Publishable Summary for 20NRM03 DC grids
Standardisation of measurements for DC electricity grids

Overview

The increasing use of distributed energy generation and storage has led to local DC grid trials becoming an extension of traditional AC distribution networks. Like AC grids, DC grids must fulfil power quality (PQ) limits to guarantee reliable operation. However, knowledge about PQ in public DC systems and its impact on DC electricity metering is currently lacking, as is the related metrology and standardisation. This project aims to address these issues, in response to needs expressed by CLC TC8X WG1 (Physical characteristics of electrical energy) and IEC TC13 WG11 (Electricity metering equipment). This project's goal is the traceable measurement and characterisation of PQ parameters to support standardisation in the further development and future use of DC grids and to ensure future customer confidence.

Need

Many sustainable technologies, such as LED lighting, photovoltaic cells, and electrical vehicles (EVs), are fundamentally DC, which results in inefficient power conversion when they are connected to traditional AC grids. Thus, the shift towards more renewable and sustainable technologies has increased the attractiveness of DC grids. The applications of DC grids are very broad, ranging from residential and business buildings to hospitals, agriculture, lighting, electrified transportation, data centres, and telecommunication.

Standardisation of DC grid control currently focusses on installations, wiring rules, safety for users (shock, burns), equipment (discharges), voltage levels, and the detection of faults. However, the metrology infrastructure required for DC grids is lacking. For traditional AC grids, the metering of electricity is well-regulated and standardised, whereas for DC, it is still in its infancy. This project is a direct response to the metrology needs expressed by CLC TC8X WG1 and IEC TC13 WG11 for the metrological underpinning for voltage characteristics in DC grids and test waveforms for DC electricity meters, respectively.

Compared to traditional AC grids, DC grids should provide such benefits as longer cables and fewer substations, improved response to EV demand, reduced power conversion, reduced disturbing harmonics, improved voltage control in distribution networks, and more viable battery storage schemes. Therefore, several DC grid trials are currently in place to test these claims. These include an industrial site in the Netherlands, local DC grids in Denmark and Finland, and a smart grid in Spain. However, these trials need metrological support.

Whilst DC grids are theoretically beneficial, their implementation, however, brings many challenges and unknowns, among which the reliable metering and the accurate measurement of PQ issues such as current and voltage ripple, inrush currents, voltage fluctuations, and short circuit events. PQ is well established in traditional AC grids, however widely accepted and standardised methods for measuring PQ aspects for DC metering or PQ measurement methods for DC grids are not currently available. Therefore, the corresponding measurement techniques and traceability for DC grids urgently need to be developed.

Objectives

The overall goal of this project is the traceable measurement and characterisation of PQ parameters to support standardisation in further development and future use of DC grids. The specific objectives of the project are:

1. To develop on-site measurement equipment and to capture dynamic voltage and current signals in real low voltage DC (LVDC) grids, at voltage and current levels up to 1 kV and several hundreds of amperes, respectively, with target uncertainties below 0.1 % taking into account the presence of AC ripple and other disturbances.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

2. To analyse on-site measurement data in real LVDC grids to obtain a set of DC power quality (PQ) parameter definitions and electricity meter test waveforms, and to develop reference systems for measuring DCPQ parameters and DC energy taking into account the presence of defined PQ disturbances.
3. To define equipment specifications and methods for PQ “compatibility level” and “planning level” surveys in LVDC grids for DC parameters such as in-rush current, voltage dips, and voltage and current ripple.
4. To contribute to a revision of EN 50160 by providing the data, methods, guidelines and recommendations, which are necessary for the standardisation of voltage characteristics of public electricity supply, to CLC TC8X WG1. To contribute to a revision of IEC 62053-41 by providing the data, methods, guidelines, and recommendations, which are necessary for the standardisation of DC electricity metering, to IEC TC13 WG11. In addition, to contribute to the standards development work of the technical committees IEC TC85 WG20 and IEC SC77A WG9. Outputs should be in a form that can be incorporated into the standards at the earliest opportunity and communicated through a variety of media to the standards community and to end users (e.g. electric suppliers for general public and industrial applications).

Progress beyond the state of the art

On-site Measurements in LVDC Grids (Objective 1)

The number of DC trial grids worldwide is growing rapidly, but the behaviour of PQ phenomena in DC grids is not yet adequately understood. Consequently, standardisation is still in its infancy and the corresponding measurement techniques need to be developed. The earlier project 16ENG04 MyRailS made a first step made a first step towards measuring specific DCPQ events between railway supply systems and rolling stock, but further work is needed.

This project is going beyond the state of the art by developing new measurement systems with new trigger mechanisms to detect PQ events associated with DC grid applications. Subsequently, these systems will be used for measurements in real-world DC trial grids in order to collect actual DCPQ events in real DC grids.

Traceability for DCPQ parameters (Objective 2)

Traceable reference systems for AC PQ are well established in NMIs and accredited laboratories, however, these do not apply to DC. New amplifiers, transducers, and data analysis techniques are under development in this project as those used for AC usually cannot be used for DC.

In this project, new DCPQ reference systems with specific analysis tools are being realised to provide traceability for DCPQ. To do this the project has identified DC-specific PQ parameters such as current and voltage ripple, voltage fluctuations, and transients, together with new traceable calibration methods, procedures, and uncertainty budgets. The results will then be fed back to CLC TC8X WG01 for a future extension of the presently AC-only EN 50160 so that it can include DC grids.

Test waveforms and reference systems for DC energy (Objective 2)

Currently, the metrological infrastructure for DC power under distorted conditions is largely missing. In addition, DC power is not yet listed among the calibration and measurement capabilities (CMCs) in the BIPM database. A first step was made towards developing this metrological infrastructure in the project 16ENG04 MyRailS for initial railway-specific parameters with an intended 0.1 % uncertainty. However, this level is insufficient for application in DC grids.

This missing metrological infrastructure is being built in this project by (i) developing new reference systems for DC energy, (ii) performing an inter-comparison of these new reference systems, and (iii) proposing new CMCs with target uncertainties below 0.01 % in the presence of DC-grid related disturbances. These new reference systems will be demonstrated for use by calibrating electricity meters using waveforms covering a wide range of applications including high-current EV charging. This demonstration should provide the necessary input and information for IEC TC13 WG11 regarding a future update of the IEC 62053-41 on DC metering.

Metrological framework for practical DCPQ "Compatibility level" and "Planning level" surveys in LVDC grids (Objective 3)

Despite the existence of several LVDC trial grids in different countries, the definition of DCPQ compatibility levels is currently hampered by a lack of knowledge and reliable measurement methodology. This project is going beyond the state of the art by developing special equipment and methods to conduct the required surveys for setting compatibility levels, that will be used as the basis of future "planning level" surveys carried out by utility companies in order to manage the PQ levels in LVDC networks.

Results

On-site Measurements in LVDC Grids (Objective 1)

Before starting any measurements in LVDC grids, PQ parameters were defined based on the existing scientific literature on PQ in LVDC grids as well as on standards for PQ in AC grids, including EN 50160, IEC 62749, IEEE 1159, the IEC 61000 series, and IEC 62586. For example, harmonics cannot be defined without a fundamental frequency as in DC grids; instead, a definition of voltage ripple is used in the time domain as well as in the frequency domain. Several time window lengths, frequency windows, sampling rates, and other measurement definitions were proposed, mostly in line with the existing AC PQ measurement definitions. Based on feedback from stakeholders a report was written describing proposals on how to define and measure DC PQ parameters, new definitions for electricity metering in DC systems, and proposed magnitudes and characteristics of typical LVDC voltage disturbances for DC PQ measurements and electricity meter testing.

The development of measurement equipment with specific broadband voltage and current sensors for onsite measurements was completed and satisfactorily tested in the laboratory for measurements up to 150 kHz. Two different approaches were realised, both involving data acquisition and storage with the actual analysis to be performed afterwards using the tools developed in objective 2. (1) The first approach is to include mechanisms to trigger the capture of sampled voltage and current waveform data prior to and after a DCPQ event, thus avoiding the unnecessary collection of continuous waveform data and the associated storage, transmission, and data processing issues. (2) The second approach is to sample and store all data locally on a large hard disk during a relatively short period (typically a few hours up to one day) in order to ensure that relevant issues are not missed; this method works well for configurable grids where events can be emulated, and network configurations changed easily to investigate various situations. For measurements in EV charging stations, the necessary adapters to connect the measurement equipment between the charging station and the EV have been designed and implemented.

Experiments were conducted at the Power Networks Demonstration Centre (PNDC) in Scotland to generate and measure specific test signals and disturbances. The measurement results and raw data have been used for the validation of data analysis tools developed in objective 2 and trigger mechanisms used in the first measurement approach detailed above.

Using the newly developed equipment, measurement campaigns have been performed at several LVDC grids to investigate DC-specific disturbances. Among these are:

- Malaga Smart City, with streetlights, micro wind turbines, and PV, linked to the AC grid, 48 V unipolar.
- Lelystad Airport, with streetlights, linked to the AC grid, 700 V unipolar.
- The Green Village in Delft, with streetlights and PV, linked to the AC grid, ± 350 V bipolar, configurable.
- A parking garage in Utrecht, with EV chargers, PV panels, and lighting, 700 V unipolar, configurable.
- Three public EV charging stations in Germany during normal operations.

The analysis of the data is still ongoing, but parts of the results, focusing on ripple and frequency content as well as on the triggering mechanism, have been already published in open-access peer-reviewed journals.

Analysis tools and reference systems for DC power, DC metering, and DCPQ (Objective 2)

The initial definitions of DC PQ parameters, developed in objective 1, have been used for the specification of analysis tools. Algorithms were developed to dynamically detect DC magnitude based on RMS and average, ripple, frequency content, voltage dips and swells, and voltage transients over different measurement window lengths. These algorithms have been tested using waveforms obtained earlier in DC railway systems and using a variety of test waveforms obtained at the PNDC (objective 1) including ripple, dips, swells, and short circuits.

In order to generate more test signals, modelling and computer simulations have been used based on frequency domain calculations.

Furthermore, algorithms have been developed for analysing DCPQ phenomena, as well as the development of a procedure to assess the reliability of the developed algorithms detecting PQ events. To improve the DC power and DCPQ analysis tools, the behaviour of DC mean, DC RMS, DC mode, and DC median parameters has been evaluated for different measurement window sizes, and under different sampling frequencies used to acquire the signal. The definitions of the most significant DCPQ parameters and potential DC electricity meter test waveforms will be completed once the real-world data obtained at the measurement campaigns in objective 1 have been analysed.

Three reference systems for DC power and DC electricity meter testing have been developed, based on different hardware. Two of the systems generate the high-magnitude DC current and the high-frequency AC current distortions in separate conductors, such that (for currents higher than about 10 A) only meters with current transducers sensing the magnetic field of the combination of the two conductors can be calibrated or tested. In the third setup, the DC current and AC distortions are merged into a single conductor, such that meters using other transducer types such as shunts can be calibrated as well. In addition, a fourth setup was realised based on reference voltage and current sensors, a calibrated wattmeter, and a metrological LED.

These three reference systems were successfully characterised and tested for DC power with and without distortion. The spectral composition of the distortions varies in the different setups (from purely sinusoidal components, up to saw-tooth additive components). Test measurements have been performed covering the full range of voltage (up to 1000 V), current (up to 800 A), and frequency (DC – 150 kHz), in order to prepare for a round-robin comparison.

The setups for DCPQ will be largely based on those for DC electricity meter testing with disturbances. The software for the DCPQ setups needs to be finalised and implemented, based on the latest definitions and improved algorithms, from the results of the measurement campaigns (objective 1).

Finally, a transfer standard is under development for the validation of the three reference systems. An initial test plan for a round-robin comparison has been discussed and agreed amongst the partners.

The round-robin comparison for DC power and DC metering will demonstrate and validate the different reference systems. A draft version of a transfer standard was finalized and circulated among two partners for testing. Preliminary comparison measurements have been performed in the presence of pre-defined distortions. However, the results were insufficient to validate the performance of the reference systems, and the design of a new transfer standard, based on a module with adjustable input range and customisable sensors, is in course. In addition, different sensors will also be used to maximize the resolution of the measurement. Using this new transfer standard, a new round-robin will take place with four partners involved. The test plan for this new round-robin has been completed.

Metrological framework for practical DCPQ “Compatibility level” and “Planning level” surveys in LVDC grids (Objective 3)

Based on literature and standards, as well as on stakeholder consultation, voltage dips and swells, and voltage ripples have been identified as the main PQ parameters required for future compatibility level and planning level surveys in LVDC grids. Severity indices for these parameters have been defined, as well as proper statistical methods for data averaging and time aggregation over different periods of time.

The need for compatibility levels for steady-state disturbances below and above 9 kHz was investigated, and existing immunity levels of DC devices were verified. In addition, a first set of values of DC voltage compatibility was proposed for further discussion. Data acquisition and online FFT analysis with a fixed window length of DFT for different frequency bands of 0-9 kHz and 9-150 kHz were also considered. Relevant DFT window types have been investigated to reduce spectral leakage of aperiodic disturbances.

A first proposal for reasonably expected compatibility levels was presented and discussed at the project’s mid-term stakeholder workshop. It was determined that in order to further specify voltage compatibility levels, actual immunity levels of existing DC devices should be investigated as well. However, this is beyond the scope of this project. As a follow-up activity, a survey was set out in which stakeholders indicated the importance of specific DC PQ phenomena and the corresponding maximum acceptable disturbance levels.

A module for the computation of DCPQ indices has been implemented in a tool for DC PQ simulation and processing of on-site recorded data. For conducted disturbance measurements in the range between 9 kHz and 150 kHz, a fully digital CISPR16 method (in line with the new edition of IEC 61000-4-30) was implemented into a PQ analyser which can monitor PQ indices and record real-time waveforms for both AC and DC grids.

The implementation of the algorithms to detect and quantify PQ phenomena during on-site measurements has been finalised by adapting their characteristics for online execution and correcting imperfections highlighted in the testing phases. Testing of the algorithms by simulation has been completed by analysing different signals including flagging: pure DC, ramped DC voltage signals, DC with sinusoidal ripple, voltage dips, and composite signals. Furthermore, the algorithms were implemented in a hardware system based on a data acquisition module for testing with real signals generated in the laboratory using a programmable arbitrary waveform generator. Testing is still ongoing due to some algorithm changes required during the implementation phase.

Impact

Impact on industrial and other user communities

This project is demonstrating on-site metrology-grade measurement of the key parameters of DC trial grids. This demonstration of traceable measurements made on-site will support the methods uptake by end-users and will help to pave the way to the eventual large-scale roll-out of DC grids and such technologies.

Distribution System Operators require special permissions from Energy Regulatory Authorities for DC grid trials because they are beyond present regulations. This project will support the appropriate design of DC grid trials by developing an industry guide so that DCPQ “planning level” surveys can be reliably performed. Further to this, DC grid trials require special permissions from Energy Regulatory Authorities because they deviate from present regulations. One of the outcomes of this project will be an industry guide on compatibility and planning level surveys of DCPQ in LVDC grids which will support utility companies and authorities and will help them to reliably perform future level surveys.

Furthermore, Energy Suppliers will need to install enormous amounts of DC electricity meters. Their reliability is extremely important, especially when exposed to PQ disturbances. The metrological infrastructure to be developed by this project is a prerequisite for Notified Bodies to perform type approval for Meter Manufacturers which in turn is essential for proving reliability as required by EU regulation. To help support this, the project will produce an industry guide on proposed test waveforms for DC electricity meter testing.

This project is also directly liaising with energy suppliers and stakeholders via the stakeholder committee. The project’s stakeholder committee currently includes 12 institutions from multiple countries, including utilities, technology manufacturers, and engineering companies. An online stakeholder meeting was organised to present the first project results and to receive feedback, in particular on the proposed initial definitions of DCPQ parameters and the measurement equipment for the project’s on-site measurement campaigns. In addition, this project also involves site owners and utility companies via measurement campaigns of DC power and DCPQ parameters at real LVDC grids and facilities. This is done to promote the real-world applicability and uptake of the project’s results by the energy suppliers.

Impact on the metrology and scientific communities

This project aligns with the strategic research agenda for EURAMET’s European Metrology Network (EMN) on Smart Electricity Grids and is supported by the EURAMET Technical Committee on Electromagnetic Metrology (TC-EM). The new reference setups developed by this project for DC power and energy and DC-specific PQ parameters will provide the missing metrological infrastructure for these quantities This will allow NMIs to propose new (and much-needed) CMCs and future intercomparisons for DC grid measurements. In addition, new reference DCPQ setups will be implemented on DC-specific PQ parameters such as ripple and in-rush. Such reference set-ups are needed for NMIs to be able to provide the assured traceability required by Notified Body testing laboratories and legal metrology verification authorities.

The application of this project’s DC grid measurement techniques and the definition of DCPQ events and related metrics will be of great interest to the wider scientific and metrology community dealing with DC distribution grids. To support the transfer of this knowledge, the project publishes its work in open-access papers; so far 13 publications have been completed that can be downloaded from the project’s Zenodo community at https://zenodo.org/communities/dcgrids/.

The project’s results are also presented at scientific conferences. A special session on “Standardisation of measurements for low-voltage DC electricity grids” was organised by the project at the International Conference on Harmonics and Quality of Power (ICHQP, May 2022). Four papers on the project’s results were presented as oral presentations. The project's results were also presented at the CIGRE 2022 Paris Session (Aug. 2022), the IEEE International Workshop on Applied Measurements for Power Systems (AMPS, Sept. 2022 and Sept. 2023), and the Conference on Precision Electromagnetic Measurements (CPEM, Dec. 2022).

The project also plans to host two stakeholder workshops; the mid-term stakeholder workshop on "On-site measurements in LVDC grids and their interpretation" was organised and hosted by the project in Malaga, Spain, on 28 October 2022. The status of the project's work on on-site measurements in LVDC grids was presented by partners as well as by the chief stakeholder and the local meeting host Innovation Enel Grids. More than 50 stakeholders attended the workshop, either in person or online, and the stakeholders represented standard development organisations, grid operators, utility companies, technology manufacturers, universities, and research institutions.

Impact on relevant standards

Links with the most relevant standardisation working groups have been initiated: IEC SC77A WG8 & WG9, IEC TC85 WG20, IEC TC8 JWG9, IEC TC13 WG11, and CLC TC13 WG01 have been informed about the project and its first results. Further relevant IEC WGs for DC metering have also been identified and initial contacts have been established.

The results of this project are expected to provide valuable input for standardisation on DC grids, for example, for CLC TC8X WG1 to include DC in the EN 50160 on voltage characteristics of electricity supply grids, IEC TC8 JWG9 to develop a document on PQ requirements for LVDC electricity distribution, IEC SC77A WG9 to include DC in the PQ measurement standard IEC 61000-4-30 and IEC TC85 WG20 to accordingly adjust the related IEC 62586-2 testing standard.

The newly developed measurement techniques will also support the Measuring Instruments Directive 2014/32/EU, as well as IEC TC13 WG11 which is presently working on a new edition of the IEC 62053-41 on DC electricity metering equipment. Further to this, the outcomes of this project will be disseminated to IEC SC77A WG9 which oversees IEC 61000-4-30 on the definition of AC PQ parameters and will be adapted in the future to include DCPQ parameters and IEC TC85 WG20 which is responsible for IEC 62586-2 on the measurement equipment and test methods for PQ in power supply systems as defined in the IEC 61000-4-30.

Finally, the results of this project will also be an important input to IEC TC8, CLC TC13 WG01, IEC/CISPR/CIS/H/JWG6, IEC SyC LVDC, IEC SC77A WG1 & WG2, CEN/CENELEC/ETSI SG-CG, WELMEC WG5, WG8 & WG11, CIGRE/CIRED C4.40, IEC TC38 WG47, IEC TC38 JWG55, EURAMET TC-EM and BIPM CCEM.

Longer-term economic, social, and environmental impacts

Many claims have been made over recent years regarding the advantages of moving to DC distribution networks, but such a conversion is an immense investment decision for a highly conservative electricity industry. The PQ compatibility and planning level surveys developed in this project are essential for supporting the future rollout of DC grid trials and increasing confidence in the resulting benefit analysis from the trials. Thus, the project is supporting the future rollout of DC grids by the electricity industry.

In the future, it is expected that through the operation of electrical products via DC grids, Europe can improve its energy efficiency, and reduce manufacturing costs and temperatures by obviating the need for transformers and power electronics. Whilst initial redesign and implementation costs will be needed for this, the longer-term cost benefits for European consumers and manufacturers should outweigh this. For example, by removing conversion stages (AC to DC or DC to AC), this will improve energy efficiency, reduce energy losses, and reduce material usage (i.e., fewer copper transformers, and fewer wall chargers). In addition, reduced network reinforcement costs brought about by better and smarter use of networks will reduce the costs passed on to electricity consumers.

In the long term, the efficient integration of renewables (photovoltaic cells, heat pumps) and EVs into DC grids integrated with local storage will become the ideal model for distributed energy generation with improved supply reliability. Such distributed energy generation should increase supply security and, in some cases, improve supply reliability. Therefore, the use of DC grids is already attracting attention in hospitals, shipping, and other community projects.

Publications

[1] H. van den Brom, Z. Marais and R. van Leeuwen, "Testing of DC Electricity Meters with Broadband Conducted Electromagnetic Disturbances," 2022 20th International Conference on Harmonics & Quality of Power (ICHQP), 2022, pp. 1-6, https://zenodo.org/record/7181217

[2] J. J. Melero, J. Bruna and J. Leiva, "On-site PQ Measurements in a Real DC Micro-grid," 2022 20th International Conference on Harmonics & Quality of Power (ICHQP), 2022, pp. 1-5, doi: https://zenodo.org/record/7448466

[3] G. Frigo and J. Braun, "Measurement Setup for a DC Power Reference for Electricity Meter Calibration," 2022 20th International Conference on Harmonics & Quality of Power (ICHQP), 2022, pp. 1-5, doi: https://zenodo.org/record/7243555

[4] G. Cipolletta, A. D. Femine, D. Gallo, Y. Seferi, F. Fan and B. G. Stewart, "Detection of Dips, Swells and Interruptions in DC Power Network," 2022 20th International Conference on Harmonics & Quality of Power (ICHQP), 2022, pp. 1-6, https://doi.org/10.1109/ICHQP53011.2022.9808830

[5] X. Yang, X. Niu, J. Fei, C. Zhang, H. Tong, C. Liu and L. Zhang, “DC Power Quality assessment on real MVDC and LVDC power systems”, CIGRE 2022 Paris Session, Paris, France, 2022, doi: https://doi.org/10.5281/zenodo.8435000

[6] G. Cipolletta, A. D. Femine, D. Gallo, C. Landi and M. Luiso, "Considerations on Voltage Ripple Assessment in dc Power Network," 2022 IEEE 12th International Workshop on Applied Measurements for Power Systems (AMPS), Cagliari, Italy, 2022, doi: https://zenodo.org/record/7258157

[7] G. Frigo and M. Agustoni, "Development of a Transfer Standard for DC Power Quality Reference Systems," 2022 IEEE 12th International Workshop on Applied Measurements for Power Systems (AMPS), Cagliari, Italy, 2022, doi: https://zenodo.org/record/7243629

[8] C. Mester, "DC active electrical energy meters: Accuracy tests," 2022 IEEE 12th International Workshop on Applied Measurements for Power Systems (AMPS), Cagliari, Italy, 2022, doi: https://zenodo.org/record/7573510

[9] H. van den Brom, J. Melero, V. Cuk, G. Frigo, D. Gallo, D. Istrate, D. Giordano, M. Blaz, B. Stewart, and X. Yang, “Traceable Power Quality Measurements in DC Electricity Grids”, 2022 Conference on Precision Electromagnetic Measurements, Wellington, New Zealand, 2022, doi: https://zenodo.org/record/7441360

[10] D. Signorino, G. Frigo, M. Agustoni, A. Agosto, and D. Giordano, “Novel Method for Accurate Measurement of Ripple for Power Quality Applications in DC Grids”, 2022 Conference on Precision Electromagnetic Measurements, Wellington, New Zealand, 2022, doi: https://zenodo.org/record/7442331

[11] G. Frigo and M. Agustoni, "A Transfer Standard for DC Power Inter-Laboratory Comparison”, 2022 Conference on Precision Electromagnetic Measurements, Wellington, New Zealand, 2022, doi: https://zenodo.org/record/7243673

[12] M. A. Oliván, J. J. Pérez-Aragüés, and J. J. Melero, “A High-Frequency Digitiser System for Real-Time Analysis of DC Grids with DC and AC Power Quality Triggering,” Applied Sciences, vol. 13, no. 6, p. 3871, Mar. 2023, doi: https://doi.org/10.3390/app13063871

[13] H. E. van den Brom, R. van Leeuwen, G. Maroulis, S. Shah, and L. Mackay, “Power Quality Measurement Results for a Configurable Urban Low-Voltage DC Microgrid,” Energies, vol. 16, no. 12, p. 4623, Jun. 2023, doi: https://doi.org/10.3390/en16124623

This list is also available at https://www.euramet.org/repository/research-publications-repository-link/

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2021, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Helko van den Brom, VSL Tel: +31 15 269 1500 E-mail: hvdbrom@vsl.nl
Project website address: https://www.dc-grids.nl</td></tr>
<tr><td colspan="2">Chief Stakeholder Organisation: e-distribución Redes Digitales</td><td>Chief Stakeholder Contact: F. Javier Leiva Rojo</td></tr>
<tr><td>Internal Funded Partners:
1. VSL, the Netherlands
2. INRIM, Italy
3. LNE, France
4. METAS, Switzerland
5. PTB, Germany</td><td>External Funded Partners:
6. CIRCE, Spain
7. STRATH, United Kingdom
8. SUN, Italy
9. TU-E, the Netherlands</td><td>Unfunded Partners:
10.EDF, France</td></tr>
<tr><td colspan="3">RMG: N/A</td></tr>
</table>