SMART GRID AND ENABLING TECHNOLOGIES

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Contents

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Omar Ellabban (S'10–M'12–SM'13) is a senior researcher and creative manager with more than 20 years of combined experiences (teaching, research, industrial experience, consulting services and project management) between academia, research institutes, industry and power utility companies in various fields.

Dr. Ellabban is conducting and leading many research projects in different areas, such as: power electronics, electric vehicles, automatic control, motor drive, energy management, grid control, renewable energy, energy storage devices, distributed energy systems and their integration into the smart grid. Dr. Ellabban received his BS (Hons) degree in electrical machines and power engineering from

Helwan University, Egypt; his MS degree in electrical machines and power engineering from Cairo University, Egypt; and his PhD (Hons.) degree in electrical engineering from Free University of Brussels, Belgium, in 1998, 2005, and 2011, respectively. He joined the Research and Development Department, Punch Powertrain, Sint-Truiden, Belgium, in 2011, where he and his team developed a next-generation, high-performance hybrid powertrain. In 2012, he joined Texas A&M University in Qatar as a postdoctoral research associate and became an assistant research scientist in 2013, where he is involved in different renewable energy integration projects. In 2016, he joined Iberdrola Innovation Middle East as the Research and Development Director to lead a number of research, development and innovation projects under various topics focusing on transforming the current electric grid into a smart grid and integrating renewable energies and energy storage systems interfaced by power electronics converters as microgrids penetrating the distribution networks. In 2020, he joined CSA Catapult as Principal Power Electronics Engineer to lead different projects focusing on Compound Semiconductors applications across different sectors.

Dr. Ellabban has authored more than 70 journal and conference papers, one book chapter, two books entitled, "Impedance Source Power Electronic Converters, 2016" and "Smart Grid Enabling Technologies, 2020" and many international conference tutorials. His current research interests include renewable energies, grid control, smart grid, automatic control, motor drives, power electronics, and electric vehicles. He is a Senior Member of the IEEE, IET member and currently serves as an Associate Editor of the IEEE Transactions on Industrial Electronics.

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Dr. Bayhan is the recipient of many prestigious international awards, such as the Research Fellow Excellence Award in recognition of his research achievements and exceptional contributions to the Texas A&M University at Qatar in 2018, the Best Paper Presentation Recognition at the 41st and 42nd Annual Conference of the IEEE Industrial Electronics Society in 2015 and 2016, Research Excellence Travel Awards in 2014 and 2015 (Texas A&M University at Qatar), and Researcher Support Awards from the Scientific and Technological Research Council of Turkey (TUBITAK). He has acquired $13 M in research

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Dr. Bayhan has been an active Senior Member of IEEE. Because of the visibility of his research, he has recently been elected as Chair of IES Power Electronics Technical Committee and selected as a Co-Chair of IEEE-IES Student and Young Professional Activity Program. He currently serves as Associate Editor for IEEE Transactions on Industrial Electronics, IEEE Journal of Emerging and Selected Topics in Industrial Electronics, and IEEE Industrial Electronics Technology News, and Guest Editor for the IEEE Transactions on Industrial Informatics.

Haitham Abu-Rub is a full professor holding two PhDs from Gdansk University of Technology (1995) and from Gdansk University (2004). Dr. Abu Rub has much teaching and research experience at many universities in a number of countries including Qatar, Poland, Palestine, the USA, and Germany.

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Frede Blaabjerg (S'86–M'88–SM'97–F'03) was with ABB-Scandia, Randers, Denmark, from 1987 to 1988. He became an Assistant Professor in 1992, an Associate Professor in 1996, and a Full Professor of power electronics and drives in 1998. From 2017, he became a Villum Investigator. He is *honoris causa* at University Politehnica Timisoara (UPT), Romania and Tallinn Technical University (TTU) in Estonia. His current research interests include power electronics and its applications such as in wind turbines, PV systems, reliability, harmonics and adjustable speed drives. He has published more than 600 journal papers in the fields of power electronics and its applications. He is the co-author of four

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Miroslav M. Begovic (FIEEE'04) is Department Head of Electrical and Computer Engineering and Carolyn S. & Tommie E. Lohman '59 Professor at Texas A&M University. Prior to that, he was Professor and Chair of the Electric Energy Research Group in the School of Electrical and Computer Engineering, and an affiliated faculty member of the Brook Byers Institute for Sustainable Systems and University Center of Excellence in Photovoltaic Research at Georgia Tech. Dr. Begovic obtained his PhD from Virginia Tech University. His research interests are in monitoring, analysis, and control of power systems, as well as development and applications of renewable and sustainable energy systems. For the Centennial Olympic Games in 1996 in Atlanta, he designed with Professor Ajeet Rohatgi, a 340 kW photovoltaic system on the roof of Aquatic Center at Georgia Tech, which at that time was the largest roof-mounted PV system in the world. He has been a member of the IEEE PES Power System Relaying Committee for two decades and chaired a number of its working groups. Professor Begovic was Editor of the section on Transmission Systems and Smart Grids in the *Springer Encyclopedia on Sustainability* (published in 2012), coordinated by an Editorial Board consisting of five Nobel Prize Laureats, has also served as guest editor of the IET Generation, Transmission & Distribution Special Issue on Wide Area Monitoring and Control in 2010, authored one section of a book, nearly 200 journal and conference papers, two IEEE special publications, and delivered more than 100 keynote and invited presentations. He authored invited papers in three Special issues of IEEE Proceedings: on Future Energy Systems (2010), on Critical Infrastructures (2005) and on Renewable Energy (2001).

Dr. Begovic is a Fellow of IEEE and member of Sigma Xi, Tau Beta Pi, Phi Kappa Phi and Eta Kappa Nu. Dr. Begovic is a former Chair of the Emerging Technologies Coordinating Committee of IEEE PES, IEEE PES Treasurer (2010–2011), IEEE PES Distinguished Lecturer, and serves as President of the IEEE Power and Energy Society.

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Preface

Smart grid (SG) is an emerging area of engineering and technology which integrates electricity, communication, and information infrastructures to ensure an efficient, clean, and reliable electric energy supply. This is an extremely complex field with different disciplines and engineering areas pooled together. This book aims to cover SG technologies and their applications in a systematic and comprehensive way. Different areas of SGs have been included in this book, such as architectural aspects of the SG, renewable energy integration, power electronics domination in the SG, energy storage technologies for SG applications, smart transportation, communication and security aspects, the pivotal role of artificial intelligence toward the evolution of SGs, SG challenges and barriers, standardization, and future vision. For this reason, the book has been written by experienced individuals who specialize in various areas of SGs.

The objective of this book is to equip readers with up-to-date knowledge of the fundamentals, emerging grid structure, current research status, and future vision in the development and deployment of SGs. The concepts presented in this book include four main areas of SGs and its applications: **Advanced SG Architecture** which includes smart power systems, communication systems, information technology, security, and the advancement of microgrids. **Renewables energies,** entail technologies of both energy storages, and power electronics suitable for renewable energy systems and SG applications. **SG applications** are divided into fundamental and emerging applications. The fundamental applications refer to energy management strategies, reliability models, security, and privacy, in addition to promoting demand-side management (DSM). Emerging applications include the deployment of electric vehicles (EVs) and mobile charging stations. **SG tools** are divided into crucial tools for distribution grids such as Big Data management and analytics, cloud management and monitoring tools, consumer engagement, and artificial intelligence for the SG, the requirements for the simulation tools and the recently adopted standards, in addition to the challenges and future business models of SGs.

The book builds its foundation by introducing the SG architecture and integrating renewable energy sources and energy storage systems in the next generation power grid. The first chapter provides a basic discussion on the infrastructure of SGs followed by the technologies used in the SG. An overview of different renewable energy resources is discussed in Chapter 2 showing their current status, future opportunities, and the challenges of integrating them with the grid. Energy storage systems and power electronics converters as grid integration units are presented in Chapters 3–4. A comprehensive review of

microgrids, including their characteristics, challenges, design, control, and operation either in grid-connected or islanded modes are introduced in Chapter 5. Chapter 6 is devoted to one of the most emerging applications of SGs, which is smart transportation. This chapter presents an overview of EVs; their current status and future opportunities, in addition to the challenges of integrating them into the SG. The impact of EVs on SG operation and modeling EV mobility in energy service networks are also exemplified in this chapter. The net-zero energy cost building uses energy efficiency and renewable energy strategies as part of the business model. Chapter 7 describes the zero energy buildings (ZEBs) definition, design, modeling, control, and optimization. This chapter discusses the benefits and barriers of the current state and the future trends of ZEBs as a step to reduce energy consumption in the building sector. The goal of Chapter 8 is focused on the SG features utilizing multi-way communication among energy production, transmission, distribution, and usage facilities. The multi-way communication among energy generation, transmission, distribution, and usage facilities is discussed in Chapter 8. The reliable, efficient, and intelligent management of complex power systems necessitates an employment of high-speed, reliable, and secure data information and communication technology into the SG to manage and control power production and usage; this topic is described in Chapter 9. The electric energy sector is sitting on a data goldmine, the so-called Big Data. The real value of Big Data utilization resides in a good understanding of its analytics technologies, promise, and potential applications in SGs, which is discussed in Chapter 10. Driven by concerns regarding electric sustainability, energy security, and economic growth, it is essential to have a coordination mechanism based on heuristic rules to manage the energy demand and enhance the survivability of the system when failures occur or at peak periods, which is achieved by the principle of DSM systems defined in Chapter 11. It is essential to know the business model concepts, their main components, and how they can be used to analyze the impact of SG technology to create, deliver, and capture values for the utility business. The value chain for both traditional and smart energy industries are needed. The different electricity markets have been described and presented in Chapter 12. Chapter 13 aims to provide energy systems researchers and decision-makers with proper insight into the underlying drivers of consumer acceptance of the SG and the logical steps for their engagement to promote SG technology and make it feasible promptly. The fundamental relationship between SG and cloud computing services is also covered. The architectural principles, characteristics of cloud computing services, and the examination of the advantages and disadvantages of those characteristics for SG are defined. Furthermore, the opportunities and challenges of using cloud computing in SGs, and the major categories of data security challenges of cloud computing are described in Chapter 14.

In Chapter 15, the latest taxonomy of Artificial Intelligence (AI) applications in SGs is discussed, including load and renewable energy forecasting, power optimization, electricity price forecasting, fault diagnosis, and cyber and physical layers security. Chapter 16 discusses the current state of simulation-based approaches including multi-domain simulation, co-simulation, and real-time simulation and hardware-in-the-loop for SGs. Furthermore, some SG planning and analysis software are summarized with their advantages and disadvantages. Chapter 17 presents an overview of SG standards; new standardization studies, SG policies of some countries, and some important standards for the smart grid. Chapter 18 depicts the concepts of distributed generation, micro-grid, SG, and

distributed operation, which all pose more complexity and challenges to the modern power systems. This chapter presents the challenges and barriers that modern SGs face from different perspectives.

This book has the typical attributes of a contemporary book and discusses several aspects that will appeal to students, researchers, professionals, and engineers from various disciplines looking to increase their knowledge, insights, and ideas for the future development of SG as the next energy paradigm. This work perfectly fills the current gap and contributes to the realization and a better understanding of SG and its enabling technologies.

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