Chapter 6

Conclusion and future scope

6.1 Main contribution

In light of the research presented in this thesis, the subsequent major conclusions are outlined as follows -

1. The literature or state of the art primarily recommends the utilization of traveling wave arrival time principles for the primary protection and fault localization of multi terminal HVDC grids. However, a morphological undecimated wavelet based approach is used to analyze the polarity and arrival time information of the first incident traveling wave. This analysis is used to classify faults into internal, forward external, and backward external zones, serving as both primary and backup protection mechanisms for MTDC grids.

2. Most of the conventional traveling wave based protection and fault localization scheme discussed in the literature are not compliant to IEC-61869-9 measurement standard. Therefore, a novel double ended traveling wave based primary protection and real time DC fault localization scheme is proposed, which is compliant to IEC 61869-9 measurement protocol. The proposed scheme's practical feasibility is verified through hardware-in-loop validation, employing a real-time digital simulator and a cost-effective hardware prototype of IED based on the TI TMS320F28379D DSP board.

3. The conventional single ended TW based fault localization scheme in the literature can not detect traveling wave for close-in fault which is identified as dead zone.

To solve this issue, a single-ended traveling wave based fault localization scheme utilizing sliding matrix pencil method technique is designed for MTDC grids. It offers improved accuracy in detecting close-in fault locations (dead zones) compared to conventional traveling wave-based fault localization methods.

4. None of the research in the literature have addressed protection issue for the mixed transmission line system. Therefore a wide-area backup protection scheme, combining graph theory and successive matrix pencil algorithm, is developed for mixed cable and OHTL of HVAC grid network supplied by MMC converter based HVDC. The scheme leverages traveling wave principles for secured wide area backup protection and fault localization.

6.2 Advantages and limitations

The advantages of proposed protection and fault localization scheme, described in the thesis, are summarized below -

1. In Chapter 2, the proposed protection and fault localization scheme uses same extracted TWAT information for both primary and backup protection scheme. In literature, the current/voltage derivative or machine learning based technique has been suggested for backup protection. But the proposed backup protection scheme uses the same TW principle which can be further extended to fault localization estimation.

2. The low sampling frequency based protection and fault localization scheme, proposed in Chapter 3, is one of the first TWAT based scheme which is compliant to IEC-61869-9 measurement standards which limits the maximum sampling frequency to 96 kHz.

3. The proposed single ended TWAT based fault localization technique, described in Chapter 4, overcomes the challenges of locating close-in fault to category of single ended TWAT based fault localization scheme.

4. In Chapter 5, the proposed WABPS scheme is demonstrated to be robust against MMC converter control algorithm such as LVRT. Moreover, it also provides TW

based distance protection for mixed OHTL and cable in HVAC network, whereas conventional distance protection scheme fails to correctly identify protection zones for mixed lines.

The limitations of proposed research work are also summarized here -

1. The proposed primary and backup protection scheme in Chapter 2 requires a dedicated communication channel and it is non-compliant to IEC-61869-9 measurement standard.

2. In Chapter 3, the proposed protection and fault localization scheme would require a dedicated communication channel between the DC terminal for its implementation.

3. The performance of the proposed TWAT based fault localization scheme, described in Chapter 4, depends on the DC link (OHTL and cable) parameters and sampling frequency selection which varies the velocity factor of the proposed scheme. Moreover, the proposed TWAT based scheme could not be extended to protection function due to high computational burden of matrix pencil algorithm.

4. The dependence of the proposed WABPS, described in Chapter 5, on the dedicated IEC-61850 compliant communication network limits its efficacy in the even of communication failure.

6.3 Scope for future work

The potential for further development in this research is rooted in expanding upon the work presented in the thesis, and the following possibilities are described below -

1. The proposed traveling wave based primary and backup protection scheme, utilizing morphological undecimated wavelet technique, is only valid for the radial and ring MTDC system. And there is a need to develop robust and secured traveling wave based primary and backup protection scheme for meshed MTDC system.

2. A single ended traveling wave based protection and fault localization scheme should be designed for MTDC grid, which can detect and locate close-in fault to DC terminal while adhering to IEC 61869-9 measurement standard.

3. The design of WABPS for the HVAC grid interfacing an MMC converter-based HVDC system could be expanded to other VSC based renewable energy sources such as offshore wind farm integrated HVAC network.

4. Further analysis is needed to assess the impact of MMC control and Sub-Synchronous Torsional Interaction (SSTI) between HVDC systems and synchronous generators on the conventional distance protection of HVAC grids. This analysis should lead to the exploration of a robust protection strategy for HVAC transmission lines interfacing PE based converters.