Energy Systems in Electrical Engineering

Ersan Kabalci · Yasin Kabalci *Editors*

Smart Grids and Their Communication Systems

Springer

Energy Systems in Electrical Engineering

Series editor

Muhammad H. Rashid, Pensacola, USA

More information about this series at http://www.springer.com/series/13509

Ersan Kabalci · Yasin Kabalci
Editors

Smart Grids and Their Communication Systems

Springer

Editors
Ersan Kabalci
Department of Electrical and Electronics Engineering
Nevşehir Hacı Bektaş Veli University
Nevşehir, Turkey

Yasin Kabalci
Department of Electrical and Electronics Engineering
Ömer Halisdemir University
Niğde, Turkey

ISSN 2199-8582 ISSN 2199-8590 (electronic)
Energy Systems in Electrical Engineering
ISBN 978-981-13-1767-5 ISBN 978-981-13-1768-2 (eBook)
https://doi.org/10.1007/978-981-13-1768-2

Library of Congress Control Number: 2018949341

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Although the traditional power grid has been spread all over the world, it has degraded since its first installation. The architectural structure of a typical power network is comprised of generation, transmission, distribution, and consumption sections. A wide variety of conventional and modern power generation systems such as hydro-generators, combined heat and power (CHP) plants, microsources, nuclear power sources exist in the bulk generation level. The generated power is increased to high-voltage (HV) levels to decrease line losses and leakages in the transmission system where transformers and substations are used in addition to overhead or underground lines. The substations and step-down transformers are used to distribute generated and transmitted power at the distribution stations. The degraded utility has numerous deficiencies that distort the power quality and reliability. The widely known power system deficiencies are caused by voltage instability, intermittency, curtailments, blackouts, and unbalanced or heavy load situations. The conventional consumption of power network is far from being remote monitoring or controlling capabilities. However, the transformation from the conventional grid to the smart grid forces transmission system operators (TSOs) and distribution system operators (DSOs) to improve the grid infrastructure. The remote monitoring and control systems have been improved and integrated into the conventional grid in order to cope with the grid deficiencies. The smart grid infrastructure is implemented to provide a data communication medium in order to carry several signals for measurement, monitoring, management, and control purposes. The smart grid interface is integrated into utility grid at any section including bulk generation, transmission, distribution, consumption, and microgrid installations. The communication interface and medium are required to provide secure, reliable, and efficient transmission. Several research groups have improved the smart grid concept, and a number of white papers, reference works, standards, laws, and applications have been introduced.

The energy market and utility grid operators have promoted the use of renewable energy sources (RESs) in order to manage increased demand on the customer side. Furthermore, governments and authorities encouraged the use of RES to compensate greenhouse gas emissions and to decrease carbon emission. The wind turbines and photovoltaic (PV) power plants have been paid much attention among other alternative energy sources. The multi-megawatt plants have been installed in gradually increasing ratios, and the technological improvements have been triggered due to required operation and management services. Many governments provided incentives and enabled to shift distributed generation (DG) approach at the customer level that converted consumers to prosumers by installing their own microgrids (MGs). These improvements have led to improvement in various demand-side management (DSM) and DR programs by generation and distribution companies. In addition to DG and MGs, energy storage systems (ESSs) have been widely required to provide a balance between generation and consumption demands. The technological innovations in transmission, distribution, consumption, and monitoring sections are required as well as in smart generation. A wide variety of heterogeneous grid infrastructure and technologies are being used in smart grid improvements. A comprehensive smart grid infrastructure is implemented in this way.

Smart Grids and Their Communication Systems is aimed to highlight the smart grid architectures, applications, and requirements, technical challenges and enhancements in control and communication concepts to provide further understanding on how they are affected by distributed generation, transmissions and distribution systems, and smart loads using different monitoring and control methods. A large number of specialists joined as authors of the book to provide their potentially innovative solutions and research related to smart grid infrastructure, power network architecture, and communication systems, in order to be useful in developing new ways in smart grid design and operational technologies. Several theoretical researches, case analyses, and practical implementation processes are put together in this book that aims to act as a research and design guide to help graduates, postgraduates, and researchers in electric power engineering, communication engineering, and energy systems. The book, which presents significant results obtained by leading professionals from industries and research and academic fields, can be useful to a variety of groups in specific areas. All works in this book are new, previously unpublished material, or extended version of published papers in the proceedings of international conferences and transactions on international journals. The book consists of 17 chapters in two parts.

Part I Smart Grids

The first part of this book, which is comprised of eight chapters, presents the fundamentals of smart grid architectures in terms of power network infrastructures. The topics in the first part include smart grid applications, introduction to smart grid requirements and communication systems, key technologies for smart grid, technical challenges and enhancements, smart metering systems, frequency estimation methods for smart grid systems, DSM and DR applications, energy management systems for RES DG applications, and energy storage technologies. Chapter 1 presents an introduction to smart grid architectures and describes the novel technologies in terms of power electronics, power converters, information and communication technologies (ICTs), ESSs, electric vehicles (EVs), and microgeneration systems in the context of smart grid applications. This chapter introduces essential components and novel technologies of smart grids such as sensor networks, smart metering and monitoring systems, smart management systems, wired and wireless communication technologies, security requirements, and standards and regulations for this concept. First of all, this chapter focuses on the main components of smart grids such as smart sensors and sensor networks, phasor measurement unit (PMU), smart meters (SMs), and wireless sensor networks (WSNs). Then, smart grid applications and main requirements are explained on the basis of advanced metering infrastructure (AMI), DR, station and substation automation, and DSM. Later, communication systems of the smart grid are presented in which the communication systems are classified into two groups as wired and wireless communication systems, and they are comprehensively analyzed. Furthermore, the area networks related to the smart grid concept such as home area network (HAN), building area network (BAN), industrial area network (IAN), neighborhood area network (NAN), field area network (FAN), and wide area network (WAN) are presented in a logical way beginning from generation systems to the user side. Chapter 2 presents a summary of conventional grid problems and evolution of power grid in terms of electricity delivery infrastructure consisting of power plants, transmission lines, and distribution systems. The power grid in its present form is one of the most remarkable engineering developments. The grid infrastructure has played a critical role in making electric power reach the common people in a reliable and economic way. The key technologies such as DG, real-time monitoring, sensing and measurement, phasor measurement units (PMUs), and worldwide developments of the smart grid are presented in this chapter.

Chapter 3 describes novel power electronic devices that have been widely adopted to smart grid infrastructure. The contributions of power converters and inverter and communication-enabled power converters have been introduced in this chapter. The recent SG applications have drawn much more featured profiles comparing to previous phases. At the beginning, the SG has been improved by integrating ICT into the existing conventional grid. The bidirectional or two-way data and energy flow capability have been brought to smart grid infrastructure due to emerging communication methods, network structures, and developed power electronics. On the other hand, several power sources and energy generation structures have been improved and integrated into the existing utility grid. The microgrid was one of the most recent power infrastructures that enables DSOs to integrate various DERs to integrate their conventional generation sources. The microgrids have also been used by consumers where they participate in the generation and can be shifted to prosumers. The emerging technologies have been presented regarding power electronics, communication systems, microgrid generation systems, ESSs, and EVs that are most recent and innovative technologies promoting the improvement of SG infrastructure. The solid-state transformer and communication-enabled power converters have been analyzed in detail in this chapter. Chapter 4 presents a comprehensive description on a smart metering system based on power-line communications (PLCs) technologies such as narrowband PLC (NB-PLC) and broadband PLC (BB-PLC) systems. In recent years, the electricity grid has experienced a significant transformation in the generation side, with an increasing use of distributed energy sources that have a more decentralized structure and unpredictable availability than conventional ones. Similarly, the expected penetration of electric vehicles would considerably change the consumption patterns. These new circumstances require an improved monitoring and control of the electricity grid assets, and smart metering is a key element to achieve both ends that are presented in the context of this chapter. Chapter 5 deals with frequency estimation and adaptive real-time frequency estimation applications in smart grid and presents a set of algorithms for the estimation operations. The presented algorithms and forthcoming properties of these algorithms under both balanced and unbalanced conditions have been proven by simulations in this chapter, while DSM and DR management processes are presented in detail in Chap. 6. DSM is an emerging initiative which is one of the key elements of restructured power systems. An objective of any DSM program could be peak load clipping instead of adding generation supply, by simply shifting timing from the peak load period to off-peak period. DR seeks to adjust load demand instead of adjusting generation supply. Different types of load shaping objectives, such as peak clipping, valley filling, load shifting, have been presented in the context of DR programs. Compensation for DR is triggered by diverse policies, market mechanism, and implementation models. The recent advent of communication technologies and metering infrastructure and the integration of DR resources in electric power system worldwide have been discussed. Chapter 7 presents an algorithmic solution to investigate the potential economic benefits of improving matching between domestic DG and power loads with explicit consideration of the real-time pricing information. The proposed energy dispatch solution is evaluated and validated using a set of operational scenarios through numerical simulations. The obtained experimental result clearly demonstrates that the domestic energy can be appropriately controlled to meet the required domestic demand with significantly improved resource utilization efficiency and reduced purchase cost. The robustness of the solution under inaccurate prediction information is also validated considering the presence of inaccurate prediction of real-time pricing and DG. Chapter 8 describes potentials, barriers, and solutions for DR from residential consumers in distribution networks as the final chapter of Part I. The first and foremost goal of this chapter is to quantify potential benefits of demand response to distribution network operation. To do so, a brief definition of demand response is followed by explanations about different demand response programs. Then, demand response benefits are counted. Thereafter, a distribution network hosting several residential customers is utilized to quantify the benefits of demand response in the operation of distribution networks. Disaggregated load profiles associated with residential customers and their flexibility are employed to modify the total load profile. Then, by applying the modified load profile to the network, impacts of demand response on the network losses, voltage profiles, and loading levels are studied. It is demonstrated that even activating demand response potential of a portion of customers can lead to significant improvements in the parameters. Finally, demand response barriers and associated solutions are described.

Part II Emerging Communication Systems for Smart Grids

The second part of this book highlights the novel and improved communication systems in nine chapters. The topics include standards and communication systems in smart grid, fifth-generation (5G) mobile communication systems in terms of smart grid technologies and modulation schemes, optical communications systems, Internet of things (IoT) application for PLC and adaptive approaches, IEEE 802.15.4 technologies, robust and advanced metering infrastructures, and cyber security objectives.

Chapter 9 presents a comprehensive discussion of the various smart grid communication standards and smart grid communication systems. Communication standards for substation automation, cyber security, EMS, DMS, V2G, AMI, synchrophasor data transfer have been comprehensively presented. Several other miscellaneous communication standards such as OpenADR, BACnet, the IEEE 1901 standard have been briefly described. Next, the communication technologies for the smart grid application such as PLC, optical fiber, WLAN, ZigBee have been discussed. These technologies have been mapped to the various smart grid applications. Even though the smart grid can enhance the quality of power generation and distribution, there are several major challenges that are to be addressed such as the standardization of the diverse smart grid technologies, enhancement of reliability, minimization of latency. Finally, two future smart grid technologies, namely IoT and 5G, have been briefly discussed. Chapter 10 which is on 5G mobile communication systems presents the evolution of mobile communication systems that are considered from the first-generation to fourth-generation systems. The advantages and weaknesses of each generation are explained comparatively. Later, technical infrastructure of the development of the 5G communication systems has been evaluated in the context of system requirements and new experiences of users such as 4K video streaming, tactile Internet, and augmented reality. After the main goals and requirements of the 5G networks are described, the planned targets to be provided in real applications by this new generation systems are clarified. In addition, different usage scenarios and minimum requirements for ITU-2020 are evaluated. On the other hand, there are several challenges to be overcome for achieving the intended purpose of 5G. Besides, potential application areas and application examples of the 5G communication systems are covered at the end of this chapter, while Chap. 11 deals with modulation schemes and next-generation smart grid communication systems in the context of wired and wireless communication technologies. Wired and wireless communication technologies are widely leveraged for bilateral communications between the utility and the end user in smart grid environments. With mobile technologies evolving, optical communications are projected to play an essential role in emerging 5G networks. Chapter 12 first introduces fiber-optic communications and briefly addresses optical attenuation, dispersion, and nonlinear effects for a variety of modulation devices in the present and future fiber-optic transmission and multiplexing technologies. Second, the development of optical wireless communications is introduced, including free-space optical communication and visible-light communication (VLC) systems. Third, waveform designs and modulation techniques in 5G for the smart grid are addressed, including amplitude-shift keying (ASK), differential phase-shift keying (DPSK), quadrature phase-shift keying (QPSK), multiple quadrature amplitude modulation (MQAM), polarization shift keying (PolSK), plus other digital modulation and pulse modulation formats, as well as coding technologies. Finally, an overview of the prospects is given for future development, application fields, and socio-economic influence in terms of the smart grid. Chap. 13 presents a feasibility study on the joint adoption of PLC and IoT paradigms in heterogeneous scenarios, highlighting that the power-line medium guarantees acceptable transmission data rates for IoT devices by adopting standard communication protocols (e.g., CoAP, CoSIP, HTTP). In order to validate a PLC/IoT communication strategy, an extensive experimental evaluation has been carried out using a vendor-provided tool and a self-developed Java library, adopting the G3-PLC specification as PLC communication protocol standard. Experimental performance tests have been carried out on both cold and hot electrical lines with variable lengths.

Nowadays, the growth of the Internet of things makes necessary to improve systems in terms of reliability, autonomy, and adaptation. Some research lines are focused on these issues to be part of new necessities. The main idea of Chap. 14 is to go further than a wide extended communication among devices or remote control focusing on decision making of cooperative systems. Two different weighted methods are analyzed in this chapter. The first one establishes the definition of how weights have to evolve depending on the matches between the solution of each device and the final cooperative solution. In contrast, the second weighted approach estimates weights using a stochastic-based method which gives weight assignments after analyzing multiple combinations. The proposed algorithms have been presented in detail and analyzed in smart environments. Chapter 15 is a detailed chapter on IEEE 802.15.4 technologies for smart grid including physical (PHY) and medium access control (MAC) layers. In recent years, WSNs have received growing attention owing to their remarkable advantages, and they are widely being utilized in various metering and monitoring application areas such as IoT, smart grids, smart cities, smart homes, cloud computing, healthcare monitoring, military investigation, environmental surveillance systems. The most widely utilized standard in the WSN applications is IEEE 802.15.4 that is developed to enable short-range applications with low data rates and low power consumption features. This chapter aims to provide comprehensive information concerning the WSNs, general specifications of the IEEE 802.15.4 standard, recently developed new technologies based on this standard, and several practical WSN applications performed for smart grid concept. This chapter firstly introduces the fundamentals, application areas, and advantages of the WSNs in detail. Later, the chapter continues by explaining the technical backgrounds of the WSNs where the IEEE 802.15.4 standard is examined in terms of layer stacks. The PHY and MAC layers of the IEEE 802.15.4 standard are comprehensively analyzed since these layers are the basis of new technologies such as ZigBee, WirelessHART, ISA100.11a, 6LoWPAN, and 6TiSCH. Afterward, these novel technologies are introduced and analyzed by considering Open Systems Interconnection (OSI) reference model. Finally, practical examples of the WSNs regarding metering and monitoring applications of smart grids are presented at the end of this chapter. Chapter 16 provides a comprehensive discussion on fault-tolerance and reliability for AMI communication. The AMI is one of the main applications in smart grids, and several references have discussed performance requirements for its correct functioning. While, in isolation, the requirements for each user are not high, the scale and density of the network make meeting them a challenge. Moreover, any downtime for this network is harmful, which strongly suggests the need for some degree of fault-tolerance. In this chapter, the main enabling technologies and architectures for AMI communication, highlighting the currently dominating architecture, based on wireless communication between meters and data aggregation points (DAPs), are discussed. Chapter 17 which is the final chapter is organized into seven parts as an introduction to smart grid-related developments in the last decades and the architecture of a smart grid network with all its features and utilities. The third part refers to the cyber security area of the smart grid network which involves challenges, requirements, features, and objectives to secure smart grid. The smart grid networks may be posed to serious attacks that exploits the vulnerabilities of existing grid system. The fifth part refers to the methods and countermeasures used to avoid or to minimize effects of complex attacks which are presented with an innovative methodology for security assessment based on vulnerability scanning and honeypots usage.

The editors recommend this book as suitable for an audience professional in electric power systems, as well as researchers and developers in the fields of energy, communication, and power engineering. It is anticipated that the readers have sufficient knowledge in electric power engineering and also advanced mathematical background. The editors have made efforts to cover the essential topics of smart grid and communication systems to balance theoretical and applicative aspects in the chapters of this book. At the same time, the application and case studies are intended for real understanding and operation. Finally, the editors hope that this book will be useful to undergraduate and graduate students, researchers, and engineers, trying to solve reactive electric power problems using modern technical and intelligent systems based on theoretical aspects and application case studies.

Nevşehir, Turkey Dr. Ersan Kabalci
Tampa, FL, USA Dr. Yasin Kabalci

Contents

About the Editors

Ersan Kabalci is Associate Professor and Department Head of Electrical and Electronics at Nevsehir University, Turkey. He received his M.Sc. and Ph.D. in electrical and electronics engineering from Gazi University, Turkey, where his research focused on implementing an enhanced modulation scheme for multilevel inverters. He also serves as an associate editor for several international indexed journals and as a reviewer for more than 25 international journals on power electronics and renewable energy sources. His current research interests include power electronic applications and drives for renewable energy sources, microgrids, distributed generation, power-line communication, and smart grid applications. He has been a member of IEEE since 2009. He has published more than 80 research papers in journals and conferences proceedings and has authored seven chapters.

Yasin Kabalci is Assistant Professor in the Department of Electrical and Electronics Engineering at Omer Halisdemir University. He completed his B.Sc. and Ph.D. in electrical and electronics engineering at Erciyes University, Turkey. He has previously worked as Lecturer at Nigde University, Erciyes University, and Nevsehir University in Turkey. His research interests include power-line communications, wireless communications, smart grids, remote monitoring of renewable energy sources, and IoT. He has published more than 50 scientific articles in journals and conferences and authored a chapter in *Energy Harvesting and Energy Efficiency* (Springer).

Abbreviations and Acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third-Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
6LoWPAN	IPv6 over Low-Power WPAN
8PSK	Eight-Phase-Shift Keying
AAA	Authentication/Authorization/Accounting
ACK	Acknowledge
ACSI	Abstract Communication Service Interface
ADALINE	Adaptive Linear Neuron
ADC	Analog–Digital Conversion
ADMI	Additive Decrease Multiplicative Increase
ADP	Adaptation Sublayer
ADSL	Asymmetric Digital Subscriber Line
AER	All Electric Range
AES	Advanced Encryption Standard
AES-CBC	Advanced Encryption Standard–Cipher Block Chaining
AFB	Analysis Filter Bank
AFC	Alkaline Fuel Cell
AGC	Automatic Generation Control
AI	Artificial Intelligent
AM	Amplitude modulation
AMI	Advanced Metering Infrastructure
AMM	Automatic Meter Management
AMPS	Advanced Mobile Phone System
AMR	Automatic Meter Reading
ANN	Artificial Neural Network
ANSI	American National Standards Institute

AoA	Angle of Arrival
AoD	Angle of Departure
AODV	Ad Hoc On-Demand Distance Vector
AONs	All-Optical Networks
AOWC	All-Optical Wavelength Conversion
APC	Application Protocol Convergence Sublayer
APD	Avalanche Photodiode
APDU	Application Protocol Data Unit
AR	Augmented Reality
ARIB	Association of Radio Industries and Businesses
ARQ	Automatic Repeat Request
ASD	Adjustable Speed Drive
ASDU	Application Service Data Unit
ASE	Amplified Spontaneous Emission
ASK	Amplitude-Shift Keying
AWF	All Wave Fiber
AWGN	Additive White Gaussian Noise
BAN	Building Area Network
BAS	Building Automation System
BB	Broadband
BB-PLC	Broadband Power-Line Communication
BEC	Binary Input Erasure Channel
BER	Bit Error Rate
BEV	Battery EV
BFDM	Bi-Orthogonal Frequency-Division Multiplexing
BGA	Ball Grid Array
BI	Beacon Interval
BN	Base Node
BP	Belief Propagation
BPF	Band-Pass Filter
BPSK	Binary Phase-Shift Keying
C&C	Command-and-Control
CA	Certification Authority
CAISO	California Independent System Operator
CAP	Contention Access Period
CB	Capacitor Bank
CC	Convolutional Code
CCA	Clear Channel Assessment
CD	Charge-depleting
CDC	Common Data Classes
CDF	Cumulative Distribution Function
CDM	Code-Division Multiplexing
CDMA	Code-Division Multiple Access
CELESC	Centrais Elétricas de Santa Catarina
CENELEC	Comité Européen de Normalisation Électrotechnique

CFO	Carrier Frequency Offset
CFP	Contention-Free Period
CFS	Contention-Free Slot
CHP	Combined Heat and Power
CIM RDF	Common Information Model Resource Description Framework
CIM	Common Information Model
CIS	Customer Information System
CISPR	Comité International Spécial des Perturbations Radioélectriques
CL	Convergence Layer
CLMP	Complex-Valued Least Mean Phase
CLMS	Complex-Valued Least Mean Square
CLNP	Connectionless-mode Network Service Protocol
CM	Common Mode
CNLMS	Complex-Valued Normalized Least Mean Square
CoAP	Constrained Application Protocol
COMSEM	Companion Specification for Energy Metering
COSEM	Companion Specification for Energy Metering
CoSIP	Constrained Session Initiation Protocol
CP	Cyclic Prefix
CPCS	Common Part Convergence Sublayer
CPP	Critical Peak Pricing
CPS	Cyber Physical System
CR	Cognitive Radio
CRC	Cyclic Redundancy Check
CRLS	Complex-Valued Recursive Least Square
CRN	Cognitive Radio Network
CS	Customer Support
CSI	Channel State Information
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSRZ	Carrier-Suppressed Return-to-Zero
CTS	Clear-to-Send
CVaR	Conditional Value at Risk
CVD	Chemical Vapor Deposition
CVEs	Common Vulnerabilities and Exposures
CW	Contention Window
D2D	Device-to-Device
D8PSK	Differential 8-phase-shift keying
DA	Distributed Automation
D-AMPS	Digital AMPS
DAP	Data Aggregation Point
DC	Data Concentrator
DCF	Dispersion Compensating Fiber
DDoS	Distributed Denial-of-Service

DDSA	Dynamic DAP Selection Algorithm
DER	Distributed Energy Resource
DES	Data Encryption Standard
DESDs	Distributed Energy Storage Devices
DFG	Difference Frequency Generation
DfPSK	Differential in Frequency Phase-Shift Keying
DFT	Discrete Fourier Transform
DG	Distributed Generation
DHCP	Dynamic Host Configuration Protocol
DH-PIM	Dual Header Pulse Interval Modulation
DLC	Direct Load Control
DLL	Data Link Layer
DLMS	Device Language Message Specification
DM	Domain Master
DMFC	Direct Methanol Fuel Cell
DMP	Data Management Point
DMS	Distribution Management System
DNO	Distribution Network Operator
DNP	Distributed Network Protocol
DO	Data Object
DoE	Department of Energy
DoS	Denial-of-Service
DPIM	Digital Pulse Interval Modulation
DPPM	Differential Pulse Position Modulation
DPSK	Differential Phase-Shift Keying
DQPSK	Differential Quadrature Phase-Shift Keying
DR	Demand Response
DRX	Demand Response Exchange
DRXO	Demand Response Exchange Operator
DSE	Distribution State Estimation
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Demand-Side Management
DSME	Deterministic and Synchronous Multichannel Extension
DSOs	Distribution Service Operators
DSR	Dynamic Source Routing
DSSS	Direct Sequence Spread Spectrum
DTH	Direct-To-Home
DTN	Delay-Tolerant Network
DUNS	Data Universal Numbering System
DWDM	Dense Wave Division Multiplexing
E2E	End-to-End
EAM	Electro-Absorption Modulator
EAP-PSK	Extensible Authentication Protocol with Pre-Shared Key
ECC	Error-Correcting Code

ECT	Electronic Current Transformer
ED	Energy Detection
EDFA	Erbium-Doped Fiber Amplifier
EDGE	Enhanced Data Rates for GSM Evolution
EEGI	European Electric Grids Initiative
EHF	Extremely High Frequency
EISA	Energy Independence and Security Act
eMBB	Enhanced Mobile Broadband
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMO	European Mobile Observatory
EMS	Energy Management System
EMS-API	Energy Management Services Application Program Interface
EPRI	Electric Power Research Institute
ERDF	Electricite Reseau Distribution France
ES	Energy Storage
ESPs	Energy Service Providers
ESS	Energy Storage System
ETSI	European Telecommunication Standards Institute
ETT	Expected Transmission Time
ETX	Expected Transmission Count
EU	European Union
EV	Electrical Vehicle
EVDO	Evolution-Data Optimized
EVSE	Electric Vehicle Supply Equipment
EVT	Electronic Voltage Transformer
FACTS	Flexible Alternative Current Transmission Systems
FAN	Field Area Network
FBG	Fiber Bragg Grating
FBMC	Filter Bank Multicarrier
FCC	Federal Communications Commission
FCH	Frame Control Header
FCI	Fault Circuit Indicator
FDD	Frequency-Division Duplex
FDE	Frequency-Division Equalization
FDM	Frequency-Division Multiplexing
FDMA	Frequency-Division Multiple Access
FEC	Forward Error Correction
FER	Frame Error Rate
FERC	Federal Energy Regulatory Commission
FFD	Full-Function Device
FFT	Fast Fourier Transform
FID	Fault Isolation Device
FIR	Finite Impulse Response
FlexE	Flexible Ethernet

FM	Frequency Modulation
FMF	Few-Mode Fiber
FO	Fiber Optics
FQAM	Frequency and Quadrature Amplitude Modulation
FREEDM	Future Renewable Electric Energy Delivery and Management
FS	Frequency Spreading
FSK	Frequency-Shift Keying
FTN	Faster-Than-Nyquist
FTP	File Transfer Protocol
FTTH	Fiber To The Home
FTTX	Fiber To The X
FWM	Four-Wave Mixing
GA	Genetic Algorithm
GAMS	General Algebraic Modeling System
GaN	Gallium Nitride
GenCos	Generation Companies
Gen-I	First generation
Gen-II	Second generation
Gen-III	Third generation
GEO	Geostationary Earth Orbit
GFDM	Generalized Frequency-Division Multiplexing
GI	Guard Interval
GIS	Geographical Information System
GLPK	GNU Linear Programming Kit
GMK	Group Master Key
GOOSE	Generic Object-Oriented Substation Event
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSO	Generation System Operator
GSSE	Generic Substation Status Event
GTS	Guaranteed Time Slot
GUI	Graphical User Interface
GVD	Group Velocity Dispersion
HAN	Home Area Network
HAS	Home Automation System
HDLC	High-Level Data Link Control
HD-PLC	High-Definition PLC
HDR	High Data Rate
HEMS	Home Energy Management System
HEV	Hybrid EV
HIH	High Interaction Honeypot
HMI	Human Machine Interface
HMS	Home Management System

HNLF	Highly Nonlinear Fiber
HomePlug	HomePlug Power-line Alliance
HPCW	High-Priority Contention Window
HSDA	High-Speed Data Access
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSUPA	High-Speed Uplink Packet Access
HTTP	Hypertext Transfer Protocol
HV	High Voltage
HVAC	High-Voltage Alternative Current
HVDC	High-Voltage Direct Current
HWMP	Hybrid Wireless Mesh Protocol
HWMP-RE	HWMP-Reliability Enhancement
IAN	Industrial Area Network
IBC	Identity-Based Cryptography
IBI	Inter-Block Interference
IBP	Incentive-Based Program
IBR	Inclining Block Rate
ICCP	Inter-Control Center Communications Protocol
ICE	Internal Combustion Engine
ICI	Inter-Channel Interference
ICMP	Internet Control Message Protocol
ICTs	Information and Communication Technologies
IDB	Inter-Domain Bridge
IDFT	Inverse Discrete Fourier Transform
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFFT	Inverse Fast Fourier Transform
IFWM	Intra-Channel Four-Wave Mixing
ILC	Indirect Load Control
IMDD	Intensity Modulation and Direct Detection
IMT-2020	International Mobile Telecommunications-2020
IMT-Advanced	International Mobile Telecommunications Advanced
IoT	Internet of Things
IoV	Internet of Vehicles
IP	Internet Protocol
IPMI	Intelligent Platform Management Interface
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IQ	In-phase and Quadrature
IRM	Interface Reference Model
ISA	International Society of Automation
ISGF	Indian Smart Grid Forum

ISGTF	Indian Smart Grid Task Force
ISI	Inter-Symbol Interference
ISM	Industrial, Scientific and Medical
ISO	International Standards Organization
ITU	International Telecommunication Union
IUT	Intelligent Universal Transformer
IXPM	Intra-Channel Cross-Phase Modulation
KGC	Key Generation Center
KKT	Karush–Kuhn–Tucker
KNN	K-Nearest Neighbors
KPI	Key Performance Indicator
KSP-OFDM	Known Symbol Padded OFDM
LAN	Local Area Network
LC	Load Controller
LD	Logical Devices
LDC	Load Duration Curve
LDPC	Low-Density Parity-Check
LDR	Low Data Rate
LED	Light-Emitting Diode
LEO	Low Earth Orbit
LiFi	Light Fidelity
LIH	Low Interaction Honeypot
LLC	Logical Link Control Sublayer
LMP	Least Mean Phase
LMS	Least Mean Square
LN	Logical Nodes
LOADng	Lightweight On-demand Ad hoc Distance-vector Routing Protocol Next Generation
LPG	Liquefied Petroleum Gas
LPTV	Linear and Periodically Time-Varying
LQI	Link Quality Indication
LR-WPAN	Low-Rate Wireless Personal Area Network
LSE	Load Serving Entity
LISN	Line Impedance Stabilization Network
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution Advanced
LTI	Linear and Time-Invariant
LV	Low Voltage
LVRT	Low-Voltage Right Through
M2M	Machine-to-Machine
MAC	Medium Access Control Layer
MARA	Metric Aware Rate Adaptation
MAS	Multi-Agent System
MASK	Multiple Amplitude-Shift Keying
MBB	Mechanical Building Block

MBS	Macrocell Base Station
MC	Maintenance and Construction
MCF	Multi-Core Fiber
MCFC	Molten Carbonate Fuel Cell
MCM	Market Clearing Problem
MDI	Medium-Dependent Interface
MDMS	Metering Data Management System
ME	Mechanical Electrical
MEO	Medium Earth Orbit
MFSK	Multiple Frequency-Shift Keying
MG	Microgrid
MGCC	Microgrid Central Controller
MGSC	Microgrid Supervisory Control
MIB	Management Information Base
MILP	Mixed-Integer Linear Programming
MIMO	Multi-Input Multi-Output
MINLP	Mixed-Integer Nonlinear Programming
MITM	Man-In-The-Middle
ML	Minimum Loss
MLI	Multilevel Inverter
MLME	MAC Layer Management Entity
MLP	Multi-Layer Perceptron
MMF	Multimode Fiber
MMS	Manufacturing Message Specification
MMSE	Minimum Mean Squared Error
mMTC	Massive Machine-Type Communications
mmWave	Millimeter Wave
MOSKOU	Memory-Oriented Split using K-Means with Post-Optimization Unification
MP	Management Plane
MPDU	MAC Protocol Data Unit
MPEC	Mathematical Problem with Equilibrium Constraint
MPPM	Multiple Pulse Position Modulation
MPPT	Maximum Power Point Tracking
MPR	MultiPoint Relays
MPSK	Multiple Phase-Shift Keying
MQAM	Multiple Quadrature Amplitude Modulation
MR	Meter Reading and Control
MRC	Maximal Ratio Combining
MRT	Maximal Ratio Transmission
MTU	Maximum Transmission Unit
MU	Merging Unit
MV	Medium Voltage
MZM	Mach–Zehnder modulator
NACK	Negative Acknowledge

NAN	Neighborhood Area Network
NASPI	North American Synchrophasors Initiative
NAT	Network Address Translation
NB	Narrowband
NBI	Narrowband Interference
NB-PLC	Narrowband Power-Line Communication
NCIT	Non-Conventional Instrument Transformer
NCP-SC	Null Cyclic Prefix Single Carrier
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory
NFV	Network Function Virtualization
NIST	National Institute of Standards and Technology
NLMS	Normalized Least Mean Square
NMT	Nordic Mobile Telephone
NO	Network Operations
NOMA	Nonorthogonal Multiple Access
NPC	Neutral Point Clamped
NPCW	Normal Priority Contention Window
NRZ	Non-return-to-Zero
NSGM	National Smart Grid Mission
OADM	Optical Add-Drop Multiplexer
OAM	Orbital Angular Momentum
OBIS	Object Identification System
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OG	Onsite Generation
OL	Overhead Line
OLC	OLE for Process Control
OLSR	Optimized Link State Routing
OLTC	On-Load Tap Changer of Transformer
OMS	Outage Management System
OOB	Out-Of-Band
OOK	On–off keying
OpenADR	Open Automated Demand Response
OPERA	Open PLC European Research Alliance
OPF	Optimal Power Flow
OQAM	Offset Quadrature Amplitude Modulation
OQPSK	Offset-QPSK
OSI	Open Systems Interconnection
OWC	Optical Wireless Communications
P.U	Per Unit
P2P	Peer-to-Peer
PAFC	Phosphoric Acid Fuel Cell
PAM4	Four-Level Pulse Amplitude Modulation
PAN	Personal Area Network

PAPR	Peak-to-Average Power Ratio
PAR	Peak-to-Average Ratio
PBP	Price-Based Program
PCC	Point of Common Coupling
PCS	Physical Coding Sublayer
PDC	Phasor Data Concentrator
PDL	Polarization-Dependent Loss
PDM	Polarization Division Multiplexing
PEBB	Power Electronic Building Block
PEMFC	Proton Exchange Membrane Fuel Cell
PEV	Plug-in Electric Vehicle
PFC	Power Factor Correction
PHEV	Plug-in Hybrid Electric Vehicles
PHY	Physical Layer
PIC	Parallel Interference Canceler
PIoT	Power Internet of Things
PKI	Public Key Infrastructure
PLC	Power-Line Communication
PLL	Phase-Locked Loop
PLME	PHY Layer Management Entity
PM	Polarization Multiplexing
PMA	Physical Medium Attachment Sublayer
PMD	Physical Medium-Dependent Sublayer
PMI	Physical Medium-Independent Interface
PM-QPSK	Polarization Multiplexed-QPSK
PMU	Phasor Measurement Unit
PolSK	Polarization Shift Keying
PON	Passive Optical Networks
PPDU	PHY Protocol Data Unit
PPLN	Periodically Poled Lithium Niobate
PPM	Pulse Position Modulation
PPN	Poly-Phase Network
PQA	Power Quality Analyzer
PRIME	PoweR-line Intelligent Metering Evolution
PS	Primary Substation
PSD	Power Spectral Density
PSDU	PHY Service Data Unit
PSO	Particle Swarm Optimization
PSSS	Parallel Sequence Spread Spectrum
PSTN	Public Switched Telephone Network
PTN	Packet Transport Networks
PU	Primary User
PV	Photovoltaic
PWM	Pulse Width Modulation
QAM	Quadrature Amplitude Modulation

QKD	Quantum Key Distribution
QoE	Quality of the User Experience
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RAN	Radio Access Network
RBAC	Role-Based Access Control
RC	Repetition Code
RDH-PIM	Reverse Dual Header Pulse Interval Modulation
RESs	Renewable Energy Sources
RFD	Reduced Function Device
RFID	Radio Frequency Identification
RF-Mesh	Radio Frequency Mesh
RLS	Recursive Least Square
RMS	Root Mean Square
RoCoF	Rate of Change of Frequency
RRC	Root-Raised-Cosine
RREP	Route Replay
RREQ	Route Request
RS	Reed–Solomon
RSA	Rivest–Shamir–Adleman
RTDSM	Real-Time Dynamic State Measurement System
RTN	Resources task network
RTO	Regional Transmission Operator
RTP	Real-Time Pricing
RTS	Request-to-Send
RTU	Remote Terminal Unit
RZ	Return-to-Zero
SAE	Society of Automotive Engineers
SAM	Spin Angular Momentum
SAR	Segmentation and Reassembly
SAS	Substation Automation System
SBA	Service-Based Architecture
SBS	Stimulated Brillouin Scattering
SC	Source Controller
SCADA	Supervisory Control and Data Acquisition System
SC-FDMA	Single Carrier Frequency-Division Multiple Access
SCL	Successive Cancelation List
SCMA	Sparse-Coded Multiple Access
SCPs	Shared Contention Periods
SCSM	Specific Communication Service Mapping
SD	Superframe Duration
SDH	Synchronous Digital Hierarchy
SDM	Space Division Multiplexing
SDN	Software-Defined Networks
SDO	Standard Developing Organization

SDR	Software-Defined Radio
SDSL	Symmetric Digital Subscriber Line
SDU	Service Data Unit
SE	State Estimator
SFB	Synthesis Filter Bank
SFG	Sum Frequency Generation
SFO	Sampling Frequency Offset
SG	Smart Grid
SGMM	Smart Grid Maturity Model
SHDSL	Single-Pair High-Speed Digital Subscriber Line
SHF	Super High Frequency
SHMS	Smart Home Management System
Si IGBT	Silicon-Insulated Gate Bipolar Transistor
SiC MOSFET	Silicon Carbide MOSFET
SISO	Single-Input Single-Output
SLM	Spatial light modulator
SM	Smart Meter
SMB	Server Message Block
SMF	Single-Mode Fiber
SMS	Short Message Service
SMTP	Simple Mail Transfer Protocol
SMV	Sampled Measured Value
SN	Service Node
SNMP	Simple Network Management Protocol
SNR	Signal-to-Noise Ratio
SOA	Semiconductor Optical Amplifier
SoC	State-of-Charge
SoF	Start-of-Frame
SOFC	Solid Oxide Fuel Cell
SoH	State-of-Health
SPM	Self-Phase Modulation
SPS	Special Protection Schemes
SPWM	Sinusoidal Pulse Width Modulation Method
SRS	Stimulated Raman Scattering
SS	Spread Spectrum
SSC	Substation Controller
SSCS	Service Specific Convergence Sublayer
SS-FSK	Spread Spectrum Frequency Shift Keying
SSH	Secure Shell
SST	Solid-State Transformer
STN	State Task Network
STO	Symbol Timing Offset
SU	Secondary User
SuS	Step-up Substation
SVMs	Support Vector Machines

TACS	Total Access Communication System
TASE	Tele-control Application Service Element
TCLs	Thermostatically Controlled Loads
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TCR	Thyristor Controlled Reactor
TDD	Time Division Duplex
TDM	Time-Division Multiplexing
TDMA	Time-Division Multiple Access
TFP	Time–Frequency Packing
TMR	Tone Mask Request
TOU	Time-Of-Use
TSCH	Time Slotted Channel Hopping
TSDA	Time Series Data Access
TSNs	Time-Sensitive Networks
TSO	Transmission System Operator
TT&C	Tracking Telemetry and Control
TVE	Total Vector Error
UDP	User Datagram Protocol
UFMC	Universal Filtered Multicarrier
UF-OFDM	Universal Filtered OFDM
UHF	Ultra-High Frequency
UL	Underground Line
ULA	Uniform Linear Array
UML	Unified Modeling Language
UMTS	Universal Mobile Telecommunications System
UNB	Ultra Narrowband
UPA	Universal Power-line Association
UPS	Uninterruptible Power Supply
uRLLC	Ultra-Reliable Low Latency Communications
U-SNAP	Utility Smart Network Access Port
UTC	Universal Time Coordinated
UWB	Ultra-Wide Band
UW-OFDM	Unique Word OFDM
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VANET	Vehicular Ad Hoc Network
VaR	Value at Risk
VDSL	Very-high-bit-rate Digital Subscriber Line
VHDSL	Very-High-bit-rate DSL
VLCs	Visible Light Communications
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network

VPP	Virtual Power Plant
VR	Voltage Regulator
VVO	Volt-VAR Optimization
W3C	World Wide Web Consortium
WAMPAC	Wide Area Monitoring, Protection and Control
WAMS	Wide Area Measurement System
WAN	Wide Area Network
WCDMA	Wideband CDMA
WDM	Wavelength Division Multiplexing
WEH	Wireless Energy Harvesting
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WL	Widely Linear
WLAN	Wireless Local Area Network
WL-CLMP	Widely Linear Complex-Valued Least-Mean Phase
WL-CLMS	Widely Linear Complex-Valued Least Mean Square
WL-CNLMS	Widely Linear Complex-Valued Normalized Least Mean Square
WL-CRLS	Widely Linear Complex-Valued Recursive Least Square
WMN	Wireless Mesh Network
WoT	Web of Things
WPAN	Wireless Personal Area Network
WRAN	Wireless Regional Area Network
WSN	Wireless Sensor Network
WT	Wind Turbine
XGM	Cross-Gain Modulation
XPM	Cross-Phase Modulation
ZF	Zero Forcing
ZP-OFDM	Zero-Padded OFDM
ZT-DFT-S-OFDM	Zero-Tail DFT Spread OFDM