The Role of Energy Storage with Renewable Energy

Course Number: ME-02-501

PDH: 10

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1 Introduction

Renewable energy sources, such as wind and solar, have vast potential to reduce dependence on fossil fuels and greenhouse gas emissions in the electric sector. Climate change concerns, state initiatives including renewable portfolio standards, and consumer efforts are resulting in increased deployments of both technologies. Both solar photovoltaics (PV) and wind energy have variable and uncertain (sometimes referred to as “intermittent”)[1] output, which are unlike the dispatchable sources used for the majority of electricity generation in the United States. The variability of these sources has led to concerns regarding the reliability of an electric grid that derives a large fraction of its energy from these sources as well as the cost of reliably integrating large amounts of variable generation into the electric grid. Because the wind doesn’t always blow and the sun doesn’t always shine at any given location, there has been an increased call for the deployment of energy storage as an essential component of future energy systems that use large amounts of variable renewable resources. However, this often-characterized “need” for energy storage to enable renewable integration is actually an economic question. The answer requires comparing the options to maintain the required system reliability, which include a number of technologies and changes in operational practices. The amount of storage or any other “enabling” technology used will depend on the costs and benefits of each technology relative to the other available options.

To determine the potential role of storage in the grid of the future, it is important to examine the technical and economic impacts of variable renewable energy sources. It is also important to examine the economics of a variety of potentially competing technologies including demand response, transmission, flexible generation, and improved operational practices. In addition, while there are clear benefits of using energy storage to enable greater penetration of wind and solar, it is important to consider the potential role of energy storage in relation to the needs of the electric power system as a whole.

In this course, we explore the role of energy storage in the electricity grid, focusing on the effects of large-scale deployment of variable renewable sources (primarily wind and solar energy). We begin by discussing the existing grid and the current role that energy storage has in meeting the constantly varying demand for electricity, as well as the need for operating reserves to achieve reliable service. The impact of variable renewables on the grid is then discussed, including how these energy sources will require a variety of enabling techniques and technologies to reach their full potential. Finally, we evaluate the potential role of several forms of enabling technologies, including energy storage.

[1] The use of the term “intermittent” has been questioned by the wind energy community as being technically inaccurate. Intermittent implies a short-term “on-off” cycle while the output of wind experiences maximum variations more typically on the order of 10% per hour. Solar PV is perhaps somewhat more “intermittent” because it follows a daily on-off cycle. The description “variable” or “variable and uncertain” has been proposed as a more technically accurate description of the output of a wind power plant (Smith and Parsons 2007).

2 Operation of the Electric Grid

The operation of electric power systems involves a complex process of forecasting the demand for electricity, and scheduling and operating a large number of power plants to meet that varying demand. The instantaneous supply of electricity must always meet the constantly changing demand, as indicated in Figure 2.1. It shows the electricity demand patterns for three weeks for the Electric Reliability Council of Texas (ERCOT) grid during 2005.[2] The seasonal and daily patterns are driven by factors such as the need for heating, cooling, lighting, etc. While the demand patterns in Figure 2.1 are for a specific region of the United States, many of the general trends shown in the demand patterns are common throughout the country. To meet this demand, utilities build and operate a variety of power plant types. Baseload plants are used to meet the large constant demand for electricity. In the United States, these are often nuclear and coal-fired plants, and utilities try to run these plants at full output as much as possible. While these plants (especially coal) can vary output, their high capital costs, and low variable costs (largely fuel), encourage continuous operation. Furthermore, technical constraints (especially in nuclear plants) restrict rapid change in output needed to follow load. Variation in load is typically met with load-following or "cycling" plants. These units are typically hydroelectric generators or plants fueled with natural gas or oil. These "load-following" units are further categorized as intermediate load plants, which are used to meet most of the day-to-day variable demand; and peaking units, which meet the peak demand and often run less than a few hundred hours per year.

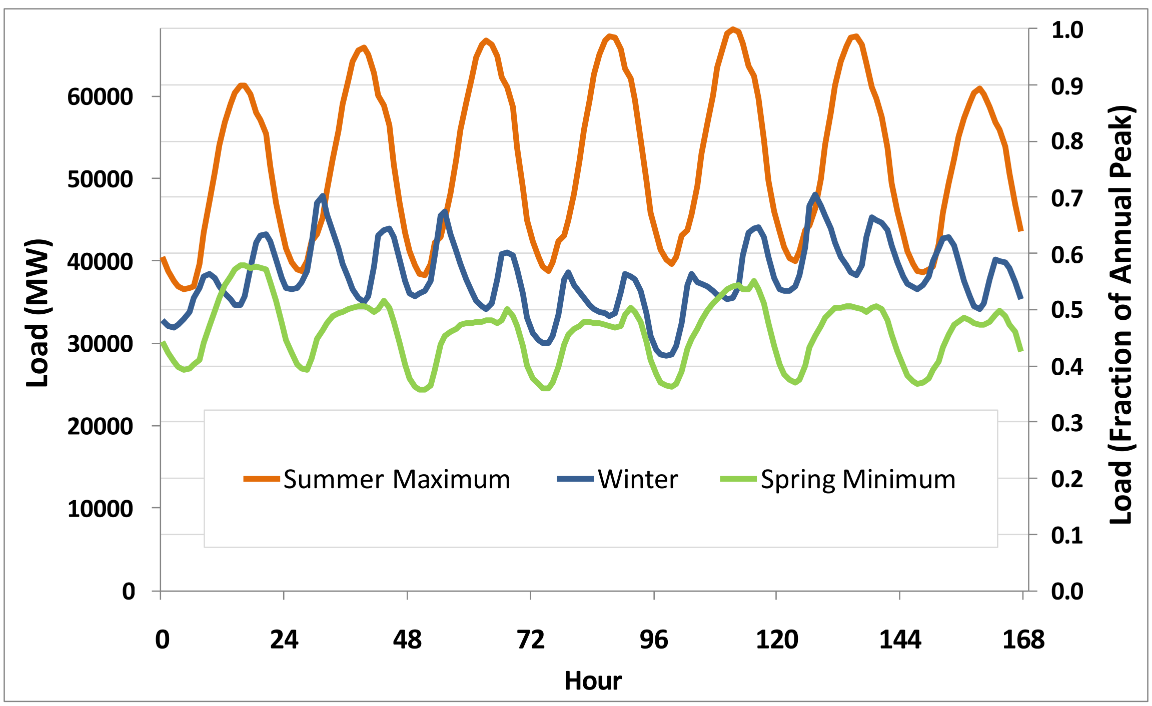

Figure 2.1. Hourly loads from ERCOT 2005

[2] Most of Texas (about 85% of the population) is within the ERCOT grid, which is largely independent of the two larger U.S. grids.

In addition to meeting the predictable daily, weekly, and seasonal variation in demand, utilities must keep additional plants available to meet unforeseen increases in demand, losses of conventional plants and transmission lines, and other contingencies. This class of responsive reserves is often referred to as operating reserves and includes meeting frequency regulation (the ability to respond to small, random fluctuations around normal load), load-forecasting errors (the ability to respond to a greater or less than predicted change in demand), and contingencies (the ability to respond to a major contingency such as an unscheduled power plant or transmission line outage) (NERC 2008).[3] Both frequency regulation and contingency reserves are among a larger class of services often referred to as ancillary services, which require units that can rapidly change output.

Figure 2.2 illustrates the need for rapidly responding frequency regulation (red) in addition to the longer-term ramping requirements (blue). In this utility system, the morning load increases smoothly by about 400 megawatts (MW) in two hours. During this period, however, there are rapid short-term ramps of +/- 50 (MW) within a few minutes.

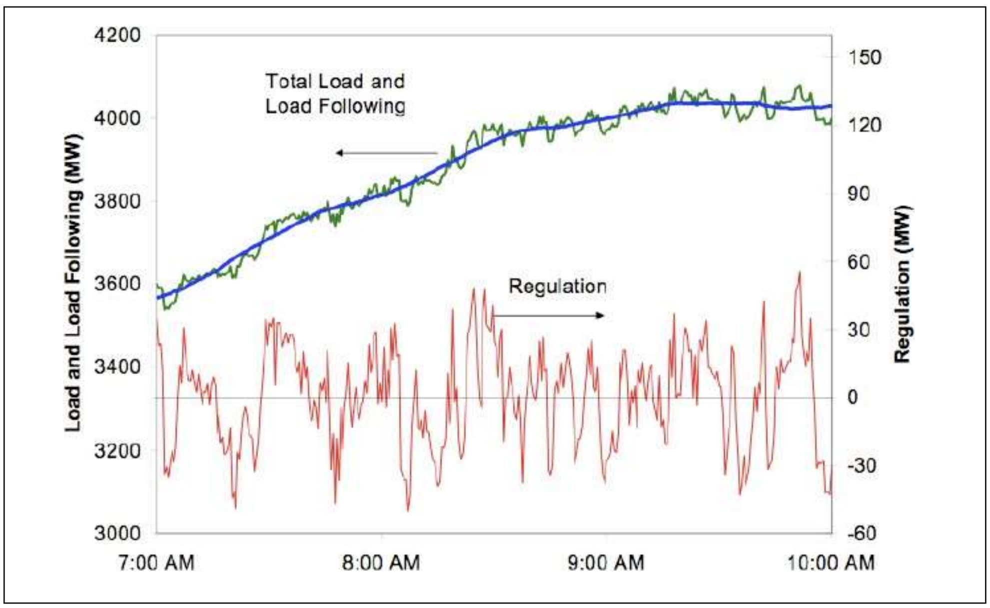

Figure 2.2. System load following and regulation. Regulation (red) is the fast-fluctuating component of total load (green) while load following (blue) is the slower trend (Kirby 2004)

Because of the rapid response needed by both regulation and contingency reserves, a large fraction of these reserves are provided by plants that are online and "spinning" (as a result, operating reserves met by spinning units are sometimes referred to as spinning reserves.)[4] Spinning reserves are provided by a mix of partially loaded power plants or responsive loads. The need for reserves increases the costs and decreases the efficiency of

[3] Operating reserves are primarily capacity services (the ability to provide energy on demand) as opposed to actual energy services.

[4] The nomenclature around various ancillary services (especially spinning reserves) varies significantly. While the NERC glossary indicates that spinning reserve applies to both contingency and frequency regulation, the term spinning reserve often is used to refer to only contingency reserves. For additional discussion of nomenclature around contingency and spinning reserves, see Rebours and Kirschen 2005.

an electric power system compared to a system that is perfectly predictable and does not experience unforeseen contingencies. These costs result from several factors. First, the need for fast-responding units results in uneconomic dispatch – because plants providing spinning reserve must be operated at part load, they potentially displace more economic units.[5] (Flexible load-following units are often either less efficient or burn more expensive fuel than "baseload" coal or nuclear units.) Second, partial loading can reduce the efficiency of individual power plants. Finally, the reserve requirements increase the number of plants that are online at any time, which increases the capital and O&M costs.

Figure 2.3 provides a simplified illustration of the change in dispatch (and possible cost impacts) needed to provide operating reserves. The figure on the left shows an "ideal" dispatch of a small electric power system. Two baseload units provide most of the energy, while an intermediate load and two peaking units provide load following. In the "ideal" dispatch, it is possible that the intermediate load unit cannot rapidly increase output to provide operating reserves. Furthermore, during the transition periods when the load-following units are nearing their full output – but before additional units are turned on – there may be insufficient capacity left in the load-following units to provide necessary operating capacity for regulation or contingencies. A dispatch that provides the necessary reserves is provided on the right. In this case, lower-cost units reduce output to accommodate the more flexible units providing reserves. This increases the overall cost of operating the entire system.

[5] This "opportunity cost" associated with uneconomic dispatch is the dominant source of reserve costs (Kirby 2004).