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**Benchmarking of Six Different Frequency Scan Tools – Insights
and Lessons Learned**
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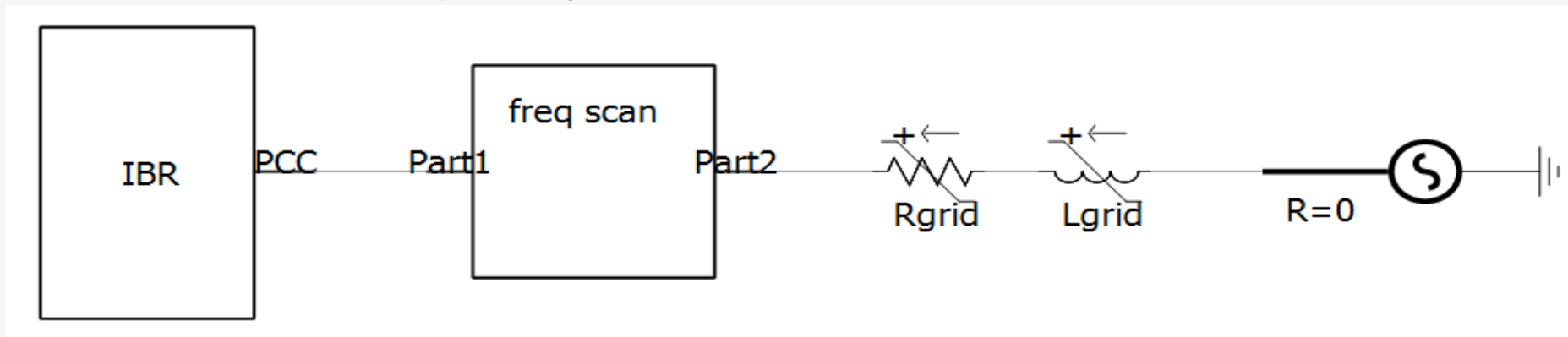
Outline



1. Background
2. Overview of Frequency Scan Method
3. Benchmarking for Six Different Tools
 - With White Box Model
 - With Black Box Solar Farm Model
 - Summary of results
4. Tool usage trends
5. Conclusion

Background

- The increase in Inverter-Based Resources (IBR) is introducing new challenges, including controlling Sub-Synchronous Oscillations (SSO), power quality, and reduction in inertia.
- Frequency domain admittance-based methods have gained increasing interest to analyse the potential of SSO risk.
- This presentation covers the results obtained from the benchmarking exercise with **six different Frequency Scan tools** and the **lessons learned**.



Grid-connected IBR with frequency scanning tool ('Freq scan' box) between the inverter and grid

Tools and Models

- **Tools**

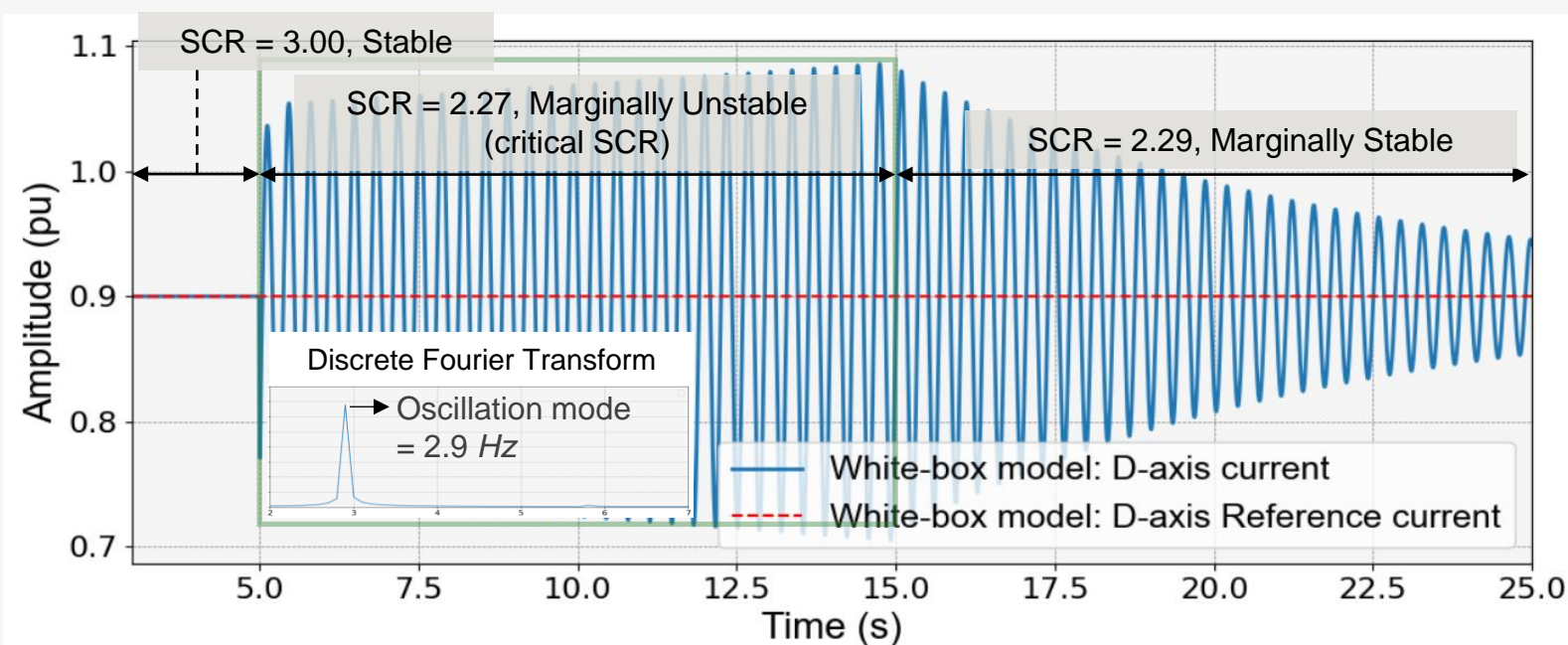
- Three from System Operators
- Two from Universities
- One from established modelling tool supplier

- **Models**

- **A white-box model** without power plant controller (PPC), developed by AEMO using a design in public domain
- **A solar farm and a wind farm black-box model** (including PPC and collector system)

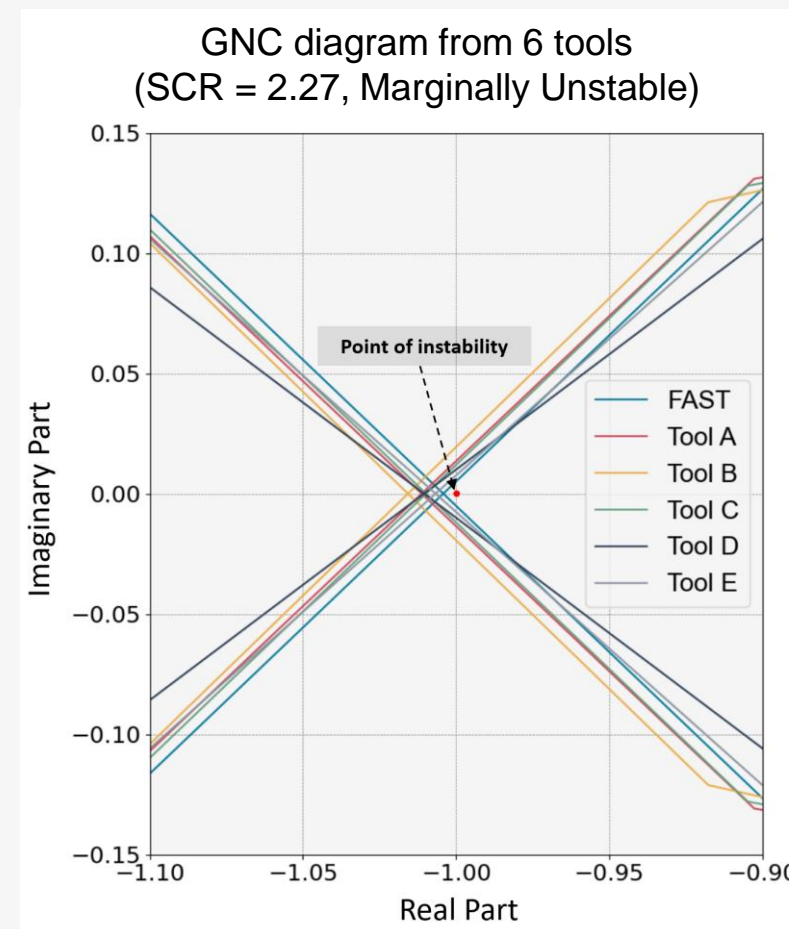
Validation methodology

- Test cases with varying short-circuit ratio (SCR) were simulated with results analysed in the time domain.
- Frequency scan tools were used to identify the critical SCR and the oscillation mode through generalized Nyquist criterion (GNC)



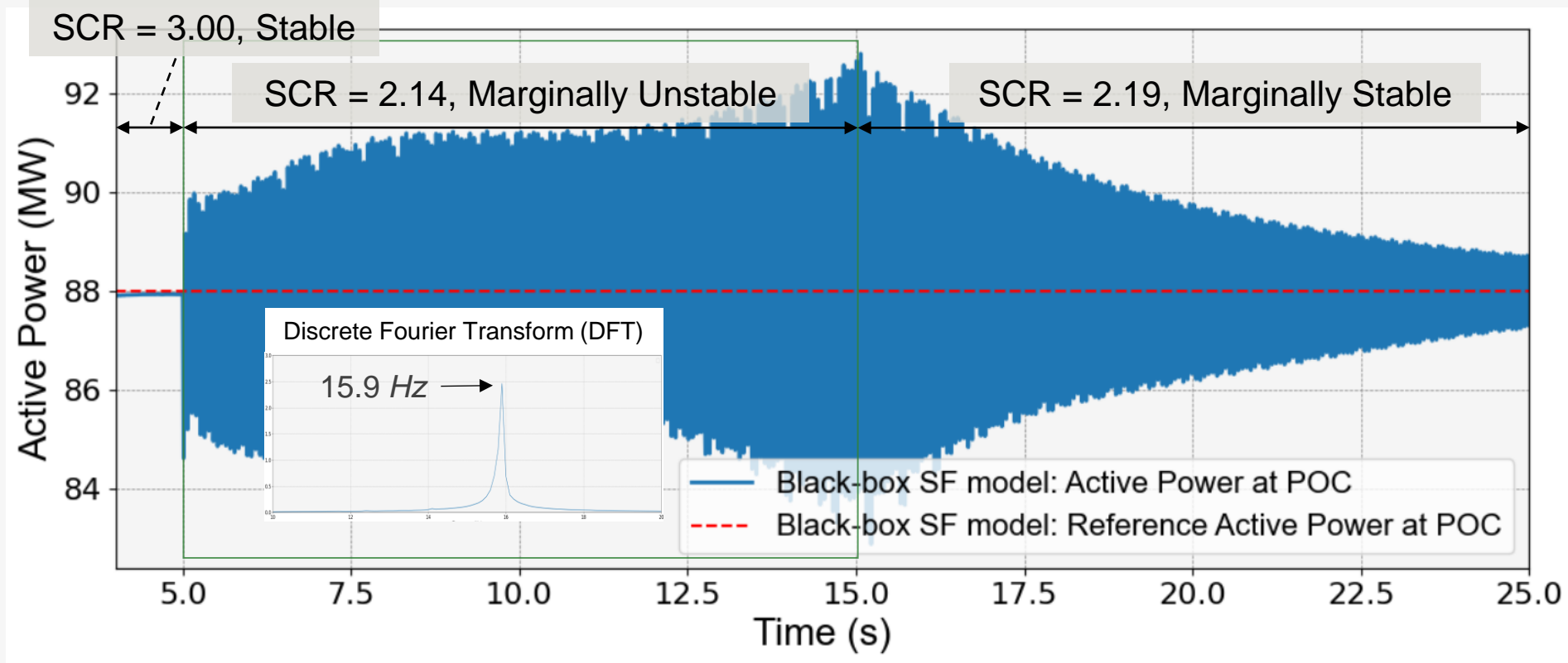
White box validation

1. All tools were validated successfully against theoretical (mathematical) response in bode plots.
2. All tools were able to identify the critical SCR (2.27) and oscillation mode ($\sim 3\text{Hz}$) in the test case.



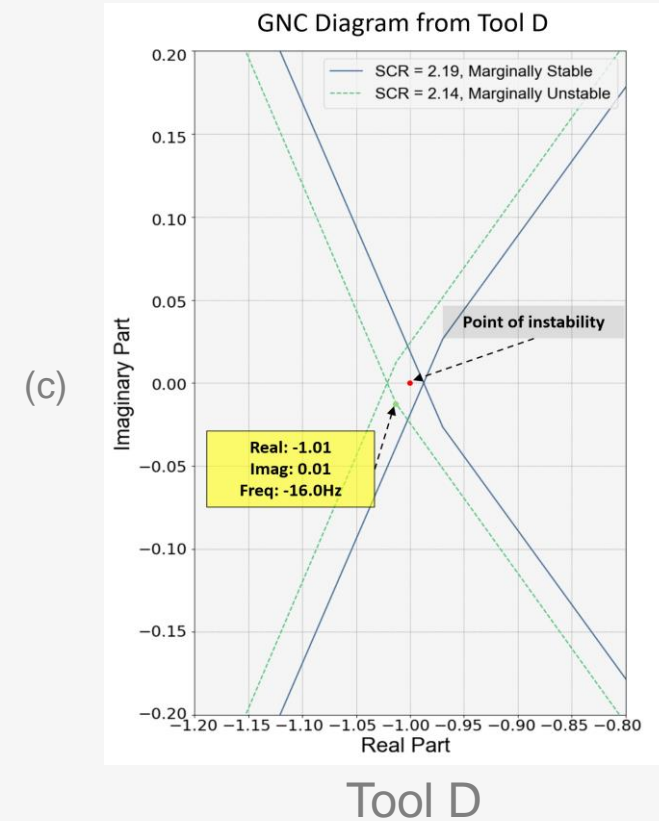
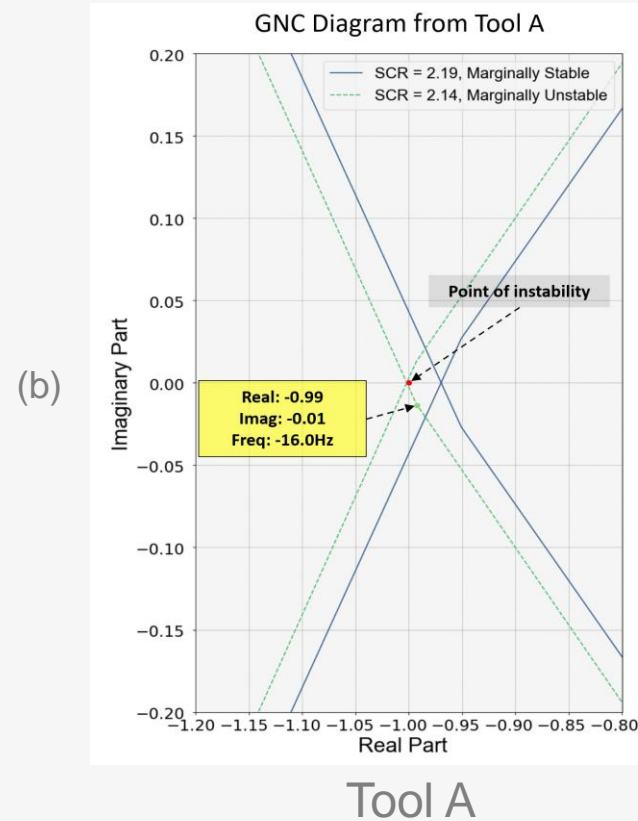
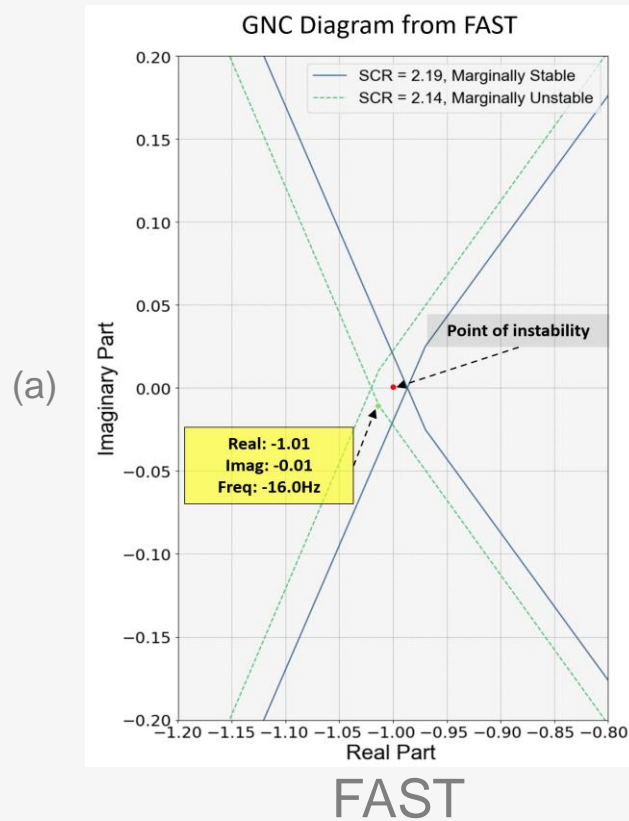
Solar Farm Model – EMT Results

- Test case developed in time domain EMT for a **critical SCR of 2.14** and **oscillation mode of 15.9 Hz**



Solar Farm Model – Nyquist plots

- The critical SCR and the oscillation frequency were successfully identified by the three tools tested.



Summary

Despite design differences of the tools, **consistent results were observed.**

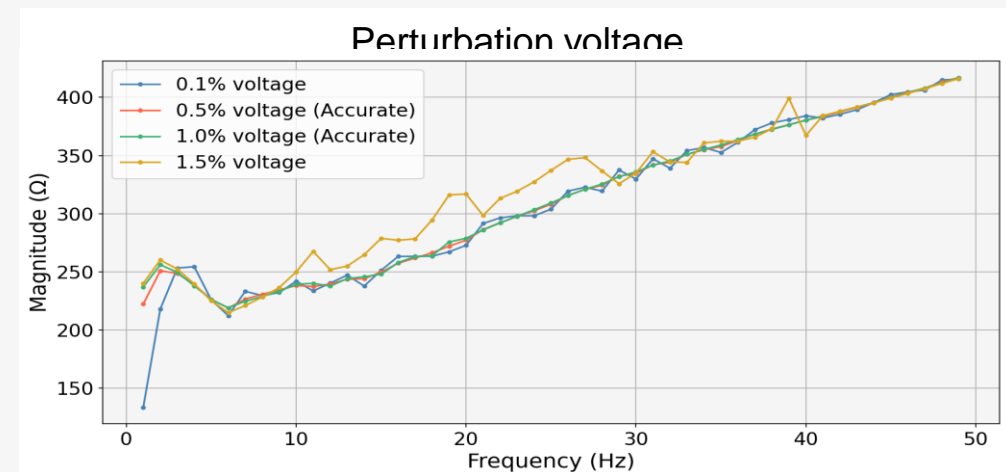
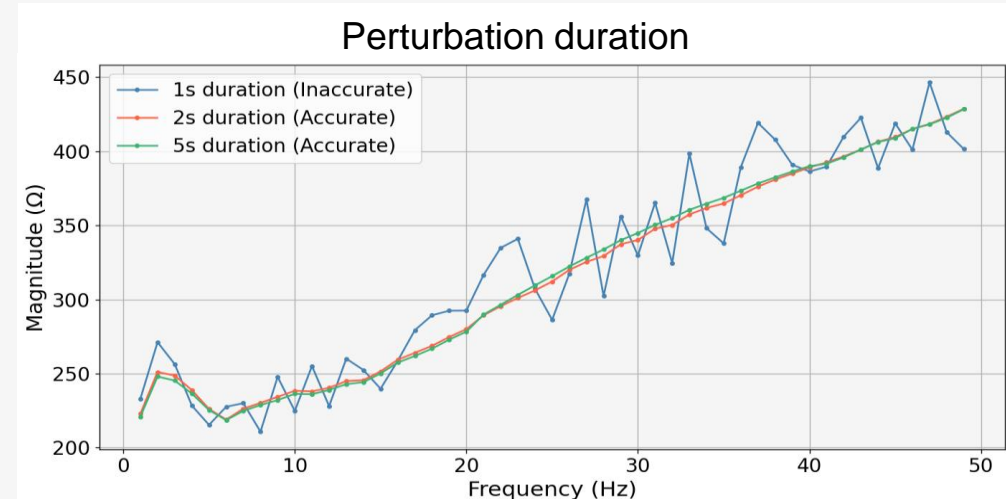
- The **white-box model proved to be a reliable reference** for testing the accuracy of frequency scanning tools.
- Small variations arise between known and identified oscillation mode for the wind farm model for all tools tested. Discrepancies are likely due to non-linear model characteristics. Accuracy is sufficient for most applications.
- Tool **output format is not common** and requires post-processing for benchmarking purposes.

Summary of Tool Performance Across IBR Test Cases

Tool	White-box Model Generic IBR model with full control access and analytical admittance available	Solar Farm Black-box PV model linked to known instability issues	Wind Farm Black-box wind farm model linked to known instability issues
FAST	✓ Accurate	✓ Accurate	✓ Accurate
Tool A	✓ Accurate	✓ Accurate	✓ Accurate
Tool B	✓ Accurate	N/A (not tested)	✓ Accurate
Tool C	✓ Accurate	N/A (not tested)	N/A (not tested)
Tool D	✓ Accurate	✓ Accurate	N/A (not tested)
Tool E	✓ Accurate	N/A (not tested)	N/A (not tested)

Tool usage trends

Parameter	Conclusion
Number of injection frequencies	<p>Single:</p> <ul style="list-style-type: none"> • Greater accuracy, though time consuming. • Ideal for spot checks at a specific frequency. <p>Multi:</p> <ul style="list-style-type: none"> • Ideal for quick frequency sweeps and data gathering. • Acceptable accuracy up to 10 frequencies.
Perturbation duration	<ul style="list-style-type: none"> • Needs at least cycle of the lowest frequency
Perturbation voltage	<ul style="list-style-type: none"> • Best accuracy observed between 0.5% and 1%



Conclusion

- A comprehensive benchmarking study of **six different frequency scan** tools was conducted by AEMO and NESO.
- The benchmarking results showed **strong consistency across all tools**:
 - White-box model: All tools closely match with theoretical values.
 - Black-box model: All tools identify similar critical SCR and oscillation mode.
- All tools found to be suitable for application in IBR integration studies
 - Provides choice and flexibility to industry
 - Avoids vendor lock in for new assessment methodology

Future Work

- **Investigate contribution of frequency scan techniques in the connection process**
 - Using "passivity" margins for resilient and rapid settings.
 - Streamlined assessment of minimum stable system strength using a single frequency scan.
 - Early stability assessments during connections process to streamline "Full assessment" and due-diligence stability analysis.
- **Potential further applications**
 - Applying frequency scan techniques to assist in controller tuning across operating points and grid conditions.
 - Model validation after firmware changes via pre/post-scan comparison.
 - Low-frequency electromechanical mode screening ($\approx 0.1\text{--}2$ Hz).
 - Targeted controller retuning as the system evolves (load, topology, IBR mix) with scan-to-set update procedures.