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Energy Intermittency

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More information on the author's work is available at http://energy.ruc.dk

Preface

Energy variation and intermittency are key issues for all existing energy systems and particularly for new energy systems such as those based on renewable energy sources that flow irregularly. Variations in source flow can hinder the ability to match supply and demand, even if the source drop is not to zero, and so can insufficient transmission capacity or insufficient energy conversion equipment. This is why the word *intermittency* is used to cover both situations, i.e., those with no flow into the system and those situations where variations in conjunction with the system structure make the supply fall short of the desired demand, thus causing intermittency on the demand side unless countermeasures are undertaken.

Despite its importance, intermittency has received only sporadic mention in the energy literature. This book sets out to remedy that situation by describing the causes of intermittency as well as potential countermeasures across the board for conventional energy systems based on fossil or nuclear fuels as well as for renewable energy systems. Three types of solutions are discussed: trade arrangements, such as by power grid interconnections; active energy storage at different scales; and demand management. After a general technical description of the options, a number of case studies are presented to show how to solve the problems and furnish a resilient, working energy system for all types of energy resources, including systems with 100% reliance on intermittent energy sources. The case studies are for regions in North America, Europe, and Southeast Asia, where the combination of population size and resource availability in countries such as Japan, Korea, and China puts the construction of a sustainable energy system to a severe test.

The book is written at a broadly accessible level and should cater to energy planners in government and industry, to technical people involved in energy science, and to the broad range of political and grassroots communities engaging in discussions of the energy issues facing all regions of the world over the coming decades.

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Bent Sørensen is professor emeritus at Roskilde University. He previously held academic positions at the Universities of New South Wales (Australia), Grenoble (France), Kyoto (Japan), Copenhagen (Denmark), Yale (Connecticut), and Berkeley (California), and at the National Renewable Energy Laboratory (Colorado), and he has been technical director of Denmark's largest engineering firm. He served as advisor for OECD (Organisation for Economic Co-operation and Development) and several governments and UN agencies. In addition, he was a lead author for the IPCC (Intergovernmental Panel on Climate Change) Second Assessment Report. He is the recipient of several awards and honours, including the European Solar Prize.

Contents

Part I Cooperation across Areas and Regions

Part II Energy Storage

Part III Managing Load Matching

Part IV Transitions and Cost

1
INTRODUCTION

Current energy systems are to a large extent based on fossil and nuclear fuels, and thus they are subject to rising long-term concerns over the associated emissions (greenhouse gases for combustion of fossil fuels and the risk of accidental releases of radioactive substances for nuclear reactors) and, in the medium term, issues of resource depletion. Alternatives without such problems include the renewable energy sources derived from the disposition of solar energy on the Earth. Several renewable energy sources are characterized by an intermittent flow, such as that of wind energy, which depends on passing weather systems, or that of solar radiation, which is absent at night and variable on cloudy days, in addition to the seasonal variation at higher latitudes. As regards energy systems, intermittency and variability should be seen in the light of energy production matching energy demand. The title of this book only mentions intermittency, but the book intends to deal with both intermittency and variability, which in many cases leads to intermittency if the variability causes inability to cover the demand at a given moment in time. The system may therefore be unable to follow changes in demand, even if the energy source flow is not intermittent. There are several ways of handling the issues posed by supply-demand mismatch, and these are the issues this book examines in detail.

For fuel-based energy production, such as by fossil fuels or fuels of fresh biomass origin as well as by nuclear fuels, a storage-before-conversion option immediately offers itself. However, even here, there may be intermittency issues, because retrieving and making use of stored fuels may involve a time delay, for example, caused by the start-up times for facilities such as coal or nuclear power plants, which can be a problem in cases of unexpected demand change. Generally, many such problems may be addressed by planned production, for example, by operating several power plants at less than full capacity, so that regulation up and down is possible. For many types of nuclear power plants, such regulation is undesirable because it increases the risk of instability, and these plants are therefore often operated at a fixed output level. Handling intermittency may involve any—or a combination—of energy storage, production planning, and demand planning.

Production planning may consist of operating a system with surplus capacity, as in the example of fossil fuel power plants, but it also extends to a collaboration between more than one "system," usually implying collaboration agreements or import–export between different energy utilities, enabling them to borrow from each other in cases of deficit and to get rid of surpluses. The energy form used for such trade agreements may be electricity or piped heat or fuel (gas or oil pipelines), or the storable fuels may of course be traded by use of ships, trains, or other vehicles. A scheme employing both energy storage and power exchange between operators is the collaboration between a hydropower system based on large upper storage reservoirs and a wind or photovoltaic power system, which may import hydropower at times of insufficient wind or solar production and then pay it back in periods of surplus production. The only extra cost is to have the hydro turbines rated at so high a power level that they can furnish the additional power for export, which is usually a very small part of the cost of constructing a reservoir-based hydro system. (The key cost components are usually dams and environmentally acceptable management of the flooded reservoir areas.) When there is a wind or solar surplus, they satisfy demand, and the hydro turbines are regulated down correspondingly. This solution is clearly both less expensive and more energy efficient than the pure storage option, for example, where surplus wind power is used to pump water upwards for later use in hydropower generation. If the reservoirs deliver seasonal storage (as they do in areas where reservoirs are filled in spring by melting snow and emptied over the rest of the year, e.g., in Norway or Canada), then the disturbance of the reservoir water level by serving as backup for, say, a wind energy system is often only a few centimeters change in average filling level.

Demand management consists of performing energy-intensive jobs at specific times that suit the capability of the energy system. This could involve having a washing machine stand filled and awaiting the time when a surplus of power is available on the electricity grid. The control could be by a combination of signals sent by the power company over the grid and decisions made by a computer program in the home. There are other management options furnished by the many battery-operated portable devices currently in use. Recharging batteries can be done when it suits the electricity supply system, creating a store of charged batteries to be used over a following period of time. A combination of demand management and power exchange is offered by the diurnal variations in demand characteristic in most user communities. For example, the peak use of electricity may happen around 5 p.m. in a number of locations situated in different time zones, allowing peak consumption to be covered from neighboring longitude zones that are off-peak at the time in question. This was exploited quite early in the former Soviet Union, presumably due to the presence of only one electric utility company across the several time zones between Europe and Vladivostok. However, this idea can also be put to use in other places if the relevant utility companies can agree on a suitable power-exchange arrangement.

When simple import–export arrangements and the always limited demand-management options (some tasks cannot be postponed) are not sufficient, dedicated use of energy stores must be explored, even if storage options are often more expensive than management solutions. The case of batteries for portable equipment (smartphones, portable computers, drilling machines, lawn mowers, and so on) already shows examples of technology that consumers find attractive and are willing to pay the extra price of battery operation to get. A straight extrapolation of these ideas is to create smart buildings, where energy production (rooftop solar cells) and energy import (district heating, electric power) are combined with storage at the building level, such as basement or underground hot-water and hydrogen stores operated in conjunction with reversible fuel cell units. The next step would be to take advantage of the cost reductions often associated with communal energy stores, as compared with single-building integrated ones. This can be a complex issue, because the space taken up by the communal installation, although smaller than that of the individual solution, may be seen as less easy to accommodate into city planning. Most such installations are today placed on marginal land at the outskirts of cities, e.g., in conjunction with district heating systems.

Energy-storage devices are characterized by the intended storage duration and the speed of charging and discharging such devices. Capacitors and flywheels are intended for short-term storage and stabilization of the delivered power, while long-term storage is increasingly offered by electrochemical and superconducting stores, heat capacity and phase-change stores, compressed gas, pumped hydropower, and finally hydrogen and more complex synthetic fuels intended to perform like the fossil fuels upon which we have thrived for a short period in the history of human presence on the Earth.

Before going into these issues, the following two chapters provide some basic data for the dependence of intermittency on the kind of energy system being investigated and on the types of primary energy sources to be employed.

2

Intermittency Dependence on Type of Energy System

Energy systems range from small, individual ones, such as a three-stone cooking fire in a remote African village, to over local systems not communicating with their environments (for example, the energy system of an isolated city without grid or pipeline connection to other energy systems), to large interconnected energy systems with many built-in options for power exchange and other trade of fuels or processed energy. These systems also differ in their response to intermittency of primary energy inputs.

Consider first an individual energy system, as depicted in an idealized form in Figure 2.2 (the symbols used in this and the two following illustrations are explained in Figure 2.1). The primary energy sources may be purchased fuels, purchased energy stores (such as batteries), or the energy may come from renewable energy conversion equipment (wind turbines, solar thermal or photovoltaic panels, draft animals). The demands would typically be in the form of electric power for consumer devices, energy for space heating or cooling, or use in equipment for cooking, for food preservation, for operating tools in local manufacture, and for mobility. In-house or extremely local distribution networks of power may be present, and in regions with a space-heating demand, possibly also a heat distribution system (such as water pipes or air ducts), but rarely other types of energy transfer.

Figure 2.3 shows schematically an example of a typical conventional energy system for a supply area that may be a utility servicing area such as a city or a region. The example has energy input from fuels (e.g., fossil or nuclear) converted into grid electricity, district heat (e.g., through combined power and heat plants), and pipeline-quality gases such as town gas, natural gas, or hydrogen, and inputs from renewable sources (wind, solar, biomass), of which a part goes through energy stores for heat or for regeneration of high-quality

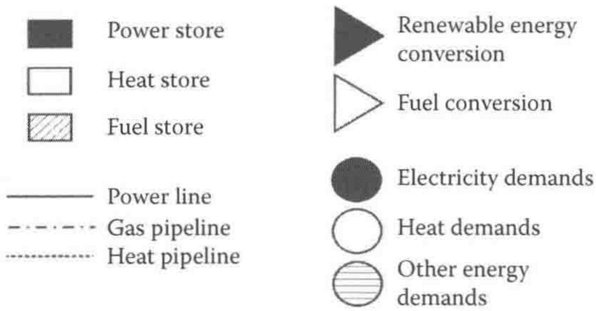

Figure 2.1 Symbols used in Figures 2.2–2.4. By "power store" is understood an energy store capable of regenerating the energy in the form of electricity.

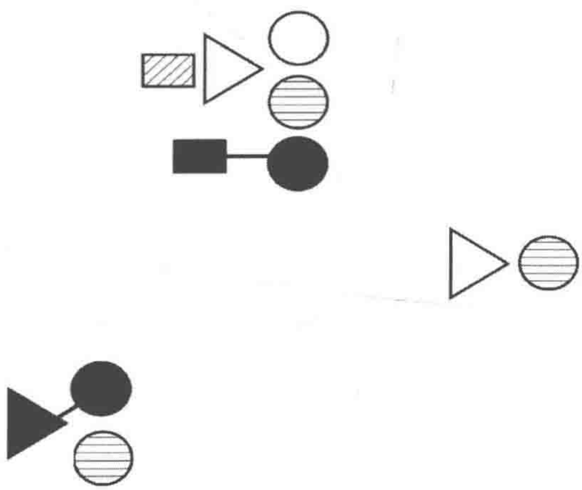

Figure 2.2 Example of independent consumers without a common grid, of which some use fuels for energy generation (say fuelwood for cooking), perhaps also for space heating (top), and where renewable systems (such as solar panels, used when solar radiation is available) or batteries (top) are used to generate electric power.

energy, mostly in the form of electricity. The system depicted thus has a network of transmission lines for electric power, gas, and heat. Local systems (e.g., in buildings) differ, and some have only power input from the transmission grid, while others are also connected to the district heating lines. Just five examples are shown: The top one on the left is characterized by distributing both electricity through power lines and hot water through a district heating grid, thereby covering power and heat loads, while other loads such as industrial process heat can be covered directly from the (natural) gas transmission lines.

The middle local area represented on top has its own fuel-based production of heat, based, e.g., on oil or wood fuel, while the local system to the right produces heat based on the gas grid. At the bottom,