Impact Studies & Mitigation Measures for Integration of Solar Photovoltaic Distributed Generation

Utilities in North America and around the world are experiencing rapid proliferation of Solar Photovoltaic Distributed Generation (PV-DG) which is prompted by several factors including compliance with Renewable Portfolio Standards (RPS). This can represent an important challenge for utilities since the intermittent nature of PV-DG leads to diverse impacts on distribution system operations and planning. These impacts are not only of steady state but also of dynamic/transient nature. Quanta Technology has broad expertise with the assessment and mitigation of these impacts to allow the integration of PV-DG on power distribution systems. Our methodology includes identifying feeder level and/or system-wide impacts, providing utilities with guidelines regarding expected impacts as a function of penetration level, determining potential mitigation measures, developing and reviewing interconnection guidelines and standards, and testing inverters in a laboratory setting.

Potential Benefits of Solar PV-DG Integration
Quanta Technology can help identify and leverage potential benefits of PV-DG such as:

- **Capacity release**: for moderate penetration levels (enough for offsetting the feeder load) PV-DG may help unloading feeder sections, moderately reducing feeder losses and releasing feeder and substation capacity. This applies only to feeders that peak during daylight. However, it is necessary to deal with intermittency due to clouding. Distributed energy storage is a potential solution for increasing the “firmness” of PV-DG to minimize the impact of clouding phenomena.

- **Local voltage support**: if located on areas where this is required and if interaction with capacitor banks, LTCs, voltage regulators and PV-DG intermittency are properly managed.

- **Increased operational flexibility**: PV-DG can help release neighbor feeder capacity or offset the affected feeder's load during restoration. This may facilitate restoration of the affected feeder and improve system reliability.

Feeder Level Studies
Impacts can either be evaluated on individual feeders or at system level. Individual feeder studies are conducted using a set of predefined scenarios including different loading and PV-DG conditions.

System Wide Level Studies
System wide studies evaluate impacts due to gradual proliferation of PV-DG on the overall service territory. Since it is labor, time and cost prohibitive to study all system feeders, in this case a set of representative circuits is identified using a clustering algorithm. Each characteristic circuit represents a cluster of feeders with similar features (length, customer density, loading, etc.). Then simulations are performed on each representative circuit for a variety of scenarios that simulate, not only varying loading and PV-DG generation conditions, but also a variety of penetration levels that represent gradual proliferation of PV-DG. Simulations are conducted using a statistical approach to model uncertainty about PV-DG location. Results obtained for each representative feeder are evaluated, impacts are identified and corresponding costs of mitigation measures are estimated. Individual feeder costs are extrapolated to each cluster to estimate system wide costs.
Steady State Impact Assessment

Quanta Technology builds detailed steady state computational models of feeders to assess the impact of PV-DG output variation as the feeder goes thru the typical daily load profile. These simulations produce hourly load and voltage profiles at substations and feeders, PV-DG plant locations, capacitor banks and line voltage regulator sites and feeder lowest voltage locations. This study also summarizes capacitor, LTC and line voltage regulator operations. All results are based on actual feeder hourly active and reactive power demands and expected PV-DG output profiles. Depending on the level of detail of the study, simulations can cover a broad range of feeder demand conditions, from "worst case scenario" based on annual minimum load to in depth 8760-hour load profiles. Quanta Technology has developed specialized algorithms and software programs that allow conducting comprehensive analyses. Studies may include performing thousands of power flow simulations for varying loading and PV-DG output conditions to obtain a realistic depiction of steady state impacts.

Typical Impacts

Typical impacts include: voltage rise, voltage fluctuations (steady state and transient), interaction with LTC, line voltage regulators and capacitor banks, increased maintenance of distribution equipment, reactive power fluctuations, line and equipment loading increase, reverse power flow, losses increase and voltage unbalance increase, impacts on overcurrent and overvoltage protection systems, harmonic distortion increase, temporary overvoltages (TOV) and flicker. These impacts are not localized and may grow as PV-DG penetration level increases.

Mitigation Measures

Impacts are addressed via typical approaches including modification of settings and operation modes of LTCs, line voltage regulators and capacitor banks, line reconductoring and equipment upgrade, relocating capacitor bank and voltage regulation equipment, using express feeders, or through smart distribution approaches such as implementation of dynamic VAR compensation via PV-DG inverters. If significant impacts, complex equipment interactions and voltage-VAR fluctuations are identified, additional mitigation measures such as implementation of STATCOMs, SVCs, distributed storage and adaptive protection systems are evaluated.

Dynamic Impact Evaluation

Quanta Technology builds detailed computational models of distribution feeders and PV-DG plants that are used to estimate dynamic and transient impacts. The results of the steady state analyses are used to identify critical operation conditions. Then comprehensive simulations are conducted for those conditions to estimate impacts of PV-DG on feeder voltage, and operation of capacitor banks, LTCs and line voltage regulators.

Simulations include:

- Disconnection and connection of PV-DG: this test simulates the sudden disconnection and connection of the PV-DG for various generation conditions
- PV-DG islanding: this test analyzes impact of PV-DG on feeder voltage during sudden operation of over-current protection devices (main breaker, reclosers)
- PV-DG intermittent output impact: this test determines voltage fluctuations due to PV-DG output intermittency. A pre-specified PV-DG output profile (ideally second or sub-second profile) is used to change power output of the PV-DG plant. Magnitude and frequency of the voltage variations is compared with maximum permissible voltage fluctuations as per IEEE 1453-2015 standard. The impact of these variations on capacitor banks, LTCs and line voltage regulators will be reported as well.
Synergies with PHEVs & Energy Storage

Quanta Technology can help leverage the synergies among PV-DG, Plug-in Hybrid Electric Vehicles (PHEVs) and distributed energy storages. If the energy generated by PV-DG plants could be stored during the day (when demands are usually low) and released during evenings and early mornings (when demands are usually high), then it could mitigate the impacts caused by PV-DG (e.g., overvoltages) and mitigate the impacts caused by PHEVs (e.g., overloads). The utilization of distributed storage may allow utilities "killing two birds with one stone".

Review of Process, Standards & Guidelines

Quanta Technology can assist in the review of existing processes, standards and guidelines for integration of PV-DG. This review includes interviews with key personnel involved in the DER application process to identify potential issues that need to be addressed or procedures that require update or modification. These processes, standards and guidelines are benchmarked against those used by the industry to identify potential gaps with respect to accepted best practices. Quanta Technology uses the results of the interviews, benchmarks, literature review and its expertise in the subject to perform a gap analysis and identify procedures, standards and criteria that require modification and/or improvement. Assistance for preparing PV-DG integration guidelines and criteria can also be provided.

Inverter Testing

The first step of the dynamic analyses is to ensure that valid models of PV-DG inverters are available. The objective is to use these models for the following studies: short-circuit, transient and voltage stability, flicker, harmonic, fault ride-through studies and Real-time Dynamic Analysis (RTDS). The inverter models are normally not available from manufacturers. Quanta Technology can test inverters in a laboratory setting and validate these models. Then the inverter models can be used to build generic computational models of individual and aggregated PV-DG for dynamic/transient studies.

About Quanta Technology

Quanta Technology, LLC is an expertise-based independent technical consulting firm that helps electric utilities and other power industry entities by providing smart, practical solutions to their most complex transmission and distribution challenges. In addition to offering a complete range of capabilities for evaluating DG systems, Quanta Technology also offers the following services:

- Strategic and asset management planning
- Transmission and distribution infrastructure planning and analysis
- Sustainable energy impact evaluation and portfolio assessment
- Energy storage conceptual design, specifications and integration
- Equipment condition, design and maintenance standards assessment
- Best practices assessment and utilization
- RTO/ISO, regulatory, Electric Reliability Organization (ERO) and Regional Reliability
- System protection and automation
- “Smart Grid / Grid of the Future” development and deployment
- Enterprise systems integration
- Staff training

The company draws from a vast network of experienced power system experts from around the world, ensuring efficient objective and credible outcomes. As an independent consulting arm of Quanta Services, we are able to deliver end-to-end solutions that span the entire transmission and distribution (T&D) spectrum, from business consulting all the way through to engineering, procurement and construction.

For more information on Quanta Technology's Impact Studies and Mitigation Measures for Integration of PV-DG, please contact:

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