ELECTRIC POWER RESEARCH INSTITUTE

THE
INTEGRATED GRID
A BENEFIT-COST FRAMEWORK

Executive Summary for EPRI Report 3002004878

Statement of Purpose

The role and operation of the electric power system is evolving to accommodate changes in the ways electricity is produced, delivered, and used. Through a combination of technological improvements, policy incentives, and consumer choices in technology and service, the framework of the industry is changing.

Consumers have increasing choice and control over their electricity service. The range of choice is diverse: Owning or leasing generating systems (such as photovoltaic [PV], solar, thermal, wind, and biomass), and using storage options and technology to manage when and how they use electricity to manage costs. In this report these *distributed energy resources* are referred to collectively as *DER*.

Center stage is the increased integration of energy resources as part of strategies to make the power system more flexible, connected and resilient. Utilities are balancing daily and long-term strategies; the need to ensure that existing assets perform effectively while the utilities adapt their assets to a changing grid, and also create new technologies for a genuinely Integrated Grid.

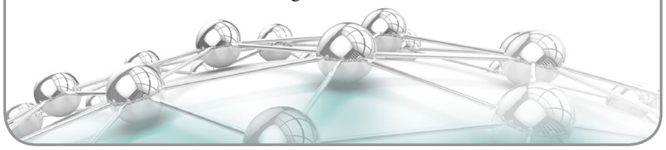
The concept of an Integrated Grid was outlined by EPRI[1] noting the goals to realize the full value of a transformed power system – its diverse inputs, efficiencies and innovation. An Integrated Grid should make it possible for stakeholders to identify optimal architectures and the most promising configurations, recognizing that solutions vary with local circumstances, goals, and interconnections.

The question is about the ways in which DER interacts with the power system infrastructure. The formula for this answer has multiple dimensions. Beneficial and adverse circumstances can arise at differing levels of DER saturation. The interaction is dependent on the specific characteristics of the distribution circuits (design and equipment), existing loads, time variations of loads and generation, environmental conditions, and other local factors. Benefits and costs must be characterized at the local level and the aggregated level of the overall power grid.

EPRI recognizes the need for the industry to systematically and thoroughly address the implications of DER. This requires adopting planning protocols and operating procedures that see interconnected assets from end to end, and that operate the system in an integrated manner. This systematic approach to DER benefit-cost assessment is the focus of this report.

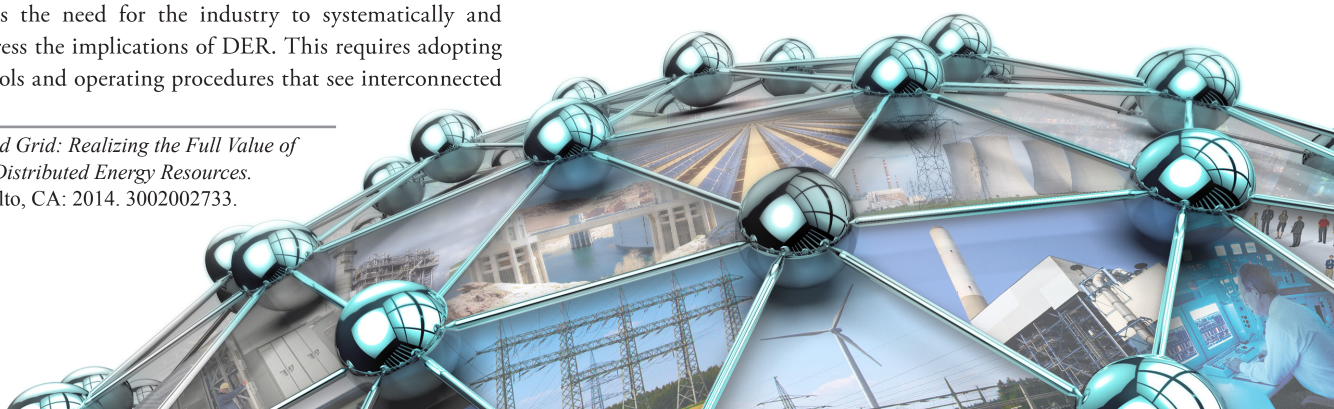
Distributed Energy Resources (DER) are electricity supply sources that fulfill the first criterion, and one of the second, third or fourth criteria:

1. Interconnected to the electric grid, in an approved manner, at or below IEEE medium voltage (69 kV).
2. Generate electricity using any primary fuel source.
3. Store energy and can supply electricity to the grid from that reservoir.
4. Involve load changes undertaken by end-use (retail) customers specifically in response to price or other inducements or arrangements.



An Integrated Perspective and Approach

DER are typically connected to the radial arms of the grid; however, they have repercussions that resound throughout the electric system. Kilowatts generated on a distribution line can affect the performance of that circuit (and maybe adjacent circuits), the operation of the interconnected transmission system, and how the central generation fleet is dispatched. The influence extends to how the system is designed and built, what assets are added, and what assets were anticipated but no longer needed (avoided capital expenditures). Those effects, or impacts, include both benefits and costs. Enumerating and quantifying them requires a departure from conventional, function-centric planning and operation practices to look at the electric system as a whole—an Integrated Grid that extends beyond the retail meter and affects many new interests throughout the economy.



1 *The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources.* EPRI, Palo Alto, CA: 2014. 3002002733.

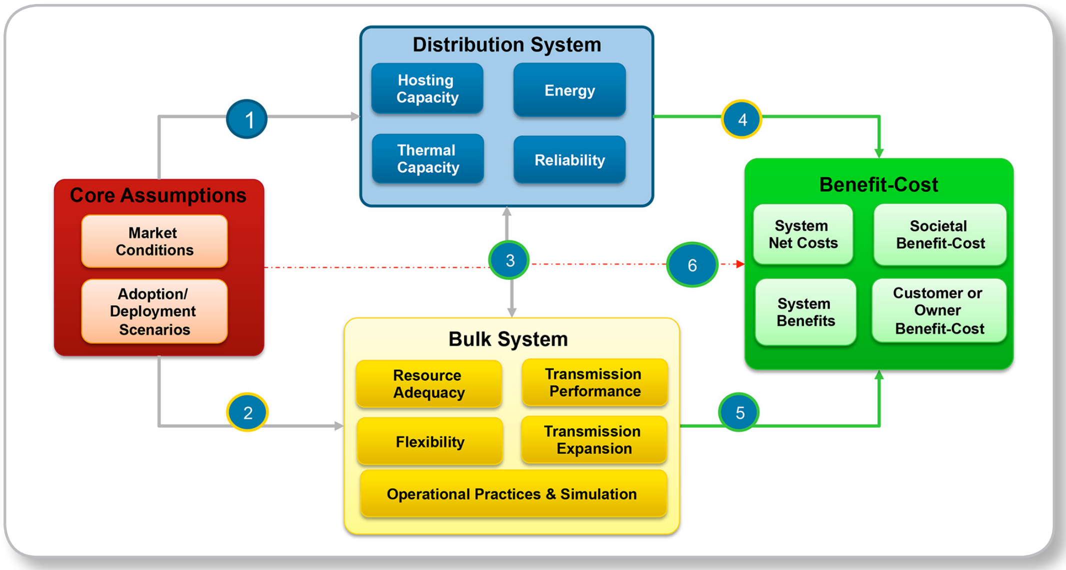


Figure ES-1
The EPRI Integrated Grid Framework

Integrated Grid Benefit-Cost Framework

EPRI's benefit-cost methodology, described in this report, defines the tools, protocols, and methods necessary to conduct consistent, repeatable, and transparent studies to anticipate and accommodate DER. The framework is rooted in the fundamentals of power system engineering and economics, making the methods applicable to all regions, systems, markets, technologies, and research questions. Widespread application of EPRI's Integrated Grid framework brings essential coherence, consistency, and accuracy to evaluations of the net benefits that result from the proliferation of DER.

By using a common evaluation methodology, utilities and other stakeholders can compare and contrast studies and articulate their findings in ways that make the results understandable and applicable to others. It accelerates developing a comprehensive understanding of the impacts of DER adoption at low and high levels, on distribution systems with different loads and designs, and serving different electricity demands in all electricity markets. The effort and resources required to properly conduct an integrated grid analysis are substantial. Coordinated efforts employing a common evaluation framework accelerate the pace of understanding of the net benefits of DER and how to maximize them. They do so at a fraction of the cost and time compared to studies being conducted in isolation using different approaches and reporting results differently.

The Integrated Grid framework described in this report is summarized in Figure ES-1.

The framework is composed of four core analytic elements that correspond to the steps undertaken to conduct a fully integrated system study. It begins by specifying the Core Assumptions: market conditions, DER adoption, and scenario definitions. These data populate and parameterize the analyses conducted to identify and quantify the impacts of DER on the distribution system and on the bulk power system.

A study of DER integration begins by identifying and quantifying the distribution system impacts attributed to interconnected DER. This is accomplished by conducting hosting capacity studies that determine the level of DER interconnection that can be locally accommodated without impacting the quality of supply for the existing infrastructure. Subsequently, energy, capacity, and reliability analyses are undertaken to identify designs and approaches that take advantage of the DER benefits while avoiding adverse impacts.

The bulk power system's focus begins with resource adequacy, making sure that sufficient resources are available to meet electricity demand. Next, transmission expansion studies determine whether the power generated can be delivered to the distribution system without a drop in service reliability (including the benefits and impacts of distributed resources). Three additional analyses—transmission performance, system flexibility, and operations practices and simulation—ensure that all system benefits and impacts are considered.

As depicted in the figure, distribution and bulk power system analyses might be construed as separate endeavors. That is not the case. The analyses are performed sequentially and, in some cases, iteratively. The distribution studies describe how power flows change at the substation—where the two elements of the electric system come together. The first pass through an integrated analysis of DER accommodation calculates the distribution impacts and passes them for analysis to identify benefits and impacts at the bulk power system level. The analyses at this level may suggest that the best way to maximize DER benefits involves making changes to the distribution system. For example, utility control of DER inverters may provide a more cost-effective means to manage distribution voltage levels while achieving additional, collateral system benefits.

The Benefit-Cost step is where the accumulated impacts are processed and measures of net benefits are constructed. It anticipates that a study requires a reference case to establish a basis for comparing DER interconnection cases. The reference case may omit DER or include DER connected only at the time of the study. Alternatively, the study may stipulate a level (or levels) of DER adoption and determine the impacts that result. Either approach launches a study that exposes the implications of different levels of DER adoption on distribution circuits, as well as different approaches for the related system design modifications.

Many of the impacts identified in the distribution and bulk power system analyses are costs or costs saved—the former incurred to mitigate adverse impacts, and the latter those that would have otherwise been incurred but are avoided. These are aggregated categorically, making a distinction between benefits and costs. Other impacts define changes in the system that are tangible and should be identified and quantified but that are not readily monetized because they are not transacted in the electricity (or any) market. Emissions associated with electricity generation, changes in delivery reliability, and changes in the economy (such as employments and wages) are examples of externalities for which there are no market transactions to definitively set a value for their level.

From a societal perspective, as many benefits and costs as possible should be monetized so that the net benefits derived are all-inclusive to reflect the utility's and its customers' interests as well as those of all economic sectors and all citizens. Alternatives for doing so are proposed in the framework. Studies that focus on a utility's production costs and associated financial implications typically include only those costs that the utility incurs. These are accommodated in the framework by the careful categorization of costs and benefits in terms of how they apply to specific decision criteria.

Next Steps: Industry Coordination and Collaboration

Integrated Grid Framework Application and Maturation

EPRI's benefit-cost framework is ready for widespread application, but it is a work in progress. The methodology employs available power system and economic models, methods, and data to construct a complete, end-to-end portrayal of how DER impact the electric system, how to translate those impacts into changes in utility cost, and how those impacts generate societal benefits. This report also points out shortcomings in modeling the electric grid as an integrated power system.

The complexities brought about by DER integration require the development of new planning tools and operating methods. Better estimates of DER output are essential to ascertaining system needs and meeting them cost-effectively. Communication with and control of field devices to improve system response to state changes such as voltage fluctuations tax current modeling capability to simulate their operation. Improved modeling capability is essential for devising operational strategies that realize the benefits that are possible.

Storage and demand response—which are DER by virtue of their impact on actual generation requirements—can mitigate some of the adverse impacts of DER, but how they affect distribution system operation must be better characterized and incorporated into dynamic system models. Standards can play a significant role in DER accommodation in the distribution system, but finding the necessary consensus on what they entail requires substantial impact and implications modeling support.

The temporal nature and nuances of the bulk power system require dynamic load modeling and forecasting capabilities along with probabilistic capacity adequacy analyses to account for the inherently intermittent nature of supply of some DER. The same holds for assessing impacts on the transmission system. Distribution planning models need to be integrated with those of the bulk power system for planning to be truly integrated.

A better understanding of the wants and needs of customers as well as when and how they use electricity is paramount to achieving the Integrated Grid vision. DER are installed by customers to serve their interests. Knowing the key drivers to the DER adoption decision—and forecasting how electricity demand changes as a result—are the first steps toward forecasting how much and what kinds of DER are likely to be interconnected.

EPRI seeks and welcomes ongoing collaboration with industry stakeholders to improve on the Integrated Grid framework to ensure that it develops intelligently and purposefully and is accessible to and used by the industry at large as well as by those who study the operation and performance of the electric system.

Integrated Grid Pilot Projects

Creating a robust grid modeling framework is essential, but it is not enough—it's just the first step. The technologies developed and operating procedures formulated must be subjected to rigorous, *in situ* field testing to ensure that they perform as intended. Coordinated pilot projects implemented by utilities and others fulfill that obligation. EPRI proposes that pilots be launched to test technologies such as the following:

- Utility-scale PV, with and without storage. These are centrally controlled and dispatched renewable supplies attached to the distribution system. Pilots are needed to confirm the level and timing of the output of the PV system and to ensure that interconnection and grid coordination systems operate as designed—and that the design itself achieves effective integration. Coordinated storage system operating performance needs to be verified in a production environment, and strategies for maximizing its value need to be verified or shortcomings revealed and resolved.
- Distributed storage (customer-side systems) operated in conjunction with intermittent DER. Field tests are needed to confirm that storage coordination strategies that appear to be beneficial to the customer and the grid, based on simulations, are in fact beneficial when operated on consumers' and businesses' premises to serve their interests.
- Microgrids serve local customers' needs for greater electric service reliability and resiliency. They can also serve as a system support asset, but the benefits are speculative until confirmed in practical applications in which systems are fully interconnected with and operated in coordination with the grid.

- EV charging infrastructure can be built to serve the needs of electric vehicles but operated to achieve grid benefits as well. Because the frequency of use of these facilities is a matter of conjecture, therefore so are the impacts and benefits. The operation of at-scale facilities will resolve how the system is impacted, verify operating strategies, and inform refinements.
- Customer-side technologies, such as PV (with and without storage) and devices used by customers to control when and how much electricity they use. The relatively high rate of adoption of PV in some areas provides a testing ground to resolve both technical and behavioral questions about how DER affect the electric system. In areas in which adoption has been light, pilots that install and monitor systems will provide the data and experience needed to prepare for adoption should it accelerate in the future. Devices that control electricity may be adopted and used to advance the interests of the customer, or some aspects of that control can be made available to the utility to deploy for system operating purposes. Both situations warrant rigorous studies to quantify the impacts and implications for the operation of the electric grid.

Pilot projects are expensive to implement if they are designed to answer questions about performance and integration to a high degree of resolution. This is especially the case when rigorous experimental protocols are employed to attach a high degree of credibility to the findings and result in inference that extends to many other circumstances. Collaboration in the design of these pilots ensures findings that are useful across the industry.

Collaboration Is Key

The transition to the Integrated Grid is beyond the scope of any one organization. It requires careful collaboration among multiple parties sharing a mutual interest in DER integration. EPRI intends to promote and support ongoing technology assessments and performance documentation efforts in conjunction with other stakeholders. It plans to work with utilities in the United States and around the globe to coordinate system pilots, deployments, and modeling efforts that contribute to the improved understanding of how to accommodate DER. EPRI intends to engage with utilities around the world, the National Association of Regulatory Utility Commissioners (NARUC), Institute of Electrical and Electronics Engineers (IEEE), International Council on Large Electric Systems (CIGRÉ), and the U.S. Department of Energy (DOE) and its network of national laboratories, trade associations {including Edison Electric Institute (EEI), the National Rural Electric Cooperative Association, the American Public Power Association (APPA)} and other organizations to both apply and hone the Integrated Grid benefit-cost framework.

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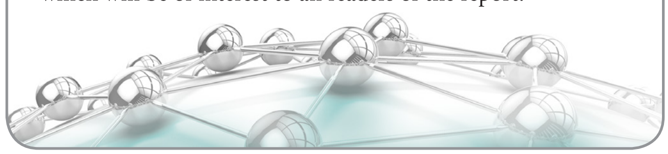
A Guide to Reading the Report

EPRI report 3002004878, *The Integrated Grid, Phase II: A Benefit-Cost Framework* is organized as follows:

- Section 1 introduces the concept of an Integrated Grid, identifies who benefits from using it, and describes how they would employ it.
- Section 2 identifies issues that must be addressed to employ DER efficiently and effectively, laying the groundwork for devising an Integrated Grid study.
- Section 3 provides an overview of the Integrated Grid framework's components—the distribution, bulk power system, and cost-benefit analysis—and how they are employed.
- Section 4 provides an overview and primer on DER characteristics and their impact on grid operation. The characteristics of the distribution grid, including items such as voltage regulation and protection coordination are described, as are impacts on the bulk power system of DER—how resource adequacy and the flexibility of the bulk power system are affected.
- Section 5 introduces the concept of *hosting capacity*, a measure of a circuit's ability to accommodate DER without an adverse impact on its reliable delivery of power to all connected loads.
- Section 6 defines ways to increase the hosting capacity when DER penetration reaches the accommodation threshold.
- Section 7 describes how DER impacts to the bulk power system are identified and analyzed.
- Section 8 discusses how to mitigate adverse impacts of DER to the bulk power system to maximize the net benefit realized from power supplied by DER.
- Section 9 describes how impacts identified in the modeling stages are organized into a benefit-cost framework to support several perspectives on net benefits attributable to DER.
- Section 10 discusses the next steps for advancing the Integrated Grid initiative.

A good grasp of the Integrated Grid concept and its application requirements can be acquired by skipping the most technical sections (Sections 5–8). Those desiring an in-depth discussion of the technical details of the Integrated Grid framework and its application will find that in those sections. Section 9 describes how costs and benefits are characterized and monetized and the summary metrics constructed to summarize case studies, which will be of interest to all readers of the report.



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