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Valuing Wind Generation on Integrated Power Systems

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Preface

Thank you for sending me a copy of your book—I'll waste no time reading it.

Moses Hadas, 1900–1966

The purpose of this book is to help power system analysts, consultants, and regulators understand, undertake or better understand wind integration studies. A significant diversity exists in the power industry with respect to operating practices, level of sophistication in the industry's analyses, and in the very language used. For that reason, there is no single way to serve all analytical needs with respect to wind valuation studies. A range of approaches to the analytical problems will be presented where possible. A fairly complete glossary is included in the back of the book to address the various usages of terms such as 'capacity' and 'reserves'. It is not practical at this point to suggest that common definitions of certain terms be adopted. The purpose of the glossary is to make as clear as possible what is meant by important words and terms as they are used in this book.

Acknowledgements

There is no way to adequately express the gratitude I feel toward everyone who contributed to this book. First of all must be Phil Carmical, who suggested the seemingly crazy idea that I might write a book about wind power. I am also totally indebted to Rachel Shimshak and the Renewable Northwest Project who gave me my all-time dream job, and who encouraged this work.

I have learned the hard way that books are really the work of many people who have to set the author straight. It is hard to find the words to thank all the contributors who tried to keep me on the right track, helping make the book reasonably complete and pointing out where I may have gotten things wrong or just garbled. The remaining errors are all mine (one of the perks of writing a book). This work would have been much less complete, accurate, and understandable without the generous help of subject matter experts: Brendan Kirby, Michael Milligan, Hannele Holtinen, Charlie Smith, Cameron Potter, Justin Sharp, and Esben Hegnsholt Olsen. Special recognition is due to Brendan Kirby and Charlie Smith, who came through when time was short. Thanks also to Michael Schilmoeller, Katie Kalinowski, Sam Lowry, Diane Nowicki, and Cindy Towle for their editing assistance.

Thanks also to Steve Wasserman for acting on my behalf in a first-ever book endeavor. Thanks to my wife and family for putting up with my being missing in action nights and weekends to put this work together. And, of course, thanks to all the readers of this book who will help move wind power into the mainstream as a resource forming a vitally important part of the generating resource mix in the USA and abroad.

Contents

Introduction

Wisdom sails with wind and time.

John Florio, linguist and lexicographer, 1553–1625

Wind power has become one of the fastest growing technologies in the world for producing electric power (WWEA, 2009). Environmental concerns are driving public and private industry policies that help promote this relatively economical, emission-free source of electric power. The US Department of Energy reports that wind energy may supply 20% of all electric power consumed in the USA by the year 2030 (US DOE, 2008), the percentage roughly equivalent to the load currently served by nuclear energy. Although wind energy production in the USA recently topped other nations, Europe still leads North America in installed wind generation by nearly two to one (WWEA, 2009), planning to reach 30% or more. The top four countries in percentage of energy generated by wind generation are Denmark (20%), Portugal (15%), Spain (14%), and Germany (9%). Figure 1.1 shows the growth of installed wind generating capacity from 2001 to 2010.

Several factors fuel European dominance over the USA. Chief among them is stronger government policies in Europe mandating renewable energy development as an important means to address the climate change crisis. Other factors may also be at work. Historically tasked with finding the most cost-effective means of ensuring reliability of power systems, American planners and power system operators are not natural allies of a resource perceived to be more costly and less reliable than traditional power sources. The prospect of meeting load with a resource as variable and uncertain as wind power is often accompanied by a rather skeptical attitude over how such a power source can reliably and economically meet demand. This book is intended to help analysts understand the value of wind energy in the context of complex power systems and to demonstrate that wind energy can contribute to meeting load in an economical, efficient, and reliable manner.

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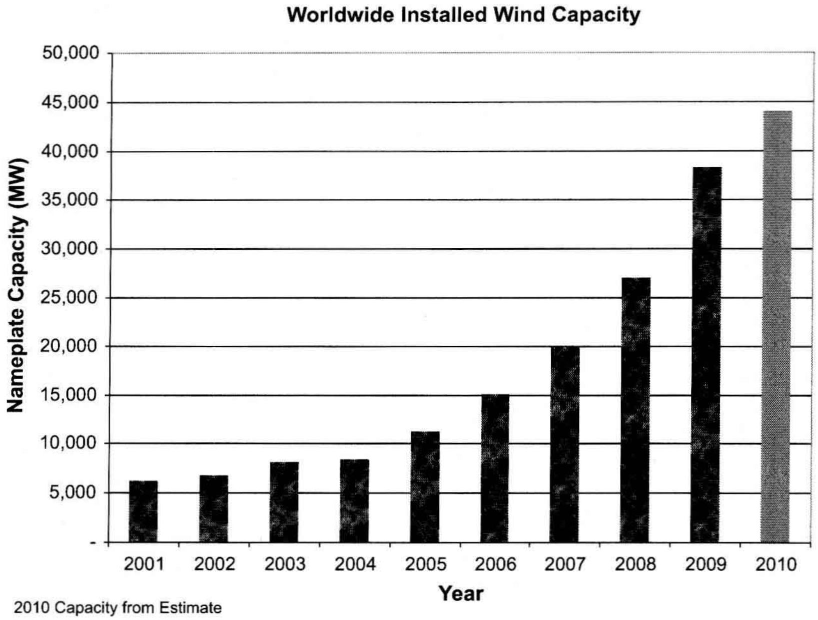

FIGURE 1.1 Installed worldwide wind-generating capacity. *Source: World Wind Energy Report 2009.*

Every type of electric power generation brings its own peculiar set of advantages and disadvantages. Coal and nuclear plants tend to generate at relatively consistent levels, but are subject to significant maintenance outages for repair work or refueling. They have limited ability to adjust to the dynamic nature of demand, and may take days to reach full output from a full shutdown. Power plants fueled by natural gas tend to be relatively flexible in changing output to meet the dynamic characteristics of demand through the day, but are also subject to relatively volatile fuel prices. Hydro units are often some of the most flexible generation resources in a utility portfolio, but have complex time-dependent behavior that can become constrained during extremes of streamflow conditions or by operations dictated by environmental concerns. Many utilities have adopted integrated resource planning techniques to evaluate the economics of incremental generators added to a diverse portfolio of generators. Such techniques are invaluable in weighing the economics of incremental generating units with different fixed and variable costs, and that may have different effects on the operations and economics of the existing units.

Wind has its own peculiarities—generation that is variable, relatively uncontrollable, and less predictable than most other types of generation. Power system operations staff may be understandably vexed at the prospect of a resource over which they may have little or no control, and which they may feel cannot be predicted. Indeed, one real-time operator remarked to me that wind brings no value whatsoever to the power system. It is important to understand the true characteristics of wind (not entirely unpredictable, not entirely uncontrollable), and to acknowledge its limitations. While wind generation will never be the favored child of operators charged with constantly adjusting generation to meet load through time, it brings great value in reducing fossil-fuel consumption, associated atmospheric emissions, and dependence on imported fuels.

A complete understanding of the value of wind on an integrated power system is not a simple matter, and many utilities have undertaken complex studies, often with the help of specialized consulting firms, to help determine wind integration costs. The complexity of some of the studies, and the lack of uniformity of what is meant by integration costs, has contributed to some of the wide variation in results along with real differences in system characteristics. This book will provide some perspectives on the analysis, pointing out different methods that have been used, and pitfalls awaiting the unwary. It is important to realize that the subject is a very active area of investigation and improvement, and it is therefore likely that over time new and important approaches and results will be developed. The idea of this book is to help out anyone considering undertaking a wind valuation study for the first time, looking into improving a first- or second-generation analysis already performed, or monitoring the work of a consultant hired to perform a wind study. Areas that need additional attention are pointed out along the way.

Although the specifics of the interactions of a wind project and its interconnected power system can be complex, the analysis need not be overly complex. Every study of the behavior of power systems is an approximation. Determining a reasonable and sufficient level of modeling complexity is a key function of the competent analyst. Increased complexity does not necessarily result in increased accuracy for a variety of reasons. Probably the biggest reason is that the likelihood of error increases dramatically with complexity. Computer models of power system dispatch will contain many thousands of numbers representing the characteristics of the power system. Some percentage of these numbers will be wrong—possibly entered incorrectly, misinterpreted, or overlooked in the latest update, etc. Some errors may be tolerated, but some of them are likely capable of rendering the study completely invalid. In the press of time and staffing, the level of sophistication in error detection and study verification often lags to a dangerous degree.

In addition to outright data errors, model logic is often highly tuned to existing operations with traditional power generators, often making it necessary to change algorithm logic to correctly model a power system with substantial amounts of a resource with significantly different operating characteristics such as wind. In the complexity of modern power systems and computer models, changing the logic of one part of a computer model can have unexpected consequences, resulting in unrealistic simulations of actual operations in other areas.

In other words, given available staff and tools, modeling all the complexity inherent in a large power system's interaction with wind generation may not be the best approach for every study. There is no single best way to analyze wind on your power system. There are many approaches, and some are simpler than others. The simpler methods are not always inferior, and in some cases may well be superior to the more complex methods discussed. In most cases, simpler methods should be employed at least as a check on a more complex analysis. This book will try to be clear on the applicability of different methods.

One last note is that this subject is not only important from a social and environmental perspective, but it is also intellectually engaging and rewarding. Consider these intriguing challenges:

- The effect of a specific wind power project cannot be expressed separately from the power system into which it interconnects.
- The effects of one wind project can be markedly different from the effects of two or more acting together in a power system even if individually they act identically.
- The statistical behavior of wind generation cannot be easily or simply characterized.
- While average wind generation may be deduced from on-site wind speed measurements, the temporal behavior is a much more complicated matter.

There are interesting problems here, and the prospect of a non-polluting resource with no fuel costs is an enticement that makes the endeavor both socially and intellectually compelling.

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Overview of System Impacts of Wind Generation on Power Systems

If a man does not know what port he is steering for, no wind is favorable to him.

Seneca, mid first century philosopher

Power systems typically consist of many interdependent components, including power-generating units, high-voltage transmission lines, substations, and customer loads. Adding new power plants to an existing portfolio of resources and loads can result in substantial operational changes for the pre-existing components. For example, adding a baseload thermal unit will reduce the frequency of dispatch for higher variable-cost resources such as natural gas powered generators. Similarly, adding a peaking unit may reduce the need to vary the output of intermediate units. It is not surprising then that the addition of wind generation to a power system similarly affects the operations of other power units in the power system. The effects of wind generation on a power system may be less familiar to the analyst and can be rather complex, potentially driving new operating procedures in order to maximize the economic efficiency of the joint power system that includes wind.

This chapter explores the effects of wind generation on other generators on an integrated power system in a qualitative sense, with the quantitative methods to follow in subsequent chapters. How wind affects other generation depends largely on the physical characteristics of the existing system, but also on the market structure of the power system—such elements as the length of the operating period (5, 10, 60 minutes, etc.), the

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existence of liquid ancillary service markets, interconnection with other balancing area authorities, and interconnection with other liquid market points. For the purposes of this chapter, we will make the simplifying assumption of a vertically integrated utility with limited interconnection to other systems. Such systems do exist (e.g. Hawaii), and the more complex interactions involving other utilities or balancing areas through market mechanisms will be taken up in subsequent chapters.

2.1 PRIMARY ECONOMIC EFFECTS OF WIND POWER

Conceptually, treating wind generation as negative load is helpful in understanding the fundamental effect wind has on the balance of the power system generation. Because wind generation has no fuel costs and low variable operating costs, many analyses of the effects of wind on power systems treat wind as a must-run resource; contributing variability and uncertainty characteristics that are somewhat similar to load. Generation from other resources is adjusted in such a way as to meet the net load after subtracting wind generation. This is sometimes referred to as 'treating wind as negative load'. Figure 2.1 shows a typical week of wind and load for a power system, illustrating netting out the wind. The simplifying assumption that wind can be treated as a load deduction is reasonably valid for systems with relatively small amounts of interconnected wind generation.

The primary effect of wind on other power system generation stems from examining how other generators behave with and without the wind subtracted from the load. Economics dictates that there is a priority order of dispatching generating plants based on their variable costs. Generators with relatively low variable costs (fuel, and operation and maintenance) tend to be operated most of the time, and given the highest priority.

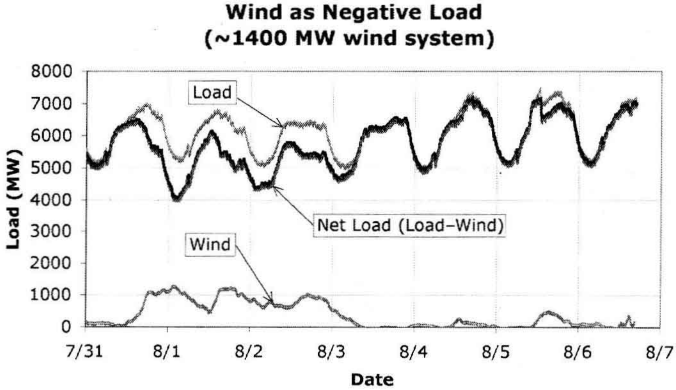

FIGURE 2.1 One week of load and wind on a system with about 1400 MW of wind.

Generators that experience significant savings when not operating will be given lower priority. The prioritized, or 'merit order', dispatch means power plants with the lowest variable costs are operated most frequently, and those with the highest variable costs are operated least frequently. In a generic sense, analysts group generators into three broad categories: peaking, intermediate load, and baseload units. Peaking units have the highest operating costs, baseload units the lowest operating costs, and intermediate load units are in between. These resources are 'stacked up' in their merit order as illustrated in Figure 2.2 to meet customer demand, with baseload generation at the bottom of the stack, intermediate next, and peaking generation on top as needed. The ordering of generating unit dispatch minimizes overall operating costs.

Much of the value of wind power is derived from the savings in operating costs and emissions associated with reducing generation from peaking and intermediate load units, as illustrated in Figure 2.2.[1] Peaking units are usually made up of lower efficiency single-cycle combustion turbines, or highly inefficient fossil-fueled steam boilers. The most expensive power plants to operate are energized with lowest priority in order to keep costs down. To the extent that wind generation causes greater sales or reduced purchases from liquid markets, the savings may alternatively be tied to prevailing market prices at the time the wind generation occurs (saving variable costs on generation from other power systems). The ability to take advantage of markets depends strongly on the market structure and the ability to forecast wind generation ahead of time. Utilities find they may be able to sell some portion of the wind generation into the sub-hourly market or forward (hour-, day-, or week-ahead) markets depending on the availability and accuracy of wind forecasts.

2.2 ROLE OF WIND FORECASTS IN WIND POWER ECONOMICS

The importance of wind forecasts is widely touted, but often poorly understood. Schedules of estimated loads and power generation are

[1] It should be noted that the situation for power systems with hydro resources could be somewhat different. Hydro may be broken into baseload, intermediate load, and peaking components. Savings in energy dispatched from hydro units may accrue as water in reservoirs that may be released at a later time to displace thermal generation at other times, or for market sales to other systems that accomplish the same. In addition, coal plants are generally considered low-variable cost, baseload generation that are not primarily displaced by wind (one study in Texas estimated that each megawatt-hour of wind energy displaced 0.19 megawatt-hours of coal (Cullen, 2008)). This situation could change dramatically if a carbon dioxide penalty (e.g. a tax) is levied on coal plants. In that case, the position of coal in the merit order dispatch could change, resulting in wind energy displacing more coal generation than is currently the case in the USA. Displacement of coal may also become more prevalent at higher wind penetration levels considered in Chapter 14.

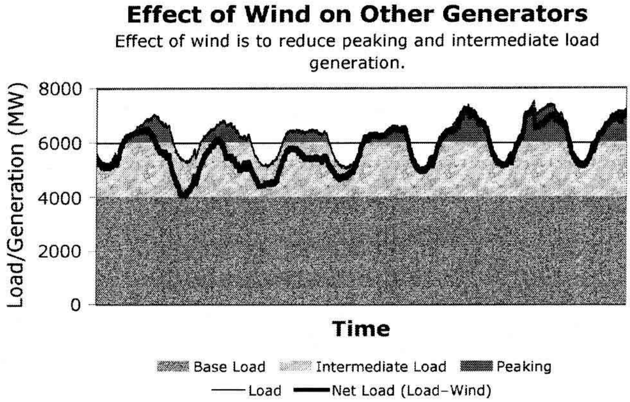

FIGURE 2.2 Resources needed to meet the load without wind (top line) and after taking the wind into account. The difference between the lines represents power generation from other sources that is not needed due to the presence of wind on the system.

developed a day in advance, and improved estimates are provided typically an hour in advance of the operating period, and finalized 15 minutes to 2 hours before the beginning of the operating period. Accurate schedules reduce the need for power systems to maintain the ability to increase or decrease generation due to unaccounted changes in wind output or system demand. Responding to unforecast load or generation is accomplished primarily by especially flexible reserve generating capability. Conversely, variability of wind and load that is reflected in the schedules can be accommodated using the most cost-effective means available. The accuracy of wind forecasts that inform wind schedules is an important factor in determining the level of reserve generation needed, and hence importantly contribute to the value of the wind generation.

Most utilities have experience with forecasting loads hours, days, weeks, and even years ahead. Forecasts for up to a week or two are usually based on weather models and historical behavior of loads. Electric demand is a strong function of temperatures, wind speed, and humidity. Other factors are also important, such as hour of the day, day of the week and year (e.g. weekends or holidays), and industrial load characteristics (e.g. dependence of irrigation loads on time of year and precipitation). Weather models take into account prevailing temperatures, pressures, wind speeds, insolation, ground reflectivity, and other relevant data to predict the movement of air using physics-based equations of motion. These same models are also used to predict wind speed and direction. The data can be translated into power generation using information specific to a wind project, such as power curves and unit availability.