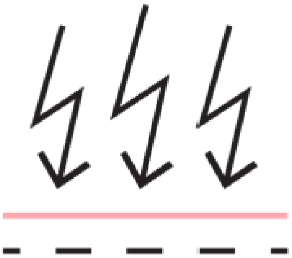
Strategic Technology Plan
Implementation Working Group Direct Current technologies

Subgroup on
LVDC – Low Voltage Direct Current Systems
Implementation Plan

Endorsed by the SET Plan Steering Group on 12 September 2024



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1. EXECUTIVE SUMMARY

This Implementation Plan focusses on Low-Voltage Direct Current (LVDC) technologies and systems, it was drafted by the LVDC subgroup of the SET Plan Implementation Working Group ‘Direct Current Technologies’. High Voltage Direct Current technologies are addressed in a dedicated Implementation Plan[1]

1.1. Why is low-voltage direct-current (LVDC) important now?

Many low/medium-voltage applications already use DC internally:

- Photovoltaics produce DC directly.
- Wind turbines have a DC circuit internally that converts the rotation of the blades to the fixed Alternating Current (AC) grid frequency.
- Battery storage systems are DC, as are electric cars.
- Electrolysis needs DC, e.g., to produce “green hydrogen”.
- Many loads are DC or use DC internally:
  - LED lighting is directly DC-powered.
  - IT equipment runs on DC.
  - Motors, in industry or in residential appliances, are controlled by variable speed drives, with frequency converters that have an internal DC link.
  - Heating and cooling systems, like heat pumps, use DC or are ready for DC supply.

DC-to-DC conversion can be implemented more efficiently than AC-to-DC conversion due to the rapid advances of power semiconductors**.**

- In the early days of electricity, the deciding factor for choosing AC was the lack of efficient DC-DC step-up and step-down converters, which has now been resolved with the progress of power electronic technology.

1.2. What are the benefits of LVDC versus AC?

- DC is more **resource and energy efficient**, reducing material and losses in wiring and converters.
  - Many conversion steps between DC applications to AC are not needed anymore. Step-up or step-down **DC-to-DC converters are simpler than AC-DC converters**, requiring fewer components and material, while achieving higher efficiency.
  - Low-voltage distribution **cabling mass (copper or aluminium) is reduced by 25 to 55% and power losses can be reduced by up to 35%[2],** compared to the prevalent three-phase AC system, for the following reasons.
    - In AC, the insulation must be dimensioned for the peak of the sinusoidal voltage. But the effective (RMS) voltage in AC is lower than the peak voltage[3]. In DC, the voltage is constant and the peak voltage is equal to the effective voltage. Hence, **for the same peak voltage and same power transfer, the current is lower in DC than AC**, thereby requiring smaller wire cross-section. In case of reactive loads (e.g., motors), the total current is higher in AC systems, but not in DC systems. Hence DC cabling section and/or losses are reduced compared to AC.
    - **Only two active wires (plus one earth wire) are needed in DC**, compared to three (plus one earth wire) in the AC three-phase system. In AC three-phase system, the electrical loads have to be allocated between the three phases. The imperfect balance of loads between the 3 phases induces sub-optimal use of the cabling in AC, this is not the case in DC.

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[1] High voltage direct current (HVDC) & direct current (DC) technologies - European Commission (europa.eu) October 2021

[2] With the same peak voltage, the cabling mass is reduced by 25% in case of non-reactive load (power factor = 1); in case of reactive load with a power factor of 0.625, the cabling mass is reduced by 55% and losses by 35%. With bidirectional connection to the AC supply grid, at a higher DC-voltage, the copper savings reach 50%.

[3] The effective voltage (Vrms) is equal to the root mean square (RMS) of the peak voltage: Vrms = Vpeak / Sqrt(2) = Vpeak/1.41

- DC microgrids **facilitate the integration of local renewables, demand response and storage**, thereby optimising self-consumption and increasing resilience.
  - The voltage level of a DC-microgrid can be modulated within a range, so that **the DC voltage level itself reflects the balance of power demand and supply** at any time, this is the ‘droop control’ principle, without the need for a data communication channel (unlike in AC grid).
  - The DC voltage level itself is **used as a signal to activate local storage or a load (e.g., heat pump), thereby optimising the self-consumption** of local renewable energy sources**.**
  - Local storage can be dimensioned to supply energy for emergency operation or for a controlled shutdown in case of a wider power outage of the AC supply grid.
  - In response to the DC voltage level signal, the **braking energy of electric motors is easily and efficiently recovered.**
    - It is not wasted into heat as in most present AC applications where kinetic energy of motors or lift applications needs to be disposed of. On the contrary, it can be fed back into other loads or storage within the DC microgrid.
    - This also reduces the energy consumption of air-conditioning units at production sites.
- DC microgrids **reduce the required connection capacity** to the AC distribution grid, thereby avoiding AC grid reinforcements.
  - In response to the DC voltage level, **local storage can easily supply peak power demand in applications such as motors**. This relieves the supply grid from having to supply peak power at exactly the moment it is used and **reduces the required capacity of the connection to the grid by up to 85%,** as experienced in buildings and industry (see 2.2).
- DC microgrids **contribute to AC grid stability and voltage quality.**
  - As more and more directly coupled rotating synchronous generators (e.g., thermal power plants) are replaced with inverter-coupled units (e.g., solar photovoltaic and wind energy), the 50Hz frequency inertia of the AC grid is decreasing, and oscillations and other stability related phenomena are increasing. Current distortion due to superimposed interferences leads to voltage quality problems and overloading of network components.
  - Moving the AC/DC interface to a higher level in the power system architecture (by utilising a local DC microgrid) enables the solution of local problems in the local network and prevents the propagation of distortions to the AC power system.

1.3. What do we suggest?

Priorities for the advancement of LVDC are described in detail in section 5, and the proposed activities are described in detail in section 7.1.

LVDC technologies and components are already well developed, but further **R&I effort is needed** to:

- demonstrate innovative LVDC microgrids in buildings or industrial plants,
- develop models, tools, strategies and guidelines for designing and using sustainable LVDC systems,
- study the effects of DC stray currents on building structures and human body, as well as develop protection schemes,
- optimise power semiconductors for DC specific applications.

Further actions are needed beyond the scope of R&I to enable the deployment of LVDC:

- develop standards for LVDC systems characteristics and requirements (IEC, CEN-CENELEC),
- raise public awareness about the benefits and implications of LVDC systems among decision makers and the public,
- establish education and training curricula,
- remove regulatory barriers (at national level), inhibiting use of LVDC, and harmonise the regulatory framework across the Member States.

2. INTRODUCTION AND POLICY CONTEXT

2.1. Policy context

LVDC sub-group experts see LVDC technology as a key enabler for achieving the sustainability goals of the “fit for 55” / “green deal” initiative as well as an enabler for UN sustainability goals 7, 9, 11 and 12 [3] , considering also social sustainability and system aspects in addition to environmental sustainability:

- Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all,
- Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation,
- Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable,
- Goal 12: Ensure sustainable consumption and production patterns,

In addition, the benefits of LVDC described above are supporting the **Climate Strategy and Targets of the European Union** [Climate strategies & targets]. The LVDC systems can contribute to the targets of energy efficiency in the **Energy Efficiency Directive** (EED)[4]. They also facilitate the integration of larger shares of renewable energy sources and so contribute to the targets of the **Renewable Energy Sources Directive** (RED)[5]. LVDC systems can help maximise self-consumption of local, renewable energy sources and provide flexibility through demand response, thereby contributing to the objectives of the **EU Strategy for Energy System Integration**[6] and **Electricity Market Design** directive and regulation[7]. While LVDC systems can reduce the need for materials in simpler DC/DC converters, the LVDC hardware should be designed to be more durable, repairable, upgradable and recyclable according to the principles of the **EU Circular Economy Action Plan**[8].

The European Commission communication on the **EU Solar Energy Strategy**[9] recognises that *increasing the use of DC technologies could be beneficial to the electricity system: as renewable power from solar is produced in Direct Current (DC), conversion to Alternating Current (AC) to feed into the grid and then converting back to DC, e.g. to store energy, leads to energy losses; such conversion losses are currently growing because more devices and system, such as batteries, heat-pumps, data centres, electric vehicles or appliances, operate in DC*.

The transition to renewable-based clean energy is one necessary step amongst many in the move to a more sustainable society. The goal is to lower human consumption of natural resources to a level that no longer exceeds the regenerative capability of the Earth. With regard to electrical power, this is only possible through greater efficiency in energy production, distribution and consumption and the use of zero-carbon renewable energy sources. At the same time, manufacturing must become more efficient, digitalised, integrated and personalised/customised. The increase in the use of electronics as well as many sensitive production processes, calls for maximum security of electricity supply.

This Implementation Plan of the LVDC sub-group of the SET Plan Implementation Working Group on ‘DC technologies’ is aimed at stakeholders in industry, research and politics. The goal is to provide insights into the concept of low voltage direct current (LVDC) systems as the basis for resolving the challenges associated with an environmentally friendly and sustainable energy use. Falling prices for renewable decentralized energy use will, in addition to the widespread desire for self-sufficiency in the population, lead to increased economic and strategic interests for further decentralization with renewable energy systems.

The LVDC subgroup envisages possible cooperation with other SET Plan IWGs, notably IWGs ‘Energy Systems’, ‘Energy Efficiency in buildings’, ‘Sustainable and efficient energy use in industry’

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[4] DIRECTIVE (EU) 2023/1791
[5] DIRECTIVE (EU) 2023/2413
[6] COM(2020) 299 final
[7] EU/2019/944 and EU/2019/943
[8] COM(2020) 98 final
[9] COM(2022) 221 final, p14

2.2. Description of low-voltage DC systems

Low-voltage DC systems are already used in different domains. This section describes examples.

In industrial environment, LVDC systems have been in continuous use since the beginning of electrification and were never fully replaced by AC systems in all applications (status is similar to traction systems). Particularly DC motor drives and related distribution systems have been and are in widespread use in forest and steel industries. Now the use of DC has started to gain interest also amongst goods manufacturing industry and for uses going beyond motor drives and backup power supply applications, as proven by the DC-INDUSTRIE and DC-INDUSTRIE2 projects in Germany, in which implementations have been developed and rigorously tested by more than 40 industrial partners and research institutions with more than 150 experts collaborating intensely [4]. Within those projects, in the years 2016 through 2023, ten DC model applications were built and tested in industrial and research settings. Figure 1 shows a sketch of a system layout used in the DC-INDUSTRIE with a central bi-directional connection to the AC supply grid (top left). Sources such as renewable energy and storage devices (e.g., battery storage) are connected to the central DC grid as are the loads (bottom part of the figure). The results of the projects are summarized in the DC Industry system concept [5].

Also in residential and commercial applications, DC is more widespread now. For instance, LED lighting, office equipment, electrical vehicles, stationary batteries and photovoltaic installations are generically DC. The general layout of these applications is also covered by Figure 2.

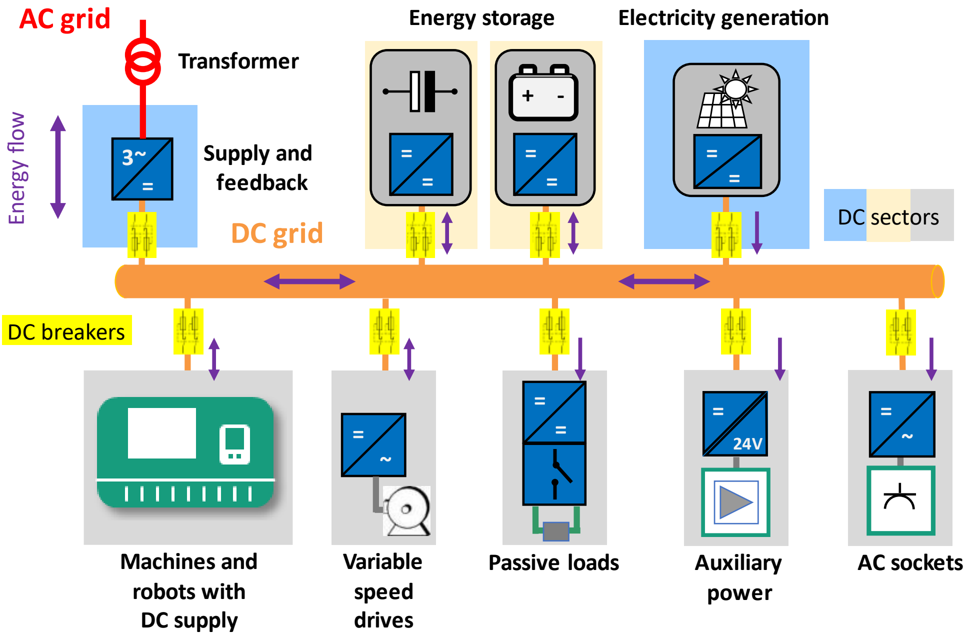

Figure 1 LVDC system, behind the meter

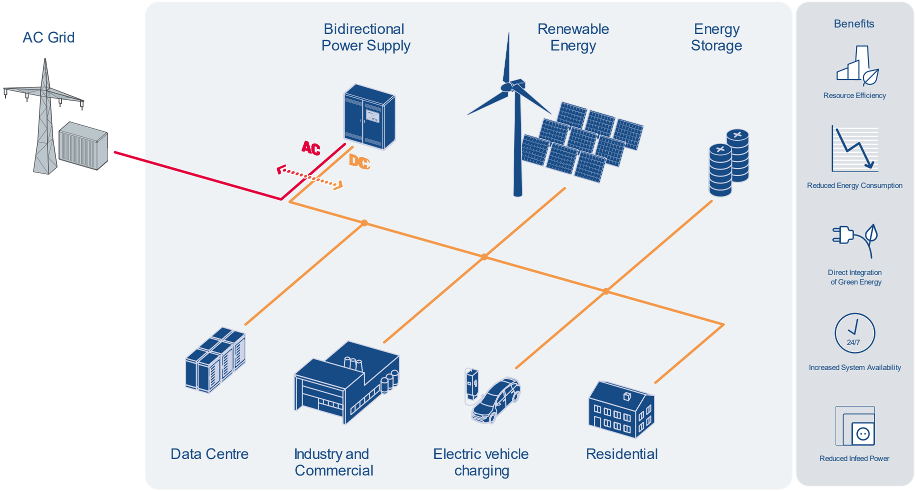

Figure 2 LVDC System – public microgrid (© ODCA [7])

2.3. Real-world DC system examples

Other LVDC projects can be found in the living annex 7.3

2.3.1. Micro-grid in industrial plant: Schaltbau

In Germany, DC products supplier Schaltbau, opened a new, DC-operated building at their company headquarters in Velden in southern Germany. Figure 3 Aerial view of Schaltbau building [10] shows an aerial view of the site that now includes 1.3 MWp photovoltaic panels on the roof, a DC-powered completely automated high-bay warehouse for the factory, battery storage and thermal storage, as well as e-car charging stations. They have achieved significant savings with this building already:

- 85% reduction of the feed-in power from the supply grid for the high-bay warehouse by using a DC microgrid compared to the traditional AC system.
- 70% self-utilization of the energy supplied by photovoltaic.
- 35% lower energy cost.
- 800 MWh energy saving per year.

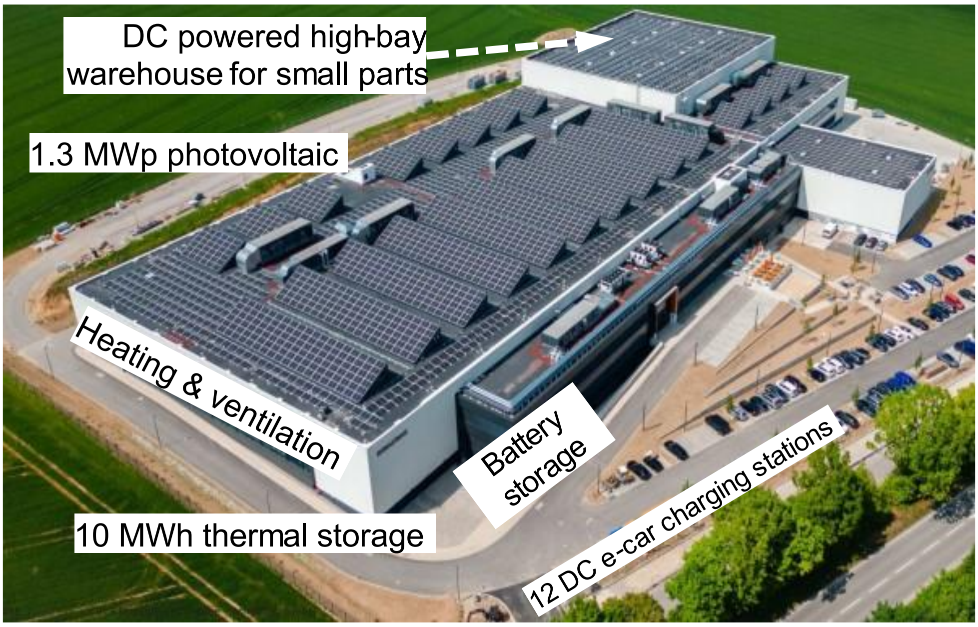

Figure 3 Aerial view of Schaltbau building [10]

2.3.2. Micro-grid in industrial plant: Phoenix Contact

Phoenix Contact has implemented a new production and technology centre called building 60 (G60) aiming at the integration of all manufacturing technology related know how driving the value chains of the company. The new building is directly located at the company's headquarter in Blomberg Germany. Figure 4 provides an aerial view of the new building[10].

Figure 4 View of new Phoenix Contact technology and production building G60

A 2.6 MWp photovoltaic systems serves as main renewable energy source, of which 1.1 MWp are already installed at the flat roof and further 1.5 MWp are still to be installed at the adjacent free field. Finally, the building will be energy positive because on a balance sheet perspective it will be capable of producing around 2.5 GWh/y, i.e. 600 MWh more energy per year than the building and the integrated use cases including production will consume per year. In addition to the large renewable energy source within the building various modern technologies are being linked together: a thermal network including heat pumps and an ice energy storage (1500 m³, 150 MWh), battery storage (300 kWh + 280kWh separate battery) and also the installation of a DC grid in combination with bi-directional electrical vehicle charging technology. Figure 5 illustrates the complete grid topology of the new building integrated into the company's local properties.

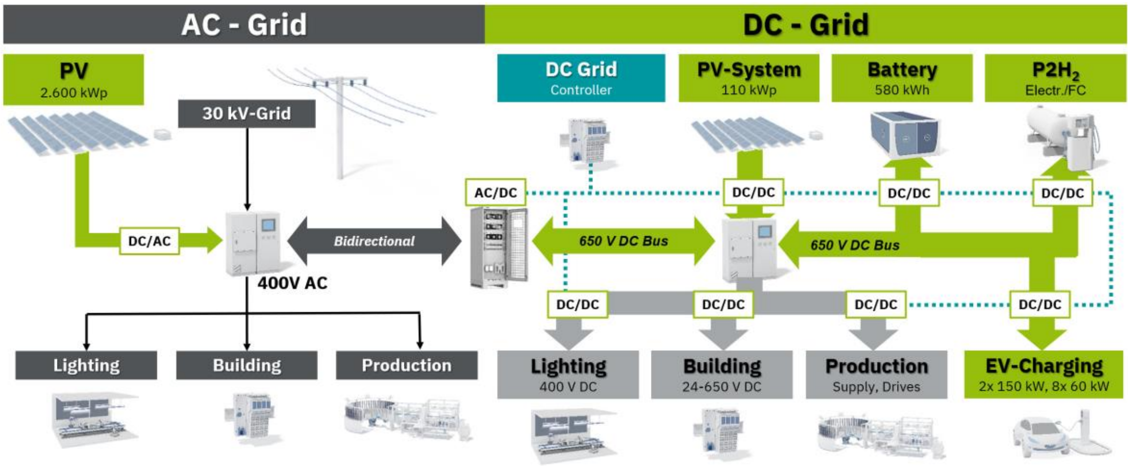

Figure 5 DC grid topology in the new Phoenix Contact building G60

Further to enabling the bidirectional integrated flow of electric energy as main backbone of the new building, the installed DC grid will be qualified and used for driving the automated assembly within the

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[10] https://www.cencenelec.eu/media/CEN-CENELEC/Events/Events/2023/AES/aes_presentation_possel-doelken_2023-12-04.pdf

production facilities. In this context the company aims at efficiently using direct-current based solutions for the complete supply of electric energy at different voltage levels between the single applications in the assembly machines. Therefore, dedicated sub-grids at lower voltage levels will be established and used. Figure 5and Figure 6 the related topology and the focused production use cases relevant to the grid design and the optimization of occurring energy flows when applying DC drives instead of AC.

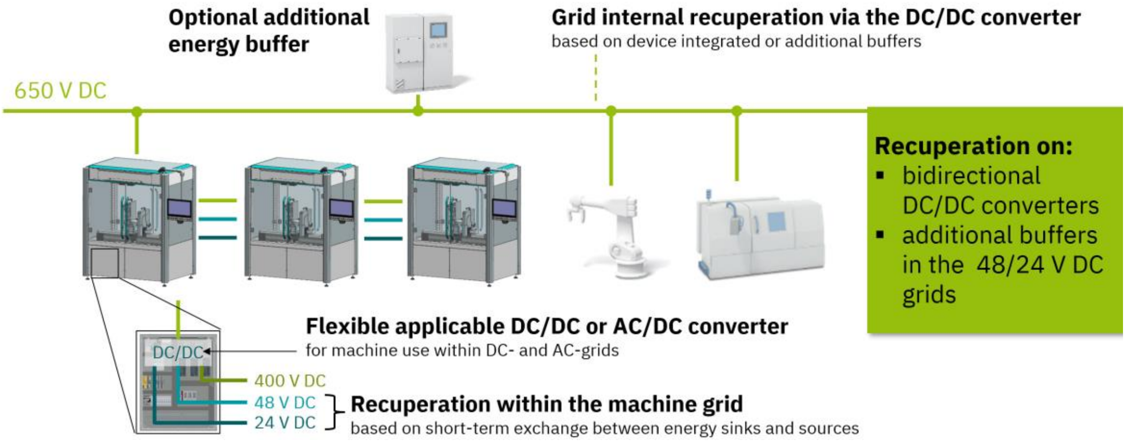

Figure 6 Potential usage of DC micro grids for production machines

Phoenix Contact aims at increasing the energy efficiency by reducing the necessary AC/DC conversion interfaces also allowing AC peak shaving causing lower capacity connection and lower electricity bills. In addition to the direct efficiency increases the underlaying infrastructure topology allows for less material consumption by on the one hand using a 3 conductors system for DC (L+, L-, and PE) instead of 5 conductors and on the other hand by applying a higher 650V DC standard in the bus, which reduces the required current. The direct integration compatibility with renewable energy sources and battery storage allows for both the simpler architecture design and the bidirectional usage within a prosumer structure. Current efforts refer to the implementation of the DC controller and the grid installation due to the lack of standardized DC components on the market. The 650 V DC grid is an AC grounded TN system. The source is directly grounded, occurring short circuit currents can directly flow through the source. The final DC end circuit is designed as 400 V IT grid allowing conventional end user to operate and maintain without additional safety approvals. The bidirectional AIC (active infeed converter) still needs to be certified according to VDE 4110 (Technical Connection Rules for Medium-Voltage in Germany) in order to refeed surplus energy by the PV system to the local property AC grid.

2.3.3. Micro-grid in building

Circl is a pavilion in Amsterdam's Zuidas district as shown in Figure 7. A place created by ABN AMRO bank. A building designed and constructed according to sustainable and circular principles. Circl has been created to be energy efficient and easy to disassemble, to make as little impact as possible on the planet.

Circl has been commissioned in September 2017 and disassembled end of 2023 to be rebuilt in another place. Circl demonstrating to the market that this is a normal tender within the existing ecosystem of electrical actors. This is NOT a demonstration project or a POC (“proof of concept”).

The main benefit of the Direct Current electrical installation was to divide by 3 the impact and power demand on the public distribution network compared to a similar AC building. A classical AC design would have required a 250 kVA delivery substation. Circl never exceeded 80 kW power demand during its 6 years of operations.

In addition, Circl shown a great resilience offering constant comfort and full operations during the few public grid power cuts that happened over the 6 years.

Figure 7 DC-powered Circl building in Amsterdam, The Netherlands

2.3.4. Public micro-grid: N470 road in The Netherlands

The provincial road N470 was a one-of-a-kind project for the region, involving multiple partners. South Holland aspires to manage and maintain its roads, waterways, bridges, and locks in a carbon-neutral manner. These spectacular goals have been realized in the N470 project by creating the most sustainable road in the Netherlands, see Figure 8.

The N470 road full DC installation is 4.7 km long 700 V DC bus with 100 kWp solar panels, 100 kW / 1 MWh battery storage system and 100 kW connection to the public grid to power 300 street light poles and traffic information system. From the electrical contractor Dynniq Energy, the N470 road installation has demonstrated the following benefits:

- 10% efficiency gain to power the same load.
- 35% copper saving
- 10% less batteries and photovoltaic panels
- Downsizing of the grid connection from 240 kW down to 100 kW thanks to DC and distributed control principles.
- 100% renewable powered (grid supply only used during battery maintenance).

Figure 8 public road N470 www.dc.systems/projects/highway-n470

3. STATUS QUO AND STAKEHOLDERS

3.1. Status in LVDC Technologies

While the technology has already been developed at component level and has been demonstrated in some applications, a few of which have been described in chapter 2.3, there has not been a widespread uptake of this technology. Additional R&I is needed to realise the transition towards the full roll-out of DC based systems. The following sections describe in more detail the status of different aspects.

3.1.1. Energy management of LVDC installations and compatibility with existing infrastructure

Energy management deals with how the power flow is controlled in LVDC grids and their loads, e.g. from the AC grid and / or from renewable sources such as photovoltaics or wind turbines. This includes the operator making decisions which energy source supplies the energy including considering forecast for generation which depends on weather conditions. Energy storage systems on the LVDC level are available for balancing differences in supply and demand of electrical energy. The batteries of the more widely introduced electric cars can play a role in the residential and commercial spheres; again, relieving some demand from the supply grid.

Aspects of grid management, i.e. making sure that on an instantaneous time scale the necessary power is available, are covered in chapter 3.1.3.

3.1.2. Protection

The term “protection” is referring to both equipment and people.

The difference for DC compared to AC is that there is a steady current flow, whereas in AC the current changes direction every 10 ms (in 50 Hz systems). In order to interrupt current, it has to reach zero ampere. Thus, new circuit breaker technologies have been developed, such as semiconductor and hybrid circuit-breakers that “create” such a current zero without the electrical arc used in traditional AC circuit breakers. They are proven to work reliably, however, so far there is very limited commercial availability, mainly because of the lack of market demand.

Fault characteristics in AC- and DC systems are different since LVDC systems are often connected to many energy sources. Consequently, obtaining fast and selective protection, i.e., ensuring that only the faulty sector is disconnected, is more challenging than in AC. But solutions do exist and have been proven, e.g., within the scope of DC-INDUSTRIE [4] and the Open DC Alliance [7].

3.1.3. Power balance and voltage quality

For stable operation of a DC system, it is necessary that the DC mains voltage is kept within defined limits. In DC systems, an imbalance between supplied power and drawn power leads to a change in local voltage: when local supply is higher than consumption voltage increases and vice versa.

In DC, power balance, i.e., the balancing of power demand of the loads and power supply of the sources, can be managed easily by measuring the voltage between both active conductors. When more power is needed than available, the voltage drops and vice-versa. Active components such as converters in the DC grid measure this voltage and adjust their current accordingly. as shown in Figure 9. If supply is too low (i.e., the local voltage drops) uncritical loads can be reduced or dropped and stored energy, e.g., from batteries, can be used to feed the loads. In the opposite case with higher supply than demand, voltage rises, and storage is filled, power supply from the grid is reduced and opportunity loads can be added. This principle is similar to the control principle of AC grids: the stable operation of AC grids is guaranteed by the control of frequency and real power as well as voltage and reactive power in defined limits (e. g. for the frequency 50 Hz in Europe). For DC only the measurement of one quantity, namely the voltage, is needed, much simpler than measuring frequency, voltage, current, and phase shift in AC.

Regarding DC system-grid management, several droop control methods and strategies have already been developed, tested and they are in use; but their scalability, usability in different kinds of system setups, installations and operational environments still must be investigated. A clear and well-defined market mechanism is also needed for the DSOs to purchase flexibility services for network support purposes from the individual network users. Thus, a need for both AC and DC network management.

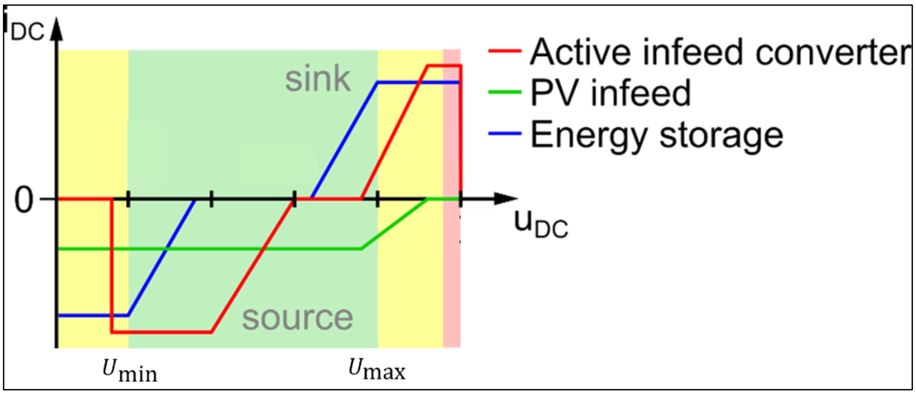

Figure 9 Example of droop curves of active supply devices (DC-INDUSTRIE system concept, [5]; Current/OS, [6])

3.1.4. Basic system configuration

LVDC systems can be operated in unipolar or bipolar configurations. In unipolar systems, one of the active poles (L+ or L-) is connected to earth, i.e., only the other pole has a voltage potential vs. earth. In bipolar systems both active poles have a voltage potential different from earth, typically equal in magnitude but with opposite polarity.

Systems earthing arrangements are similar to existing AC systems, with either one active pole connected to earth, an earthed mid-point conductor, or systems isolated from ground potential.

Common to all systems is that only two active wires are needed to transmit a constant power. In single-pole AC systems, the power fluctuates between peak power and zero power due to the sinusoidal wave form of both current and voltage. In three-phase AC systems, the three-phase power, e.g., transmitted to an electric motor, is constant, but it needs three wires and 50% more conductor material (usually copper) to achieve this.

One topic specific to DC is the effect of stray currents in the protective earthing (PE) system. Stray current corrosion takes place in locations where a leakage DC current (so-called stray current) enters an electrolytic medium (concrete / soil) from a metallic conductor. Electrochemically, this process is called an anodic partial reaction, which must be avoided. These stray currents can cause corrosion with the potential to weaken building structures if they are not properly managed.

3.2. Status in LVDC Standardisation

Important topics in the field of standardisation are the electrical safety, mainly: protection against electric shock (e.g. earthing concepts, earth fault current protective devices such as circuit breakers, galvanic isolation), fire and building corrosion protection (e.g. protection against earth leakage, protection against arc faults), protection against overcurrent (e.g. short circuits and over/under voltage), power electronics and grid control.

Currently there is no standard for a LVDC grid control (including voltage standardization, see IEC TR 63282:2020).

Grid Codes and regulations like the Network Code Requirements for Generators (RfG) and Network Code on Demand Connection (DCC) and Standards and regulations for TSO and DSO, as defined by ENTSO-E [https://www.entsoe.eu/network_codes/] are historically AC 50Hz oriented, not with the intend to exclude DC but as the image of the state of the art. For example: EN50160:2022 requires 230/400V AC 50Hz for LV distribution and 1kV-36kV / 50Hz for MV distribution.

The International Electrotechnical Commission (IEC) is an international standards organisation that prepares and publishes international standards for all electrical, electronic and related technologies.

IEC has already set up a so-called System Committee (SyC) to realize the needed coordination task between different Technical Committees (TCs). The Committee IEC SyC LVDC is responsible to coordinate the standardization of LVDC.

Until January 2024, The European CENELEC body only had a secretary to mirror the IEC SyC LVDC committee. A mirror may be not enough to push European interests ahead and to endorse and ease pilots of the most advanced LVDC architectures (Current/OS [6], DC-Industrie [4] and Open DC Alliance [7]). Therefore, the LVDC-STD project was launched on 01 January 2024 with European Commission funding.

- Project name: European Standardization for Low Voltage Direct Current Technologies
- Project acronym: LVDC-STD
- Project Coordinator: CEN-CENELEC, partner: AFNOR
- Project duration: 12 months (Jan- Dec 2024)
- Project summary: The Low Voltage Direct Current (LVDC) technologies have a strong potential to promote the efficient and cost-effective deployment and integration of renewable energy sources and storage in residential, commercial and industrial buildings (including data centres). The objectives of the project are to establish a European (CENELEC) Technical Committee on LVDC to accompany the roll-out of this technology. To achieve this, the work plan is organized into 3 work packages in charge of, the organization of a workshop in order to share current works (state of the art) and strategic orientations for the future of LVDC with the European expertise so as to gather the best skills before launching a European technical committee to standardize LVDC technologies (in collaboration with the IEC in the framework of Frankfort Agreement); one of these work packages being dedicated to the overall coordination and management of the project).

3.3. Status in LVDC Education

Because LVDC is less frequently used than LVAC, most electrical technicians and engineers have rarely, if ever, worked with DC. Therefore, DC technology is less known than other energy topics, even among technical people.

There are currently little education initiatives specifically targeted at LVDC. Especially when it comes to prosumer installations and professional designers and installers.

Education programmes do not cover DC technology as thoroughly as they do with AC:

- At vocational level, courses on PV installations and battery storage systems do exist, but DC power distribution more generally is not covered as a topic.
- At university level, courses dedicated to LVDC exist (e.g. [9]), but very uncommon.

The situation of training / demonstration initiatives is:

- Large amount of published academic research (papers, etc), very fragmented.
- Few wide-scope documentation on LVDC by standardization bodies / industry associations
- Technical documentation about specific components, issued by manufacturers.
- Several pilot / demo installations have been built, but mostly designed as research facilities, not for the purpose of education / training.

3.4. Status in LVDC Regulation

In general, the grid codes or regulations should be technology neutral. As the MV/LVDC networks have not yet been placed anywhere in the power systems at National/EU level, the existing EU directives, such as the Directive on Common Rules for the Internal Market for Electricity (EU/2019/944) and the Regulation on the Internal Market for Electricity (EU/2019/943) do not have any specific regulatory framework for LVDC or integration of DC in AC networks. For example, there is no specific regulation on how an LVDC network can be connected to the existing LVAC network, the grid-forming capability requirement for the LVDC network or the functional requirement for AC/DC hybrid converters, how the MVDC-LVDC network can be formed, or a DC smart substation can be formed/operated.

It remains unknown if any EU Member sState has yet developed any specific regulation in this regard. Other than EU, at national level, BS7671 in the UK and the National Electric Code (NEC) regulations in the US contain some guidelines for the DC connections. Such as, BS7671 covers circuits supplied at nominal voltages up to and including 1500 VDC but does not make specific recommendations on DC distribution voltage levels or the protection requirements for more complex DC systems. NEC also has sections dedicated to the implementation of DC micro-grids, solar PV, energy storage. Indian National Electric Code defines DC distribution voltage level as 220/440 VDC and provide guidelines on cable colours, fault current calculations and solar PV recommendations. Japan specifies the upper limit of low voltage DC at 750 VDC and China currently has national standards in the area of DC-powered telecom installations.

With the changes in the generation, distribution and consumption processes in the transition toward the decarbonisation and smartening of the energy system, the Council of European Energy Regulators (CEER) suggests the current and future roles of DSO should be to act as a neutral market facilitator, plan for alternatives to system expansion, use flexibility - demand and generation resources, as well as fair sharing of distribution tariffs, to optimise network capacity, minimise grid reinforcement, reduce losses, lower connection costs and DSO investments.

LVDC regulation can play a vital role in this space to enhance and improve the operation of DSO in achieving the goal of a decarbonised smart grid.

4. CHALLENGES TO ADDRESS

Existing technical challenges are listed in the subsections below. However, the main hurdles to the use of LVDC are not only technical in nature but rather on the regulatory side. Technology development, so far, has been ahead of standardization and regulation. To facilitate component and product development and to speed-up market availability, standardization and close cooperation between technology development and regulation are strongly recommended.

4.1. Technical challenges

4.1.1. Protection

- Lack of widely accepted **protection schemes and components** for a variety of system architectures (with different earthing schemes, and cases with bidirectional power flow), including methods for calculation of fault currents
- Lack of knowledge on short-term and long-term **effects on human bodies** of stray DC current
- Missing knowledge on **effect of DC currents on corrosion** of building structures with relationship to the earthing system. For example, the magnitude of stray currents in typical installations and the subsequent stray currents and corrosion effects on building structures.

4.1.2. Grid management and operation

- DC components and sub-systems are currently not present in **grid planning & calculation tools** (standardization of protection devices is needed in parallel)
- **Engineering practices/guidelines for grid control and protection selectivity** coordination are missing when more than one power-supply unit feeds a DC grid. This includes: grid black start, islanding, autonomous operation, connection, interoperability requirements, architectures and limitations of droop control, prescriptions on system expansion, stability analysis, grid-forming and grid-following safe operations schemes for LVDC grids.
- Lack of **communication standards and protocols** for power-flow and energy management
- Parameters and **methods for power quality assessment**, including measurement practices (voltage fluctuation bands, measurement timings, aggregation, etc) and electromagnetic compatibility EMC are incomplete.
- Guidelines and engineering practices for the **connection of the DC microgrid to the (AC) supply grid** are missing, for the potential provision of supply grid services (grid forming, frequency support, black start), as well as for the assessing the **impact of the DC-microgrids on the wider distribution and transmission system**.
- Guidelines and engineering practices for the **design and operation of mixed AC and DC** systems are missing; particularly in the case of retrofit / brownfield projects in which LVDC is used to replace or extend part of an existing AC installation.

4.1.3. Components

- Lack of methods for assessing reliability and end-of-life assessment / prediction of power semiconductors and new components of LVDC protection devices (notably for preventive maintenance)
- Lack of criteria for compatibility between different converters, e.g., required control criteria for a parallel operation of converters of different suppliers.
- Lack of widely adopted engineering methods for selecting components (converters) particularly in complex, multi-vendor situations.
- Lack of testing methods to verify compliance of LVDC devices, equipment and installations with the respective specifications.
- Lack of protection devices for low to medium power applications (100 W – 1 kW)

4.2. Standardisation challenges

Electrical standards need to be extended to LVDC Systems. Standardization is a slow process by nature as this process requires consensus, country consultation, votes, translations etc. Another reason is that it is driven by market needs, but there is no real market yet because everyone is waiting for standards. Regulation authorities could speed up this chicken-and-egg problem. Therefore, needed regulation and standardisation work should be initiated or accelerated.

This is a traditional process and requires good knowledge of the internal design, behaviour and use of products and systems. Due to the relatively young LVDC technology, such experience is hardly available and can only be defined with difficulty. There are not enough real-world **pilots' installations** for developing experience and growing the knowledge.

The goal of **standards for LVDC DSO is to define quality of power** for users. The existing standard does not need to be modified because it is dedicated to AC Public distribution, while an equivalent document is missing for a public DC distribution with DC power quality requirements. In addition, no LVDC energy meter standards exist today for measurement and billing. There is an opportunity to define LVDC grid codes at the EU level, to avoid disparate national rules, resulting in excessive testing and approval costs for the industry.

Applications in **Residential, Commercial and Industrial buildings** etc need **standards for selection and erection of DC electrical installation**. Despite the many research projects on LVDC, few results have been transposed to the standardization level.

- No standardized DC voltage levels and voltage bands
- No or limited standardized DC socket e.g. for KW-range appliances, which is not covered by USB or Combined charging systems (CCS) for vehicle charging.
- Electrical installation standards (IEC HD 60364) are not covering DC installations with the same level of detail as for AC.
- No standard for “Interlink converter”: AC/DC converter for connection of an LVDC installation to an AC grid.
- No standardized method for DC short-circuit (including earth fault) calculation for protection against electric shock and protection against overcurrent. (One document only is existing today: IEC/EN 61660 Short-circuit currents in DC auxiliary installations in power plants and substations). To be noted CENELEC has decided this year to open activity in TC64 WG18 in charge of short-circuit calculation.

IEC and related CENELEC technical committees in particular TC 8, 64, 23, 121 standards usually cover both AC and DC application but in a lot of standards the requirements are “AC minded”**.**

- IEC TC64 (Low voltage electrical installation) have started some years ago to identify and improve gaps during planned maintenance of documents. (For example, the ongoing maintenance of IEC / HD 60364-1 is improving a lot the description of LVDC system)
- IEC TC64 JWG44 (CENELEC WG30) has started a work for Prosumer installations with a DC system.
- Product committees such as IEC SC121A has started a work on IEC/EN 60947-10 “Semiconductor circuit-breaker" in particular for DC. IEC SC23E initiated a work on semiconductor RCBO (IEC/EN 63464-1) in particular for DC.

All these works are following “Parallel procedures” between IEC and CENELEC. And for installation rules dealing with safety, it must **be translated in national regulation, as well as in the future European regulation**, HD 60364 needs to be implemented in national wiring rules / building codes etc.

In some **specific applications, (Data Centre, Marine, Street lighting…)** different approaches and / or installation standards are applicable.

4.3. Challenges in education and awareness

Perceived most important challenges/gaps (in order of importance):

- Lack of **knowledge and support for decision makers and communities**, who need technical, economic and social information on LVDC technology. Business-related aspects are probably those where education is most needed. Decisions about projects, and evaluation of alternatives, are currently made based on Return on Investment, Full Cost of Ownership, and similar parameters. Albeit methods for calculations of such parameters are generally known, they are rarely applied to compare LVDC as an alternative to AC because calculations on LVDC suffer from limitations on experience and data (including on the manufacturers' side). As a consequence, calculations are focused on AC solutions, because there used to be no alternative. There is a gap in **education curricula / training courses and teaching materials for engineers / technicians**. On technical level, there is a gap of system-level training, aimed at making design engineers aware of how the existing technologies and components can fit into an overall architecture. In particular, existing education do not cover planning, design, operation, evaluation of technical parameters of DC installations in comparison to AC installations.
- Lack of **information on LVDC among end users / consumers**. Particularly on non-technical issues (e.g., what is a DC network, what are the benefits …) as well as safety aspects.
- Lack of **planning, design, and documentation guidelines and software** tools. Current guidelines and software packages typically don't include DC, nor provide a way to compare AC with DC in terms of energy efficiency, resource usage and resilience. Technical aspects that are insufficiently covered in existing guidelines include:
  - Methods for **interfacing LVDC components** in possible applications and for different stakeholders (end user, DSO, DNO, …), and
  - methods for **selecting components** (converters) particularly in complex, multi-vendor situations,
  - parameters and methods for **power quality** assessment, including measurement practices,
  - methods to **verify compliance of LVDC devices**, equipment and installations with the respective specifications,
  - methods for **servicing and repairing,**
  - **engineering retrofit or brownfield situations**, in which LVDC is used to replace or extend part of an existing AC installation.

4.4. Challenges in Regulation

4.4.1. Challenges in regulation at public networks and distributors level

A CIRED survey finds that the DC technologies can be integrated into the existing network both in horizontal and vertical directions[11]. As the existing power system networks, especially MV and LV, are in AC, the developed EU regulations mainly focus on AC systems and their integration into the networks. There is a need to update/develop new regulations that should cover the use of both AC and DC. However, there are no separate regulatory documents for DC. The DC grid code/regulations (especially for MV/LVDC) should be developed at different levels and points of connection in the network depicted in Fig 10 [11]. From a regulatory perspective, the use of **DC should be allowed** both in public distribution networks and in behind-the-meter private installations.

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[11] Vertical depth of DC integration: DC needs to be connected to the main AC grid at some point; this point currently resides at the low voltage end, but move up to higher voltages. Horizontal DC links refer to the exchange of power between decentralized energy assets (e.g. renewable energy sources, storage, ...) at the same voltage level, resulting in a meshed structure of transmission grids.

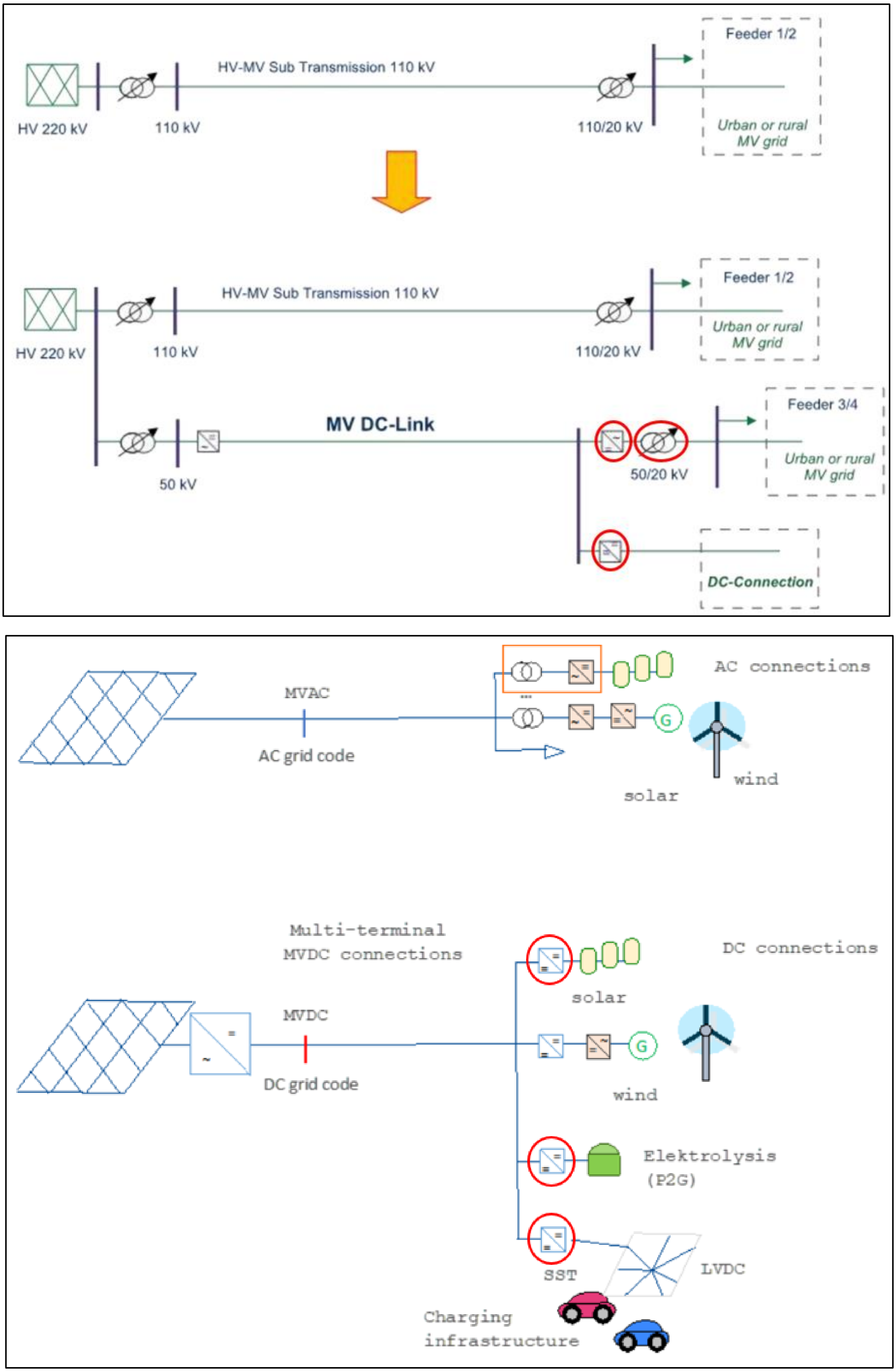

Figure 10. Some possible points of connection where DC grid codes/regulations are needed [11]

The **voltage range for LVDC** is defined in electrical safety legislation in all countries. This is based on the nominal voltage (75 V to 1,500 V) in accordance with EU Directive 2014/35/EU. The general product safety directive (2001/95/EC) covers **consumer goods** with a voltage below 50 V for alternating current or below 75 V for direct current. One of the main challenges here is that the standard voltages to be used for the distribution of DC (HV/MV/LV) power will not be the same as those used in AC but could be aligned with the AC voltage levels. HVDC levels are already established. MV/LV levels need to be standardised urgently. Regulations could also be developed to adopt these standard levels and mainly for interconnections at different HVDC/MVDC/LVDC levels.

Another challenge is to define the regulations for AC-DC interoperability. Rules on how to connect an LVDC grid to the AC grid are needed with bi-directional power flow. The application of **LVDC** installation **depends on the regulations related to its interconnection with the AC grid**. If the DC installation contains or may contain generation or storage in the future, which can be used to feed power into a higher-level AC network, the **AC/DC interfacing technologies/devices must** meet the same grid connection codes/regulations. Thus, the harmonisation of AC-DC networks is highly important and needs to be defined. Generally, this should be equivalent to the connection codes for inverter-based generation (RfG directive 2016/631 as defined by ENTSO-E and EN 50549 series). The current technical problems associated with this interoperability of AC-DC systems can be outlined as the lack of EU-level harmonisation, lack of energy supplier knowledge, lack of competence, lack of system integrators, lack of equipment interoperability - here are DC products readily available on the market, but their specifications are vendor-specific, no best practice examples for DC are available, less technical guidelines and tools are available, unclear regulatory rules, grid codes and installation practice.

Thus, the existing **grid connection codes and national regulations** often **discourage installing LVDC applications,** including energy generation and storage systems. One of the major regulatory gaps concerns recognising LVDC as a technical option for developing public distribution networks. Although the use of DC has not been prohibited, the return on LVDC investments allowed to the DSOs by the regulatory models is unclear.

4.4.2. Challenges in regulation at installations level, in a residential and office building

Here is the example of a French property developer who intended to install a LVDC microgrid in a residential and office building in Nantes area, west of France. The LVDC installation project was finally abandoned in 2022 and done in AC due to many barriers, notably regulatory, described below:

1. Insurance (difficult and costly to pass on to DO), [*DO stands for Dommage Ouvrage : damage to works 10 years insurance*]

2. A shortage of insured [*Electrical contractor*] companies qualified to carry out this [*LVDC installation*] type of work,

3. The derogations required by Consuel [*French National Committee for the Safety of Electricity Users*] and NFC 15-100 [*French regulation for electrical installation rules*], among others. After taking over the project, I was very surprised to discover this myself, without anyone having broached the subject in previous years spent on the project.

4. Related to the difficulties encountered by the Bureau de Contrôle [*Electrical Inspectors*] in reaching technical agreement on the proposed solutions.

Items 3 and 4 refer to the difficulty to justify deviations from the local installation rules. These local installation rules are mainly derived from IEC 60 364[12]. This refers to the standardization challenges listed before but also to the possibility of regulatory sandboxes. Please note that regulatory sandboxes are often associated to a limited period of time (4 or 5 years) that is a showstopper for real world show cases. Investors can hardly resell a building that will have significant electrical revamping to go back to AC after a few years only.

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[12] IEC 60364 series: “Low-voltage electrical installations”

Item 2 refer to the education challenges listed before as well and the consequence on the possibility for these company to deliver 10 years works insurance.

Item 1 refers to the overall challenge to ensure works and estates that have deviations to the local electrical installation rules.

It is also needed to highlight the complexity of pilot projects in the commercial building field. This is way more complex than industrial plants pilots where a single company owns the premises, the electrical design, the electrical maintenance and overall operations. In commercial building, the contributions and associated liabilities are fragmented over multiple contributors (engineering consultant, electrical contractor) and building ownership is transferred from the property developer company to the property owner company.

For these reasons a specific attention is required to regulatory barriers that can forbid LVDC pilot installations in commercial buildings. The Netherlands can be here a best practice example. Authorities provided a kind of legal endorsement to the deviations to the electrical rules in the ‘Circl’ building mentioned in chapter 2.3.3. and other pilot sites across the country.

5. PRIORITIES AND TARGETS

Proposed actions address the most significant hurdles to the deployment of LVDC:

5.1. Technology development

- Develop **models** of devices for system-level simulation, and for developing LVDC system **design tools**, optimising sustainability over the complete life-cycle.
- Develop **strategies and guidelines for using LVDC systems** in a variety of use cases, including: system architectures and earthing; protection schemes; system monitoring, control and optimization; connection to AC grid; installation and approval.
- Develop methodologies and assess the **cost-benefits of LVDC-microgrids**, for the application itself and on the overall energy system, from technical, economic, environmental and social aspects, and compare with AC solution.
- Study **effects of DC stray currents** on human body and building structures and prevention (earthing)
- Optimise **power semiconductors for DC specific applications**, especially DC protection devices (e.g. ON-resistance); improve reliability and assessment of end-of-life for predictive maintenance of power semiconductors.

By 2028, develop models, tools, strategies, and guidelines for designing and using LVDC systems.

5.2. Standardisation of LVDC components and systems

Standardisation effort shall address as a priority:

- LVDC nominal **voltages** and voltage bands,
- Power **connectors** for LVDC appliances,
- System **electrical rules** and protocols (to operate stable and safe LVDC systems),
- **Interoperability** rules for electrical equipment and **EMC** emissions/immunity levels,
- Certification and testing of LVDC devices.

By 2026, standards for LVDC systems general characteristics should be developed and approved *(e.g. by CEN-CENELEC), including: system voltages, conductors and earthing arrangements.*

By 2027, standards for LVDC systems minimum requirements should be developed and approved *(e.g. by CEN-CENELEC)* ***and contribute to international standardisation (IEC),*** *including: system electrical rules, connectors; devices electromagnetic compatibility, interoperability, certification, and testing.*

EU should encourage **research projects to disseminate their results in conferences and publications, and to standardization bodies**. EU should support the **collection of experiences and learnings** of electrical professionals (installers, maintenance) from field tests and pilots, as an input for standardization strategy and activities. One example is the HSbooster.eu (a Coordination and Support Action) of the EU.

5.3. Education, Training, Awareness

- Education of decision-makers and community officers
- Establish education and training paths for students and technical workforce (including recognition/certification schemes)
- Raise awareness by spreading information about successful pilot projects.
- Increase awareness about LVDC among public.

From 2024 onwards, raise awareness about the benefits and constraints (or implications) of LVDC systems *among decision makers and public.*

By 2026, establish education and training curricula for students and technical workforce *(incl. certification schemes)*

5.4. Regulatory framework suggestions

- Fair access to AC grid for **behind-the-meter DC microgrids** (or hybrid DC/AC microgrids) needs to be guaranteed, including bidirectional energy exchange between the AC distribution grid and the DC microgrid
- Regulations for **LVDC Distribution and AC/DC/Hybrid grids** are needed to operate in island- and grid-connected mode, and to ensure that energy at direct voltage can be delivered and invoiced.

Regulatory barriers (at national level), against the bidirectional connection of behind-the-meter LVDC grids to the AC network, should be identified and removed.

Regulatory barriers, against the operation of public LVDC grids in island mode or interconnected with the AC network, should be identified and removed.

The regulatory framework related to DC systems should be harmonised among the Member States

As exposed in previous chapters, a lack of standards and regulations can represent a barrier to deploying LVDC networks. EC issued on 29/08/2023 a guidance on sandboxes(2023) 277/2 and this can be used to test innovative products, services, and LVDC methodologies for a certain period. It can also help set a general framework that innovators can apply, involving a specific derogation (waiver or exception) from standard regulations, subject to conditions imposed by the regulator. Sometimes, the sandbox can include additional support, such as bespoke guidance and comfort (about compliance and enforcement) that the innovator can rely on for the trial period. This tool allows innovators to trial their ideas while preventing severe risks for innovators, other market participants, and final customers; the regulator’s approval is intended to avoid discrimination or the foreclosure of competition.

The existing EU directives and national regulations could be reviewed to identify and update regulations, if needed, for the smooth integration of DC technologies and LVDC networks in the existing AC networks.

Considering the existing differences between the Member States, a clear guideline should be issued concerning:

- the connection regulatory framework revision to address metering, operation and maintenance aspects,
- the responsibilities for the performance indicators threshold compliance,
- the responsibilities for the management and control of the micro-grid behind the meter and for the LVDC grids of the network operators.

Regulation bodies, both European and National, are invited to recognize organizations such as Open DC Alliance, https://odca.zvei.org [7], and Current/OS, https://currentos.foundation [6], as experts to approve DC installations.

6. GLOSSARY

AC:	Alternating current: Sinusoidal current waveform. It changes direction every 10 ms in 50 Hz systems.
AIC:	Active Infeed converter. This is a bi-directional conversion device that links an AC system to a DC system.
Converters:	Devices that change voltage from AC to DC, DC to AC, or DC to DC, or frequency from AC to AC
DC:	Direct current. Current flows in one direction under normal operating conditions. Current flow can reverse, if intended, e.g., for charging or discharging batteries.
DCC:	(Network Code on) Demand Connection
Droop control:	Current-voltage characteristic. By measuring voltage, which is a “mirror” of the load balance in a DC system, active components set their current output or input, respectively. This is a simple methodology to ensure stability of the system; it uses the voltage as information carrier and does not need a separate layer of communication.
DSO:	Distribution System Operator
EMI:	Electromagnetic Interference, i.e., how components influence other components or their environment and vice-versa.
HVDC:	High-voltage Direct Current; this covers nominal voltages larger than 1500 V
Islanding:	When an electrical system loses connection to the main supply grid. In other words, it operates as an autonomous “island”.
LVDC:	Low-voltage Direct Current; this covers nominal voltages between 75 V and 1500 V (according to EU low-voltage directive)
Stray currents:	Current that bypasses the regular earthing conductors. It can lead to corrosion on metal-to-electrolyte interfaces.
RfG:	Requirements for Generators (in Network Codes)
TRL:	Technical Readiness Level, on a rating of 1 (basic knowledge) to 10 (fully developed and used)
TSO:	Transmission System Operators

7. ANNEXES

7.1. Activity fiches

7.1.1. Activity 1 - Research & Innovation topic description, covering several technological, standardisation, regulatory and education aspects

Title: Demonstration of innovative LVDC behind-the-meter solutions in buildings or industrial plants

Description

- Demonstrations of innovative and sustainable LVDC (Low Voltage Direct Current) microgrids in buildings or industrial plants, interconnecting DC-based generation (PV), storage (stationary and vehicle batteries) and applications (LED lighting, IT equipment, adjustable speed motor drives for robots, heat pumps and other appliances ...), with improved energy and materials efficiency (replacing DC/AC and AC/DC converters by simpler DC/DC converters) and inherent optimization of self-consumption, storage and demand response (e.g. driven by controlled DC voltage level).
- Sustainability and supply chain resilience should be optimised from the design phase, encompassing the complete life cycle: manufacturing resources efficiency, energy efficiency in operation, durability, repairability, recyclability, as well as reducing dependence on critical raw materials.
- Demonstration projects to cover the various use cases: residential / office / commercial buildings and industrial plants, ending at TRL7-8 at system level.

Deliverables

- Assessment of the life-cycle costs/benefits of DC microgrids compared to traditional AC installations.
- Development of LVDC grids simulation, control and optimization tools; development of design and operation guidelines.
- Contribution to standardization (CEN-CENELEC, IEC).
- Development of awareness, education and training material.
- Identification of regulatory barriers at European, national and distribution system operator levels, and suggestions to resolve them.

7.1.2. Activity 2 - Technology for power semiconductors

Title: Define dedicated programs for further improvement of efficiency, reliability, and assessment of end-of-life for predictive maintenance of power semiconductors.

Description

- Power semiconductors are available and reliable already. However, with many more power semiconductors being used in DC systems, further reduction of power loss is important.
- Reliability will be further improved with methods for predictive maintenance of these components. E.g., the on-resistance of the power semiconductors can be monitored.
- Sustainability of semiconductors shall be optimised from the design phase, encompassing the complete life cycle: manufacturing resources efficiency, energy efficiency in operation, durability, repairability, recyclability
- The improvement of power semiconductors shall be coordinated with other applications, such as automotive, to avoid duplication of efforts.

Deliverables

- Improved power semiconductors (e.g. power loss in operation reduced by 30% vs. 2023) are available by European suppliers
- Methodology for predictive maintenance and end-of-life prediction of power semiconductors

7.1.3. Activity 3 - Technology – system aspects

Title: Guidelines and tools for DC systems and their impact on the wider energy system

Description

- DC installations, e.g., microgrids, are still relatively new. Hence, not many tools or guidelines are available.
- Planners and installers need to be able to design DC systems in their existing software working environment, which is presently based on existing AC installations. They need to assess the cost/benefit of DC systems compared to traditional AC systems.
- Public authorities, transmission and distribution system operators need to be aware of the wider impact of DC-microgrids (vs. AC installations) on the energy system (e.g. not only the copper and energy savings in the cabling and converters within the DC microgrid, but also the benefit of peak power shaving for the dimensioning of distribution and transmission grids, for example)

Deliverables

- Existing simulation models incorporate DC microgrids and / or new tools specific for DC microgrid system design and simulation, including notably the techno-economic aspects for enabling the cost/ benefit comparison with traditional AC systems.
- Guidelines and handbooks for the design and installation of sustainable (environment impact, circularity, social acceptance) DC microgrids, including regulatory aspects.
- Tools for control and optimization of DC microgrids
- Studies assessing the cost/benefit of DC-microgrids within the DC-microgrid itself and on the transmission and distribution grids in concrete use cases.
- Methodologies and tools to assess the impact (cost-benefit) of DC-microgrids on the energy system.

7.1.4. Activity 4 - Effects of DC currents on the human body and building structures

Title: Effects of DC currents on the human body and building structures

Description

- WP1 - DC currents can flow through the **human body** upon touching a conductor with a potential vs. ground (same as in AC). For protection against electric shock, known as residual current devices, it is important to know how fast protection devices shall interrupt the current flow.
- WP2 - **Stray current corrosion** takes place in locations where a leakage DC current (so-called stray current) enters an electrolytic medium (concrete / soil) from a metallic conductor. The effects of DC currents on the corrosion of building structures with relationship to the earthing system, should be observed on the long-term. Protective earthing (PE) system need to be designed to prevent this phenomenon which is specific to DC systems.

Deliverables

- WP1 - Thresholds for residual current protection for the human body
- WP2 – Report on the long-term effects of stray current on building structure; guidelines for handling DC stray currents with protective earthing systems

7.1.5. Activity 5 - Education, Training, Awareness

Title: Education, Training, Awareness on LVDC

Description

- WP1: Awareness-raising and education of private and public decision-makers

  In cooperation with universities or other educational entities in the different member states, create awareness and education opportunities and material about LVDC from the environmental, economic and social points of view. Target of the education are investors, managers, public officers who may have the opportunity to decide on energy projects, and particularly to evaluate proposals where LVDC is used. The material shall build on the assessment of the technical, economic, environmental and social costs/benefits of DC microgrids compared to traditional AC installations, produced in the frame of 7.1.3.

- WP2: Technical education (for students) and training (for professionals)

  Establish training and education opportunities, and produce educational material, for installers, technicians, operators and engineers (EQF levels 2 to 7) who may be required to plan, design, approve, install, operate and repair an LVDC system. This includes certification/recognition schemes. Training activities (aimed to workforce) and education activities (aimed to students) in this WP shall be carried out in cooperation with educational entities and with professional/trade associations in the different member states, possibly with the participation of equipment manufacturers.

- WP3: Engineering guidelines

  In cooperation with standardization bodies and with professional associations in the different member states, issue engineering guidelines planning, design, approval, installation of LVDC systems, including safety aspects. Additionally, develop or extend existing software packages so that the prescriptions are embedded in future designs.

- WP4: Increase general public awareness

  Produce information material for the general public on applications of LVDC, including description of successful pilot projects. In addition to documentation, deliverables may include digital audio-visual content, or other software.

Deliverables

- WP1 - Awareness material and courses for decision makers (evaluated by number of established courses, number of attendees) in all Member States and interested SET Plan Countries
- WP2 - Courses, educational material, and recognition schemes for the different target audiences (evaluated by number of established and recognized courses and number of attendees)
- WP3 - Engineering guidelines for design, installation and operation of the most relevant LVDC applications
- WP4 – Information material and digital content / dissemination events about LVDC for the general public

7.2. LVDC subgroup members of the SET Plan IWG ‘Direct Current technologies’

7.2.1. Representatives of Member States and Associated Countries

Country	First name	Last name	Organisation name	Organisation type
Belgium	Dirk	Van Hertem	KULeuven	Academia
Cyprus	Venizelos	Efthymiou	FOSS Research Centre of the University of Cyprus	Research institution
Denmark	Nicolaos A.	Cutululis	Technical University og Denmark	Academia
France	Xavier	MONTAGNE	French Ministry of Higher education and Research	National government or agency
France	Bruno	LUSCAN	Supergrid Institute	Private company
Germany	Ralf	Eickhoff	Forschungszentrum Juelich (FZJ) GmbH	National government or agency
Italy	Angelo	L'Abbate	RSE	Research institution
Italy	Eleonora	Riva Sanseverino	University of Palermo	Academia
Lithuania	Audrius	Jonaitis	Kaunas University of Technology	Research institution
Netherlands	Mart	van der Meijden	TenneT TSO B.V.	Private company
Portugal	Ana	Andrade	DGEG - Direção Geral de Energia e Geologia	National government or agency
Portugal	Bernardo	Silva	INESC-TEC	Research institution
Romania	Oana	Zachia	CNTEE Transelectrica SA (HVDC group)	National government or agency
Romania	Adelina	Marin	E-Distributie (DSO) (MV&LVDC subgroup)	Private company
Spain	Ignacio	Cruz	CIEMAT	Research institution
Spain	Jesus	Pulido	Ministry for the Ecological Transition	National government or agency
Turkey	Cagri	YILDIRIM	The Scientific and Technological Research Council of Türkiye	National government or agency
Turkey	Tulay	Avci	The Scientific and Technological Research Council of Türkiye	National government or agency

7.2.2. TWG Members

First name	Last name	Organisation name	Organisation type
Antonello	Antoniazzi	ABB	Industry
Luca	Ghezzi	ABB	Industry
Monica	Meda	ABB	Industry
Enrico	Ragaini	ABB	Industry
Claudio	Amadori	ABB	Industry
Marco	Riva	ABB	
Erik	Fosselmann	Danfoss GmbH	Industry
Ludwig	Rüdel	Danfoss GmbH	Industry
Panagiotis	Kolios	DC Systems	Industry
Harry	Stokman	DC Systems by Schneider Electric	Industry
Giel	Van den Broeck	Direct Energy Partners	Industry
Hartwig	Stammberger	Eaton	Industry
Kenan	Askan	Eaton	Industry
Martina	Josevski	Eaton	Industry
Sarah	NASR	EDF R&D	Industry
Eric	Lecomte	European Commission	European institution
Ralf	Eickhoff	Forschungszentrum Juelich GmbH	Research institution
Venizelos	Efthymiou	FOSS Research Centre of the University of Cyprus	Research institution
Bernd	Wunder	Fraunhofer IISB	Research institution
Isabella	Bianchini	Fraunhofer Institute for Manufacturing Engineering and Automation IPA	Research institution
Dr. Sandipan	Patra	International Energy Research Center	Research institution
Shafi	Khadem	International Energy Research Centre, Tyndall National Institute	Research institution

Johan	Driesen	KU Leuven	Academia
Martin	Ehlich	Lenze SE	Industry
Pasi	Peltoniemi	LUT University	Academia
Marco	Stieneker	Maschinenfabrik Reinhausen	Industry
Roberto	Faranda	Politecnico di Milano	Academia
Simone	Negri	Politecnico di Milano	Academia
Francesca	Oliva	Politecnico di Milano	Academia
Luigi	Piegari	Politecnico di Milano	Academia
Mihaela	Albu	Politehnica University of Bucharest	Academia
Ion	TRISTIU	Politehnica University of Bucharest	Research institution
Riccardo	Bucci	Prysmian S.p.A.	Industry
Chiara	Gandolfi	RSE Ricerca sul Sistema Energetico	Research institution
Antonello	Monti	RWTH Aachen University	Academia
Marco	Carminati	Schneider Electric	Industry
Michael	Laheurte	Schneider Electric	Industry
Yannick	Neyret	Schneider Electric	Industry
Alfredo	Samperio	Schneider Electric	Industry
GUILLOT	Mathieu	Schneider Electric	Industry
Eric	Brun	Schneider Electric	Industry
Dominique	SERVE	Schneider Electric	Industry
Dagmar	Jarásová	SFÉRA, a.s.	Research institution
Joachim	Seidl	Siemens Aktiengesellschaft	Industry
Ulrich	Boeke	Signify Netherlands BV	Industry
Rad	Stanev	Technical University of Sofia	Academia
Dirk	Müller	UL	Research institution
Federico	Silvestro	UniGe	Academia
Daniele	Gallo	University of Campania "Luigi Vanvitelli"	Academia
Tony	Castillo		Academia
Fabio	D'Agostino	University of Genova	Academia
SARA	GUTTILLA	University of Trieste	Academia
Giorgio	Sulligoi	University of Trieste	Academia
Andrea	Vicenzutti	University of Trieste	Academia
Tero	Kaipia	Zero Hertz Systems Oy	Industry

7.3. Other LVDC projects – list to be updated periodically

7.3.1. LOV (Lowering Ortigia's Voltage) project

https://www.lovenergydc.it/

7.3.2. Mission Innovation – Smart Grid project

https://mission-innovation.it/smart-grid/#

7.3.3. Shift2DC – European Union funded project

Website: https://shift2dc.eu. The project started in Dec. 2023 and is scheduled to run for 42 months.

Overview (taken from the website): With a substantial funding of over 11 million euros, **the SHIFT to Direct Current (SHIFT2DC) project has the goal of creating smarter, more efficient, and environmentally friendly energy infrastructures through direct current (DC) solutions.** The Horizon Europe Project counts with the expertise of thirty-three partners, including affiliated and associated partners, from twelve countries, under the coordination of the Portuguese Research & Innovation Institute **INESC-ID.**

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