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Distributed Energy Resources Supporting Power Grid Reliability

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SUMMARY

As penetration levels of Distributed Energy Resources (DER) around the world increase, considerations of such technologies in the total generation resource pool become necessary from a system operations perspective. This paper examines the potential impacts of the growth in DER and its potential for supporting the reliability of the Transmission and Distribution power grid. Conventional system reliability considerations have a distinctive set of indicators for transmission systems and distribution systems due to separation of these systems' control and operation. However, it is important to have a futuristic view of the challenges that exist and to understand what can be done to maintain reliability of the integrated power grid with an ever-increasing level of DER penetration. This paper uniquely examines the technical and regulatory approaches that will enable DER to support reliability considering both transmission systems and distribution systems together as power grid.

KEYWORDS

Distributed Energy Resources (DER), Power Grid, Transmission Systems, Distribution Systems, Reliability Metrics, Reliability Indicators, Microgrid

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1. INTRODUCTION

Distributed Energy Resources (DER) have received greater attention in recent years due to their accelerated levels of integration into existing power grids and for their associations with microgrid development. DER are defined as power sources interconnected to a power grid in an approved manner, at or below IEEE medium voltage (69kV) [1]. The type of power source has evolved from the conventional back-up generators to renewable energy resources, including wind and solar generation, energy storage technologies (e.g., batteries and electric vehicles), and controllable loads. Moreover, in contrast to conventional centralized generation plants that inject power directly into the bulk power grid, DER can be integrated into the power network from either side of the end-user's electric meter.

Existing reliability requirements do not require DER of small capacity to provide voltage or frequency support due to the small capacity of individual DER and the relatively low penetration level of DER collectively. However, with the increased DER integration into distribution systems, adverse impacts of these technologies can be difficult for the power grid to absorb. Establishing appropriate control methodologies or schemes to ensure that DER do not negatively impact the system under normal and abnormal system conditions will provide confidence to utilities as DER levels increase in their system footprints. Initially, DER were considered able to provide benefits mainly to electric power end-users in close proximity to the DER due to their functionality as alternative back-up generators. More recently, transmission and distribution system reliability benefits from aggregated DER capacity has become a very important topic. This paper explores the reliability benefits of aggregated DER capacity in both transmission and distribution networks and will provide additional insights for future DER development.

2. DER IMPACT ON POWER GRID RELIABILITY

DER provides economic benefits to the end-user while also improving reliability of the end-user's energy supply, complementary to the conventional resources which make up the energy supply from the bulk power grid. With the recent advancements in DER technologies like solar PV, wind turbines, battery storage, and inverters, DER implementation has expanded quickly, with unprecedented capacity implemented with these new technologies.

One indicator of DER growth is the growth of generation capacity from net metering customers. Figure 1 shows net metering capacity growth from 2010 to 2014 per technology type. Majority growth is with solar PV technology.

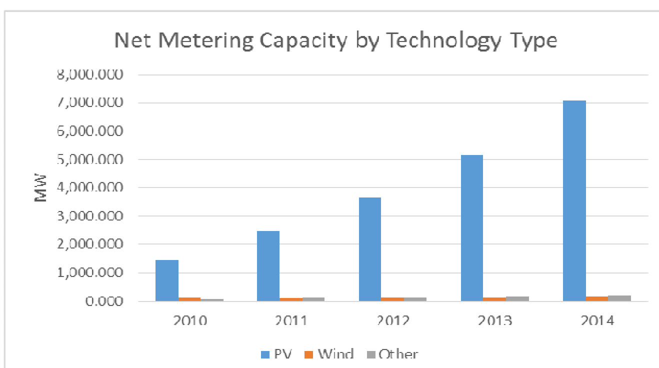

Figure 1: Growth of U.S. Generation Capacity from Net Metering Customers

Further, the policy and market promotion of renewable energy resources has aided in increasing the amount of renewable energy deployed. As DER capacity increases, it becomes necessary for system operators to recognize DER as a participator in the generation resource pool along with their conventional, centralized generation counterparts. In this sense, DER contribution presents new challenges, including how these resources are reflected in terms of power grid reliability. The term "power grid" is used in this paper to refer to the transmission and distribution systems where centralized control and operation is performed by Transmission System Operators and electric distribution utilities.

Beyond providing savings directly to the end-user, DER also provide benefits to distribution utilities. These include energy savings, reduced system losses, and deferral of network capacity upgrades. However, with higher penetration levels of DER, utility planning and operation engineers are concerned with addressing impacts of the DER on system operation. The intermittent nature of renewable resources produces higher volatility in power flow fluctuation, including the potential for power flow reversing direction, which causes larger deviations of loading change and greater difficulty for customer demand forecasting. These and other impacts from DER could potentially jeopardize power grid reliability if appropriate action is not taken. Without proper planning to mitigate these adverse impacts, potential benefits from DER cannot be fully realized.

When DER are tied directly to distribution systems, e.g., behind a customer's meter or interconnected at a distribution feeder or substation, distribution system reliability is impacted directly. DER impact on transmission system reliability is indirect, however, becomes more pronounced when DER capacity increases beyond a certain threshold. These notions are due to the structure of the power system itself. In a typical power system, the distribution network is downstream from the transmission system, and the distribution system depends heavily upon the transmission system being rigid and maintaining system frequency and voltage stability at all times. Correspondingly, transmission system reliability is also reflected downstream to the distribution system via centralized network control reaching as far as distribution substations to provide grid support in terms of both frequency and voltage regulation. As aggregated DER capacity increases, utilities and DER developers started exploring adoptions in both technical capabilities and regulatory requirements which would allow DER to participate in voltage support as such an application is most prominent in distribution systems, and frequency support which further extends the capability of DER to support transmission systems. If these capabilities are realized, DER will provide beneficial impacts on overall power grid reliability. The subsequent sections of the paper explore what and how to realize this potential benefit from DER.

3. DER Supporting Distribution System Reliability

Traditionally, distribution system reliability has been evaluated according to indices reflecting interruption of customer services. The most commonly used indices are SAIFI, SAIDI, CAIDI and ASAI [3]. Distribution system operators have been collecting data supporting these indices and tracking their evolution for decades, and the indices reflect average system performance. Individual distribution utilities collect data and calculate reliability indices on a feeder basis, and they also use internal indices to aid in managing and improving system reliability.

DER in distribution systems can be connected at a number of points in a distribution network. These include at distribution substations, at taps along a primary feeder, on the secondary side of distribution transformers, and at end-users' utilization point behind the meter. Challenges associated with high penetration levels of DER in distribution systems arise mostly due to two factors:

- The distribution systems in the field were designed and implemented for the purpose of carrying power from higher voltage levels toward lower voltage levels and delivering electricity to the end-user through a radial path under normal operation conditions. The distribution system was not designed to carry the injection from DER that flows in the reverse direction.
- The distribution system equipment capacity was designed and implemented to satisfy power demand from the end-user. The intermittent characteristic of power output from the renewable DER causes larger variations in customer demand and could violate equipment ratings or exceed equipment control capabilities

To address these issues, certain distribution system upgrades and DER developments need to be implemented. These include:

- Voltage regulator control with bi-directional capability to allow Distributed Generation
- Power transformer and feeder protection schemes with bi-directional capability
- Monitoring and control capability extended beyond the substation
- Updated load restoration schemes which consider DER and Microgrids
- DER with smart inverter capability participating in utility voltage/VAR control [4]
- Renewable DER with battery storage

Besides these two main causes, high concentration of DER in a cluster could cause capacity issues in feeder sections and equipment. Attention should be given to this fact during the system planning process to account for DER allocation and feeder upgrades to accommodate for the capacity issue.

With advancements gradually being deployed in the field, distribution system operation can consider DER for reliability purposes and draw upon DER support to sustain customer power supply and avoid service interruption.

Further, the indices used to evaluate distribution system reliability could also shift towards being an indicator of system availability if end-user power interruption is effectively eliminated with sufficient support from DER.

4. DER Supporting Transmission System Reliability

Reliability in a Transmission System is determined using metrics related to a number of system operating characteristics. These include system availability-focused, end-user-focused, and major equipment specific data-focused [5]. In the context of this paper, transmission system reliability is considered from the standpoint of system availability. As the reliability overseeing body of the North America transmission system, NERC periodically publishes both seasonal and long-term assessments of the reliability and adequacy of the bulk power system of North America. NERC uses a bottom-up approach by collecting case data such as projected on-peak demand and energy, Demand Response (DR), resource capacity, and transmission projects [6]. Rather than using system indices focus on end-user interruption, transmission system reliability is reflected in two fundamental metrics: adequacy and operating reliability [7]. Transmission system reliability is evaluated by assessing Reserve Margin, Demand-Side Management, Generation, Capacity Transaction and Transmission Issues [8].

DER impact on transmission system reliability can be investigated by examining potential changes DER bring to the two fundamental assessing aspects:

- Resource adequacy – including DER capacity in assessment of resource adequacy requires a regulatory and/or market mechanism to make certain levels of commitment from DER accountable so that transmission system planners can include DER capacity in evaluating capacity and reserve margin.
- Transmission Issue – as DER capacity increases, DER could cause issues seen in distribution systems to appear in transmission systems. These include exceeding transmission line and equipment capacity and power flow direction change that requires upgrades of control devices.

As DER are not directly interconnected into the transmission system, DER impacts on the transmission system is indirect, and reflected by collective capacity. Recently developed DER with renewable resources and battery storages have inverter interfaces with the main power grid. With aggregated DER capacity increasing, a lack of inertia due to these technologies is of concern [9]. Impacts of inverter based energy resource in system inertia cannot be neglected, and shall be considered as an important factor in both the reliability planning process and operation process.

Furthermore, growth of other renewable energy sources directly interconnected into transmission system becomes significant, and causes accelerated retirement of old power plants such as coal plants which further decreases system inertia. The figure below is reproduced from the NERC 2015 Long-Term Reliability Assessment showing increasing nameplate capacity of nonsynchronous generation compared to synchronous generation which is the majority source of system inertia.

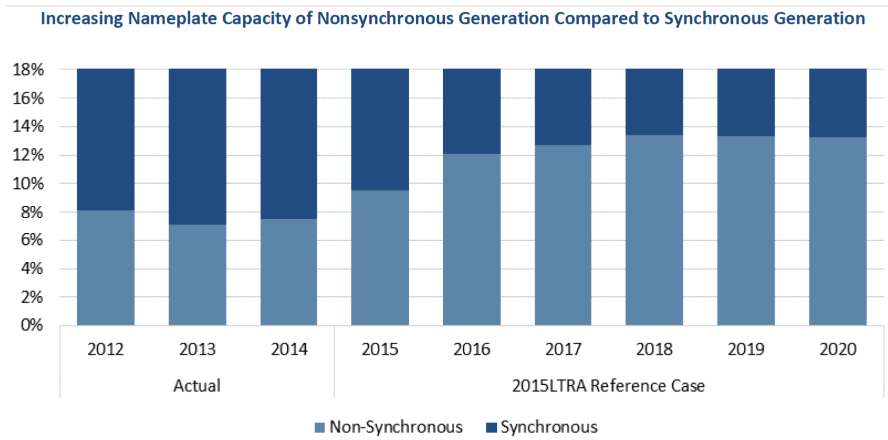

Figure 3: Nameplate capacity of nonsynchronous generation compared to synchronous generation

Some areas in the bulk power system overseen by NERC have observed a downward trend in Reserve Margin, and it is anticipated that some of these areas will fall below their respective Reference Margin Levels [6]. With limitations of demand growth in the bulk power system, the figure clearly indicates that adding new renewable resources effectively replaces conventional generation resources in the power grid.

Looking into the future, it becomes necessary to consider what policy steering and technology advancements are needed to enable higher penetration of DER and to allow DER to participate in power grid reliability considerations. The NERC 2015 LTRA showed that visibility, controllability and new forecasting methods of DERs are of vital importance. One key view as pointed out in this paper is that even though DER are interconnected into the distribution system, their aggregated capacity impacts the transmission system as well. Deregulation divided control of the power grid between the authority of the Transmission System Operator and Distribution System Operator. With increased DER penetration, new mechanisms are needed to link transmission control and distribution control so that DER can be reflected the generation resource pool. This will enable DER participation in supporting power system reliability, both in local distribution systems and in upstream transmission systems.

5. A Futuristic View

This paper discusses the needs and requirements for DER to support power grid reliability. In a distribution system to which DER are directly interconnected at various points, upgrades and technology developments are needed to overcome obstacles limiting necessary levels of DER penetration. In the transmission system, regulatory and market rules are needed which recognize cumulative DER capacity and determine its level of commitment to be considered in resource adequacy. With these, further advancement in DER development will continue, enabling DER to be valid source of support for power grid reliability.

A few foreseeable approaches are presented below:

- Smart inverter technology that enables DER to provide proper voltage response in supporting system voltage control.
- Smart inverter technology that enables DER to provide proper frequency response in supporting system frequency control. This approach aims to use faster responses from the

inverter together with energy storage to provide frequency response and an inertia effect similar to that of a conventional generator's rotating mass.

- Enable energy storage to provide centralized and distributed voltage and frequency support.
- Develop a new concept of a Distributed Energy Resources Management System that provides visibility, control capability and proper interfacing with the transmission and distribution operation and control systems.
- Develop policy that enables DER accountability and reflects aggregated DER capacity in reliability planning processes as an essential part of generation resources.
- A DER market platform allowing DER to participate in energy and ancillary service trades.

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