

Oscillatory Interaction Mechanisms in AC-DC Systems: Coupling Dynamics of Grid-Forming Converters and Synchronous Condensers

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Abstract-

This paper presents a fundamental analytical demonstration of the dynamic interaction between the AC and DC domains in an islanded power system supplied by a Grid-Forming (GFM) converter. While the integration of Synchronous Condensers (SCs) is widely considered a universal solution for enhancing grid strength, this study reveals that SCs do not inherently improve system performance. By formally deriving the equivalent electromechanical coupling, this work demonstrates that the AC and DC sides are strongly coupled. Under specific operating conditions dictated by the primary energy source time constant, the DC-link capacitance and the DC-link control parameters, the highly stiff AC coupling introduced by the SC can trigger a detrimental response due to a frequency-dependent resonance with the DC-side control dynamics. The proposed analytical framework is validated through detailed large-signal transient simulations and experimentally evaluating over 750 operating points. The results successfully map the operational boundaries of the system, proving that SC integration can exacerbate instability if the AC-DC interaction mechanisms are not properly addressed.

Index Terms- Grid-Forming Converter, Small-Signal Stability, Primary Energy Source Dynamics, Synchronous Condenser, Synchronous Compensator, Virtual Synchronous Machine, Power System Stabilizer.

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