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Research, Development, and Demonstration Needs for Large-Scale, Reliability-Enhancing, Integration of Distributed Energy Resources

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Abstract

Distributed energy resources (DER) are in transition from the lab to the marketplace. The defining characteristic of DER is that they are active devices installed at the distribution system level, as opposed to the transmission level. While no specific size range has been defined, most distribution systems would have difficulty accommodating distributed generating resources larger than 10 MW/MVA at any single location and many systems may have even lower limits. Distributed energy resources include generation resources such as fuel cells, micro-turbines, photovoltaics, and hybrid power plants or storage technologies such as batteries, flywheels, ultra capacitors and superconducting magnetic energy storage. They may also consist of dynamic reactive power control devices and possibly customer end-use load controls.

This paper summarizes technical requirements for large-scale integration of active devices into the existing distribution infrastructure to maintain or enhance reliability. The paper is intended to lay the groundwork for a multi-year program of research necessary to facilitate the transition to such a system. The scope of the research includes consideration of control systems, including the sensors and instruments necessary to gather intelligence for real-time power management, and dispatch or coordination among distributed generation resources and with utility distribution systems. It also includes improved modeling techniques to better characterize the technologies and their impacts on the distribution (and ultimately the transmission) system.

1. Introduction

Distributed energy resources (DER) are in transition from the lab to the marketplace. The defining characteristic of DER is that they are active devices installed at the distribution system level, as opposed to the transmission level. While no specific size range has been defined, most distribution systems would have difficulty accommodating distributed generating resources larger than 10 MW/MVA at any single location and many systems may have even lower limits. Distributed energy resources include generation resources such as fuel cells, micro-turbines, photovoltaics, and hybrid power plants or storage technologies such as batteries, flywheels, ultra capacitors and superconducting magnetic energy storage. They may also consist of dynamic reactive power control devices and possibly customer end-use load controls.

Electric industry restructuring, increased customer demands for reliable and high quality power, the widespread availability of inexpensive natural gas, falling prices and improving efficiencies for new, smaller-scale generating resources, and market offerings for innovative bundles of energy and non-energy product and services all combine to suggest that in the future society will increase its reliance on distributed energy resources to meet its electricity service needs. Some postulate a future in which distributed generating technologies meet a significant fraction of electricity demand [1, 2].

This paper examines the likely features of such a future and summarizes the resulting technical requirements necessary to support the large-scale integration of DER into the existing distribution infrastructure [3]. First, five market development scenarios for DER are described, which correspond to pathways by which the industry could evolve toward a future involving greatly increased reliance on DER. Second, likely customer and utility needs or applications for DER within the market development scenarios are described, which in turn identify performance requirements for DER. Third, current technical and economic barriers for DER in meeting these requirements are listed. Fourth, research, development, and demonstration (RD&D) priorities to reduce or remove these barriers are described.

2. DER market development scenarios

The technical requirements for large-scale, reliability-enhancing integration of DER into the existing distribution system infrastructure and the priorities among them depend on the evolution of the markets that will rely on them. Currently, there are two primary markets: back-up generation — a customer-driven market, and utility distribution system enhancement —a utility-driven market. In the future, we expect these will markets lead to three additional ones: local micro-grids, interconnected local micro-grids, and interconnected local micro-grids and utility distribution systems.

2.1. Back-up generation

DER are already used extensively for selected applications in response to specialized customer needs. Back-up/emergency generators owned almost exclusively by customers provide electricity when the electric utility grid cannot. Uninterruptible Power Supplies (UPSs) essentially batteries and a charge/discharge control system are also used, especially for computer-related, ride-through applications. As improved distributed resources enter the market, the tendency will be to extend the operating hours of the technologies; for example, inexpensive, efficient fuel cells would be operated as a baseload facility.

2.2. Distribution system enhancement

Utilities are currently exploring applications of DER on the utility-side of the meter, which consequently is fully integrated with the distribution (and transmission) system. DER will be installed in various sizes and utility locations throughout the grid to meet the following needs:

- Feeder Relief
- Transformer bank relief
- Reactive support for the T&D Grid
- Serve remote loads
- Power Quality
- Peak shaving
- Energy needs (load growth) and Ancillary Services
- Loss reduction
- Transmission and distribution deferral
- Improve grid asset utilization

2.3. Local micro-grid

Under the right combination of economic conditions, customers will leave the grid entirely. Accordingly, they will meet their on-site needs (energy, power quality, power back up, peak shaving, co-generation) through micro-grids. A micro-grid assumes a cluster of small generators (typically, each with a capacity of less than 500 kW) and storage, which are operated as a single unit independent of or interconnected with the utility T&D grid.

2.4. Interconnected local micro-grids

This market segment will consist interconnected micro-grids or clusters (customer micro-grids) installed to meet energy, power quality, power back-up, peak shaving and co-generation needs of groups of commercial, industrial, and residential customers. Micro-grids are intra-connected together to satisfy common energy, reliability, quality and efficiency needs and to allow sharing of resources within a common infrastructure. They are interconnected following safety and reliability guidelines but without specific, standard interconnections with utility grids.

2.5. Interconnected local micro-grids and utility distribution systems

This market segment consists of interconnected micro- and utility grids. The interconnections will be based in agreeable, standardized national guidelines that will allow customer micro-grids to participate in competitive energy and ancillary services markets. The micro- and utility grids will serve as back up for each other while still maintaining each group of customers energy, reliability, and power quality needs. See Figure 1.

3. Customer and utility DER applications

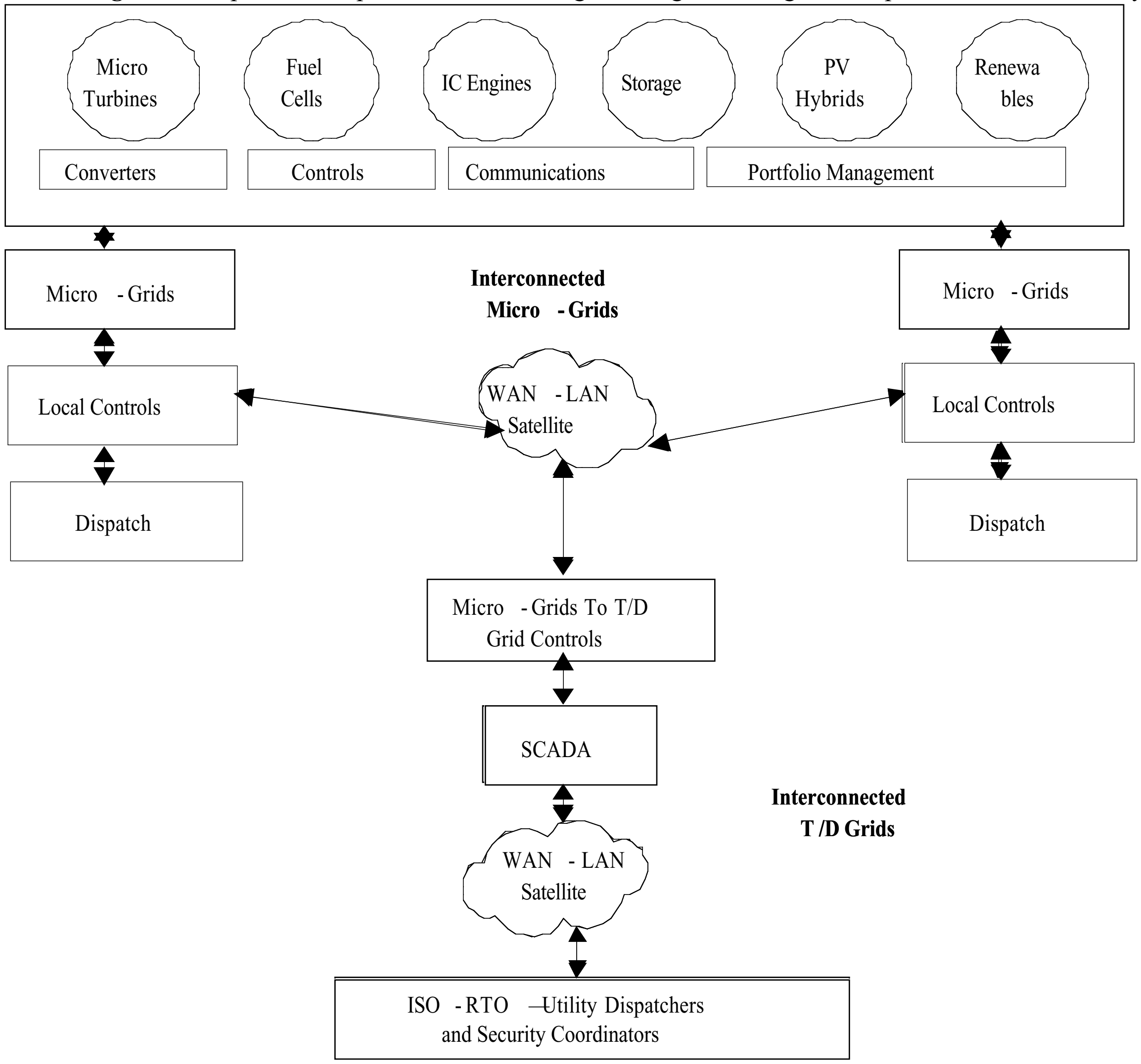
Within each of these market development scenarios, the adoption of DER will be driven by the ability of DER to meet customer or utility needs. Meeting these needs defines the applications for DER and, in turn, helps to identify needed RD&D.

3.1 Customer-driven DER applications

3.1.1. Stand-by power, reliability firming - Any DER option that is used to provide readily dispatchable, reliable backup power for use during outages of more than a few minutes is an emergency or stand-by generator. They may or may not be interconnected with the utility; most often they are not.

3.1.2. Premium power - DER can improve power quality and/or allow the customer to ride through short duration power outages of a few minutes or less.

Figure 1 - Interconnected Micro-Grids and Interconnected T/D Grids



3.1.3. Peak shaving - DER options that provide means for a utility customer to generate all or part of their power needs on-site, during periods of high electric demand (for either the facility or the power grid) so as to avoid excessive electric demand charges and/or or time-of-use energy charges.

3.1.4. Low-cost energy - In some cases, customers can produce significant amounts of electric energy at a cost than is lower than the price to purchase equivalent electric energy from the utility. In these situations, DER is used by electric utility customers to reduce electric energy costs. Demand charge reductions may accrue also, if DER produce electricity during peak demand periods. DER used for low cost energy operate for 4,000 — 8,000 hours per year. In most cases DER used for low cost energy must also yield thermal energy as described next for combined heat and power applications.

3.1.5. Combined heat and power - Many DER generating technologies can produce both electricity and heat known as combined heat and power (CHP) or co-generation. Generators used for CHP are operated for most or almost all hours per year.

3.2 Utility-driven DER applications

3.2.1 Augment distribution systems — feeder and bank relief - In the near term electric utilities will use an increasing amount of distributed generation to augment their power distribution system. Virtually all DER used by utilities for this application will not be used to produce significant amounts of electric energy. Instead those DER capacity augments the utility s power distribution system during periods of peak demand, when the DER has a lower overall cost than alternatives.

For example, small DER modules may be added to augment the capacity of a nearly overloaded substation or delay the need for a feeder upgrade. DER may be installed as needed to delay the need for an expensive replacement of the substation. Utilities may even use DER to provide more permanent distribution capacity, if the DER lifecycle cost is lower. Substation and feeder upgrades can cost upwards of $500/kW.

The benefits for such applications come in the form of delayed wires investments (this is especially rewarding under performance based ratemaking, or PBR), firming up weak reliability feeders, and for voltage support. The owner of such a grid support unit would in theory also be able to dispatch the unit to supply high peak central station loads, adding further value.

3.2.2 Central dispatch of DER - Significant benefits can accrue to a utility, which has emergency access to reserve power plants such as activation of customer owner standby generators. With severe system peaks becoming more commonplace in the US, the ability to call up easily and quickly a fleet of 100 MW of standby generators can be very valuable.

3.2.3. Service power quality and reliability - Utilities can also use DER to maintain power quality and/or reliability of electric service within specific parts of the power distribution system. For example, if voltage is below acceptable levels, at certain times of the day, for only a few days per year, on a specific distribution wire, then a utility-owned UPS or generator may be used to improve the voltage.

Similarly if the reliability of an area is poor, a distributed generator could be placed on the feeder to pickup at least the most valuable loads if service is otherwise interrupted. If a feeder has had high outage rates, say 10 hours per year, and customers value their reliability at $5.00 per kWh of lost service, the equivalent value of serving that lost load with distributed resources would be $50/kW-year, or an equivalent capital cost of about $500/kW using utility financing.

3.2.4. Power quality and reliability firming - Utilities will also use DERs to improve power quality and/or reliability in targeted parts of the power distribution system and/or to meet the power quality and/or reliability needs of specific high value customers. Distributed resources can be used to prop up sagging voltage profiles in relatively weak distribution systems, or obviate the need for bringing a second feed in to a customer with special reliability requirements. Customers with sensitive loads may begin to group them into high power quality service within their site; either filtering the power or adding distributed generation and storage to firm up the reliability to that hardware.

3.2.5. Energy services - A growing number of utilities will offer a rapidly expanding suite of energy services. Many of those utilities do/will include DER as elements of their broader energy services offerings. DER may be incremental in nature, used to address specific customer needs such as power quality that is superior to normal serving a customer with high value-added computer operations and who is willing to pay for superior service. A stand-by generator located on the utility side of the meter could be used to provide high reliability service to specific customers.

DER may also be offered by utilities as part of an overall energy strategy and/or utility bill consolidation, customer productivity enhancement partnerships, CHP installations etc. Energy services will be market priced.

4. Current technical and economic barriers

Currently, a variety of technical and economical barriers hinder the development of markets to address these customer and utility needs with DER applications.

- **High cost and uncertain performance of DER technologies -** The initial capital cost of DER technologies, including balance of plant costs (converters and controls), and nascent experience with O&M costs pose significant economic barriers. Both end use customers and utilities are reluctant to implement new technologies without proven performance expectations, O&M experience, and cost information.
- **Lack of uniform standards for power quality and absence of information on DER power quality characteristics** — Sensitive load customers and utilities have requirements for high quality power. However, there are no uniform standards for different levels and types of power quality. For DER technologies in particular manufacturers data on power quality impacts are non-existent.
- **Lack of tools for control of DER for peak shaving applications** —Operational strategies to optimize performance of DER for peak shaving applications, primarily on the customer-side of the meter, in response to price signals from the utility, have not been developed or demonstrated.
- **Lack of tools to plan for and operate DER to defer transmission and distribution upgrades -** Integration and interconnection standards for DER to interface with the grid, controls for dispatchability and control of DER to perform load following are not available. In addition, planning and operational tools to realistically quantify and capture economic benefits from deferral of T&D investments through increased reliance on DER are lacking.
- **Lack of knowledge for the control of significant numbers of DER technologies —** Performance information on the dispatchability and controllability of DER in real time, dynamic models of DER for simulation studies, the design and testing of controls for dispatchability and controllability of DER, and protection and islanding of DERs are new concepts that have not yet been developed or demonstrated for both the end use customer and the utility.
- **Lack of standards and protocols to permit DER participation in competitive energy markets —**

There are no uniform standards for real time data acquisition and data communication protocols, or for the types of controls and performance verification data required. Lack of real time dispatch software for optimization of DER portfolios.

- **Lack of knowledge and absence of institutional arrangements necessary to coordinate utility and DER operations** —There is a lack of independent identified operational requirements for the deployment of the various DER technologies that would operate interconnected to the utility grid and or as part of an isolated micro-grid. The following is a list of operational issues that require coordination of operations between the utility and non-utility entities:
- Short term planning process for energy, capacity, ancillary service and maintenance.
- Real time management process for energy, capacity, ancillary service and maintenance.
- Jurisdictional authority of electrical facilities.
- Reporting of events.
- Voltage and VAR schedules.
- Authority to request a deviation from normal operation.
- Operating requirements during normal and unplanned events.
- Operation during the loss of metering or control capability.
- Operation during a system black start.
- Operation during a system energy or capacity deficiency.
- Electrical equipment safe work practices.
- Data and voice communications for operations.

5. Federal DER RD&D Priorities

The priorities for federal RD&D offered in this section are based on the following considerations: a) federal support is appropriate for RD&D that advances national interests and will otherwise be inadequately supported by the private market; b) currently, those with the greatest potential interest in an expanded role for DER — customer and equipment manufacturers on the one hand, and the utilities on the other hand — either lack the information needed to or face uncertain or negative incentives to pursue RD&D on DER, respectively; and c) current RD&D is focussed primarily on individual DER technologies, but not on issue of system integration and interconnection. Accordingly, the following federal program for RD&D on DER system integration and interconnection is proposed.

System protection. The protective devices used to the traditional electric distribution system are normally very simple in nature. A typical distribution feeder may only have straight overload and ground protection at the source bus, fuses on feeder taps and directional overload where lines are operated looped at remote stations. These simple relay or protective applications may be extremely inadequate as DER technology is deployed in large pockets on the distribution system.

Recommendation —Create DER demonstration test bed that will allow the protective engineering experts to evaluate various advanced or new protective schemes and define minimum requirements for the various DER protection technologies.

Power electronics - The current higher cost of power electronics converters and controls, unproven operational performance and maintenance requirements and lack of field demonstration sites have caused both customer and utilities to be cautious in their implementation of DER technology.

Recommendation —Create DER demonstration field test bed(s) that will provide power electronics manufacturers, consumers, and utilities with actual performance data of the DER, interface equipment and grid. The performance data will build the necessary confidence to support DER technology, with a result of driving the per-unit cost down.

Demand-side response. Outside of load management and time-of-use pricing, the electric industry has paid little attention to the impact a customers load may have on reliability or the capability of managing it to solve short term reliability needs.

Recommendation - Create demand-side demonstration test bed(s) for the purpose of developing new methods and technologies to better understand the characteristics of the different types of load under various system conditions. With this better understanding the industry can develop the necessary strategies, infrastructure requirements and support systems that can better respond during grid disturbances and enhance overall reliability, while providing benefits to the customer.

Load following. DER will be deployed by both the utility and customer with the expectation that it has load following capability. This capability will be utilized to either provide peak shaving or to unload electrical facilities. Currently there is little or no data available that can support or discount any manufacturers claim to have this capability. Poor performance of a DER in this area could have an undesirable impact on reliability.

Recommendation —Create DER demonstration test bed that will allow the testing and evaluating the load following capability of the various DER technologies.

Dynamic behavior of DER technologies. There are no adequate DER manufacturer or actual data available to conduct simulation studies of the dynamic behavior of these various DER technologies and their impact on customer power quality and system reliability.

Recommendation — Create DER demonstration field test bed(s), with the adequate real time metering capability that will provide the T&D grid and micro-grid planners and operators with the necessary experience to identify dynamic characteristics, models and corresponding data requirements.

System reliability impacts. There is a need for new methods to assess the effects of large numbers of distributed technologies (e.g., storage) on local area and system reliability. Conventional transmission planning models treat the entire distribution system as individual loads at substation buses, while distribution system planning models treat the transmission network as a voltage source at the each substation low-voltage bus. In order to assess the impact of large numbers of distributed resources on the dynamics of a regional electric grid as well as on local service conditions during a disturbance, it will be necessary to develop methods that treat the distribution system bi-directional and integrated with the transmission network in a consistent (if not integrated) fashion.

Recommendation 1 —Develop and fund a team of modeling experts to identify the needs and requirements for future T&D grid and micro-grid planning and operational models that reflect DER, transmission and distribution systems as an integrated system.

Recommendation 2 - Create DER demonstration test beds that would provide engineers with sufficient real time MW, VAR and voltage data, from both the local grid and the DERs. Utilize the compiled data to evaluate and identify reliability impacts. Experiment with various DER control schemes to identify minimum control and performance standards to mitigate negative reliability impacts.

Data and communications. Currently, many utilities have limited or no real time data from and communication infrastructure to their own local distribution substations let alone having any information pertaining to operations on the customers side of the meter. In some applications, to allow full integration of DER, both for the benefit of the customer and utility, may require extensive real time data communications in the form of Wide Area Networks (WAN), protocol standards and other support infrastructure for the purpose of reliable managing and controlling DERs, the local distribution grid and even the transmission grid.

Recommendation - Create DER demonstration test bed(s) for the purpose of defining the minimum real time data communications WAN, protocols and infrastructure requirements to insure reliable operation in areas that have the potential for significant amounts of DER being deployed.

Coordinated, interconnected operation. One of the emerging markets that will flourish as a result of industry restructuring and recent technology enhancements is the deployment of DERs. DERs will be operating both interconnected with the utility grid and as part of an isolated micro-grid. The owners and operators of these facilities will have to assume their respective role(s) in meeting the industry and local reliability requirements. The challenge for both the local utility and customer is how to manage both planned and unplanned operations that could have a negative reliability impact on others, as well as themselves. Both the utility and customer will have to closely coordinate their electrical operations to ensure the established reliability standards are maintained.

Recommendations —Develop and fund a team of independent industry experts, who could assist in or facilitate in the definition and development of the necessary DER operational requirements. The identified operational requirements, to the extent possible, would have their practical application evaluated at the established DER demonstration test beds. There would be significant benefits for both the utility and non-utility entities, as well as regulatory authorities, in performing the necessary RD&D in the area of operational requirements.

6. Conclusion

The North American power grid will require significant investments in new generating capacity over the next decade to meet ever-increasing customer needs for reliable electric service. A variety of market drivers will motivate both customers and utilities to rely on DER to meet some of these needs. At this time, however, there are significant technical and economic barriers to widespread market adoption of DER. In particular, there has been little RD&D focussed on the system integration and interconnection technologies necessary to support a future in which DER provides a large fraction of future generating capacity (e.g., 20 percent of new generation capacity in 2010). Without adequate investment in this RD&D, the contribution and benefits offered by DER will be slow to materialize.

In assessing an appropriate role for federal RD&D in this area it is important to recognize that the parties with the greatest potential interests in pursuing this RD&D are either limited in their ability to do so (e.g., customers or equipment manufacturers) or face significant uncertainties or disincentives that will prevent them from pursuing this RD&D aggressively (e.g., utilities).

This paper has outlined DER system integration and interconnection RD&D needs appropriate for a federal program to maintain and enhance the reliability and efficiency of the nation s electric system through increased reliance on DER.

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8. References

[1] EPRI, *Distribute Resources Strategic Review, Market Drivers Impacting Future Business Prospects*, EPRI TR-110245, EPRI, Palo Alto, CA, April, 1998.

[2] California Energy Commission, *Public Interest Energy Research, Strategic Energy Program*, California Energy Commission, Sacramento, CA, January, 1999.

[3] V. Budhraja, C. Martinez, J. Dyer, M. Kondragunta, *Interconnection and Controls for Reliable, Large Scale Integration of Distributed Energy Resources,* Lawrence Berkeley National Laboratory, Berkeley, CA, October, 1999.