Power Systems

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Microgrid Architectures, Control and Protection Methods

Springer

Power Systems

Electrical power has been the technological foundation of industrial societies for many years. Although the systems designed to provide and apply electrical energy have reached a high degree of maturity, unforeseen problems are constantly encountered, necessitating the design of more efficient and reliable systems based on novel technologies. The book series Power Systems is aimed at providing detailed, accurate and sound technical information about these new developments in electrical power engineering. It includes topics on power generation, storage and transmission as well as electrical machines. The monographs and advanced textbooks in this series address researchers, lecturers, industrial engineers and senior students in electrical engineering. ** Power Systems is indexed in Scopus**

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Dedicated to
all our teachers and colleagues
who enabled us to write this book,
and our family and friends
for supporting us all along

Foreword

There are specific interests for the integration of distributed generation systems and reliable consuming networks in the microgrid architectures. The microgrid topologies are designed as the innovative electrical systems, power distribution networks and also independent small power grids. The nature of microgrid operations includes ownership, reliability and locality. The microgrid development is mostly dependent on microprocessors and communication technologies to provide more complicated inverters and load controllers and also offer adequate bandwidth.

Microgrid control and protection based on different interfaces are also important concepts in combining power balancing, optimization and smart activating as grid-connected or islanded modes. The microgrid control and protection include the regulation of voltage and frequency and managing of real and reactive power for the generation units and energy storages.

The book generally explains the fundamentals and contemporary materials in microgrid architectures, control and protection. It will be very efficient for electrical engineers and researchers to have the book which contains important subjects in considering modeling, analysis and practice related to microgrids. The book comprises knowledge, theoretical and practical issues as well as up-to-date contents in these issues and methods for designing, controlling and protecting of AC–DC microgrid networks.

Some textbooks and monographs are previously presented for people who want to learn more on the microgrids. The worth of the present book is that it tries to put forward some practical ways for microgrid planning and modeling, control, protection, infrastructure, converters, energy storage systems, efficiencies, assessments and quality issues which are now more organized. The editors wisely designated the topics to be preserved, and the chapters written by well-recognized experts in the field are placed in three parts.

The book introduces the reader to the modeling, analysis, operation, control and protection of the microgrids. Then, the main subjects related to planning, converters, hybrid energy resources, energy management, adaptive and modified control and protection are presented and explained. The book also includes informative case studies and many instances.

The book can be used in the classroom, to teach microgrid courses to graduate students, and be suggested as further reading to undergraduate students in engineering sciences. It will also be a valuable information resource for the researchers and engineers concerned with microgrid issues or involved in the development of distributed generation applications.

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Preface

The microgrid researches have been extensively increased and widespread since the last decade. The enhanced use of distributed generation, distributed energy resources, renewable energy sources, energy storage technologies and increased power requirements has promoted microgrid researches. The improvements and outcomes of microgrid researches facilitate to overcome power system problems related to resiliency, flexibility, stability, efficiency and capacity limitations. A crucial component of this new grid type is apparently power electronics devices interfacing sources and utility grid. This interface is required to provide control and protection features depending on device topologies and control software.

Moreover, the generated and converted power should meet the grid codes and should comply with international standards in terms of power quality, efficiency and sustainability. The purpose of this book is to present a broader view of emerging microgrid architectures, control and protection methods and communication systems, approaching the following subjects: (1) presenting detailed surveys for a wide variety of microgrid architectures and emerging microgrid approaches; (2) concepts and visualization of microgrid concepts and related power electronics applications for improved microgrids; (3) providing detailed knowledge on wireless and emerging communication methods used for control and protection issues in microgrids; (4) presenting the virtual inertia and energy storage systems that are key components of microgrid integration to utility grid; (5) contents on relation of smart grid and microgrid applications along IoT and wireless communication systems; and (6) discussions on the issues related to deployment and development of control, protection and communication technologies at future microgrid scope.

Microgrid Architectures, Control and Protection Methods is a book aimed to highlight the microgrid operation and planning issues using different methods which include planning and modeling, AC and DC hybrid microgrid, microgrid infrastructure, power electronic converters in microgrid, energy storage systems in microgrid, energy management in microgrids, PV microgrids, microgrid control strategies, intelligent and adaptive control in microgrid, optimal microgrid operational planning, microgrid protection and automations, adaptive protection systems in microgrid, IEC 61850-based protection systems and also control and protection of smart microgrids.

A large number of specialists are joined as the authors of the chapters to provide their potentially innovative solutions and research related to microgrid operation, in order to be useful in developing updated approaches in electric power analysis, design and operational strategies. Several theoretical researches, case analysis and practical implementation processes are put together in this book that aims to act as research and design guides to help the graduates, postgraduates and researchers in electric power engineering and energy systems. The book presents significant results obtained by leading professionals from the industry, research and academic fields that can be useful to the variety of groups in specific areas analyzed in this book.

This book comprises 31 chapters structured in three parts as follows: Part I introduces in 12 chapters the microgrid architectures and the used power converters; Part II makes in 12 chapters a deep presentation of microgrid control systems; Part III highlights in 7 chapters the current issues of the microgrid protection systems. A brief introduction for readers on the contents of all chapters will be made below.

AC and DC microgrids and converters consisting of their modeling and operation are discussed in the chapters of Part I.

Chapter 1 presents an overview of microgrid concept, modeling, architectures and operation by presenting the main type of distributed energy resources (DERs) and networks based on renewable energy sources (RESs). The chapter also comprises a brief review of microgrid modeling studies based on the microgrid architectures and operation types in AC, DC and hybrid microgrid models.

Chapter 2 details the microgrid concepts by introducing the fundamentals of microgrids, with focus on microgrid planning and energy management considering the variability of the RES power due to environmental and weather conditions. The RES power is modeled using several different probability distributions, and the optimization strategies for microgrid planning have been proposed based on stochastic programming and deterministic mathematical models.

Chapter 3 explains the advantages and disadvantages of the microgrid architectures based on DC bus, AC bus, or hybrid DC and AC bus using modeling and case studies. The chapter consists of two parallel operated AC and DC microsystems including renewable AC sources of power, and AC–DC loads and power sources.

Chapter 4 details the DER concept and potential issues due to high penetration of DER-based microgrids with their technical characteristics in electrical power systems (EPSs) by presenting and discussing the main models for DER-based microgrids proposed in the literature.

Chapter 5 studies how the DERs dispersed throughout the network can be brought together based on the concept of virtual power plant (VPP), which turns them into active resources that function as a single centralized generating power plant, with the capacity to respond intelligently to variable load demand. The VPP is a technical, operational and economic concept that is located in the digital part of the microgrids and provides facilities that allow greater flexibility of the EPS.

The power electronic converters have been detailed in Chaps. 6 and 7 in terms of AC–DC rectifiers, inverters (DC–AC converters) and DC–DC converters used in DC and AC microgrids. So, Chap. 6 analyzes the main types, circuit structures and functions of power electronic converters used in DC microgrid and highlights the major advantage of DC microgrids compared to AC microgrids. Then, Chap. 7 analyzes the main power electronic converters used in AC microgrid and highlights the major advantage of AC microgrids compared to DC microgrids. The chapters review the main performance indicators and standards for DC and AC microgrids, respectively, and the conclusions are supported by simulation performed for some topologies.

Chapter 8 explains the important role of the energy storage system (ESS) in enhancing the stability of grid-connected and islanded microgrid by modeling the power flow balance on DC or AC buses and including appropriate case studies. The standards IEC/ISO 62264 and IEEE 2000 related to interconnection of the wind turbine farms and photovoltaic systems into microgrids have been presented as well.

Chapter 9 shows the design and experimental investigations of a fuel cell (FC)–electrolyzer-based energy storage system integrated into a microgrid. The hydrogen-based ESS based on proton-exchange membrane (PEM) FC system and solid polymer electrolyzer seem to be the best alternative to store energy due to their simple structure, high power density, quick start, no moving parts and superior reliability and durability, low operating temperature and environmental aspects.

Chapter 10 analyzes the requirements for the energy management system (EMS), which are identified as follows: (1) determining the amount of produced/consumed energy by the generation units/consumers; (2) ensuring the generation and consumption balance; (3) ensuring compliance and implementation of the rules for connecting the microgrid to the upper distribution system; (4) optimal utilization of its existing resources; (5) minimizing the overall operational costs; (6) separating the microgrid from the upper grid in case of emergencies; and (7) providing convenient control strategy for re-connecting to the upper network after the islanded operation. The role of subsystems of the energy management system (such as communication systems and smart meters) is also discussed in the frame of the main EMSs proposed in the literature, highlighting the pro and cons of the centralized and decentralized EMSs. The supervisory control and data acquisition (SCADA) system can be a solution for decentralized EMSs.

Chapter 11 proposes a technical solution to improve the efficiency of a photovoltaic (PV) power plant within an area of seventy hectares through control, surveillance, metering and monitoring of the system from distance. The SCADA system offers information in real time for the control system about total and daily energy delivered (kWh), weather info, alarms, etc. The received information can be compared with the data stored in the same period of the past years, in order to establish the productive efficiency of the PV power plant.

Chapter 12 analyzes the extremum seeking control (ESC)-based global maximum power point tracking (GMPPT) control for PV microgrids under partially shaded conditions. The influence of photovoltaic array topologies to multimodal PV characteristic and new materials like ferrite nano-core–shell (NCS) multilayer used to construct efficient PV cells based on thin-film transistors are also highlighted.

Part II includes the control of AC and DC microgrids and related strategies, requirements and challenges.

Chapter 13 emphasizes on the current controlling strategies of power converters operating in different modes with AC microgrids, which has the main advantage of compatibility with the existing AC EPS. So, from control point of view, converters are classified as grid forming, grid supporting and grid feeding converter. Anyway, the complexity of reactive power control and frequency issues as stability and synchronization make the DC to be very attractive.

Chapter 14 introduces the centralized, decentralized and distributed DC microgrid architectures and their control. Also, the most used standards related to DC microgrids and cyber-physical system (CPS) related to the power system field are presented. The advanced control of the utility converter has been developed and simulated.

Chapter 15 deals with the basic principles of microgrid control analyzing the local control, central control and emergency control. Also, being the most used control into the microgrids, the hierarchical control is presented. Since centralized control to split the reactive and active power is costly and difficult to be implemented, the decentralized and distributed control techniques will be analyzed in the next chapters.

Chapter 16 discusses the advantages of the hierarchical control in the frame of distributed control systems used in microgrids. The droop-based control algorithms are analyzed, being considered to be the most effective in terms of the stability of network voltage and reactive power sharing.

Chapter 17 analyzes different intelligent and adaptive control techniques proposed in the literature as a response to the difficulty of controlling highly complex and indeterminate nonlinear systems. The chapter provides new designs, at the cutting edge of true intelligent control, and shows directions for future research to improve the real-world applications of the intelligent and adaptive control.

Chapter 18 deals with the basic principles of operating the microgrid in emergency conditions, by analyzing the load shedding, emergency and local control considering uncertainties. The chapter focuses on developing a coordination control algorithm using emergency demand response (EDR) resources and under-frequency load shedding (UFLS) methods considering various probabilistic scenarios. It is worth to mention that the emergence of smart metering system (SMS) has been implemented at the level of majority of distribution grid operators (DGOs) as real-time information about the consumed and produced electricity to take technical measures for efficiently operating the microgrid.

Chapter 19 analyzes the aforementioned solutions to be implemented in smart metering-based strategies for improving energy efficiency in microgrids. The new methods proposed for load modeling, phase load balancing and voltage control are tested using real microgrids.

Chapter 20 proposes the optimal microgrid operational planning (OMOP) approach for DERs, considering wind and photovoltaic power generations, combined heat and power generation units, electrical energy storages and interruptible loads. The OMOP based on a two-level optimization under system uncertainties has been detailed in this chapter.

Chapter 21 analyzes the outage problem that occurs due to weaknesses of the power system infrastructure or the occurrence of human or natural faults in the EPS. The self-healing is presented in this chapter as one of the main abilities of the smart grids to automatically retrieve system after fault occurrence or keep away system from critical conditions. So, the definition, requirements and challenges of self-healing are introduced, and some tools and methods like demand response, load shedding, distributed energy resources and autonomous microgrids which can facilitate self-healing process are assessed.

Chapter 22 further analyzes various droop-based control strategies and shows simulation of some prevalent ones to assess the strength and weakness of each approach. The droop control does not require communication infrastructure and reduces the complexity for implementation, less cost for system maintenance, which improves the reliability indices. Besides the droop controllers, the fuzzy logic (FL)-based controllers have been markedly developed in order to be used in various microgrid applications due to their simple structure, easy implementation and adaptive behavior.

Chapter 23 analyzes in detail the adaptive controlling mechanisms and dynamic efficiencies based on FL-based PID controller. Different control strategies based on fuzzy PID-type controller for controlling microgrids are also described and discussed in this chapter.

Chapter 24 proposes an innovative control structure of the reinforcement learning (RL) based on PID controller to enhance the frequency fluctuations of a hybrid microgrid with a high RESs penetration. The RL algorithms can be used to learn the optimal control policy from interaction with the environment of the system. It is worth mentioning the new applications of RL algorithms in EPS control.

As it was mentioned before, the chapters in Part III focus on microgrid protection techniques.

Chapter 25 introduces the microgrid protection techniques highlighting the close connection between the Internet of things (IoT) and the development of the smart grids. The methods for increasing the microgrid resilience to extreme disruptions and shocks posed by natural, man-made or random events are presented. The chapter presents protection solutions closely with international standards for both DC and AC networks, considering the technical requirements of the microgrids and by using different topology. Therefore, the conventional protection and control systems need to be improved to overcome current difficulties, offering reliable protection and control for grid-connected and islanded microgrids, as will be shown in the next chapters.

Chapter 26 deals with the protection and automation requirements of the microgrids in the frame of smart grid, including the protection schemes and developments in the related fields. The chapter concentrates on devolution of power generation and the conversion of the radial distribution network into a microgrid. It also discusses on the protection and control requirements of a microgrid, islanding detection and management scheme.

Chapter 27 presents the fault detection methods and protection devices in low-voltage DC (LVDC), medium-voltage DC (MVDC) and high-voltage DC (HVDC) grids. The main protection schemes are presented regarding DC microgrids. The fault detection methods are surveyed considering voltage prediction, disturbance detection, and fault classification and locating methods.

Chapter 28 analyzes the solutions for protecting smart grids using the protocol IEC 61850 based on intelligent electronic devices (IEDs). Based on case studies, the chapter presents the remote-controlled reclosed scheme, the adaptive protection of a distributed system based on the loop automation scheme and the main advantages for the consumers by implementing the restoration scheme.

Chapter 29 presents the protection techniques based on the IEC 61850 protocol using case studies for data communication systems between substations. The IEC 61850 is implemented for real-time communication between IEDs based on Generic Object Oriented Substation Event (GOOSE) messages.

Chapter 30 highlights the main power quality issues in the microgrid, and solutions to handle these issues and their operating principle are explained. Load pulses are frequently encountered in microgrid and need to be mitigated using appropriate control of hybrid energy storage system (ESS) based on different power storage devices such as the ultracapacitors (UCs) stacks, superconducting magnetic energy storage (SMES) devices and high-speed flywheel energy systems (FESs).

Chapter 31 approaches the control and protection of the smart microgrids using the concepts from IoT and highlights the IoT role in creating and developing smart microgrids, including benefits, challenges and risks, in order to reveal a variety of mechanisms, methods and procedures built to control and protect smart microgrids. Thus, microgrids must benefit by large opportunity to implement the IoT mechanisms, because they are composed of equipment that demands sensing, connectivity and analytics technologies to operate at the highest level.

Therefore, the proposed book tries to clear the aforementioned approaches, by presenting intuition explanations about principles and application of microgrid structure and operation. Moreover, the book tries to put forward some practical ways for microgrid analysis.

Moreover, the book will be helpful for the future research to be done in the field of electrical engineering and communication engineering. It also explores the recent progress on several microgrid control and protection technologies and their performance evaluation. The book has the wider coverage ranging the topics from essentials of microgrids to enhanced communication systems such as wireless and Internet of things (IoT). It can also help in understanding the role of emerging communication systems such as the Internet of things (IoT), wireless communication and IEC 61850-based networks in microgrids.

We hope that this book will be helpful for young researchers and practitioners in the area of electrical engineering. The editors and authors made all efforts to have a good book and hope interested readers to enjoy by reading this book and to be satisfied by its content.

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Abbreviations and Acronyms

5G	5th Generation
AAFC	Aqueous Alkaline Fuel Cell
AC	Alternative Current
ACE	Area Correction Error
ACMG	Alternating Current Microgrid
ACS	Ant Colony System
ADC	Analog-to-Digital Converter
ADM	Alternating Direction Method
ADN	Active Distribution Network
AE	Aqua Electrolyzer
AES	All-Electric Ship
AFC	Alkaline Fuel Cell
AGC	Automatic Generation Control
AHC	Adaptive Heuristic Critic
AI	Artificial Intelligence
AMI	Advanced Metering Infrastructure
ANN	Artificial Neural Network
ANSI	American National Standards Institute
aPESC	Asymptotic PESC
aPESCH1	Asymptotic PESC based on FFT
APP	Auxiliary Problem Principle
AR	Average Reward
ARR	Automatic Release of Reserve
AS	Ancillary Services
ATS	Automatic Transfer Switch
AVR	Automatic Voltage Regulator
BCBG	Bottom-Contact Bottom Gate
BESS	Battery Energy Storage Systems
BOS	Balance of System
BPDC	Bipolar DC

BPF	Band-Pass Filter
BTC	Bay Template Configurator
CAA	Central Agent Architecture
CAES	Compressed Air Energy Storage
CAULSC	Centralized Adaptive UFLS Controller
CB	Circuit Breaker
CC	Central Controller
CCM	Continuous Transmission Mode
CDF	Cumulative Distribution Function
CEI	Italian Electrotechnical Committee
CEMS	Central Energy Management System
CHP	Combined Heat and Power
CIU	Communication Interface Unit
CNT	Carbon Nanotube
CPP	Critical Peak Pricing
CPS	Cyber-Physical System
CPU	Central Processing Unit
CRM	Critical Transmission Mode
CS	Centralized System
CSI	Current Source Inverter
CT	Current Transformer
CU	Control Unit
CUF	Current Unbalance Factor
DA	Day Ahead
DA	Distribution Automation
DAA	Decentralized Agent Architecture
DAB	Dual Active Bridge
DC	Direct Current
DCM	Discontinuous Conduction Mode
DCMG	Direct Current Microgrid
DCS	Distributed Control System
DDoS	Distributed Denial of Service
DE	Differential Evolution
DEG	Diesel Engine Generator
DER	Distributed Energy Resource
DES	Distributed Energy Storage
DFIG	Double-Fed Induction Generator
DG	Distributed Generation
DGR	Distributed Generation Resource
DLC	Direct Load Control
DLS	Dynamic Light Scattering
DLSC	Determined Load Shedding Calculator
DMMA	Data Model Manager Application
DMS	Distribution Management System
DN	Distribution Network

DNO	Distribution Network Operator
DNP	Distributed Network Protocol
DO	Distribution Operator
DOD	Depth of Discharge
DOE	Department of Energy
DOR	Directional Overload Relay
DoS	Denial of Service
DOS	Density of States at a Semiconductor Surface
DP	Disconnection Priority
DPC	Direct Power Control
DR	Demand Response
DRPs	Demand Response Programs
DS	Decentralized System
DS	Distribution System
DSE	Distribution State Estimator
DSG	Dispersed Storage and Generation
DSI	Distributed Signaling Interface
DSM	Demand-Side Management
DSO	Distribution System Operator
DSS	Decision Support System
DSTATCOM	Distribution STATCOM
DVR	Dynamic Voltage Restorer
E/P	Energy-to-Power Ratio
EA	Energy Arbitrage
EA	Evolutionary Algorithms
EDG	Electric Distribution Grid
EDP	Economic Dispatch Problem
EDR	Emergency Demand Response
EDS	Electrical Distribution System
ELZ	Electrolyzer
EMI	Electromagnetic Interference
EMS	Energy Management System
EN	European Standard
ENS	Energy Not Supplied
ENSC	Energy Not-Supplied Cost
EPRI	Electric Power System Research Institute
ES	Expert System
ESC	Extremum Seeking Control
ESD	Energy Storage Device
ESM	Energy Surety Microgrid™ Technology
ESS	Electrical Storage System
ESS	Energy Storage System
EU	European Union
EUE	Maximum Permissible Level of Unmet Power
EV	Electrical Vehicle

FAR	Frequency Ancillary Reserves
FB	Full Bridge
FC	Fuel Cell
FCAS	Frequency Control Ancillary Services
FCTS	Fuel Cell Test Stand
FEH	Fire Emblem Heroes
FESS	Flywheel Energy Storage System
FET	Field-Effect Transistor
FFT	Fast Fourier Transform
FL	Fuzzy Logic
FLC	Fuzzy Logic Controller
FLES	Flywheel Energy System
FLISR	Fault Location Isolation Service Restoration
FLL	Frequency-Locked Loop
FPID	Fuzzy PID
FTD	Frequency's First Time Derivative
GA	Genetic Algorithm
GAAS	Gallium Arsenide
GAPC	Grid Active Power Converter
GaPESC	Global aPESC scheme based on one BPF
GaPESCbpf	Global aPESC scheme based on two BPFs
GaPESCd	Global aPESC scheme based on derivative operator
GaPESCH1	Global aPESC scheme based on FFT
GCI	Grid-connected Inverter
Gd	Signal which modulates the dither
GDB	Governor Dead Band
GIO	Generic Inputs/Outputs
GMPP	Global Maximum Power Point
GMPPT	Global Maximum Power Point Tracking
GOOSE	Generic Object Oriented Substation Event
GPS	Global Positioning System
GRC	Generation Rate Constraint
GTG	Gas Turbine Generator
GTO	Gate Turn-Off Thyristor
GUI	Graphical User Interface
H1	First Harmonic of a Signal
HAA	Hierarchical Agent Architecture
HAN	Home Area Network
HC	Hill Climbing
HEM	Home Energy Management
HERIC	High-Efficiency Reliable Inverter Concept
HESS	Hybrid Energy Storage System
HFAC	High-Frequency AC
HHVCB	Hybrid HV Circuit Breaker
HMG	Hybrid Microgrid

HMI	Human–Machine Interface
HOMO	Highest Occupied Molecular Orbital
HPF	High-Pass Filter
H-PLB	Heuristic Phase Load Balancing
HPS	Hybrid Power System
HRE	High Reliable and Efficient Power Inverter
HR-ZVR	Hybrid Zero-Voltage Rectifier
HSFES	High-Speed Flywheel Energy Storage
HSS	Hybrid Storage System
HV	High Voltage
HVAC	Heating, Ventilation, and Air Conditioning
HVDC	High-Voltage DC
IBP	Incentive-Based Program
IC	Incremental Conductance
ICC	Incremental Cost Consensus
ICCB	Isolated Case CB
ICP	Internet Communication Protocol
ICT	Information and Communication Technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated-Gate Bipolar Transistor
ILs	Interruptible Loads
IO	Inputs/Outputs
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
ITAE	Integral of Time Multiplied by Absolute Error
ITOC	Inverse Time Overcurrent
LC	Local Control
LCA	Life Cycle Assessment
LD	Logic Device
LED	Light-Emitting Diode
LF	Load Flow
LFAC	Low-Frequency AC
LFC	Load Frequency Controller
LMPP	Local Maximum Power Point
LN	Logical Node
LP	Linear Programming
LQR	Linear–Quadratic Regulator
LS	Load Shedding
LSFES	Low-Speed Flywheel Energy Storage
LUMO	Lowest Unoccupied Molecular Orbital
LV	Low Voltage

LVDC	Low-Voltage DC
LVG	Low-Voltage Grid
LVRT	Low Voltage Ride Through
M2M	Machine to Machine
MAC	Media Access Control
MACCB	Mechanical AC Circuit Breaker
MAPE	Mean Absolute Percentage Error
MAS	Multi-Agent System
MC	Microgeneration Control
MCB	Mechanical Circuit Breaker
MCCB	Molded Case CB
MCCS	Microgrid Central Control System
MCFC	Molten Carbonate Fuel Cell
MCL	MiCOM Configuration Language
MCS	Microsource Control System
MCT	MOS-Controlled Thyristor
MDMS	Meter Data Management System
MEC	Microgrid Emergency Control
MEMS	Microgrid Energy Management System
MF	Membership Function
MG	Microgrid
MGCC	Microgrid Central Controller
MGMS	Microgrid Management System
MGO	Microgrid Operator
MGOS	Microgrid Operation State
MILP	Mixed Integer Linear Programming
MINLP	Mixed Integer Nonlinear Programming
MLI	Multilevel Inverter
MMC	Multi-Modular Converter
MMS	Manufacturing Messaging Specification
MN	Micro-Network
MOSFET	Metal–Oxide–Semiconductor Field-Effect Transistor
MP	Multilayer Perception
MPC	Model Prediction Control
MPI	Message Passing Interface
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MU	Merging Unit
MUT	Master User Terminal
MV	Mean Value
MV	Medium Voltage
MVA	Mega-Volt-Ampere
MVDC	Medium-Voltage DC
NCS	Nano-Core–Shell
NCS-TFT	Thin Film Transistors with Nano-Core-Shell materials

NLP	Nonlinear Programming
NOCT	Normal Cell Operating Temperature
NPC	Neutral Point Diode Clamped
OC	Operating and Contingency
OECD	Organisation for Economic Co-operation and Development
oH5	Optimized H5
OMOP	Optimal Microgrid Operational Planning
OPF	Optimal Power Flow
OPL	Overhead Power Line
OSC	Organic Solar Cell
OSI	Open Systems Interconnection
OTFT	Organic Thin-Film Transistor
P&O	Perturb and Observation
PABA	Para-Aminobenzoic Acid
PAFC	Phosphoric Acid Fuel Cell
PBP	Price-Based Program
PC	Primary Control
PCC	Point of Common Coupling
PCE	Power Conversion Efficiency
PCPM	Predictor-Corrective Proximal Multiplier Method
PD	Physical Device
PDF	Probability Density Function
PE	Protective Earth
PEM	Proton-Exchange Membrane
PEMFC	Proton-Exchange Membrane Fuel Cell
PESC	Perturbed-Based Extremum Seeking Control
PEV	Plug-in Electric Vehicle
PFC	Power Factor Correction
PFR	Primary Frequency Regulating
PG	Power Grid
PHC	Percent of the Hit Count
PHES	Pumped Heat Electrical Storage
PI	Proportional–Integral
PID	Proportional–Integrative–Derivative
PLC	Power Line Communication
PLL	Phase-Locked Loop
PLSC	Pre-determined Load Shedding Calculator
PMSG	Permanent Magnet Synchronous Generator
PMU	Phasor Measurement Unit
PP	Pre-disturbance Preparation
PPI	Payment Protection Insurance
PQ	Power Quality
PR	Proportional Resonance
PS	Power System
PSC	Partially Shaded Condition