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AI·SW HVDC Integrated Power System Innovation Research Center

September Highlights





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Invited Seminar by Soohyun Nam of KEPCO

C2 Grid Hub hosted an invited seminar by Soohyun Nam of KEPCO on underground transmission operations. The seminar introduced the basic configuration of underground cables and joints and the importance of field inspection and condition assessment.

Underground transmission equipment
The seminar reviewed the roles of underground cables and joints and discussed how insulation and electric-field management affect equipment reliability.

Operation and inspection
Regular field inspection and condition-based diagnostics were presented as essential practices for reliable underground transmission operation.

Connection to research and education
Participants discussed field needs and potential applications of cable diagnostics and data-driven condition assessment.




Impact of MMC Arm Dynamics on the Small-Signal Stability Analysis of Bipolar MTDC System Under DC Droop Control

Chanho Ji*, Seungyun Lee*, and Kyeon Hur†

Abstract — This paper investigates the small-signal stability of a bipolar three-terminal MTDC system under hybrid GFL/GFM droop control. A full-order system model retaining MMC internal arm dynamics is compared with a reduced-order model. While the reduced-order model indicates stable operation, the full-order model reveals that the system can enter an unstable mode of oscillatory mode. Participation factor analysis shows that the instability is governed not only by the VSM states but also by the arm-sum capacitor voltage and the arm-sequence circulating current states. Time-domain simulations confirm that the oscillatory instability identified in the eigenvalue analysis is also observed in the full-order model. These results highlight the importance of MMC internal arm dynamics for reliable small-signal stability assessment under GFM DC droop control.

Keywords: DC droop control, Grid-Forming, Modular Multi-level Converter, Multi-Terminal DC, Small-Signal Analysis.

1. Introduction

Multi-terminal high-voltage direct current (MTDC) systems based on modular multilevel converters (MMC) are widely regarded as a promising technology for large-scale offshore wind integration and interconnection of asynchronous AC systems. DC voltage droop control is generally preferred over master–slave control in such systems because it enables multiple converter stations to be decentralized, thereby improving reliability compared with conventional master–slave control [1]. However, droop control with relatively aggressive droop gains [1-4] p.u.) are often required to ensure adequate N–1 ride-through capability, and such gains may degrade system stability when grid-following (GFL) control [5] is employed.

With the progressive replacement of synchronous generators, grid-forming (GFM) control has become increasingly important for maintaining system strength and stability [6]. Recent studies have investigated the use of Grid-forming GFM control with DC voltage droop in a practically relevant operating mode for future MTDC systems. Small-signal analysis of a bipolar MTDC system with GFM converters have shown that low-frequency interactions may arise under such conditions, making small-signal stability assessment essential [7].

Despite this growing interest, existing studies have mainly relied on reduced-order MMC models. However, detailed MMC modeling studies have shown that reduced-order representations do not necessarily preserve the internal arm-

energy and circulating-current dynamics of the converter [3]. In practice future MTDC systems are likely to include hybrid configurations combining GFL and GFM stations, especially in large-scale and gradually expanded networks. In such systems, reduced-order models may not only miss important eigenvalues, but also conceal the emergence of critical oscillatory modes. This issue becomes particularly important when determining the stable operating range of the droop gain.

This paper addresses this gap by presenting a small-signal stability analysis of a bipolar three-terminal MTDC system in which one GFL station and two GFM stations simultaneously participate in DC voltage droop control. A full-order model retaining MMC internal arm energy and circulating current dynamics is formulated and compared with a reduced-order model. Eigenvalue analysis and participation factor decomposition are used to identify the dominant instability mechanism and to examine how the GFM DC droop gain affects the instability threshold.

2. Small-Signal Model of MTDC System

The system under study is a bipolar three-terminal MTDC system with a dedicated metallic return (DMR), as shown in Fig. 1. The positive-pole terminals 1 and 2 employ droop control, whereas Terminals B and C are operated in virtual synchronous machine (VSM) with DC voltage droop control. The AC systems connected to the terminals are represented by Thévenin equivalents. The GFM terminals are connected to strong AC systems with short-circuit ratios within the GFL terminal is connected to a grid with an SCR of 3. The nominal power flow is set as follows: Terminal B injects 800 MW, Terminal C absorbs 500 MW, and Terminal

Chanho Ji receives the ICEE 2026 Best Oral Presentation Award

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Chanho Ji Receives the ICEE 2026 Best Oral Presentation Award

Chanho Ji received the ICEE 2026 Best Oral Presentation Award for his study on the small-signal stability of an MMC-based bipolar MTDC system.

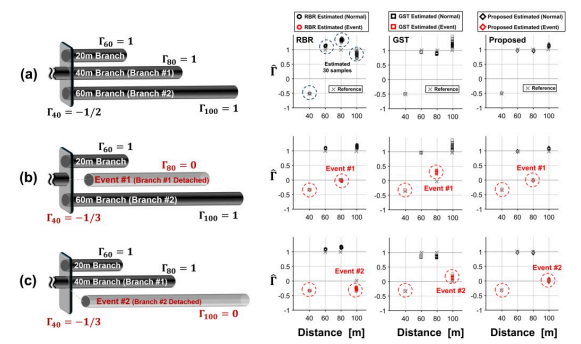
Stability model with MMC arm dynamics
A full-order model retaining arm-energy and circulating-current dynamics was developed and compared with a reduced-order representation.

Coupled oscillatory mode
The unstable mode was linked to both the VSM outer control and an internal energy-feedback path involving arm-capacitor voltage and zero-sequence circulating current.

Time-domain validation
Time-domain simulations confirmed the instability identified through eigenvalue and participation-factor analyses, demonstrating the need for detailed MMC modeling.

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Cable Network Condition Assessment Study Published

A study on quantitative condition assessment for industrial multi-branch cable networks was published in IEEE Transactions on Instrumentation and Measurement in September 2026.

Topology-informed sparse recovery
The method incorporates cable-network connectivity into sparse signal recovery to estimate the condition of multiple branch sections.

Reduced error propagation
A recursive mapping based on the Bewley lattice mitigates the propagation of upstream estimation errors to downstream sections.

Experimental validation
Tests on cable networks with multiple branch conditions confirmed stable assessment performance in complex reflection environments.

First author: Dr. Hobin Lim · Corresponding author: Prof. Yong-Jun Shin · IF 7.0 / JCR 5.6%