GRID-INTEGRATED DISTRIBUTED SOLAR: ADDRESSING CHALLENGES FOR OPERATIONS AND PLANNING

GREENING THE GRID

Distributed, grid-connected photovoltaic (PV) solar power poses a unique set of benefits and challenges. This brief overviews common technical impacts of PV on electric distribution systems and utility operations (as distinct from other utility concerns such as tariffs, rates, and billing), as well as emerging strategies for successfully managing some of the priority issues.

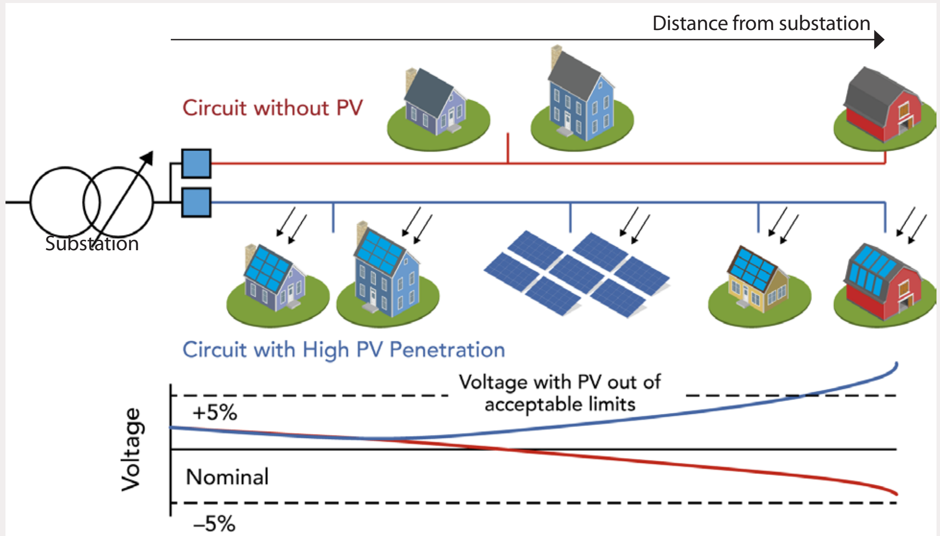

Figure 1: An illustration of the increased voltage range in systems with high PV penetration. On a circuit with no PV present (red line), the voltage along the feeder decreases as distance from the substation increases. If the PV power injected into the circuit (blue line) is high enough, the voltage will increase, potentially raising the voltage above normal operational conditions.

BENEFITS OF DISTRIBUTED SOLAR

In distributed solar applications, small (1-25 kilowatt [kW]) PV systems generate electricity for on-site consumption and interconnect at low-voltage points of the grid, typically 600 volts and below. Deploying distributed PV can reduce transmission and distribution line losses, increase grid resilience, lower generation costs, and reduce requirements to invest in new utility generation capacity. Distributed PV systems can also mitigate reliability issues experienced in developing areas by providing standby capacity capable of offering stable power during times of poor power quality.[1]

CHALLENGES OF DISTRIBUTED SOLAR

Operation. In most electric utility systems, power flows in one direction, from centralized generators to substations, and then to consumers. With distributed generation (DG), power can flow in both directions. Most electric distribution systems were not designed to accommodate widespread DG and two-way flow of power. For distribution feeder circuits that are long and serve rural or developing areas, even small amounts of PV may impact system parameters if the load and PV generation are not closely matched [1]. When distributed PV generation exceeds local energy demand, energy will move through the distribution feeder and possibly through the local substation, increasing the potential for damage to the utility grid and for impacts to other utility customers served by the same distribution circuit [2].

Maintaining acceptable voltage levels at all points along a distribution feeder is a fundamental operating requirement of all electric distribution utilities, large or small, rural or urban. Fluctuating power generation from distributed PV can impact the operation of any voltage regulation devices and complicate the task of maintaining the voltage levels within regulated limits (see Figure 1). The occasional cloud variability affecting solar energy production may accelerate cycling—and associated wear and tear—of voltage regulation equipment, especially critical for longer, rural feeders.

Planning. Traditional, distribution and transmission planning do not addresses the benefits and challenges of DG systems. Quantifying the ability of distributed PV to reliably help meet electricity demand can be challenging.[2] Additionally, traditional distribution planning procedures use load growth to inform investments in new distribution infrastructure, with little regard for DG systems and for PV development.

DISTRIBUTED SOLAR TERMS

Distribution feeder: Power lines within the distribution system that carry electricity from the substation to the load.

Distribution system operator: An entity responsible for operating, maintaining, and developing the distribution system and its interconnections with other systems.

Fault ride-through: The capability of electrical devices to be able to operate through periods of lower grid voltage.

Grid hosting capacity: The amount of DG a distribution circuit can accommodate, without problems of any type, with no upgrades to the circuit. This level may be increased by various circuit upgrades or by using advanced inverter functions.

Inverter: A power electronics device that transforms variable direct current to alternating current.

Voltage: The difference in electrical potential between any two conductors or between a conductor and ground. Voltage is a measure of the electric energy per electron that electrons can acquire and/or give up as they move between the two conductors.

1. *Poor power quality (e.g., low voltage or outages) is proven to damage many electric devices; thus, stable voltage and frequency are desired and have international standards offering guiding parameters*
2. *For more information, see a related fact sheet, "Using Wind and Solar to Reliably Meet Electricity Demand."*

EMERGING STRATEGIES FOR MEETING THE CHALLENGES

Interconnection Standards and Codes

Interconnection standards and codes define the requirements for distributed generators to interconnect with the grid and ensure that the behavior of these generators supports reliable distribution system operations. Traditionally, these standards require inverters to disconnect from the grid and interrupt energy production when certain grid disturbances (e.g., over/under-voltage or frequency) are detected. Germany, which leads the world in distributed PV deployment, has updated its interconnection requirements instead to require PV inverters to support appropriate frequency levels (e.g., by implementing fault ride-through capabilities) that prevent large-scale simultaneous PV disconnection in over-frequency situations. These standards also require distributed PV to use equipment to remotely and selectively curtail system output when generation significantly exceeds demand at the substation level [3, 4]. For distribution systems in developing countries where voltage and frequency problems are more common, especially on longer rural feeders, interconnection standards and codes can require the use of commercially available battery inverters to enable off-grid and stand-alone operation of PV systems.

Interconnection standards can be accompanied by equipment requirements that define the parameters that distributed PV components must meet. For example, interconnection requirements in most North American power systems are based on the IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. The related equipment standard—UL 1741 Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources—provides certification requirements for distributed generator equipment that operates according to the parameters established in IEEE 1547.

Interconnection Procedures

Interconnection procedures balance the goals of facilitating deployment of distributed PV and ensuring reliable operation of the distribution system. As penetration levels of distributed PV increase, it may become important to replace 'first-come, first-served' interconnection processes with a transparent process based on system impacts [3]. For instance, most distribution system operators in high PV contexts require detailed impact studies for new PV applicants above a specific size in capacity (e.g., kW) or for triggering other technical screens. Interconnection procedures requiring PV inverters to comply with interconnection and equipment standards can enable utility screening procedures to be carried out quickly and may reduce interconnection process time and costs. Recent trends in interconnection screens can be found in [5].

System and Distribution Planning

Planning that anticipates PV growth can facilitate least-cost development. Many regions with high PV penetration are updating distribution planning methodologies to better reflect the characteristics of distributed PV and to improve overall grid hosting capacity. Distributed PV can be incorporated into integrated resource planning and modeling of system capacity expansion to optimize the amount of distributed PV in the system in the future [4]. Planning for higher PV penetration in designated zones—defined by regulatory criteria or created through targeted grid reinforcements and upgrades—is another growing approach. These zones can be identified by utilities through a process administered by a regulatory body that considers stakeholder needs and is based on sound engineering principles [5, 6].

In addition to these approaches, the emerging concept of "Integrated Distribution Planning" proposes a proactive planning methodology to enable distributed PV. In this concept, utilities or distribution system operators study the hosting capacity of distribution circuits, the ability of these distribution circuits to accommodate growth in DG, and any necessary infrastructure upgrades in advance of receiving interconnection requests from generators [7].

Finally, at the transmission level, system operators are beginning to plan for increased overall flexibility by encouraging dispatchable sources of power and flexible demand in anticipation of higher levels of grid-connected, distributed PV [8].

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Written by M. Coddington, M. Miller, and J. Katz, National Renewable Energy Laboratory.

Greening the Grid provides technical assistance to energy system planners, regulators, and grid operators to overcome challenges associated with integrating variable renewable energy into the grid.

FOR MORE INFORMATION

Jennifer Leisch
USAID Office of Global Climate Change
Tel: +1-202-712-0760
Email: jleisch@usaid.gov

Jaquelin Cochran
National Renewable Energy Laboratory
Tel: +1-303-275-3766
Email: jaquelin.cochran@nrel.gov

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