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Fernando Lopes · Helder Coelho
Editors

Electricity Markets with Increasing Levels of Renewable Generation: Structure, Operation, Agent-based Simulation, and Emerging Designs

Springer

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To my son, Nuno Lopes,
and my parents,
Apolinário Lopes and Maria Lopes,
who taught me two valuable lessons in life,
which guided me on this journey:
to work with people from different backgrounds
and to respect humanity and nature.

F. L.

Foreword I

The power sector is undeniably going through deep structural changes. The impact of these changes is amplified by the speed at which they are occurring and by the diversity of their nature. In the European Union, the decarbonization agenda is the biggest driver of change. It has direct impact on generation given the required quick pace of investments in low-carbon generation. It also impacts electricity demand as it becomes the clean energy carrier of choice for other sectors such as transport and heating and cooling.

Technological advancements are also impacting the sector. The rise of diverse and increasingly cheap decentralized resources, such as distributed generation and storage, are challenging the past logic of fully centralized systems. Digitalization of the sector is also enabling customers to become increasingly involved in electricity markets. This involvement allows customers to be at the center of power systems and reap benefits from demand-side participation in markets and energy efficiency.

All of the changes that the sector is undergoing have one common underlying economic feature. We are evolving toward a sector increasingly based on fixed costs along the whole value chain. In the upstream, low-carbon investments are mostly based on capital expenditure, e.g., renewables, nuclear or carbon capture and store, in stark contrast with traditional thermal generation. In the midstream, intermittency management is achieved through storage, interconnections, and under-utilized thermal backup thus, all fixed costs. At the downstream level, energy efficiency is also achieved through a replacement of variable costs (e.g., burning gas to heat homes) with fixed costs (e.g., deploying capital in homes like insulation or more efficient appliances).

However, the current electricity market design is based on an energy-only pool with marginal pricing which was conceived for the 1990s liberalization of the power sector. This period coincided with low commodity prices and a thermal technology investment cycle (namely the dash for gas using combined cycle gas turbines, a variable cost technology). However, this market design is clearly not adequate anymore in the current context of investments in capital-intensive technologies (with zero or very low marginal prices) and volatile commodities.

Exposing technologies with these characteristics to market risk, in a marginalist system, makes therefore little sense: it can either lead to overcompensation if the marginal fuel price is very high or to stranded costs if it is too low. In any case, it is a (price) risk these infra-marginal technologies cannot manage since they are composed of fixed (sunk) costs. The current market arrangements therefore make it difficult to invest because investors are forced to take on too many risks (regulatory, price, policy, economic cycle, etc.), far beyond the ones it can and should manage (development, construction, operation, financing).

This book provides very insightful contributions on how electricity markets will behave in the future and how they should be modeled. It is a welcome technical and economic contribution to the long-term policy discussions that are continuously held across the European Union.

Lisbon, Portugal
June 2017

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Foreword II

The liberalization of electricity markets was promoted with the assumption that the competition of different actors should bring an improvement on the efficiency and security of electricity supply, and, as a consequence, better prices and quality of service for customers. This process has been enforced in Europe during the last decade, not only at national level, but increasing the interconnectedness of European energy markets toward building a common market. However, contrary to other liberalized markets, such as the telecommunications, both private and industrial consumers have experienced rather steep price increases, and the market stays highly concentrated on the same players. Furthermore, the progressive installation of new sources of renewable energy, which are very dependent on changing climate conditions, introduces new variables for consideration. There is also an impact of the evolution of prices on other markets, such as those of oil, gas, and carbon, which are still prevalent for electricity generation.

All these factors make a difficult task for the regulator to establish the appropriate directives for the electricity market. Tools are required to test the consequences and validate the norms that control the interactions among stakeholders. Pure mathematical models are difficult to implement because of the evolutionary and distributed nature of the electricity markets, as well as challenging scalability requirements when analyzing real cases. This book promotes agent-based modeling as a tool to simulate the complexity and dynamics of electricity markets. Agents facilitate modeling of market competition where each actor is an agent with its own goals and strategies. They also allow to model the consequences of misbehaviors of individual or groups of actors, disruptive events, such as abrupt variations on the renewable generation, or unexpected events such as failures and accidents on key elements of the supply network. Their simulation facilitates the characterization of emergent behaviors that result from the interactions of the agents on particular scenarios. Nevertheless, the specification of the agents and their interactions, and the setup of the simulation configurations, require a methodical design, which has been the subject of research during the last decade. This book shows relevant contributions from leading experts in the field.

One of the merits of this book is the ability to integrate works from selected research groups in a coherent progression, which allows the reader to move from the basics of agent-based modeling of electricity markets toward more complex scenarios that result from the addition of more heterogeneous electricity generation systems. The application to real markets, which is illustrated in some chapters, and recommendations derived from the corresponding analysis, show the potential of the agent-based approach in this context.

Works on this concrete application of agent-based modeling and simulation have been appearing in conferences and scientific journals during the last decade. This book comes in the right moment, as the tools and results have got maturity, and there was a need to put together the major contributions to get a comprehensive view of the state of the art. We have to acknowledge the great effort of the editors to involve the most representative researchers in this field, as well as their ability to cooperate in producing a coherent ensemble. It is important to note also that, given the multidisciplinary nature of the subject, the editors and the authors have succeeded to make the text quite accessible to a variety of audiences, so it is not required to have a very specific expertise to go through the working of agent models and electricity markets. The result is a reference book for those interested on a better understanding of the complex interactions of the different actors in electricity markets.

Madrid, Spain
June 2017

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Preface

The electricity industry was traditionally heavily regulated, with extensive public ownership, federalized organizational structures, and inefficient competition. In the past, most electric power companies operated as vertically integrated systems, having complete control over power production, transmission, and distribution, and were therefore considered natural monopolies. Typically, customers paid a tariff that reflected all associated costs plus a reasonable rate of return that was controlled by specific regulation. At present, the electricity industry has evolved into a distributed and competitive industry in which market forces drive the price of energy and reduce the net cost through increased competition among suppliers. The economic operation of most power systems is now managed by market operators responsible for balancing supply and demand and for setting energy prices. The security of the systems is normally assigned to independent system operators. Market participants have open access to transmission networks and can freely engage in electricity trades between any two points in a specific network, subject only to the laws of physics and the capacity of transmission lines.

Most existing electricity markets (EMs) were designed according to the principles proposed in the standard market design. The "common" design framework reflects a pool-based market in which there exists a two-settlement system for day-ahead and balancing markets, with ancillary services, and a financial transmission rights market for financial hedging. This framework was, however, set out when the vast majority of power plants were controllable and fired with fossil fuels.

Today, a significant part of the traded power comes from renewable energy sources that are variable and uncertain, largely due to the inability to precisely forecast their output. In fact, renewable generation or variable generation (VG), such as wind and photovoltaic solar power, has increased substantially in recent years. The European Union has been one of the major drivers of the development of renewable energies. The energy policies of most European countries have involved subsidized tariffs—such as, the feed-in tariff in Portugal, the regulated tariff and the market price plus premium in Spain, and the Renewables Obligation in UK. In the United States, many states have also incentives or requirements that will provide for a further increase in variable generation in the coming years.

VG has several unique characteristics compared to the traditional technologies that supply energy in electricity markets. Specifically, VG has significant fixed capital costs but near-zero or zero variable production costs, increases the variability and uncertainty of the net load, and has unique diurnal and seasonal patterns. Together, these characteristics may significantly influence the outcomes of EMs. In particular, large penetrations of VG may reduce market-clearing prices due to their low-bid costs, and increase price volatility because of their increased variability.

As noted earlier, most existing market designs are unique in their complex relationships between economics and the physics of electricity, but were created without the notion that large penetrations of VG would be part of the supply mix. Accordingly, the potential impacts of VG should be monitored to determine if the original designs are still effective. If existing market designs lead to inefficiency, reduced competition or increased market power, improvements to these designs may be required or newer designs may be needed. Simply put, there is a growing need to accurately model, analyze in detail, and fully understand the behavior of today's evolving electricity markets and how market participants may act and react to the changing economic and regulatory environments in which they operate.

Multi-agent systems (MAS) represent a relatively new and rapidly expanding area of research and development. MAS are essentially systems composed of software agents that interact to solve problems that are beyond the individual capabilities of each agent. Software agents are elements situated in some environment and capable of flexible autonomous action in order to meet their design objectives. The major motivations for the increasing interest in MAS include the ability to solve problems in which data, expertise, or control is distributed, and the ability to enhance performance along the dimensions of computational efficiency, reliability, and robustness. Conceptually, a multi-agent approach presents itself as an advanced modeling approach to simulate the behavior of power markets over time. Software agents can be designed to act in an open and distributed environment, with incomplete and uncertain information, limited resources, and may efficiently manage cooperative and competitive interactions with other agents.

This book is about the common ground between two fields of inquiry: electricity markets and multi-agent systems (or artificial intelligence generally). The field of electricity markets has grown significantly in the past few years resulting in a substantial body of work and well-established technical literature. There are several journals that focus on research in this area (e.g., IEEE Transactions on Power Systems and Applied Energy) and several books have been presented in the literature. Also, research on multi-agent systems has a vigorous, exciting tradition, and has generated many useful ideas and concepts, leading to important theories and relevant computing systems. Various journals and forums have been dedicated almost exclusively to the study of intelligent agents, such as the Autonomous Agents and Multi-Agent Systems journal and the AAMAS Conference series. And development has occurred on the practitioner side as well. This book lets these different strands come together—it includes methods and techniques from energy and power systems, economics, artificial intelligence, and the social sciences.

Agent-based simulation has been an important approach to model and analyze electricity markets over the past decade. Several agent-based energy management tools have emerged, including the Electricity Market Complex Adaptive System (EMCAS), developed by the Argonne National Laboratory, and the Simulator for the Electric Power Industry Agents (SEPIA), developed by the Honeywell Technology Center and the University of Minnesota. However, despite the power and elegance of these and other relevant tools, they were arguably developed to simulate traditional market mechanisms.

At present, the study of existing and emerging market designs to manage the potential challenges of VG, making use of software agents and methods from artificial intelligence (AI), has received only selective attention from both scholars and practitioners. Although some valuable journal articles and technical reports exist, there is not an up-to-date introduction to the area nor a comprehensive presentation of the research progress and achievements. Also, efforts to integrate research contributions from different fields into a broader understanding of electricity markets to meet the variability and uncertainty of VG were only beginning to occur. The main purpose of this book is to fulfill these needs.

The book has 11 chapters organized into three major parts: Electricity Markets and Autonomous Computational Agents (Part I), Electricity Markets with Large Penetrations of Variable Generation: Current and Emerging Designs (Part II), and Agent-based Simulation of Electricity Markets with Increasing Levels of Variable Generation: Traditional and New Design Elements (Part III). A comprehensive overview of the book is as follows.

Part I introduces the reader to the essentials of electricity markets and software agents. This part contains three chapters. Chapter 1 focuses on EMs and introduces the various markets for the different electrical related products: energy, reserves, transmission rights, and capacity. The chapter ends with a list of the potential impacts of VG on market outcomes. Chapters 2 and 3 introduce a generic framework for agent-based simulation of EMs. The framework provides a coherent set of concepts related to electricity markets and software agents, helps to compare disparate research efforts, and facilitates the development of future models and systems. It includes three groups of dimensions: market architecture, market structure, and software agents.

In particular, Chap. 2 deals with EMs and discusses, in considerable detail, the architecture and core structure of power markets. The chapter introduces the three key market sectors: wholesaling, retailing, and central coordination and transmission. It also describes some important market types (notably, pool, and bilateral) and discusses the role of the main entities operating in EMs. Chapter 3 deals with intelligent agents and presents some important features of agency. The chapter introduces the concepts of "agent architecture" and "agent capability", and discusses six key types of agents: purely reactive, model-based, goal-based, utility-based, and learning agents. It also presents a core set of capabilities central to the definition and development of agents for EMs, including autonomy, proactiveness, social ability, and adaptability.

Part II discusses existing electricity markets and evolving market designs, notably potential improvements to current market designs to manage the challenges of VG. This part contains four chapters. Chapter 4 looks at the current design of the Nordic power market (Nord Pool). The chapter analyzes the hourly market data for Western Denmark in the period from 2004 to 2014, particularly the occurrence of extreme events (e.g., 100 < price < 5 €/MWh or 100% < wind < 1% of the hourly demand). The authors conclude that the current market organization has been able to handle the amount of wind power installed so far (in 2014, wind power provided 51.7% of the electricity consumption in Western Denmark). They point out, however, that the hydro power capacity is limited and larger penetrations of wind power will require additional measures. Chapters 5 and 6 focus on two key issues related to market design: incentivizing flexibility in short-term operations and revenue sufficiency for long-term reliability.

Specifically, Chap. 5 discusses whether existing market designs provide adequate incentives for suppliers to offer their flexibility into markets to meet the increased levels of variability and uncertainty introduced by VG. The chapter provides a definition of power system flexibility and examines how the introduction of VG may increase the need for flexibility. It analyzes five existing market design elements to incentivize flexibility: centralized scheduling and efficient dispatch, frequent scheduling and frequent settlement intervals, existing ancillary service markets, make-whole payment guarantees, and day-ahead profit guarantees. It also discusses a number of emerging market design elements that impact flexibility incentives, including pay-for-performance regulation, primary frequency control, convex hull pricing, and explicit products for flexible ramping provision.

Chapter 6 discusses whether suppliers who are needed to ensure a reliable system in the long run have sufficient opportunity to recover their variable and fixed costs to remain in the market. The focus is mainly on the investment time horizon and the installation of sufficient generation capability (operational issues, which are closely related, are discussed in Chap. 5). The chapter examines how increasing penetrations of VG may exacerbate the missing-money problem. It describes the two primary market mechanisms traditionally adopted by EMs to mitigate the issues of resource adequacy and revenue sufficiency: scarcity pricing (both through administrative prices as well as offered prices) and forward capacity markets. It also discusses the most recent market design changes to address these issues, with a focus on how they are evolving to meet the needs due to increased VG. Significant changes include scarcity pricing through dynamic demand curves for operating reserve and forward flexible capacity requirements.

As in part of Chap. 6, Chap. 7 looks at the impact of significant levels of VG on reliability requirements. The focus is on capacity markets to ensure the long-term viability of suppliers. The chapter considers three situations differing mainly in the mix of generation technologies: open cycle gas turbines (OCGTs) only, OCGTs and wind power plants, and OCGTs and nuclear plants. The author uses data from Sweden (e.g., the Swedish load and real Swedish wind power production data) to perform a detailed analysis of the influence of VG on capacity adequacy requirements, and makes a systematic comparison with the results of the nuclear case.

Part III is devoted to agent-based simulation of electricity markets with large penetrations of renewable generation. This part analyzes the potential impacts of VG on EMs and discusses the advantages of specific market design elements. Also, it explores new opportunities to bridge EMs and emerging technologies—such as demand response (DR) and distributed generation (DG)—and examines specific market designs that are inclusive of such technologies. It contains four chapters.

Chapter 8 introduces the agent-based simulation tool MATREM (for Multi-Agent TRading in Electricity Markets), which allows the user to simulate the behavior and outcomes of EMs, including markets with large penetrations of VG. The chapter begins by describing the two exchanges supported by the tool: a power exchange, comprising a day-ahead market and an intra-day market, and a derivatives exchange, comprising a futures market for trading standardized bilateral contracts. Next, it describes the marketplace for negotiating the details of tailored (or customized) long-term bilateral contracts and presents the various market entities currently being implemented (e.g., generating companies, retailers, consumers and market operators). Following this material, the chapter presents the paradigm of human-computer interaction (involving both direct manipulation interface techniques and intelligent assistant agents). The final part of the chapter delves into the technical details of the agent model: a belief-desire-intention (BDI) model.

Chapter 9 focuses on variable generation, support policies, and the merit order effect (MOE). The first part of the chapter analyzes the sustained growth of VG worldwide and discusses the global policy landscape. The second part describes in detail the principles underlying the MOE. Following this introductory material, the chapter investigates the reduction in the Portuguese day-ahead prices achieved by wind power as a result of the MOE in the first half of 2016. The results generated by MATREM indicate an average price reduction of about 17 €/MWh. The net cost of the wind energy support policy was −8.248 million € in January 2016, indicating that a net profit has occurred in the month. The net cost for the entire study period reached, however, the value of 69.011 million €. Although considerable, this cost should be interpreted carefully, since it takes into account the feed-in tariff for wind energy, the market value of the wind electricity, and the financial volume of the MOE, but does not account for the carbon price effect on the electricity market.

Chapter 10 looks at demand response (DR) in electricity markets to incentivize system flexibility and help managing the variability and uncertainty introduced by VG. The authors introduce two key categories of DR programs and present a brief overview of DR in Spain and Portugal. Following this introductory material, the authors investigate the price effect of DR on the Iberian market (MIBEL) during the period 2014–2017. The results generated by MATREM are striking. They indicate that modest amounts of DR—modeled as load reductions between 1 and 5% when prices rise above a threshold between 80 and 100 €/MWh—have a relatively large effect on market prices, creating substantial benefits to market participants (and most retail customers). For instance, in 2017, a load reduction of 5% when prices rose above 80 €/MWh yielded the benefit of 76.62 million €. The chapter concludes with recommendations—for consideration by state institutions, system operators, electric utilities, and other market participants—to foster DR in Portugal.

Chapter 11 brings an additional impact to agent-based modeling and simulation of power and energy systems, by combining the simulation of electricity markets and smart grids with the physical emulation of a laboratory micro-grid. The chapter introduces the Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) and the Multi-Agent Smart grid Platform (MASGriP). It also presents a case study based on real data, which involves a smart grid (SG) composed by a simulated distribution network with several real loads, including eight residential houses, eight residential buildings, and one commercial building, and also accommodating distributed generation (photovoltaic and wind power generation) and storage units. The case study illustrates the potentialities of integrating the two agent-based systems into a unified platform. The authors conclude that the cooperation between MASCEM and MASGriP opens important studying opportunities under different perspectives, resulting in an important contribution to the fields of transactive energy, electricity markets, and SGs.

Overall, the book is a confluence of a comprehensive exploration and a deep exposition of the common ground between electricity markets and multi-agent systems. While no single volume could cover the entire rich terrain at the intersection between these two areas of inquiry, the book gives the reader an insightful view of a landscape of stimulating ideas and offers a number of features, notably:

- Scope. The text is organized into three major parts. The book covers the fundamentals of electricity markets and software agents (Part I), discusses both traditional and emerging market designs to accommodate the variability and uncertainty of VG (Part II), and deals with agent-based simulation of electricity markets with increasing levels of renewable generation (Part III).
- Theory. The book gives a clear and careful presentation of the key concepts and methods from the two aforementioned areas as well as techniques from the common ground between these areas. We try to avoid excessive formality in the text while retaining precision. Several examples and illustrative case studies are provided.
- Practice. The emphasis is not only on theory but also on practice. The methods and techniques presented in the book are supplemented with actual cases involving real-world electricity markets and applications drawn from real-world situations.
- Expertise. The chapters have been written by leading and outstanding researchers, who have helped shaped the two areas of inquiry. The book is thus built on a diverse basis of knowledge and experience.

An explanatory and cautionary note is in order here. Broadly speaking, any book prepared by just a few authors is likely to be more coherent than any book in which several authors are involved. But as the reader will see, the editors have invested a considerable effort in ensuring the coherence of this book. The order of the chapters—and the chapters' topics—was done carefully to produce a highly organized text. Also, the contributors had the chance to review specific chapters, helping to significantly improve the quality of the book.

The intended audience of the book includes professionals associated mainly with the electric industry and electricity markets, including utility business leaders, engineers (notably, electrical, industrial, software, computer, power, and systems engineers), market operators, market players, energy economics, and investors related to energy projects. Also, the book is intended to be very valuable to researchers and academics who wish to better understand the areas of energy markets (with increasing levels of VG) and software agents, and mainly to investigate the common ground between these two fascinating areas—the book successfully integrates theory, scientific research, and real-world applications, and is sufficiently informative to earn the respect of specialists. Given the scope and the depth of the chapters—and since the book is written in a highly accessible style, the concepts and methods are carefully explained, and the text is liberally supported with practical applications—we are confident that the content of the book should also provide a coherent foundation for several different graduate courses.

This book could not have been completed without the help of many people. We are most grateful to:

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In conclusion, this book is very much a team effort of different people, whose credentials as researchers are excellent, and whose research efforts have made the growth of the two areas of inquiry possible.

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Fernando Lopes
Helder Coelho

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Acronyms and Abbreviations

AAMAS	Autonomous agents and multi-agent systems
ABS	Agent-based simulation
AC	Alternating current
ACE	Agent-based computational economics
ACL	Agent communication language
AI	Artificial intelligence
AID	Agent IDentifier
ALBidS	Adaptive Learning Strategic Bidding System
AMS	Agent management system
API	Application programming interface
AS	Ancillary service provider
ASCP	Ancillary service clearing price
BDI	Belief–desire–intention
CAISO	California Independent System Operator
CBA	Coordinated balancing activity
CBL	Customer base load
CCP	Central counter-party
CFD	Contract for difference
CHP	Combined heat and power
CIC	Curtailment initiation cost
CONE	Cost of new entry
CPP	Critical peak pricing
DAM	Day-ahead market
DAMAP	Day-ahead margin assurance payment
DF	Directory facilitator
DG	Distributed Generation
DistCo	Distribution company
dMARS	distributed Multi-Agent Reasoning System
DR	Demand response
DRA	Demand response aggregator

DSV	Delivery settlement value
ECB	European Central Bank
EEX	European electricity exchange (Germany)
ElBAS	Electricity Balance Adjustment Service
ELCC	Effective load-carrying capability
ELDC	Equivalent load duration curve
ELMP	Extended LMP
EM	Electricity market
EMCAS	Electricity Market Complex Adaptive System
EPSA	Electric Power Supply Association
ERCOT	Electric Reliability Council of Texas
ERM	Energy resource management
ERSE	Portuguese Energy Services Regulatory Authority
ETS	Emission trading system
EU	European Union
EUA	European Union Allowance (CO_2 emissions)
EUE	Expected unserved energy
EV	Electric vehicle
FERC	Federal Energy Regulatory Commission
FIPA	Foundation for Intelligent Physical Agents
FIT	Feed-in tariff
FOR	Forced outage rate
FTD	First trading day
FTR	Financial transmission rights
GECAD	Knowledge Engineering and Decision Support Research Group
GenCo	Generating company
GWEC	Global Wind Energy Council
HVAC	Heating, ventilation, and air conditioning
HVDC	High-voltage direct current
ICAP	Installed capacity
IEA	International Energy Agency
IMF	International Monetary Fund
ISO	Independent system operator
ISO-NE	Independent System Operator of New England
JADE	Java Agent DEvelopment (framework)
KB	Knowledge base
KQML	Knowledge query and manipulation language
LDC	Load duration curve
LMP	Locational marginal pricing
LOLE	Loss-of-load expectancy
LOLH	Loss-of-load hours
LOLP	Loss-of-load probability
LRT	Last resort trader
LSE	Load-serving entity
LTD	Last trading day

MAS	Multi-agent systems
MASCEM	Multi-Agent Simulator of Competitive Electricity Markets
MASGriP	Multi-Agent Smart Grid Platform
MATREM	Multi-Agent TRading in Electricity Markets
MIBEL	Iberian Electricity Market (or “Mercado IBérico de ELectricidade)”
MISO	Midcontinent Independent System Operator
MO	Market operator
MOE	Merit order effect
MRC	Multiregional coupling
MTS	Message transport service
NAPRE	National Action Plan for Renewable Energy
NEMO	Nominated Electricity Market Operator
NERC	North American Electric Reliability Corporation
NYISO	New York Independent System Operator
OCGT	Open cycle gas turbine
OMIE	Spanish electricity market operator (or “Operador del Mercado Ibérico de electricidade—polo Espanol, S.A.”)
OMIP	Portuguese electricity market operator (or “Operador do Mercado Ibérico de electricidade—pólo Português, S.A.”)
OPF	Optimal power flow (procedure)
ORDC	Operating reserve demand curve
OTC	Over-the-counter
OWL	Web ontology language
PCR	Price coupling of regions
PFC	Primary frequency control
PJM	Pennsylvania-New Jersey-Maryland Independent System Operator
PRM	Planning reserve margin
PRS	Procedural reasoning system
PV	Photovoltaic
PX	Power exchange
RE	Renewable energy
REE	Spanish electrical grid (or “Red Eléctrica de Espana”)
REN	Portuguese electrical grid (or “Redes Energéticas Nacionais”)
RES	Renewable energy sources
RetailCo	Retailer
RTM	Real-time market
RTO	Regional transmission organization
RTP	Real-time pricing
RUC	Reliability unit commitment
SC	Scheduling coordinator
SCADA	Supervisory Control and Data Acquisition
SCUC	Security-constrained unit commitment
SEDC	Smart Energy Demand Coalition
SEG	Solar electricity generation (or electricity generation from solar power)

SEK	Swedish krona
SEPIA	Simulator for the Electric Power Industry Agents
SG	Smart grid
SMP	System marginal pricing
SO	System operator
SOICAM	SCADA Office Intelligent Context Awareness Management
SP	Settlement price
SPP	Southwest Power Pool
SQL	Structured Query Language
SRP	Spot reference price
TO	Transmission owner
TOU	Time-of-use
TransCo	Transmission company
TSO	Transmission system operator
UCAP	Unforced capacity
UML	Unified modeling language
US	United States
VG	Variable generation
VOLL	Value of lost load
VPP	Virtual power player
VPSC	Voluntary Price for Small Consumers
WWSIS-2	Western Wind and Solar Integration Study Phase 2
XML	Extensible markup language

Units Used to Measure Energy (and Costs)

A	amp (the unit of electrical current)
h	hour (time)
k	kilo (used, e.g., in kW, kWh and kV)
M	mega (million) (used, e.g., in MW and M€)
G	giga (used, e.g., in GW and GWh)
T	tera (used, e.g., in TWh)
V	volt (the unit of electrical pressure)
W	watt (power)
Wh	watt-hour (energy)