# A back-of-the-envelope system-strength metric for inverter-dominated grids

**This ESGI195 challenge is presented by DNV: dnv.com**

## Problem statement

The stability of an electricity network depends on its *system strength*: the ability of the grid at any given point to hold voltage steady and recover cleanly after a disturbance. For decades the industry has measured this with the **Short-Circuit Ratio (SCR)**, the ratio of the fault level (short-circuit MVA) available at a connection point to the rated power of the device connecting there. The appeal of SCR is its simplicity. It can be estimated on the back of an envelope, and a low value flags a weak part of the network before any detailed study is done. This is why it has been a standard screening tool in power-system planning and connection assessment for so long.

SCR was designed for a grid dominated by synchronous machines, whose fault-current contribution is large (typically five to seven times rated current) and determined almost entirely by machine and network impedance. That assumption no longer holds. As synchronous generation is displaced by **inverter-based resources (IBRs)** such as wind, solar PV, battery storage and HVDC links, stability is increasingly governed by converter control software and current-limited fault response rather than by machine physics. In these conditions SCR can be misleading. It does not capture the control interactions between neighbouring converters, nor the ways in which a weak grid actually becomes unstable, and it can either overstate or understate the true headroom at a connection.

There is active debate in the power-systems community about what should replace it. A useful starting point is to recognise that, for inverter-based resources, system strength has two distinct aspects: a *small-signal* aspect (the damping of oscillations around an operating point) and a *large-signal* aspect (whether a bus can recover from a fault or a deep voltage dip). SCR captures neither reliably for largely IBR dominated networks. Several refinements have been proposed, including the weighted (WSCR), composite (CSCR) and equivalent circuit-based (ESCR) short-circuit ratios, but these still miss converter control modes and the interactions between devices. Specifically, control types of IBRs can be either grid-forming (GFM) or grid-following (GFL) and each must be considered differently in how they respond to faults on the network; this being not well-addressed in the SCR calculation.

Recently, NESO's 'Strength to Connect' project worked with Imperial College London (Qiu, Green and Gu) to tackle both aspects: an Impedance Margin Ratio (IMR) for small-signal strength, and a 'Power Margin Ratio (PMR)' for large-signal strength in IBR-dominated power systems. PMR is a control-type-dependent metric, defined as the ratio between the maximum power that can be injected at a bus without causing instability and the nominal power of the device. It reduces to SCR for a single-infeed connection and generalises properly to multi-infeed systems, though its own authors are candid that it is a quasi-static metric rather than a rigorous stability certificate, and can give an optimistic reading of how well a system will actually recover from a fault.

However, the calculation for PMR requires computation with a modified power-flow algorithm. It avoids the need for detailed vendor models, but it still requires an iterative load-flow solve, so it is not the quick, transparent 'back of the envelope' calculation that made SCR so useful in the first place.

This leads to a fundamental question: **can we find a new analytical formula that better captures the behaviour of all connected devices, synchronous and inverter-based alike, while remaining simple**

**enough to evaluate by hand?**. In other words, is there a closed-form successor to SCR that keeps its back-of-the-envelope character but can actually be trusted on an inverter-dominated grid?

## Objective of this study project

The objective is to formulate and test candidate analytical system-strength metrics for IBR-rich networks. A good metric should reflect the stability-relevant behaviour of both synchronous and inverter-based devices. It should be expressible in closed form from quantities available at the planning stage, such as the network impedance at the connection point, device ratings and a small number of converter control parameters. And it should be cheap enough to compute that it can serve, like SCR, as a first-pass screening tool. Success would be a formula that tracks the answers given by richer methods such as PMR or detailed dynamic simulation, using only arithmetic rather than an iterative solver. As with PMR and IMR, the goal is a useful approximation rather than a rigorous stability certificate.

This is intended as a mathematical and analytical problem rather than a software-engineering one and should suit participants who enjoy reduced-order modelling, stability analysis and finding good approximations.

## Possible (but not prescriptive) directions for investigation

A promising approach might be to work from reduced-order network models, representative converter control descriptions and reference cases to benchmark against.

As a guideline to the study you might consider:

- Setting out mathematically what SCR (and variants such as WSCR, CSCR and ESCR) actually measures, the assumptions behind it, and where and why it fails once inverter-based resources dominate a connection point, distinguishing the small-signal and large-signal notions of system strength.
- Building a reduced-order model of a connection point and its immediate neighbourhood that captures the essentials of converter dynamics and grid impedance, while staying simple enough to work with in closed form.
- Proposing one or more analytical expressions, built from the network impedance and device parameters, that relate directly to stability margins, and explaining the physical meaning of each.
- Comparing the candidate metrics against PMR and/or detailed load-flow and dynamic-simulation results, to quantify how well the simple formulae reproduce the full answer.
- Examining the trade-off between simplicity and accuracy, test sensitivity to the input assumptions, and considering how a metric defined at a single connection point extends to several co-located or interacting IBRs.

However, we leave the precise areas of investigation up to you.

## Available data and resources

Participants will not need proprietary network models; the problem can be explored end to end with openly available Great Britain data.

- PyPSA-GB (https://github.com/andrewlyden/PyPSA-GB) is an open-source model of the GB power system built on PyPSA (Python for Power System Analysis). It provides network representations at several levels of detail (a full ETYS model with over 2,000 buses, a reduced 32-bus model and a 17-zone model) together with generation, storage, interconnector and demand data for historical years and future scenarios. This gives ready-made topologies and impedance data on which candidate metrics can be derived and tested. Note that fault levels are not provided directly and would need to be computed from the network impedances.
- BMRS (the Balancing Mechanism Reporting Service, Elexon Insights, https://bmrs.elexon.co.uk/) publishes near-real-time and historical operational data for the GB electricity system, including generation by fuel type, unit-level output, demand and system events. It can be used to construct

realistic operating points and dispatch scenarios, for example high-IBR, low-synchronous conditions where system strength is most stressed.

Together these data sets will allow participants to build a reduced-order test network, apply candidate metrics to it, and benchmark them against fuller power-flow-based calculations such as PMR. DNV can advise on realistic parameter ranges and on how connection assessments are done in practice.

## Why this is valuable

The grid is decarbonising faster than the tools used to plan it. As inverter-based resources become the majority, engineers still need a quick, defensible way to answer the question "is this part of the network strong enough?" before committing to expensive detailed studies. A validated analytical successor to SCR would let planners, operators and connection applicants screen weak points in seconds rather than through full simulation studies, speeding up the connection of new generation without losing sight of stability. Even a partial result, such as an improved formula for a restricted class of cases or clear guidance on where SCR can and cannot be trusted, would be of real practical value, because this is a question the power-systems community is actively trying to answer.

## About DNV

DNV is an independent assurance and risk-management provider and a technical advisor to the energy industry. We work across power, renewables and grids, helping utilities, system operators, developers and regulators manage the transition to a decarbonised and increasingly decentralised energy system. Our power-system engineers advise on grid planning, connection assessment and stability for networks around the world, so we see at first hand the practical problems created as conventional generation gives way to inverter-based resources. This problem comes directly from that work: a planning metric the industry has relied on for decades is becoming unreliable, and we need a replacement that engineers can still use quickly and transparently.

Gabriel Griffin-Booth, July 2026