

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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Table of Contents Hvdc Circuit Breakers A Review Identifying Future Research Needs

1. Understanding the eBook Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - The Rise of Digital Reading Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Advantages of eBooks Over Traditional Books
2. Identifying Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - User-Friendly Interface
4. Exploring eBook Recommendations from Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Personalized Recommendations
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs User Reviews and Ratings
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs and Bestseller Lists

5. Accessing Hvdc Circuit Breakers A Review Identifying Future Research Needs Free and Paid eBooks
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs Public Domain eBooks
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs eBook Subscription Services
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs Budget-Friendly Options
6. Navigating Hvdc Circuit Breakers A Review Identifying Future Research Needs eBook Formats
 - ePub, PDF, MOBI, and More
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs Compatibility with Devices
 - Hvdc Circuit Breakers A Review Identifying Future Research Needs Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Highlighting and Note-Taking Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Interactive Elements Hvdc Circuit Breakers A Review Identifying Future Research Needs
8. Staying Engaged with Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Hvdc Circuit Breakers A Review Identifying Future Research Needs
9. Balancing eBooks and Physical Books Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Hvdc Circuit Breakers A Review Identifying Future Research Needs
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Setting Reading Goals Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Fact-Checking eBook Content of Hvdc Circuit Breakers A Review Identifying Future Research Needs
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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