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The Role of Energy Storage with Renewable Energy

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Module 1: Introduction

Learning Objectives

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

- **Identify** the core technical challenges associated with integrating variable generation (VG) into the electric grid.
- **Evaluate** the "need" for energy storage as an economic trade-off rather than a strictly technical requirement.
- **Analyze** the relationship between renewable energy deployment and the requirement for system reliability through enabling technologies.

Executive Summary: The integration of large-scale wind and solar energy into the electric grid introduces variability and uncertainty that challenge traditional reliability models. While energy storage is often cited as a primary solution, its deployment is ultimately an economic decision that must be weighed against alternative strategies such as flexible generation, transmission upgrades, and improved operational practices.

Renewable Energy Drivers and Grid Reliability

Renewable energy sources, specifically wind and solar, possess significant potential to **reduce dependence on fossil fuels** and lower greenhouse gas emissions within the power sector. Current growth in these technologies is driven by **renewable portfolio standards**, climate change concerns, and consumer efforts.

However, unlike the dispatchable sources that constitute the majority of U.S. electricity generation, wind and solar are characterized by **variable and uncertain output**. This variability raises two primary concerns for power engineers:

- **Grid Reliability:** Maintaining stable operations when a large fraction of energy is derived from these non-dispatchable sources.
- **Integration Costs:** Managing the expense associated with reliably incorporating large amounts of variable generation (VG) into the existing grid infrastructure.

The Economics of Energy Storage

Because wind and solar output fluctuate based on local environmental conditions—the wind does not always blow and the sun does not always shine—there has been an increased call for **energy storage** as an essential component of future energy systems. From a design perspective, this "need" must be viewed through an economic lens rather than a purely technical one.

Reliability Maintenance Options

To maintain required system reliability, engineers must compare the costs and benefits of storage against several **competing technologies and practices**:



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- **Demand Response:** Incentivizing shifts in load to match available generation.
- **Flexible Generation:** Utilizing conventional plants that can rapidly adjust output.
- **Transmission:** Moving energy from resource-rich areas to load centers to mitigate local variability.
- **Operational Practices:** Implementing improved forecasting and scheduling to manage uncertainty.

💡 **Design Tip:** When evaluating storage requirements, always consider the potential role of energy storage in relation to the **needs of the electric power system as a whole** rather than focusing solely on "firming" the output of an individual wind or solar plant.

Scope of Analysis

Effective grid planning requires a comprehensive examination of the technical and economic impacts of variable renewables on the existing grid. This includes understanding:

1. How the current grid utilizes energy storage to meet **constantly varying demand**.
2. The role of **operating reserves** in achieving and maintaining reliable service.
3. The suite of **enabling techniques** and technologies required for variable renewables to reach their full potential.

Checkpoint Quiz

1. **Why is the "need" for energy storage in renewable integration considered an economic question rather than a technical one?**
 - a) Because storage technologies are currently too expensive for any practical application.
 - b) Because reliability can be maintained through various competing technologies and operational changes, depending on their relative costs.
 - c) Because state renewable portfolio standards strictly limit the amount of storage that can be built.
 - d) Because wind and solar generation do not actually require any backup if the grid is large enough.

Answer: (b). The amount of storage used depends on its cost relative to other available options like demand response or flexible generation.



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- 2. Which term is proposed as a more technically accurate description of wind and solar output than "intermittent"?**
- a) Dispatchable generation.
 - b) Constant and predictable.
 - c) Variable and uncertain.
 - d) High-frequency oscillation.

Answer: (c). While "intermittent" is common, "variable and uncertain" is a more technically accurate description for wind and solar power plants.

- 3. When determining the potential role of storage in the future grid, which factor must engineers examine alongside energy storage?**
- a) Only the reduction in greenhouse gas emissions.
 - b) The technical and economic impacts of variable renewable energy sources and competing technologies.
 - c) Strict adherence to historical grid operational models without modification.
 - d) The immediate elimination of all fossil fuel plants regardless of system impact.

Answer: (b). A holistic approach is required to evaluate storage in relation to demand response, transmission, and improved operational practices.

Module 2: Operation of the Electric Grid

Learning Objectives

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

- **Categorize** different types of power plants based on their operational roles and technical constraints.
- **Identify** the specific requirements and cost impacts of providing operating reserves and ancillary services.
- **Evaluate** the economic trade-offs between "ideal" dispatch and reserve-constrained dispatch in power system operations.

Executive Summary: Power system operation requires a continuous, instantaneous balance between electricity supply and varying demand. To maintain reliability against unforeseen contingencies, utilities must operate a diverse mix of baseload and flexible generators, though the requirement for operating reserves often forces uneconomic dispatch and increases overall system costs.

Demand Patterns and Plant Roles

The operation of electric power systems involves complex forecasting to schedule and operate various power plants to meet varying demand. This demand is driven by seasonal and daily patterns related to heating, cooling, and lighting.

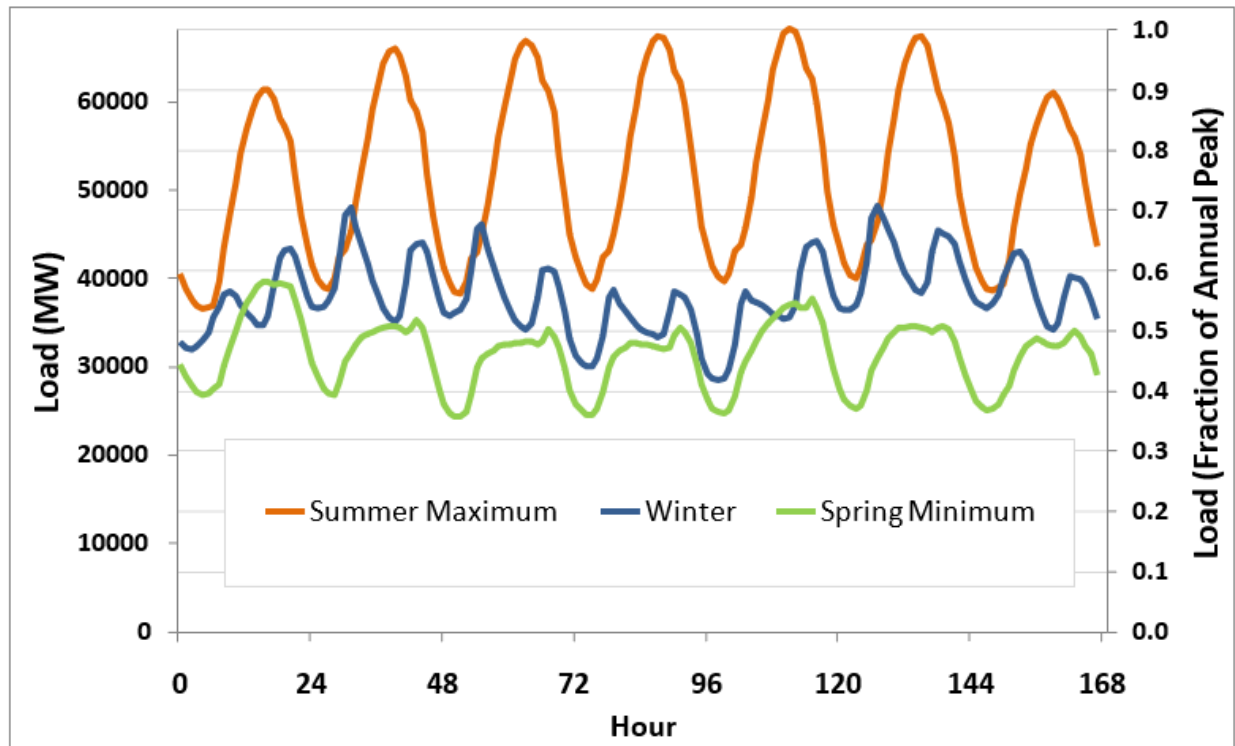


Figure 2.1. Hourly loads from ERCOT 2005

To meet these patterns, utilities utilize three primary plant categories:

- **Baseload Plants:** Often nuclear or coal-fired, these units meet large, constant demand. Due to high capital costs, low variable costs, and technical constraints on rapid output changes, they are run at full output as much as possible.
- **Intermediate Load Plants:** Typically fueled by natural gas or oil, or utilizing hydroelectric generators, these "cycling" units meet most day-to-day variable demand.
- **Peaking Units:** These plants address the highest demand periods and may only operate for a few hundred hours annually.

Operating Reserves and Ancillary Services

Beyond predictable demand, utilities must maintain **operating reserves** to handle unforeseen demand increases, transmission failures, or plant outages. These services, often called **ancillary services**, require units that can change output rapidly.

Key Components of Operating Reserves

- **Frequency Regulation:** Addressing small, random fluctuations around normal load.
- **Load-Forecasting Errors:** Responding to greater or less than predicted changes in demand.
- **Contingencies:** Responding to major unscheduled outages.

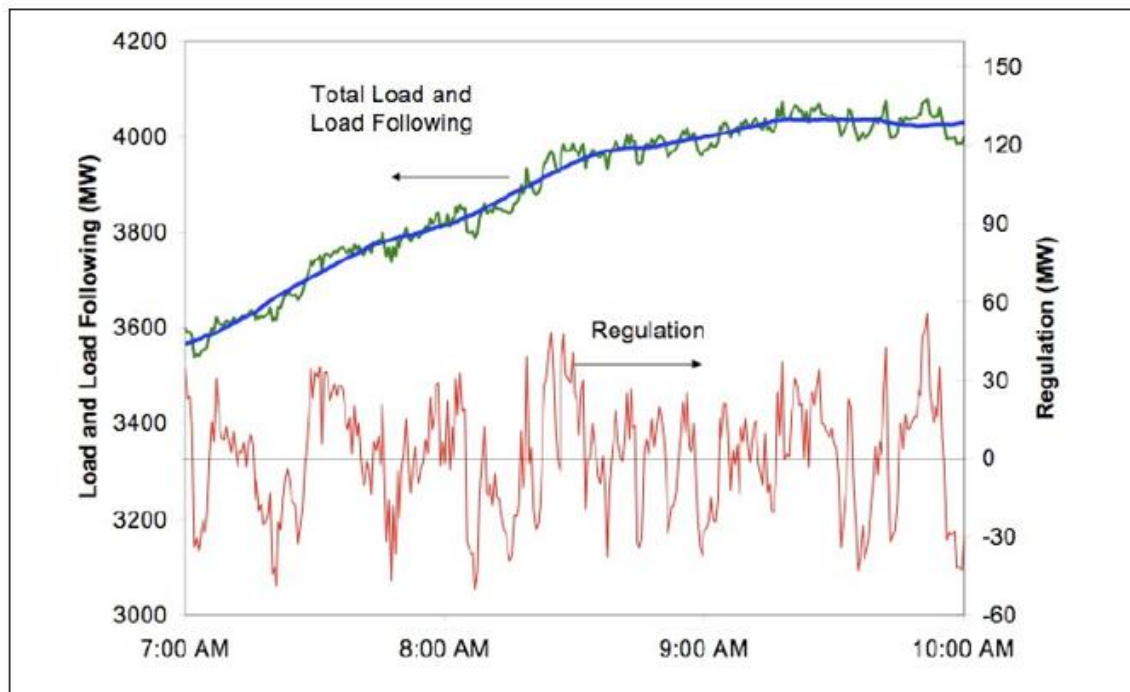


Figure 2.2. System load following and regulation. Regulation (red) is the fast-fluctuating component of total load (green) while load following (blue) is the slower trend (Kirby 2004)



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