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Introduction

EPRI launched its Integrated Grid initiative with a concept paper [1] and the goal of aligning power system stakeholders on key issues. With widespread adoption of distributed energy resources (DER), potentially fundamental changes in the grid will require careful assessment of the benefits, costs, and opportunities of different technological or policy pathways. Four main areas requiring global collaboration were identified:

- Interconnection rules and standards
- Grid modernization
- Strategies and tools for grid planning and operations
- Enabling policy and regulation

Work on the three-phase Integrated Grid initiative is intended to provide stakeholders with information and tools that are integral to these four areas.

Phase I – Stakeholder alignment, including the production of a concept paper, supporting documents, and related knowledge transfer efforts

Phase II – Development of a benefit-cost framework, interconnection technical guidelines, and recommendations for grid operations and planning with DER

Phase III – Global demonstrations and modeling to provide comprehensive data that stakeholders will need for transitioning to an integrated grid
A major portion of Phase II will address a critical industry need by developing a methodology for evaluating benefits and costs of potential technical and policy pathways associated with an integrated grid, including the distributed resources themselves. The methodology will be transparent and reproducible in multiple jurisdictions, accounting for the unique characteristics of individual distribution systems, transmission grids, resource availability, markets, regulatory environments, and various electricity users.

Even with Phase II underway, Phase I is continuing to provide webcasts, whitepapers, and other knowledge transfer efforts related to the issues presented in the concept paper. Leading up to its final deployment as a technical guide in the third quarter of this year, EPRI will continue to provide periodic updates on Phase II developments. Also included will be a test and reporting protocol, which will inform the demonstrations anticipated in Phase III. In addition, Phase II output will include guidelines for new interconnection rules and recommendations for the changing relationships between transmission and distribution operators.

Prior Work
Phase II will draw upon a significant body of available research. Southern California Edison in 2012 reported on transmission and distribution expansion needs based on expected photovoltaic (PV) deployment, and this work continues under the California Solar Initiative (CSI) Round IV [2]. The European Union’s PV GRID initiative [3] and DERlab consortium [4] have classified distribution enhancement options. “Value of Solar” studies by SAIC [5], Xcel Energy [6], Clean Power Research (CPR) [7],[8], and others provide example approaches for itemizing costs and benefits associated with DER and for classifying value streams by stakeholder. EPRI, as part of Department of Energy (DOE)-funded efforts, has developed a cost-benefit framework for smart grid investments that will aid in categorizing investments and identifying stakeholders [9]. The impact of cost allocation and recovery on utility customer classes has been studied extensively by Energy and Environmental Economics, Inc. (E3) for both California [10] and Hawaii [11].
Phase II Technical Description

It is difficult to assess a large and complex power system in a holistic manner. Researchers have yet to combine the technical attributes of DER and the potential for grid modernization, with consideration of associated costs and benefits. EPRI’s framework will combine an enhanced analysis of distribution and transmission systems with a detailed cost-benefit methodology. This will enable stakeholders to develop an integrated grid in a strategic way. The Phase II framework development includes three components:

- DER Penetration and Scenario Development
- Power System Impacts
- Overall Benefit-Cost Methodology

DER Penetration & Scenario Development

A benefit-cost framework may serve a number of purposes related to the adoption of DER, including determining the “value of solar,” optimizing deployment of storage, minimizing system upgrade costs, and justifying improvements to grid infrastructure. For any such study, two major elements are needed: an understanding of the system infrastructure and an expectation of DER deployment.

Fundamental to understanding current infrastructure is determining its “hosting capacity,” a measure of distribution feeder’s ability to support distributed resources such as PV, wind, demand response, gas-fueled generation, and combined heat-and-power (CHP). Hosting capacity is a function of DER technology, size, location, and feeder topography. Limits can arise in the form of voltage constraints, thermal issues, or protection coordination. Traditionally, utilities have determined hosting capacity by performing detailed analyses of selected feeders and applying the results unilaterally across their system, assuming that all feeders perform similarly. However, EPRI research has demonstrated significant variation in hosting capacity among distribution feeders, even when they appear similar in construction.

EPRI’s experience with hosting capacity has led to a proposed two-level procedure for determining a system-wide hosting capacity. The first involves simplified modeling techniques (in development) that may be applied to all feeders in a system, without the need for extensive simulations. Feeders may be “clustered” based on characteristics that are likely to impact their ability to integrate distributed resources. General hosting capacity guidelines can be developed for these groups of feeders. This limits the detailed simulation work required, making for a simple method that can be applied to thousands of feeders in a timely manner. This process step is critical as it presents a range of hosting capacities, limiting factors that must be overcome with increasing DER adoption, and the relative impact of DER location.

Many factors will influence the expected deployment and adoption of distributed resources, including utility priorities, regulatory and social policies, customer preferences, and future costs and characteristics of the
distributed resources. With all of these variables, many different scenarios will arise for increasing penetration of distributed resources on different systems. The framework will support scenario development by identifying each scenario’s key characteristics. These may include regulatory considerations, interconnection requirements and standards, financial incentives, expected future costs of technologies (e.g., PV, fuel cells, energy storage, etc.), ability to influence the location of distributed resources, customer adoption preferences, and related system modernization objectives (e.g., resiliency investments, automation for reliability, voltage control priorities, communication infrastructure, etc.).

Utilities, regulators, and policymakers may need to coordinate objectives such as energy efficiency, resiliency, storage, or voltage control requirements with their DER policies and objectives. Understanding the relationships between generation, transmission, and distribution systems is critical, as market characteristics and transmission system operators (TSO)/distribution system operators (DSO) coordination may significantly impact the results. Scenarios characterizing DER adoption can provide the basis for evaluating system modernization and technology investment alternatives.

**Power System Impacts**

Understanding the level of DER penetration and outlining the system requirements provides the necessary background for evaluating investment alternatives necessary for increasing system hosting capacity in combination with other distribution infrastructure objectives. Solutions may involve investments by the system operator, the DER owner, or collaboration between the two, as shown in the table below. This task will provide an approach for mapping a range of investment options that should be evaluated for each scenario, based on characteristics of the distribution systems and related objectives. With the entire system modeled and the most cost-effective solutions determined, it is then possible to determine system-wide integration costs for a given DER penetration scenario.

Integration costs should be weighed against distributed resources’ benefits such as loss reduction, environmental impacts, and deferral of upgrade investments that would otherwise be needed. Other costs and benefits must be

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characterized, including impacts to reliability, resiliency, efficiency, and flexibility. This task will provide recommended categories and an approach for characterizing these benefits.

Though DER deployment occurs at the distribution level, adoption patterns and actions taken to enhance the distribution system will impact bulk system operations as well. Specifically, the potential impact of DER on frequency regulation, reserve requirements, contingency analysis, and flexibility metrics must be considered. To preserve system reliability, changes may be necessary in design, infrastructure, and operation of both transmission and generation resources.

These bulk system alterations affect both long-term integrated resource planning (IRP) and shorter-term capacity expansion and generation retirement. Changes in infrastructure cause changes in generation and transmission capital or operating cost. As a starting point, EPRI will develop a set of DER Impact matrices that qualitatively highlight DER influence on key transmission system criteria. Building on recent studies for Arizona Public Service, Southern California Edison, and others, EPRI will determine a set of guiding principles for evaluating system performance using existing commercial-grade toolsets for analyzing unit commitment, economic dispatch, power flow, and transient stability. These principles would include recommendations for modeling DER in bulk transmission analysis, assessing performance impact of mitigation options, as well as the impact of DER on production costs and resource adequacy. These elements may be broken down into components such as fuel, maintenance, or asset depreciation. Under these categories, DER expansion may increase or decrease bulk system costs. The detailed analysis of transmission and generation resource impacts can be determined using scenarios combined with the distribution-level modeling to assess overall costs and benefits.

Overall Benefit-Cost Methodology

The two components outlined above involve characterizing impacts of distributed resources at the distribution and grid levels. Many recent studies have referred to the “Value of Solar” or other forms of DER [5]-[8]. Although such studies put forward a number of seemingly independent value streams, general themes have emerged. One of the most significant is the realization that DER often has both operational (financial) value and indirect societal value. Operational values may include avoided energy cost, reduced ancillary services cost, reduced losses, and deferral of some generation, transmission and distribution upgrade investments. It is highly dependent on the given system and requires a comprehensive analysis. Meanwhile, societal value may include environmental benefits, economic growth, and job creation. Assessing societal values can be challenging because some values (such as environmental benefits) cannot be determined precisely.

Analysts are gaining experience at assessing the impact of DER under the current system structure. However, the nature and magnitude of those benefits and costs may change dramatically with the widespread adoption of DER. For example, grid modernization and inverter technology
improvements will allow DER to assist in voltage and reactive power control at a local level, and to provide system services at the bulk level. This opens the possibility for new DER value streams beyond those originally proposed. However, as greater amounts of variable DER such as PV are added to the system, the amount of capacity it avoids and the value of its energy diminish, and the cost of ancillary services may increase. The goal of this task is to develop a comprehensive method for recognizing DER value streams, both operational and societal, in the context of a larger system study.

The transition to an integrated grid will result in both benefits and costs to many stakeholders. This is true especially for modernization and “smart grid” efforts that involve multiple value streams and may serve multiple objectives. Moreover, these innovations may be classified as “discretionary investments” and carry a burden of proving net benefits over costs. Organization of identified value streams by stakeholder group will require an omnibus benefit-cost framework for the overall system. Such a framework will need to take a view that includes the utility, customers, and society, consistent with a framework developed by DOE and EPRI as part of the Smart Grid demonstration program. The objective of this methodology is to identify, for a particular investment, how the costs and benefits flow among stakeholders, and to identify gross gains and losses.

The utility model will need to accurately represent perspectives for multiple utility types and business approaches. The output of this stage is intended to provide data that conforms to utility business cases and communicates the net value of modernizing investments for DER integration.
Coordination and Collaboration

The transition to the integrated grid is beyond the scope of any one organization, and it will require careful collaboration among multiple parties sharing a mutual interest in DER integration. EPRI has engaged the Fraunhofer Institute to provide background information on the ongoing integration efforts in Germany, and to review materials generated during the course of the project. Researchers at Électricité de France (EDF) are also working to assess the hosting capacity of distribution systems and the impact of DER on utility operations. And discussions are ongoing with National Renewable Energy Laboratory (NREL) regarding the testing and demonstration of grid modernization technologies at their new Energy Systems Integration Facility (ESIF) and at other laboratories.

The Phase II framework will provide a foundation for overall assessment of investment options that can facilitate the integration of distributed resources. Investment scenarios depend strongly on the technology options that are available, their performance characteristics, and their integration with the overall grid operation. Consequently, the importance of an approach for documenting new technologies, their performance, application issues, and costs cannot be understated. This will involve both testing in labs such as ESIF (with common testing and documentation protocols) and the evaluation of performance in field applications. It is the focus of Phase III – ongoing technology assessments and performance documentation through lab testing and system demonstrations/deployments. A collaborative effort will provide a common data collection and repository for technology information that can then be plugged into the assessment framework for ongoing system evaluations. The framework itself will evolve as more information about new technology options and economics are characterized.
Results and Delivery

The level of interest in this effort and the desire for extensive peer review of the methodology drive the need to deliver a quality product within an aggressive schedule. By segmenting the framework, EPRI will be able to introduce portions of the development throughout the next six months. Feedback may then be incorporated prior to release of the Phase II methodology in the fall of 2014. The final report of the methodology will comprise the tasks outlined herein and provide the insight required for Phase III demonstrations. More in-depth webcasts and whitepapers will be delivered during the interval leading up to the release of the methodology.

Though the development of Phase II is a short-term goal, the emphasis on the integration of DER into the power system will continue to impact EPRI’s annual research portfolio (ARP) over the next several years in a number of programs. This portfolio alignment will provide the Integrated Grid initiative with the long-term impact necessary to adequately support power system transformation and optimize the grid while maintaining established levels of safety, quality and reliability.
References


The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI’s members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI’s principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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