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Study on transient overvoltages in converter station of MMC-HVDC links

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ABSTRACT

Transient overvoltages in converter station equipment are difficult to predict using analytical tools, therefore it is conducted by means of EMT simulations. To obtain the worst case values, several HVDC set point configurations (active/reactive power set points) and fault locations inside the converter station must be simulated. In this paper, parametric studies using EMT-type software are conducted, in this paper to simulate large number of scenarios. A generic MMC based HVDC link and the impact of arm inductance location are considered. Transient overvoltages at each electrical node in the converter station are provided and analyzed. These results and studies provide insight for researchers and engineers who are involved in insulation coordination or transient study of MMC based HVDC link.

1. Introduction

The inclusion of High Voltage Direct Current (HVDC) transmission links in ac grids is expanding rapidly. The use of Voltage Source Converters (VSCs) based on Modular Multilevel Converter (MMC) topology is becoming more attractive mainly due to their higher performances and lower cost.

During the design phase of a HVDC project, insulation coordination studies are a crucial point for the lifetime of the system and, therefore, must be addressed carefully. In a MMC based HVDC link system, if the equipment withstand voltage is chosen to be too high, converter equipment manufacturer can be difficult to design and will increase the total cost of the system. If the withstand voltage of equipment is chosen to be too low, the failure probability due to malfunction and faults will consequentially increase, causing unavailability of the HVDC link in return.

Therefore, one of the main objectives of insulation coordination studies is to establish the maximum steady-state, temporary and transient voltage levels to which the various components of the system will be exposed [3]. Internal faults in the converter station must be evaluated to determine these maximum overvoltages at each equipment. These maximum overvoltages are difficult to predict using analytical tools, therefore they are determined by means of EMT simulations. However, to obtain the worst case value, several HVDC set point configurations (active/reactive power set points) and fault locations inside the converter station must be simulated. Several articles and research work have been performed on insulation coordination (and fault behavior) of LCC HVDC links as in Refs. [2] and [3]. However, there is only few articles dealing with insulation coordination on MMC HVDC link, taking into account internal converter station faults. In Ref. [1], an overview on the overvoltages in MMC station is presented and in Refs. [4,5] studies on transient overvoltages and the impact on the dc cable are performed. In this paper, parametric studies using EMTP-RV software [8] are conducted to simulate a large number of scenarios and to identify the worst case scenario.

Circuit configuration of a converter station can vary depending on project specification and manufacturers. The impact of the arm reactor location on equipment stresses is also studied. A generic HVDC-MMC link based on [7] and on the Cigré DC grid benchmark [6] is considered. Overvoltage at each electrical node in the converter station are presented. These results and studies are useful for researchers and engineers who are involved in insulation coordination of MMC MMC-HVDC station.

XLPE technology is used more and more for HVDC cables projects. The main advantages of XLPE cables compared with Mass Impregnated (MI) and OF (oil-filled) cables are their cost and their environment impact. Nevertheless they are more sensitive to volt-

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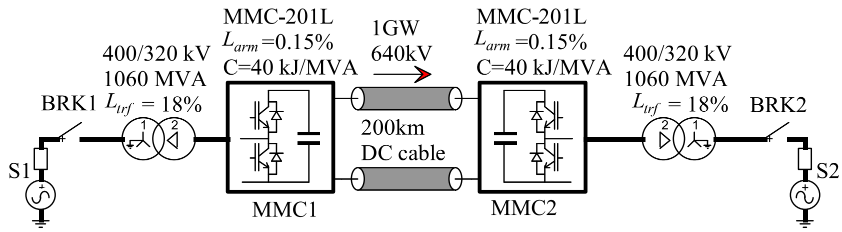


Fig. 1. MMC-HVDC transmission system.

age transients and especially polarity reversal [5]. This paper also contributes to a better assessment of transients that can stress HV DC cables.

The paper is organized as follow: Section 2 introduces the VSC-HVDC generic model used in this study. Section 3 describes the parametric test setup considered for running transient fault studies. Section 4 displays and analyses the maximal voltage stress on different components, while providing time domain results for relevant situations. Section 5 analyses the behaviour of the worst case faults. Finally, Section 6 resumes the overvoltage study considering DC surge arresters to protect the XLPE cable.

2. HVDC setup

The generic monopolar HVDC point-to-point link based on the Cigré brochure B4-57 [6] and discribed in Ref. [7] is considered (Fig. 1). The ac grids (50 Hz) are presented as equivalent sources with a short-circuit level. The transmission capacity of the link is 1000 MW. The dc cable is rated ±320 kV with a 200 km lentgh and is modeled using a wideband line model [9]. A MMC 201-level (200 SMs/arm) is considered with a time step of 25 µs. Accurate MMC model must be used, because internal faults lead to fast dynamic transients. Non-linear IGBT/diodes model are used in the converter Model #3 as defined in Ref. [7], to account for switching surges when MMC blocks [10].

The control strategy considers an active/reactive power flow control on MMC-1 and a dc voltage/reactive power control on MMC-2. Control system details are reported in Ref. [6]. In this paper, the protection system has been further developped to trip the link when a fault occurs. The considered protections are: AC undervoltages, overcurrent on each arm, DC overcurrents and overvoltage on DC terminals.

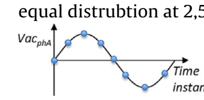
After fault occurence, the protection system sends the trip order, i.e. the converter is blocked and the ac circuit breaker is opened. In order to account for delays between protection system and power circuit equipement, artificial delays are added between the order reception and the action: 200 µs for blocking the MMC and 40 ms for opening the AC circuit breaker (BRK1 and BRK2 in Fig. 1).

3. Paremetric study setup

To identify the worst case scenario that leads to the maximum transient overvoltage on each converter station equipment, a wide range of scenarios is simulated. Parametric studies are conducted using EMTP-RV software. Maximum active/reactive power transit and solid faults are considered for all scenarios. Parametric studies consider: HVDC active/reactive power transit directions, internal fault types, internal fault instant occurring on the AC point on wave, and AC grid short-circuit level (SCL). Table 1 summarizes these parameter variations and the number of configurations. In Fig. 2, the MMC topology and fault locations are depicted.

From Table 1, the total number of configurations to be simulated is 512. DC pole-to-pole fault and AC faults on the primary side (i.e. AC grid side) are not considered since it is expected that such faults

Table 1
Setup configuration for parametric study.

Parameter	Number of configurations
Fault type	8 configurations (see Fig. 2): F1—phase-to-ground fault F2—three phase-to-ground fault F3—two phase-to-ground fault F4—phase-to-phase fault F5—positive arm-to-ground fault F6—negative arm-to-ground fault F7—positive DC pole-to-ground fault F8—negative DC pole-to-ground fault
Fault instant	8 configurations: fault instant with equal distrubtion at 2,5 ms intervals 
Transit of active power	2 configurations: ±1000 MW
Transit of reactive power	2 configurations: ±300 MVar
Short circuit level	2 configurations for S1/S2 SCLmax = 50 GVA and SCLmin = 3 GVA

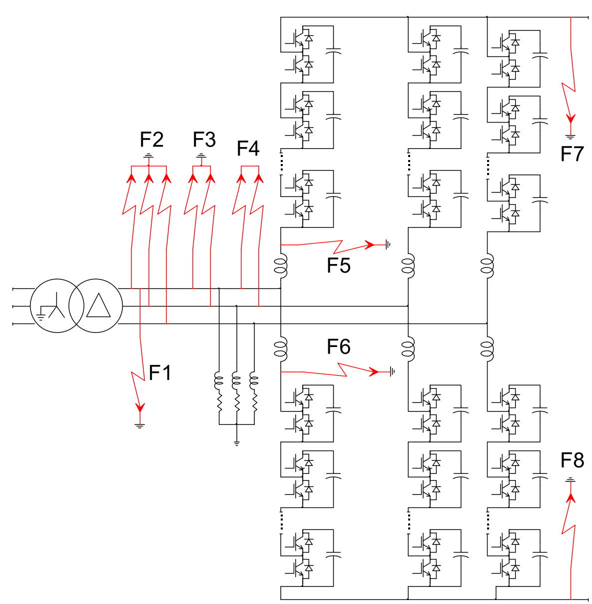


Fig. 2. Internal fault locations.

will not lead to higher overvoltages on converter equipement. Solid metalic faults (i.e. with no impedance) are considered because they intend to generate the worst transients.

For each configuration, absolute maximum peak overvoltage values are measured at each electrical node of the converter station as depicted in Fig. 3. The voltages are: AC primary ($v_{prim_{abc}}$), AC secondary ($v_{sec_{abc}}$), arm-to-ground ($v^{g}_{u\ell_{abc}}$), arm pole-to-pole ($v_{u\ell_{abc}}$) and DC pole-to-ground (V^{-}_{dc} and V^{+}_{dc}).