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Introduction

1.1 Overview

This chapter provides an introduction and a general description of the present book, *Microgrids: Dynamic Modeling, Stability and Control*; and emphasizes its role in explaining the important relevant issues in a systematic and understandable way. *Microgrid dynamic modeling, stability, and control* addresses modeling methodologies and application of control theorems and relevant technologies to stability analysis and enhance the microgrid (MG) functions during real-world operations. The MGs' stability and control refer to keeping the desired performance and stabilizing of MGs following various disturbances, such as loss of distributed energy resources (DERs) and/or load units.

The capacity of installed inverter-based DERs and renewable energy sources (RESs) individually or through the MGs in power systems is rapidly growing, and a high penetration level is targeted for the next decade. Nowadays, increased needs for electrical energy and environmental concerns besides growing attempts to reduce dependency on fossil fuel resources have caused power grid industries to set an ambitious target on DERs/RESs. Most of the mentioned microsources connect to the power grid through the MGs as essential blocks of smart grids. The MGs can also operate independently as islanded small grids [1, 2].

MG control is becoming more significant today due to the changing structure, high penetration of RESs/DERs, environmental constraints, and increasing uncertainties of power grids. Moreover, modeling and stability analysis is a basic study, which is necessary for MGs to provide a secure operation. Both small-signal and dynamic stability analyses are important to fully identify the role of different MG subsystems in the overall MG stability [3]. Nevertheless, the stability studies, in turn, are based on dynamic modeling of MGs. In addition, many control methods use the dynamic model to design the controller. Therefore, the first step of stability analysis and model-based controller synthesis is finding an appropriate model for these systems. To go step by step with the stability analysis and the control of MGs, basic and new facilitating dynamic modeling methods of MGs are discussed in this book. The state space representations are obtained as small-signal models, and nonlinear models are represented to investigate large-signal disturbances.

The potential of much more flexibility has been revealed for MGs once the idea of interconnected microgrids (IMGs) was presented. IMGs provide a new operation mode in addition to the islanded and grid-connected modes, where the new MG provides higher capacity than the individual MGs [4]. Therefore, the flexibility of supplying consumers and optimized operating DERs/RESs increases. Moreover, reliability, resiliency, sustainability, and supply security improve with respect to the individual MGs. This new operating mode permits IMGs to exchange power to support the

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frequency/voltage of a critical MG in an emergency condition as well as supply power deficits in a planned manner [5]. IMGs are also able to be connected to the utility grid to profit from power selling and purchasing when it is required [6]. The idea of MGs interconnection can also be beneficial to divide an active distribution network into some financially independent MGs, while they are connected physically and have power exchanges. In such a new configuration and correlated electricity market, the energy consumption will be more economical. However, this interconnected system is very challenging in terms of modeling, stability assessment, and control architecture. The present book addresses these important issues in a systematic and understandable way.

1.2 Microgrid Concept and Capabilities

The MG concept provides a quite appealing solution for integrating DERs and RESs into power grids. The increasing interest in penetrating renewable energy power into the power grid among the MGs highlights the importance of these systems and addresses serious stability and control challenges in MGs design and operation.

The MGs are small electrical distribution systems that connect multiple customers to multiple DERs/RESs and storage systems. The MGs are typically characterized by multipurpose electrical power services to communities that are connected via low-voltage (LV) networks. A great interest is that these hybrid power grids have the potential to provide reliable power supply to remote communities where connection to transmission supply is unreasonable economically. In general, the MG concept assumes a cluster of loads and DERs/RESs operating as a controllable system that provides both power and heat to its local area. The benefits of MG, such as the enhancement of local reliability, the reduction of feeder losses, and the control of the local voltage, provide increased efficiency through the use of waste heat from combined heat and power (CHP) generators, the voltage sag correction or the provision of uninterruptible power supply functions [3].

With a high integration of DERs/RESs, various challenges in power grid reliability, stability, and efficiency are born. Recently, a complete view of the challenges appeared by the penetration of DERs/RESs and MGs is given by the researchers and engineers. The MG was introduced as a proper response to most challenges [2]. Indeed, studies show that MG is a solution to manage some new challenges and adds a valuable capability such as managing/creating desirable behaviors in modern power grids [7, 8]. In fact, in the energy production process, the behavior of MGs, their impact on the power grid, and the quality of produced energy can be comprehensively managed using appropriate MG controls [3, 9].

The MGs provide various capabilities, the most important of them are shown in Figure 1.1. Some of these capabilities are operating in different operation modes, simple circuitry and low-cost implementation, high efficiency and reliability, high flexibility and power quality, grid supporting and ancillary services, black start and expandable properties, fast response, and wide applications.

1.3 Microgrid Structure

The MGs comprise dispersed energy resources like wind turbines, photovoltaic (PV) panels, microgas turbines, and storage devices like flywheels, super-capacitors, fuel cells, and batteries, as well as controllable loads and electric vehicles (EVs). Generally, an MG is centrally controlled and managed by a microgrid central controller (MGCC) installed at the medium-voltage

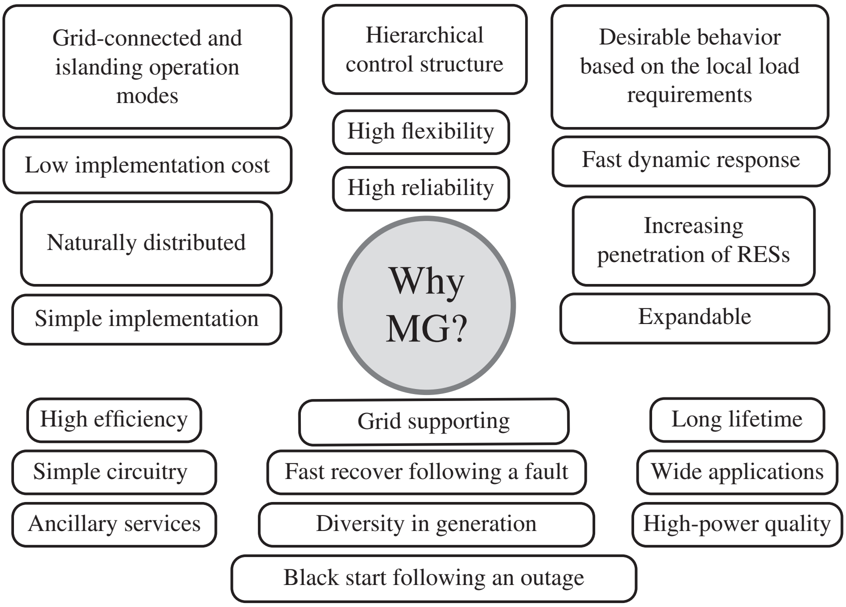

Figure 1.1 Microgrids capabilities.

(MV)/low-voltage (LV) substation [3, 10]. The MGCC includes several key functions, such as economic management and some overall control functionalities as the top point of the MG hierarchical control system. At the low hierarchical control level, load controllers (LCs) and microsource controllers (MCs) exchange information with the MGCC for managing the MG operation by providing set points to the LCs and MCs.

As mentioned, the MG is intended to operate in two different operating modes, i.e. the normal interconnected mode with a distribution network or other MGs, and the islanding operation mode. Most DERs/RESs installed in an MG are connected to the MG feeders and loads via power electronic interfaces. The MG is connected to the main grid (distribution system) or other MGs through a static switch (SS) or a circuit breaker (CB), at the point of common coupling (PCC). A general structure of an MG that can operate in both connected and islanded operation modes is shown in Figure 1.2.

In emergency conditions, e.g. following a serious fault in the main grid or other connected MGs, the MG can be disconnected from the main grid via SSs, as smoothly as possible. Before reconnection, the MGCC must implement the synchronization between the MG and the connected MGs/main grid.

The MG can be also islanded intentionally for specific reasons, even though there is no disturbance or serious fault in the main grid side. The balance between generation and demand of power is one of the most important requirements of MG management in islanded operation mode [3, 11].

The MG has a hierarchical control structure with different layers. The secure operation of MGs in different operation modes, as well as successful disconnection or reconnection processes, depend upon the MG control and protection systems. The controllers must guarantee seamless operation processes and safe working in the specified operating points. In an interconnected distribution network, each MG is locally controlled by the MGCC via its MCs and LCs. The LCs are installed at the controllable loads to provide load control capabilities, specifically for load shedding and demand

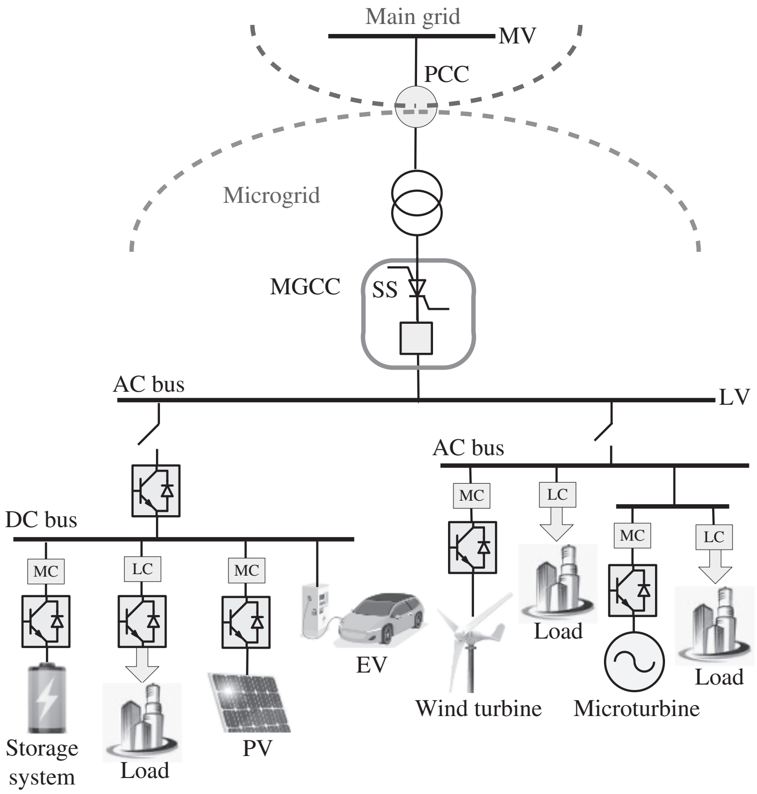

Figure 1.2 Microgrid structure.

response functionalities. For each MG, the MGCC interfaces with the distribution network operator (DNO) and the connected MGs. The DNO has the responsibility to manage the power exchange and operation of medium- and low-voltage areas in which more than one MG may exist [3].

The MG's control levels can be mainly classified into four control groups [3, 12]: local (primary), secondary, central, and global controls. The first three levels are associated with the operation of the MG itself, and the fourth level (global control) demonstrates the coordinated operation of the MG and neighbor MGs as well as the main grid. In contrast to the local control, operating without communication; secondary, central, and global controls may need communication channels. While the local controls are known as *decentralized* controllers, the other controllers may operate as *centralized* controllers.

The *local (primary) control* deals with initial primary control such as current and voltage control loops in the DERs/RESs. The *secondary control* ensures that the frequency and average voltage deviation of the MG are regulated toward zero after every change in load or supply. It is also responsible for local ancillary services. The *central control* covers all possible emergency control schemes and special protection plans to maintain the MG stability and availability in the face of contingencies. The emergency controls identify proper preventive and corrective measures that mitigate the effects of critical contingencies. The *global control* allows MG operation at an economic optimum and organizes the relation between an MG and the main grid as well as other connected MGs. Figure 1.3 represents the MG hierarchical control structure in an interconnected network of MGs with the main grid. These issues are well described in Chapter 5.

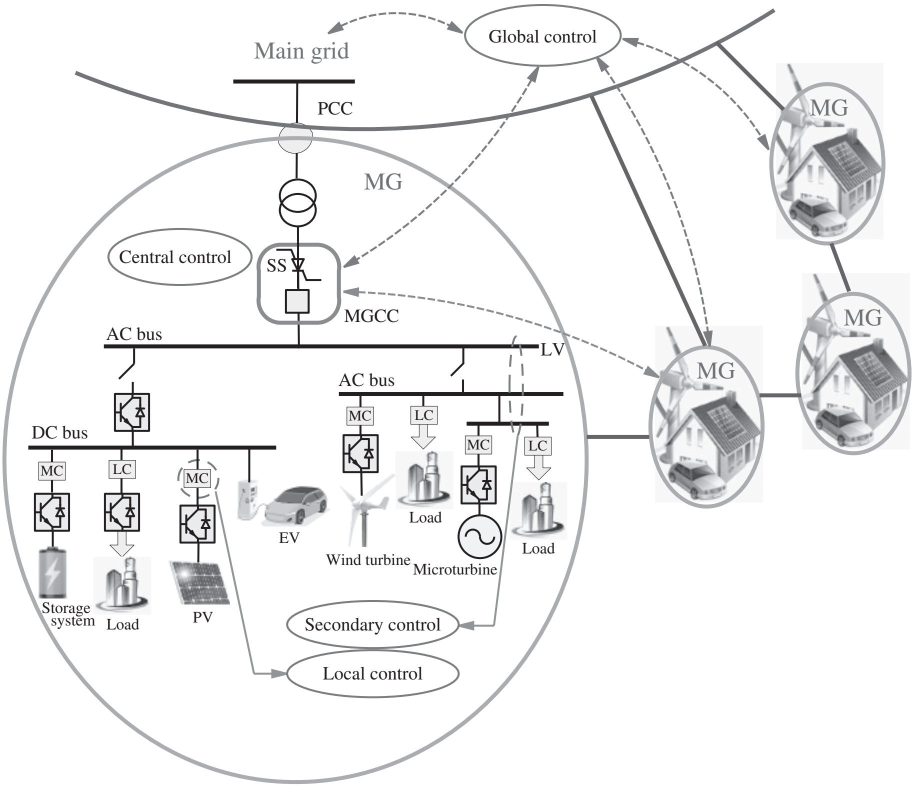

Figure 1.3 Microgrid with a hierarchical control structure in an interconnected distribution network.

1.4 Microgrids in the Future Smart Grids

The growing integration of MGs with power electronic-based DERs and loads has created new challenges in the operation and control of a modern power grid which is also known as smart grid. The conventional power system is challenged by environmental concerns, losses, and an increasing need for electric energy. In most countries, this system is in transition from a conventional hierarchical centralized structure with a one-way communication of power and data between generation and demand sides to a smart power grid with bidirectional exchange networks.

In a conventional power system, the electric network is not fully observable and controllable due to a limited number of sensors, flexible actuators, and appropriate control systems. Most of the operation and control processes, even the system restoration procedures, are accomplished manually. A smart grid makes a compromise between environmental needs, economic and efficiency issues, as well as system reliability. It is a fully sensor-enabled system with self-monitoring and self-healing capabilities.

A smart grid performs a network of DERs/RESs/MGs, with decentralized and distributed pervasive control and operation systems. In a smart grid, remote and automatic monitoring/control is dominant with a high diversity in both generation and demand. In addition to full generation/load control, emerging numerous DERs/RESs and MGs, as well as a wide network of monitoring units can be considered as new characteristics of smart grids.

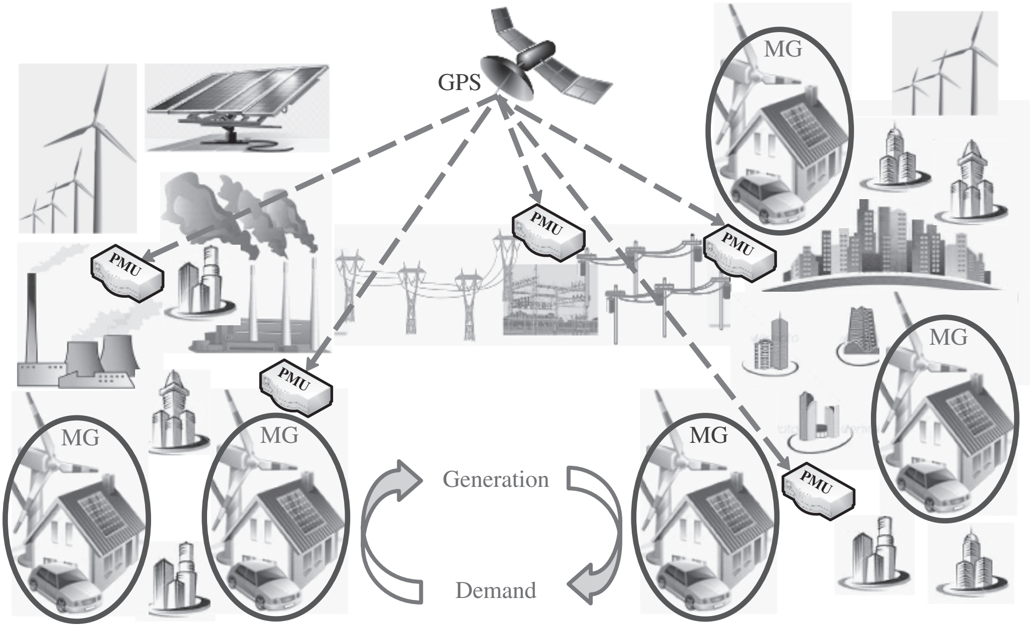

Figure 1.4 Conceptual representation of a smart grid.

The structure of a smart grid is conceptually shown in Figure 1.4. The system variables can be measured with distributed advanced sensors such as intelligent electronic devices (IEDs) and phasor measurement units (PMUs). These sensors can be synchronized by the global positioning system (GPS) via satellites [13].

The need for fast numerical calculating and data processing algorithms, facing a highly decentralized control structure with significant uncertainty, intermittent nature of RESs, reducing system inertia, as well as the necessity of updating grid codes and conventional dynamic analysis and control synthesis methods are the main challenges associated with the smart grid and MG integrated power systems. On the other hand, using smart wide-area monitoring and adaptive control systems, flexible demand response capabilities, regulation and ancillary services supports from the MGs, and constructive virtual dynamics emulation are some promising solutions in response to the mentioned challenges.

The main dynamic performance and stability concerns in a smart grid can be caused by the reduction of the system rotational inertia, as MGs with power converters gradually replace conventional power plants. Reducing rotational inertia in a smart grid can negatively affect the system response and may degrade the control capability and performance. This may lead to significant fluctuation in grid frequency, angle, and voltage, and even system instability [14].

Decreasing smart grid inertia due to the high integration of low-inertia DERs and MGs makes load-power balancing and frequency regulation extremely challenging. The intermittency of renewable power generation significantly magnifies this issue. Emulation of inertia and proper shaping of injected power from the controlled MGs and grid-connected converters [15] are promising solutions and may improve the grid robustness against various disturbances and reduce power fluctuations and parameter perturbations. Due to the fast response of MGs, this supplementary regulation power makes an effective impact in a short period.

Although MGs increase flexibility in the operation and regulation of power requirements, the high integration of RESs-based MGs in smart grids reduces system rotational inertia. The grid-connected MGs can receive the required operation/control set-points and references from the corresponding electric utility to produce the required regulation power support. These references are distributed between the existing MGs to determine the amount of contribution for each participant MG in the grid power regulation.

According to the initial objectives, an MG can operate in the grid-connected mode and supply a part of its load by the grid. However, in the case of any failure, which may result in a deviation of frequency and voltage of the main grid, the MG should disconnect from the grid and supply the loads autonomously by its microsources and existing energy storage systems (ESSs) which have been charged during the grid-connected mode. This characteristic will be served by modern MGs. In addition to the typical responsibility of converting the output power of resources to their own loads at a desired level, MGs control the voltage and frequency of DERs/RESs by adjusting the relevant set points. The enhancement of MGs' capabilities and control functionalities accelerates their integration into the smart grid as a service provider [16].

1.5 Microgrids-Integrated Power Grids

The capacity of installed MGs with converter-based DERs in modern power grids is rapidly growing, and a high integration level is expected for the next decade. A schematic diagram of an MG-integrated power grid with distributed PMUs is shown in Figure 1.5.

The increase of converter-based MGs in modern power grids has an important impact on CO_2 reduction and environmental pollution; however, this integration may have some undesirable impacts on smart grid dynamics, frequency, and voltage regulation.

The impacts of MGs on power grids' dynamic response, performance, and stability have been discussed in numerous reports over recent years. Whether a low inertia due to the high integration of the converter-based MGs can negatively affect the grid frequency dynamic performance and stability is investigated. Since the electric industry seeks to reliably integrate large amounts of MGs into the power grid in a secure environment, a considerable effort is needed to accommodate and effectively manage the installed distributed MGs.

A significant share of MGs increases the total system generation power, while mostly not contributing to the system rotational inertia, and requires the update of traditional control schemes because these well-known control schemes may fail in a modern power grid with lower inertia and faster dynamics.

For MG controllers' design in different control layers, usually reduced-order linearized models around the system operating points are used, and it is assumed that all MG parameters are known and time-invariant. These assumptions, however, are not valid in real MGs with dominated converter-based DERs. The main dynamic modes of the MG vary stochastically during the day because of the variation of load and system parameters, and a fixed linearized time-invariant model will not correctly represent the behavior of the MG.

Reduction in the cost of electricity transmission infrastructure from utilizing distributed energy resources has increased the integration of MGs. As mentioned, the modern MGs, in addition to participation in the electricity market, can offer some services such as improving inertia response and voltage/frequency regulation. These characteristics have brought the opportunity of employing MGs as ancillary service providers in a smart grid. With a proper design of MG control systems, they

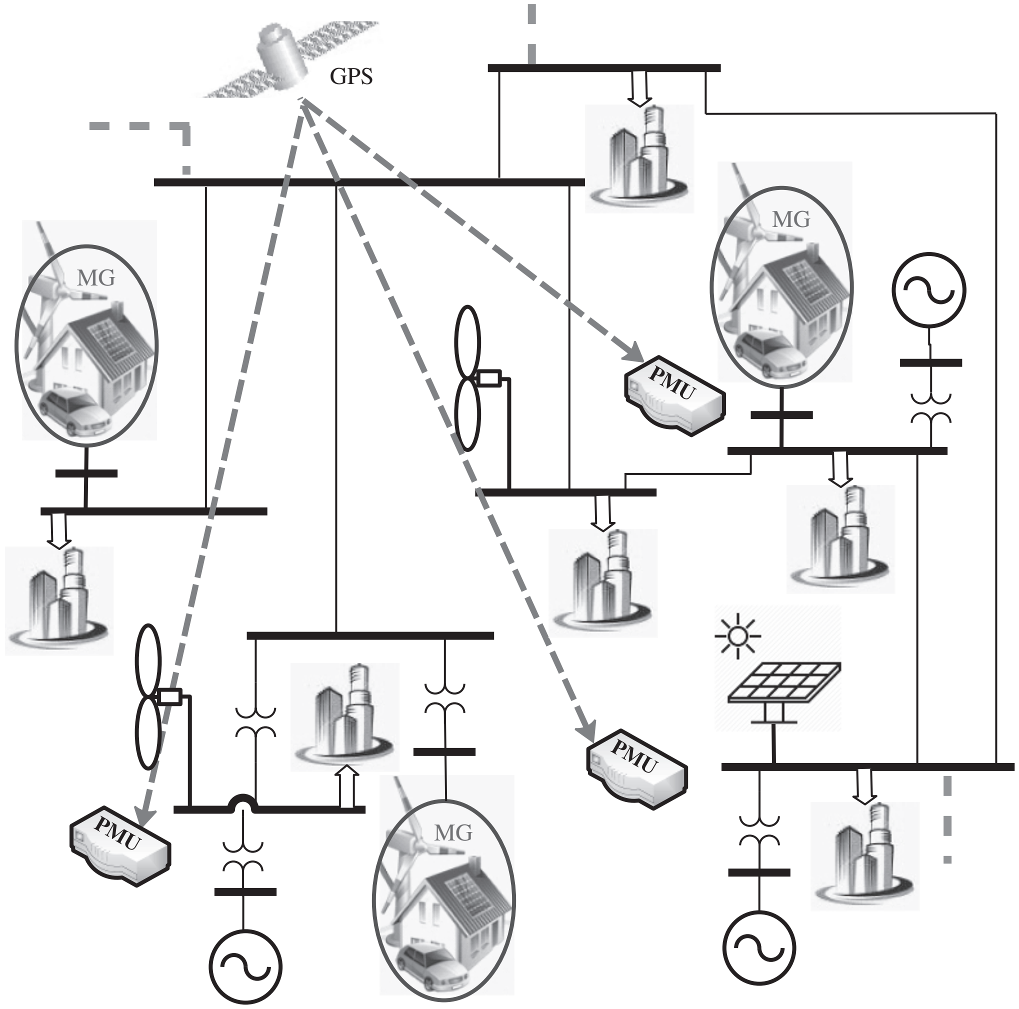

Figure 1.5 Microgrids-integrated power grid.

can contribute to power grid control and provide some services which are traditionally provided by conventional power plants.

1.6 Current Trends and Future Directions

Most current research activities in the field of MGs modeling, stability, and control rely on the assumption that they are working in nominal operating points. However, due to nonlinearities, and changes in system parameters and operation state, the MG dynamic response is becoming more changeable. Consequently, the MG dynamics characteristics may affect the operation of power grid relaying, power quality management and monitoring, and other grid operation and control issues.

To this end, proper MG dynamics estimation and modeling play an important role in modern power grids. It is also important to consider the concept of resilience in MG operation and control issues. This attempt aims to increase the resilience of MG control systems against cyber-attacks

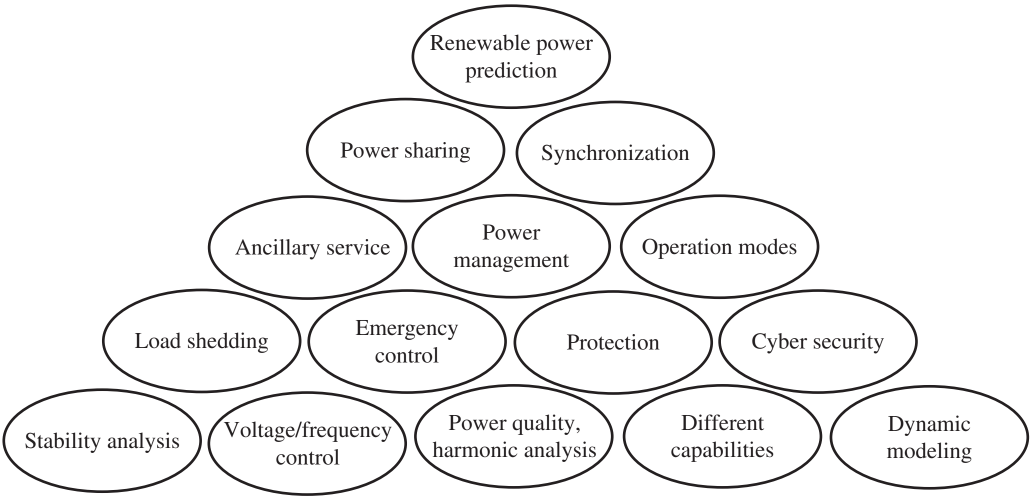

Figure 1.6 Most important topics in microgrids.

and the resulting manipulations. To facilitate a higher penetration level of DERs/RESs, it is also necessary to take benefit of the additional virtual inertia created by grid-forming converters individually or through the MGs for improving the grid dynamic performance and stability [16–18]. The most important MGs research trends and issues are presented in Figure 1.6. These topics include islanded and connected operation modes, active and reactive power sharing, synchronization methods, ancillary and regulatory services, dynamic modeling and parameter estimation, stability analysis, voltage and frequency control, load shedding and emergency control, cyber-security, renewable power prediction, protection schemes, power/energy management, power qualities and harmonic analysis, and various MGs capabilities.

The unpredictability of load is also an important challenge in MG control. Loads are becoming more and more erratic, especially in the distribution grids with electric transportation systems. These grids, without a global control system, can only rely on appropriate control of DERs set points for desirable dynamic shaping of output active and reactive power.

Recent works show the high capability of MGs as the main blocks of future smart grids to contribute to grid performance enhancement and control. The worldwide power grid utilities are going to revise their grid codes for this purpose [19, 20].

The ability of MGs to contribute to power reserve regulation is now required by the grid code of some utilities. Furthermore, if due to congestion management, sufficient inertia, and reserve provision, some MGs are disconnected, their energy can be used to produce upward energy reserves. The allocation of the ancillary reserve by the MGs in future smart communities will be different from the same method for the conventional plants, despite flexibility in control, since the RESs' outputs experience high intermittency. Here, some important directions in the application of MGs are briefly emphasized.

1.6.1 Dynamic Behavior of MGs and Their Impacts on Power Grids

Due to the different dynamic behavior of MGs compared to that of the conventional grids, the increasing share of MGs in modern power systems leads to a new classification in power system stability phenomena [21]. The high integration of the MGs provides a wider range of dynamic time scales in a modern power system. The time scale of MG control loops ranges from a few microseconds to tens of milliseconds, which belong to the wave and electromagnetic phenomena. Therefore, for analyzing the dynamic impacts of MGs on modern power grid stability and performance, there is a need to extend the bandwidth of the power system stability phenomena to cover this time scale. Stabilizing, protection, ride-through capability, and dynamic modeling are basic important technical issues in MGs-integrated power systems [3, 22, 23].

1.6.2 Microgrid-Based Ancillary Services

Contribution in the power grid demand response and inertia are key supportive services of the MGs in the smart grids. These abilities effectively support the power grid in all fields of voltage/frequency control, active/reactive control, reliability, security, and power quality. Although the contribution of the demand side to the power grid control support using the MGs is an important issue, it is still difficult to consider demand-side control support as a fixed participant in the overall power grid regulation requirement. Virtual inertia emulation requires the MG to be able to store or release an amount of energy depending on the grid frequency deviation from its nominal value, analogous to the inertia of a conventional generator [24]. This provides a promising solution to improve power grid stability and performance in the presence of high penetration of RESs.

1.6.3 Dynamic Modeling and Control

Measurement-based dynamics identification and modeling for adaptive control and online parameter tuning of the MGs is vital. The online tuning of MG set-points considering the unpredictable load changes can be quite challenging in operation and control. This emphasizes the significant role of data-driven modeling and control techniques for the distributed MGs in future relevant studies. A complete understanding of reliability considerations via effective modeling/aggregation techniques is vital to identifying a variety of ways that MGs in power grids can accommodate the large-scale integration of renewable power in the future. A proper dynamic modeling and aggregation of the MGs, for performance and stability studies, is a key issue to understanding the dynamic impact of distributed DERs/RESs and simulating their functions in a new environment [25, 26].

Effective control solutions for the MGs in a power grid with high integration of DERs/RESs, particularly in islanded grids due to their relatively low inertia, significant power fluctuation, and various uncertainties are needed [27]. In this direction, providing appropriate coordination between the MGs with conventional power plants and the large-scale ESSs is important. This direction also requires highlighting the cyber-security in the control and operation of MG systems.

1.7 The Book Content and Organization

The electric power industry can be significantly affected by the high integration of MGs. The essential knowledge about MG *modeling, stability, and control* helps engineers to design more efficient MGs in both grid-connected and islanding operation modes. They would be able to carry out systematic MG modeling, stability analysis, and control synthesis considering required constraints and physical limitations. In this book, these constraints and limitations are fully addressed. Moreover, some developed dynamic modeling methods are presented for IMGs, which facilitate the modeling process of such networked systems. Small-signal stability of IMGs is analyzed using eigenvalue and sensitivity analyses. Moreover, the transient stability is investigated using nonlinear models and time-domain simulations. Control of IMGs in both planned and emergency operations is taken into consideration. Finally, modeling, stability, and control of IMG synchronization are studied.

The book provides a comprehensive and strong handbook for students, researchers, and engineers working on modeling, stability, and control of MGs and IMGs; and it will also demonstrate a valid reference for further developments in the mentioned fields. The book tries to make a strong link between the fundamental concepts of MGs and advances in dynamic modeling, stability analysis, and control theory/techniques, together with practical engineering considerations.

The reader is motivated to be engaged with the content via numerous application examples of MG modeling, stability analysis, and controllers' design for single and interconnected MGs. This approach not only provides relevant readers with a better understanding of basic concepts but also reveals a systematic method of control synthesis in the real-world MGs. The content of the book is arranged and ordered so that anyone with a basic background in electrical engineering and mathematics can follow the chapters.

The book includes two parts, i.e. individual MGs (in six chapters) and interconnected MGs (in five chapters), which contain various issues of modeling, stability analysis, and control of MG/IMG. Most chapters are demonstrated by the outcomes of laboratory and real-time simulations. This book is organized into 11 chapters where their contents are briefly explained here.

Chapter 2 investigates the essential concepts and fundamentals of MG dynamic modeling. Firstly, terminology, concepts, and classification of dynamics and modeling of MGs are addressed. Fundamental analysis tools and corresponding requirements are studied including state-space modeling, module interconnection, detailed modeling, and simplification (order reduction) methods. Small-signal modeling of MG components is represented consisting of different types of power converters, loads, DERs as well as power networks and the corresponding considerations. Finally, small-signal modeling of MG controllers is considered including different converter control strategies in the primary control level of MG hierarchical control architecture, the secondary control level, and some considerations about higher control layers.

Chapter 3 clarifies the process of overall modeling of an MG using several case studies. The knowledge learned from Chapter 2 is extended to perform an overall representation structure of an MG. In this chapter, various cases of MG modeling are presented including small-signal modeling of a single grid-connected PV, a grid-connected ac MG with two grids following distributed energy resources, two autonomous ac MGs an autonomous dc MG, and large-signal (transient) modeling of an ac MG with different load types. Detailed modeling of an MG is emphasized, and a simplified frequency response model using low-order transfer functions is introduced.

Chapter 4 presents a classification of MGs' stability and the basic requirements for their stability analysis. Several small-signal stability analyses are provided using eigenvalue analysis, participation matrix, and sensitivity analysis to study different types of MGs and discuss their parameters and control gains. MGs under study consist of both ac and dc MGs. In stability analyses, the most important parameters of the MGs are investigated, e.g. droop characteristic gains, phase-locked loop (PLL) gains, coupling line parameters, virtual impedance gains, and secondary control gains. Finally, the chapter ends with a stabilization case for synchronverters, which are a type of virtual synchronous machines.

Chapter 5 emphasizes the most important concepts and basics of MG control. A general overview of the main control layers and loops is presented. The chapter classifies MG control strategies into four control levels: local (primary), secondary, central, and global, where the first three levels are associated with the operation of the MG itself, and the fourth level (global control) demonstrates the coordinated operation of the MG and neighbor MGs as well as the main grid. The mentioned control levels are discussed with some examples.

Chapter 6 addresses the applications of control methodologies for designing MG controllers. The topics are supplemented by several control synthesis examples.

Chapter 7 discusses the architectures, definitions, benefits, opportunities, and challenges of IMGs. In addition to giving a brief literature review on the relevant topics, the operation of IMGs is explained and vacancies for future research are emphasized.

Chapter 8 addresses the dynamic modeling of IMGs, which is realized in short-term studies in minute-timescale, rather than the static modeling in larger time slots. First, the module-based modeling process is discussed, and then the results are used to perform some comprehensive closed-loop models. The obtained IMG models are useful for stability analysis and parameter behavior identification. The accuracy of models is validated comparing real-time data, and finally, some reduced-order models are represented, which can be used in the controller synthesis.

Chapter 9 discusses the stability of the IMGs. Following a brief review, small-signal stability analysis is explained. Then, the applications of eigenvalues and sensitivity analysis in stability analysis of different IMG technologies are presented. To analyze the large-signal stability of IMGs, time-domain simulations are performed for two different case studies.

Chapter 10 focuses on the control of IMGs with different structures. Among the control loops, frequency control and power sharing control are emphasized. Moreover, both planned and emergency operations are represented, which focus on power exchange control among IMGs, and frequency/voltage support of a critical MG. The explained examples are supplemented by simulations and real-time experimental tests.

Finally, *Chapter 11* addresses the synchronization control requirements and stability analysis in IMGs. The impacts of the secondary control loop, high loads, and physical constraints on the synchronization performance and stability are discussed using examples and simulation results.

References

1 Robert Lasseter, Abbas Akhil, Chris Marnay, John Stephens, Jeff Dagle, Ross Guttromson, A Meliopoulos, Robert Yinger, and Joe Eto. White paper on integration of distributed energy resources. The CERTS microgrid concept. *Consortium for Electric Reliability Technology Solutions*, pages 1–27, 2002.

2 R H Lasseter and P Paigi. Microgrid: A conceptual solution. In *2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No. 04CH37551)*, volume 6, pages 4285–4290, 2004. doi: 10.1109/PESC.2004.1354758.

3 Hassan Bevrani, Bruno François, and Toshifumi Ise. *Microgrid dynamics and control*. John Wiley & Sons, Hoboken, NJ, 2017.

4 Peng Zhang. *Networked microgrids*. Cambridge University Press, 2021.

5 Mobin Naderi, Yousef Khayat, Qobad Shafiee, Tomislav Dragicevic, Frede Blaabjerg, and Hassan Bevrani. An emergency active and reactive power exchange solution for interconnected microgrids. *IEEE J. Emerging Sel. Top. Power Electron.*, 9(5):5206–5218, 2019.

6 Mobin Naderi, Yousef Khayat, Qobad Shafiee, Frede Blaabjerg, and Hassan Bevrani. Dynamic modeling, stability analysis and control of inter- connected microgrids: A review. *Appl. Energy*, 334:120647, 2023.

7 Robert H Lasseter. Smart distribution: Coupled microgrids. *Proc. IEEE*, 99(6):1074–1082, 2011. doi: 10.1109/JPROC.2011.2114630.

8 Hêmin Golpîra, Arturo Román-Messina, and Hassan Bevrani. *Renewable integrated power system stability and control*. IEEE-Wiley, 2021.

9 Lilia Tightiz, Hyosik Yang, and Hassan Bevrani. An interoperable communication framework for grid frequency regulation support from microgrids. *Sensors (Basel, Switzerland)*, 21(13):4555, 2021.

10 Nikos Hatziargyriou, Hiroshi Asano, Reza Iravani, and Chris Marnay. An overview of ongoing research, development, and demonstration projects. *IEEE Power Energy Mag.*, 5(4):79–94, 2007.

11 Hassan Bevrani. *Robust power system frequency control*. Springer, 2014.

12 H Bevrani, M Watanabe, and Y Mitani. Microgrid controls. *Standard handbook for electrical engineers*, pages 160–176, 2012.

13 Hassan Bevrani, Masayuki Watanabe, and Yasunori Mitani. *Power system monitoring and control*. John Wiley & Sons, 2014.

14 Hassan Bevrani, Hêmin Golpîra, Arturo Román Messina, Nikos Hatziargyriou, Federico Milano, and Toshifumi Ise. Power system frequency control: An updated review of current solutions and new challenges. *Electr. Power Syst. Res.*, 194:107114, 2021. ISSN 0378-7796.

15 H Bevrani, T Kato, T Ise, and K Inoue. *Grid connected converters: Modeling, stability and control*. Elsevier Science, 2022. ISBN 9780323999021.

16 Hassan Bevrani, Masaki Imanaka, and Takeyoshi Kato. Grid dynamics shaping using flexible controlled power converters. *Energy Rep.*, 6:1490–1495, 2020. ISSN 2352-4847. doi: 10.1016/j.egyr.2020.10.065 URL https://www.sciencedirect.com/science/article/pii/S2352484720314189. 2020 The 7th International Conference on Power and Energy Systems Engineering.

17 Jia Liu, Yushi Miura, Hassan Bevrani, and Toshifumi Ise. Enhanced virtual synchronous generator control for parallel inverters in micro-grids. *IEEE Trans. Smart Grid*, 8(5):2268–2277, 2017. doi: 10.1109/TSG.2016.2521405.

18 Hassan Bevrani, Toshifumi Ise, and Yushi Miura. Virtual synchronous generators: A survey and new perspectives. *Int. J. Electr. Power Energy Syst.*, 54:244–254, 2014. ISSN 0142- 0615. doi: 10.1016/j.ijepes.2013.07.009 URL https://www.sciencedirect.com/science/article/pii/S0142061513003062.

19 IEEE standard for interconnecting distributed resources with electric power systems. *IEEE Std 1547-2003*, pages 1–28, 2003. doi: 10.1109/IEEESTD.2003.94285.

20 IEEE standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces. *IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003)*, pages 1–138, 2018. doi: 10.1109/IEEESTD.2018.8332112.

21 Nikos D Hatziargyriou, Jovica V Milanović, Claudia Rahmann, Venkataramana Ajjarapu, Claudio A Cañizares, István Erlich, David J Hill, Ian A Hiskens, I Kamwa, Bikash Chandra Pal, Pouyan Pourbeik, Juanita Gasca, Alexander M Stankovic, Thierry Van Cutsem, Vijay Vittal, and Costas D Vournas. Stability definitions and characterization of dynamic behavior in systems with high penetration of power electronic interfaced technologies. 2020.

22 Mobin Naderi, Qobad Shafiee, Hassan Bevrani, and Frede Blaabjerg. Low-frequency small-signal modeling of interconnected AC microgrids. *IEEE Trans. Power Syst.*, 36(4):2786–2797, 2021. doi: 10.1109/TPWRS.2020.3040804.

23 Mobin Naderi, Yousef Khayat, Qobad Shafiee, Tomislav Dragicevic, Hassan Bevrani, and Frede Blaabjerg. Comprehensive small-signal modeling and Prony analysis-based validation of synchronous interconnected microgrids. *Energy Rep.*, 7:6677–6689, 2021. ISSN 2352-4847.

24 Prabha Kundur, Neal J Balu, and Mark G Lauby. *Power system stability and control*. McGraw-Hill, New York, 1994.

25 Daniel E Olivares, Ali Mehrizi-Sani, Amir H Etemadi, Claudio A Cañizares, Reza Iravani, Mehrdad Kazerani, Amir H Hajimiragha, Oriol Gomis-Bellmunt, Maryam Saeedifard, Rodrigo Palma-Behnke, Guillermo A Jiménez-Estévez, and Nikos D Hatziargyriou. Trends in microgrid control. *IEEE Trans. Smart Grid*, 5(4):1905–1919, 2014. doi: 10.1109/TSG.2013.2295514.

26 Ritwik Majumder. Some aspects of stability in microgrids. *IEEE Trans. Power Syst.*, 28(3):3243–3252, 2013. doi: 10.1109/TPWRS.2012.2234146

27 IEEE Standards. IEEE standard for interconnecting distributed resources with electric power systems. https://fglongatt.org/OLD/Archivos/Archivos/SistGD/IEEE1547.pdf.