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Internal converter- and DC-fault handling for a single point grounded bipolar MMC-HVDC system

S. Wenig[a,*], M. Goertz[a], M. Heinisch[a], S. Beckler[b,*], M. Kahl[b], M. Suriyah[a], T. Leibfried[a], J. Christian[b]

[a] Karlsruhe Institute of Technology (KIT), Institute of Electric Energy Systems and High Voltage Technology (IEH), Karlsruhe BW 76131, Germany
[b] TransnetBW TSO, Stuttgart BW 70173, Germany

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ABSTRACT

In order to address challenges caused by an increasing need for power transmission, embedded bipolar HVDC links utilizing Modular Multilevel Converter (MMC-HVDC) technology present a preferred solution as several operational and dynamic advantages compared to conventional ac grid enforcement are provided. In this paper, an approach to quickly detect and handle internal as well as dc-side faults in a full-bridge bipolar MMC-HVDC link is presented. Due to non-technical reasons and environmental constraints, the system is comprised of mixed overheadline-cable (OHL-cable) transmission and single point solid grounding with dedicated metallic return (DMR). To validate and evaluate the proposed concept, detailed electromagnetic transient (EMT) simulations are provided. These highlight effects of mixed transmission system design on transient voltage and current stresses as well as on converter-internal quantities.

1. Introduction

Technological progress in power electronics and controls led to advanced voltage source converter (VSC) HVDC technology [1]. In particular the commercial introduction of state of the art Modular Multilevel Converters (MMC) triggered numerous projects and research to connect remote offshore wind power resources [2]. Today, increasingly powerful designs additionally provide promising means to transmit renewable energy from coastal locations to the main load centres within existing ac grids.

Especially in Europe, the ongoing energy system transition is significantly changing power generation patterns in the upcoming years. Therefore bulk power embedded HVDC links are proposed by involved authorities. To avoid high transmission capacity outages in case of contingencies, bipolar systems with dedicated metallic return (DMR) and full-bridge (FB) submodules to extend operational flexibility have been recently approved or are discussed for upcoming projects [3]. Furthermore, due to a lack of social acceptance for visible transmission system equipment, some countries prioritize cable solutions by law. However, local geographical constraints might still lead to a significant share of scattered overheadline (OHL) segments. Triggered by these circumstances, this work investigates occurring fault transients in a 525 kV single point grounded bipolar FB-MMC scheme with mixed OHL-cable transmission. In contrast to previous research [4,5] and extended to [6], FB submodules are actively controlled during dc-side contingencies. This enables a continuing STATCOM functionality, as submodules are only blocked in case of converter-internal faults. To differentiate between fault locations, a fast detection and differentiation methodology related to initial considerations given in [7] is presented.

This contribution is organized as follows. Section 2 introduces basics of bipolar MMC-HVDC and highlights suitable fault clearing possibilities with FB-MMC technology. Section 3 introduces a detection concept which enables a reliable and fast differentiation between various system faults. Section 4 introduces the investigated scenario and specifies technical and protection parameters. Section 5 presents obtained detailed results for three different fault scenarios as well as a general evaluation and further research opportunities. Section 6 concludes the work.

2. Bipolar MMC-HVDC

A bipolar MMC-HVDC terminal (Tx), where x is an index numbered consecutively according to the system expansion, consists

* Corresponding authors.
E-mail addresses: simon.wenig@kit.edu (S. Wenig), s.beckler@transnetbw.de (S. Beckler).

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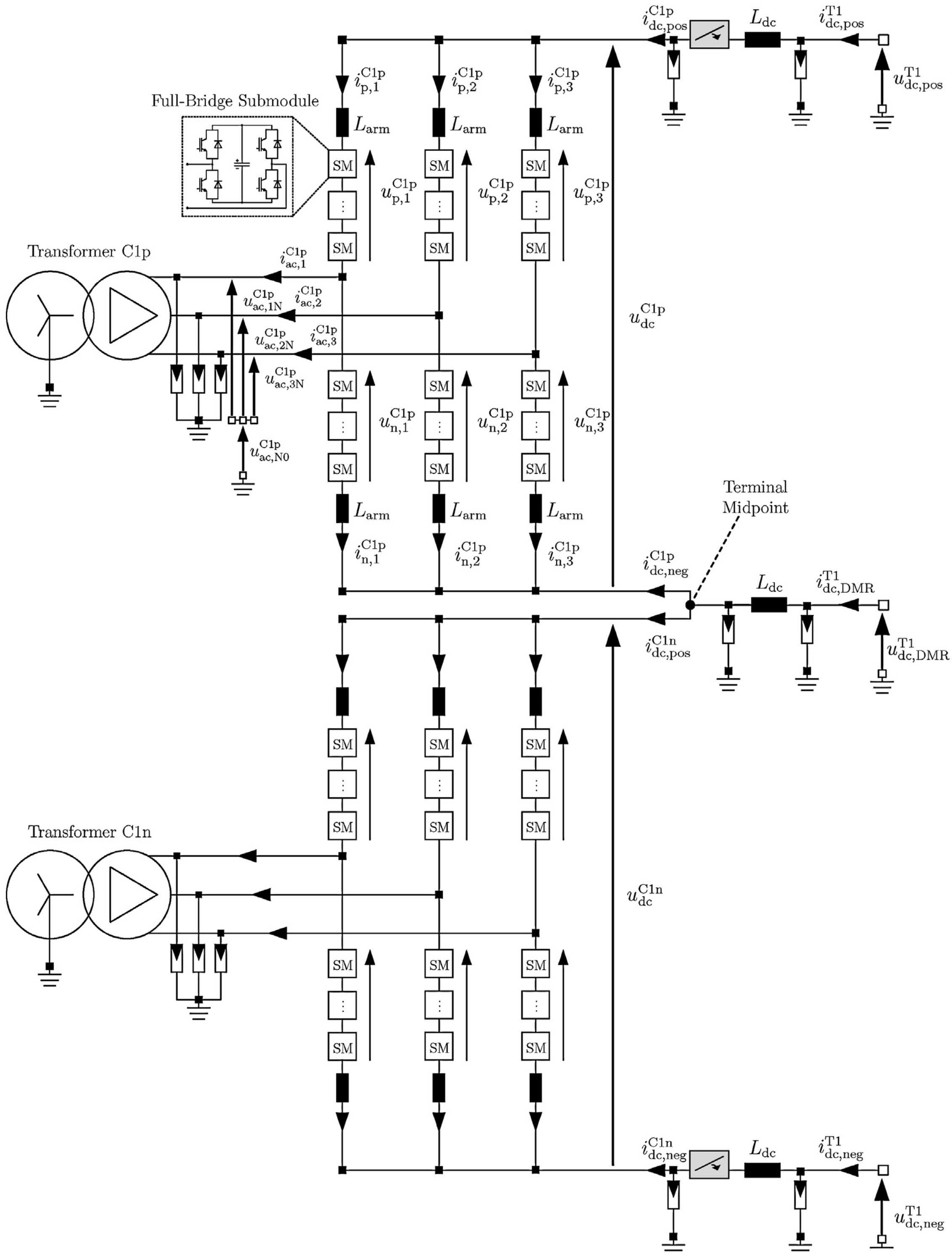

Fig. 1. Bipolar MMC-HVDC terminal three-phase equivalent circuit (terminal T1, non-grounded station).

of a series connected upper and lower converter (C*x*p, C*x*n). At the converter dc clamp contact point, called terminal midpoint, either a DMR path or a solid grounding electrode are present. On the ac-side, each converter is connected with a wye-delta transformer to the grid.

2.1. Control basics

To derive the basic control concept, the upper converter equivalent circuit of a non-grounded terminal T1 shown in Fig. 1 is analysed for a single phase. This leads to, neglecting resistive components and assuming steady state conditions $di^{T1}_{dc,DMR}/dt = 0$:

$$u^{C1p}_{ac,N0} + u^{C1p}_{ac,1N} + u^{C1p}_{p,1} + di^{C1p}_{p,1}/dt \cdot L_{arm} - u^{C1p}_{dc} - u^{T1}_{dc,DMR} = 0, \quad (1)$$

$$u^{C1p}_{ac,N0} + u^{C1p}_{ac,1N} - u^{C1p}_{n,1} - di^{C1p}_{n,1}/dt \cdot L_{arm} - u^{T1}_{dc,DMR} = 0. \quad (2)$$

Equivalent to [8–10], a full decoupling of an alternating current (ac) and phasemodule current (phm) system can be executed. Therefore, we define