wide Area Protection and Isolation**
  (FAC 001 – Facilities Connection Requirements)
  - Transfer Trip
  - Islanding: purpose is to prevent the following conditions:
    - Generator supplying load while not connected to Dominion
    - Reclosing on a generator that has lost synchronism
  - Interconnection Protection

- **Examples of requirements:**
  Line Transfer –Trip, Anti-islanding, Point of Interconnection Requirements (e.g. Ring Bus, Single Breaker Protection on tap line, etc.), Interconnection Generator Step-up Transformer Requirements, Instrument Transformer Requirements, Transmission Protection Elements requirements (bus, Line protection for long and short TL)
Other protection packages (distribution and transmission)

Protection Design (Standard or Specific)

- SEL 735 Power Quality Package
- SEL 651R-2 Solar Passive Back-up Protection Package
- Transformer Overload / Power Quality Application
- Standard Distribution Transfer Trip Application
- Currently Exploring Multiple Solar Radio Transfer Trip Applications
- Currently Exploring Synchrophasors Reactive DER Application (For Voltage / VAR Support)
- Application: Membership Cooperative Bus Power Monitor Control/Trip to prevent DER Reverse Flow onto Transmission
- Directional Overcurrent Protection
- \(3E_0\) Protection for Substation Transformer (D-Y)
- Islanding Control Scheme (ICS)
Challenges during DER Interconnection Review Process
The Wait

- Funding
- Interconnect Agreement
- Property Purchase or Lease
- Inverter Design/Purchase
• Connect Dates are Negotiated
• Substation Design & Build
• Easements
• Distribution Build
Main Challenges associated with DERs connected to the Distribution System
The existing distribution system was designed to serve load and regulate voltage radially, from a single source, in a tree fashion with progressively smaller conductors, at lower cost.

Distribution system is regulated to +/- 5% of nominal voltage in the radial direction to provide proper voltage automatically from zero load to full load to distribution customer equipment.

It was not designed for bi-directional flow associated with generation.

It also was not designed for frequent large power fluctuations that may occur with intermittent sources such as PV.
Grid Stability Considerations

- **Steady-State Voltages** - no voltages outside of our filing with Commission
- **Transient Voltage Swings** - no complaints from customers due to variation in Photo Voltaic (PV) output
- **Transient Over Voltages (TOV)**, specifically associated with the mode of Neutral-Ground shift
- **Harmonics** - no excessive harmonic distortion
- **Flicker**
Grid Stability Considerations: Reliability Concerns

- Load Rejection Overvoltage (LRO) stressing equipment / line devices
- Example: 44% of data points are within 5% margin of MCOV rating, with all outside the ITIC voltage tolerance envelope
- 0.02 s decision to ask DER to stop generating could help mitigate issue
Arc Flash Considerations

• Increased DER MVA size increases exposure:
  – (10 MVA) 0.20%, (20 MVA) 2.13%, (30 MVA) 5.70%

• Longer Clearing times will substantially increase exposure:
  – Approx. 14% increase in cal / cm^2 for each (1s) second @ 34.5 kV and 20MW

• Transfer Trip is preferred to control exposure from DER

• Yg / D requires NGR to manage exposure

• Yg-Y is preferred

• **Low Set INST.** decreases exposure by sacrificing downline coordination
Maintenance & other Considerations

As with any piece of equipment, with time, there is degradation in components which leads to degradation of functionality. That explains why we generally have a maintenance schedule established for all Intelligent Electronic Devices (IEDs) by utilities and mandated by regulators such as NERC.

- Want assurance that interconnected DG will operate properly after years of service in the field (i.e. Photovoltaic systems for instance are designed to be operated for about 20 years).

- With higher penetration of inverter based DG expected, it is our opinion that all inverter protection should be verified as well to show continued manufacturer. But how do we enforce it?

- Utility Grade relays & other control systems have a Fail Safe mode that act as protection against system / equipment failures. In contrast, with DER smart capabilities, there is not currently any similar function that guarantee DER equipment will return to a safe operating condition when communication loss occurs for e.g. with controller(s)
Other challenges associated with DERs

• Impact to Dominion Customers
  – Unregulated Generation
  – Harmonics

• Modeling Software / Tips, Shortcomings, etc.
  – Inverters: Ideal Current Source; Current Limits Enabled
    Current Short Circuit modeling tools are inadequate for modeling PV inverters
    and vender development is slow
  – Zero Sequence Component: Infinite Impedance
  – Negative Sequence Component: Questionable!
  – Inverters: Voltage Source Models
Field / Witness Testing or Commissioning: Challenges and Requirements
Site Visual Inspection & Verification

Objective
The main purpose of this Site Visual Configuration and Verification is to establish configuration control between the documentation on file (Interconnection Agreement/One Line Diagram) and the existing field conditions on the site. The field conditions need to match the documentation on file.

Personnel Requirements: Prior to the Site visit the customer needs to ensure

- Safe Environment for Field Verification
- Site is disconnected from the POI
- There is an appropriate customer representative at the site who has knowledge of the Inverter operation and can successfully navigate through the inverter software to verify the set points/clearing times.
## Under-Frequency Clearing Time

<table>
<thead>
<tr>
<th>Customer Setting Name</th>
<th>61850 Name</th>
<th>Context/Viewer Screen (Settings/inverter/Grid interconnect/*)</th>
<th>IEEE-1547</th>
<th>Gauss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under Frequency 1 Trip Time</td>
<td>AcPTUF/Gr11TrpCntIntr</td>
<td>/Grid Interconnect Disconnects</td>
<td>192</td>
<td>0</td>
</tr>
<tr>
<td>Under Frequency 2</td>
<td>AcPTUF/Gr12LimVol</td>
<td>/Grid Interconnect Disconnects</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Under Frequency 2 Trip Time</td>
<td>AcPTOF/Gr12TrpCntIntr</td>
<td>/Grid Interconnect Disconnects</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Over Frequency 1</td>
<td>AcPTOF/Gr11LimVol</td>
<td>/Grid Interconnect Disconnects</td>
<td>60.5</td>
<td>60.5</td>
</tr>
<tr>
<td>Over Frequency 1 Trip Time</td>
<td>AcPTOF/Gr11TrpCntIntr</td>
<td>/Grid Interconnect Disconnects</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Over Frequency 2</td>
<td>AcPTOF/Gr12LimVol</td>
<td>/Grid Interconnect Disconnects</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Over Frequency 2 Trip Time</td>
<td>AcPTOF/Gr12TrpCntIntr</td>
<td>/Grid Interconnect Disconnects</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Power Factor</td>
<td>PwrDGSM/CmdDP</td>
<td>/Power Manager</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Real Power Output</td>
<td>GenZINV/WinampLt</td>
<td>/Inverter state machine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restart Timer</td>
<td>GenDRCT/DictTim2</td>
<td>/Grid Interconnect Disconnects</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Enable Inverter’s active islanding detection</td>
<td>AntiIDOPI/Ena</td>
<td>/Anti Islanding</td>
<td>on</td>
<td>on</td>
</tr>
<tr>
<td>Enable LVRT detection and ACC during voltage sag</td>
<td>BrgRDGS/ActIEna</td>
<td>/Anti Islanding</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>Enable DRCS (Dynamic Reactive Current Support)</td>
<td>GenRDGS/ActIEna</td>
<td>/Dynamic Reactive Current Support</td>
<td>off</td>
<td>off</td>
</tr>
<tr>
<td>Enable AGSF for ($\Delta f$, $\Delta P(v)$, $P_{max}(f)$, $P_{min}(f)$, $P_{max}(v)$, and $P_{min}(v)$)</td>
<td>PwrDGSM/ModTyp</td>
<td>/Power Manager</td>
<td>on</td>
<td>on</td>
</tr>
</tbody>
</table>

### The Formula:

Clearing Time = $8 \times 0.010 + 0.080 = 0.16$ s

### IEEE 1547 Default Settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering value (s)</td>
<td>$(\text{Raw Value [count]} \times 0.010 \pm \text{count}) \times 0.080$ [s]</td>
</tr>
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</table>

### Inverter Settings at the Solar Site

**Site Visual Inspection & Verification**
# Under-Frequency Clearing Time

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<td>Under Frequency 2 Trip Time</td>
<td>AcPTUF/GrII2TrpCntlIntr</td>
<td>/Grid Interconnect Disconnects</td>
<td>8</td>
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</tr>
<tr>
<td>Enable AGSF for (△P(f), △P(v), Pmax(f), Pmin(f), Pmax(v), and Pmin(v))</td>
<td>PwrDGSN/ModTyp</td>
<td>/Power Manager</td>
<td>on</td>
<td>on</td>
</tr>
</tbody>
</table>

### Further Notes

For trip times (IEEE 1547):

Engineering value [s] = (Raw Value [count] * 0.010 [s/count]) + 0.080 [s]

- **Clearing Time = 192 * 0.010 + 0.080 = 2s**
Difficulties maintaining “Configuration Control” of Inverter settings

- Ambiguous (subject to interpretation)
- Incomplete
- Inconsistent
- Non-Verifiable
- Non-Modifiable
- Non-Traceable
- Undefined Precedence
- User Preference Settings Undefined
- Engineer Defined Settings ()
- Default Settings Not Questioned
- No Controls Established (the user can change settings whenever they desire)
Field / Witness Testing or Commissioning

Commissioning Test is required after DER system is installed and ready for operation, per IEEE Std. 1547.1-2005(R2011) section 7.1

- Test will verify that completed and installed DER system meet all IEEE Std. 1547 requirements
- At a proper power level, verify that DER system cease to energize EPS during a system operation (1 phase & 3 phase operations)
- Verify that DER system does not reconnect immediately after re-energization or reconnection to Area EPS
- Other verification include Overvoltage, VAR (injection/absorption) Harmonic Injection, etc.
SITE 1 – Open A phase pole on Dominion Recloser

Overvoltage persisted for 2 seconds until Dominion POI Recloser Opened for Overvoltage
DER Technical Requirements for connecting to the EPS: associated drivers
IEEE Standard 1547

IEEE 1547 - IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems - Provides a platform for standardizing DER interconnection procedures in the nation; brings certainty for developers. It includes:

- **General Requirements**: Voltage Regulation, Overvoltage, Synchronization/Voltage Fluctuation/Flicker, Spot Network, Monitoring, Isolation Device, Electromagnetic Interference, Surge withstand.
- **Response to abnormal conditions**
- **Power Quality**
- **Islanding**
IEEE Standard 1547.1

IEEE 1547.1 - IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems - Provides test procedures for verifying conformance to IEEE 1547, including:

- Verification and inspections
- Field-conducted type and production tests
- Unintentional islanding functionality test
- Cease-to-Energize functionality test
- Revised settings (i.e. after factory testing)
- Periodic interconnection tests
What does UL 1741 certification provide?

By achieving UL1741 certification, listed and labeled, individual inverter functionality has been tested. An example of a functionality test would be the passive and active anti-islanding protection of the inverter.

UL 1741 certification also requires that components have met the stringent requirements for safety and quality.

- Electrical Hazards
- Fire Hazards
- Mechanical Hazards
- Verification of electrical ratings
What does UL 1741 certification not provide?

UL 1741 does not certify functionality of multiple inverters sharing a point of common coupling. Multiple inverters sharing a point of common coupling increases the risk that different anti-islanding algorithms may have a cancelling effect on the certified individual algorithm.

UL 1741 does not certify functionality when you have a combination of generation technology such as synchronous machines and inverter coupled generation.

UL 1741 does not certify that the inverters have been installed in accordance with the manufacturer’s specifications.
Conclusion
Insufficient Clearance Between Concentric Neutral and Other Phase Terminator

Why we care....
Thank you

Distribution connected Solar Farm

Transmission connected Solar Farm

Wind Farm
Dominion Energy is built on a proud legacy of public service, innovation and community involvement.