

REVIEW

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Circuit breakers in HVDC systems: state-of-the-art review and future trends

Erfan Taherzadeh¹, Hamid Radmanesh^{1*} , Shahram Javadi¹ and G. B. Gharehpetian²

Abstract

High voltage direct current (HVDC) systems are efficient solutions for the integration of large-scale renewable energy sources with the main power grids. The rapid development of the HVDC grid has resulted in a growing interest in DC circuit breakers (DCCBs). A fast and reliable circuit breaker is a necessary requirement in the development of large scale HVDC grids. This paper provides a comprehensive review and survey of the HVDC CBs and discusses potential research directions. Operational principles and the main features of various DCCBs are described and their merits and shortcomings are also highlighted.

Keywords DC circuit breakers (DCCBs), High voltage direct current (HVDC) system, Multi-terminal HVDC (MT-HVDC), Fault current isolation, Renewable energies, Voltage clamping

1 Introduction

HVDC technology is an attractive solution for transmitting large amounts of power via long-distance and asynchronous network interconnections. The demand for HVDC grids is continuously increasing because of large installations of renewable energy such as large-scale offshore wind farms and solar power [1–5]. In recent years, the number of HVDC projects in operation or under construction has seen significant growth and HVDC grids have been built in China [6, 7]. A basic point-to-point HVDC system comprises a converter station at each end, while a multi-terminal HVDC (MT-HVDC) system (HVDC grid) is formed when more than two substations are connected to the DC network. This can offer many benefits, e.g., loss and cost reduction, reliability and redundancy enhancement, etc. [5, 8].

HVDC systems are based on two distinct technologies, i.e., a line-commutated converter (LCC) using thyristors,

and a self-commutated voltage source converter (VSC) using insulated gate bipolar transistors (IGBTs) [9, 10]. LCC-based HVDC systems consume a large amount of reactive power, which must be compensated by filters on the AC side. Moreover, the power reversal requires voltage polarity reversal of the system, which is problematic for an HVDC grid. However, this technology is mature, has low losses, and has high voltage and power ratings. VSC-based HVDC systems only produce high-frequency harmonics because of the use of the pulse wide modulation (PWM) technique, or even near sinusoidal output because of the use of advanced converter topology, and thus, only small AC filters (or even no filter) are required. VSC-HVDC systems provide independent control of active and reactive power that can be generated or consumed by the converters [11]. For power reversal, the voltage polarity will not be changed. However, it has higher losses than those of LCC technology. Table 1 lists the general characteristics of the LCC and VSC-based HVDC systems. Because of the VSC characteristics, VSC technology is suggested for using in MT-HVDC.

In contrast to the LCC, which is vulnerable to AC side faults but has a natural ability to withstand short circuits on the DC side, VSC is vulnerable to DC side faults, which can result in fast DC line voltage collapse and fault

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Hvdc Transmission +1: Vsc Hvdc Based Mmc Topology In Power Systems Chan-ki Kim, Seung-il Moon, Kyeon Hur, Jang-mok Kim, Gilsoo Jang, 2021-04-09 HVDC grids and super grids have sparked so much interest these days that researchers and engineers across the globe are talking about them studying them supporting them or questioning them This book provides valuable information for researchers industry and policy makers It explains why HVDC is favorable over AC technologies for power transmission what the key technologies and challenges are for developing an HVDC grid how an HVDC grid will be designed and operated and how future HVDC grids will evolve The book also devotes significant attention to nontechnical aspects such as the influence of energy policy and regulatory frameworks This book is a result of collaboration between industry and academia It provides theoretical insights into the design and control of MMC technology and investigates practical aspects of the project planning design manufacture implementation and commissioning of MMC HVDC and multi terminal HVDC transmission technologies filling the knowledge gap between the technology specialists and VSC HVDC project developers and key personnel involved in those projects

HVDC/FACTS for Grid Services in Electric Power Systems José M. Maza-Ortega, Antonio Gómez-Expósito, 2020-11-23 Electric power systems are headed for a true changing of the guard due to the urgent need for achieving sustainable energy delivery Fortunately the development of new technologies is driving the transition of power systems toward a carbon free paradigm while maintaining the current standards of quality efficiency and resilience The introduction of HVDC and FACTS in the 20th century taking advantage of dramatic improvements in power electronics and control gave rise to unprecedented levels of flexibility and speed of response in comparison with traditional electromechanical devices This flexibility is nowadays required more than ever in order to solve a puzzle with pieces that do not always fit perfectly This Special Issue aims to address the role that FACTS and HVDC systems can play in helping electric power systems face the challenges of the near future

HVDC for Grid Services in Electric Power Systems Gilsoo Jang, 2019-11-18 The modern electric power system has evolved into a huge nonlinear complex system due to the interconnection of thousands of generation and transmission systems The unparalleled growth of renewable energy resources RESs has caused significant concern regarding grid stability and power quality and it is essential to find ways to control such a massive system for effective operation The controllability of HVDC and FACTS devices allows for improvement of the dynamic behavior of grids and their flexibility Research is being carried out at both the system and component levels of modelling control and stability This Special Issue aims to present novel HVDC topologies and operation strategies to prevent abnormal grid conditions

Direct Current Fault Protection Isik C. Kizilyalli, Z. John Shen, Daniel W. Cunningham, 2023-05-23 The lack of effective DC fault protection technology remains a major barrier for the DC paradigm shift In addressing the key challenges Direct Current Fault Protection Basic Concepts and Technology Advances starts with an introduction to the advantages of DC power systems before moving on to an in depth review of DC

fault protection technologies including mechanical circuit breaker MCB solid state circuit breaker SSCB hybrid circuit breaker HCB converter based breakerless protection and fault current limiter FCL Coverage includes a comprehensive comparison of various DC fault interruption technologies and their suitable applications state of the art DC fault protection concepts and advances in research identification of fundamental challenges and future directions in the field and commercialization aspects This book will be a valuable reference for practicing engineers researchers and graduate students in the field of power electronics and DC power systems

HVDC Grids Dirk Van Hertem, Oriol Gomis-Bellmunt, Jun Liang, 2016-02-23 This book discusses HVDC grids based on multi terminal voltage source converters VSC which is suitable for the connection of offshore wind farms and a possible solution for a continent wide overlay grid HVDC Grids For Offshore and Supergrid of the Future begins by introducing and analyzing the motivations and energy policy drives for developing offshore grids and the European Supergrid HVDC transmission technology and offshore equipment are described in the second part of the book The third part of the book discusses how HVDC grids can be developed and integrated in the existing power system The fourth part of the book focuses on HVDC grid integration in studies for different time domains of electric power systems The book concludes by discussing developments of advanced control methods and control devices for enabling DC grids Presents the technology of the future offshore and HVDC grid Explains how offshore and HVDC grids can be integrated in the existing power system Provides the required models to analyse the different time domains of power system studies from steady state to electromagnetic transients This book is intended for power system engineers and academics with an interest in HVDC or power systems and policy makers The book also provides a solid background for researchers working with VSC HVDC technologies power electronic devices offshore wind farm integration and DC grid protection

DC Microgrids Nikita Gupta, Mahajan Sagar Bhaskar, Sanjeevikumar Padmanaban, Dhafer Almakhlles, 2022-05-26 DC MICROGRIDS Written and edited by a team of well known and respected experts in the field this new volume on DC microgrids presents the state of the art developments and challenges in the field of microgrids for sustainability and scalability for engineers researchers academicians industry professionals consultants and designers The electric grid is on the threshold of a paradigm shift In the past few years the picture of the grid has changed dramatically due to the introduction of renewable energy sources advancements in power electronics digitalization and other factors All these megatrends are pointing toward a new electrical system based on Direct Current DC DC power systems have inherent advantages of no harmonics no reactive power high efficiency over the conventional AC power systems Hence DC power systems have become an emerging and promising alternative in various emerging applications which include distributed energy sources like wind solar and Energy Storage System ESS distribution networks smart buildings remote telecom systems and transport electrification like electric vehicles EVs All these applications are designed at different voltages to meet their specific requirements individually because of the lack of standardization Thus the factors influencing the DC

voltages and system operation needed to be surveyed and analyzed which include voltage standards architecture for existing and emerging applications topologies and control strategies of power electronic interfaces fault diagnosis and design of the protection system optimal economical operation and system reliability

Medium-Voltage Direct Current Grid M. M. Eissa, 2019-05-03 Medium Voltage Direct Current Grid is the first comprehensive reference to provide advanced methods and best practices with case studies to Medium Voltage Direct Current Grid MVDC for Resilience Operation Protection and Control It also provides technical details to tackle emerging challenges and discuss knowledge and best practices about Modeling and Operation Energy management of MVDC grid MVDC Grid Protection Power quality management of MVDC grid Power quality analysis and control methods AC DC DC DC modular power converter Renewable energy applications and Energy storage technologies In addition includes support to end users to integrate their systems to smart grid Covers advanced methods and global case studies for reference Provides technical details and best practices for the individual modeling and operation of MVDC systems Includes guidance to tackle emerging challenges and support users in integrating their systems to smart grids

Fundamentals of Smart Grid Systems Muhammad Kamran, 2022-12-01 Fundamentals of Smart Grid Systems offers an expansive introduction to the operationalization integration and management of smart grids the distributed renewable responsive and highly efficient power grid on the verge of radically transforming our energy system The book reviews the design of smart grid systems their associated technologies and operations helping users develop a modern foundational understanding of smart grid systems and many of their advanced implementations where sophisticated technologies are employed The work serves as a guidebook and primer for early career researchers with a rich integration of current science modern applications and future implementations Presents critical enabling technologies of smart grid systems alongside relevant aspects of their design modeling control and operations accompanied by numerical examples Discusses how to approach the integration and management of renewable energy sources in smart grid environments Features didactic pedagogical elements including end of chapter problems supplemental slideshows and figurative elements to clarify and explain complex concepts Focuses on modern applications and current implementations in industry such as power electronics for smart grids AI and machine learning driven modeling advanced control strategies and electric vehicles

The Proceedings of the 11th Frontier Academic Forum of Electrical Engineering (FAFEE2024) Qingxin Yang, Jian Li, 2024-12-04 This book contains the original and refereed research papers presented at the 11th Frontier Academic Forum of Electrical Engineering FAFEE 2024 held in Chongqing China Topics covered include Power System and New Energy Motors and Systems Power Electronics and Electrical Drives High Voltage and Discharge Electrical Energy Storage and Application New Electrical Materials Advanced Electromagnetic Technology The papers share the latest findings in the field of electrical engineering making the book a valuable asset for researchers engineers and university students etc

Electromagnetic Time Reversal Farhad Rachidi, Marcos Rubinstein, Mario Paolone, 2017-01-04 The aim of this book is

to familiarize the reader with the concept of electromagnetic time reversal and introduce up to date applications of the concept found in the areas of electromagnetic compatibility and power systems It is original in its approach to describing propagation and transient issues in power networks and power line communication and is the result of the three main editors pioneering research in the area

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