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Grid modernization: challenges and opportunities

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ABSTRACT

Electric power systems around the world are undergoing an unprecedented transformation. In the U.S., this evolution has been clustered and described under various terms, including smart grid, grid/utility of the future and grid modernization. Building this intelligent grid is a monumental task – particularly on the distribution and grid-edge sides, which are vast and heterogeneous – that has led to the emergence of new concepts, technologies, and paradigms. Here is a roadmap to implementing them.

Technology developments and favorable energy policy for integration of renewable energy have led to rapid penetration of distributed generation, and the emergence of new concepts and technologies such as microgrids, energy storage, and electric vehicles, which promise to provide more flexibility, control and resiliency to end users. The adoption of these distributed energy resources has generally run ahead of regulatory policy, ratemaking, wholesale market adaptation, and especially modernization of the electric grid, which are vital to unlock the potential benefits associated to these technologies and to address challenges driven by evolving end user expectations, consumption patterns, and needs. While much progress has been made in many areas (such as interconnection standards and processes) much remains to be done. This paper focuses on modernization of the increasingly complex, dynamic and active distribution grid and its implications on distribution planning, engineering, operations, markets, energy policy, and regulatory processes. Furthermore, it discusses respective technical, procedural, and business model aspects, including discussions about challenges, opportunities and potential solutions.

1. Introduction

The electric power systems around the world are undergoing an unprecedented transformation. In the US, this evolution has been clustered and described under various terms, including smart grid, grid of the future, grid modernization, and utility of the future (Romero Aguero et al., 2017). These terms emphasize the need to build an intelligent grid that can be monitored and controlled in real-time to provide a reliable, safe, and secure service and empower customers to actively participate and benefit from greater and more diverse market opportunities and services. Building this intelligent grid is a monumental task (particularly on the distribution and grid-edge sides which are vast and heterogeneous) that has led to the emergence of new concepts, technologies, and paradigms.

2. Modern grid ingredients

The idea of the utility of the future encompasses the need for all aspects pertaining to the utility industry to evolve and adapt to a new and dynamic customer-centric reality. This new paradigm is overarching and encompasses:

- Infrastructure and engineering aspects such as system wide real-time monitoring, protection, automation and control of power delivery systems with Distributed Energy Resources (DER), and enhanced grid resiliency, reliability and power quality.
- Processes and organizational aspects such as updated planning, operations and engineering practices and standards, trained workforce and suitable stakeholder organizational structures.
- Business aspects such as asset ownership of new technologies and concepts (DER, microgrids, etc.), and service diversification.
- Regulatory and policy aspects, such as rate and market design and business models for power delivery systems with DER, etc.

An important point to emphasize is that the pace of the transition toward a modernized grid, particularly on the distribution side, is a function of the existing and expected system conditions and trends of every utility system and market. Grid modernization and DER prolif-

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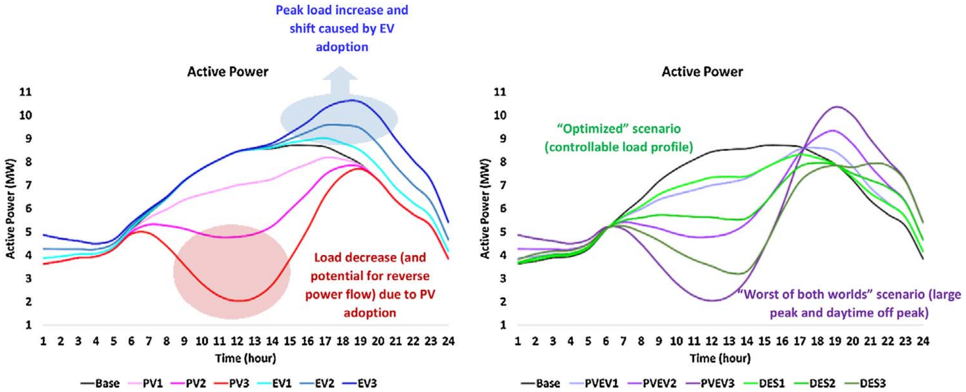

Fig. 1. Example of benefits of Distributed Energy Storage (DES) application (demand control) for integration of Photovoltaic Distributed Generation (PV) and Electric Vehicles (EV). Results show distribution circuit demands for the base case (no PV and no EV), three PV adoption scenarios (PV1, PV2, PV3), three EV adoption scenarios (EV1, EV2, EV3), three combined PV and EV adoption scenarios (PVEV1, PVEV2, PVEV3) and three combined PV, EV, and DES scenarios (DES1, DES2 and DES3). The latter three scenarios show how DES can be used to control circuit demands and mitigate impacts created by both PV and EV adoption.

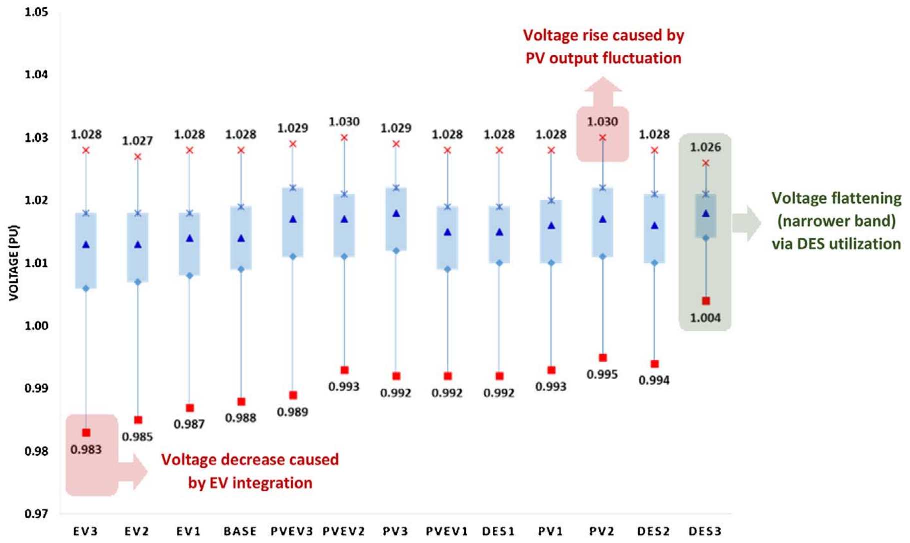

Fig. 2. Example of benefits of DES application (flattening of distribution circuit voltage profiles) for integration of PV and EV. Results show statistical distribution of all node voltages for a distribution circuit for the base case (no PV and no EV), three PV adoption scenarios (PV1, PV2, PV3), three EV adoption scenarios (EV1, EV2, EV3), three combined PV and EV adoption scenarios (PVEV1, PVEV2, PVEV3) and three combined PV, EV, and DES scenarios (DES1, DES2 and DES3). The latter three scenarios (particularly DES3) show how DES can be used to control voltage profiles and mitigate impacts created by both PV and EV adoption. Plot shows minimum, first quartile, median, third quartile, and maximum values of circuit voltages (calculated from all node voltages of the feeder for 24 h).

eration are certainly interrelated, but the latter is not a requirement for the former. Utilities such as Commonwealth Edison (ComEd) and CenterPoint, which operate in service territories with incipient penetration levels of DER, have successfully implemented grid modernization initiatives with the purpose of improving grid reliability, resiliency, and system efficiency, addressing growing expectations regarding customer service, and replacing foundational aging infrastructure. Here it is worth noting that grid modernization is certainly needed to ensure seamless adoption of DER technologies, i.e., to prepare the grid to integrate high penetration levels of DER by minimizing potential impacts and taking advantage of associated benefits (Figs. 1–4).

DER proliferation is already a reality in states such as California and Hawaii, and innovations are underway across the industry in order to proactively address potential operations, planning and engineering challenges and inefficiencies, but also to attain the potential benefits derived from the adoption of these technologies for customers and society in general.

3. Smart technologies for the changing nature of the electric power system

New technologies promise solutions to many of the challenges identified. However, legacy planning and operations analytics and systems need to be more "DER ready", including:

- **Distribution monitoring, protection, automation and control** – Advanced automation schemes needed to cost-effectively improve reliability can support DER enablement by incorporating the needed visibility and flexibility for operations.
- **DER data and cybersecurity** – While vendor and developer information systems are certainly aware of new DER sales and installations, these sources of information need to be better integrated with utility systems, and privacy and cybersecurity issues should remain a high priority along with tackling consumer privacy and data ownership implications, especially for DER not owned and operated by utilities.
- **Emerging technologies such as energy storage** promise the ability to mitigate renewable DER variability and improve grid utilization and economics, but technical, regulatory and economic barriers still impede its widespread adoption even in states with aggressive programs for deployment. Energy storage is forced to fit into one of the generation, transmission, distribution or customer "buckets" and follow rules established for that asset class, however, energy storage is in many viewpoints a new asset class of its own.