

## **Title: Metrology for efficient grid-forming converters to stabilise future power grids**

### **Abstract**

The European Union aims for a clean and secure energy supply and infrastructure as part of its Green Deal ambitions. The expansion of renewable electricity generation has greatly reduced greenhouse gas emissions, but at the same time has led to reduced grid inertia and frequency instability. Grid-forming converters that connect renewable generation or energy storage solutions to the electricity grid have the potential to compensate this reduction in grid inertia and improve frequency stability, provided that they indeed function as intended. To prove their correct functionality, proposals addressing this SRT should develop the metrological infrastructure for reliable testing and evaluating the dynamic behaviour of grid-forming converters and their efficiency.

### **Keywords**

Electricity grid, grid stability, grid reliability, grid control, grid efficiency, frequency stability, converter testing, converter efficiency, compensation of inertia, energy, green energy

### **Background to the Metrological Challenges**

Under European Climate Law, the EU's Green Deal 2050 net-zero emissions target requires the proportion of energy generated by renewable energy sources (RES) to double to 60 % by 2030 and 84 % by 2050. This surge is accompanied by an increasing presence of power converters to connect RES, which are rapidly supplanting traditional synchronous generators, posing grid stability and control challenges. Additionally, it is crucial to ensure that this transition does not come at the expense of energy efficiency in the conversion. Traditionally, fossil fuel-based synchronous generators have maintained grid stability by regulating voltage and frequency against a backdrop of fast changes of supply and demand, including faults. However, RES connected to the grid through the first generation of electronic converters have no inherent ability to regulate these dynamics. Therefore, in the near future, an electricity system dominated by electronic converters will have too few synchronous generators left to stabilise the grid. In a RES dominated grid, new-generation advanced grid-forming (GFM) power converters will be needed to mimic the dynamic power response of synchronous generators, providing active and reactive power in millisecond timescales. GFM converters will replace the stabilising dynamics of traditional synchronous generators and be capable of autonomously injecting stabilising power into the grid.

The significance of GFM converters has been highlighted by the European network of transmission system operators (ENTSO-E) and guidelines outlining their essential functional requirements are emerging in the power system industry. However, translating functional requirements for GFM into enforceable specifications proves challenging due to the lack of clear guidance on test setup and procedures for GFM resources. Therefore, systems operators (SOs) have developed guidelines which are easier to fulfil but might not fully use the GFM potential. If the reliability of GFM converter performance cannot be completely trusted, the grid operational risk will be too high for SOs, who may need to resort back to synchronous machines to secure stability. Converter testing is also a research interest for a number of institutes, some of whom use hardware in the loop simulation as a valuable assessment tool, but standardised GFM testing facilities do not yet exist. Whilst there is considerable interest in defining specifications for GFM operation, it remains crucial to define testing procedures, develop the underpinning measurement methodology and the suitable traceable infrastructure to quantify and verify GFM performances both in a controllable laboratory environment and in the field, especially for large scale converters that cannot be tested in conventional laboratories. Considering

the GFM dynamic functionality, test beds will need to provide capabilities to mimic the grid conditions in order to induce a GFM active and reactive power response and measure that response in a few milliseconds.

There is also a need to accurately determine grid converter losses under actual operating conditions to ensure that the move to RES does not incur increased grid losses due to converters. In the context of grid formation, loss evaluation under dynamic operation is particularly interesting as inverters typically only have optimal efficiency at their nominal operating point. EN 61800-9-2 and EN 60146-2 indicate the general state of the art in loss evaluation of power converters, stating that present electrical efficiency measurement techniques are not reliable for efficiencies above 97 %, and that a maximum tolerance of 20 % in loss power measurements should be allowed. Calorimetric techniques suffer from inaccuracies and furthermore are unsuitable for efficiency evaluation under dynamic conditions. For an electrical determination of power converter loss, the difference between converter output power and input power should be measured. To achieve an overall 3 % uncertainty for measurement of typical 1 % converter loss power, the power measurements at each side must have better than around 0.02 % uncertainty, which cannot be achieved by present grid instrumentation. In a grid-forming application, where inverters are used at higher frequencies and need to be evaluated under actual dynamic grid conditions, metrology for the efficiency determination with an uncertainty of even 5 % of typical losses is a serious challenge due to the complexity of the required power measurement setups. At present, no National Metrology Institute offers a metrological calibration service for this kind of application. Ideally, the measurement of grid converter losses will not only provide a value of the overall converter efficiency, but also give insight on which converter components contribute most to the overall losses, providing grid converter manufacturers insight on how to improve the efficiency of their products.

## Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The proposal shall focus on the development of metrology capability to test and evaluate the dynamic behaviour and efficiency of grid-forming converters.

The specific objectives are

1. To develop testbeds for traceable testing and performance evaluation of grid-forming power converters up to a power level of 30 kW, capable of emulating various grid conditions. The testbed will include power sink and source capabilities to test the grid-forming converters and furthermore will have measurement capabilities to assess the power-frequency response of the converter as it operates to support the grid.
2. To develop a laboratory methodology exploiting the testbeds to assess the response of grid-forming converters as they operate to: i) deliver frequency response (inertia) support; ii) deliver voltage support; iii) support power quality. To apply the methodology to the evaluation of at least two commercial grid-forming converters, with an accuracy and timing resolution at least 5 times better than the current state-of-the-art.
3. To develop methods, equipment and suitable fast power algorithms for traceable on-site testing of grid-forming converters at fundamental line frequency and harmonic frequencies up to at least 5 kHz, realising fast real-time current, voltage, power, and frequency with at least 0.1 % uncertainty under highly dynamic grid conditions. To develop and apply an on-site test methodology to assess the performance and response of at least two commercial grid-forming converters, with an accuracy and timing resolution at least 2 times better than the current state-of-the-art.
4. To develop and characterise equipment and procedures for efficiency measurements of grid-connected power converters under actual operating conditions, with at least 5 kHz bandwidth to include energy at higher (harmonic) frequencies and dynamic efficiency evaluation under non-static operating conditions. To apply this instrumentation to determine the efficiency of at least 3 converters under different operating conditions with uncertainties better than 5 % in the loss power.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (IEC TC8, TC22F, TC44 and CENELEC TC8X), and end users (e.g., manufacturers and utilities).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented needs, in particular those supporting the European Green Deal. To enhance the impact of the research, the

involvement of the appropriate user community such as industry, standardisation and regulatory bodies is strongly recommended, both prior to and during methodology development.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP project ENG52 Smart Grids 2 and EMPIR project 15NRM04 ROCOF, and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.8 M€ and has defined an upper limit of 3.5 M€ for this proposal.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

## Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g., letters of support) is also encouraged.

You should detail how your proposal's results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the energy sector.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)."

You should also detail how your approach to realising the objectives will further the aim of the Metrology Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

## Timescale

The project should be of up to 3 years duration.

## Additional information

This reference has been provided by EURAMET.

- [1] EMN Smart Electricity Grids Strategic Research Agenda  
<https://www.euramet.org/research-innovation/metrology-partnership/strategic-research-and-innovation-agendas>