

Modelling and Control of the Modular Multilevel Matrix Converter and its application to Wind Energy Conversion Systems

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Abstract—In the last past years, some countries are enforcing stringent grid codes to regulate the connection of Wind Energy Conversion Systems (WECSs) to the electrical network, mainly because of the high penetration of electric power from this renewable source. Additionally, the trend of wind turbines has shown an ongoing power rating growth, reaching sizes up to 10 MW. Multilevel converters have appeared as a solution for large WECSs, due to its high reliability, controllability and the capability to reach high power ratings. This paper presents a control strategy for the application of the Modular Multilevel Matrix Converter in Multimegawatts Wind Turbines. Extensive computer simulations and a downscaled laboratory prototype, with twenty-seven power cells, are presented to validate the effectiveness of the proposed control system.

Keywords— *Wind Turbines, Wind Energy Conversion Systems, Fault Ride-Through Capability, Modular Multilevel Matrix Converter.*

I. INTRODUCTION

Wind Energy has become in the industry with greatest and fastest growth among all the renewable energy sources. The wind energy production capacity for the whole world increased exponentially from 17.4 GW in 2000 to 432.4 GW in 2015, positioning wind power as a significant and crucial energy source in areas as China, USA and Europe. Powered 30.5 GW of new installations in China, the global wind power installed in 2015 was 63 GW, representing annual market growth of 22% [1].

A constant increment of wind power capacity is expected in the near future. Truthfully, the European Wind Energy Association (EWEA) plan for the next years is to become wind industry in the most competitive energy source, by 2020 onshore and offshore by 2030. The EWEA has stated that “wind power would be capable of contributing up to 20% of EU electricity by 2020, 30% by 2030 and 50% by 2050”.

An important part of the required future installed wind power will be offshore based, because of the higher wind-energy potential and the lower environmental impacts. Going offshore implies several technology challenges, mainly regarding reliability, efficiency and upscaling. Considering that largely expensive platforms must support the total weight of the WECS, the size and weight of components are critical, and possible weight reductions become crucial. What is more, it has been demonstrated that high power wind turbines could reduce the cost structure of offshore WECS, reason why upscaling has

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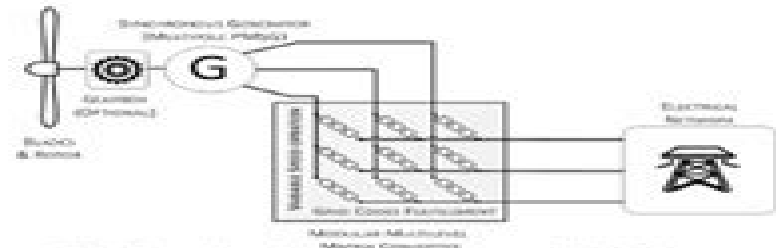


Fig. 1. Proposed topology to drive a High-power Wind Turbines.

become the focus of modern wind energy application and research [2], and why wind turbines manufacturers have been upscaling turbine dimensions.

However, most of the present WECSs are based on low-voltage two-level voltage source power converters (usually based on 1700-V IGBT devices for a 690-V voltage level), which is not the best technology for high power applications due to the high currents required. Consequently, medium or high voltage power electronic converters (e.g. multilevel converters) are well suited for high-power wind turbines. Therefore, Modular Multilevel Converters appears as a suitable technology to reach high power ratings.

The Modular Multilevel Matrix Converter (M²C) is a modular AC/AC converter able to reach medium-voltage levels by the series connection of full-bridge modules. This converter has some advantages compared to traditional two-level converters for high-power applications, fundamentally focused on the full modularity and easy extensibility to reach high voltage and high power levels, redundancy, control flexibility and power quality improvements [3], [4].

In this context, this paper introduces the application of the MPC to drive high-power WECSs, as is illustrated in Fig. 1. Comprehensive theoretical discussion on the control and modelling of the MPC is considered. Finally, the effectiveness of the proposed topology is confirmed by experiments using simulation models and a downscaled 3kW laboratory prototype.

GRID INTEGRATION REQUIREMENTS FOR WECS

In countries with a high penetration of renewable energies, dedicated grid code regulations have been enforced to ensure the

Modular Multilevel Converter Modelling Control And

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Modular Multilevel Converters Sixing Du, Apparao Dekka, Bin Wu, Navid Zargari, 2018-02-22 An invaluable academic reference for the area of high power converters covering all the latest developments in the field High power multilevel converters are well known in industry and academia as one of the preferred choices for efficient power conversion Over the past decade several power converters have been developed and commercialized in the form of standard and customized products that power a wide range of industrial applications Currently the modular multilevel converter is a fast growing technology and has received wide acceptance from both industry and academia Providing adequate technical background for graduate and undergraduate level teaching this book includes a comprehensive analysis of the conventional and advanced modular multilevel converters employed in motor drives HVDC systems and power quality improvement Modular Multilevel Converters Analysis Control and Applications provides an overview of high power converters reference frame theory classical control methods pulse width modulation schemes advanced model predictive control methods modeling of ac drives advanced drive control schemes modeling and control of HVDC systems active and reactive power control power quality problems reactive power harmonics and unbalance compensation modeling and control of static synchronous compensators STATCOM and unified power quality compensators Furthermore this book Explores technical challenges modeling and control of various modular multilevel converters in a wide range of applications such as transformer and transformerless motor drives high voltage direct current transmission systems and power quality improvement Reflects the latest developments in high power converters in medium voltage motor drive systems Offers design guidance with tables charts graphs and MATLAB simulations Modular Multilevel Converters Analysis Control and Applications is a valuable reference book for academic researchers practicing engineers and other professionals in the field of high power converters It also serves well as a textbook for graduate level students

Modular Multilevel Converter Modelling and Simulation for HVDC Systems Davide del Giudice, Federico Bizzarri, Daniele Linaro, Angelo Maurizio Brambilla, 2022-10-21 This book provides a comprehensive review of the models and approaches that can be employed to simulate modular multilevel converters MMCs Each solution is described in terms of operating principle fields of applicability advantages and limitations In addition this work proposes a novel and efficient simulation approach for MMCs based on sub circuit isomorphism This technique which has its roots in the electronics fields can be profitably exploited to simulate MMCs regardless of the model used to describe its sub modules including the most accurate ones Lastly this book considers a well known high voltage direct current HVDC benchmark system consisting of two MMCs After describing the implementation details of each benchmark component simulation results in several scenarios ranging from normal operating conditions to faults in the AC and DC grid are included to validate the proposed approach and showcase its key features Due to its educational content this book constitutes a useful guide for PhD students and researchers interested in the topic of MMCs and their simulation It also serves as a starting platform for junior

electrical engineers who work in the field of power electronic converters for HVDC systems *Design, Control, and Application of Modular Multilevel Converters for HVDC Transmission Systems* Kamran Sharifabadi, Lennart Harnefors, Hans-Peter Nee, Staffan Norrga, Remus Teodorescu, 2016-08-22 Design Control and Application of Modular Multilevel Converters for HVDC Transmission Systems is a comprehensive guide to semiconductor technologies applicable for MMC design component sizing control modulation and application of the MMC technology for HVDC transmission Separated into three distinct parts the first offers an overview of MMC technology including information on converter component sizing Control and Communication Protection and Fault Management and Generic Modelling and Simulation The second covers the applications of MMC in offshore WPP including planning technical and economic requirements and optimization options fault management dynamic and transient stability Finally the third chapter explores the applications of MMC in HVDC transmission and Multi Terminal configurations including Supergrids Key features Unique coverage of the offshore application and optimization of MMC HVDC schemes for the export of offshore wind energy to the mainland Comprehensive explanation of MMC application in HVDC and MTDC transmission technology Detailed description of MMC components control and modulation different modeling approaches converter dynamics under steady state and fault contingencies including application and housing of MMC in HVDC schemes for onshore and offshore Analysis of DC fault detection and protection technologies system studies required for the integration of HVDC terminals to offshore wind power plants and commissioning procedures for onshore and offshore HVDC terminals A set of self explanatory simulation models for HVDC test cases is available to download from the companion website This book provides essential reading for graduate students and researchers as well as field engineers and professionals who require an in depth understanding of MMC technology Multilevel Converters: Analysis, Modulation, Topologies, and Applications Gabriele Grandi, Alex Ruderman, 2019-10-14 This book is a collection of scientific papers concerning multilevel inverters examined from different points of view Many applications are considered such as renewable energy interface power conditioning systems electric drives and chargers for electric vehicles Different topologies have been examined in both new configurations and well established structures introducing novel and particular modulation strategies and examining the effect of modulation techniques on voltage and current harmonics and the total harmonic distortion Modular Multilevel Converters with Interleaved Half-Bridge Submodules Aleksandr Viatkin, 2023-03-29 This book reports on a comprehensive study on a novel high power converter i.e. a Modular Multilevel Converter with Interleaved Half bridge Submodules ISM MMC It describes in depth its average model the operating principles as well as a new control method and a hybrid modulation strategy that help to exploit the benefits of the interleaving scheme The new power converter is particularly advantageous for high current applications that require superb quality of input output waveforms Moreover this book reports on a systematic study of the current balancing problem between parallel connected units that commute in non simultaneous fashion This is a typical

issue in interleaved converters however here it is analyzed for the first time in relation to MMC based structures Two control strategies are proposed to cope with this matter By using a sensorless regulation scheme the number of required current transducers has been minimized reducing complexity cost and footprint of the hardware while providing converter with a fast and accurate current balancing This book also offers a comprehensive comparison between several practical designs of ISM MMC and classical MMC for an ultra fast electrical vehicle charger All in all it provides graduate students and researchers as well as field engineers and professionals with extensive information and essential practical details on the state of the art MMC and ISM MMC design **Control of Power Electronic Converters and Systems** Frede Blaabjerg, 2018-04-27

Control of Power Electronic Converters Volume Two gives the theory behind power electronic converter control and discusses the operation modelling and control of basic converters The main components of power electronics systems that produce a desired effect energy conversion robot motion etc by controlling system variables voltages and currents are thoroughly covered Both small mobile phones computer power supplies and very large systems trains wind turbines high voltage power lines and their power ranges from the Watt to the Gigawatt are presented and explored Users will find a focused resource on how to apply innovative control techniques for power converters and drives Discusses different applications and their control Explains the most important controller design methods both in analog and digital Describes different but important applications that can be used in future industrial products Covers voltage source converters in significant detail Demonstrates applications across a much broader context Modelling, Control and Optimisation of Low

Capacitance Modular Multilevel Converters Sumeet Singh Thakur, 2022 **ICDSMLA 2020** Amit Kumar, Sabrina Senatore, Vinit Kumar Gunjan, 2021-11-08 This book gathers selected high impact articles from the 2nd International Conference on Data Science Machine Learning Applications 2020 It highlights the latest developments in the areas of artificial intelligence machine learning soft computing human computer interaction and various data science and machine learning applications It brings together scientists and researchers from different universities and industries around the world to showcase a broad range of perspectives practices and technical expertise Model Predictive Control of High Power Converters and Industrial Drives Tobias Geyer, 2017-02-28 In this original book on model predictive control MPC for power electronics the focus is put on high power applications with multilevel converters operating at switching frequencies well below 1 kHz such as medium voltage drives and modular multi level converters Consisting of two main parts the first offers a detailed review of three phase power electronics electrical machines carrier based pulse width modulation optimized pulse patterns state of the art converter control methods and the principle of MPC The second part is an in depth treatment of MPC methods that fully exploit the performance potential of high power converters These control methods combine the fast control responses of deadbeat control with the optimal steady state performance of optimized pulse patterns by resolving the antagonism between the two MPC is expected to evolve into the control method of choice for power electronic systems

operating at low pulse numbers with multiple coupled variables and tight operating constraints it Model Predictive Control of High Power Converters and Industrial Drives will enable to reader to learn how to increase the power capability of the converter lower the current distortions reduce the filter size achieve very fast transient responses and ensure the reliable operation within safe operating area constraints Targeted at power electronic practitioners working on control related aspects as well as control engineers the material is intuitively accessible and the mathematical formulations are augmented by illustrations simple examples and a book companion website featuring animations Readers benefit from a concise and comprehensive treatment of MPC for industrial power electronics enabling them to understand implement and advance the field of high performance MPC schemes **Modular Multilevel Converters** Fujin Deng,Chengkai Liu,Zhe

Chen,2023-04-11 Modular Multilevel Converters Expert discussions of cutting edge methods used in MMC control protection and fault detection In Modular Multilevel Converters Control Fault Detection and Protection a team of distinguished researchers delivers a comprehensive discussion of fault detection protection and tolerant control of modular multilevel converters MMCs under internal and external faults Beginning with a description of the configuration of MMCs their operation principles modulation schemes mathematical models and component design the authors go on to explore output control fault detection capacitor monitoring and other topics of central importance in the field The book offers summaries of centralized capacitor voltage balancing control methods and presents several capacitor monitoring methods like the direct and sorting based techniques It also describes full bridge and half bridge submodule based hybrid MMC protection methods and alternative fault blocking SM based MMCs Readers will also find A thorough introduction to modular multilevel converters including circuits operation principles modulation mathematical models components and design constraints In depth discussions of the control of modular multilevel converters including output control centralized capacitor voltage control and individual capacitor voltage control Comprehensive explorations of fault detection of MMCs under IGBT faults including short circuit and open circuit faults as well as fault tolerant control of MMCs Fulsome treatments of the control of MMCs under AC grid faults including discussions of AC side current control Perfect for electrical engineering researchers Modular Multilevel Converters Control Fault Detection and Protection will also earn a place in the libraries of electrical engineers working in industry as well as undergraduate and graduate students with an interest in MMCs **Industrial**

Applications of Power Electronics Eduardo M. G. Rodrigues,Edris Pouresmaeil,Radu Godina,2020-12-01 In recent years power electronics have been intensely contributing to the development and evolution of new structures for the processing of energy They can be used in a wide range of applications ranging from power systems and electrical machines to electric vehicles and robot arm drives In conjunction with the evolution of microprocessors and advanced control theories power electronics are playing an increasingly essential role in our society Thus in order to cope with the obstacles lying ahead this book presents a collection of original studies and modeling methods which were developed and published in the field of

electrical energy conditioning and control by using circuits and electronic devices with an emphasis on power applications and industrial control Researchers have contributed 19 selected and peer reviewed papers covering a wide range of topics by addressing a wide variety of themes such as motor drives AC DC and DC DC converters multilevel converters varistors and electromagnetic compatibility among others The overall result is a book that represents a cohesive collection of inter multidisciplinary works regarding the industrial applications of power electronics **High Voltage Direct Current**

Transmission Dragan Jovcic, 2019-07-01 Presents the latest developments in switchgear and DC DC converters for DC grids and includes substantially expanded material on MMC HVDC This newly updated edition covers all HVDC transmission technologies including Line Commutated Converter LCC HVDC Voltage Source Converter VSC HVDC and the latest VSC HVDC based on Modular Multilevel Converters MMC as well as the principles of building DC transmission grids Featuring new material throughout High Voltage Direct Current Transmission Converters Systems and DC Grids 2nd Edition offers several new chapters sections including one on the newest MMC converters It also provides extended coverage of switchgear DC grid protection and DC DC converters following the latest developments on the market and in research projects All three HVDC technologies are studied in a wide range of topics including the basic converter operating principles calculation of losses system modelling including dynamic modelling system control HVDC protection including AC and DC fault studies and integration with AC systems and fundamental frequency analysis The text includes A chapter dedicated to hybrid and mechanical DC circuit breakers Half bridge and full bridge MMC modelling control start up and fault management A chapter dedicated to unbalanced operation and control of MMC HVDC The advancement of protection methods for DC grids Wideband and high order modeling of DC cables Novel treatment of topics not found in similar books including SimPowerSystems models and examples for all HVDC topologies hosted by the 1st edition companion site High Voltage Direct Current Transmission Converters Systems and DC Grids 2nd Edition serves as an ideal textbook for a graduate level course or a professional development course *Low-Carbon Oriented Market Mechanism and Reliability Improvement of*

Multi-energy Systems Minglei Bao, Sheng Wang, Liang Du, Zhengmao Li, Weiqi Hua, 2024-12-17 The energy crisis has brought great challenges to the low carbon and economic development of the energy system To achieve net zero emissions energy systems can have an increasing penetration of renewable energy and a deep coupling of multiple energy sectors i e electricity gas and heat To deal with the increasing fluctuations of renewable energy in multi energy systems the market mechanism is an effective solution for the optimal allocation of resources An optimal market design could stimulate different resources to actively assist the carbon reduction and reliability improvement of multi energy systems Therefore research on low carbon oriented market design and optimal operation is expected to improve the reliability and sustainability of multi energy systems The objective of this Research Topic is to explore the latest advances in market design and reliability improvement technologies of multi energy systems with a focus on low carbon reliability and resilience We have the following

research goals 1 Effective market mechanisms and interaction frameworks to support the operation of energy systems 2 Advanced operation and control methods for flexible resources such as traditional units energy storage electric vehicles electric hydrogen production etc 3 Advanced planning strategies and portfolio management for flexible resources in multi energy systems 4 Advanced evaluation methods for flexibility resilience and carbon emissions of energy systems 5 Effective applications of integrated demand response in energy systems with new technical and economic models Original research and review articles in theoretical methodological or practical focuses such as models policies algorithms and applications are all welcome Research areas may include but are not limited to the following Low carbon oriented market mechanism Interaction framework designs for flexible resources Modeling and optimization technologies for multi energy systems Evaluation methods for the system resilience flexibility and carbon emissions Operation control and planning methods of multi energy systems Applications of artificial intelligence technology in reliability improvement Renewable energy prediction and integration

Communications in Microgrids Peter Xiaoping Liu, Wenchao Meng, Hui Chen, Chuanlin Zhang, 2020-03-19 This book presents some latest treatments of several specific but fundamental problems about the data communication and control of smart microgrids It provides readers some valuable insights into advanced control and communication of microgrids With the help of mathematical tools graduate students will benefit with a deep understanding of microgrids and explore some new research directions In the meantime this book gives various pictures and flowcharts to show how to address some challenges in microgrids In addition it provides solutions to several specific technical problems which might be helpful as references for the R D staff about power systems in utilities and industry Specifically the book introduces the applications of advanced control methods such as sliding mode control and model predictive control for microgrids After getting in depth understanding of these advanced control methods the readers are able to design their own improved controllers for not only microgrids but also for other real world power plants Besides the readers will also learn how to design distributed transaction mechanisms for power market based on the cutting edge blockchain technology

ELECTRIMACS 2019 Walter Zamboni, Giovanni Petrone, 2020-04-25 This book collects a selection of papers presented at ELECTRIMACS 2019 the 13th international conference of the IMACS TC1 Committee held in Salerno Italy on 21st 23rd May 2019 The conference papers deal with modelling simulation analysis control power management design optimization identification and diagnostics in electrical power engineering The main application fields include electric machines and electromagnetic devices power electronics transportation systems smart grids electric and hybrid vehicles renewable energy systems energy storage batteries supercapacitors and fuel cells and wireless power transfer The contributions included in Volume 1 are particularly focused on electrical engineering simulation aspects and innovative applications

Multilevel Converters: Control Techniques for Renewable Energy Resources Sudhakar Babu Thanikanti, Sudhakar Natarajan, Umashankar Subramaniam, Sam Sichilalu, 2022-01-13

Proceedings of 2020 Chinese Intelligent Systems

Conference Yingmin Jia, Weicun Zhang, Yongling Fu, 2020-09-23 The book focuses on new theoretical results and techniques in the field of intelligent systems and control. It provides in-depth studies on a number of major topics such as Multi Agent Systems, Complex Networks, Intelligent Robots, Complex System Theory and Swarm Behavior, Event Triggered Control and Data Driven Control, Robust and Adaptive Control, Big Data and Brain Science, Process Control, Intelligent Sensor and Detection Technology, Deep learning and Learning Control, Guidance Navigation and Control of Flight Vehicles and so on. Given its scope, the book will benefit all researchers, engineers and graduate students who want to learn about cutting-edge advances in intelligent systems, intelligent control and artificial intelligence. Intelligent Operation and Control in Next Generation Urban Power Grid Ke-Jun Li, Shutang You, Kaiqi Sun, Xingpeng Li, Huangqing Xiao, Zhaohao Ding, 2022-10-21

Multilevel Inverters Ersan Kabalci, 2021-03-27 Multilevel Inverters: Control Methods and Power Electronics Applications provides a suite of powerful control methods for conventional and emerging inverter topologies instrumentalized in power electronics applications. It introduces readers to the conventional pulse width modulation control of multilevel voltage source inverter topologies before moving through more advanced approaches including hysteresis control, proportional resonance control and model predictive control. Later chapters survey the power electronics connection between device topologies and control methods, particularly focusing on conversion in renewable energy systems, electric vehicles, static VAR compensators and solid state transformers. Examines modern design configurations for multilevel inverter controllers, emerging control methods and their applications. Presents detailed application examples of multilevel inverters deployed in modern and recent power electronic areas including renewable energy sources, electric vehicles and grid management. Discusses deployment and development of future power converter implementation. ELECTRIMACS 2024 Enrique Belenguer, Hector Beltran, 2025-01-30 This book collects a selection of papers presented at ELECTRIMACS 2024. The conference papers deal with modelling, simulation, analysis, control, power management, design, optimization, machine learning, techniques and identification and diagnostics in electrical power engineering. The main application fields include electric machines and electromagnetic devices, power electronics, transportation systems, smart grids, electric and hybrid vehicles, renewable energy and energy storage systems, batteries, supercapacitors and fuel cells and wireless power transfer among others. Contributions included in Volume 1 are particularly focused on electrical engineering, simulation aspects and innovative applications.

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