

Publishable Summary for 23IND06 Met4EVCS Metrology for electric vehicle charging systems

Overview

Electrical Vehicles (EVs) are the core of the European Commission's transition plan for the transport sector towards electromobility. The successful integration of EVs requires the deployment of an extensive infrastructure for EV Charging Stations (EVCSs) covering the overall charging needs of the consumers. This project will tackle the challenges of power quality effects on and as a result of EVCSs, and evaluate the associated losses and reliability of metering under actual on-site conditions. The project aims to cover several charging modes, such as direct DC charging at low and high power, smart charging, and bi-directional charging. The project will support the industry needs through the development of a metrology infrastructure for traceable testing of EV charging systems which remains a major bottleneck at the moment. The project will also provide input to OIML TC 12, WELMEC WG 11, and the European Commission (EC) Working group WgMI E01349 for uptake in their guidelines and regulations which will, in turn, support the EV charging industry through standardisation.

Need

The EC has adopted an ambitious roadmap for a competitive and sustainable transport system by 2050. With the expected integration of EVs, EVCSs are a key element in electromobility and, therefore, the Alternative Fuels Infrastructure Directive 2014/94/EU took measures to increase the number of standardised EVCSs. Though EVCSs may be considered simple meters, additional factors, such as grid distortion and dynamic impedance during charging, challenge their reliable operation. In addition, the detailed characterisation of the effects that EVCSs may have on the grid will be valuable to anticipate deteriorating Electromagnetic Compatibility (EMC) or Power Quality (PQ). Therefore, there is a need to characterise on-site local grid conditions in various charging scenarios.

The methods and standards applied in existing EVCS test benches do not reflect representative operating conditions. Also, characterisation of newer charging modes, such as DC charging at low power and ultra-fast charging at high power, smart charging, and bi-directional charging, is not well covered in standards.

Therefore, there is a need for establishing EVCS test benches for both DC and AC, implementing new measurement methods and standards reflecting representative operational conditions at low, medium, and high power levels, following IEC 61851-1. These test benches shall be capable of evaluating (i) metering accuracy and energy transfer efficiency with a target uncertainty of 0.1 %, and (ii) generated conducted emissions up to 150 kHz.

Knowing that the number of EVCSs is growing rapidly, there is a need to develop the metrological infrastructure for on-site verification of EVCS energy metering, in support of legal metrology. On-site verification requires reliable and efficient measurement procedures, based on commercially available equipment capable of handling representative operating conditions and charging scenarios. The uncertainty of the metering accuracy verification is targeted at 0.5 %.

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METROLOGY PARTNERSHIP 

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Objectives

The project focuses on the development of metrology capabilities for the traceable evaluation of EVCSs under realistic operating conditions.

The specific objectives are:

1. To define representative on-site operating conditions for EVCSs in terms of local grid disturbances and local grid impedance under live grid operation. For this, dedicated measuring equipment will be developed for measuring local grid disturbances and local grid impedances up to 150 kHz. With this equipment measurements will be performed at, at least, five sites with DC chargers and five sites with AC chargers with a variety of (i) charger brands, (ii) operating modes and (iii) charging power levels.
2. To develop traceable methods and test benches for the characterisation of EVCSs under representative operating conditions for both AC and DC charging in accordance with IEC 61851-1. For AC chargers, the characterisation will be performed at low and medium power, and for DC chargers the characterisation will be done at low, medium and high power. The characterisation involves the evaluation of (i) metering accuracy and energy transfer efficiency with a target uncertainty of 0.1 % (with respect to nominal power) and (ii) generated conducted emissions up to 150 kHz. For AC EVCSs, test benches will be developed for three-phase systems at 230 V up to 100 A and charging power levels up to 44 kW; for DC EVCSs, test benches will be developed for voltages up to 800 V, currents up to 500 A and charging power levels up to 350 kW.
3. To develop the required metrological infrastructure for on-site verification of EVCS energy metering, in support of legal metrology and acceptance testing, with a target uncertainty of 0.5 %. This will include the development of reliable methods for EVCS energy metering evaluation based on commercially available equipment, which have been validated under representative operation conditions, including smart charging and bidirectional energy transfer.
4. To facilitate the uptake of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (IEC TC 69, WELMEC WG 11, OIML TC 12/p 3, EC WgMI E01349), and end users (e.g., EMN Smart Electricity Grids, EMN Clean Energy, EVCS operators, grid operators, EVCS manufacturers).

Progress beyond the state of the art and results

Definition of representative on-site operating conditions for EVCSs and characterisation of local grid disturbances and local grid impedance (objective 1):

A complete and traceable set of measurement methods for determining local grid disturbances and local grid impedances up to 150 kHz has been developed, validated, and implemented. Practical measurement setups were designed and assembled, combining broadband voltage and current sensors, coupling arrangements suitable for connection under live-grid conditions, and acquisition systems capable of capturing both time-domain waveforms and frequency-domain characteristics over the required range. Particular attention was given to ensuring sufficient dynamic range and robustness in the presence of high fundamental components and rapidly varying charging currents.

Laboratory verification and traceable calibration activities were performed to confirm correct operation of the measurement chains and to ensure consistent performance across the participating laboratories. In addition, reference impedance artefacts were designed, constructed, and characterised to support verification of impedance measurement procedures and to prepare for later intercomparison activities. The developed methods, instrumentation, calibration approaches, and uncertainty considerations were consolidated into a dedicated report on measurement methods for grid disturbances and grid impedance up to 150 kHz. This report has been finalised and made publicly available through the project website and now serves as the common methodological reference for all field campaigns and subsequent analyses.

Using the developed measurement framework, coordinated on-site measurement campaigns have been planned and executed at multiple EVCS locations across Europe. Measurements of both AC and DC charging stations have been carried out in Italy, Spain, Sweden, and the Netherlands, with all sites considered equally important in building a representative and geographically diverse dataset.

In Italy, measurements of AC and DC EVCSs were performed in Bologna. The measurement data have been fully processed, and preliminary analyses have been completed. In parallel, an electrical model of the two

tested grid configurations and associated charging systems was prepared and is currently being validated. This model will be further refined using additional grid tests and subsequently combined with the measurement results to support consistent interpretation and further analytical work.

In Spain, measurements of AC and DC EVCSs were conducted in Madrid. The acquired datasets have been processed, and detailed analysis is ongoing, focusing on disturbance behaviour, impedance characteristics, and representative operating conditions under real charging scenarios.

In Sweden, measurements were performed at three DC charging sites, including commercial heavy-duty charging installations. The data from these sites have been processed, and analysis is in progress, providing insight into high-power DC charging behaviour and its interaction with the local grid environment.

In the Netherlands, two measurement campaigns have already been executed at EVCS sites equipped with multiple AC and DC chargers. These measurements were carried out at carefully selected times to capture representative and high-impact operating conditions, such as periods of high utilisation. Additional measurement activities in the Netherlands have been defined to further extend coverage across different charging hub configurations.

Across all countries, similar data-processing procedures are being applied to ensure that results from the different sites are comparable. The collected datasets describe realistic charging conditions, grid disturbance levels, and impedance behaviour in the vicinity of EVCSs and form the empirical basis for subsequent modelling activities, verification concepts, and good practice guides.

Development of traceable methods and measurement standards for the characterisation of EVCSs under representative operating conditions for both AC and DC charging (objective 2):

In parallel with the field campaigns, laboratory infrastructure for AC EVCS characterisation has been developed and verified. AC test benches were prepared to support measurements under both nominal and non-ideal supply conditions, including facilities capable of injecting controlled distortion components and reproducing representative waveform characteristics observed during on-site measurements. Laboratory verification activities confirmed the suitability of the measurement equipment, sensor chains, and test procedures prior to systematic application.

The AC laboratory setups are being prepared to support characterisation at low and medium charging power levels for three-phase systems and to accommodate advanced charging features such as smart charging and bidirectional energy transfer. Preparatory work has also been undertaken to integrate EV emulation and communication capabilities aligned with modern charging standards, enabling future tests to reflect realistic operational behaviour rather than simplified load conditions.

For DC charging, substantial progress has been made in developing reference test benches and measurement systems covering low, medium, and high charging power levels. Implemented systems include high-voltage and high-current measurement chains, broadband voltage and current transducers, reference power and energy meters, and coupling networks that allow the superposition of disturbances up to 150 kHz. These capabilities support combined evaluation of metering accuracy, energy transfer efficiency, and conducted emissions under DC charging conditions.

Several DC reference systems have undergone internal validation and preliminary calibration activities, and work is ongoing to finalise traceability chains and data-processing algorithms. Scalability and flexibility have been explicitly considered so that the setups can be adapted to a wide range of charger types and operating conditions, including future high-power charging scenarios. In addition to reference-grade systems, industrial-grade configurations are being designed to support later verification and acceptance-testing use cases.

Development of metrological infrastructure for on-site verification of EVCS energy metering (objective 3):

Preparatory work has been carried out to translate the laboratory-based metrology framework into practical on-site verification procedures for EVCS energy metering. Draft test protocols have been defined based on regulatory and standardisation requirements, and prototype on-site setups have been assembled. Initial operational testing has been performed using EV loads and dummy loads, including extended-range tests at higher current levels.

Work has also begun to identify and engage suitable on-site locations for future verification activities, with the aim of covering a range of environmental and operational conditions. While full traceability implementation and

systematic field validation of on-site verification setups are planned for later stages of the project, the activities completed so far have established functional test environments and clarified the technical requirements for data acquisition performance under disturbed grid conditions.

Outcomes and impact

Key dissemination and communication activities

A public project website has been established (<https://www.vsl.nl/en/met4evcs/>) and is regularly updated with information on objectives, progress, and publications. A first stakeholder workshop was organised in November 2024 to obtain feedback on the project plans, technical scope, and proposed methodologies. The workshop was attended by more than 50 stakeholders representing EV charging infrastructure manufacturers, charging point operators, EV manufacturers, grid operators, and equipment manufacturers. In addition, the audience included regulators, testing and certification companies, academic researchers, and metrology institutes. The discussions during the workshop provided valuable input on practical constraints, industrial relevance, and regulatory expectations, and the consortium has included this in refining the measurement campaigns, test-bench development, and verification concepts.

Other dissemination activities include regular presentation of project results at international scientific conferences and workshops, as well as the use of newsletters, a project flyer and poster, and LinkedIn to maintain continuous visibility. Engagement with standardisation bodies and professional networks complements these activities and supports early alignment of technical developments with ongoing regulatory and standardisation work.

Outcomes for industrial and other user communities

The project is delivering concrete results that directly support manufacturers, charge point operators, grid operators, testing laboratories, and regulators involved in the deployment and assessment of electric vehicle charging systems (EVCSs). A key result is the development of traceable laboratory test benches for both AC and DC EVCSs, covering representative operating ranges and realistic supply conditions. The availability of these test benches will provide industry with practical outcomes for product development, validation, and conformity assessment. EVCS manufacturers and equipment suppliers can use the results to verify performance under realistic operating conditions, while testing laboratories and conformity-assessment bodies will benefit from harmonised, traceable infrastructures that support consistent evaluation across Europe. In addition, work on industrial-grade configurations addresses cost and usability constraints, facilitating uptake beyond national metrology institutes.

Complementing the laboratory infrastructure, the execution of coordinated measurement campaigns at AC and DC EVCS sites in Italy, Spain, Sweden, and the Netherlands has generated representative datasets describing real charging conditions, grid disturbances, and impedance behaviour. These measurements provide an empirical basis that links laboratory test-bench results with real-world operation. Together, the developed test benches, measurement methods, and field data support fair billing, reliable infrastructure deployment, and improved confidence in EVCS performance for all industrial stakeholders.

Outcomes for the metrology and scientific communities

For the metrology and scientific communities, the project is establishing a coherent framework for EVCS measurement that links laboratory traceability with field applicability. Preliminary project results have been actively disseminated through presentations at international scientific conferences, including GPECOM, CIRED, PCIM, AMPS, and MetroAutomotive, as well as through several national conferences and workshops. These contributions have enabled early exchange with researchers and practitioners working on power quality, power electronics, and energy metering.

In parallel, project results have been published in open-access peer-reviewed journals, including *Electric Power Systems Research*, *Computers and Electrical Engineering*, *Measurement*, and the *IEEE Open Access Journal of Power and Energy*. These publications document methodological developments, measurement results, and analysis approaches, and provide a citable scientific foundation for further research and standardisation. Together, these activities strengthen Europe's metrological capability for EVCS evaluation and support future calibration services and interlaboratory comparability.

Outcomes for relevant standards

The project has already contributed to standardisation and regulatory activities through direct technical exchange with relevant committees. Preliminary results and methodological concepts have been discussed with IEC SC 77A WG 8, IEC SC 77A WG 9, OIML TC 12, WELMEC WG 11, CENELEC TC 219, CENELEC TC 219 WG 11, and with several national mirror committees. These discussions have focused on measurement methods, verification concepts, and the practical implications of EVCS-related disturbances, impedance behaviour, and metering accuracy.

This early engagement ensures that project outputs are aligned with ongoing standardisation work and that emerging guidance and documentary standards can benefit from traceable measurement evidence and field experience. Continued interaction with these bodies is expected to support the translation of project results into harmonised regulatory and standardisation frameworks.

Longer-term economic, social and environmental impacts

In the longer term, the project contributes to increased consumer trust, market transparency, and regulatory consistency by supporting reliable and comparable EVCS energy metering across Europe. Improved confidence in billing accuracy and grid compatibility facilitates cross-border interoperability and the efficient deployment of charging infrastructure, thereby supporting the transition toward a resilient and sustainable European transport and energy system.

List of publications

1. Angulo, I. et al (2025) 'Measurement framework for the consistent and fast measurement of conducted grid emissions in the 9-500 kHz range', *Computers and Electrical Engineering*, 124(110314) p. 1-20. Available at <https://doi.org/10.1016/j.compeleceng.2025.110314>
2. Artale, Giovanni et al (2025) 'Charging of an AC Three-Phase Electric Vehicle: Power Quality Analysis up to 150 kHz', *2025 IEEE International Workshop on Metrology for Automotive (MetroAutomotive)* p. 157-161. Available at <https://zenodo.org/records/16748198>
3. Costanzo, D. et al (2025) 'ISO-15118 Manipulation for Field Calibration of DC Electric Vehicle Supply Equipment', *2025 IEEE International Workshop on Metrology for Automotive (MetroAutomotive)* p. 151-156. Available at <https://doi.org/10.1109/MetroAutomotive64646.2025.11119201>
4. De la Vega, D. et al (2025) 'On the definition of measurement use cases for the assessment of LV grid emissions in the supraharmic (2–500 kHz) region', *Electric Power Systems Research*, 242(111459) p. 1-13. Available at <https://doi.org/10.1016/j.epsr.2025.111459>
5. Delle Femine, A. et al (2024) 'Metrology for Electric Vehicle Charging Systems: An Overview of the European Research Project', *2024 IEEE International Workshop on Metrology for Automotive (MetroAutomotive)* p. 118-123. Available at <https://doi.org/10.5281/zenodo.16748589>
6. Femine, A. et al (2025) 'EVSE Metrological Verification Through IEC 61851 Protocol Hacking', *2024 IEEE International Workshop on Metrology for Automotive (MetroAutomotive)* p. 130-135. Available at <https://doi.org/10.5281/zenodo.16748527>
7. GALLARRETA, A. et al (2025) 'Is CISPR quasi-peak an appropriate metric for evaluating power line communications?', *28th International Conference and Exhibition on Electricity Distribution (CIRED 2025)*. Available at <https://doi.org/10.5281/zenodo.17431581>
8. GONZALEZ-RAMOS, J. et al (2025) 'Characterization of the Long-Term Impedance Variations due to Electric Vehicle Charging from 20 kHz to 500 kHz', *IEEE Open Access Journal of Power and Energy*. Available at <https://doi.org/10.1109/OAJPE.2025.3562091>
9. GONZALEZ-RAMOS, J. et al (2025) 'Influence of the grid topology on the grid access impedance in the 20-500 kHz frequency range', *28th International Conference and Exhibition on Electricity Distribution (CIRED 2025)*. Available at <https://doi.org/10.5281/zenodo.17433888>
10. Larrucea, I. et al (2025) 'Characterization of a Reconstructed Low Voltage Grid as Propagation Medium for Narrowband Power Line Communications', *IEEE GPECOM2025*. Available at <https://zenodo.org/records/18063410>
11. Mariscotti, A. (2026) 'Design and experimental verification of an isolated voltage probe for the 2 kHz–30 MHz interval operating in live conditions', *Measurement*, 263 p. 119920. Available at <https://doi.org/10.1016/j.measurement.2025.119920>

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Project website address: https://www.vsl.nl/en/met4evcs/		
Internal Beneficiaries: 1. VSL, Netherlands 2. BEV-PTP, Austria 3. BFKH, Hungary 4. CEM, Spain 5. CMI, Czechia 6. JV, Norway 7. LNE, France 8. RISE, Sweden 9. TUBITAK, Türkiye 10. VTT, Finland	External Beneficiaries: 11. CIRCE, Spain 12. Elaad, Netherlands 13. EMC-BCN, Spain 14. INM, Republic of Moldova 15. INTI, Argentina 16. ITE, Spain 17. UniCampania, Italy 18. UNIGE, Italy 19. UPV/EHU, Spain 20. UTwente, Netherlands	Unfunded Beneficiaries: 21. MIRS, Slovenia
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