

Preface

High voltage direct current (HVDC) technology has been instrumental in transmitting renewable power efficiently over long distances with minimal energy losses. Within the HVDC system, voltage source converters (VSCs) technology has gained prominence as a better alternative to traditional line commutated converters (LCCs). Modular multilevel converter (MMC), a type of VSC which provides more flexibility and higher power rating, offer several distinct advantages such as compact & flexible converter station layout, black start operations capability, and independent reactive & active power control. These individual HVDC links are integrated together to form a multi terminal HVDC (MTDC) grid, which has the potential to reduce the need for converter stations and transmission lines compared to point-to-point configurations. While MTDC grids offer improved functionality and control for existing AC grids, they face a significant challenges with lack of fast and secured protection mechanisms for DC grids. The low inductance in DC circuits can result in rapid DC voltage and current changes during short-circuits, and DC networks are unable to prevent voltage collapse following a fault. Converters, designed to provide voltage support, often block themselves to protect against substantial DC fault currents. This can lead to persistent AC current feeding into the DC fault from the AC side. Therefore, there is a pressing need for an ultra-fast DC protection scheme capable of detecting and isolating DC faults within the required speed limit of 4 to 5 milliseconds (including DC circuit breaker (DCCB) opening time). Additionally, the integration of an MMC converter-based HVDC system into the HVAC network has a significant impact on the performance of distance relays installed in AC transmission lines, potentially resulting in distance relay malfunctions, including under-reach and overreach. This dissertation investigates and addresses protection & fault localization challenges in the MTDC grid and HVAC grid interfacing VSC converter based HVDC link.

In practical HVDC/MTDC projects, ABB uses the pole mode traveling wave (TW)

and its derivatives to detect the DC fault and Siemens uses TW integration principle for primary protection of HVDC grid. For resilient protection, the backup protection scheme is generally provided with voltage/current derivative or current differential protection scheme which suffers from abnormal differential current of shunt capacitance discharge. Therefore, a robust, noise tolerant and setting less primary and backup protection scheme for MTDC grid is needed. Till now, the TW principle is generally suggested for primary protection and fault localization in the MTDC grid in the literature. To solve this issue, a traveling wave based primary and backup protection scheme is designed for the MTDC grid in Chapter 2. Based on the polarity and arrival time (AT) information of the fault induced TW at the DC transmission line terminal, the fault can be categorized as internal zone (primary protection), its forward & backward external zone (backup protection).

Another major problem associated with conventional TW-based MTDC protection systems is its non adherence to the IEC 61869-9 measurement standard due to their high sampling frequency requirements, typically ranging from 500 kHz to 1 MHz. To address this issue, a novel primary protection and real-time DC fault localization system that complies with the IEC 61869-9 protocol has been introduced in chapter 3. This novel approach utilizes modified mathematical morphological gradient (MMG), the Sobel operator, and linear regression techniques to accurately extract AT information from the fault induced TW, even with lower sampling frequencies (up to 50 kHz) which makes it compliant to IEC-61869-9 measurement standard. The practical viability of proposed scheme is also demonstrated through control hardware-in-loop (CHIL) setup of real-time digital simulation and intelligent electronic device prototype based on TI TMS320F28379D DSP board.

In the next chapter, a novel single ended TW based fault localization scheme is developed, which only relies on first incident TW arrival time (TWAT) information of high sampling frequency and low sampling frequency measured (derived from high sampling frequency using downsampler and low pass filter) of the aerial mode signal at the local terminal of the MTDC grid. It overcomes the challenging task of detecting reflected TW for close-in fault near line terminal in a conventional single ended TW based fault localization scheme which need TWAT information for the first and second TW at the local DC terminal.

Apart from the MTDC protection challenges, there are several issues associated

with conventional distance protection for HVAC network interfaced with MMC-HVDC transmission system. The low voltage ride through (LVRT) control of the MMC converter changes the grid characteristics during fault near the point of common coupling (PCC) in the HVAC grid, which might lead to distance relay maloperation. Moreover, there are very few research work in the literature that explores the protection algorithm challenges associated with mixed cable & overhead transmission line (OHTL) in the HVAC grid. Therefore, a TW based wide area backup protection scheme (WABPS) is designed, using fast sliding matrix pencil (SMPA) and graph theory algorithm, for mixed cable & OHTL in the HVAC grid interfaced with HVDC link. At last, Chapter 8 concludes whole thesis and presents the scope for future work.