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Energy and CO2 Benefits of the Smart Grid

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Module 1: Introduction

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary mission and strategic objectives of the DOE Office of Electricity Delivery and Energy Reliability (OE) regarding grid modernization.
- **Evaluate** the ten defining characteristics of a smart grid as established by the Energy Independence and Security Act (EISA) of 2007.
- **Analyze** the specific goals of the PNNL assessment in quantifying energy and carbon benefits.

Executive Summary: The smart grid represents a transition to a modernized electrical infrastructure that leverages information technology to improve cost-effectiveness, reliability, and environmental performance. While historically justified by operational stability, this framework focuses on quantifying the "additional benefits" of the smart grid: its capacity to mitigate climate change by reducing electricity consumption and the national carbon footprint.

Strategic Mission and Context

The U.S. Department of Energy (DOE), through the **Office of Electricity Delivery and Energy Reliability (OE)**, leads national efforts to modernize the electric grid and enhance the security and reliability of energy infrastructure. A cornerstone of this strategy is the integration of **information technology** to transform operational and control strategies.

Key Strategic Drivers

- **Affordability:** Improving the cost-effectiveness of grid infrastructure investments.
- **Reliability:** Increasing the stability of electricity supply and delivery to customers.
- **Modernization:** Transitioning from traditional methods to digital, automated, and interactive systems.

Assessment Objectives

The **Pacific Northwest National Laboratory (PNNL)** was tasked with estimating the potential energy and carbon benefits resulting from smart grid deployment. This assessment focuses on:

- **Defining Mechanisms:** Identifying how the smart grid contributes to energy efficiency and renewable generation integration.
- **Quantification:** Measuring reductions in electricity consumption and **CO2 emissions**.
- **Climate Mitigation:** Shifting focus toward the carbon footprint of the electric power system rather than just cost-benefit analysis.

Policy Framework: EISA 2007

The **Energy Independence and Security Act (EISA) of 2007** formally established the policy for grid modernization. Under Section 1301, a "smart grid" is characterized by the following ten digital and operational advancements:

1. **Digital Integration:** Increased use of digital information and controls to improve grid efficiency and security.
2. **Dynamic Optimization:** Real-time optimization of grid operations with full **cyber-security**.
3. **Distributed Resources:** Integration of distributed generation, particularly renewable resources.
4. **Demand-Side Management:** Incorporation of demand response and energy-efficiency resources.
5. **Automated Technologies:** Deployment of real-time, interactive technologies for metering and distribution automation.
6. **Smart Appliances:** Integration of consumer devices capable of responding to grid signals.
7. **Advanced Storage:** Incorporation of electricity storage and peak-shaving technologies, including **EVs and PHEVs**.
8. **Consumer Empowerment:** Providing timely information and control options to end-users.
9. **Interoperability Standards:** Development of communication standards for all equipment connected to the grid.
10. **Barrier Reduction:** Identifying and lowering unnecessary barriers to smart grid technology adoption.

⚠ Safety Constraint: Grid modernization efforts must maintain a reliable and secure electricity infrastructure while meeting future demand growth. Cyber-security is a mandatory component of dynamic grid optimization.

💡 Design Tip: While cost-effective operation and reliability are the traditional "twin pillars" of the smart grid business case, engineers should now prioritize the integration of renewable resources to meet emerging carbon management goals.

Report Methodology and Benchmarking

This assessment articulates **nine mechanisms** for energy and carbon reduction. It serves as a companion to other first-order estimates provided by:

- **Electric Power Research Institute (EPRI).**
- **The Climate Group.**



- **The Electricity Journal.**

Checkpoint Quiz

1. According to EISA 2007, which of the following is a core characteristic of a smart grid?

- a) Exclusively centralized power generation.
- b) Elimination of consumer information options.
- c) Deployment and integration of advanced electricity storage, including EVs.
- d) Manual optimization of grid resources.

Answer: (c). Section 1301 (7) specifically includes advanced storage and electric vehicles as characterizing a smart grid.

2. What is the primary focus of the PNNL assessment described in this section?

- a) Justifying the cost-effectiveness of smart meters.
- b) Quantifying energy and carbon benefits of the smart grid.
- c) Developing new hardware for substation transformers.
- d) Writing new cyber-security protocols.

Answer: (b). The goals of the project are to define mechanisms and quantify reductions in electricity and CO2.

3. Which document formally established the 10 points characterizing the smart grid effort?

- a) The PNNL Strategic Plan.
- b) The Electricity Journal.
- c) Energy Independence and Security Act of 2007.
- d) The EPRI Green Grid Study.

Answer: (c). EISA 2007 Sec. 1301 provides the policy framework and 10-point characterization

Module 2: Smart Grid – What it Is, What it Does, and Who it Benefits

Learning Objectives

By the end of this section, you will be able to:

- **Distinguish** between primary and enabling smart grid assets and their specific roles in grid modernization.
- **Evaluate** the functional objectives of the smart grid, including peak load management and ancillary services.
- **Analyze** the business case for smart grid deployment by weighing capital investments against derived value streams.

Executive Summary: The smart grid is an evolution of the traditional electrical delivery system into a distributed, high-fidelity network enabled by information technology. By integrating two-way communication and sensing from generation to the customer meter, it leverages new and existing assets to provide enhanced reliability, cost efficiencies, and environmental benefits.

The Evolution of Electricity Delivery

Historically, the U.S. grid has relied on large, central-station power plants to deliver electricity through a hierarchical system of transmission and distribution lines. As of 2007, this system supported over 142 million customers but relied on traditional **SCADA** (supervisory control and data acquisition) systems with significant limitations.

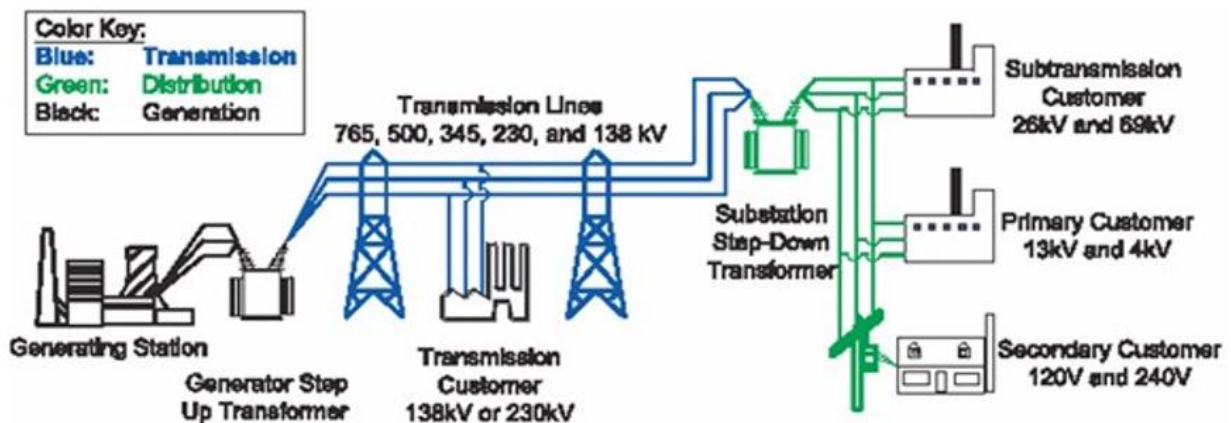


Figure 2.1. Today's Electricity Delivery System (Source: DOE/FEMP [2009], Electricity 101)

SCADA System Constraints

- **Limited Bandwidth:** Response times to system changes or alarms often take several seconds or more.
- **Low Visibility:** There is little to no monitoring capability in the distribution network below the substation level.

Defining the Smart Grid Vision

The smart grid is not a single technology but a distributed, "internet-like" system vision. It acts as a **transactive agent** designed to:

- **Enable active participation** by consumers in energy management.
- **Accommodate all generation** and storage options, including renewables.
- **Provide "self-healing"** capabilities to anticipate and respond to disturbances.
- **Optimize asset utilization** to operate the grid more efficiently and securely.

Smart Grid Framework: Assets and Functions

To understand the practical application of the smart grid, it is helpful to categorize its components into **Assets** (what is purchased) and **Functions** (how they are used).

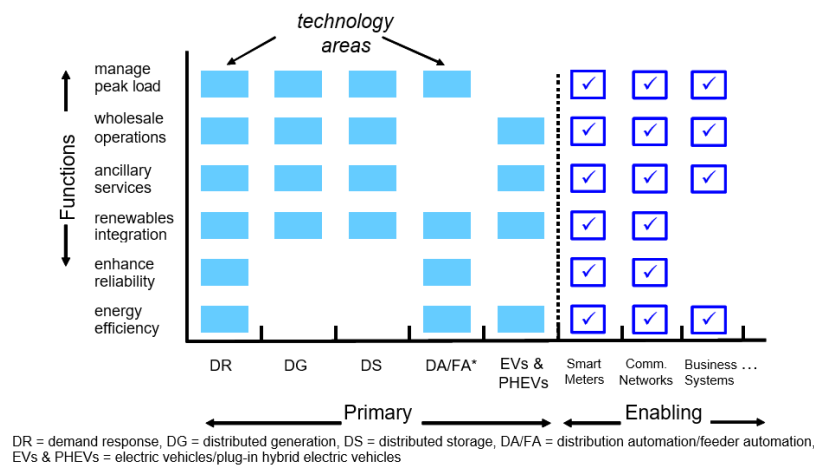


Figure 2.2. Defining the Smart Grid in Terms of Assets and Functions

Primary Assets

These are the "prime movers" of the grid—non-traditional assets that are actively controlled to change operating conditions:

- **Demand Response (DR):** Controls for end-use devices to shift or reduce demand at specific times.
- **Distributed Generation (DG):** Small-scale solar, wind, or turbine systems at the distribution level.
- **Distributed Storage (DS):** Batteries, flywheels, and thermal storage technologies.
- **Distribution/Feeder Automation (DA/FA):** Advanced relays and switches that allow the network to reconfigure itself.



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