

Invited Speaker: Professor Khaled Ahmed, University of Strathclyde, Glasgow, UK

Unlocking Stability and Control for VSC-HVDC in Ultra-Weak Grids

Summary:

As the global energy transition accelerates, the integration of large-scale renewable energy sources often located far from load centres has become a paramount challenge. Voltage Source Converter (VSC) based High-Voltage Direct Current (HVDC) technology is the key enabler for this transition, offering unparalleled flexibility and control. However, a critical and often underestimated challenge emerges when these VSC-HVDC systems are connected to "very weak" AC grids, a scenario increasingly common at the edges of our power systems, such as in remote renewable energy hubs or on offshore platforms.

In such grids, the low short-circuit ratio (SCR) fundamentally alters the dynamic behaviour of the converter, leading to a host of instability phenomena: from classic loss of synchronisation and voltage collapse to Sub-Synchronous Oscillations (SSO) and complex, non-linear interactions that defy traditional analysis and control paradigms. The conventional "stiff grid" assumptions, upon which most control designs are based, no longer hold, creating a significant barrier to reliable and efficient power transmission.

This keynote will place special emphasis on the phenomenon of Sub-Synchronous Oscillations a silent but devastating threat to VSC-HVDC systems in weak grids. We will dissect the root causes of SSO, exploring the intricate interplay between the converter's Phase-Locked Loop (PLL), inner current control loops, and the grid impedance. We will examine how the negative resistance effect, introduced by the converter's control dynamics at sub-synchronous frequencies, can lead to catastrophic oscillations and, in severe cases, system collapse as witnessed in several high-profile incidents worldwide.

The talk will then journey through the state-of-the-art in stability analysis, contrasting traditional impedance-based methods with advanced techniques like eigenvalue analysis, harmonic state-space modelling, and non-linear bifurcation theory. We will explore how these tools can be used to predict and mitigate SSO risk before it manifests in the field.

The core of the talk will focus on the paradigm shift in control design required to overcome these challenges. We will examine cutting-edge solutions, including:

- Grid-Forming Control: Moving beyond conventional grid-following to emulate the inertia and voltage support of synchronous machines, inherently damping SSO.
- Advanced PLL Structures and Virtual Impedance: Techniques to decouple the converter's dynamics from grid weaknesses and actively dampen sub-synchronous modes.
- Active Damping Control and Wide-Area Monitoring: Real-time detection and mitigation strategies to suppress SSO as it emerges.
- Robust and Adaptive Control: Strategies that can dynamically adjust to changing grid conditions in real-time.