Energy and CO2 Benefits of the Smart Grid

Course Number: EE-02-701

PDH: 5

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Acronyms and Abbreviations

AC	alternating current
AEO	Annual Energy Outlook
AFDD	automated fault detection and diagnostics
AMI	advanced metering infrastructure
ANSI	American National Standards Institute
BPA	Bonneville Power Administration
Btu	British thermal unit(s)
CFC	chlorofluorocarbon
CT	combustion turbine
CVR	conservation voltage reduction
CVRf	conservation voltage reduction savings factor
DC	direct current
DEGI	dispatchable emergency generator initiatives
DOE	U.S. Department of Energy
EAC	Electricity Advisory Committee
ECAR	East Central Area Reliability Coordinating Agreement
EEI	Edison Electric Institute
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act
EMCS	energy management and control systems
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESPC	Energy Savings Performance Contract
ESPP	Energy-Smart Pricing Plan
EV	electric vehicle
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
GFA	Grid Friendly™ appliance
GHG	greenhouse gas
GREET	greenhouse gases, regulated emissions, and energy use in transportation
GW	gigawatt, one billion watts of generating capacity
HCFC	hydro-chlorofluorocarbon
HEV	hybrid electric vehicle
HVAC	heating, ventilating, and air conditioning

ICT	information and control technologies
IM	interval meters
IPMVP	International Performance Measurement & Verification Protocol
ISO	Independent System Operations
kW	kilowatt(s)
kWh	kilowatt hour(s)
LC/S	load curtailment/shifting
LDV	light-duty vehicle
LoanSTAR	Loans to Save Taxes and Resources
m	meter(s)
m^2	square meter(s)
MMT	million metric tonnes
M&V	measurement & verification
MW	megawatt(s)
MWh	megawatt hour(s)
NERC	North American Electric Reliability Corporation
NHTS	National Household Travel Survey
NYSERDA	New York State Energy Research and Development Authority
OE	Office of Electricity Delivery and Energy Reliability
ORNL	Oak Ridge National Laboratory
PDRE	permanent demand reduction efforts
PHEV	plug-in hybrid electric vehicle
PLRP	Peak Load Reduction Program
PNNL	Pacific Northwest National Laboratory
PRISM	Princeton Scorekeeping Method
PV	photovoltaic
RECAP	Regional Capacity Planning
RPS	renewable portfolio standard
RTO	Regional Transmission Organization
SCADA	supervisory control and data acquisition
SUV	Sport Utility Vehicle
T&D	transmission and distribution
TWh	terawatt hour(s)
VAR	volt-ampere reactive
VMT	vehicle-mile(s) traveled

Contents

1.0 Introduction

One key element for modernizing the electric grid is to take advantage of the potential for information technology to change the operational and control strategies it uses to help keep electricity affordable by improving the cost-effectiveness of grid infrastructure investments and increasing the reliability of electricity supply and delivery to customers. Proponents of modernizing the grid, which has come to be known generically as the "smart grid," articulate its benefits to industry, policy makers, customers, and other stakeholders, by advancing key technologies and funding field demonstrations to prove its performance advantages.

This course articulates nine mechanisms by which the smart grid can reduce energy use and carbon impacts associated with generating and delivering electricity. To the extent possible, it presents quantitative estimates of potential impacts for each of the mechanisms through a detailed search of published results and by conducting simple analyses of the potential effects. This course does not attempt to justify the cost effectiveness of the smart grid, which to date has been based primarily upon the twin pillars of cost-effective operation and improved reliability. Rather, it attempts to quantify the *additional* benefits inherent in the smart grid's potential contribution to the nation's goal of mitigating climate change by reducing the carbon footprint of the electric power system.

Energy Independence and Security Act
Sec. 1301. Policy on Modernization of Electricity Grid

… support the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a smart grid:

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.

(2) Dynamic optimization of grid operations and resources, with full cyber-security.

(3) Deployment and integration of distributed resources and generation, including renewable resources.

(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.

(5) Deployment of "smart" technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.

(6) Integration of "smart" appliances and consumer devices.

(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.

(8) Provision to consumers of timely information and control options.

(9) Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.

(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

Related assessments by the Electric Power Research Institute (EPRI) and The Climate Group, and an article in *The Electricity Journal*, also examined the electricity and CO_2 benefits that may result from implementation of the smart grid (EPRI 2018; GeSI 2018; Hledik 2009). These assessments also provide first-order estimates of the energy and carbon benefits for the emerging smart grid area and provide useful comparative benchmarks for this effort.

The course is organized into five sections. Section 2.0 provides an overview of the current electrical grid and a definition of the smart grid with its costs and benefits. Section 3.0 presents the assessment methodology, summarizes each mechanism and the results of its assessment, and Section 4.0 compares the results from EPRI and The Climate Group studies, and *The Electricity Journal* article. Further details of the assessments for the mechanism are provided in Attachments 1 and 2. The last section (Section 1.0) provides recommendations on mechanisms and benefits that deserve further exploration.

2.0 Smart Grid – What it Is, What it Does, and Who it Benefits

A basic perspective of this analysis is that, over the next 20 years, smart grid technology will become pervasive in the United States because of the cost efficiencies it provides for the electric power system, and that it could be leveraged to provided additional benefits of reduced energy consumption and carbon emissions. Therefore, it is important to understand the kinds of assets involved in a smart grid and how they are functionally engaged to provide cost efficiencies. This sets the context for why a smart grid is likely to be deployed and what assets it is likely to contain that can be leveraged for these additional environmental benefits. The discussion in this section attempts to outline this perspective.

Electricity has historically been generated at central station power plants and distributed to customers, as shown in Figure 2.1. In 2017, an estimated 995 GW of generating capacity delivered 4.2 GWh to 142 million customers over approximately 158,000 miles of transmission line >230 kV. Estimates of distribution lines are in the range of 1 million miles. The voltage is stepped- up from large central generating stations for transmission through 10,287 transmission stations, stepped- down for utility distribution in 2,178 distribution substations (DOE/OE 2006), may be further stepped- down at points along the utility distribution lines (feeders), and again at pad- and pole-mounted transformers to provide low-voltage service to one or a several customers.

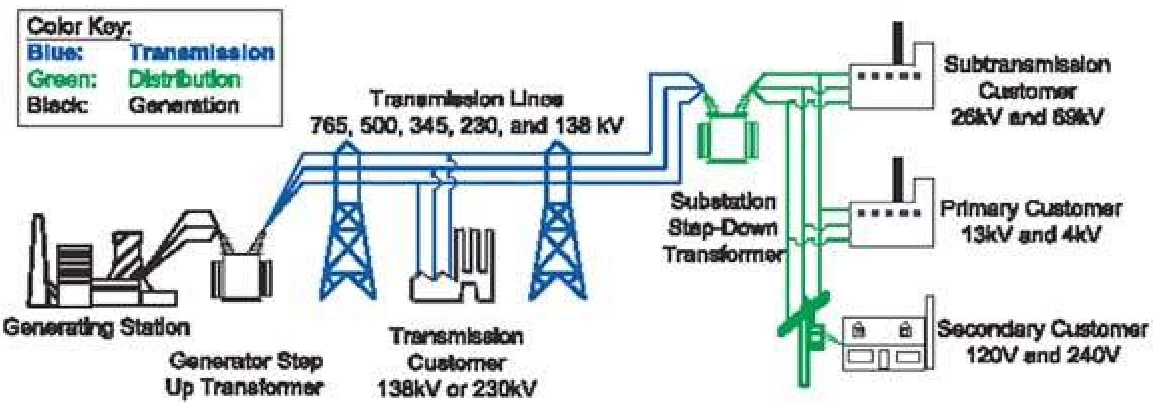

Figure 2.1. Today's Electricity Delivery System

The delivery of electricity typically utilizes a supervisory control and data acquisition system (SCADA) that provides monitoring and control from generation through the step-down substation to detect the need for an increase/reduction in generating resources, and to respond to system instabilities. Key limitations of SCADA systems are the following:

- limited bandwidths and relatively slow data transmission rates that often require several seconds or more to respond to an alarm or system change
- limited or no visibility in the distribution network below the substation.

The coming evolution in the delivery of electricity is the smart grid, which is the application of information technology that enables more visibility and control of both the existing grid infrastructure and new grid assets, such as customer demand response and distributed energy resources consisting of small generators and electricity storage devices. The smart grid's much higher fidelity control is provided through high-speed, two-way communication, sensing, and real-time coordination of all assets down to the customer meter and the end-use devices. Thus, the smart grid is not characterized by a single technology or a device, but instead is a vision for a distributed, internet-like system that will:

- provide better control of existing grid infrastructure assets
- provide additional functionality and benefits from existing assets
- integrate new (often small, widely distributed) assets into the existing operational paradigm
- engage these new assets to provide entirely new benefits to the grid.

The next immediate developments in SCADA technology for utilities are to increase bandwidth and begin to measure and control assets below the substation level, at which time the system will begin to become part of a distributed control system—and a key part of the smart grid.

This vision is perhaps best described by a set of essential characteristics, or outcomes (see box).

> "The smart grid isn't a thing but rather a vision… It must be more reliable...more secure...more economic…more efficient…more environmentally friendly…(and) It must be safer. A "smart grid" can be (characterized as) a "transactive" agent…(that) will:
>
> - Enable active participation by consumers…
> - Accommodate all generation and storage options...
> - Enable new products, services, and markets…
> - Provide power quality for the digital economy...
> - Optimize asset utilization and operate efficiently…
> - Anticipate and respond to system disturbances (self-heal).
> - Operate resiliently against attack and natural disaster.
>
> Achieving the vision is dependent upon participant circumstances and involves:
>
> - Empowering consumers by giving them the information and education they need to effectively utilize the new options provided by the smart grid…
> - Improved reliability and "self-healing" of the distribution system…
> - Integration of the transmission and distribution systems to enable improved overall grid operations and reduced transmission congestion…
> - Integration of the grid intelligence acquired to achieving with new and existing asset management applications…

Beyond describing the smart grid as a vision, it is helpful to describe what the smart grid ***consists of*** in terms of

- the assets that would be purchased
- the functions for which they would be used, and from which benefits are derived.

This is illustrated in the matrix in Figure 2.2, with a number of key assets on the horizontal axis and broadly defined categories of major functions on the vertical axis. This illustration of the current and emerging vision for the smart grid is not intended to be definitive or comprehensive, but rather will evolve over time.

Assets are divided into primary and enabling assets. *Primary assets* are the smart grid's "prime movers," i.e., non-traditional assets that are actively controlled to effect change in the grid's operating conditions.

