Metrics and Benefits Analysis and Challenges for Smart Grid Field Projects

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Abstract—This paper describes approaches to determine metrics, costs, and benefits from Smart Grid field projects including the 140 Smart Grid Investment Grants and Smart Grid Demonstration Projects funded by the U.S. Department of Energy (DOE) through the American Recovery and Reinvestment Act. The paper describes DOE's metrics and benefits framework that links Smart Grid technologies with their applications and the benefits that result from those applications. Benefits are derived by comparison of grid performance before and after installation and operation of Smart Grid components. These benefits are accrued to utilities/ratepayers, consumers, and society. There are significant challenges in attempting to collect field information and convert the information to metrics, costs, and benefits. For example, determining the monetary value of performance benefits such as reduced environmental emissions, reduced outages, and reduced peak load requires assumptions based on experience and must be rooted in solid technical and financial bases.

Index Terms—analysis, grid assets, grid modernization, metrics and benefits, Smart Grid, Smart Grid functions, Smart Grid Demonstration Program, Smart Grid Investment Grant

I. INTRODUCTION

Through the American Recovery and Reinvestment Act, the U.S. Department of Energy (DOE) and other funding has initiated 99 Smart Grid Investment Grants and 41 Smart Grid Demonstration Projects. Collectively, these projects are valued at about $10 billion and constitute the single large investment and deployment of Smart Grid technologies and systems in our nation's history. In addition, the Electric Power Research Institute has launched a similar Smart Grid Demonstration Program which includes 11 demonstration projects. The deployment of these Smart Grid projects represents the first significant opportunity to collect field information to determine the benefits of Smart Grid, compare the benefits to the costs, and build future business cases. Information from these projects is expected to better inform investors and decision makers on future deployments of Smart Grid.

Previous paper studies have shown a benefit-to-cost ratio ranging from 4:1 to 6:1 [3,4,5]. An intent of the collecting data from Smart Grid projects is to confirm that the benefits of Smart Grid greatly outweigh its costs.

This paper describes analytical approaches being used to determine the performance metrics, benefits, and cost of Smart Grid projects along with several of the challenges.

II. SMART GRID METRICS AND BENEFITS

A. Metrics and Benefits Framework

DOE's analytical framework will link Smart Grid technologies deployed or leveraged under DOE's Smart Grid projects to up to 25 benefits accrued by three stakeholder groups (i.e., utility/ratepayer, consumer, and society). The framework asks several key questions (Fig. 1):

- What is the technology? (i.e., "Assets")
- What does the technology do? (i.e., "Functions" or "Storage Applications" for energy storage technologies)
- How does it do that? (i.e., "Mechanisms (Impacts)")
- What goodness results? (i.e., "Benefits")
- What is the goodness worth? (i.e., "Monetary Value")

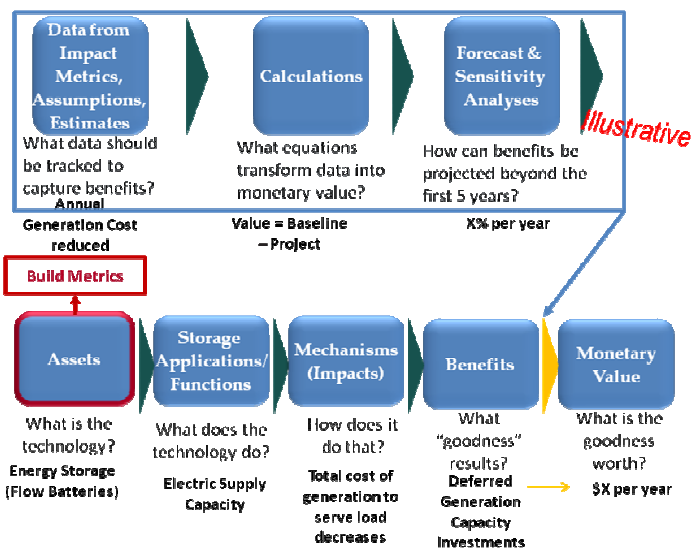Fig. 1. Smart Grid Metrics and Benefits Analytical Framework

DOE is attempting to answer these questions by defining and tracking the Smart Grid Program's assets and their impact on the grid, consumers, and society. DOE is tracking "Assets" via build metrics reporting by projects, which includes monetary investments (i.e., installed equipment costs), the creation and retention of jobs, and Smart Grid technologies

and pricing programs (grouped under the categories of Advanced Metering Infrastructure, Customer Systems, Pricing Programs, Distributed Energy Resources, Distribution, and Transmission).

DOE is tracking "Mechanisms (Impacts)" via impact metrics reporting by projects, which include metrics that measure how and to what extent the project is affecting grid operations and performance, or how it is enabling customer programs. For example, a project might show a reduction in truck rolls by implementing automated feeder switching. Another project might show a drop in peak demand from a real-time pricing program.

Projects will report both baseline and project and system-level build and impact metrics. Baseline should reflect the parameter values without the DOE Smart Grid Program project, analogous to "business as usual" in a business case analysis. For example, baseline could be established using historical performance data on the feeder(s) or data collected on the feeder(s) during the project prior to the operation of the Smart Grid technologies. Project-level metrics pertain to the project-funded technologies and the impact of those technologies on operations in the demonstration area(s). System-level metrics pertain to technologies that already exist or are being installed in a project separate from the DOE Smart Grid Program, or impacts from project-funded technologies that extend beyond the demonstration area(s) into the broader utility system. For example, a project demonstrates power flow control by installing FACTS devices funded by the DOE Smart Grid Program and using existing phase angle regulating transformers. The project should capture FACTS devices under project-level and phase angle regulating transformers under system-level.

Furthermore, for energy storage-specific projects, DOE will be tracking energy storage applications, which include specific technical considerations such as minimum discharge duration, and the following system performance information:

- System Characteristics—profile of the system such as footprint and energy density
- Data Measurements—storage system measurements and recordings such as battery system state of charge and import/export energy signals
- System Performance Parameters—technical, economic, and environmental health & safety (EHS) performance characteristics that will be measured or calculated during the project such as round-trip efficiency and operating temperature
- Projected Performance Parameters—performance characteristics that will require extrapolating or forecasting based on data collected during the demonstration such as long-term capacity degradation and cycle life

DOE has identified and mapped key Smart Grid "Assets" to 13 "Functions" that may be enabled by Smart Grid (Fig. 2). The "Functions" and three energy resources have then been mapped to 25 Economic, Reliability, Environmental, and Security "Benefits" (Fig. 3).

In order to quantify these benefits (i.e., "Monetary Value"), DOE has supported the development of a Smart Grid Computational Tool. This tool identifies, organizes, and processes the inputs (e.g., "Assets", "Functions", "Mechanisms (Impacts)", and "Benefits") required to analyze a project. For example, the "Function" of Enhanced Fault Protection can realize a "Benefit" of Reduced Equipment Failures through the following calculation: ($) = Capital Replacement of Failed Equipment ($) * Portion of Failed Equipment Caused by Fault Current or Overloaded Equipment (%). The tool can also perform Net Present Value and sensitivity analyses [5,6].

B. Categories of Benefits

It is important to recognize that not all stakeholders will benefit from the Smart Grid equally and DOE is making efforts to use the Smart Grid field information to delineate the benefits to utilities/ratepayers, consumers, and society. Utilities will benefit from Smart Grid through improved operations including more accurate and automated metering and billing, better outage management, reduced electrical losses, better asset utilization, improved maintenance, and improved planning processes. Consumers will benefit through more reliable service, reduced businesses losses, potential bill savings, reduced transportation costs through electric vehicles, and ability to access real-time information with options to control their electrical use. Society will benefit from the Smart Grid by reducing import of crude oil by transportation electrification, improving the security of electricity delivery, and reducing environmental emissions by enabling more renewable energy resources. Smart Grid represents an opportunity to create new domestic jobs for design, construction, operation and maintenance of Smart Grid; for manufacturing Smart Grid components, and for providing Smart Grid services. Smart Grid is a vital component that enables U.S. companies and economy to compete in the global marketplace.

C. Challenges

Metrics, cost and benefits analysis of Smart Grid field projects has some major challenges. These challenges include:
- Enabling a fair comparison of baseline performance and Smart Grid performance
- Collecting proper data at appropriate frequency and location
- Determining societal benefits
- Monetizing benefits
- Extrapolating results from a few circuits to larger control area
- Interpreting Smart Grid response to electrical disturbance
- Recognizing regional differences for electric service provider and consumer
- Using appropriate assumptions and calculation methods

More discussion is warranted for some of these challenges. For example, to enable a fair comparison of baseline and the Smart Grid system, it may be necessary make adjustments to account for differences in weather conditions, abnormal system disturbances, maintenance, load and other factors

between the baseline period and the Smart Grid demonstration/deployment period.

Appropriate field data needs to be collected in the proper frequency and location as it provides the raw information that must be used in calculations to determine performance metrics and benefits. Since these Smart Grid projects represent the first large opportunity to collect field data, we must be prepared to adjust our data collection requirements as we learn more about operation of the Smart Grid system.

Among the societal benefits of Smart Grid are cleaner air, improved safety, reduced dependency on foreign oil, and reduced costs of goods and services. These benefits are real, but difficult to calculate and monetize based on field data from Smart Grid projects. However, it is important to account for these improvements made possible by Smart Grid in the business case and decision making for Smart Grid. We will be exploring the underlying assumptions and calculation methods for determining societal benefits to assure that they are as credible as possible.

During periods of disturbances on the electric grid (e.g., outages or power quality issues), it may be important to adjust the data collection approach by changing the type, frequency, and location of data collected during transient conditions. One of the benefits of Smart Grid is "self-healing" by being able to anticipate and respond to system disturbances before they become a major problem. One of the challenges of the "self healing" feature of Smart Grid is to demonstrate how Smart Grid was able to prevent the occurrence of a major event such as outages, equipment damage, and power quality issues and determine the value associated with preventing those events.

D. Observations

In addition to quantifying and monetizing performance of the Smart Grid and impacts to consumers and society, it is important to record observations and reactions to Smart Grid from utility workers (e.g., planners, designers, operators, and maintenance crews), consumers, regulatory commissioners, and other stakeholders. There is a need to understand how Smart Grid has improved or worsened the ability of utility workers to perform their jobs and how Smart Grid has impacted the convenience, comfort, and electricity bills for consumers. In fact, several of the Smart Grid Investment Grant (SGIG) projects have volunteered to participate in consumer behavior studies on dynamic pricing to better understand how Smart Grid education and dynamic pricing affect consumer behavior. Often, these observations will reveal unintended consequences of Smart Grid – both good and bad.

E. Performance Feedback

The DOE has initiated a Performance Feedback Program to capture and share case studies, best practices, and lessons learned from Smart Grid field projects. It is vital that organizations moving forward with Smart Grid learn from theirs and others experiences and apply those experiences to their implementation approaches. The Performance Feedback Program is a focused effort to share those experiences so that mistakes are not repeated and state-of-the-art for Smart Grid is continually advanced. The Performance Feedback Program will help keep implementation costs down, provide input for codes and standards development, create processes for corrective actions, and enable organizations to benchmark their Smart Grid projects with best-in-class for various Smart Grid applications.

III. APPENDIX

Fig. 2. Smart Grid Assets Mapped to Functions

Smart Grid Assets	Fault Current Limiting	Wide Area Monitoring, Visualization, and Control	Dynamic Capability Rating	Power Flow Control	Adaptive Protection	Automated Feeder Switching	Automated Islanding and Reconnection	Automated Voltage and VAR Control	Diagnosis & Notification of Equipment Condition	Enhanced Fault Protection	Real-Time Load Measurement & Management	Real-time Load Transfer	Customer Electricity Use Optimization
Advanced Interrupting Switch										•			
AMI/Smart Meters								•			•		•
Controllable/Regulating Inverter							•	•					
Customer EMS/Display/Portal													•
Distribution Automation					•	•		•				•	
Distribution Management System			•		•	•					•	•	
Enhanced Fault Detection Technology										•			
Equipment Health Sensor			•						•				
FACTS Device				•									
Fault Current Limiter	•												
Loading Monitor			•						•			•	
Microgrid Controller							•						
Phase Angle Regulating Transformer				•									
Phasor Measurement Technology		•	•	•	•		•	•		•			
Smart Appliances and Equipment (Customer)													•
Software - Advanced Analysis/Visualization		•	•										
Two-way Communications (high bandwidth)		•			•	•	•	•			•	•	
Vehicle to Grid Charging Station													•
VLI (HTS) Cables				•									

Fig. 3. Benefits Mapped to Functions and Energy Resources

Benefits			Fault Current Limiting	Wide Area Monitoring, Visualization, and Control	Dynamic Capability Rating	Power Flow Control	Adaptive Protection	Automated Feeder Switching	Automated Islanding and Reconnection	Automated Voltage and VAR Control	Diagnosis & Notification of Equipment Condition	Enhanced Fault Protection	Real-Time Load Measurement & Management	Real-time Load Transfer	Customer Electricity Use Optimization	Distributed Generation	Stationary Electricity Storage	Plug-in Electric Vehicles
Economic	Market Revenue	Arbitrage Revenue															•	
		Capacity Revenue															•	
		Ancillary Services Revenue															•	
	Improved Asset Utilization	Optimized Generator Operation		•													•	•
		Deferred Generation Capacity Investments													•	•	•	•
		Reduced Ancillary Service Cost		•							•		•			•	•	•
		Reduced Congestion Cost		•	•	•									•	•	•	•
	T&D Capital Savings	Deferred Transmission Capacity Investments	•	•	•	•									•	•	•	•
		Deferred Distribution Capacity Investments						•					•	•	•	•	•	•
		Reduced Equipment Failures	•		•						•	•						
	T&D O&M Savings	Reduced Distribution Equipment Maintenance Cost									•							
		Reduced Distribution Operations Cost						•			•							
		Reduced Meter Reading Cost											•					
	Theft Reduction	Reduced Electricity Theft											•					
	Energy	Reduced Electricity Losses									•		•	•	•	•	•	
	Electricty Cost Savings	Reduced Electricity Cost													•	•	•	•
Reliability	Power Interruptions	Reduced Sustained Outages					•	•	•			•	•			•	•	
		Reduced Major Outages		•					•				•	•				
		Reduced Restoration Cost						•	•		•	•						
	Power Quality	Reduced Momentary Outages										•					•	
		Reduced Sags and Swells										•					•	
Environmental	Air Emissions	Reduced CO$_2$ Emissions				•		•			•		•			•	•	•
		Reduced SO$_x$, NO$_x$, and PM-2.5 Emissions						•		•	•		•			•	•	•
Security	Energy Security	Reduced Oil Usage (not monetized)							•			•	•					•
		Reduced Widescale Blackouts		•	•													

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VI. BIOGRAPHIES

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