Technology Report

LVDC: electricity for the 21st century

Executive summary

Global situation overview

In the last decades, with the advent of electronics, devices we use have changed to operate with direct current (DC): multimedia and mobile equipment, LED lighting, IT equipment, electric vehicles, etc. More recently, washing machines, refrigerators, fans, or heating/cooling systems have also adopted DC motors, allowing speed control and improved energy efficiency. Power generation has also moved to DC with the proliferation of renewable energy power systems using solar and wind energy. With the latest improvements in battery technology, DC has also become the most used form of stored energy. This exceptional convergence of technological evolutions is happening together with a drastic reduction of the cost of DC devices. This is why the time has now come to review the predominance of alternative current (AC) with a view to favouring DC. In developed economies, the main drivers for the use of DC are the improvement of energy efficiency and the conversion to renewable energy. In developing economies, DC brings the opportunity for a drastic living improvement to 1,2 billion people on the planet who do not have access to electricity.

LVDC stakeholders

A very large number of stakeholders are involved: industrial-scale users of the low voltage direct current (LVDC) technology; equipment and product manufacturers; academia, education and research institutes; standardization organizations; industry consortia; development banks and multi-lateral financial and aid institutions; governmental bodies and regulatory authorities. The most active industries in this regard have been telecom, data centres and transportation. The electricity distribution companies and the electrical contractors are still rather passive, at least from the standardization perspective. LVDC standardization work requires specific expertise, and the IEC community will have to reach out to related industrial associations and consortia.

LVDC market assessment

The approach adopted to assess the market is based on the collection of use cases, which have been defined taking into consideration the environment (domestic, tertiary, industry and geographical area), the amount of power required by the user(s) and the distances over which the power needs to be transported. All of these parameters will influence the characteristics of the electricity, which in turn will influence the size of the market and its evolution. The main classes of use cases established are: energy access; renewables and energy storage; data centres; commercial, industry and private lodging buildings; electric mobility; Power over Ethernet (PoE) and USB Type-C™; LED lighting and signalling including public areas; and the “last mile” of the public power distribution network.

LVDC for electricity access

Electricity access is not a yes/no concept, but instead is mainly based on the power level and the number of hours of availability per day. It applies not only to rural but also to peri-urban and urban areas. With respect to existing product Standards, there is a need for publications about the implementation strategy, the grid topology and the key performance indicators. This will support users, installers and financing organizations in the implementation of the projects.

LVDC voltages standardization

Standardization of voltages is a key and urgent issue. Before defining voltages, it is necessary to establish the criteria to consider for voltage selection. The main criterion is the energy to be delivered. Once the voltage is selected for a given energy, the current and cable size will define the power efficiency at a given line length. The size of the cables will also impact the cost. A threshold of 120 V is globally agreed to be the limit over which DC becomes lethal.

LVDC safety

The LVDC safety principles are already known, and related Standards can be applied for product requirements. Standardization work should be considered concerning overvoltage protection, power quality, protective devices (e.g. residual current devices (RCDs) for electric shock or arc fault detection devices (AFDDs) for arcing), device coordination and selection, wiring rules and islanded installations. Throughout the process of developing this Technology Report, there was total unanimity among all experts that regardless of the use case, LVDC must not be less safe than AC is today.

LVDC in today's standardization

DC involves some differences vis-à-vis AC that will require addressing three main aspects differently, namely power voltages, plugs and sockets and the effects on the human body. Other aspects also need to be reconsidered, including overvoltage and overcurrent protection, earthing principles, fault detection and corrosion. Most of the standardization work needed consists in adding provisions and requirements for DC into the existing AC Standards. A very large number of publications, issued by over 30 IEC technical committees (TCs), are concerned and will need updating. This maintenance work will require close coordination in order to introduce coherent and synchronized Standards, while addressing the need for a migration path that will allow reusing parts of the existing AC fixed installations.

Table of contents

Foreword

We have been living in a world of direct current (DC), we just didn't realize it!

Over the last two decades, three mega-trends have created a groundswell of demand for low voltage direct current (LVDC). The first of these, solar photovoltaics (PV)-based power generation, has become far more reasonably priced and is growing exponentially. The second, LED lighting, has taken the world by storm, making conventional incandescent and fluorescent lamps a thing of the past. And the third, and perhaps most important, trend is the renewed and urgent focus on energy efficiency and sustainability, taking power generation increasingly away from fossil fuels.

Today, some cities are beginning to use DC in public networks. Utilities are beginning to connect consumers via LVDC. These trends, combined, challenge the traditional model of electricity distribution and lead us to ask why we still carry on distributing electricity via AC when generation and consumption, both increasingly involve DC. This very question lies at the root of the decision by the IEC (International Electrotechnical Commission) to set up the Systems Evaluation Group 4 (SEG 4) – LVDC. Seeing the potential involved, the IEC community is now commencing standardization of LVDC through the newly formed Systems Committee LVDC and LVDC for electricity access (SyC LVDC). The SyC LVDC will address standardization through a systems approach developed within the IEC, which involves a holistic and proven methodology containing various stages of analysis. This will help to build a comprehensive understanding of systems based on LVDC for various use cases, including electricity access, and to individuate gaps where International Standards are needed.

Around 165 experts from across the world have spent countless hours on research and development, meetings, dialogue and analysis to bring this Technology Report capturing the past, present and future of LVDC. The standardization of various aspects of LVDC is likely to have a profound impact not only on developing economies, by providing the framework for enabling electricity access even in the remotest locations, but also in developed economies where LVDC is already seen as a solution toward greener and more sustainable energy.

More information can be found by contacting lvdc@iec.ch or by visiting the IEC LVDC web zone at www.iec.ch/lvdc. The web zone provides news updates on the Systems Committee for LVDC and its activities, including related events and topics, through social media and IEC *e-tech* articles. Other materials include mini videos, links to other relevant publications and brochures:

- Electricity access - More than a promise: LVDC go.iec.ch/elecaccess
- LVDC: the better way go.iec.ch/betterway

Section 1

Introduction

1.1 Introduction to DC transmission

It was more than 100 years ago that T.A. Edison built a system of power generation, distribution and consumption and started the electricity business in DC. DC distribution was also used in Japan from the moment the electric power industry began to operate. There were some difficulties in step-up/down voltage when the DC system was introduced by Edison. Since the wiring distance from power plants to customers was limited at the time, it gradually shifted to an AC system and mostly replaced the DC-based system in modern times. However, a great deal of equipment uses DC today, not only in industries, but also in some fields of consumer and general household. Cases involving application of DC today and typical voltage ranges involved are shown in Figure 1-1.

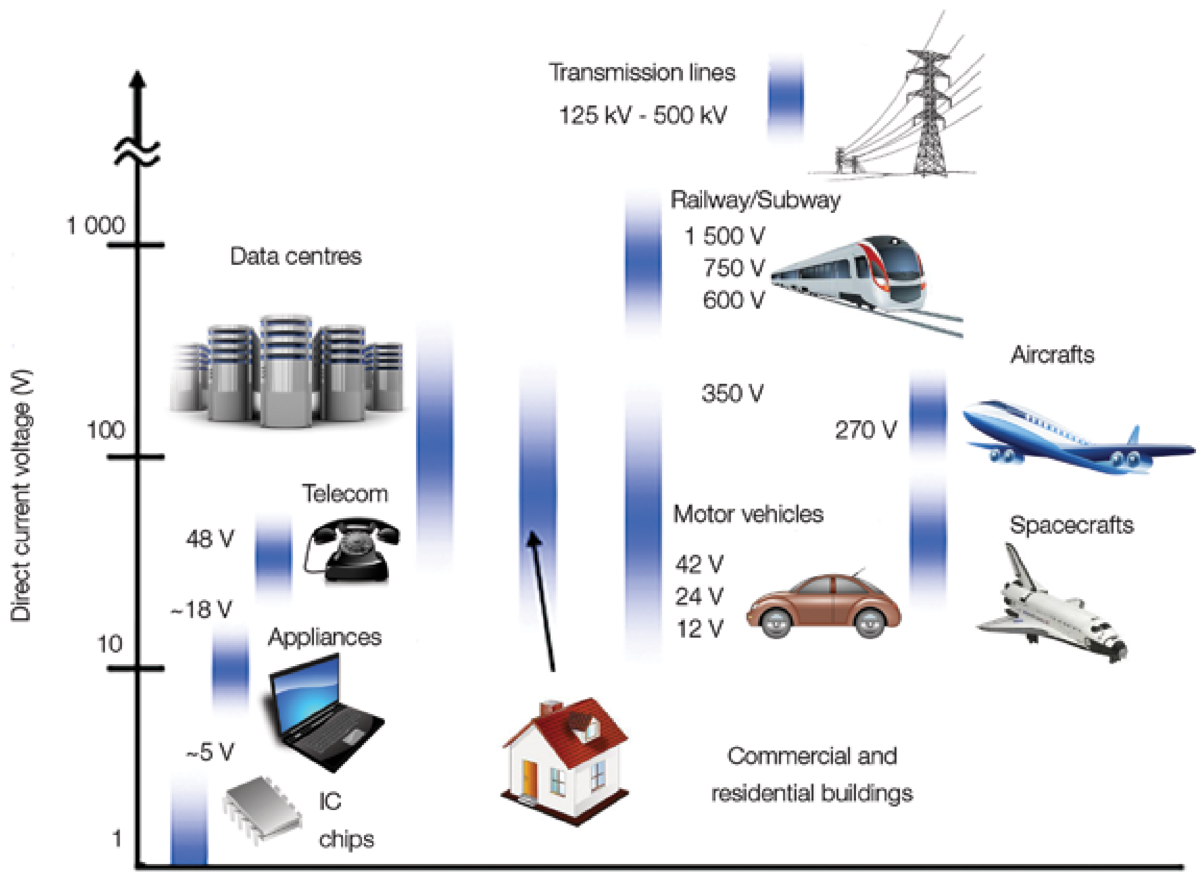
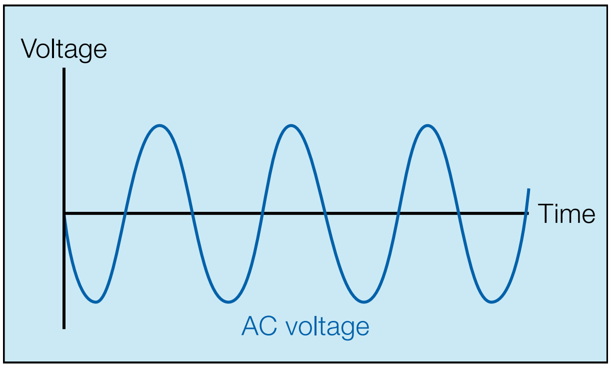
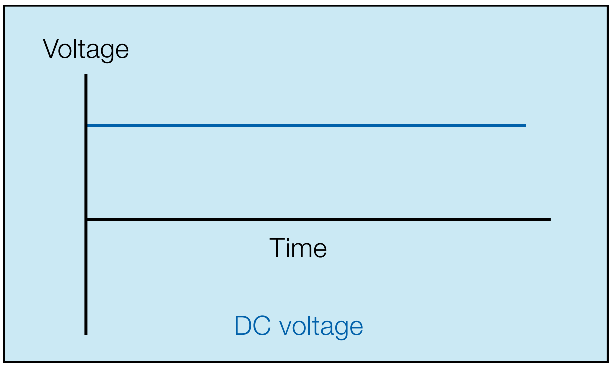


Figure 1-1 | Voltage range for some DC applications of today

1.1.1 About DC and AC

Reminder for non-technical readers: in DC the voltage does not change over time, in AC the voltage changes as a sinusoidal function of time.





1.1.2 Moving from an AC to a DC world

In recent decades, with the development of electronics, most of the devices we use have changed in order to operate with DC. Such devices are delivered with adapters which convert the AC available through the wall plug to DC. Multimedia, mobile and information technology devices were the first to effect this change. Over the last few years, LED lights have replaced a large number of traditional bulbs, and their use continues to expand. The latest evolution concerns the electric motors integrated in our home appliances and many other devices: they have also moved to DC with a power supply which adds speed control and improves energy efficiency.

Today's private houses and larger (commercial and office) buildings are mostly equipped with DC loads. In developed countries, the main driver for moving to DC is energy efficiency.

On the power generating side, the move from AC to DC has followed the generalization of renewable energy power systems. At this point there is no further need to develop arguments in favour of the extremely fast development of solar and wind energy.

A more recent technology evolution is the development of energy storage systems. The improvement of smaller capacity batteries was a key factor for the development of mobile devices. This technology is now applied to larger storage devices that are used for electric vehicles, and more recently as a power source in houses.

Currently there is an ever-increasing proportion of power generation systems providing DC. One major difference is that these systems have smaller capacities, compared to traditional power plants, and are distributed in a large number of locations.

1.1.3 Moving from top-down power distribution to a networked structure

The traditional AC power distribution architecture involves generating power in large capacity power plants. Long distance power distribution is effected via high voltage overhead lines, which feed power substations for conversion to medium voltage. Medium voltage overhead lines then dispatch the power in smaller regions, and final low voltage conversion is made to feed the "last mile" of the public power distribution network. This traditional top-down structure is now being challenged by the emergence of distributed power sources.

DC can change the future power distribution structure. Power generation is intended to become more and more distributed and consumed locally.

Houses and buildings, which previously were only power loads, will also become power generators. They will run autonomously with DC power generation, storage and consumption. The link to the public distribution network will be used to trade power in and out, depending on periods of high needs and the periods of generation overcapacity. Energy trading could be made at the neighbourhood level, the town level or even at a larger level.

The future structure of the power distribution system will be a network-style structure involving a large number of distributed power sources and loads which trade power. Most of these entities will be able to generate power for their own needs and will trade power to address periods of over- or under-capacity. This could end up in some kind of internet of energy.

1.1.4 DC power distribution installations

Another key technology evolution which supports the development of DC power is the possibility to change the DC voltage by using efficient DC-to-DC voltage converters. Before DC-to-DC power converters, there was no easy way to change DC voltage.

In future DC installations, these devices could be used in fixed installations to control the voltage delivered, and in home devices to adapt the voltage to the internal needs of the device. These electronic power converters could embed solid-state switching devices for functional safety purposes, and broadband communication for power management and home automation purposes.

The development of DC power distribution installations is the opportunity to move into intelligent power distribution systems.

1.1.5 DC, an opportunity for electricity access in developing countries

More than 1,2 billion people in the world do not have access to electricity. The previous electrification strategy using the top-down power distribution model did not allow delivery of electricity to the numerous remote locations that exist in developing economies. The reduction in cost of photovoltaic (PV) panels, the development of LED lighting and the recent availability of low-cost high-performance batteries, involves a conjunction of technical evolutions which allow for rapid development of local power supply installations not connected to the main grid. This type of islanded installations is also developing quickly in peri-urban areas, backed up by heavy governmental programmes supporting such installations.

The low initial installation cost and the long term maintainability using locally sourced components are the key success factors for such electricity access solutions.

1.2 LVDC specific requirements

1.2.1 Voltages

The standard voltages to be used for the distribution of DC power are not the same as those used in AC. The standardization of DC voltages is a key and urgent work needing to be addressed. The ranges of voltage variation also need to be reconsidered, mainly for installations which include batteries. The output voltage of the batteries changes depending on their load level, state of charge and other parameters, so the DC installation should allow for extended voltage ranges.

1.2.2 Plugs and sockets

Traditional AC plugs and sockets cannot be used for DC installations. New plugs and sockets need to be standardized, which will address the issue of dangerous arcing when disconnecting a load while it is active. With AC, the current direction is inverted at twice the frequency of the power supply and goes periodically through a zero value, which cuts any possible arc.

1.2.3 Effect on the human body

The effect of DC current on the human body is different than that of AC. Investigation is required to identify protective measures against hazards other than electric shock, e.g. burns, chemical effects.

1.2.4 Other differences

DC also requires a slightly different approach regarding other safety areas, such as overvoltage protection, overcurrent protection, earthing principles, fault detection, corrosion, arcing, etc. At the standardization level, most of the needs can be addressed by adding provisions about DC into existing Standards providing provisions for AC.

1.3 Differences between DC and AC

1.3.1 Advantages of DC over AC

Distributed energy producers often produce DC or use it in their conversions. Most loads make use of direct voltage for the internal supply of the individual function components, meaning that it is already present in the devices. A DC grid would do away with the need for these conversion steps. This would result in lower material costs, and conversion losses would also be reduced. The DC-to-DC conversions would still be required. Storage and uninterruptible power supplies (UPSs) are provided by batteries using DC. A clear advantage of the DC grid is its genuinely uninterrupted operation. The 5 ms to 8 ms switching time needed for detecting deviations in phase length, phase angle and the amplitude of bypass and transfer switches is no longer necessary. Thanks to DC, it is possible to connect different DC sources to a DC grid without a synchronization procedure, so these sources and loads are plug and play. Grid quality can be improved by DC networks. The problem of AC harmonic oscillations is eliminated. Apart from the lack of reactive power losses, DC has the further advantage of yielding an energetic advantage regardless of the field of application. This is because it provides more efficient use of the existing wire cross sections. The current density is evenly distributed across the entire cross section. Current displacement (skin effect) occurs only when an alternating voltage is applied, leading to a higher near-surface current density. In some use cases where higher cross section busbars are used, there may be some advantages. This needs to be explored further.

1.3.2 Advantages of AC over DC

High voltage is preferable for the transmission and distribution of electrical energy over long distances, as it allows transport losses to be reduced in contrast to what occurs through the use of a lower voltage. Up to now, AC has been converted using transformers. Historically, this was the main advantage of AC systems. Developments in the field of semiconductor technology have made it possible to generate higher frequency AC voltages easily and highly efficiently. This in turn has reduced the material cost of internal transformers in DC-to-DC converters, because they can now be made more compact. User and component safety is ensured by proven protection concepts and protective devices. Knowledge and experience are obvious advantages of AC systems. After being in use for more than a century, the AC system has provided us with advanced knowledge of system design, construction and operation.

Section 2
Stakeholders assessment and engagement

2.1 Introduction

Engagement of stakeholders in the field of LVDC in the IEC standardization process is a key enabler of coordinated development of global LVDC Standards. Hence, it was crucial first to reach the stakeholders as widely as possible, second to compile information on their LVDC-related activities and insights and, finally, to assess the relevance of the identified stakeholder groups to the standardization process.

A public survey was carried out from September 2015 till November 2016 to collect the required stakeholder and activity information. The target audience was all LVDC experts regardless of the focus area of their work. Contacting the right people, especially those who are not currently involved in standardization work by the IEC community, proved to be one of the greatest challenges.

In order to reach a wide audience, the survey was realized in the form of a web-based questionnaire that was developed into its current published form in June-August 2015 in collaboration with the IEC working groups and the IEC secretariat. The questionnaire contained 149 questions, partly quantitative and partly qualitative, and was organized into five parts:

Part 1: Respondent general background information

Part 2: LVDC activities

Part 3: Technical information for standardization development

Part 4: Market prospects and business potential

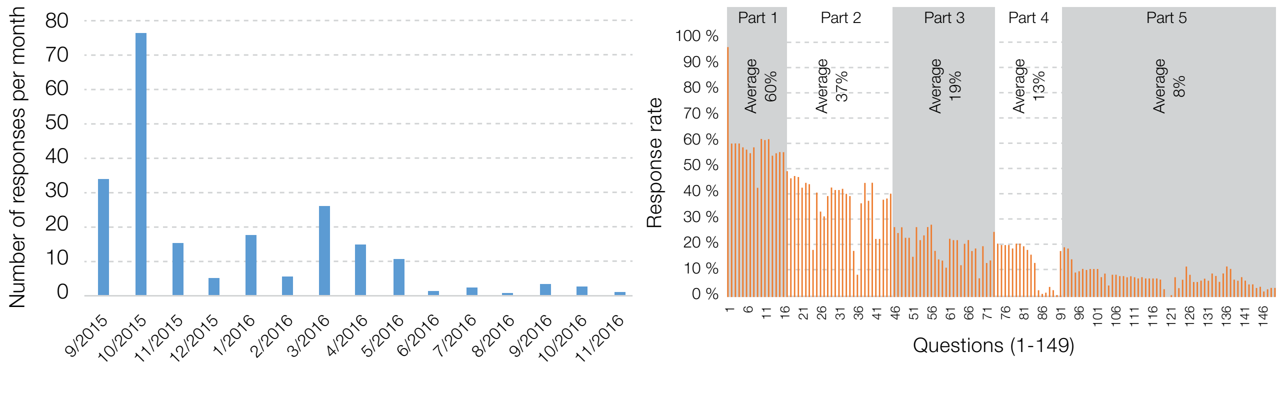
Part 5: LVDC for electricity access

Following a spike soon after publication of the questionnaire, the total number of responses has increased at a pace inversely proportional to the time since publication. By mid-November 2016 the total number of responses was 214. The number of responses varies greatly between the different parts, which is important to acknowledge. The development in the number of responses since the start of the survey and the distribution of responses between the five parts in November 2016 are illustrated in Figure 2-1.

Parts 1 and 2 of the questionnaire were aimed at producing information on the stakeholders and their activities. Analysis of the responses reveals the types of organizations and fields of industry involved, but also the dependencies between the use cases, types of activities and the status of the work. Knowing the background of the respondents is crucial for correct deciphering of the results.

Figure 2-2 presents the distribution of the respondents' nationalities and the types of represented organizations. Almost 40% of the respondents did not report their country or organization type, which complicates the estimation of the bias resulting from the regional practices, attitudes and from the local focuses of the LVDC-related activities. However, in the analysis it could be assumed that the organization and nationality of these respondents follow the known distribution.

Around 47% of the respondents who have reported their country of origin come either from India or the Netherlands. Furthermore, the respondents coming from those countries mostly represent the private sector, where as in many other countries the majority of the respondents represent academia.



Accumulation of the number of responses

Number of responses per question

Figure 2-1 | Received responses to questionnaire

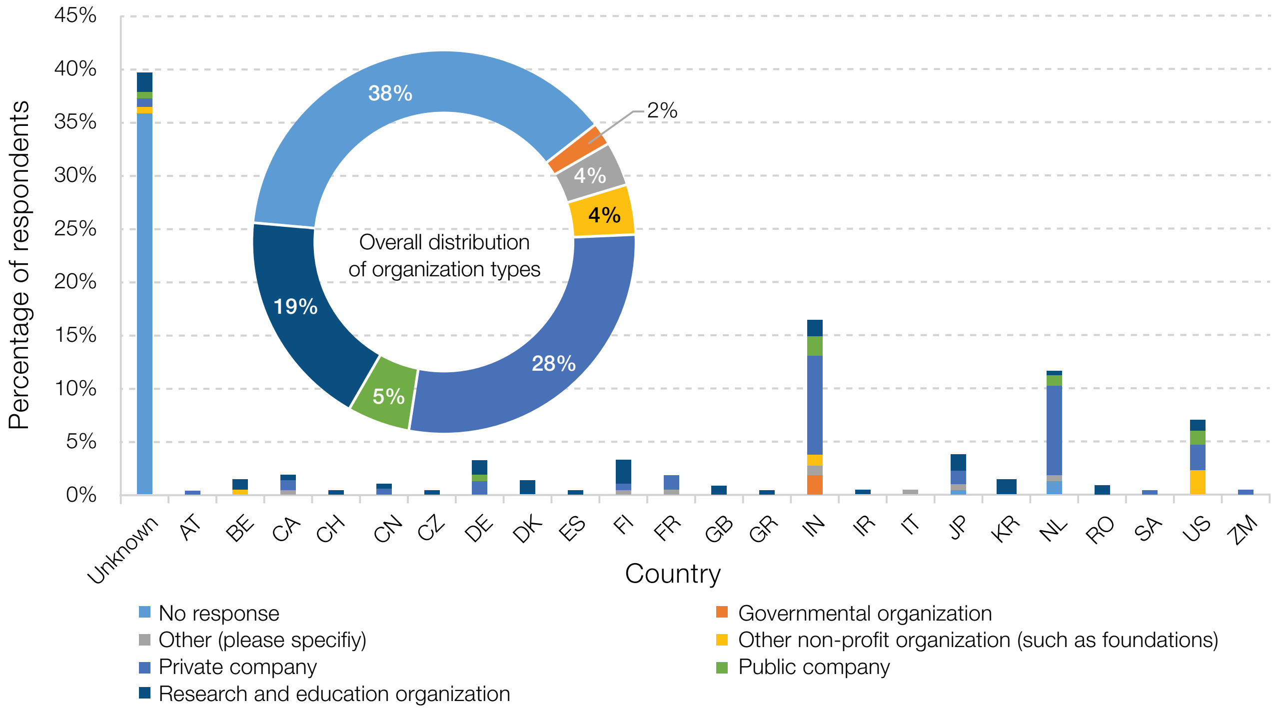


Figure 2-2 | Nationalities and organization types represented by the respondents

Among the respondents, the share of industry (private and public companies) representatives is 80% higher than the share of representatives from research and education organizations, suggesting that industry has taken the leading role over academia in LVDC activities. Intermediate result in

Spring 2016 gave an almost opposite result, which proves the importance of long-term data collection and persistent marketing of the survey through various channels.

Still, the share of research organizations is high compared to governmental organizations and other advocacies.

Equipment manufacturers and academia are the most active players at the moment. Among industrial-scale users, the most active have been the telecom and data centre industry and the transportation industry. Activities are also taking place in the real estate sector. Sixty percent of the respondents represent large organizations. The electricity distribution companies and the electrical contractors are still rather passive, at least in standardization development. However, it should be mentioned that several distribution utilities around the world are also among the forerunners.

The analysis of the survey results, together with discussions in the SEG 4 and working group meetings, led to the following non-inclusive list of identified main stakeholder groups and their division under four categories:

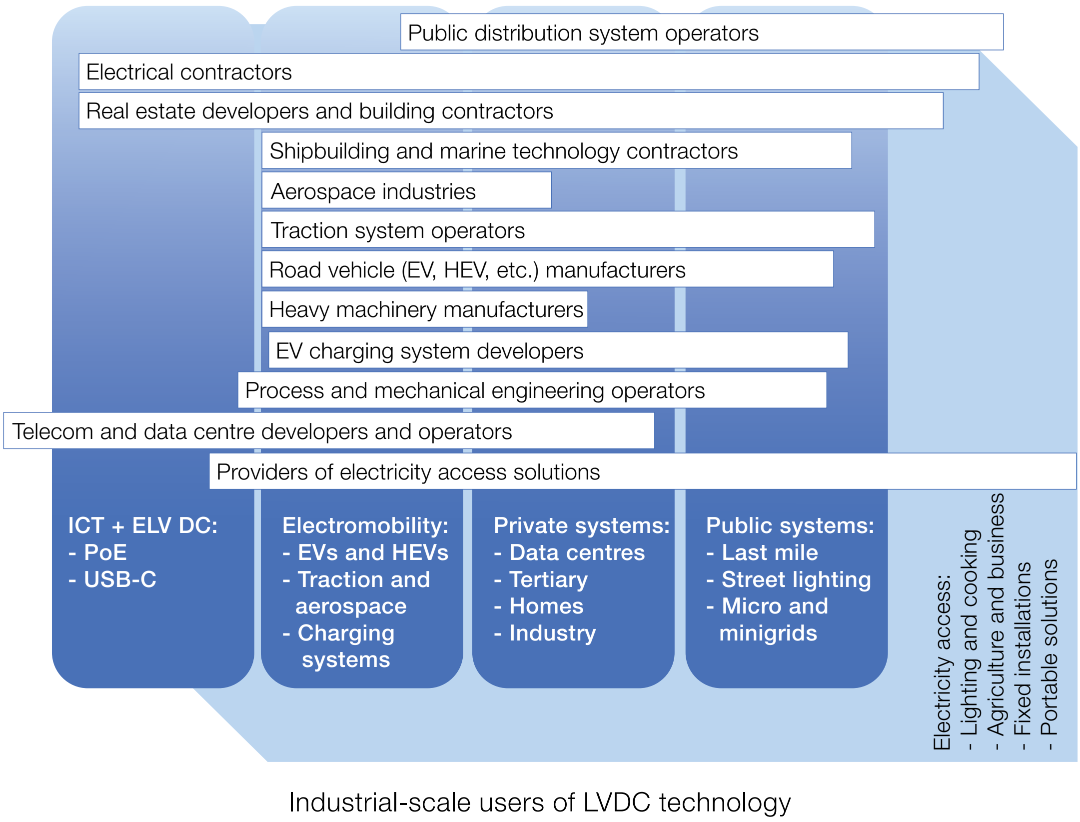
1) Industrial-scale users of the LVDC technology
   - Distribution network operators and electrical utilities (also partly represent consumers)
   - Electrical contractors (also partly represent consumers)
   - Builders, real estate (also partly represent consumers)
   - Transportation industry and related service providers (marine, aerospace, road vehicles, charging systems, etc.)
   - Telecom and data centre operators, builders and related service providers
2) Manufacturers and vendors of equipment and products
   - Consumer appliances
   - Lighting products
   - Power converters
   - Power cables and power line components
   - Switching and protection devices, installation accessories
   - Photovoltaic power plant equipment
   - Battery and other electrical energy storage systems
3) Standards organizations
   - The IEC community, including liaison organizations (more details available on the IEC website)
     - Relevant technical committees
     - National committees (both full members and associate members)
     - Partner organizations, such as AFSEC, CANENA, CENELEC, CIGRE, ETSI, IEEE, ISO, ITU-T, UN, WTO, etc.
     - National electrotechnical committees of the affiliate country programme participants
   - Other standards organizations and industry alliances developing LVDC-related recommendations, such as IET, EMerge Alliance, etc.
4) Other supporting stakeholders
   - Governmental bodies and regulatory authorities
   - Universities and technical colleges (academia and education)
   - Research institutes
   - Testing and certification institutes and laboratories
   - Industry and consumer associations including trade and policy interest groups (similar to IEA)
   - Development banks and multilateral financial and aid institutions, such as World Bank, African Development Bank, USAID, etc.

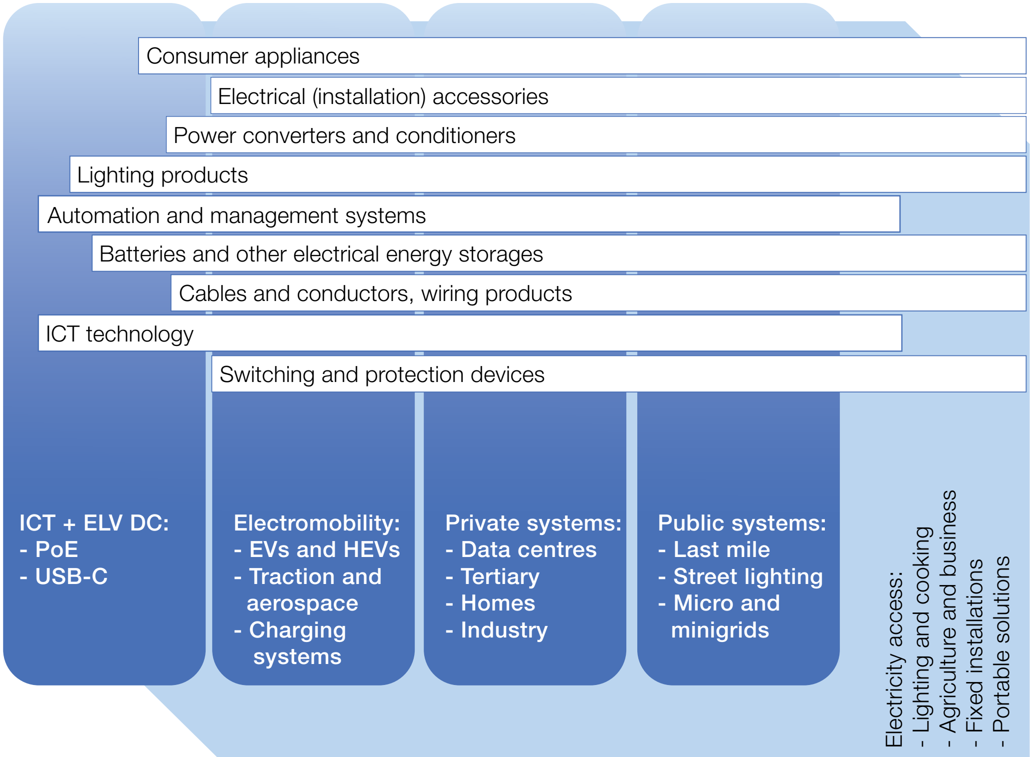
The stakeholder groups in the last two bullets of category 4) are not expected to participate in the technical standardization work directly, but the decisions related to energy policies and funding of the energy-related investments will strongly affect the development of the markets and thus the focuses of the standardization.

As for the stakeholders, the following list presents a summary of the identified use case groups organized into five categories. The mentioned use cases are merely examples, as it would be nearly impossible to provide a comprehensive list at this point.

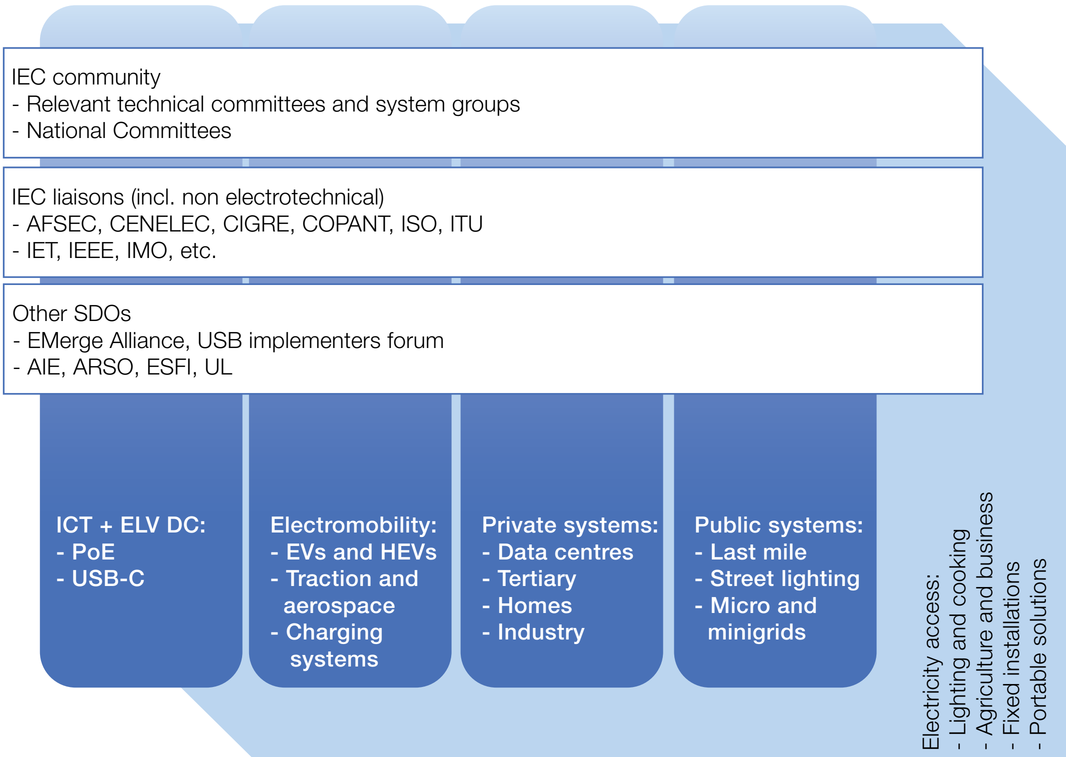
1) ICT and automation-related use cases for extra low voltage (ELV) DC systems, such as:
   - USB Type-C™ and Power over Ethernet (PoE)
   - Actuator and sensor networks of versatile automation systems, mainly in buildings
2) Electromobility systems-related use cases:
   - Road vehicles, traction systems, marine vessels and aircrafts
   - Charging systems, ground power units and shore power connection
3) Private electrical systems-related use cases:
   - Distribution systems in data centres and industry
   - Distribution systems for buildings and building-scale microgrids
4) Public electrical systems-related use cases:
   - Last-mile utility power distribution, settlement or community-scale microgrids
   - Street and other public areas lighting
5) Electricity access-related use cases:
   - Solutions for livelihood, e.g. agriculture and small workshops
   - Electric lighting, cooking and ventilation systems for homes and production buildings

Figure 2-3 gives a rough estimation of the four stakeholder groups relevant for the standardization work pertaining to the five use case categories.





Manufacturers and vendors



Standards organizations

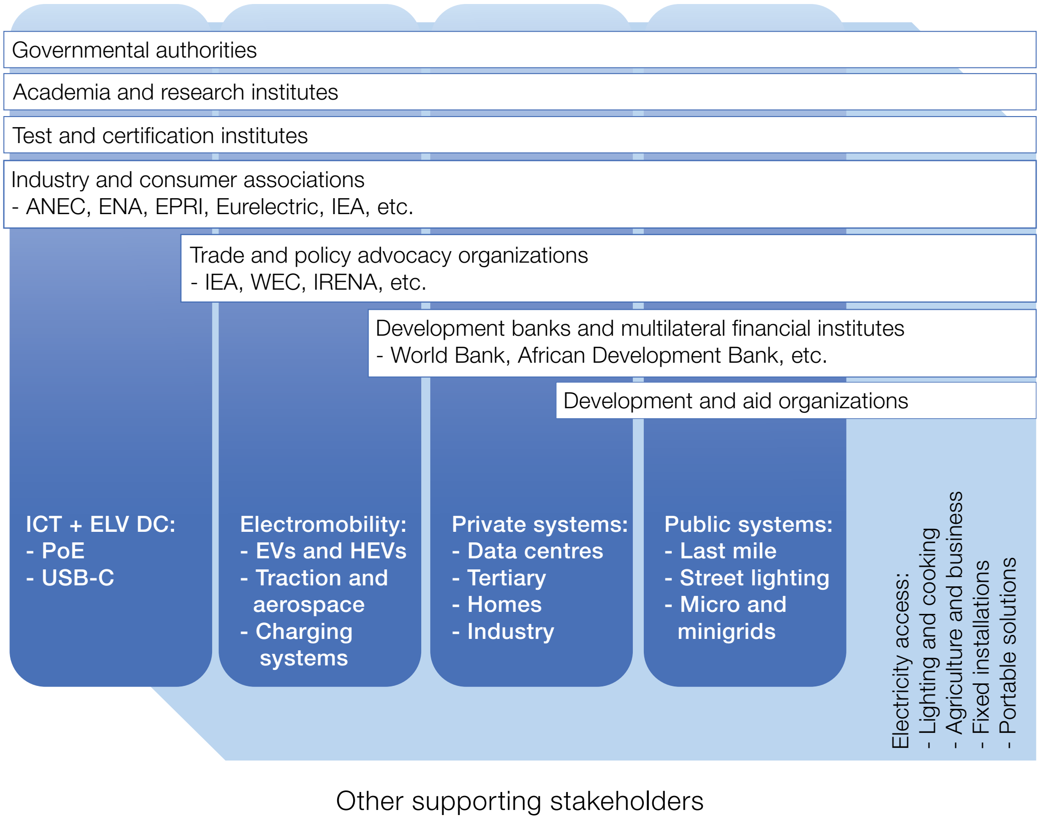


Figure 2-3 | Relationships between stakeholders and use case categories

2.2 Stakeholder assessment and LVDC activities

Most of the respondents have a background in versatile branches of energy technologies and electrical engineering or in the field of information and communication technology (ICT) and telecommunications. However, a wide range of applications is covered from water supply to healthcare. The distribution of the fields of industries represented by the respondents is illustrated in Figure 2-4. The figure clearly illustrates the breadth of business branches touched by the LVDC technology. Organizations belonging to the defined four stakeholder groups are well-represented among the respondents.

Some 39% of respondents did not mention their industry field, but most of those who did named one or two main fields, which indicates the narrowness of the insights of a single respondent. Considering this fact, together with the wide range of the LVDC use cases and applications, it can be concluded that the definition of the transversal generic Standards for LVDC is likely to require involvement of a substantially wide group of experts.

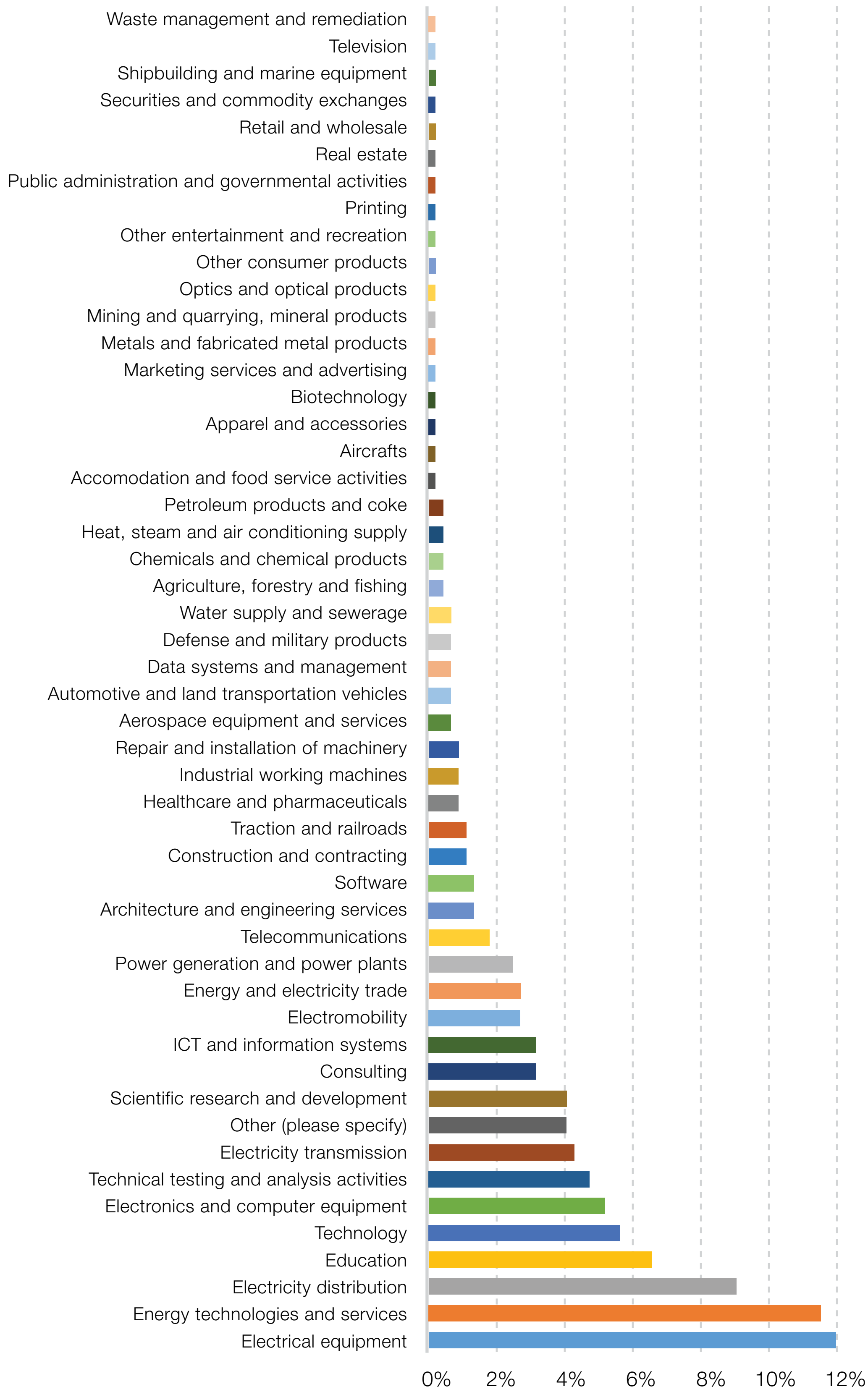
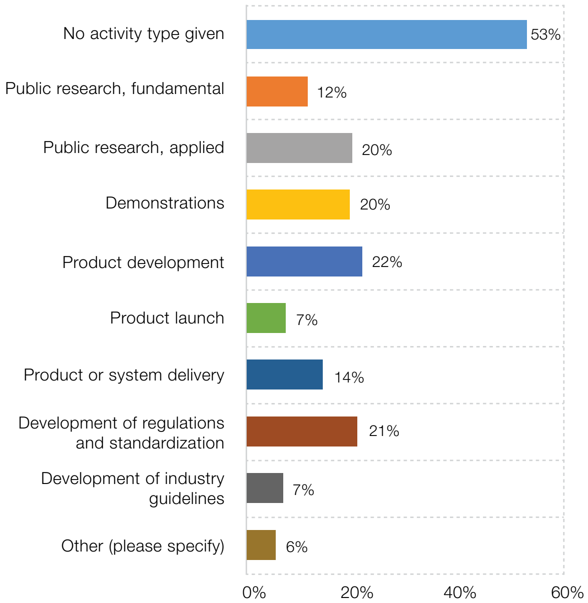
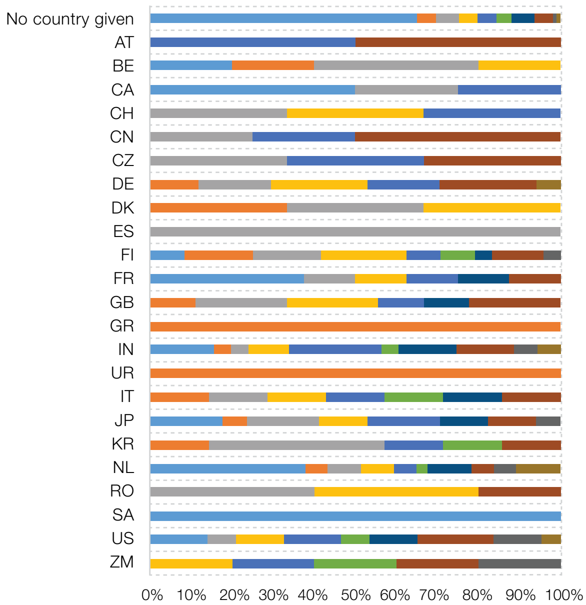


Figure 2-4 | Represented main fields of industry

Clear regional differences exist in the activities, reflecting both local energy sector development needs and hotspots, but also the focuses of local industry. Most of the respondents have both theoretical competence and practical experiences. The reported activity types per country are presented in Figure 2-5, and the shares of activities focusing on public or private electrical systems, transportation-related use cases or electricity access are presented in Figure 2-6. Finally, Figure 2-7 presents the focuses of the activities with respect to the organization type.

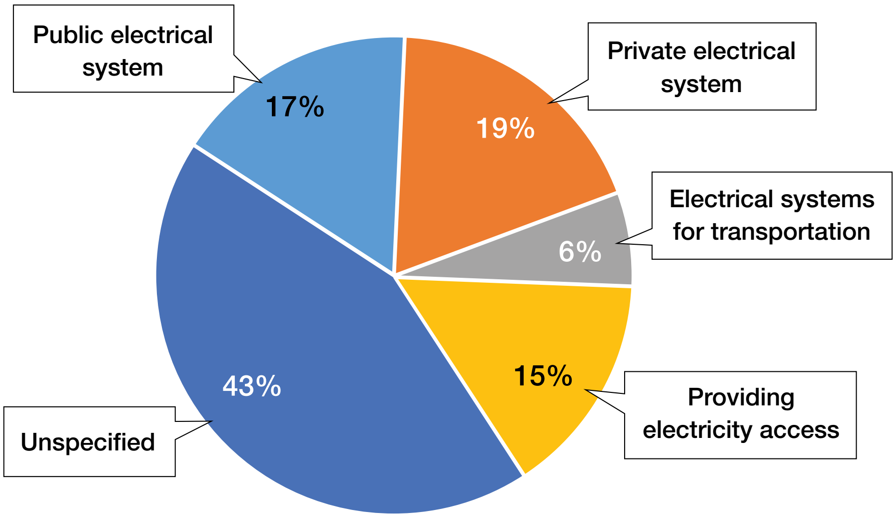


Percentage of respondents per activity types

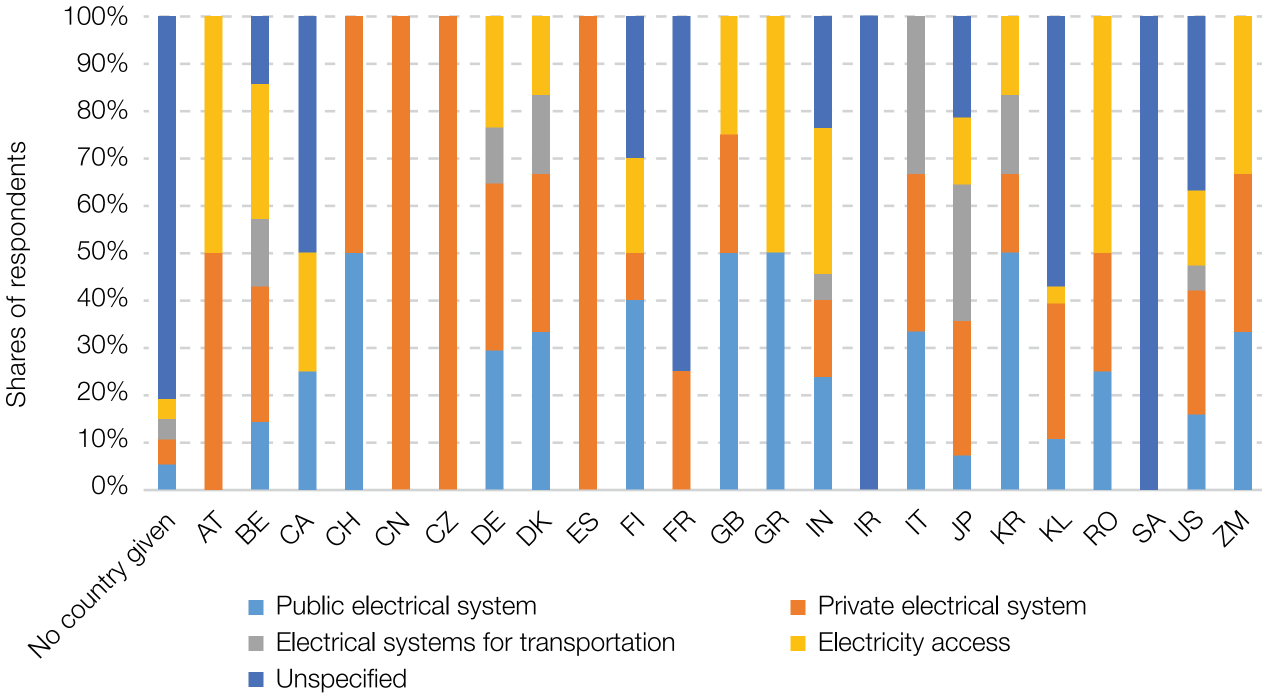


Shares of activity types per country

Figure 2-5 | Reported LVDC activity types per country



Overall focuses of activites



Country-specific shares of focused use case categories

Figure 2-6 | Focuses of activities overall and by country

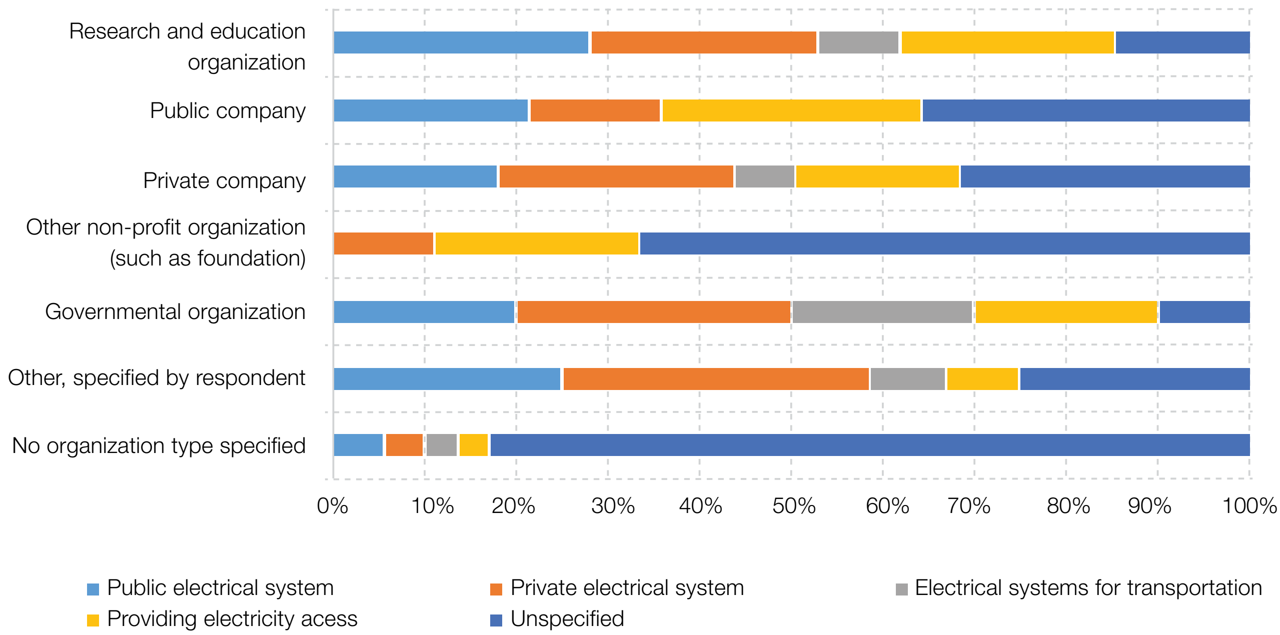


Figure 2-7 | Focuses of activities by organization type

The knowledge of the presented status of national and regional LVDC standardization activities, and the involvement of the respondents and their affiliations in such work, is pivotal. The existing national Standards and the experiences gained from national work provide foundations for global harmonization. A summary of the regional standardization activities according to the survey is illustrated in the map presented in Figure 2-8.

Naturally, the focus and scope of the national standardization activities follow the focus of the other activities and the achieved technology readiness level and maturity of the markets. According to the answers provided, either separate industrial consortia or working groups under the national committee or any other regional standards developing organization (SDO) have been established to take care of the urgent LVDC standardization issues. Furthermore, the development of international LVDC standardization is often followed, for instance, by the national mirror committees of IEC TC 8, IEC TC 64 and the IEC systems committees. The mirror committees have also undertaken national development activities.

2.3 Stakeholders especially related to electricity access

Engagement of the stakeholders in both developing and developed economies is essential to tackle the standardization issues related to electricity access. The role of the governmental bodies and standards organizations of the developing economies is essential. Authorities, bureaus or ministries have been formed in many countries to promote and coordinate activities related to improving electricity access. Also development banks and other organizations financing electricity access projects may provide channels for contacting relevant stakeholders. The key stakeholder groups include:

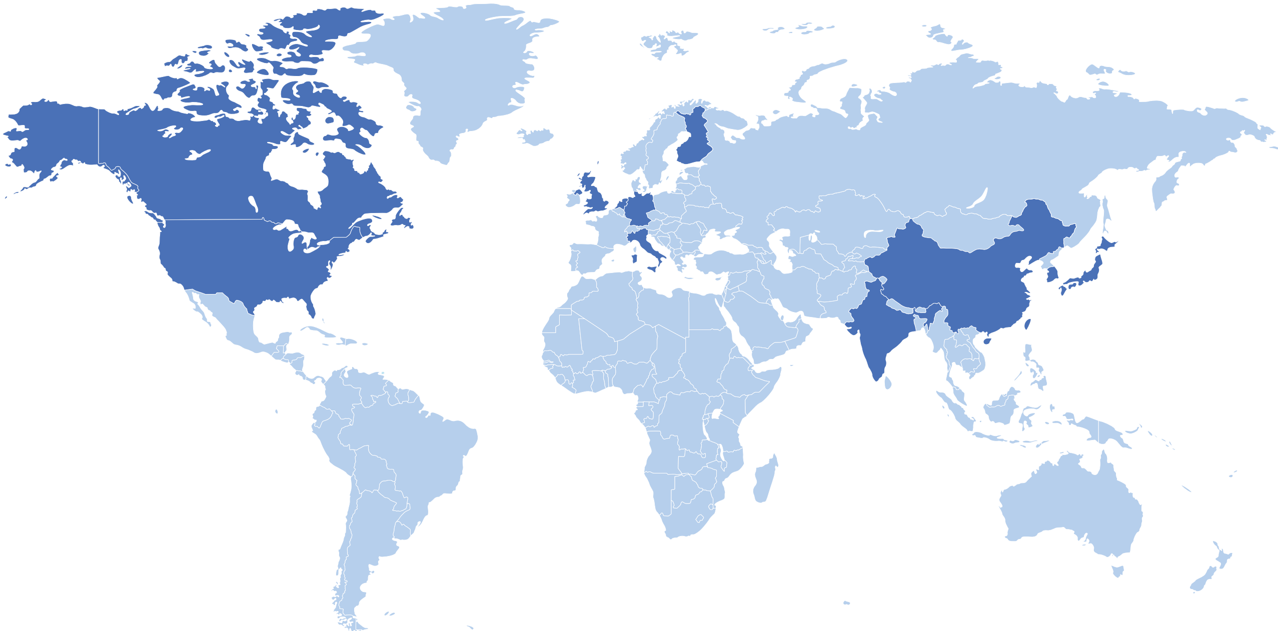


Figure 2-8 | Local (country-specific) LVDC standardization activities and awareness of respondents about the activities

NOTE The presented status is based solely on the survey and has not been verified through the national committees. A country has been highlighted if at least one respondent has reported the existence of national activities.

- Industry and academia working with
  - micro energy systems and product-like solutions to power small remote loads
  - USB-C and other easy to adapt solutions for safe low power ELV DC interfaces
  - plugs and sockets for high power LVDC interfaces applicable globally
  - electrical energy storage and renewable generation solutions
  - life cycle cost optimization of technologies and infrastructure development
  - societal development and role of technology in providing welfare
- Network operators and power suppliers in the developing economies and related industrial associations
- National and regional standards organizations based in the developing economies
- Development banks and multi-lateral financial and aid institutions
- United Nations organizations

Understanding of local socio-economics as well as overall societal development is essential for achieving sustainable solutions and Standards supporting sustainable development.

Section 3

Market assessment

3.1 Market development

Standardization has to serve market needs and thus it is necessary to estimate the size and type of both the existing markets and their evolution in the foreseeable future. Different markets have been identified, as presented in Table 3-1. The general nature of the analysis has to be noted. IEC SEG 4 was not able to compile a sufficient amount of data for performing more detailed market analysis at this time. This is partly due to the immaturity of the markets outside the traditional use cases of DC technology, although several modern solutions also exist, such as DC distribution in data centres, Power over Ethernet (PoE) and USB-C, which are already widely used and standardized.

Table 3-1 | Identified market sectors

Residential buildings	Grid interconnected (on-grid)	Urban/rural	PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
	Rural/energy access (off-grid)	Individual house	Product solution
		Village solution	Distribution by mobile batteries Wired distribution
			Hybrid distribution LVDC distribution
Tertiary buildings	Data centres	Large	PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
		Medium	PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
		Small	PoE USB-C Renewable/storage Hybrid distribution LVDC distribution

Tertiary buildings	Office building		PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
	Hospitals		PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
	Retail		PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
	Educational		PoE USB-C Renewable/storage Hybrid distribution LVDC distribution
Transport	Automotive		Charging Internal accessories
	Marine		Charging Internal accessories
	Avionics		Charging Internal accessories
	Railways	Inter-city	Charging Internal accessories
		Intra-city	Charging Internal accessories
Street fixtures	Street lighting Signalization Traffic control Toll and toll plaza		
Mining, manufacturing and warehousing	Robotics Industry automation Winches Cranes Material transportation Logistics Warehouse functions		
Agriculture and fish culture	Farm and farm equipment Water pumping		

Part 4 of the questionnaire was dedicated to collection of LVDC market information. It starts with a set of general questions about the current state of the markets and overall future market prospects in the respondents' organizations. The results are summarized in Figure 3-1.

In general, the respondents are expecting remarkable growth in LVDC-related markets within the next 5-10 years. Few respondents believe that the markets will grow and shrink rapidly as the hype first builds up and then collapses. Regarding the market importance of geographical regions, the respondents are basically unanimous about the markets in Asia and Africa, but otherwise the opinions vary greatly. Considering the background of the respondents, the result can be said to be somewhat expected. The results are presented in Figure 3-2.

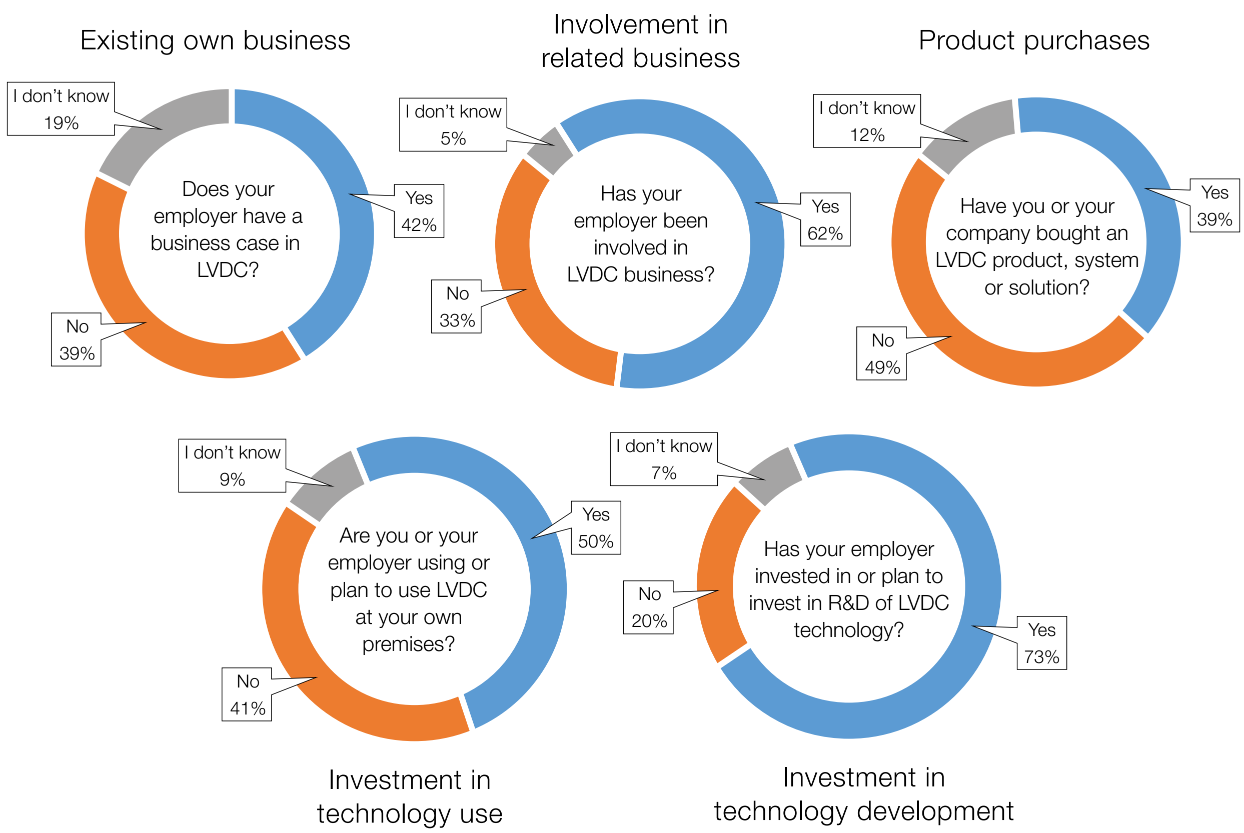
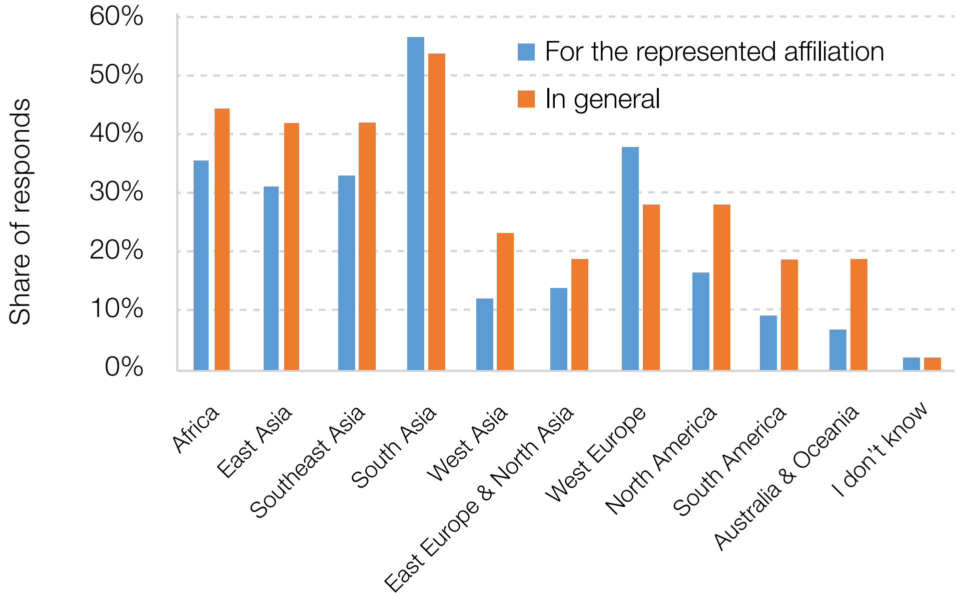


Figure 3-1 | Respondents' involvement and background knowledge of LVDC-related markets



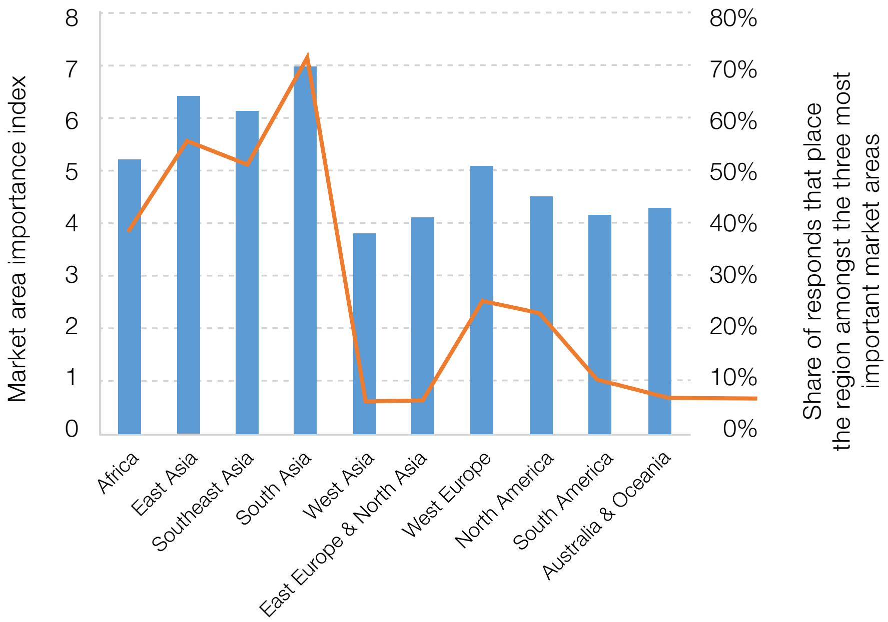
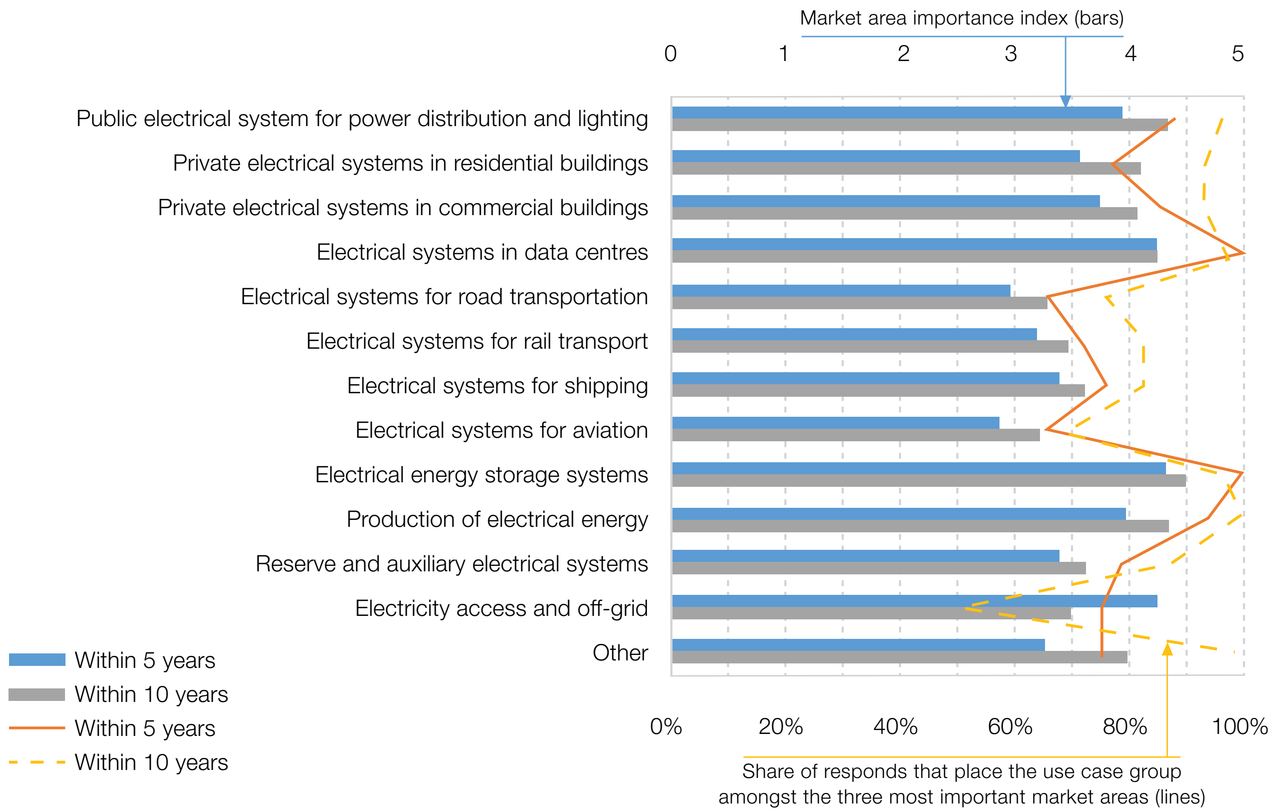


Figure 3-2 | Importance of geographical regions for LVDC business now and in the near future[1]

The respondents were also asked to estimate the development of the size of the global markets for a set of use case groups in relation to each other on a scale from one to five, five indicating the largest market and one the smallest. The respondents were requested to rate the size of the markets first within the next five years and then within 10 years. Empty responses were neglected, so the calculated market importance index depicts the insight of the 37 respondents (17%), from 15 countries. The results are presented in Figure 3-3.

1 For an explanation of the market importance index, see KAIPIA, T., et al., *Survey of Market Prospects and Standardization Development Needs of LVDC Technology*, In Proc. *24th International Conference on Electricity Distribution*, CIRED 2017, 12-15 June 2017, Glasgow, UK.



NOTE The bars present the market importance index and the lines the unanimity of the respondents.

Figure 3-3 | Market importance of different use case groups

Larger amount of respondents would enable resampling of the response data so that the bias caused by the backgrounds of the respondents could be analyzed, its impacts on the conclusions minimized and the statistical confidence of the result improved. The influence of having a fairly low amount of responses is clearly visible when comparing the results calculated from the 24 responses received by the end of the year 2015, the 30 responses received by March 2016 and finally the 37 responses received by November 2016.

Because the category "Other" has been rated significant by the respondents, it is relevant to check what applications or use cases these respondents have named. The responses fall into two categories: 1) microgrids, and 2) electricity access. However, it is not revealed whether the respondents are talking about systems serving a single building (private) or an entire community (public). Overall, there seems to be markets for technologies aimed at all of the listed application environments, but clearly the markets for technologies related to renewables, electromobility and distribution in tertiary buildings are expected to have the highest volumes.

3.2 Technology readiness level

The technology readiness level (TRL) is a generally accepted indicator of the maturity of technology. The original scale was invented by NASA, but later it has been accepted and further revised by several others, including the European Commission.

The TRL can be used as an indicator of the readiness for standardization. Technology can be considered mature enough for starting standardization, when at least TRL 7 or higher is achieved. According to the responses, the overall TRL of LVDC technology varies greatly, but in some applications the readiness for standardization has been achieved. The variation results from the large number of different LVDC applications and from deviations in the depth of experience of the respondents. Figure 3-4 presents the overall TRL of LVDC technology according to the survey. On average, the LVDC technology has achieved TRL 5 according to the responses.

3.3 Conclusions

The conclusions of this Technology Report are intended for identification of potential applications. The overall conclusion is that LVDC will be important for specific market niches:

- Renewables and storage are applications that are already widely used in power systems in many different environments, and for which standardization is in progress or where Standards are already available
- Data centres are powered by LVDC in some regions, with all the needed products easily found in the market. It is evident that there is a great potential in the market for this application. This is to be considered for hybrid (LVDC and LVAC) and pure LVDC distribution.
- Other tertiary applications, such as used in office buildings, hospitals, retail and education could follow the trends already established in data centres but with some delay.

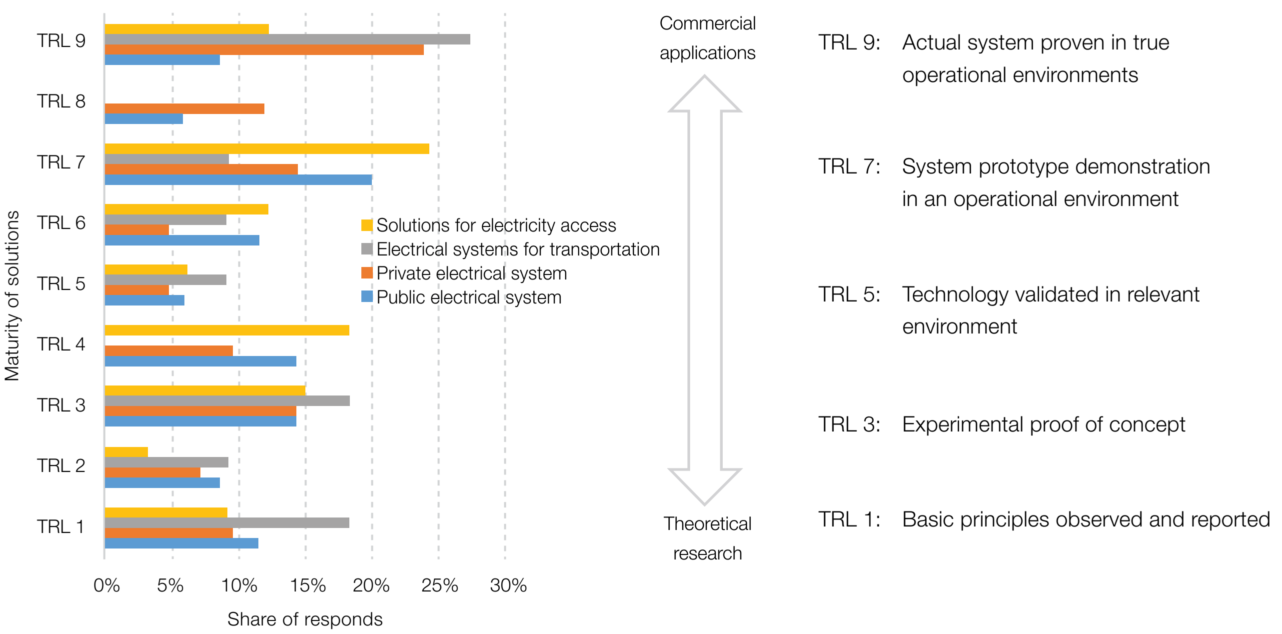


Figure 3-4 | Overall TRL of LVDC technology by use case group

- LVDC is widely used in transportation, as many trains and cars carry batteries which provide energy to installed accessories, components, and applications. In addition, LVDC will be used more frequently for charging electrical vehicles.
- PoE seems to be another important evolution, but this is mostly limited to tertiary buildings.
- USB is considered a major expanding market, especially in fixed installations, for charging and operating small mobile products such as phones, cameras, etc.
- In addition, USB Power Delivery™ (up to 100 W) represents the newest evolution as provided in USB 3.1.
- Applications such as street fixtures, public installations and the "last mile" will gain importance in the near future.
- For other applications such as mining, manufacturing, warehousing, agriculture and fishing, LVDC might be used in the future, but does not constitute a priority at this moment.
- A major new market involves resolving energy access for the 1,2 billion people who have no electricity locally.

Section 4

LVDC for electricity access

4.1 Introduction

Electricity is an essential requirement for all facets of life in any society. The concept of LVDC distribution allows for the local generation and distribution of electricity to its local consumption point without transformation to AC.

With concerns growing related to the depleting of fossil fuels and climate change, renewable energy is the natural choice for furthering the aim of energy security and energy independence. LVDC can act as an enabler for electricity access via the use of locally generated DC power through non-conventional sources, and for achieving greater energy efficiency through the avoidance of energy loss during the process of conversion from AC to DC. LVDC can also be used as an alternate energy efficient system for electricity distribution.

Universal access to energy by 2030 constitutes one of the three goals of the Sustainable Energy for All (SE4All) initiative of the United Nations (UN). The UN General Assembly declared 2012 as the "International Year of Sustainable Energy for All" under the SE4ALL programme and established three global objectives to be accomplished by 2030:

- To ensure universal access to modern energy services (including electricity and clean, modern cooking solutions)
- To double the global rate of improvement in energy efficiency
- To double the share of renewable energy in the global energy mix

The UN General Assembly has designated the years 2014 to 2024 as the "Decade of Sustainable Energy for All" and has released a comprehensive report on sustainable energy, which provides a detailed framework for energy access[2].

4.2 Challenges

Standardization will help facilitate application of LVDC technology, accelerate its commercialization by providing a platform to manufacturers and enable huge power savings for nations globally. In addition, policy and regulatory support will also promote the process of deployment of LVDC by providing incentives for taking into account issues related to the availability of energy resources, technology, economics and energy security. Standardization will help to open markets for fair competition benefitting end customers. Certain strategies can also be adopted involving incentives to business for making such developments happen, such as deployment of LVDC for public utilities; generation of investment funds and subsidies; provision of bank loans at lower interest rates; according tax-breaks for early adopters; making grants and incentives available for renewable infrastructures; promoting investments in R&D and technology trials, etc.

Various kinds of use cases can be identified on the basis of broad categories oriented toward application and use:

- Elementary use, such as in solar home lighting, solar pumps, etc.

2 ESMAP, *Beyond Connections – Energy Access Redefined*, Report, (Exec. summary), World Bank, 2015, [Online]. Available: http://bit.ly/2w3XrBN [Accessed 6 September 2017].

- Upgradable modular scheme use, such as minigrids and smart grids, as such grids are designed to trade power inward or outward depending on the balance of the resource envelope
- Utility-centralized or smart grid systematic and sustainable use, involving specialized mass power users such as extensive mobile charging stations for electric vehicles, electric locomotive metro systems and other high value services
- Use in data centres, propulsion systems, etc.

A few concerns also exist concerning the development of Standards, such as lack of knowledge, new technology, limited experience and limited markets:

- Some of the technical concerns revolve around compatibility with existing systems, availability of efficient power electronic converters/inverters, power loss in switching voltage from one level to other, surge currents, storage system aspects, safety and protection concerns, etc.
- Commercial concerns that need to be addressed include market barriers, inadequate information, lack of awareness, mobilization of financiers and modular equipment manufacturers, integration of catchment electricity access information databases, low cost business models for larger access, etc.

In the context of LVDC access, it must be ensured that the cost of establishing and operating the network is not prohibitive, as this will inhibit its adoption, particularly by developing economies where electricity access is a major challenge.

Activities aimed at electricity access can be targeted by developing suitable business models in different sectors, for example:

- Rural household activity models, such as home lighting with low power accessory charging, microgrids, minigrids, renewable energy farms, etc.
- Urban household activity models involving mixed grids (hybrid AC & DC), integrating value added services such as internet, telephony, TV entertainment, all routed through the electric lines
- Peri-urban household activity models such as supplementary grids that integrate power generation with waste disposal, commercial level electricity access, etc.

Section 5

LVDC voltage and safety

5.1 Introduction

5.1.1 The importance of a DC voltage standard

If a predetermined electric power is powered through a conductor, it is sufficient to increase the power supply voltage to reduce power loss, but system risk increases accordingly as the voltage value gets higher. There exists an upper limit voltage value when considering difficult situations, such as ensuring insulation distance and space, protecting mechanisms, guaranteeing safety, and determining how to handle system operations management. For use of DC voltage in a workplace involving a large number of people, an appropriate voltage category would be "low pressure" or less, considering the high level of safety and operation required. The following represents the voltage category at the present time.

The top priority for the players involved in DC power supply distribution systems is DC voltage. Regarding existing AC systems, the various kinds of voltage frequencies involved are not unified by countries or areas. As a result of the multiple standard types of voltage and sockets involved, this is often inconvenient not only for industry officials who import and export equipment but also for general travellers. Necessary international standardization in the sense of Standards developed in the DC areas to be created will provide beneficial results to many players including sellers, buyers and users.

5.1.2 Definition of DC voltage in IEC International Standards

IEC International Standards have defined two voltage standards:

- Low voltage: 0 to 1 500 V
- Extra low voltage: 0 to 120 V

According to the IEC definition, low voltage is categorized as causing electric shock, and extra low voltage differs in terms of the risks of arc discharge. The structure of voltage categories in IEC is given in clause 5.1.5. Compared to AC, the DC voltage range is much wider.

5.1.3 Relation between DC and safety

Safety is the first priority when equipment and systems are operated in DC. Regarding DC voltage distributions domestically and overseas, values are not calculated logically, but rather are just organized in consideration of risks and operational aspects. Careful discussions and verification are required regarding various other aspects concerning safety, but the following statement might be reliable based on the numerous references involved: “Insulating material has generally a much higher dielectric strength for DC when compared to AC. Furthermore, regarding the risk for human life, there is very little danger of commercial frequency in DC in comparison with that in AC. Moreover, there are substantial differences between DC and AC even with the same voltage; however, it is difficult to determine the exact and theoretical relationship between these two currents.”

International Standard IEC 60479-1 describes the difference between DC and AC regarding electric shock. It is said that the bodily reaction to touching a charging unit and receiving a shock is different from the relationship between the amount of electric current flowing through the human body and energizing time. Although AC (50 Hz or 60 Hz) involving more than 0,5 mA current will cause numbness when flowing in the human body, the current range would be 2 mA or more in the case of DC. Severe symptoms such as breathing difficulties will occur if the AC value is 10 mA or more, whereas similar symptoms would result from 30 mA or more when it comes to DC.

The entire system including insulation, ground and various protections for safety should be discussed. However it is difficult to univocally set only the voltage of high/low. In domestic and international definitions and regulations on the other hand, it can be seen that the range of DC low voltage is higher than that of AC. It is also necessary to consider putting together available energy supply as a power supply. Additionally, there are technical difficulties other than electric shock related to DC in accident removals such as arc, overcurrent and short circuit. Each case in DC would be different, it is not perfectly safe or totally dangerous. As consideration of adopting DC supply power distribution systems advances, the opinion is often expressed in various fields, including among end users, that "DC = dangerous". However, taking the facts mentioned above into account, the judgment that DC is dangerous is not reasonable.

5.1.4 Relevant IEC voltage bands

Voltage band	AC	DC
HV	> 1 000 V	> 1 500 V
LV	≤ 1 000 V	≤ 1 500 V
ELV	≤ 50 v	≤ 120 V

5.1.5 Standardized DC voltages and their application

Many different DC voltages are standardized in International Standard IEC 60038:

DC		AC	
Nominal values		Nominal values	
Preferred	Supplementary	Preferred	Supplementary
V	V	V	V
	2,4		
	3		
	4		
	4,5		
	5		5
6		6	
	7,5		
	9		
12		12	
	15		15
24		24	

DC		AC	
Nominal values		Nominal values	
Preferred	Supplementary	Preferred	Supplementary
V	V	V	V
	30		
36			36
	40		
48		48	
60			60
72			
	80		
96			
			100
110		110	
	125		
220			
	250		
440			
	600		

NOTE 1 Because the voltage of the primary and secondary cells is below 2,4 V, and the choice of the type of cell to be used in various applications will be based on properties other than the voltage, these values are not included in the table. The relevant IEC technical committees may specify types of cells and related voltages for specific applications.

NOTE 2 It is recognized that for technical and economic reasons, additional voltages may be required for certain specific fields of application.

However, tolerances are missing and preferred voltages for specific applications are not defined. Therefore, IEC SEG 4 determined that there is a further need to define two primary voltages in DC.

Delegates generally considered as appropriate 48 V in the ELV band and 380 V if high power is needed in the LV range. However, these are to be considered in addition to, and not as a replacement of, the work already done by various IEC TCs, as reflected in IEC 60038. In recognition of current practices in the US, it was determined that 24 V also be retained as a secondary voltage.

5.2 Collection and rationalization of LVDC safety data

5.2.1 Voltage, power capacity, earthing and protection for safety

Several questions related to the basic technical properties of a DC system were dispersed to parts 2 and 3 of the questionnaire. Similar things were asked in the form of slightly differing questions multiple times. The approach was selected to improve the reliability of the results related to these pivotal parameters.

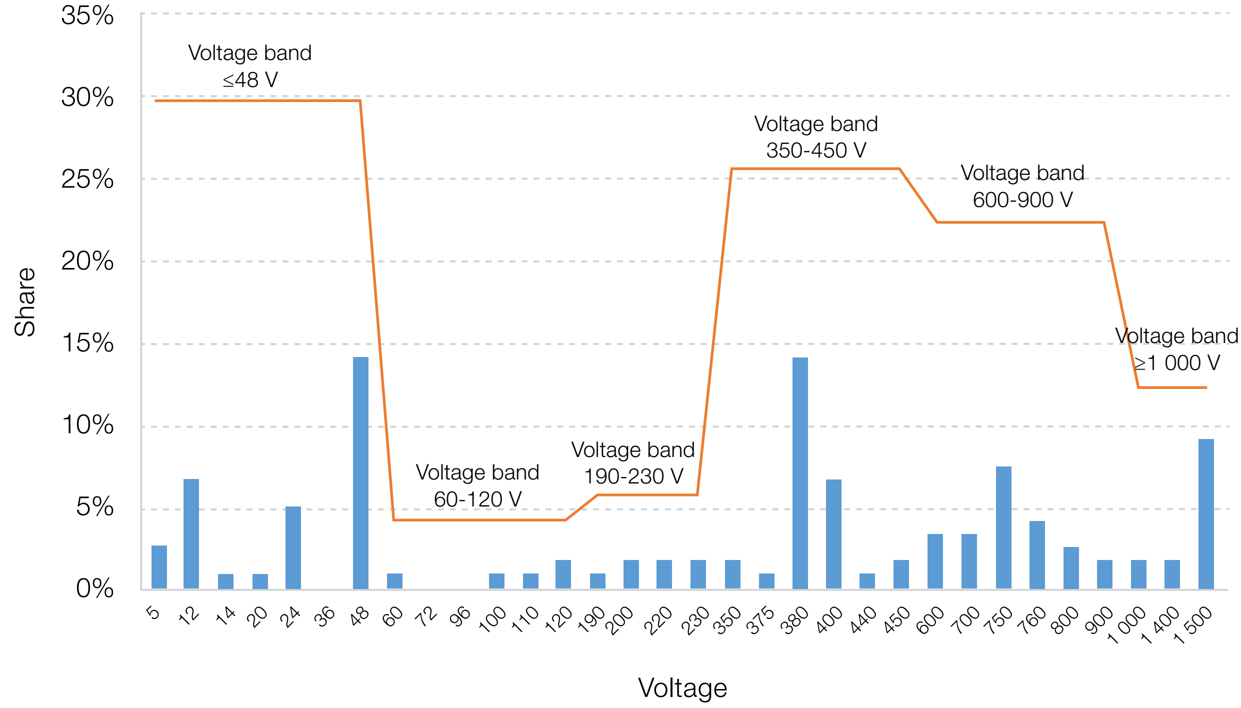


Figure 5-1 | Proposed nominal voltages and voltage bands identified based on use case descriptions

In part 2 of the questionnaire, the respondents were asked to describe the voltage parameters, earthing system and typical power rating for the use cases considered in their work. The response rate was 37%. Results are presented in Figure 5-1.

Overall, without considering the use case or application, the preferred voltages seem to be 12 V, 24 V, 48 V, 380 V, 400 V, 750 V and 1 500 V. The voltage bands in the figure are derived based on the answers to questions in part 3 of the questionnaire. Based on the responses received, typical use cases and the maximum power ratings for the voltage bands are as follows:

≤48 V

Powering light loads, such as lighting, fans and entertainment electronics as well as automation system actuators in different environments. Used in nanogrids or as an integral part of a higher voltage AC or DC installation. Often associated to systems developed for providing electricity access based on solar power and to technologies combining communication and electrical installations (i.e. PoE and USB-C). Power range up to 1 kW.

60 V-230 V

Powering typical household and office loads connected to respective AC supplies, from lighting to cooking. Proposed for DC networks or microgrids of remote areas as well as for DC installations in residential and commercial buildings.

350 V-450 V

Mains voltage for installations in residential and commercial buildings as well as for light industry. Often a bipolar system supplying installations belonging to the previous voltage band (e.g. a ±190-220 V system). Used in data centres and proposed also for lighting and building-scale microgrids and nanogrids. Also associated with electric road vehicles. Power range up to 500 kW.

600 V-900 V

This voltage band is mostly associated with industry, transportation (especially traction) as well as PV generation. Found applicable also in public power distribution and microgrids and minigrids in connection with the two lower voltage bands and with the ≥1 000 V band. Power range up to 1 MW.

≥1 000 V

Mains voltage band for traction, marine and aircraft systems, last-mile power distribution and street lights. Often connected to previous two-three voltage bands and operated as a bipolar system (e.g. ±700-750 V system, both halves of which supply ±350-375 V systems). Power range up to tens of MW.

Energy storage systems are relevant to all of the voltage bands. Naturally, as the power and energy capacities of storages increase, so does the voltage.

Figures 5-2 and 5-3 present the maximum power ratings and recommended nominal voltages with respect to the maximum power rating, according to respondents. A clear step towards the use of higher voltages occurs around the power rating of 10 kW.

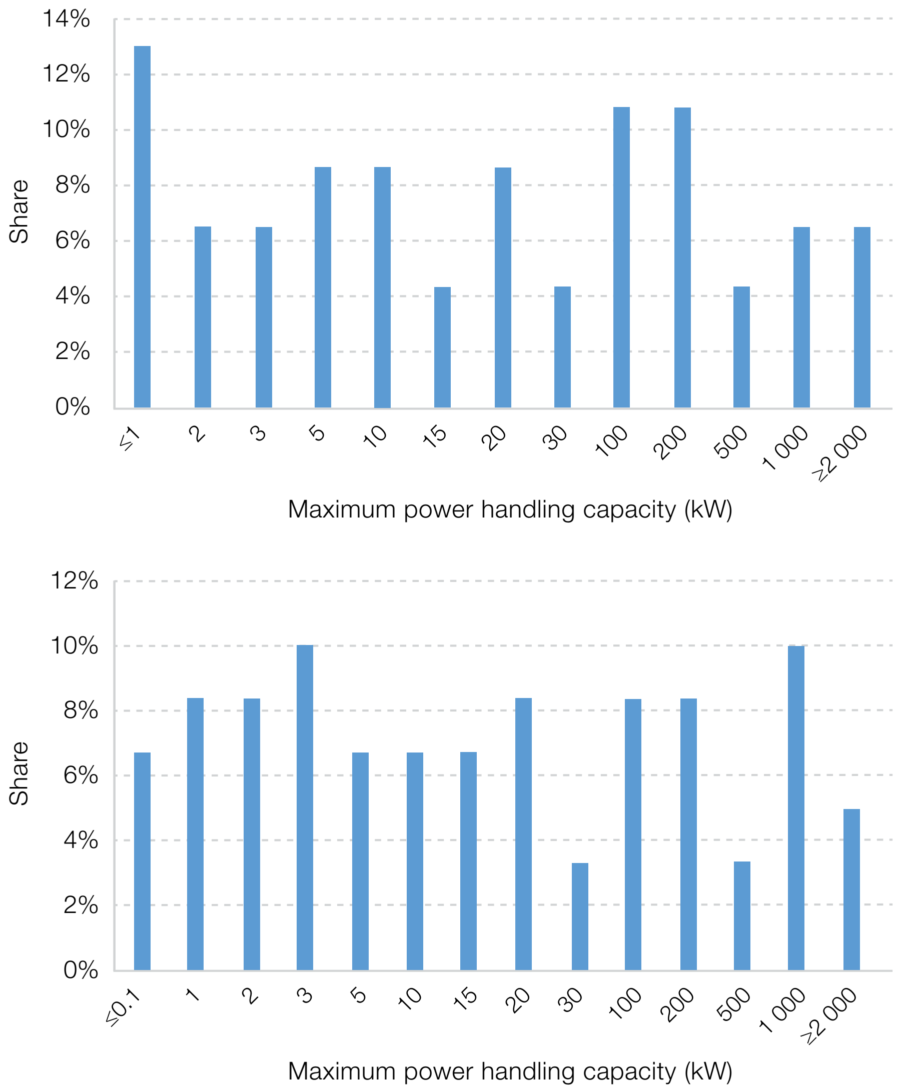


Figure 5-2 | Maximum power ratings according to the responses to the questionnaire

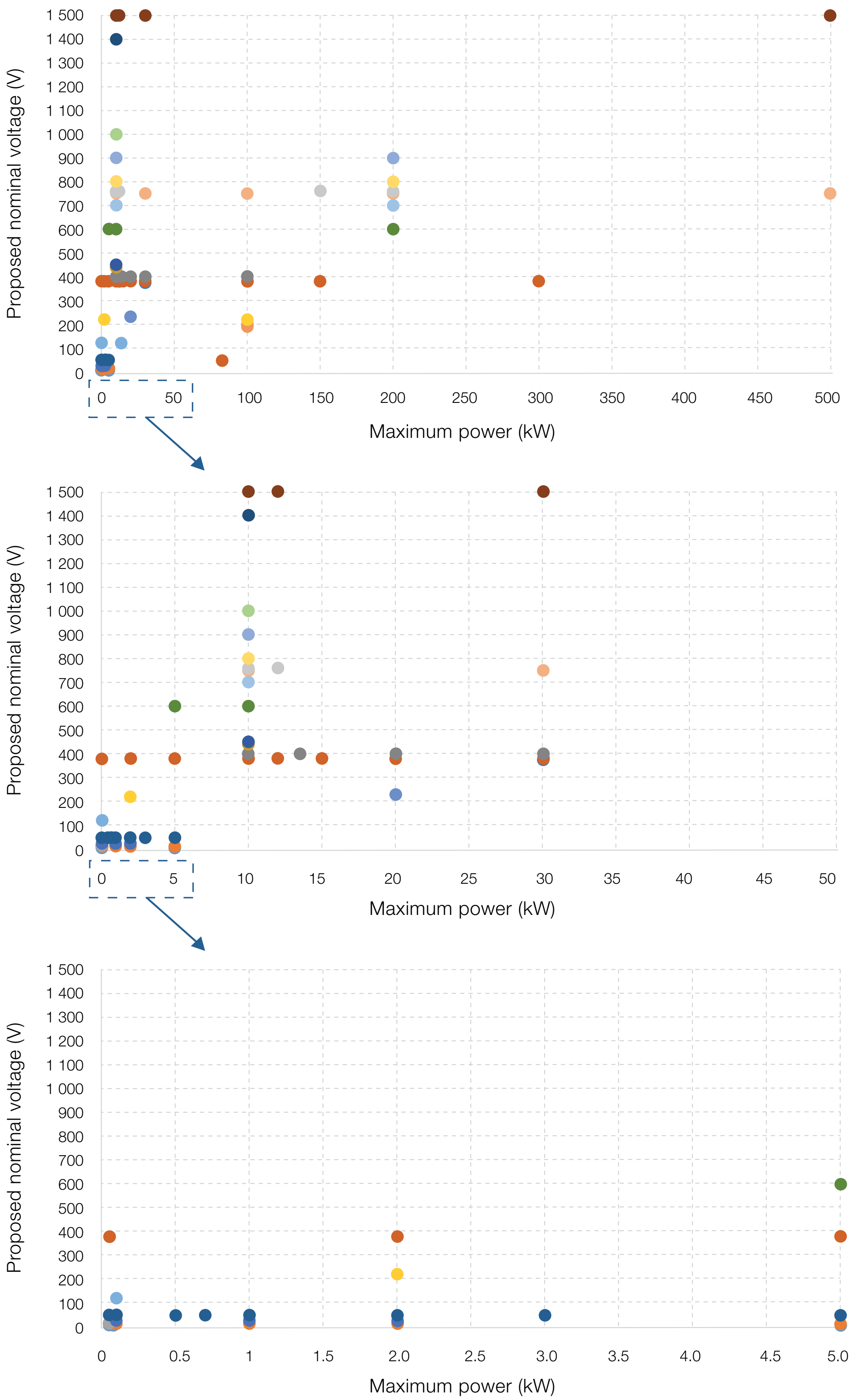


Figure 5-3 | Proposed nominal voltages with respect to maximum power rating up to 500 kW

The limits for functional voltage variation were asked in the questionnaire. It was recognized by several respondents that the voltage levels as well as the limits for the tolerable voltage variation depend on the use case and related equipment structure. Thus general definitions for voltage variation should not be drawn and included in common voltage level standardization. Examples of proposed limits for tolerable voltage variation in LVDC systems with different nominal voltages are presented in Figure 5-4.

The limits for the voltage variation need to follow the overall voltage level and the system setup, including interoperability with the surrounding AC systems. If there is battery in the system, the limits for the allowed voltage variation depend first on the type of battery connection (with or without a converter). If the battery is directly connected, then factors such as the battery chemistry, load level and state of charge will affect the voltage variation.

The respondents were also requested to identify the preferred earthing system for the use cases or applications considered in their work. All standard earthing systems were considered applicable and the result is strongly use case- and environment-dependent. The respondents were also requested to indicate the appropriate earthing system (TN, TT, IT or all three) for four applications or use cases most in need of standardization. The response rate was 12%. The distribution of the responses received is presented in Figure 5-5.

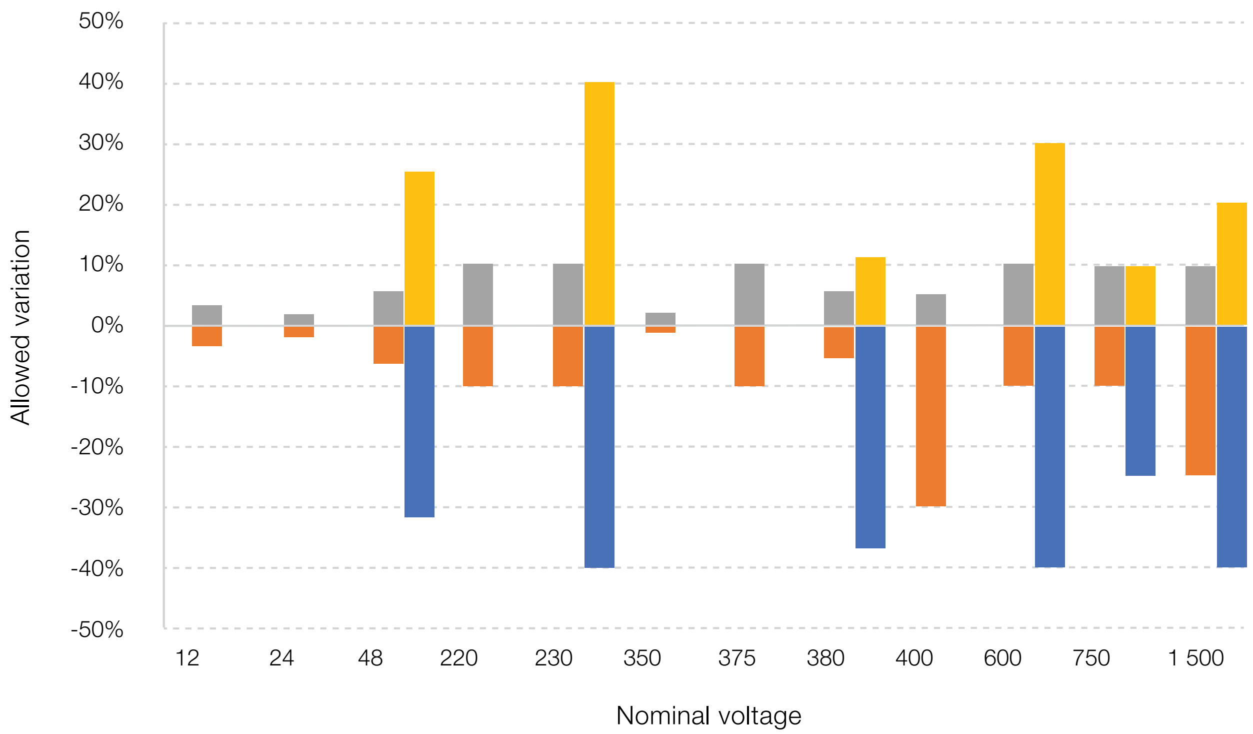


Figure 5-4 | Examples of proposed minimum (grey-orange) and maximum (yellow-blue) limits for tolerable voltage variation in systems having different nominal voltages

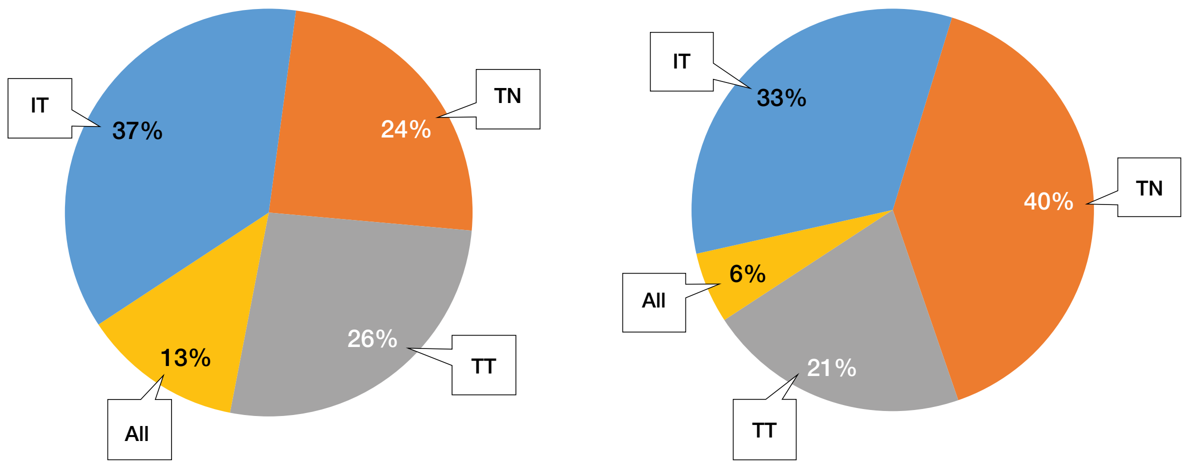


Figure 5-5 | Earthing systems applicable in LVDC installations

Based on these results, the conclusion is that all earthing systems need to be allowed. Earthing conditions as well as the safe earthing scheme vary regionally and between the LVDC use cases. Guidelines are needed to allow case-by-case design of the earthing scheme.

The respondents were asked about the fault and overcurrent protection devices or techniques used or usable in the systems related to their work. The response rate was 45%. According to the results, the power electronics integrated protection techniques are widely preferred and investigated. However, fuses and traditional mechanical protection devices continue to be considered necessary too. This is probably at least partly due to existing standard requirements for fault and overcurrent protection. Only 6% of the respondents trust only conventional protection devices and 4% only unconventional techniques. The rest consider that some kind of a hybrid solution is the most appropriate. A summary of the results is presented in Figure 5-6.

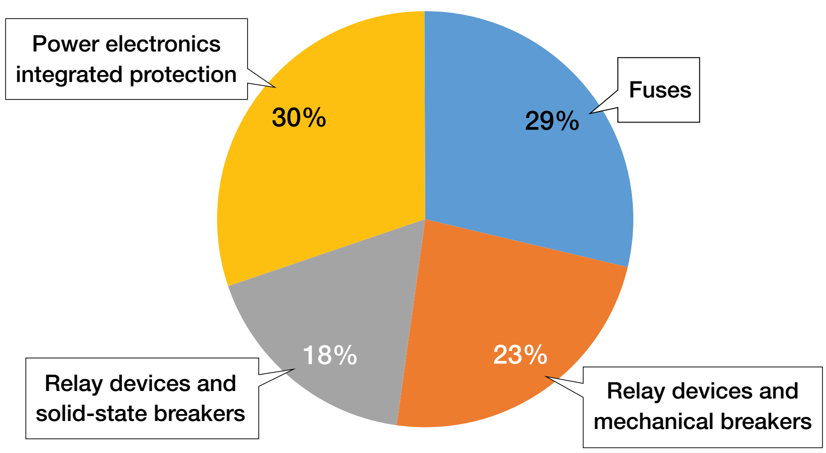


Figure 5-6 | Overcurrent and fault protection techniques

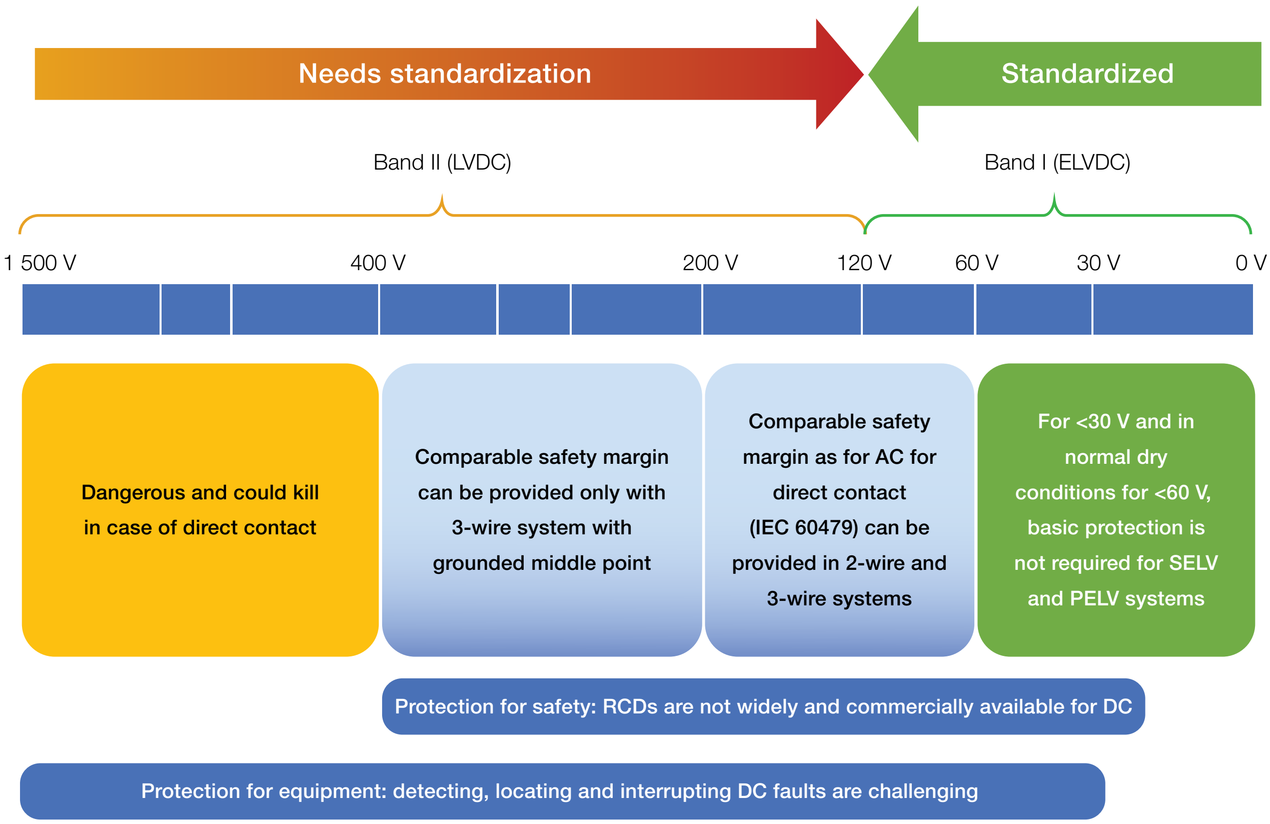
In addition, the respondents named several other relevant protection devices, such as:

- Residual current monitoring (RCM)
- Insulation monitoring device (IMD)
- Solid state current limiter or electronic by-pass switch
- Various arc detecting devices

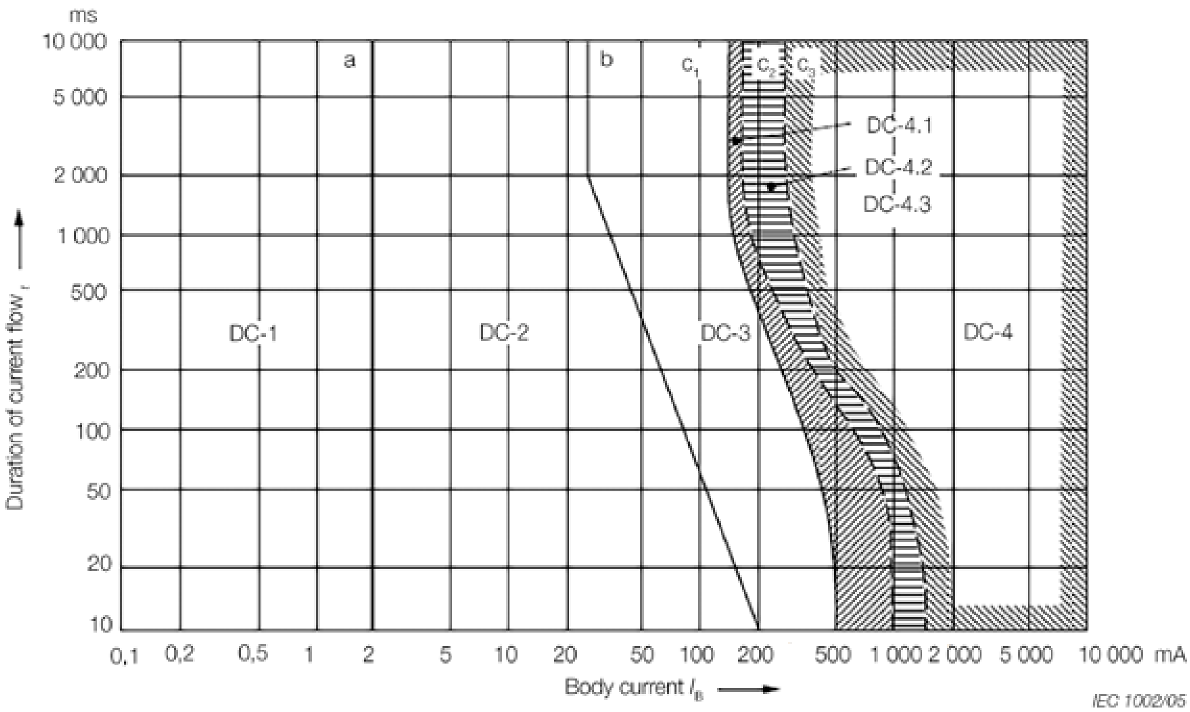
Finally, a majority of respondents indicated a clear need for developing working safety regulations. According to the respondents, electricians are currently not sufficiently educated to work with DC. As DC installations may differ radically from the existing AC installations, and because of the characteristics of DC, the electricians may not be able to identify the risks related, for instance to DC arc and electrostatic charges. The importance of proper labelling to identify DC and AC installations was also emphasized.

5.2.2 Safety principles are known

A considerable amount of literature exists already on the safety aspects of DC. One example is IEC TR 60479-5, a technical report published by IEC TC 64, concerning the safety level in DC compared to that of AC. The conclusion reached in this document is that up to 200 V DC supply voltage, the same level of safety can be assumed as for 200 V AC – based on an analysis of realistic disconnection times for protection against electric shock (need to consider the upward and downward current depending on the earthing of one polarity, if any).



* The IEC 23E/WG2 group, "DC distribution system and consequences for RCDs"



Time current zones for DC (perception, muscular reaction, ventricular fibrillation) are known and deviate clearly from those for AC.

See IEC TR 60479-5.

Section 6

LVDC standardization

6.1 Recent activities in standards organizations and related organizations

6.1.1 Activities in IEC

Technical committees (TC) and subcommittees (SC) are established in IEC for each technology type, with the number of committees currently standing at over 100. Effective use and development of DC power supply distribution systems which have increasingly attracted attention in recent years, is expected not only in information and communication facilities but also in many other areas, such as commercial buildings requiring a reliable high performance, future housing, energy systems incorporating a distributed power source, and charging for electric cars. Based on the above, establishment of a strategic group (SG) to consider standardization of DC distribution systems up to 1 500 V was proposed by the IEC National Committee of Sweden and approved by IEC. Activities in SG 4: LVDC distribution systems up to 1 500 V DC, have started accordingly, following activities in conventional SG 1: Energy efficiency and renewable resources, SG 2: Standardization of UHV technologies, and SG 3: Smart grid, since the end of 2009. SG 4 consists of members from 15 countries, with the participating representatives being recommended by the national committee in each country. SG activities are as specific as those in TCs and SCs, which focus on specific standardization. The role of SG 4 is to organize consideration of individual issues, such as clarifying the range to be considered in each TC, preventing duplication and leakage, collecting information in the TC's specific field, creating roadmaps and clarifying the challenges facing the TC. The voltage target defined in IEC is 1 500 V DC or less, with specific fields related to individual TCs being as follows:

- Power generation facilities, with a focus on distributed power sources such as PV
- Wiring protection equipment such as switches, circuit breakers, and fuses
- Digital electronic devices such as ICT and AVI
- Lighting equipment
- Load equipment, such as home appliances and medical equipment
- EMC and insulation related to all common power generation/distribution/load
- Technical fields such as refractory

6.1.2 Activities in ITU and ETSI

Since 2009, ITU and ETSI have been considering DC power supply and distribution systems for ICT technology, in order to cope with increasing energy needs of information and communication installations. Under the lead of various telecom operators and the telecom equipment manufacturers, ITU established Study Group 5: Environment and climate change. SG 5 is organized into several working parties (WP), equivalent to IEC working groups (WGs). WP 3 focuses on power feeding systems and has started formal discussions about voltage values in the range of 400 V.

As an organization for standardization in the European area, ETSI has already published a Standard for voltage values up to 400 V. However, since this Standard is both for AC and DC, a revision of this document is scheduled with a focus on DC distribution, including reconsideration of the voltage range.

Recently, ITU-T and ETSI issued the following DC power Standards:

- ITU-T L.1200 (2012-05), *Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment*
- ITU-T L.1201 (2014-03), *Architecture of power feeding systems of up to 400 VDC*
- ITU-T L.1202 (2015-04), *Methodologies for evaluating the performance of an up to 400 VDC power feeding system and its environmental impact*
- ITU-T L.1203 (2016-02), *Colour and marking identification of up to 400 VDC power distribution for information and communication technology systems*
- EN 300 132-3-1 V2.1.1 (2012-02), *Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V; Sub-part 1: Direct current source up to 400 V*

Related activities and Standards for ICT applications are listed below:

- UL (several products listed today) – Cover all distribution system components
- ETSI EN 300 132-3-0 – Power interface standard
- ETSI EN 301 605, *Environmental Engineering (EE); Earthing and bonding of 400 VDC data and telecom (ICT) equipment*
- IEC TS 62735-1:2015, *Direct current (DC) plugs and socket-outlets for information and communication technology (ICT) equipment installed in data centres and telecom central offices - Part 1: Plug and socket-outlet system for 2,6 kW*
- IEC/IEEE (SG 22H) – Working group in place – New DC UPS standard released in 2015
- ITU – (ITU-T I.1200) – Adopted ETSI voltage levels
- ATIS 0600315.01.2015, *Voltage Levels for 380 V DC-Powered Equipment Used in the Telecommunications Environment*
- NEC – Current edition applies to both AC and DC: wiring, protection, safety (continuous upgrades on 3 year cycle)
- EMerge Alliance – Focus on site and system interfaces
- YD/T 2089-2016 (China Standard), *336 V Direct current power supply system for telecommunication*
- YD/T 2378-2011 (China Standard), *240 V direct current power supply system for telecommunications*
- YD/T 2555-2013 (China Standard), *Distribution equipment of 240 V direct current power supply for telecommunications*
- YD/T 2556-2013 (China Standard), *Maintenance requirements of 240 V direct current power supply system for telecommunications*
- YD/T 2656-2013 (China Standard), *Technical requirements and testing methods for 240 V/336 V direct current telecom equipment power supply unit input interface*
- YD/T 3091-2016 (China Standard), *The assessment requirements and methods of online running 240 V/336 V DC system for telecommunications*
- NEMA/EPRI – Work in progress

6.2 Identified gaps requiring IEC TC coordination (systems level gaps)

Area of work	Why this is relevant	Collaboration platform
Matrix of voltage, current and distance applicable in DC installations, and economical recommendations for wire cross sections for copper and aluminium	Approach from a systems prospective. This is at the core of LVDC distribution in ELV.	TC 8, TC 48, TC 64, JTC 1, etc.
Selectivity of connectors for LVDC (criterion of selection and use cases)	Besides defining voltages, the single largest impact on LVDC proliferation will be by defining the connectors. Today at the ELV level, USB-C and PoE are being considered. There are several other connectors also available. Time has come to consider finalizing a global single Standard for universal DC connector for various possible scenarios of power delivery (UDC Standard)	TC 8, TC 23, TC 34, TC 48, TC 59, TC 64, TC 100, JTC 1
Topology for creating capacity for EVs/charging of EVs and integrating EVs with renewable energy	EV and renewable energy are entering the dwellings of consumers. Prosumers are replacing consumers. In this environment, EV provides a challenge and opportunity. Likewise grid connectivity can be a potential source for energy and also for storage. This Standard will set guidelines and criterion for utilities, electrical consultants and engineers to design buildings of the future which intend to integrate renewable energy sources with EV and rest of the loads.	TC 8, SC 8A, TC 23, TC 64, TC 69, PC 118, SEG 6, ACTAD, SyC Smart Energy, IECRE, ISO TC 22/SC 37
Classification and topology for practical DC microgrids in on-grid and off-grid environments	There are several examples of DC grids in off-grid environments: ▪ Single hut, PV module on roof, storage in devices ▪ Single hut, PV module on roof, storage centralized inside hut ▪ Cluster of huts, single centralized PV panel, centralized storage	TC 64, TC 82, SEG 6, IECRE

Area of work	Why this is relevant	Collaboration platform
	▪ Cluster of huts, distributed PV panels, centralized storage ▪ Cluster of huts, centralized PV panel, distributed storage ▪ Cluster of huts, distributed PV panels, distributed storage It is obvious that the power delivery, distribution and protection criterion for such applications could be different for each scenario. The Standard will provide classification and guidelines for optimizing such networks.	
Classification of minimum power delivery for DC microgrids in on-grid and off-grid environments	Different environments in developed and developing economies will demand a different level of power delivery to dwellings. This Standard will classify power requirements, design criterion and safety requirements in such settings.	SEG 6, SyC Smart Energy, IECRE
Recommended topology of DC microgrids for utilities	Utilities are increasingly considering supplying DC to consumers. This Standard will provide guidelines and specifications for utilities to evaluate customer demands and set up grid infrastructure for enabling DC supply.	ACEE, SEG 6, SyC Smart Energy, IECRE
Guide for application of Standards for rural electrification	There are already a large number of IEC International Standards published about the subject, and for a non-experienced person, finding the appropriate set of Standards relevant for a specific context can be quite difficult. This overarching document will present the lists of the existing Standards and guide the users for the application of the Standards relevant to the related environment.	TC 23, TC 34, TC 37, TC 64, TC 82, etc., national and regional organizations
Standard for application of World Bank multi-tier framework for classification of energy access	Energy access cannot be defined as a yes/no question when a power cable reaches the housing. Several service levels should be defined depending on the availability, reliability and power level delivered.	TC 8, TC 64, TC 82, SyC Smart Energy, IRENA, World Bank

Area of work	Why this is relevant	Collaboration platform
Commissioning, verification and inspection of DC installations	The existing Standards only deal with inspections of AC installations. DC installations should be added.	TC 23, TC 34, TC 37, TC 64, etc.
Guide to application of World Bank multi-tier framework for classification of energy access	The multi-tier framework is being used by many developing countries to help plan, budget and implement their rural electrification processes. IEC work in this area will help all developing economies.	TC 64, TC 82, TC 88, TC 117, IECRE
Safety and installation of photo-voltaics for productive use applic-ations (DC devices)	Many DC devices and applications are available in off-grid space. All these devices run on DC, so it will be beneficial to recommend installation and safety practices for such devices.	TC 23, TC 64, TC 82, TC 117, IECRE
DC power consumption metering	Until Standards are available and recognized by relevant national regulatory authorities, building op-erators and power utilities, it will not be possible for LVDC to expand in economic importance, both within buildings, campuses and other LVDC microgrids environments.	TC 13

6.3 Identified gaps which could be addressed at the IEC TC level

IEC SEG 4 identified gaps not considered as highly transversal and which could be addressed by specific IEC TCs with eventual liaisons:

- Tolerances for preferred DC voltages should be standardized (TC 8).
- Check whether product Standards for DC circuit breakers, RCDs and AFDDs have to be established, if not yet available. Are enough requirements for electronic protection devices in place, including functional safety requirements? (TC 23, SC 121 A).
- Evaluate the gaps regarding applicability of DC for home appliances (TC 57, TC 61).
- Evaluate whether the existing protection measures and installation rules are sufficient for DC (TC 64).
- Protection against electric shock: devices (RCDs) are not widely available for DC.
- IEC TR 60479 needs to be updated due to the latest research results on DC.
- Coordination in DC systems needs to be reconsidered: operating time and selectivity.
- Identify the specifications for ordinary persons and skilled people (may require different safety measures).
- Segregation between AC and DC circuits.
- Different footprints for AC and DC.
- Mutual influence of AC and DC voltage in case of fault (e.g. hybrid installation).
- Corrosion of earth electrode: effect of DC on earth electrode.

6.4 Liaisons

IEC SEG 4 has identified IEC TCs and other groups active in LVDC standardization that could be part of the collaboration platform. The number of TCs is quite important, but when operating, the collaboration platform would require the attendance of only the TCs involved in the subject matter.

IEC SEG 4 experts have developed a detailed list of relevant TCs, which is available at lvdc@iec.ch.

Section 7

Conclusions and recommendations

For the last 100 years, AC was the dominant electric current used in power generation, distribution and consumption. Most Standards today cater to AC. DC offers a number of opportunities that carry distinct sets of advantages for developed and developing countries, ranging from power quality to energy efficiency and energy access. To truly benefit from them, standardization has an important role to play in terms of enhancing safety and usability. LVDC standardization in the IEC is far advanced but some work remains to be completed.

The following recommendations outline activities that need to be undertaken to make LVDC a reality.

7.1 General recommendations

- **Broad, open participation needed**

  While IEC work on LVDC is among the most advanced globally, relevant and related work is also being undertaken outside of the IEC community. It is therefore important that the IEC community (members and affiliates), as well as industry and research institutes, and friendly entities such as regional and international organizations, for example AFSEC, APEC, CANENA, CENELEC, CIGRE, ETSI, IEEE, ISO, ITU-T, WTO COPANT PASC, etc. promote IEC work for LVDC and incite their respective experts to participate in IEC work for LVDC to share their know-how and expertise.

  The IEC needs to promote, foster and nurture liaisons with such organizations to enable the long-term development of meaningful LVDC Systems Standards.

  The IEC systems committee (SyC) LVDC is open to all, including those who do not currently participate in IEC work. Such experts and organizations should apply for participation through their national committee www.iec.ch/members or outside of member countries directly by sending an email to lvdc@iec.ch.

- **A single, widely applicable Standards series**

  Ultimately, the aim should be to achieve a single IEC Standards series that covers all aspects of LVDC and applies both in developed and developing economies. For this all relevant expertise needs to be brought on board. Duplication will slow down technology development and adoption.

- **Addressing universal energy access**

  LVDC standardization is imminent and will facilitate the acceptance of DC as the preferred electric current for universal energy access. However, while experts in the IEC have a profound understanding of the technical challenges of LVDC, in order to fully address the challenges of LVDC in the context of electricity access, experts and stakeholder groups specialized in this area need to be urgently brought on board.

  Relevant organizations include for example UN development bodies such as UNDP, SE4ALL, etc., funding agencies such as the World Bank, IFC, ADB, AfDB, etc., and other global and implementing organizations working in this area such as IRENA, ARE, CLEAN, GOGLA, etc.

7.2 Recommendations for industry leaders

Board-level industry strategy and decision makers, should stimulate active engagement in DC related developments to anticipate challenges to their conventional AC business and to partake in new DC opportunities that are promised to come to fruition. They should trigger internal discussions to understand future implications of this technology and set the corporate strategy that will allow them to be prepared for business opportunities related to LVDC for energy efficiency improvements and energy access.

7.3 Recommendations to the IEC, its members, affiliates and technical experts

- **Orchestrate stakeholder involvement**

  IEC national committees need to broadly promote the IEC standardization work in the area of LVDC among national industry and stakeholder groups, including government and regulators so as to elevate awareness and promote participation.

  The IEC community should encourage, facilitate and enable the participation of relevant experts who have not traditionally participated in IEC work in SyC LVDC.

  Furthermore IEC technical committees (TCs) currently may not have DC competence among traditional participants. NCs need to augment current pool of experts with new talent having DC-related competencies and experience.

- **Standardization gap analysis**

  To accelerate LVDC in terms of installations, devices and use, a standardization gap analysis needs to be conducted including by each technical committee.

  Existing, relevant AC Standards need to be adapted for DC use. New Standards need to be initiated as needed.

  The most urgent standardization work needs to focus on safety aspects and the standardization of voltages as well as installation rules and tolerances.

  A number of DC-related gaps have already been identified including for example, circuit breakers, arc fault detecting devices, protection measures (overvoltage, shock, current effects of DC on human beings and livestock), power quality, wiring rules, island installations, to name just a few. Work on these items needs to be accelerated.

- **Use cases**

  There is an urgent need to establish a use case mapping tool to identify applications and expected market relevance for LVDC.

- **Systems approach**

  LVDC clearly calls for a systems approach. No single TC will be able to develop all Standards needed for LVDC. All relevant IEC TCs are asked to support the SyC and accept its role as facilitating entity rather than as competition.

  The IEC CO should also immediately embark on speedy development of systems approach-related tools, templates and training materials to support systems approach deployment across the IEC community.

- **Collaboration platform**

  Global collaboration of experts who have not previously been involved with the IEC might require the development of a common platform or a similar technology solution.

- **National LVDC activities**

  IEC members should consider establishing LVDC mirror committees and identify, reach out and bring on board national entities that work on LDVC standardization with an aim to increase contributions to global IEC LVDC work.

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About the IEC

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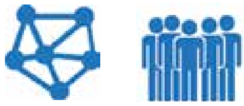

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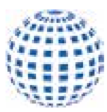

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Key figures

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