Integration of Distributed Energy Resources & Electric Transportation in Distribution Systems

Dr. Julio Romero Agüero
Vice President, Membership & Image – IEEE PES
Vice President, Strategy & Business Innovation – Quanta Technology

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Key Attributes of Future Electricity System

- **Grid Modernization**
  - Increasing Dynamics and Uncertainty
  - Affordable
  - Adaptable, Flexible
  - Resilient
  - Secure
  - Reliable
  - Clean
  - Safe
  - Accessible

1940s and 1950s Federal Power Act

NERC CIP Standards

EPA Emissions Standards

Emerging metrics

NERC CIP Standards

DER Integration Challenges and Impacts

- Depending on size, type, technology, location, engineering practices, and penetration level DER may have various impacts and benefits on utility grids:
  - **Main concerns**: voltage increase and fluctuations, thermal rating violations, protection issues, load masking, wear and tear of circuit apparatus (tap changers and switches)
  - **Main benefits**: voltage support (especially toward the end of the feeders), peak shaving (potential for investment deferral), loss reduction, potential for intentional islanding (microgrid) to enhance reliability, emissions reduction (renewables)

- DER can change grid dynamics and daily utility operations and business practices:
  - Bidirectional power flows and feeder and substation back-feeding
  - Need for DER interconnection studies
  - More complex planning and operations, e.g., need for sophisticated load and generation forecasting
DER Integration Challenges

December 2011: Tennessee 1MW PV System Power

Source: https://www.puco.ohio.gov/industry-information/industry-topics/powerforward/phase-2-exploring-technologies/presentations/tom-key/
DER Impacts – Background

- DER interconnection may violate the basic assumption of unidirectional power flow and may perturb distribution system operations if required measures are not implemented.

- DER has diverse **impacts** on distribution system planning and operations (e.g., solar **intermittency** due to cloud cover can have a significant impact on voltage variations).

- Impacts are not only of steady state but also of **dynamic** nature (e.g., Temporary Overvoltage TOV).

- This represents an important challenge for most planners, who are used to deal with steady state studies but not with **dynamic modeling and analysis**.

- Impacts are not localized and grow as proliferation increases.
Potential impacts include:

- Voltage increase
- Voltage fluctuations
- Reverse power flow
- Interaction with LTC, switched capacitor banks and line voltage regulators
- Reactive power fluctuations
- Voltage and current unbalance (single-phase DG)
- Equipment loading increase
- Fault duty increase
- Losses increase and power factor modification
- Potential impacts on overcurrent and overvoltage protection systems, including Temporary Overvoltage (TOV), sympathetic tripping, reach modification
- Total Harmonic Distortion (THD) increase
Examples of DER Impacts – Voltage Increase

- DER interconnection generally leads to a voltage increase since it compensates the voltage drop caused by load current. However, reverse power flow caused by DG may lead to voltages outside allowable limits (e.g., ANSI 84.1) and interactions with voltage regulation and control equipment (LTCs, voltage regulators, capacitor banks).

DER power fluctuations (e.g., from PV-DG) lead to voltage fluctuations on distribution systems.

Voltage fluctuations increase operation of voltage regulation and control equipment (Load Tap Changers – LTC, line voltage regulators, voltage/reactive power-controlled capacitor banks).
- Voltage goes beyond permissible range
- Equipment tries to re-adjust voltage
- Frequent voltage changes increase number of operations of equipment

Interactions can impact equipment lifecycle and increase $\text{dv/dt}$ (flicker)

Examples of DER Impacts – Voltage Fluctuation (1)

Examples of DER Impacts – Voltage Fluctuation (2)

Examples of DER Impacts – Interaction with Protection Systems (1)

- Changes in fault current levels
  - Locally, DER fault current contribution may have an adverse impact on “fuse saving” overcurrent protection schemes used in distribution systems. During a temporary fault, DER fault current contribution may melt fuses before first fast trip operation of reclosers.
  - Globally, there may be a decrease in fault current levels, because of power electronic-based DERs replacing synchronous machines.

- Sympathetic tripping:
  - When DER penetration level on a feeder is high, faults on neighbor feeders may trip circuit breaker. This can be solved by using directional relays or selecting DER interconnection transformer configurations that limit fault current contribution.
Reach modification or “protection blinding” (overcurrent protection)

- Overcurrent protection schemes are very sensitive during peak loading conditions (long reach), not too much additional current is required to trip protective devices, even faults located far from protective devices (low fault current) can be detected.

- However, DER interconnection may modify the reach of overcurrent protection devices, and faults located far from protective devices may not draw enough fault current to be detected.
Unintentional/Accidental Islanding

- Islanding is a situation where one or more DERs and part of the distribution system operate separated from the rest of the grid.
- This generally represents an issue for utilities since it may lead to public and utility personnel safety hazards, damage to utility and customer equipment due to out-of-synchronism reconnection and temporary overvoltage (TOV).
- Selection of DER interconnection transformer configuration involves a trade-off between fault current contribution and TOV.
- Anti-islanding protection is required, other alternatives involve using grounding transformers and Direct Transfer Trip (DTT).

Source: Results from the DOE-CPUC High Penetration Solar Forum
DER Impact/Interconnection Studies

- **Type of Studies**
  - Screening
  - Steady state analyses
  - Dynamic/transient analyses
  - Overcurrent and overvoltage protection
  - Special studies: harmonic, stability, etc.
  - Hardware-in-the-loop testing in laboratory setting (RTDS)
  - Advanced applications (energy storage, microgrids)

- **Typical Scope**
  - Identify local and/or system-wide impacts of DER on the power distribution grid
  - Develop guidelines regarding expected impacts as a function of DER penetration level
  - Determine potential mitigation measures for any problems discovered in the study
  - Development or update of DER interconnection standards
Impacts and benefits can only be studied through simulations, it is necessary to use both steady state software (CYME, Synergi, SINCAL, Power Factory, etc.), and specialized simulation software such as PSCAD, EMTP, etc. to identify impacts and evaluate effectiveness of mitigation measures.

Different analysis are needed depending on DER type:

- Utility-scale DER (interconnection studies): utilities know where they will be installed (e.g., on industrial feeders, on rooftops of large warehouses, etc.), studies are more deterministic, and impacts are localized.

- Small and medium-scale DER (planning studies): they are being installed on residential and commercial feeders, studies are non-deterministic (need to study uncertainties and different penetration scenarios) and impacts are spread along the system. In order to model and handle uncertainties we need to perform thousands of simulations (statistical scenario modeling).
Example of Methodology for DER Impact Analysis

1. Identify representative feeders
2. Validate steady-state feeder models
3. Conduct steady-state system-wide analysis for small & medium-scale DG
4. Validate inverter models
5. Conduct steady-state individual analysis for utility-scale DG
6. Validate dynamic feeder models
7. Conduct dynamic/ transient analyses for utility-scale DG
8. Power flow analyses
9. Dynamic/ transient analyses
10. Develop guidelines & extrapolate to represent utility system
11. Develop conclusions and recommendations
Multi-hour (time series) analysis of base case and DER cases

- Considers different feeder loading and DER output conditions/characteristics
- Simulations can be conducted either for worst case scenarios (e.g., combination of minimum load and maximum DER output) or for 8760 hrs.
- Results include all variables of interest:
  - Feeder voltages
  - Feeder loading
  - Active and reactive power flows
  - Status and number of operations of capacitor banks, LTCs and line voltage regulators
  - Power losses

Analysis of different DER penetration scenarios

- **Inputs**
  - Typical DER output profiles
  - DER capacity (kW, kWh)
  - Feeder models (distribution analysis software)
  - Hourly/minute feeder load curves and status of voltage control equipment (voltage regulators and capacitor banks) for scenarios of interest, e.g., annual peak and off-peak conditions

Steady State Analysis

- Analysis of different DER penetration scenarios
- Inputs
  - Typical DER output profiles
  - DER capacity (kW, kWh)
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Steady State Analysis

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Steady State Analyses – Results

- Reactive power fluctuation
- PV-DG voltage profile
- Voltage Unbalance Factor vs. Distance from substation
- Loss vs. Time for different load levels
Dynamic Analysis

▪ Justification
  • Results from dynamic simulations are of critical importance for ensuring the reliable operation of feeders with utility scale DER
  • **Dynamic/transient impacts of DER cannot be identified using conventional distribution analysis software, more detailed modeling and simulations are necessary**
  • Dynamic and steady state studies are complementary. Dynamic analyses help define criteria and standard for integration and operation of DER in power distribution systems

▪ Objectives
  • Study impact of DER output variation (including intermittency) on distribution system
  • Study impact of distribution system transients and switching phenomena in DG units (including islanding)
  • Focuses on worst case scenarios (e.g., combination of minimum load and maximum DER output)
  • Results include all variables of interest:
    – Feeder voltages (including TOV)
    – Feeder loading
    – Active and reactive power flows
    – Status and number of operations of capacitor banks, LTCs and line voltage regulators
Dynamic Analysis – Results

Voltage @ PV (Real Time)

Tap Position of Regulator 1 (Real Time)
Mitigation Measures

- The objective of the mitigation measures is to reduce or minimize impacts caused by the interconnection of PV-DG to distribution systems.

- Common mitigation measures include:
  - Operating PV-DG smart inverters to absorb reactive power
  - Modifying operation mode of line voltage regulators (e.g., to cogeneration or bidirectional modes)
  - Relocating capacitor banks and modifying settings of capacitor banks (e.g., switching off fixed capacitor banks and modifying switch off and switch on settings of voltage-controlled banks)
  - Modifying reference voltage of Load Tap Changers (LTCs) and compensating current offset on Line Drop Compensation (LDC) applications
  - Using express feeders for interconnection of large utility-scale PV-DG facilities

- More advanced mitigation measures may include:
  - Using Distributed Energy Storage (DES)
  - Using Static Synchronous Compensator (D-STATCOM)
  - Implementing a dynamic VAR compensation scheme via smart PV-DG inverters
  - Increasing express feeder design voltage (e.g., using 25 kV instead of 13.2 kV)
Mitigation measures (1)
Mitigation measures (3)

Voltage Profile: Maximum Feeder Load with PV-DG

Distance from substation (miles)

Voltage (PU)

- 1  2  3  4  5  6  7  8  9  10  11  12
- 13 14 15 16 17 18 19 20 21 22 23 24
Examples of Advanced Inverter Functions in IEEE 1547-2018

Volt-VAR Function (Voltage Control)

Volt-Watt Function (Output Curtailment)
DG proliferation is not a temporary trend, it is a business paradigm shift that is here to stay. Utilities are addressing this challenge from three perspectives.

**Short-term (focus on large DG plants):**

- Utilities are conducting detailed DG integration studies for large DG plants with the objective of identifying impacts in the distribution system and proposing solutions to ensure seamless integration.
- This approach is deterministic in nature (it is well-known where and when large DG plants will be interconnected).
- It solves problems in the short-term but can be criticized as being equivalent to applying “patches” or short-term fixes to the system.
Impacts of High Penetration of Utility-Scale PV DG

2 x 5 MW solar DER on one distribution feeder, i.e., ~100% penetration (based on peak load)

Reverse power flow through substation transformer into 115 kV system

One-minute real & reactive power flow measured at distribution substation bus, 48-hour period

Source: J. Gajda, Creating sustainable and scalable interconnection requirements for high penetration of utility-scale DER on the distribution system, 2017 IEEE PES GM, Chicago, IL
What is the industry doing? (2)

- **Mid-term (focus on large and residential DG plants):**
  - Besides implementing short-term solutions, utilities are also analyzing a variety of proliferation scenarios for residential DG plants.
  - This approach is stochastic, i.e., it is not known with certainty when and where residential DG plants will be interconnected.
  - Although an individual residential DG plant may not impact the distribution system, the cumulative effect of hundreds or thousands of residential DG plants will certainly affect distribution system planning and operations.
  - This allows utilities estimate maximum limits of DG proliferation, identify system upgrades, and plan respective implementation with enough anticipation to account for lead times (e.g., build new feeders and substations).
Impacts of High Penetration of Behind-the-Meter and Utility-Scale PV DG


Source: https://www.esig.energy/wiki-main-page/time-series-power-flow-analysis-for-distribution-connected-pv-generation/
What is the industry doing? (3)

- **Long-term (focus on business processes, infrastructure and information systems):**
  - Utilities are updating applicable business processes and practices (e.g., engineering standards, annual planning cycle, load forecasting) to consider DG integration as an intrinsic component of their regular activities.
  - Utilities are upgrading distribution assets, information technology, communications, and enterprise system infrastructures to gather and process the data required to operate modern distribution systems with large penetration levels of DG (e.g., sensor, DA and PMU deployment).
  - Utilities are exploring new concepts to fully take advantage of the potential benefits of DG proliferation (e.g., microgrids).
  - Utilities are participating in industry activities to share experiences, and are training their engineers to analyze, plan and operate modern and future distribution systems.
U.S. Population Living in States or Cities Committed to 100% Clean Energy

Source: https://www.sierraclub.org/articles/2019/08/100-clean-energy-movement-keeps-moving-forward
Examples of Leading Industry Practices

- DER Interconnection Process
- Smart Inverter Standards
- DER Monitoring and Control
- DER Management Systems (DERMS)
- Grid Analytics
- Advanced Distribution Planning
- DER Hosting Capacity
- Spatial Load and DER Forecasting
- Time Series Analyses (8760 hr.)
- Value of DER
- Non-Wires Alternatives (NWA)
- Microgrids

Source: https://www.pepco.com/SmartEnergy/MyGreenPowerConnection/Pages/HostingCapacityMap.aspx
High Resolution PV Monitoring

Source: NREL
Distribution Synchronized Measurement Technologies – Industry Application Roadmap

- AG1: AVVC
- AG2: Advanced monitoring of distribution grid
- AG4: Wide Area Visualization
- AG11: High-accuracy fault detection and location
- AG13: Advanced microgrid applications and operation
- AG5: DER integration and control
- AG12: Advanced distribution protection and control
- AG10: Improved stability management
- AG16: Technical and commercial loss reduction
- AG8: Advanced distribution system planning
- AG19: PQ assessment and analysis
- AG1: AVVC
- AG6: Real-time distribution system operation
- AG15: Advanced distribution automation
- AG3: Asset management of critical infrastructure
- AG17: Monitoring and control of Electric transportation infrastructure
- AG9: Distribution load, DER, and EV forecasting
- AG18: Integrated resource, T&D system planning and analysis
- AG7: Enhanced reliability and resilience analysis
- AG8: Advanced distribution system planning
- AG19: PQ assessment and analysis

Difficulty to Implement
- LOW
- MED
- HI

Report and companion presentation available at North American Synchrophasor Initiative (NASPI) website: [https://naspi.org/node/934](https://naspi.org/node/934)
Hosting Capacity Analysis

- Hosting capacity components of interest vary by utility
- Trade-off between several factors:
  - Data and model availability (e.g., load data, AMI, Synergi model, etc.)
  - Expected accuracy (e.g., data integrity, issues, spatial and temporal resolution, etc.)
  - Complexity (e.g., data and result requirements, etc.)
  - Cost (e.g., system size, level of effort, etc.)
- Most utilities evaluate hosting capacity based on thermal limits of lines and equipment and steady state voltage limits
- Results are published and updated periodically (e.g., annually biannually, monthly)

New York Joint Utilities roadmap includes important improvements to hosting capacity analysis:

- Load capacity maps
- Hosting capacity analysis for hybrid solar + energy storage
- Calculating dynamic hosting capacity
Dynamic Hosting Capacity

- **Snapshot Hosting Capacity**
  - Traditional firm interconnection approach
  - Fit and forget
  - Analysis uses worst-case static snapshots
  - Conservative limits on the changes in device operations by using proxies for solar variability
  - Example: Hosting capacity maps, such as those used in California

- **Uncoordinated Dynamic Hosting Capacity**
  - Interconnection using autonomous advanced inverter functionalities without communication to the utility
  - Time-series analysis and probabilistic screens
  - May or may not involve curtailment risk, depending on the inverter settings and size
  - Example: Volt-var control functionality for PV inverters

- **Coordinated Dynamic Hosting Capacity**
  - Flexible interconnection, where curtailment risk is accepted by the PV developer as an alternative to paying for traditional distribution upgrades
  - Inverters have communications capabilities
  - Uses time-series analysis and probabilistic screens
  - Example: New York Flexible Interconnect Capacity Solution

Source: NREL

[Source: https://www.mdpi.com/1996-1073/12/13/2576]
Example of PV Impacts on Hosting Capacity – Voltage Fluctuation/Increase (1)

Overvoltage at service transformer due to reverse power flow caused by residential PV DG in Hawaiian Electric (HECO)'s distribution system

Source: M. Asano, Grid Modernization Applications in a High DER Environment, 2018 IEEE PES T&D Conference and Exposition, Denver CO
Example of PV Impacts on Hosting Capacity – Voltage Fluctuation/Increase (2)

Overvoltage at service transformer due to reverse power flow caused by residential PV DG in Hawaiian Electric (HECO)’s distribution system

Source: M. Asano, Grid Modernization Applications in a High DER Environment, 2018 IEEE PES T&D Conference and Exposition, Denver CO
Volt-Var Control at the Grid Edge

Sep 25 – ENGO OFF
LTC SP = 122V

Sep 26 – ENGO ON
LTC SP = 122V

Oct 26 – ENGO ON
LTC SP = 119.5V

1. Fluctuation Reduction: ENGO voltage fluctuation range reduces when ENGO units are active.

2. Daytime Operations: During the day time, ENGO units provide dynamic VAR support to compensate for PV generation volatility (e.g. cloud cover).

3. Night Time Operations: During the night time, ENGO units provide full kVAR support during peak-load times when PV generation is not available.

4. Tap Down LTC to Allow Extra PV Penetration: ENGO provides voltage support to allow the LTC to tap down permanently which will allow extra PV penetration for the system.

Source: M. Asano, Grid Modernization Applications in a High DER Environment, 2018 IEEE PES T&D Conference and Exposition, Denver CO
DERMS, is used to describe software platforms that provide a variety of functions, from controlling and aggregating fleets of behind-the-meter DER, to enabling utilities to integrate them into their grids.
Utilization of smart inverters and power electronics-based assets (e.g., distribution-class Static Var Compensators – SVC) for dynamic volt-Var control and optimization of distribution operation, including peak demand reduction, energy efficiency applications, losses reduction, hosting capacity increase (self-mitigation of voltage variability caused by PV proliferation) and multi-objective applications.
Flexible AC Transmission Systems (FACTS) devices are advanced static power electronics-based series and/or shunt equipment used to provide fast, dynamic and continuous control of voltages and/or power flows in transmission systems and increase power transfer capability, stability and controllability of the grid.

FACTS applications in transmission systems is an established and mature area, while applications in distribution are still emerging and generally targeted to custom power and DER integration use cases (e.g., volt-Var control in wind and PV farms).

Most popular distribution technologies are SVCs and STATCOMs (e.g., D-VAR by American Superconductor). Technology has been deployed by utilities such as Alliant Energy [link].

Example of application of UPFC for power flow and voltage control.

Power flow distribution **before** UPFC

Power flow distribution **after** UPFC
Non-Wires Alternatives

- Non-Wire Alternatives (NWA) - The utilities industry has developed state of the art processes to select when an NWA is a suitable solution to address a system need. The industry and research groups has developed tools to calculate the benefit cost of NWA solution.

- NWA Definition per HECO Distribution Planning Working Group (DPWG):
  
  A Non-Wire Alternative is an electricity grid project that uses non-traditional transmission and distribution (T&D) solutions, such as distributed generation (DG), energy storage, energy efficiency (EE), demand response (DR), and grid software and controls, to defer or avoid the need for conventional transmission and/or distribution infrastructure investments.

- Suitability Criteria are defined including Timing, Cost and Time Period. Example below

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Potential Elements Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Type Suitability</td>
<td>Project types include Load Relief and Reliability*. Other categories currently have minimal suitability and will be reviewed as suitability changes due to State policy or technological changes.</td>
</tr>
<tr>
<td>Timeline Suitability</td>
<td>Large Project: 36 - 60 Months</td>
</tr>
<tr>
<td></td>
<td>Small Project: 18 - 24 Months</td>
</tr>
<tr>
<td>Cost Suitability</td>
<td>Large Project: &gt; $1M</td>
</tr>
<tr>
<td></td>
<td>Small Project: &gt; $300k</td>
</tr>
</tbody>
</table>

1. Define Grid Needs
   - Size, duration, in-service date
2. Opportunity Criteria
   - Timing & Cost
3. Sourcing Options
   - Demand Response
   - EE
   - Enhanced Control
   - DER
## Locational Value Categories

<table>
<thead>
<tr>
<th>Value Category</th>
<th>California(^{27})</th>
<th>New York(^{28})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distribution</strong></td>
<td>Avoided Feeder/Substation Costs</td>
<td>Avoided Distribution Capacity Infrastructure</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Avoided Distribution O&amp;M</td>
</tr>
<tr>
<td></td>
<td>Avoided Distribution Voltage/Power Quality Costs</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Avoided Reliability Costs</td>
<td>Net Avoided Outage Costs</td>
</tr>
<tr>
<td></td>
<td>Avoided Resiliency Costs</td>
<td>Net Avoided Restoration Costs</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Avoided Distribution Losses</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>Avoided Transmission Capital Expenditures</td>
<td>Avoided Transmission Capacity Infrastructure and O&amp;M</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Avoided Transmission Losses</td>
</tr>
<tr>
<td><strong>Generation</strong></td>
<td>Avoided System Resource Adequacy (RA) and Local RA</td>
<td>Avoided Generation Capacity (ICAP), with Reserve Margin</td>
</tr>
<tr>
<td></td>
<td>Avoided Flexible RA / Avoided Renewable Integration Costs</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Avoided Energy (via LMP)</td>
<td>Avoided Energy (LBMP)</td>
</tr>
<tr>
<td></td>
<td>Avoided Ancillary Services</td>
<td>Avoided Ancillary Services</td>
</tr>
<tr>
<td></td>
<td>RPS Costs</td>
<td></td>
</tr>
<tr>
<td><strong>Environmental / Society</strong></td>
<td>Avoided GHG Costs (via LMP)</td>
<td>Net Avoided GHG (social cost of carbon)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Net Avoided Criteria Air Pollutants</td>
</tr>
<tr>
<td></td>
<td>Avoided Societal Costs / Avoided Public Safety Costs</td>
<td>Avoided Water Impacts / Avoided Land Impacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-Energy Benefits</td>
</tr>
</tbody>
</table>

- Calculate the value of DER on a locational and temporal basis in terms of grid avoided costs, especially on sub-transmission and distribution systems.

- Framework that enables a calculation of the Locational Marginal Value (LMV) of incremental kW and kVar of DER injection - DER compensated based on distribution grid needs at a given location and time vs. by type, by circuit voltage level and by region

- Value of DER as Non-Wires Alternatives (NWAs) compared to traditional investment
  - Line thermal overloads
  - Voltage violations (under-voltages or over-voltages)

LMV demonstrates the value of injections to improve power factor and reduce loadings upstream. The DER farthest from the station will have greater value than the one closer as it benefits ALL overloaded sections plus it reduces losses to a greater extent.
Value is Temporal

Winter Peak

Summer Peak

Potential value for downstream DER

Potential value for downstream DER
Example – Accounting for Impacts of Solar PV in Pepco DC/MD

In order to accurately account for the impact of Distributed PV in planning, PHI requires:

- The hourly production profile of the resource for the peak period (typically summer)
- The nameplate capacity of the resource on the circuit, transformer or substation
- The hour of the greatest feeder, circuit, or transformer peak

Note: Actual hourly production capacity will rarely achieve 100% of nameplate rating due to factors which include cloud cover, panel efficiency loss due to temperature, panel tilt and orientation, and shading.
The peak reduction impact of PV can range from 0% to ~60% of nameplate PV depending on the coincidence of the PV production with the peak load hour.

### Pepco MD Feeders

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Historical Peak (MVA)</th>
<th>Feeder Peak Hour</th>
<th>Nameplate PV (kW)</th>
<th>PV Capacity Factor for Feeder Peak Hour</th>
<th>PV Impact on Peak (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14241</td>
<td>7</td>
<td>15</td>
<td>1088.66</td>
<td>42%</td>
<td>454.30</td>
</tr>
<tr>
<td>14165</td>
<td>8.5</td>
<td>17</td>
<td>746.99</td>
<td>22%</td>
<td>166.51</td>
</tr>
<tr>
<td>14161</td>
<td>8.4</td>
<td>22</td>
<td>760.395</td>
<td>0%</td>
<td>0.00</td>
</tr>
<tr>
<td>14492</td>
<td>5.3</td>
<td>15</td>
<td>1692.88</td>
<td>42%</td>
<td>706.44</td>
</tr>
<tr>
<td>14245</td>
<td>6.5</td>
<td>14</td>
<td>1298.78</td>
<td>47%</td>
<td>609.16</td>
</tr>
</tbody>
</table>

### Pepco DC Feeders

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Historical Peak (MVA)</th>
<th>Feeder Peak Hour</th>
<th>Nameplate PV (kW)</th>
<th>PV Capacity Factor for Feeder Peak Hour</th>
<th>PV Impact on Peak (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15708</td>
<td>8.3</td>
<td>19</td>
<td>277.955</td>
<td>2%</td>
<td>4.88</td>
</tr>
<tr>
<td>15172</td>
<td>6.5</td>
<td>17</td>
<td>208.58</td>
<td>27%</td>
<td>57.10</td>
</tr>
<tr>
<td>15710</td>
<td>5.5</td>
<td>16</td>
<td>3.35</td>
<td>40%</td>
<td>1.33</td>
</tr>
<tr>
<td>14712</td>
<td>6.3</td>
<td>16</td>
<td>138.495</td>
<td>40%</td>
<td>55.05</td>
</tr>
<tr>
<td>14713</td>
<td>9.4</td>
<td>17</td>
<td>356.04</td>
<td>27%</td>
<td>97.46</td>
</tr>
<tr>
<td>15701</td>
<td>7.9</td>
<td>16</td>
<td>451.322</td>
<td>40%</td>
<td>179.40</td>
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<td>94.78</td>
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<tr>
<td>15703</td>
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<td>19</td>
<td>208.22</td>
<td>2%</td>
<td>3.66</td>
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</table>

Note: This is an extrapolation based upon the production curves presented in the previous slide. For planning purposes PHI can model each feeder individually to account for the impacts of PV.

Source: Pepco
The majority of installed PV capacity in Pepco MD/DC is interconnected on feeders with loads that peak at either 3:00 PM or 6:00 PM.

- The impacts of solar must be adjusted according both to the production profile of the resource and the attributes of the circuit, transformer, or substation.
- In some cases, where the circuit, transformer, or substation experience a peak load later in the day or early in the morning PV may not provide any capacity relief.

Source: Pepco
1) Forecasts and planning inputs
2) Resource needs and sourcing
3) Transmission and distribution needs and alternatives
4) Near-term action plan and long-term pathway
Microgrids are defined as “A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single, controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected and island mode”

Microgrids provide an opportunity to realize the potential benefits of DER adoption to

- Improve reliability and resilience via intentional islanding during utility grid disruptions,
- Enhance the operational efficiency of the grid by providing local support (e.g., volt-var control, peak shaving, etc.) when needed,
- Facilitate and manage DER integration

DER Readiness – Ability to Effectively and Seamlessly Host and Manage DER

Source: M. Asano, Grid Modernization Applications in a High DER Environment, 2018 IEEE PES T&D Conference and Exposition, Denver CO
DER Readiness Concept – Modular Framework

- DER Interconnection Process, Staffing, and Customer Interface
- Integrated Utility Information Systems
- Updated DER and T&D Standards
- DER Readiness
- Updated T&D Practices (Design, Engineering, Construction, Planning and Operations)
- Grid Analytics
- Software and Models
- Policy, Regulatory and Markets
- Technology Aspects (Telecom, Monitoring, Protection, Automation and Control)
- Foundational & Enabling Infrastructure
- Updated T&D Practices (Design, Engineering, Construction, Planning and Operations)
Foundational & Enabling Infrastructure

- Capital investments (reliable and resilient grid)
- New feeders and substations (e.g., express/dedicated feeders)
- Aging infrastructure replacement
- Infrastructure hardening
- Energy storage
- Switchgear
- Voltage regulation/control and protective devices
- Intelligent Electronic Devices (IEDs)
- Telecommunications infrastructure
- Advanced Metering Infrastructure (AMI)

U.S. utility-scale battery storage power capacity (March 2019) megawatts (MW)

Source: https://www.eia.gov/todayinenergy/detail.php?id=40072#
Updated DER and T&D Standards

- Review/update of smart inverter standards to include prospective DER applications (e.g., volt-Watt, volt-VAR, voltage and frequency ride through, etc.)
- Review/update of equipment standards to consider prospective DER penetration scenarios (e.g., service transformers, voltage regulators, load tap changers, protection relays, sensors, power electronics voltage regulation/control equipment, etc.)
- Development and/or review and update of cybersecurity standards

Source: IEEE 56
DER Interconnection Process

- Review/update of DER interconnection process:
  - Requirements for modeling, simulation and analysis of DER interconnection requests
  - Automation of DER interconnection process via online portals (customer applications, data collection, inspections, approvals, etc.)

Historical Adoption of Residential PV in APS

Source: NERC

D. Haughton, Distribution Automation and DER at APS, 2018 IEEE PES Transmission and Distribution Conference and Exposition, Denver, CO
Integrated Utility Information Systems

- Integration of automated DER interconnection process into IT system
  - Implementation of DER Management System (DERMS)
  - Integration of DER interconnection and existing processes (e.g., approved/installed DER should be added into GIS and CYME models automatically)

Updated T&D Practices

- Review/update of planning practices
  - DER hosting capacity
  - DER impact studies
  - Firm capacity contribution from DER
  - Consideration of DER in load forecasting activities
  - DER forecasting
  - Review of distribution automation practices for feeders with DER

- Review/update of operations practices for feeders with bi-direction power flow
- Review/update of design and construction practices for DER-ready feeders and substations

Grid Analytics

- Define data collection requirements for in-front and behind-the-meter DER (e.g., voltage, current, kW, kvar, kWh, kvarh, etc.)
- Identify applications and solutions for
  - DER forecasting
  - Firm capacity contribution from DER
  - DER operation under normal and abnormal conditions (e.g., voltage and frequency ride-through)
  - DER asset lifecycle analysis (e.g., failure rates, etc.)

Software and Models

- DER hosting capacity
- DER impact studies
  - DER adoption scenarios
- DER forecasting
- Firm capacity contribution from DER
- Value of DER/grid
- Distribution planning (power flow) models (time-series analysis)
- Feeder protection/control models
- Secondary system models
- Dynamic/transient models
- Irradiance models
- DER model validation (fault current contribution, volt-Var performance, etc.)

Source: Pepco Holdings Inc.
Policy, Regulatory and Markets

- Review/update of regulations for utilization/compensation of behind-the-meter DER to provide support to utility grid
- Review/update of regulations for deployment of community microgrids, virtual power plants, and community solar
- DER marketplace

Source: https://www.greentechmedia.com/articles/read/distributed-energy-poised-for-explosive-growth-on-the-us-grid
Technology Aspects

• Requirements for telecom, monitoring, protection and automation and control equipment for in-front and behind-the-meter DER and/or impacted by DER (sensors, reclosers, switchgear, relays, voltage regulators, capacitor banks, LTCs, power electronics-based voltage regulation/control equipment, etc.)

• Interoperability, cybersecurity, IoT and smart cities requirements for integration of DER

Source: ConnectDER

Source: Varentec
Conclusions

- Interconnection studies are necessary but not enough particularly when large proliferation of DER is expected.
- Studies for large scale DER tend to be “deterministic”. Studies for residential and commercial scale DG require statistical analyses for handling uncertainty about location and occurrence. Moreover, they require analyzing a set of representative feeders and extrapolating results to overall system. These studies analyze both steady state and dynamic conditions.
- Dynamic/transient impacts of DER cannot be identified using conventional distribution analysis software, more detailed modeling and simulations and specialized software are necessary.
- Typical impacts are voltage rise/fluctuations, reverse power flow, reactive power fluctuations, interaction with voltage regulation and control equipment, localized overloads (distribution transformers and lines), etc.
Integration of Electric Transportation

Electric Vehicle Charging Levels (SAE J1772)

<table>
<thead>
<tr>
<th>KNOW YOUR EV CHARGING STATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC Level One</strong></td>
</tr>
<tr>
<td><strong>VOLTAGE</strong> 120v 1-Phase AC</td>
</tr>
<tr>
<td><strong>AMPS</strong> 12–16 Amps</td>
</tr>
<tr>
<td><strong>CHARGING LOADS</strong> 1.4 to 1.9 kW</td>
</tr>
<tr>
<td><strong>CHARGE TIME FOR VEHICLE</strong> 3–5 Miles of Range Per Hour</td>
</tr>
<tr>
<td><strong>AC Level Two</strong></td>
</tr>
<tr>
<td><strong>VOLTAGE</strong> 208V or 240V 1-Phase AC</td>
</tr>
<tr>
<td><strong>AMPS</strong> 12–80 Amps (Typ. 32 Amps)</td>
</tr>
<tr>
<td><strong>CHARGING LOADS</strong> 2.5 to 9.2 kW (Typ. 7 kW)</td>
</tr>
<tr>
<td><strong>CHARGE TIME FOR VEHICLE</strong> 10–20 Miles of Range Per Hour</td>
</tr>
<tr>
<td><strong>DC Fast Charge</strong></td>
</tr>
<tr>
<td><strong>VOLTAGE</strong> 208V or 480V 3-Phase AC</td>
</tr>
<tr>
<td><strong>AMPS</strong> &lt;125 Amps (Typ. 60 Amps)</td>
</tr>
<tr>
<td><strong>CHARGING LOADS</strong> &lt;90 kW (Typ. 50 kW)</td>
</tr>
<tr>
<td><strong>CHARGE TIME FOR VEHICLE</strong> 80% Charge in 20–30 Minutes</td>
</tr>
</tbody>
</table>

Source: PNM [https://www.pnm.com/ev-charging](https://www.pnm.com/ev-charging)
Time of Use Rates and EV Charging Profile Modification

June to September (4 months)

Weekdays

- 8am: 14¢
- 4pm: 40¢
- 9pm: 14¢

Weekends

- 8am: 14¢
- 4pm: 25¢
- 9pm: 14¢

October to May (8 months)

Weekdays

- 8am: 13¢
- 4pm: 36¢
- 9pm: 13¢

Weekends

- 8am: 13¢
- 4pm: 36¢
- 9pm: 13¢


Evaluate integration impacts of Electric Vehicles (EVs) on planning and operations of power distribution systems, including those on:

- Voltage, voltage profile and current
- Equipment loading and lifecycle
- Voltage and current imbalance
- Power and energy losses
- Power factor
- Load cycling and control
- Power quality, reliability and operability of the system

Propose solutions for addressing issues created by the potential large-scale adoption of EVs on power distributions systems, including distribution capacity increase, intelligent load control, incentives and utilization of Distributed Energy Resources (DER)
Methodology

Step 1: study, scope and EV scenarios
- Geographic and customer base considerations
- T&D system layout considerations

Step 2: EV use and charging model

Step 3: representative model

Step 4: basic study scenarios
- Modular parts of step 4: coordinated study of
  - Load curve & load analysis
  - DR & smart grid
  - Power flow analysis
  - Reliability
  - Cost
- Study only customized scenarios this time

Step 5: Construct & study strategic scenarios
- Identify problems & solution strategy

Step 6: Report & workshop
- Extrapolate to entire system
- Review workshop
Simulation Approach

- **Number of EVs:**
  - Penetration rate: defined as number of EVs per household

- **Number of charging EVs:**
  - Charging scenario
  - Coincident factor: how many EVs are charging simultaneously

- **Location of charging EVs:**
  - Random assignment or based on demographic study
Results – Uncontrolled vs. Controlled EV Charging Scenarios (Example)
• Violation of feeder and substation planning limits during normal and contingency conditions due to loading increase caused by EV charging (e.g., EV charging may coincide with peak demand of residential feeders)

• Overloaded assets due to peak loading increase (e.g., service and power transformers, overhead line conductors, underground line cable, etc.)

• Low voltage due to loading increase and overloaded assets

• Reduced lifecycle of key assets due to changes in loading patterns of service and power transformers

• Voltage/current imbalance increase

• Power and energy loss increase
Impact of Electric Fleets on Distribution Feeders – **Full Charging Strategy**

Source: National Grid [https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf](https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf)
EV Integration Solutions – Examples

- Traditional T&D solutions
  - Replace overloaded transformers (upgrade)
  - Replace overloaded conductors/cable (reconductoring)
  - Eliminate undervoltage via reconductoring and capacitor banks
  - Build new feeders and substations (capacity increase)

- Intelligent solutions
  - Load control and curtailment
  - DER dispatch
  - Time-variant rates

- Usually, optimal solution portfolio includes a combination of traditional and intelligent solutions
Impact of Electric Fleets on Distribution Feeders – **Minimum Charging Strategy**

Impact on Substation Loading

Source: National Grid [https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf](https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf)
System Integration Impacts & Costs vs. EV Penetration Level – Example

- CONTROLLED
- UNCONTROLLED

% of system requiring attention

Penetration Level

Cost in millions

Penetration Level

$0
$2,000
$4,000
$6,000
$8,000
$10,000
$12,000

5% 10% 15% 20% 25% 30% 40% 50% 60% 80% 100%

Uncontrolled

Controlled

Power & Energy Society • IEEE
Spatial Characteristics of EV Integration Impacts – Annual Peak Demand
S-curve forecasting for 8 small areas (kW) – Annual Peak Demand

Forecasting for 8 Small Areas

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

A B C D E F G H
S-curve forecasting for small area A (kW) – Annual Peak Demand

Forecasting for Different Scenarios of Small Area A

- Base
- EV1
- PV1
- PV1 & EV1
- NZE1
- EE1
- DR1

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
S-curve forecasting for small area B (kW) – Annual Peak Demand

Forecasting for Different Scenarios of Small Area B

- Base
- EV1
- PV1
- PV1 & EV1
- NZE 1
- EE 1
- DR1
Consider potential impact of transportation electrification in existing downtown infrastructure

Methodology can localize future, projected charger load impacts on substations service territory:

1. Identify and map substations via GPS or latitude/longitude coordinates
2. Identify key commercial, retail, and fleet facilities in specified territory, and then estimate corresponding charger load growth
3. Facilities are linked to specific substations via a distance algorithm
4. New load growth from electrification is added to current substation rating and compared against its max rating
5. Substations are then ranked against their max rating to determine whether substation is at risk due to load
EV, PV-DG and DES synergies
EV, PV-DG and DES synergies
## EV, PV-DG and DES synergies

<table>
<thead>
<tr>
<th>Voltage (PU)</th>
<th>EV3</th>
<th>EV2</th>
<th>EV1</th>
<th>Base</th>
<th>PVEV3</th>
<th>PVEV2</th>
<th>PV3</th>
<th>PVEV1</th>
<th>DES1</th>
<th>PV1</th>
<th>PV2</th>
<th>DES2</th>
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<td>1.029</td>
</tr>
</tbody>
</table>

Voltage levels for EV, PV-DG and DES systems.
Conclusions and Recommendations

- EV integration impacts may be significant even at low penetration levels if charging is uncontrolled.

- Impacts include:
  - Overloaded distribution transformers
  - Overloaded conductors and cable
  - Low voltage to customers
  - Violations of planning limits

- Most of these impacts can be resolved by directly or indirectly controlling the time and duration of EV charging

- Utilities should understand the potential impact of EVs on their respective service territories.

- Set up a system to identify new EVs when they come onto the system. A key to managing costs and keeping impacts to a minimum through pro-active actions is to know where the EVs are before problems become serious.

- Study how EV adoption rates, particularly on a local-area basis, can be predicted or trended, in order to support planning of required additions

- EVs may have an impact at low penetration levels, especially in areas of early adopters (clusters)

2. J. Romero Aguero, S. Steffel, Integration challenges of photovoltaic distributed generation on power distribution systems, IEEE PES General Meeting, July 2011


Thank you!