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Frequency Domain Specifications for Grid-Forming Resources

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Why we Need Frequency-domain Specifications?

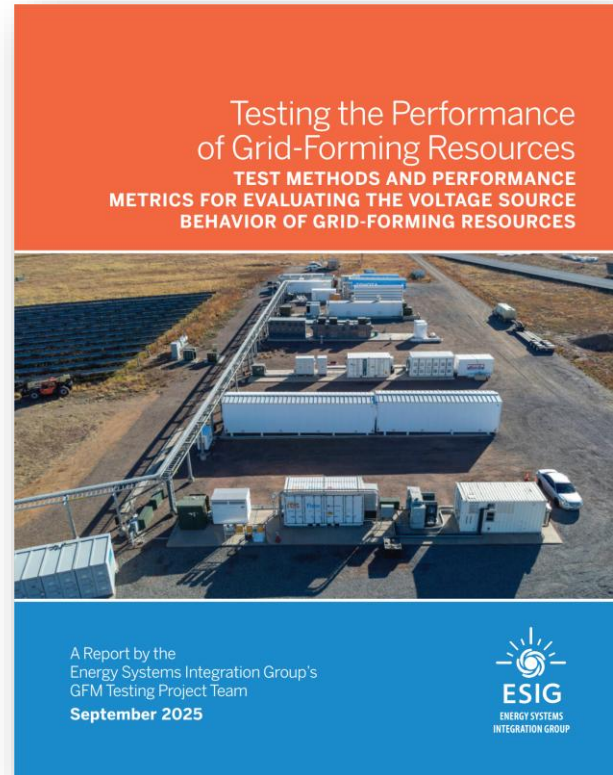
- Unlike time-domain specifications, frequency-domain specs can be defined relatively independently of the operating conditions – power output and grid strength (e.g., SCR) level.
- Frequency-domain specs directly and quantitatively show system strength contribution provided by GFM resources.
- Frequency-domain specs are strongly correlated to time-domain specs but provide higher insight on the performance of GFM resources.
- Limitations of Frequency-domain Specs:
 - They focus only on the small-signal behavior; this limitation is particularly important during operation of a GFM resource near their ratings.
- A Word of Caution:
 - **Do not duplicate:** Limited new information is obtained from defining frequency-domain specs for a performance characteristic of a GFM resource that is effectively captured by time-domain specs.
 - **Do not complicate:** It is important to keep frequency-domain specs as simple as possible.

ESIG Report Focusing on Grid-Forming Performance

- Tests and performance metrics for quantifying the **voltage source behavior** of GFM resources
 - Pass/fail criteria based on frequency scans
 - Time-domain tests
 - Phase jump test
 - Voltage jump test
 - Frequency-domain Tests
 - Impedance or V/I scan – *equivalent Thevenin impedance*
 - Q/V scan – *related to voltage jump test*
 - P/ θ scan – *related to phase jump test*

[Report Link: https://www.esig.energy/gfm-performance-testing/](https://www.esig.energy/gfm-performance-testing/)

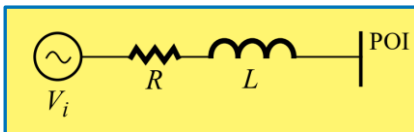
Webinar Link: https://www.youtube.com/watch?v=sNVhEOnad_w



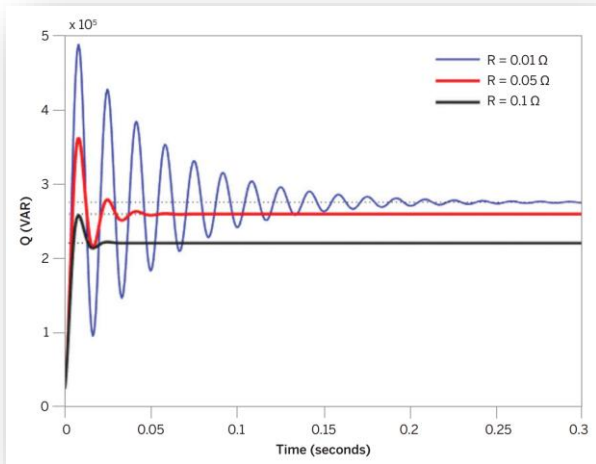
Source: ESIG

Characteristics of a Voltage Source Behind a Reactor

Time-Domain



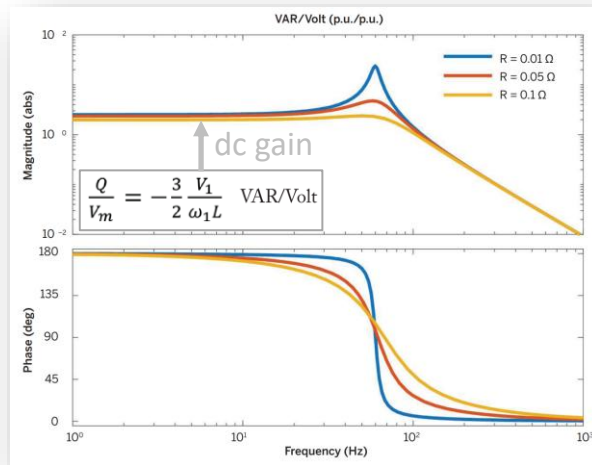
Response to 10% drop in grid voltage magnitude (V)



Ref.: S. Shah, et. al., "[A testing framework for grid-forming resources](#)," 2023 IEEE Power and Energy Society General Meeting, Orlando, FL.

Frequency-Domain

Transfer function from V to Q



$L = 0.5 \text{ mH}$ gives **SCR of 2.5** for $V_{\text{base}} = 0.69 \text{ kV}$ and $P_{\text{base}} = 1 \text{ MW}$

Characteristics of a Voltage Source Behind a Reactor

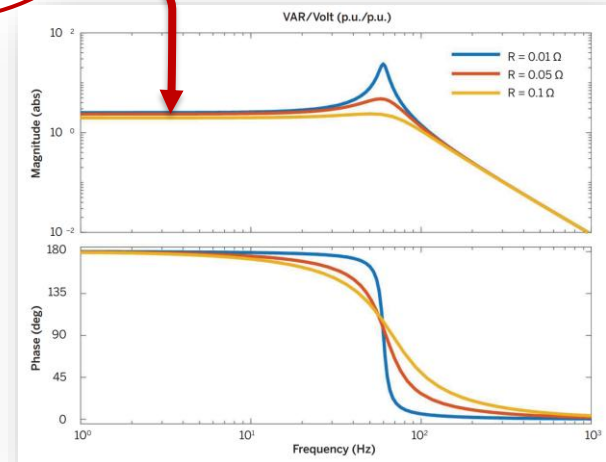
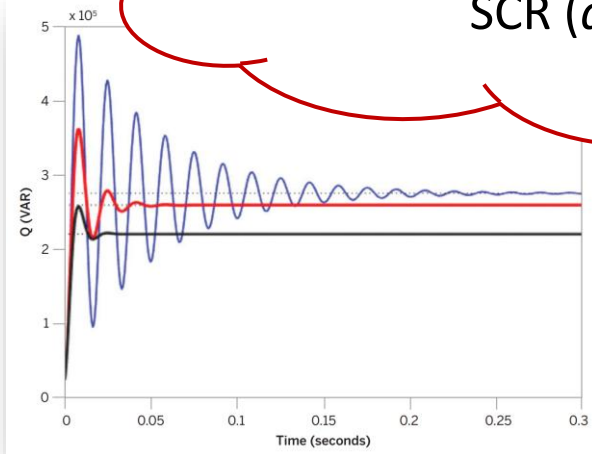
Time
Response
magnitude

Gain in p.u./p.u. gives
equivalent short circuit ratio
(SCR): path to define dynamic
SCR ($dSCR$)

Ref.: S. Shah, et. al., "[A testing framework for grid-forming resources](#)," 2023 IEEE Power and Energy Society General Meeting, Orlando, FL.

Frequency-Domain

Transfer function from V to Q

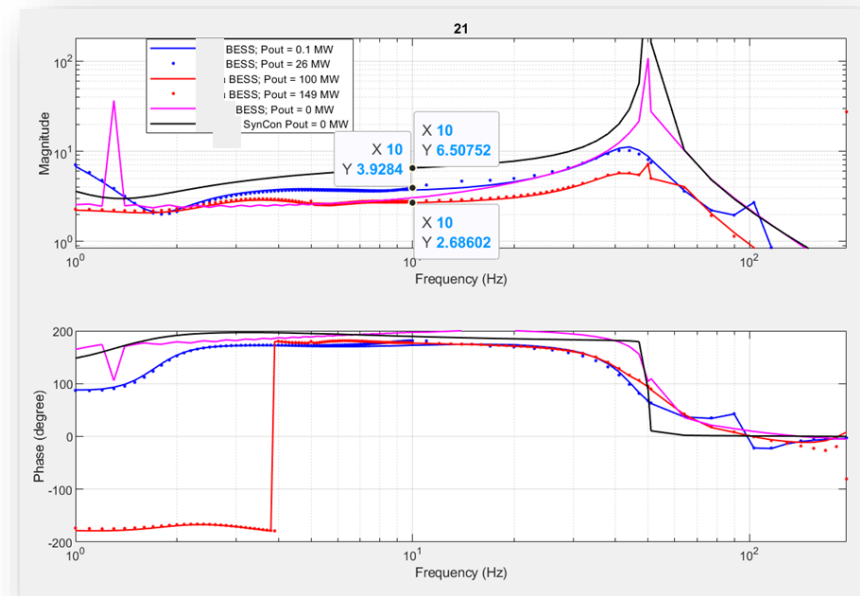


$L = 0.5$ mH gives SCR of 2.5 for $V_{base} = 0.69$ kV and $P_{base} = 1$ MW

Range of $dSCR$ and Z for SynCon and GFM BESS

- Vendor EMT models of a SynCon and three GFM Battery Plants were used to estimate their $dSCR$ and impedance Z ($= 1/dSCR$).

Resource	$dSCR$	Z
SynCon	6.5	0.15
GFM BESS #1	3.9	0.25
GFM BESS #2	3	0.33
GFM BESS #3	2.6	0.38



Performance Metrics for Q/V Frequency Scan Test

- **Magnitude response:** The magnitude of Q/V frequency scan should be higher than **2 p.u./p.u.** within the frequency range of **4 to 40 Hz**.
- **Phase response:** The phase of the Q/V frequency scan should be $\pm 180^\circ$ within the frequency range **4 to 40 Hz**. The error between the actual phase and $\pm 180^\circ$ should be smaller than **20°**.

Footnotes:

Performance parameters highlighted in bold should be changed based on the system requirements.

Resonance or mechanical considerations might require deviation from this specification around certain narrow frequency ranges.

Performance metrics for P/ θ frequency scan are similar to that of Q/V frequency scan test

Summary

- Voltage source behavior is the core function expected from GFM resources to improve grid strength and support stability of bulk power systems.
 - Time-domain and frequency-domain tests can be used to quantify the voltage source behavior or grid strength provided by them.
- Frequency-domain specs based on Q/V and P/θ frequency scan tests can quantify system strength contribution from GFM resources
 - They also highlight the quality of the GFM behavior
- **Sizing of GFM Resources**
 - Grid Strength Requirement from IBRs → Available Strength in the System
 - Deficit provided by GFM Resources

Thank You

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