Contrasting Impacts of Grid Strength on Grid-Following and Grid-Forming Inverters: An Impedance Based Analysis

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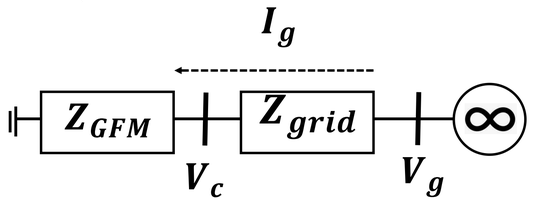
Background

- As renewable energy integration increases, interest in the dynamic behav ior of inverter-based resources (IBRs) is growing
- It is known that grid-following (GFL) inverters suffer from instability under weak grid conditions, while recent studies report that grid-forming (GFM) inverters may become unstable in strong grids
- This study models GFL and GFM dynamics using impedance (or admittan ce) transfer functions, and identifies contrasting instability patterns that in form inverter design with respect to grid strength

Impedance Modelling and Stability Analysis

Impedance model of an inverter

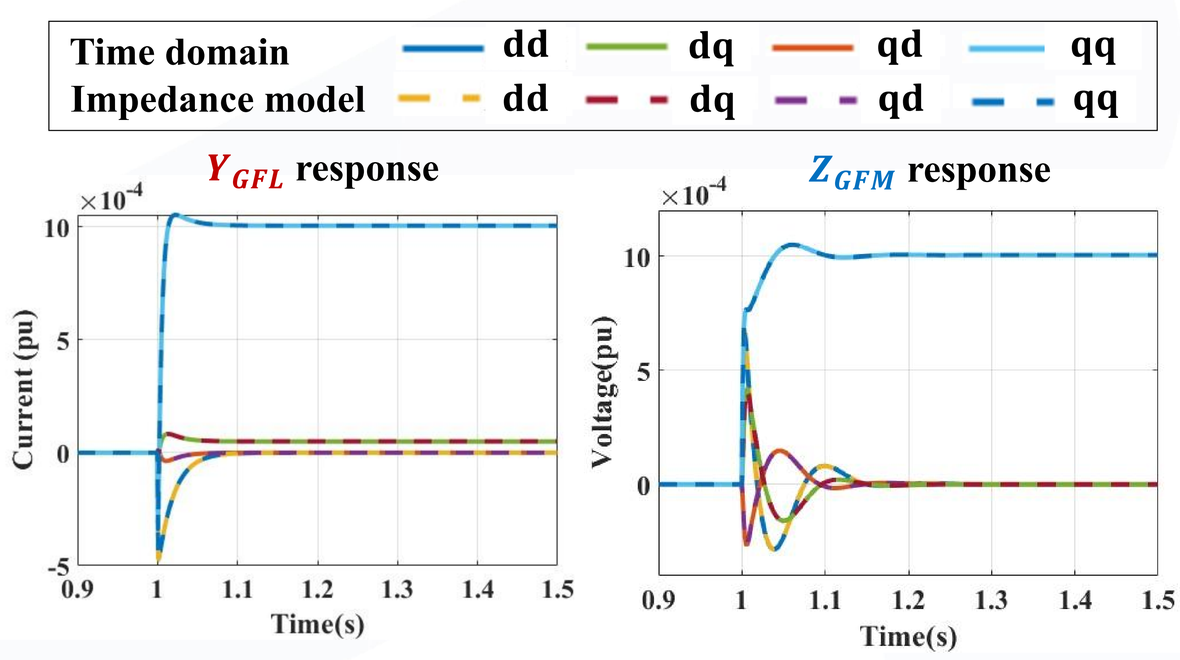
- The dynamic characteristics of an inverter's plant and controller can be represented in the S-domain using impedance or admittance matrices
  - Typically expressed as a 2×2 matrix including d-d, d-q, q-d, and q-q
  - For example, the d-d term represents the output voltage in the d-axis in response to a d-axis current input.
- Depending on the control structure, GFL inverters are modeled as admit tance, while GFM inverters are modeled as impedance



[Figure 1] Concept of inverter impedance model

Impedance model validation

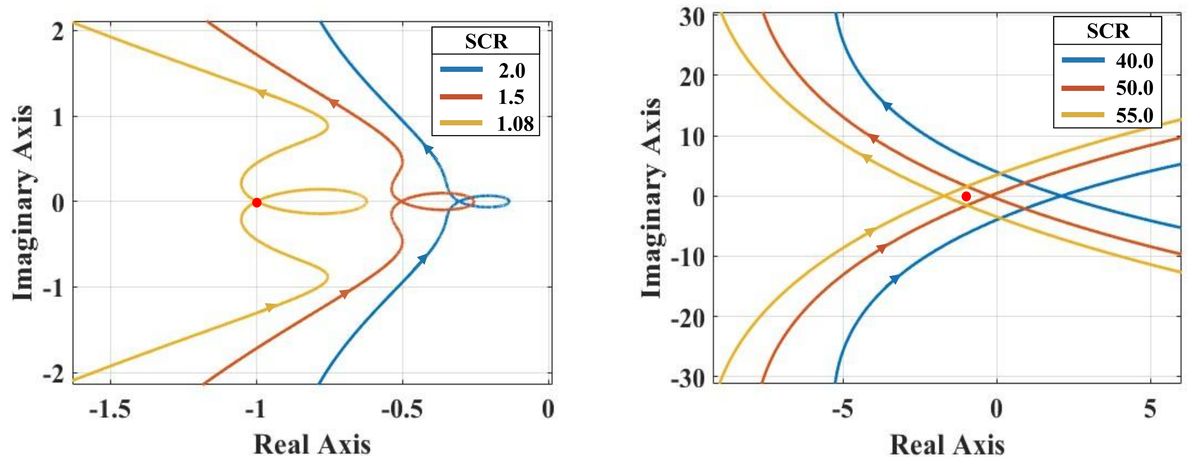
- The derived transfer functions (admittance for GFL and impedance for GFM) were validated by comparing their step responses with time-doma in simulation results



[Figure 2] Validation of derived impedance models

Nyquist stability analysis

- Once the inverter's impedance model is derived, it can be combined wit h the grid impedance (which reflects grid strength) to assess system sta bility
  - To evaluate absolute stability, the generalized Nyquist criterion is applied, as the impedance model is represented as a 2×2 matrix
- Applying this method to both GFL and GFM inverters revealed opposite stability trends depending on grid strength



[Figure 3] Nyquist stability analysis results

Stability Trends with Varying Parameters

- In both GFL and GFM, the bandwidths of current and voltage controllers, as well as synchronization-related parameters, were found to have a signi ficant influence on these stability boundaries
  - The GFL results show the minimum SCR level at which the system remains stable (Red color indicates better stability)
  - The GFM results indicate the maximum SCR level beyond which instability begins to occur (Blue color indicates better stability)

[Figure 4] Result of (top) GFL and (bottom) GFM