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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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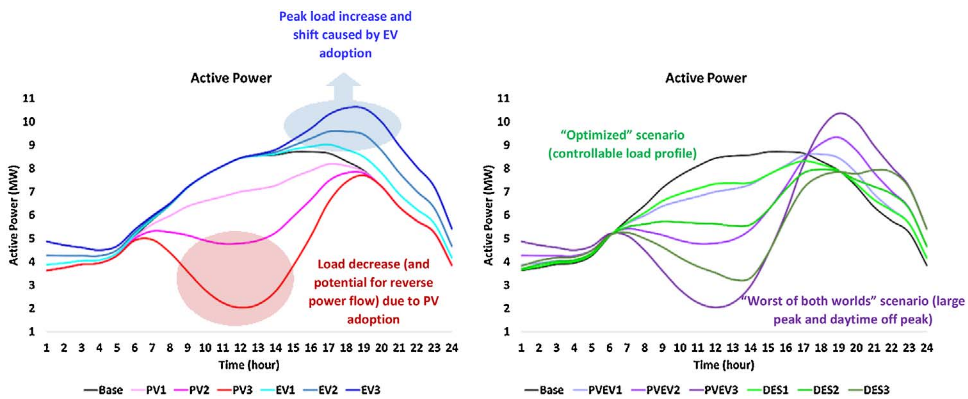

Fig. 1. Example of benefits of Distributed Energy Storage (DES) application (demand control) for integration of Photovoltaic Distributed Generation (PV) and Electric Vehicles (EV). Results show distribution circuit demands for the base case (no PV and no EV), three PV adoption scenarios (PV1, PV2, PV3), 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.

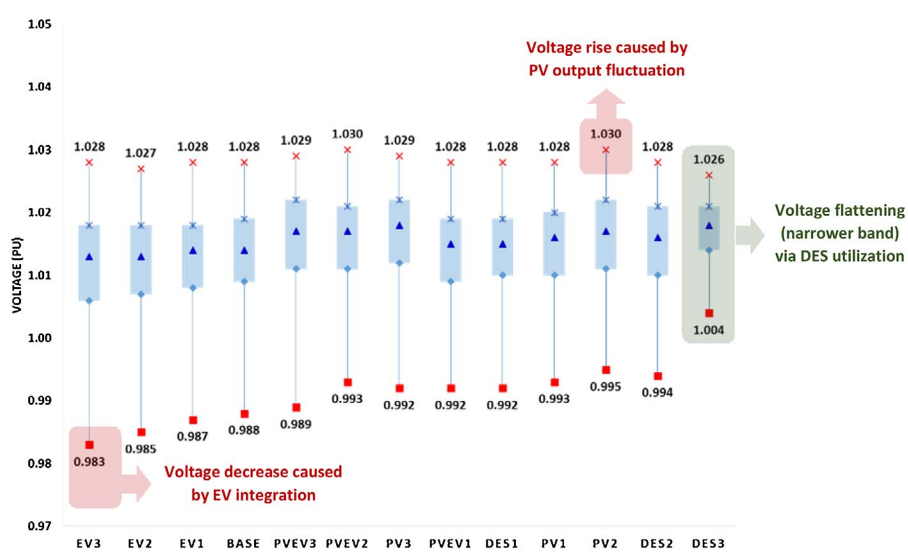

Fig. 2. Example of benefits of DES application (flattening of distribution circuit voltage profiles) for integration of PV and EV. Results show statistical distribution of all node voltages for a distribution circuit for the base case (no PV and no EV), three PV adoption scenarios (PV1, PV2, PV3), three 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.

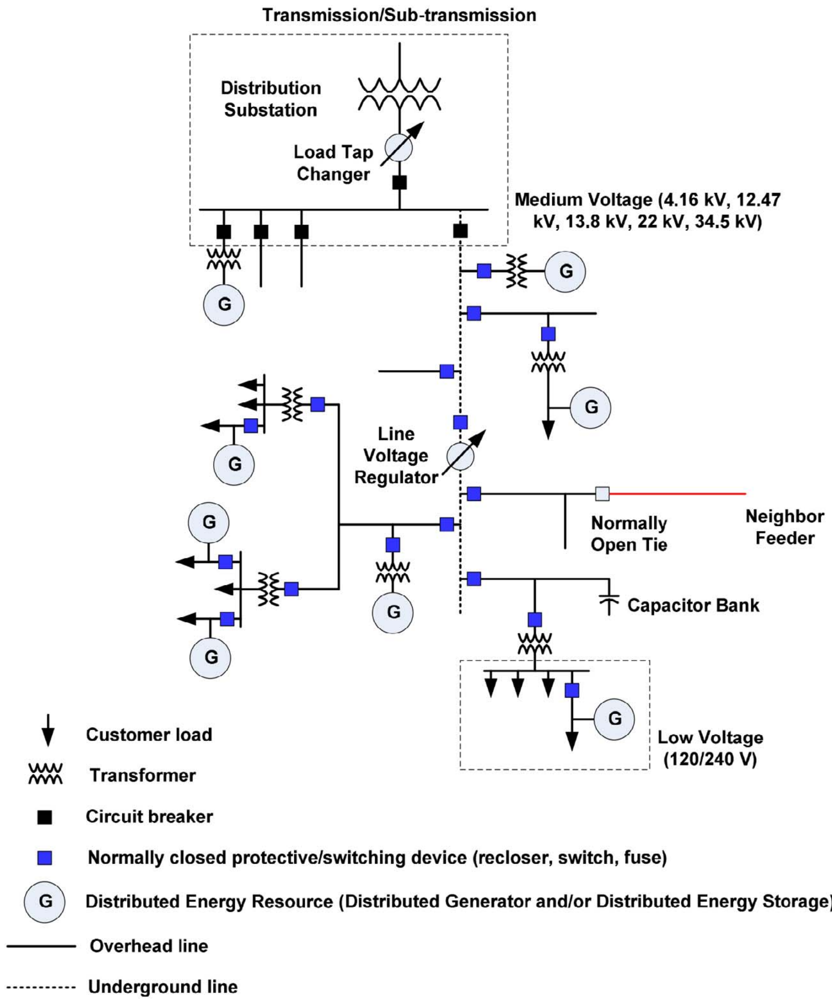

Fig. 3. Simplified conceptual example of main distribution circuit components. Distribution systems of large utilities may consist of thousands of distribution circuits, each one with hundreds of components.

4. Grid modernization requirements

The following are areas where further evolution and modernization is envisioned and needed to enable the T & D system of the future.

- **Integrated, holistic T & D planning and operations** – As the variability of distribution system net load increases, better coordination, information transfer, and joint planning of T & D systems is required. The use of DER to provide aggregated energy supply to the T & D system and ancillary services to the wholesale markets will be increasingly valuable.
- **Visibility and control of DER is vital to the electrical system of the future** – Real-time monitoring and control of all key components of distribution circuits is difficult to achieve in the short-term, given the monumental size and complexity of the distribution grid, and the large investments and required infrastructure associated to this activity. However, a gradual transition toward this vision is possible and necessary to be able to provide a reliable, resilient, safe and secure service and operate the complex and highly dynamic distribution grid associated to high penetration of DER scenarios.
- **Well-trained workforce**, capable of dealing with grid changes, is needed for the Utility of the Future.

4.1. Future distribution system architecture

The following technologies will be key elements in this distribution grid modernization, it is worth noting that their deployment and effective utilization requires the availability of robust communications and data analytics systems and infrastructures:

- **Advanced sensors and management systems** are required to provide cost-effective monitoring of key electric variables, including bi-directional power flows, voltages, currents, equipment and DER status, etc., as well as fault information to circuit breakers and other protection devices. It will be essential to have enough real-time monitoring of circuit conditions to provide situational awareness and to support advanced applications such as distribution state estimation.
- **Advanced distribution and substation automation technologies**
  - Digital relays, substation automation computers and data concentrators, and gateways to advanced SCADA, DMS, and Energy Management Systems (EMS) systems – are fully commercial and proven technologies. They need to be implemented in large scale with full utilization of their key capabilities. As emerging distribution markets develop with higher penetration of DERs, further development of enterprise systems that integrate Distributed Energy Resource Management Systems (DERMS) with SCADA, DMS, and EMS will need to be designed to create the platform to facilitate and optimize planning, grid and market operations.
- Intelligent and adaptive reclosers and switches can isolate faults in smaller sections to support increased flexibility and improve reliability with both traditional and distributed grids.

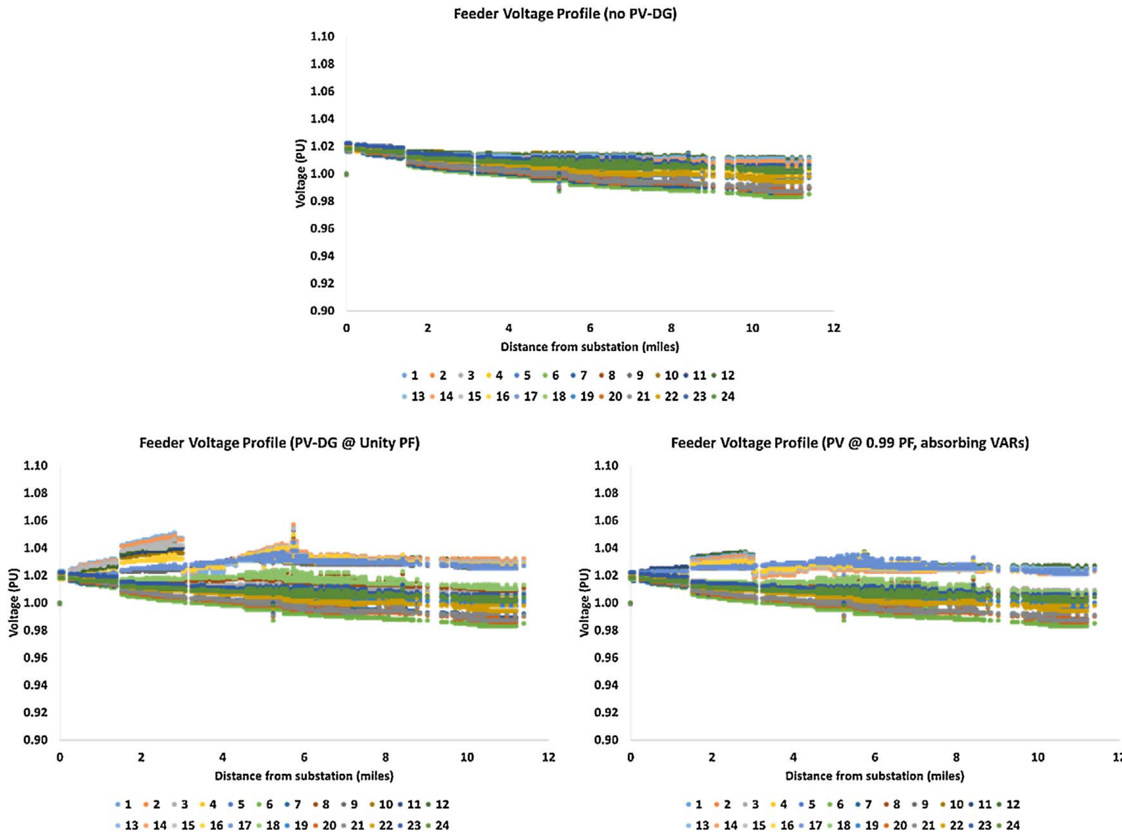

Fig. 4. Example of benefits of using advanced inverters to mitigate impacts caused by PV proliferation (over 5 MW). Voltage profiles before adding PV plant (above), after adding PV plant operating at unity power factor (left), and after setting PV plant to absorb reactive power (right) using advanced inverters (operation at 0.99 constant power factor). Each dot is the voltage magnitude (PU) of a feeder node (miles from substation) at a specific time of the day (24 h.) for the respective cases (base, PV at unity power factor, and PV absorving reactive power at 0.99 power factor).

- **Digital system protection adaptive to system conditions**, will need to be widely used. DERs with inverter technology create various operating scenarios, such as phase and current imbalance, and coordination of protection for under distribution system reconfiguration with variable intermittent resources, which are not presently addressed by existing protection schemes. Circuit power flows and fault current levels will change based on DER size, output, and location on the circuit.
- **Emerging and alternative distribution grid configurations and operation modes**, such as grid integrated microgrids and closed-loop distribution feeders that allow taking advantage of the potential benefits derived from DER adoption. It is worth noting that they require protection, sectionalizing, monitoring, automation, and – most importantly – control capabilities beyond those typically used in distribution systems today

4.2. The role of markets in grid modernization

The ongoing evolution of the electric power industry also involves changes to existing electricity market and regulatory frameworks, which are aimed at satisfying the growing expectations of end users. The advanced monitoring, protection, automation and control infrastructures and capabilities introduced by grid modernization are vital enablers for the successful implementation of these initiatives. In the specific case of electricity markets, transactive energy and the DSO are two concepts widely discussed as being key elements in the Utility of the Future, in integrating DER with wholesale markets, and in applying market concepts to DER dispatching and operations on the distribution system. The spectrum of these discussions ranges from radically new paradigms to application of wholesale market design to the distribution system, including the introduction of Distribution Locational Marginal Pricing (DLMP) (Masiello and Romero Agüero, 2017; TCR, 2016).

- **Transactive energy models** have so far not shown how real world implementation including reliability and obligations with critical customers can be made to work, and are not "mainstream" today.
- **The DSO or the Distribution System Platform (DSP) model** relies on the wholesale electricity markets model and is very much mainstream. However, its initial functionality and design should "keep things simple" to avoid error-prone complexity and to be robust against likely early stage database and data errors.

The implementation of these concepts require real-time monitoring and control capabilities that currently are not available, and that would represent an additional benefit derived from the implementation of grid modernization initiatives.

5. Conclusions and recommendations

The following are overarching recommendations to achieve reliable, resilient and cost-effective delivery of electrical energy while supporting environmental targets for years to come:

- There is a need for grid modernization, with the speed of modernization adjusted to the realities of each market and the pace of integration of clean DER and environmental and other regulatory targets.
- The architecture and design of the grid will have to be updated to accommodate very high penetration of DER and operations and planning practices driven by prosumer dynamic consumption/production patterns.
- Enabling the transition to a modern grid requires changes in

business models and regulatory policies, as well identification of the technical needs and development of new technologies.

- Continuous focus on improving reliability, resilience, safety, cost-efficiency, and customer flexibility to choose is important

5.1. Actions which utilities can take today

- **Vision**
  - ○ Develop a vision for the modernized future grid that includes, for instance, high penetration of DER, different distribution system architectures such as looped or meshed networks for enhanced operational flexibility, resiliency, reliability, and power quality and incorporation of advanced power electronics for grid control.
- **Implementation**
  - Pursue grid modernization within regulatory frameworks such as California's Integrated Distributed Energy Resources (IDER) and Distribution Resources Plan (DRP) filings and plans to address integration of DERs, and integrated with synergistic needs to address future safety, reliability, aging infrastructure, and capacity requirements (IDER, 2017; DRP, 2017).
  - Develop plans and pursue implementation of advanced distribution control and operations systems.
  - Develop communications and control architectures for grid modernization – substation and distribution automation, DER integration, control and communications systems.
  - Deployment of commercially available technologies such as digital protection, advanced automation, Fault Location Isolation and Service Restoration (FLISR), remote fault sensing, and implementation of these plans.
- **Innovation**
  - Implement pilot projects to test and validate the feasibility of innovative technologies, solutions and concepts to enable grid modernization.
  - Develop advanced facilities capable of testing the performance and operation of modern grid architectures, including advanced communications and control systems, and application of these testing methodologies to advanced pilot installations.
  - Develop utility standards for emerging technologies, DER interconnection, and utilization of advanced automation systems.
- **Partnerships**
  - Development of partnership models with suppliers, including software developers, to accelerate the detailed modeling of DER within planning and operations analytics.
  - Work with universities and community colleges on training curricula in support of the modernized grid.

5.2. Actions which regulators and state agencies can take

- Pursue regulatory frameworks, policies and business models for emerging technologies (such as microgrids and energy storage) that better allow utilities to harvest all their potential value streams and benefits – in particular, by removing some of the barriers to combining reliability and market applications, or by allowing utilities to offer services (ancillary services, local/community reliability, etc.) to groups of customers on a tariff basis.
- Support and foster open comparisons of different analytical tools that address evolving problems such as the valuation of emerging technologies and concepts. Provide incentives for utilities to embrace open platforms as the basis of new analytics in operations and planning.
- Resolve business issues around integration of DER via the Internet of Things (IOT) which could further increase the complexity of the grid and present even greater needs to address cybersecurity and privacy issues in addition to needs for greater visibility and control of DER. Where these are federal rather than state issues, support industry efforts to achieve clarity and resolution in ways that will foster rather than hinder grid modernization.
- Support the development of state level standards that help remove barriers for adoption of emerging technologies and solutions, such as energy storage and microgrids.Support experimentation and careful cost-benefit analysis of different distribution market models, emerging technologies, and grid architectures via pilot projects.

5.3. Actions which require support from industry vendors

- Development of open platform models and/or open Application Program Interfaces (API) using enterprise architecture principles for ongoing integration of advanced DER models and control algorithms into planning and operations tools. Development of advanced analytics for distribution planning, forecasting, and operations.Development of adaptive protection and control products. Actions which require cross industry attention
- Continued development and implementation of DER, energy storage, and EV integration and interoperability standards, as well as information and control models, especially via the IOT, and conversion of that information and control models into standards. There is a need for both industry standards and coordinated utility/developer deployment standards.
- Addressing third party data ownership issues in the context of distribution system operations and potentially markets.

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