ELECTRICAL ENGINEERING SERIES

Integration of Demand Response into the Electricity Chain

Challenges, Opportunities and Smart Grid Solutions

Edited by Arturo Losi
Pierluigi Mancarella and Antonio Vicino

ISTE WILEY

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First published 2015 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

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ISTE Ltd
27-37 St George's Road
London SW19 4EU
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John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
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Library of Congress Control Number: 2015948075

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-84821-854-3

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Preface

Background

In the last two decades, the power industry has undergone unprecedented changes motivated by challenging environmental targets set out by governments worldwide, increasing requirements in terms of security of supply, and the need to make electricity more affordable to end customers in a market environment.

In this context, the increasing share of renewable energy sources, such as wind and photovoltaics connected to networks at different voltage levels, is dramatically changing the classic predict-and-provide approach that has characterized the power sector since its dawn at the end of the 19th century, whereby "generation follows demand" and system control is delegated to relatively few large-scale power plants connected at the transmission level. In fact, the variability and partial uncertainty of renewable generation is posing new challenges to system balancing, with a risk of curtailing clean energy at times of system constraints. As a result, prices in day-ahead and especially balancing markets are becoming more volatile. At the same time, the ever-increasing demand for electricity associated with the increasing electrification of heating and transport is placing greater stress on distribution networks and calls for investment in new expensive generation facilities. Several solutions have been put forward to deal with these challenges within the general smart grid (SG) framework that relies on new information and communication technology (ICT) to bring together technical aspects of (close to) real-time system and network operation and market information.

In this way, monitoring and control solutions that can possibly replace more expensive asset investment can be deployed, while being cost-effective and cost-reflective. In particular, owing to ICT and within the SG thinking, consumers

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Chapter written by Arturo LOSI, Pierluigi MANCARELLA and Antonio VICINO.

can play a new active and key role by participating in system operation in exchange for (generally economic) benefits, incentives and rewards.

The concept of demand response (DR) generally concerns methodologies, technologies and commercial arrangements that could allow active participation of consumers in power system operation. The primary aim of DR is thus to overcome the "traditional" inflexibility of electrical demand and, among other benefits, create a powerful new tool to maximize deployment of renewable energy sources as well as provide active network management solutions to help reduce the impact of limited grid capabilities.

In fact, marginal system costs vary over time and location due to the physical operation of power systems. However, most end-consumers are not encouraged to make an efficient use of electricity generation resources and network capacity because they are exposed to prices that are fixed for relatively long periods. Under such conditions, consumers have no incentives to adjust their consumption in timing and volume in response to actual market and system conditions. By allowing consumers to actively participate in power system operation, thus bringing new opportunities in emerging energy markets as well as tangible system benefits, DR is therefore a key enabler of the SG concept itself. However, DR also poses a number of challenges, particularly when it is connected to the low voltage (LV) network, thus affecting all the actors involved in the electricity chain.

Why this book?

Many research contributions have appeared in recent years in the field of DR, both in journals and conference proceedings. However, most publications focus on individual aspects of the problem. A systematic treatment of the issues to be tackled to introduce DR in existing electricity grids, involving the extended value chain in terms of technical and commercial aspects, is still missing. Also, even though several recently-published books have mentioned DR as a key pillar for the SG, there is no dedicated, comprehensive and systematic contribution in this respect.

This book presents for the first time a comprehensive view on technical methodologies and architectures, commercial arrangements, and socioeconomic and regulatory factors that could facilitate the uptake of DR. The work is developed in a systematic way so as to create a comprehensive picture of challenges, benefits and opportunities involved with DR. The readers will thus be provided with a clear understanding of the complexity deriving from demand becoming active, as well as with quantitative assessment of the techno-economic value of the proposed solutions in an SG context.

Most of the material contained in this book has been developed within ADDRESS (www.addressfp7.org), a 5-year project co-funded by the European

Commission within the Seventh Framework Programme (2007/2013). ADDRESS dealt with the challenges and opportunities of DR from small domestic and commercial customers connected to the LV network. Various techno-economic solutions that DR could bring throughout the value chain were developed by 25 European partners and tested in three test sites across Europe.

ADDRESS brought together a unique team from research institutions and industry, with a wide breadth of expertise to describe an up-to-date state-of-the-art assessment of DR. This is reflected in the book from manifold points of view, ranging from technical and socioeconomic research questions through the issues of technologies that would enable DR deployment, to the needed changes in commercial arrangements and regulatory framework. ADDRESS specifically focused on the novel concepts of "Active Demand" (AD), which was intended as a subset of DR addressing residential and small commercial and industrial customers connected to LV distribution networks. In fact, this probably represents the most challenging type of DR, given the implications on the full value chain that physically spans from LV networks to large-scale generators, and given the complexity of dealing with customers mostly used to flat tariffs for electricity, and with potentially low flexibility dictated by well-consolidated habits. However, as it will be appreciated by reading the book, most findings and considerations can be readily extended to other forms of DR. Therefore, within the book, DR and AD will be used as interchangeable terms with no loss of generality.

Who is this book for?

This book is targeted to a wide readership, including: researchers in the interdisciplinary fields of power systems, electricity generation and delivery, and SGs; professionals from companies involved in transmission and distribution of electricity, producers of equipment for energy distribution and smart appliances for household applications, ICT manufacturers and providers; and governmental institutions sensitive to energy efficiency, renewable energy production and reduction of greenhouse gas emissions. In addition, the book can provide excellent support material for students who are studying the new SG field at an undergraduate and postgraduate level in various electrical, energy and ICT engineering programmes. For example, the book will be used to support the "SGs and Sustainable Electricity Systems" MSc unit taught at the University of Manchester and attended by about 100 students every year.

Structure of the book

This book is organized into 10 chapters and one appendix that cover a wide range of topics relevant to DR, ranging from general concepts of DR in an SG context to

socioeconomic aspects, and passing by various technical topics such as flexible load control and aggregation, distribution network control and representation, and so forth. More specifically, the book is structured as follows:

Chapter 1 contains a general introduction to demand-side management and DR within SGs.

Chapter 2 discusses the concepts of active consumers and their baseline demand and flexibility characterization, as well as the concepts and models of consumer aggregation and the "aggregator" as a market actor.

Chapter 3 presents the models of flexible devices available at the consumer's premises and the scheduling algorithms for their control. This control is performed by the so-called "energy box" that represents the interface between the aggregator and the local flexible load.

Chapter 4 discusses the new requirements and functionalities that are needed by the distribution system operator to set up the so-called medium-voltage control center, including the key concept of "validation" of DR services in order to prevent infeasible network operations.

Chapter 5 introduces reduced models, based on the clustering concept of "load area", to represent distribution networks in such a way that only relevant information is treated.

Chapter 6 contains a detailed overview of ICT requirements and solutions for the deployment of DR, both between houses and actors involved in the value chain and within houses.

Chapter 7 presents an overview and quantitative assessment for different European countries of the main benefits that DR can bring at the system level.

Chapter 8 analyses various techno-economic aspects of DR within a market environment, including assessment of several business cases in different European countries in terms of both energy-related services and capacity-related services.

Chapter 9 discusses a number of socioeconomic aspects of DR, with focus on consumers' feedback and acceptability on the basis of several case studies from trials carried out in the ADDRESS project.

Chapter 10 concludes the book by summarizing the main findings from various DR experiences, identifying relevant gaps and enablers for widespread DR roll out and bridging to future research and applications.

An appendix describes a methodology for defining domain interfaces, together with guidelines for embedding and implementing them into message and transport-level interfaces.

Acknowledgments

The editors would first of all like to thank all the authors for their tremendous work and contribution in the writing of this book. They would also like to thank the European Commission for the funding support, and all the partners and the team involved in the ADDRESS project, which has been an extraordinary learning and, from many perspectives, even enlightening experience. The editors would also like to acknowledge the precious help received by the following researchers from the University of Manchester: Dr Eduardo Alejandro Martínez Ceseña (Alex) for his support in setting up the electronic material, and Dr Nicholas Good and Mr Nick Chapman for their support in proofreading the book.

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September 2015

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List of Acronyms

AC	alternating current
AD	active demand
ADR	automated demand response
ANN	artificial neural network
API	application programming interface
ARMA	auto regressive moving average
ARMAX	auto regressive moving average with exogenous inputs
BAN	building area network
B2B	business to business
BRP	balancing responsible party
BCS	battery control subroutine
CAPEX	capital expenditure
CATV	community antenna television – community access television – cable television
CCGT	combined cycle gas turbine
CEER	Council of European Energy Regulators
CHP	combined heat and power
CIM	common information model
CNS	current neighborhood subroutine
COSEM	companion specification for energy metering
CPP	critical peak pricing
CRP	conditional reprofiling product
DB	database
DC	direct current
DER	distributed energy resource
DG	distributed generation
DLC	direct load control
DLMS	device language message specification
DMS	distribution management system
DR	demand response

DRMS	demand response management system
DSE	distribution state estimation
DSL	digital subscriber line
DSM	demand-side management
DSO	distribution system operator
EB	energy box
EBSP	energy box scheduling problem
EC	European Commission
EPRG	electricity policy research group
ESB	enterprise service bus
FAN	field area network
FO	fiber optic
FTTH	fiber to the home
GA	genetic algorithm
GARCH	generalized autoregressive conditional heteroskedasticity
GSM	global system for mobile communications
HAN	home area network
HFC	hybrid fiber coaxial
HTTP	hypertext transfer protocol
HTTPS	hypertext transfer protocol over secure socket layer
HV	high voltage
IAN	industrial area network
ICT	information and communication technology
IED	intelligent electronic device
IP	internet protocol
ISS	initial solution subroutine
JMS	Java message service
LA	load area
LAN	local area network
LCS	load control subroutine
LV	low voltage
MILP	mixed integer linear programming
MLA	macro load area
MV	medium voltage
MVCC	medium-voltage control center
NARX	nonlinear autoregressive with exogenus inputs
NIS	network information system
NWP	numerical weather prediction
OFDM	orthogonal frequency-division multiplexing
OLA	overload load area
OLTC	on load tap changer
OPEX	operating expenditure
OTC	over-the-counter

P	active power
PLC	power line communication
PMR	professional mobile radio
PV	photovoltaic
PVUSA	photovoltaics for utility scale application
Q	reactive power
QoS	quality of service
RD	research and development
RDFS	resource description framework schema
RES	renewable energy source
RTF	rich text format
RTP	real-time pricing
RTU	remote terminal unit
SCADA	supervisory control and data acquisition
SDH	synchronous digital hierarchy
S-FSK	spread frequency shift keying
SG	smart grid
SM	smart metering
SO	system operator
SOA	service-oriented architecture
SOAP	simple object access protocol
SOM	self-organizing map
SSH	secure shell
SVM	support vector machine
TCS	thermal control subroutine
TCP	transmission control protocol
TelCo	telecommunications company
TETRA	trans European trunked radio – terrestrial trunked radio
ToU	time of use
TSO	transmission system operator
UML	unified modeling language
UHF	ultra high frequency
VHF	very high frequency
VLA	voltage load area
VOLL	value of lost load
xDSL	generic digital subscriber line
XML	extensible markup language
XSD	XML Schema definition
W3C	world wide web consortium
WiFi	suite of IEEE_802.11 protocols
WiMAX	worldwide interoperability for microwave access
WAN	wide area network
WSDL	web services description language

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