CIGRE Study committe C4

PROPOSAL FOR THE CREATION OF A NEW WORKING GROUP

JWG C4/B4.82

NAME OF THE CONVENOR
MODI Nilesh (AUSTRALIA)

NAME OF THE SECONDARY CONVENOR
JASIM Omar (UNITED KINGDOM)

TITLE
Impedance-based Stability Assessment of Modern Power Systems

THE WG APPLIES TO DISTRIBUTION NETWORKS: YES

ENERGY TRANSITION
4 / Sustainability and Climate Change
5 / Grids and Flexibility
6 / Solar PV and Wind

POTENTIAL BENEFIT OF WG WORK
2 / potential interest from a wide range of stakeholders
3 / likely to contribute to new or revised industry standards

STRATEGIC DIRECTION
1 / The electrical power system of the future reinforcing the End-to-End nature of CIGRE: respond to speed of changes in the industry by preparing and disseminating state-ofthe-art technological advances
2 / Making the best use of the existing systems

SUSTAINABLE DEVELOPMENT GOAL
9 / Industry, innovation and infrastructure

BACKGROUND :

Modern power systems are rapidly transitioning from synchronous machine dominated generation towards systems with high penetrations of power electronics interfaced devices (PEIDs). This includes inverter-based resources (IBRs) for renewable generation and storage, alongside converter-interfaced transmission and network support technologies such as FACTS and HVDC systems and inverter-based load (IBLs) such as Data Centres. This transition supports decarbonisation, but it also changes stability mechanisms. Fast IBR control dynamics and associated interactions that are weakly represented in traditional stability assessment approaches can reduce stability margins and introduce new control driven oscillatory behaviours across sub-synchronous, fundamental-frequency, and super-synchronous ranges.

A substantial body of work already exists on impedance and admittance based stability analysis techniques. This includes academic developments (sequence-domain, dq-domain and phase-domain formulations; impedance identification; passivity-based metrics; and Nyquist based multi-variable criteria), as well as industrial developments emerging through utility and vendor R&D programmes and industry working groups. In practice, however, methods, assumptions and tools remain heterogeneous across OEMs, consultants and system operators. Stability assessment results can be sensitive to operating point condition for the power system and control mode of PEID, model representation and limits, excitation and identification approaches, network reduction techniques, and the treatment of coupling effects. There is therefore an ongoing gap between the state of the art and the consistent, repeatable application of impedance-based approaches in multi-vendor and multi-tool project environments.

Time-domain simulation, particularly EMT, remains essential for validating behaviours and capturing nonlinearities, limits and protection actions. However, EMT alone is not always an efficient or sufficiently transparent framework for routine interaction risk screening, margin quantification, sensitivity investigation, and systematic decomposition of contributing mechanisms across wide frequency ranges. Impedance-based methods can provide complementary value by enabling structured frequency-domain stability margin assessment and participation insight, improving scalability for screening and iterative design, and supporting clearer interfaces for exchanging frequency-dependent behavioural information between stakeholders when full model disclosure is impractical. Confidentiality constraints are an important practical driver for standardised exchange, but they are not the sole motivation, impedance-based approaches are also valuable as a technical lens that complements EMT evidence.

Given the breadth of impedance-based analysis methods, this joint working group (JWG) will review the wider state of the art and available tools, identify the key gaps that prevent consistent industrial application, and develop recommended practices for system-level studies. The JWG will place particular emphasis on multi-input multi-output (MIMO) impedance or admittance based assessment frameworks, because modern interaction problems are increasingly driven by multi-device couplings and multi-variable dynamics, where single-input single-output (SISO) approximations can be insufficient. The intent is not to prescribe a single proprietary implementation, but to propose a practicable process that can be applied across multiple vendors, toolchains and projects. This emphasis also reflects the need to capture inter-sequence coupling effects (positive and negative sequence, and where relevant zero sequence) that are often masked by SISO approximations.

PURPOSE / OBJECTIVE / BENEFIT OF THIS WORK :

The objective of this JWG is to develop a system-level treatment of impedance-based stability assessment for modern power systems with high penetrations of PEIDs.

The JWG will:

- Review and consolidate impedance and admittance based stability methods used in academia and industry, and clarify their applicability, strengths and limitations for system-level studies, including how they interface with complementary small-signal (Jacobian or eigenvalue-based) methods where relevant (for example SSCI).
- Recommendation on the appropriateness of the identified approaches for assessing control-driven stability assessment.
- Provide practical guidance on deriving and using frequency-domain representations (including sequence and coupling effects where material) to quantify stability margins at one or more points of interest in the network.
- Propose a structured methodology and recommended practices suitable for planning and operational studies, while acknowledging confidentiality constraints and limited model sharing.
- Identify minimum data sets, interfaces and reporting formats that support consistent decision-making across stakeholders, without prescribing specific control architectures or proprietary implementations.
- Address technical interoperability in multi-vendor and multi-tool situations, including how conclusions can be validated, compared and communicated.

SCOPE :

The JWG will address impedance-based stability assessment techniques at the power system level. The scope covers modern power systems with high penetrations of PEIDs, including IBRs, IBLs, converter-interfaced transmission, and network support devices where they materially influence system dynamics. HVDC and FACTS are included as relevant PEIDs, but the scope is not limited to HVDC systems.

The working group will study the following aspects:

1. **State of the art, applicability and use cases**
- Survey and categorise existing impedance-based approaches and tools and identify gaps that limit consistent industrial application.
- Define when impedance-based methods are appropriate and what supplementary value they provide relative to time-domain EMT and RMS/PDT studies, including typical use cases such as screening, detailed interaction investigations, remediation option evaluation, and sensitivity studies.
- Clarify the interaction phenomena in scope, including sub-synchronous and super-synchronous interactions, control interactions, and network resonances in multi-converter environments.

2. **Theoretical foundations relevant to industrial practice**
- Summarise the theoretical framework required for robust application, including the role of closed-loop impedance or admittance representations and stability criteria such as Generalised Nyquist based approaches and related multi-variable interpretations.
- Address coupling effects at a level appropriate for system studies, including positive, negative, and where relevant zero sequence behaviour, and cross-coupling terms, with guidance on when such couplings are material to conclusions.
- Discuss modelling assumptions and limitations relevant to practical studies, including plant and system operating point, control model dependency, linearisation validity, representation of limits, and uncertainty in identified frequency-domain data.

3. **Practice-driven workflow across the project lifecycle**
- Define recommended workflows by lifecycle stage, including study objectives, minimum inputs, acceptable modelling detail, tool expectations, quality checks, and decision outputs.
- Develop guidance that reflects real project implementation constraints, rather than prescribing an extensive set of bespoke studies that depend on a single tool or system.

- Address efficient generation and validation of frequency-domain representations, including traceability and evidence requirements to support project decisions.

4. **Data acquisition, implementation pathways and scalability**

- Compare implementation pathways across common toolchains and identification approaches (for example EMT-based excitation and identification, linearisation where available, and measurement-derived approaches where applicable).
- Provide guidance on excitation design, sampling and windowing, signal quality, and uncertainty, and how these choices affect reproducibility and interpretation of stability margins.
- Discuss scalability considerations, including differences between project-level studies and wide-area or system-level assessments, and how modelling detail and reduction techniques influence outcomes.

5. **Validation and reproducibility**

- Define recommended reporting formats for stability margins, assumptions and sensitivity results, to support consistent interpretation and stakeholder communication.
- Define fit-for-purpose validation and cross-checks, including repeatability, sensitivity to operating point, cross-tool comparisons, and targeted time-domain EMT evidence where needed.
- Discuss how to interpret and communicate impedance characteristics, stability margins and risk indicators in a manner meaningful for system planning and decision-making, and what compliance criteria can be used.

6. **Interoperability, data exchange and governance**

- Propose notional technical requirements for interoperability of models, tools and exchanged frequency-domain information, including minimum datasets, interfaces, validation and traceability.
- Discuss practicable approaches for exchanging frequency-domain data under confidentiality constraints, including minimum disclosure principles and options for aggregation or third-party assessment where relevant.

Note 1: legal and contractual aspects will only be addressed at a high level, recognising that these frameworks typically follow technical consensus and are not the primary focus of this JWG.

Note 2: the JWG will liaise with the any ongoing working groups to ensure the TB scopes are coordinated.

References:

1. CIGRE WG C4.49, TB 928 “Multi-frequency stability of converter-based modern power systems”. March 2024.
2. CIGRE JWG C4/B4.52 “Guidelines for sub-synchronous oscillation studies in power electronics dominated power systems”, 2023.
3. Cigre WG B4.81 TB 934 “Interaction between nearby VSCHVDC converters, FACTs devices, HV power electronic devices and conventional AC equipment”, Chapter 4.
4. Briff, P., Henderson, C., Marshall, B., Egea-Alvarez, A., Tumilty, R. and Harmer, K., “A scalable methodology for frequency-dependent impedance-based stability analysis for transmission networks”. In *22nd IET International Conference on AC and DC Power Transmission (ACDC Global 2025)*(Vol. 2025, pp. 1-12). IET.
5. Jasim, O., Monteiro, J., Reddy, N., “Application of Harmonic Loci-Based Control Design in Frequency and Time Domain for a Consistent Design of VSC HVDC Harmonic Active Solutions”, 2024, Cigre 2024, B4-10407-2024.
6. Monteiro, J., Jasim, O., Lavopa, E., Saad, H., Wijesinghe, S., “The Harmonic Loci-Based Control Design: Practical Methods in Frequency and Time Domain for a Consistent Design of VSC HVDC Harmonic Active Solutions”, Cigre 2024, B4-10112_2022.
7. Kannan, S., Jasim, O., Yurt, C., Oheidhin, G., “ An Invasive Harmonic Impedance Measurement Approach for VSC-HVDC Systems”, Cigre 2025 Canada, B4-10611_2025.
8. Testing methods for equivalent converter impedance at AC side of VSC-HVDC systems, TR 22F-21, IEC.

DELIVERABLES AND EVENTS

Deliverables Types

Annual progress and activity report to Study Committee
CSE
Electra report
Technical Brochure and Executive Summary in Electra
Tutorial
Webinar

Time schedule

Q3	2026	JWG member recruitment
Q4	2028	Draft TB for SC review
Q1	2029	TB publication

APPROVAL BY TECHNICAL COUNCIL CHAIRMAN:
Rannveig Loken
July 08th, 2026