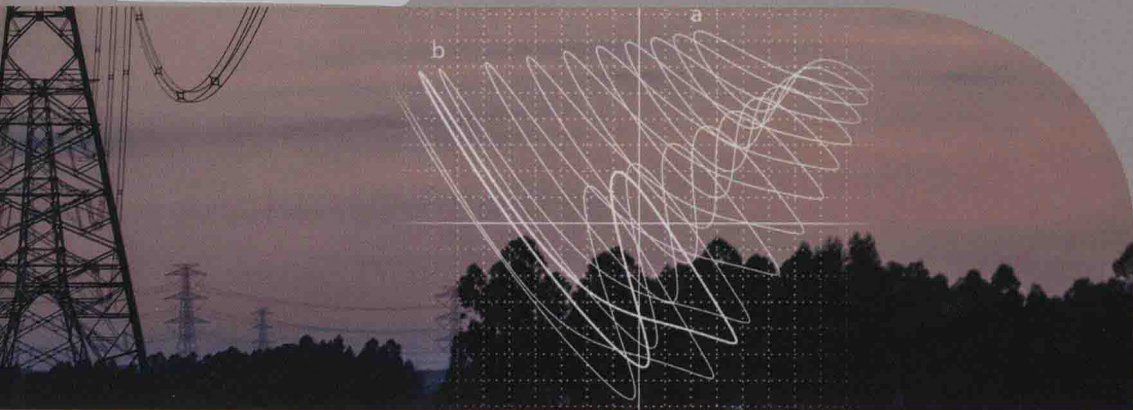IET

Advances in Power System Modelling, Control and Stability Analysis

Edited by
Federico Milano

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Preface

Electric energy is a fundamental component of the productive processes of any economic sector. The mission of modern and future power systems is to supply electric energy satisfying conflicting requirements: reliability/security of supply, economy, and finally, environmental protection. With this regard, security, quality, and stability of the electric energy supply are key aspects to maintain the productivity of the industrial sector. On the one hand, the progressive increasing concern about climate change and the effects of energy production in greenhouse gas emissions has led to the wide integration of renewable energy sources with obvious advantages in the environmental behaviour of power systems. On the other hand, the integration of communication systems has led to the redefinition of standards and practices of transmission and distribution systems and to the new concept of "smart grid". In this context, the integration of new technologies passes through the definition and validation of advanced techniques for the modelling, planning, monitoring, and control of power systems. These technical innovations point out the need either to reformulate some conventional modelling and control aspects with a modern perspective, or to address new aspects and phenomena related to issues that have not been considered in the past.

The aim of this book is to provide a collection of studies that, while focusing on specific topics, are able to capture the variety of new methodologies and technologies that are changing the way modern electric power systems are modelled, simulated and operated. The approach of the book mixes theoretical aspects with practical considerations, as well as benchmarks test systems and real-world applications. With this aim, the book is divided into three parts, namely modelling, control and stability analysis. Part I presents research works on power system modelling and includes applications of telegrapher equations, power flow analysis with inclusion of uncertainty, discrete Fourier transformation and stochastic differential equations. Part II focuses on power system operation and control and presents insights on optimal power flow, real-time control and state estimation techniques. In this part, special attention is devoted to distribution systems. Finally, Part III describes advances in the stability analysis of power systems and covers voltage stability, transient stability, time delays, and limit cycles.

The book provides a glance on the state-of-the-art of the research that has been carried out in the last decades by the authors of each chapter. The common background of lead authors is the unifying thread of the whole book. In particular, the lead authors of each chapter have obtained their degree in Electrical Engineering in Italy, which provides solid theoretical basis on modelling and stability analysis of non-linear

systems and, in most of the cases, have extended their knowledge and improved their skills with visiting periods in prestigious European and North American universities. These experiences have led to several fruitful international collaborations as well as career opportunities, as shown by the biographies included in the list of contributors. We believe that this unique cultural mix provides an added value to the book, which, as a whole, offers the reader an unconventional viewpoint on current research on electric power systems.

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Federico Milano
Dublin, February 2016

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Contributors

Vittorio Arcidiacono was born in Acireale, Italy, in 1942. In January 1966, he received his Ph.D. degree (with honours) in Electronic Engineering from the Politecnico of Torino. After a first work experience in designing special electronic equipment, in 1967, he joined ENEL (former National Electricity Board in Italy) at the Automatica Research Centre (CRA). There he has emerged as one of the leading experts in the fields of excitation and turbine control of generators, secondary and tertiary voltage control of EHV transmission system, power system dynamics and stability, mathematical modelling, high-voltage direct current (HVDC) transmission systems, advanced power electronics. He is the author of over 200 scientific publications in the fields mentioned above. He has been the creator and the designer of the secondary and tertiary voltage control of the Italian EHV transmission system. At ENEL, he has been appointed Manager in 1978, Head of Systems Department in 1984, Vice Director in 1993 and Director in 1998 of the Automatica Research Centre. Since March 2001, date of his retirement, he cooperates with MAI Control Systems Ltd., Milan, overseeing all the R&D activities.

Alberto Berizzi received his M.Sc. degree (1990) and his Ph.D. degree (1994) both in Electrical Engineering from the Politecnico di Milano, Italy. He is now Professor at the Energy Department of the Politecnico di Milano, Italy. His areas of research include power system analysis and optimisation and power system dynamics.

Federico Bizzarri received his Laurea (M.Sc.) five-year degree (*summa cum laude*) in Electronic Engineering and his Ph.D. degree in Electrical Engineering from the University of Genova, Italy, in 1998 and 2001, respectively. Since June 2010, he has been a temporary research contract assistant professor at the Electronic and Information Department of the Politecnico di Milano, Milan, Italy. In 2000, he was a visitor to EPFL, Lausanne, Switzerland. From 2002 to 2008, he had been a postdoctoral research assistant in the Biophysical and Electronic Engineering Department of the University of Genova, Italy. In 2009, he was a postdoctoral research assistant in Advanced Research Centre on Electronic Systems for Information and Communication Technologies "E. De Castro" (ARCES) at the University of Bologna, Italy. His main research interests are in the area of non-linear circuits, with emphasis on chaotic dynamics and bifurcation theory, circuit models of non-linear systems, image processing, circuit theory and simulation. He is the author or co-author of about 80 scientific papers, more than an half of which have been published in international journals. He is a Research Fellow of the Advanced Research Center on Electronic

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Vahid S. Bokharaie received his B.Sc. and M.Sc. degrees in Electrical (Control) Engineering from Ferdowsi University of Mashhad, and K. N. Toosi University of Technology in Iran. After working in industry for a few years, he joined the Hamilton Institute in National University of Ireland in Maynooth as a Ph.D. candidate working on stability analysis of different classes of control systems. His research interests involve applications of control theory in different areas, including power systems. He has worked as a researcher in Sustainable Electrical Engineering Systems (SEES) cluster in Ireland and in Turbulent Flow Simulation and Optimisation (TFSO) group in Mechanical Engineering department in KU Leuven, Belgium.

Alberto Borghetti graduated (with honours) in Electrical Engineering from the University of Bologna, Italy, in 1992. Since then he has been working with the power system group of the same university, where he was appointed Researcher in 1994 and Associate Professor in 2004. His research and teaching activities are in the areas of power system analysis, with particular reference to voltage collapse, power system restoration after black out, electromagnetic transients, optimal generation scheduling and distribution system operation. He is a Fellow of the Institute of Electrical and Electronics Engineers (class 2015) for contributions to modelling of power distribution systems under transient conditions. He has served as Technical Program Committee chairperson of the 30th International Conference on Lightning Protection (Cagliari, Italy, 2010). Currently, he serves as an Editor of *IEEE Transactions on Smart Grid* and is on the editorial board of *Electric Power System Research*.

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Claudio A. Cañizares received the Diploma in Electrical Engineering from Escuela Politénica Nacional (EPN), Quito, Ecuador, in 1984, and the M.Sc. and Ph.D. degrees in Electrical Engineering from the University of Wisconsin–Madison, Madison, WI, USA, in 1988 and 1991, respectively. He held different teaching and administrative positions with Escuela Politénica Nacional between 1983 and 1993. He is a Full Professor with the Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada, where he has held various academic and administrative positions since 1993, and currently serves as the Hydro One Endowed Chair and as an Associate Director of Waterloo Institute for Sustainable Energy (WISE), University of Waterloo, Waterloo, Ontario, Canada. His research interests include study of stability, modelling, simulation, control, optimisation, and computational issues in large and small grids, and energy systems in the context of competitive energy markets and smart grids. He is a Fellow of the IEEE as well as of the Royal Society of Canada and the Canadian Academy of Engineering. He has been the recipient of various IEEE PES Technical Council and Committee awards and recognitions, holding several leadership positions in various IEEE PES Technical Committees.

Massimiliano Chiandone graduated from University of Udine, Italy (M.Sc.) in Computer Science and from University of Trieste, Italy (B.Sc.) in Electrical Engineering. He has been working for several years at MSC Software Corporation as a system administrator and at the Synchrotron Light Laboratory in Trieste as a software developer. In 2012, he got the Ph.D. degree in Electrical Engineering at University of Padua, Italy. His main research interests are in real-time control systems and applications to the electric power system.

Konstantina Christakou graduated from the National Technical University of Athens, Greece, in 2010. She obtained her Ph.D. in 2015 from École Polytechnique Fédérale de Lausanne (EPFL), Switzerland, where she worked under the joint supervision of Professors Jean-Yves Le Boudec (LCA2) and Mario Paolone (DESL). Since February 2016, she is a postdoctoral researcher in the group of Professor Mario Paolone (DESL). Her research interests include control and real-time operation of electrical distribution grids with particular reference to voltage control and lines congestion management, demand side management and storage applications for active distribution networks, optimal power flow algorithms and optimisation under uncertainty.

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Federico Milano received the M.Sc. and Ph.D. degrees in Electrical Engineering in 1999 and 2003, respectively, from the University of Genoa, Italy. From 2001 to 2002, he was with the University of Waterloo, Canada, as a Visiting Scholar. From 2003 to 2013, he was with the University of Castilla-La Mancha, Spain. In 2013, he joined the University College Dublin, Ireland, where he is currently Professor of Power Systems Control and Protections. He is also an Editor of the *IEEE Transactions on Power Systems* and *IET Generation Transmission and Distribution*. In 2016, he has been elevated to IEEE Fellow for his contributions to power system modelling and simulation.

Fabio Napolitano is Assistant Professor at Department of Electrical, Electronic and Information Engineering of the University of Bologna, Italy. From the same university, he received the degree (with honours) in Electrical Engineering in 2003 and the Ph.D. degree in 2009. Since his M.Sc. graduation, he collaborated with the Power Systems group of the University of Bologna on the analysis of power systems transients, in particular those due to indirect lightning strikes, and lightning protection systems.

Carlo Alberto Nucci is Full Professor and Head of the Power Systems Laboratory of the Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi" of the University of Bologna, Italy. He is the author or co-author of over 300 scientific papers published on peer-reviewed journals or on proceedings of international conferences, of five book chapters edited by IEE (two), Kluwer, Rumanian Academy of Science and WIT press and of a couple of IEEE Standards and some CIGRE technical brochures. He is a Fellow of the IEEE and of the IET, CIGRE honorary member and has received some best paper/technical international awards,

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Mario Paolone received the M.Sc. (with honours) and the Ph.D. degree in Electrical Engineering from the University of Bologna, Italy, in 1998 and 2002, respectively. In 2005, he was appointed Assistant Professor in Power Systems at the University of Bologna where he was with the Power Systems Laboratory until 2011. In 2010, he received the Associate Professor eligibility from the Politecnico di Milano, Italy. Currently, he is Associate Professor at the Swiss Federal Institute of Technology, Lausanne, Switzerland, where he accepted the EOS Holding Chair of the Distributed Electrical Systems Laboratory. He was co-chairperson of the technical programme committees of the ninth edition of the International Conference of Power Systems Transients (IPST 2009) and of the 2016 Power Systems Computation Conference (PSCC 2016). In 2013, he was the recipient of the IEEE EMC Society Technical Achievement Award. He was the co-author of several papers that received the following awards: in 2014 best paper award at the 13th International Conference on Probabilistic Methods Applied to Power Systems, Durham, UK; in 2013 Basil Papadias best paper award at the 2013 IEEE PowerTech, Grenoble, France; in 2008 best paper award at the International Universities Power Engineering Conference (UPEC). He is the Editor-in-Chief of the Elsevier journal *Sustainable Energy, Grids and Networks*. His research interests are in power systems with particular reference to real-time monitoring and operation, power system protections, power systems dynamics and power system transients. He is the author or co-author of over 190 scientific papers published in reviewed journals and international conferences.

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Lorenzo Zanni received the B.Sc. and M.Sc. degrees, both with honours, in Electrical Engineering from the University of Bologna, Bologna, Italy, in 2010 and 2012, respectively. He is currently pursuing the Ph.D. degree with the Distributed Electrical System Laboratory, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland. His current research interests include real-time monitoring and control of active distribution networks with particular focus on state estimation using phasor measurement units, and synchrophasor-based fault location.

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