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Standardisation of Public LVDC distribution – Status and Development

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Research report

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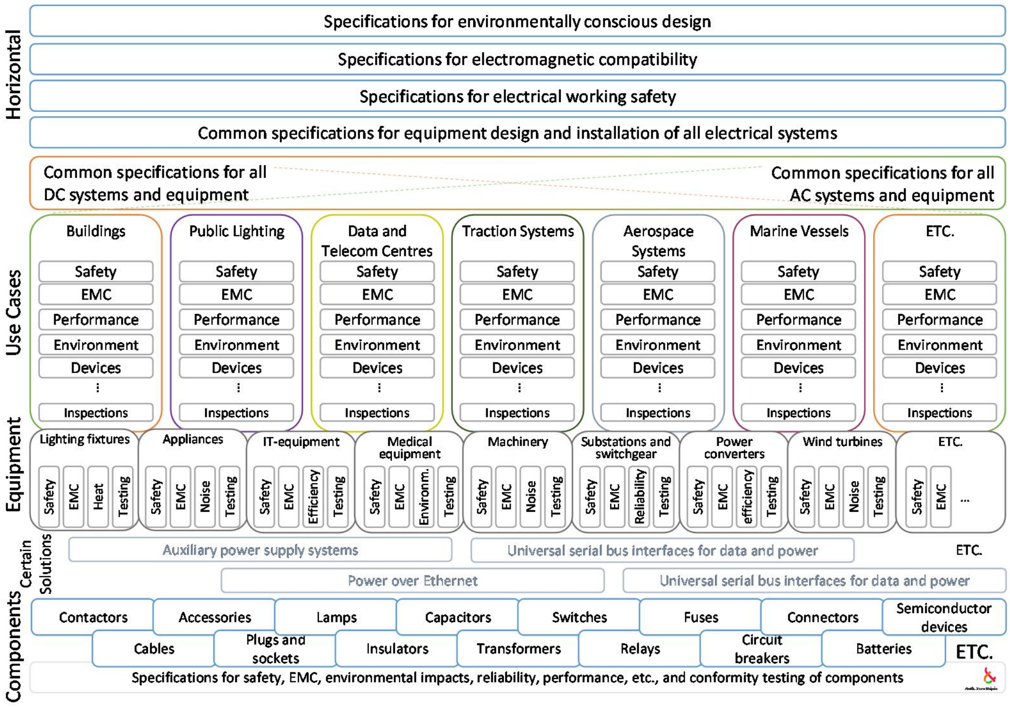
Standardisation of Public LVDC Distribution

– Status and Development



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Name of the report: Standardisation of Public LVDC Distribution – Status and Development

Key words: Standardisation, low voltage direct current, LVDC, public distribution

Summary

This report focuses on analysis of the status of currently available electrotechnical standards and development of the standardisation from the perspective of using low-voltage direct current (LVDC) networks in public power distribution. In addition to the state-of-the-art analysis, the further needs to develop the standardisation are listed and the standardisation processes discussed.

The main objectives of the investigation have been to identify the existing recommended practices pertaining to implementation of LVDC apparatus, equipment and networks, determine the major gaps in the standardisation and give recommendations for both improving the standardisation process.

Part of the presented results are based on the outcomes of the IEC SEG4 Systems Evaluation Group - Low Voltage Direct Current Applications, Distribution and Safety for use in Developed and Developing Economies). For instance, conclusions are drawn from the discussions and presentations given in the First International Conference on Low Voltage Direct Current – LVDC Redefining the Electricity.

Acknowledgement

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Lappeenranta, October 2016

CONTENTS

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Abbreviations

a.c.	Alternating current
ANSI	American National Standards Institute
BIS	Bureau of Indian Standards
CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
CISPR	Comité International Spécial des Perturbations Radioélectriques (International Special Committee on Radio Interference)
CLC	abbreviation for CENELEC
d.c.	Direct current
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE)
EMC	Electromagnetic compatibility
EN	European standard
ETSI	European Telecommunications Standards Institute
EV	Electrical vehicle
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
ITU-T	International Telecommunication Union
SAE	Society of Automotive Engineers
SFS	Suomen Standardisoimisliitto SFS ry (Finnish National Standardisation Organisation)
SEG	Systems evaluation gorup
SG	Strategy group
SESKO	Suomen Sähköteknillinen Standardoimisyhdistys ry (Electrotechnical Standardization Organization of Finland)
SK	Standardointikomitea (technical committee in Finnish)
TC	Technical Committee
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik (Association for Electrical, Electronic & Information Technologies)

Executive Summary

The lack of and the slow development standardisation are often mentioned obstacles for the deployment of novel technologies in industry. Without standardisation there are no certified products, reliable guidelines or even certainty of the availability of products compatible with a certain technology in long run. Hence, this report addresses the status and development of the standardisation of the low-voltage direct current (LVDC) distribution.

Current status of standardisation

From the perspective of public power distribution, LVDC is already quite well covered in the standards dealing with installations and basic equipment used in the utility networks. Standards defining the properties of most of the equipment already exist either as European standards (CENELEC) or Global IEC standards.

Starting from the equipment, use of typical low voltage power cables in d.c. systems is defined in the European harmonisation document CLC HD 603 and in the Finnish national standards (SFS 4879, SFS 5801). Similarly, definitions for d.c. use are incorporated in the IEC standards for switchgear and controlgear assemblies (IEC 61439-series), enclosures (IEC 62208) and breakers for industrial applications (IEC 60947-series), all of which have also been approved as harmonised European standards.

Regarding the transversal systemic standards, the IEC 60364-series (Low-voltage electrical installations), its European and Finnish national versions (CLC HD 60364 and SFS 6000) recognise the use of LVDC power distribution systems. Although, most of the series focus on a.c. installations, guidelines are given also for the protection, design and installation of d.c. systems especially in buildings.

Ongoing standardisation development

Standardisation organisations around the world have founded committees, working groups and ad hoc groups to consider the standardisation of LVDC technology. The objectives vary depending on the aims and needs of the local industry, but most of the work is focusing on the equipment for private electrical systems and certain limited industrial applications. External to official standardisation organisations, several industry consortia are also developing their own practices.

The industry activity have already resulted in the introduction of new proposals and amendments to existing standards. Work is going on in several technical committees of IEC (e.g. TC8 and TC 64), on national level (e.g. Germany, India, Japan and Netherlands), and by other standardisation organisations (CENELEC, Emerge Alliance, IET). The first set of global standards is already under development. In Finland, the work has been channelled through the SESKO SK8 (a mirror committee for the TC8).

IEC has taken the leading role in coordination of the standards development, first, by establishing the Strategy Group 4 (LVDC distribution systems up to 1500V DC) in 2009, and later in 2015, by establishing the Systems Evaluation Group 4 to continue the work. During the two-year term of the SEG 4, the development of the system level transversal

standardisation was recognised as the most critical standardisation need. Basically, this means definition of the general technical characteristics and agreeing on the form of standardisation, that are both issues in which the consensus will not be found easily. Several d.c. standardisation projects have been initiated by the IEC TCs. For instance, the TC 23 (Electrical accessories) is currently working with the standardisation of plugs and sockets used in d.c. powered data and telecom centres. Also the work in TC8 to specify the operating voltages for d.c. systems is driven by the datacentre applications.

Further development needs

Major gaps in the equipment standardisation are related to the properties and type testing of the converters and the generic system properties. The most severe deficiencies are the lack of standardised voltages, limits and testing procedures for the electromagnetic emissions caused by the converters belonging to the utility network in different applicable system setups, immunity of the equipment, measures to mitigate electromagnetic interferences between the public and private installations, and the standardised definitions for the operational properties of devices to ensure interoperability.

Without reasonable standards and coordinated standardisation development processes the first adopters of new technology are taking remarkable risks. On the other hand, the standardisation development in the electricity sector has traditionally been subsequent to the market development. For the past hundred years after agreeing on the general characteristics of electrical energy supply, the standardisation of system, equipment and device properties has been realised as an ex-post process based on compromising between regional practices and market winning technologies. Until the recent years, this has been possible partly because of the nature of technology and market development, both having the strongest focus on consumer appliances. However, considering the modern business environment and the ongoing inevitable change of the energy infrastructure, the standardisation is happening too slowly. Strong coordination and proactive approach are needed to enable development of the first set of transversal LVDC standards.

The most important enablers for the development of coherent set LVDC standards are the thorough use case mapping based on a well-defined methodology and system oriented coordination of the technical standardisation work.

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1 Introduction

There are two main goals for electrotechnical standardisation. First is obviously to ensure safety, that is further divided into safety of living organisms and property and functional safety of electrical equipment. The second is ensuring compatibility, that is further divided into electromagnetic compatibility, compatibility between equipment generations (life-cycle management) and today increasingly also compatibility with information systems. Standardisation can open markets to fare competition that benefit both the users and manufacturers. It increases the confidence to the technical solutions. When solutions manufactured and installed according to standards are used, at least some coordinated level of safety can be ensured. Furthermore, standardisation facilitates the life-cycle management by enabling compatibility between the products of different manufacturers and also between different product generations. Without standardisation, the manufacturers are uncertain of the common specifications for their products, whereas the users cannot be sure of the applicability of the products for their use cases.

At the moment, the situation of low-voltage direct current (LVDC) technology is characterised by the above mentioned uncertainties due to defective standardisation. This situation that hinders the development of both the markets and standardisation is well known amongst the industry, researchers and standardisation organisations (SDOs), and is often referred as the chicken-or-the-egg problem of LVDC. Work for resolving the situation hindering in good progress. However, there are pitfalls to beware both in the development of the contents of the standards and in the process itself. This research report focuses on analysis of the status of currently available electrotechnical standards and development of the standardisation from the perspective of using LVDC networks in public power distribution. In addition to the state-of-the-art analysis, the further needs to develop the standardisation are listed and the standardisation processes discussed. The concept of public LVDC distribution considered in this report is presented in Figure 1.1.

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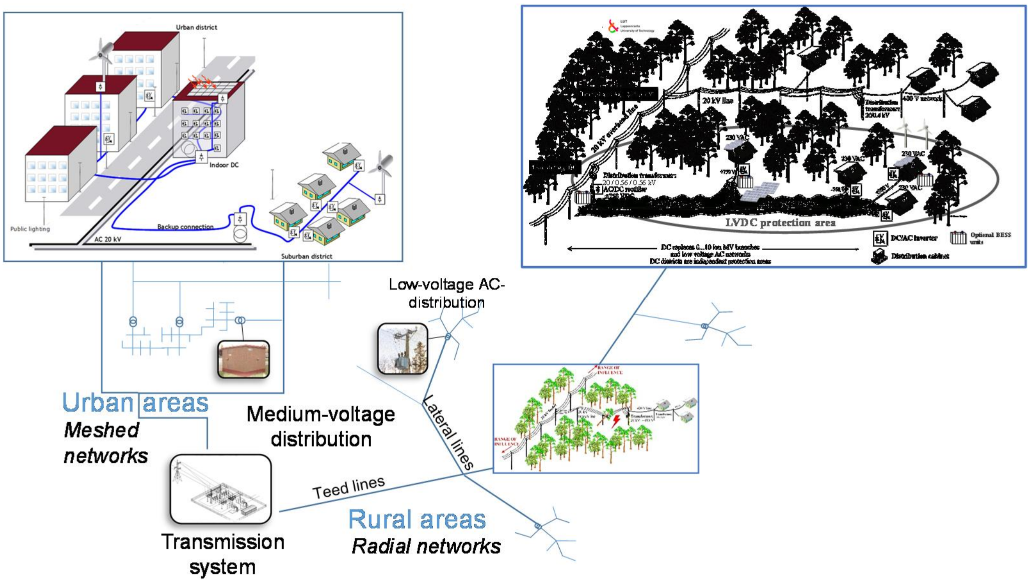

Figure 1.1 Concept of public LVDC distribution. In the considered system, the LVDC distribution is used as an intermediate distribution system between medium voltage a.c. network and customer-end a.c. installations. The LVDC network is connected with the medium voltage network through a bidirectional rectifying converter and with the building installations through a customer-end inverter. The converters belong to the utility infrastructure.

In 2016, VDE e.V. (Association for Electrical, Electronic & Information Technologies) and DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) published the German standardisation roadmap for LVDC standardisation. The report presents a wide review of the current status of German and European electrotechnical standardisation from the perspective of LVDC in general, starting from the basic safety requirements and the hazards of d.c. current on human beings and ending up to product standards. (VDE 2016) Despite of its wide spectrum, the German LVDC standardisation roadmap approaches the topic mainly from the perspective of private electrical systems, especially the building installations. The presented requirements and listed standards are mostly relevant from the perspective of public installations too, but it is likewise important to recognise the differences arising from the application environment and applicable system structures. Hence, this report expands and supplements the review of the status of LVDC standardisation presented in the German roadmap from the perspective of public LVDC networks.

The objectives of the reported work have been to:

- identify and analyse existing standard requirements for LVDC equipment and its functionalities
- compile information of ongoing standardisation development work on different levels and geographically
- identify and prioritise standardisation gaps and development needs

- discuss about the standardisation process and its organization on different levels
- support the development of standardisation by giving recommendations for the SDOs currently working with the topic

Use case specific standardisation has been published for d.c. powered data and telecom centres on the lead of ITU-T (L.1200-series) and ETSI (ETSI EN 300 132-3-series). These define the main system properties and give design guidelines for applying 400 V LVDC system in data and telecom centre environment.

In addition, several industry consortia and advocacy organisations have developed industry practices for various d.c. systems. Examples of such stakeholders are the USB implementers forum (max. 20 V, 5 A, point-to-point d.c. supply, USB Type-CTM(PD)), EMerge Alliance (24 V solution for lighting and appliance supply in occupied spaces, 380 V solution for data- and telecom centres), The IET (Code of practice for LVDC in buildings, application guide for versatile solutions from PoE to low voltage d.c. distribution over the proprietary cabling), and ACEA, SAE and CHAdeMO (DC charging of EVs, 250-600 V, up to 400 A). Major part of the work done by these groups is focused on other than utility use cases of d.c. power, but it is still likely to have strong effect on the development of transversal systemic standardisation for LVDC.

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2 Current status

LVDC represents a novel, emerging solution that is expected to have several use cases and various applications in different environments. Considering its use in public power distribution, the use cases range from rebuilding of the rural electricity distribution to reinforcing of the power intensive areas and providing electricity access in developing countries. More mature use cases are found, for instance, within the traction systems, auxiliary power supply systems, industrial drives systems, where the respective standardization is already well established. Newer use cases of LVDC, which have recently received use-case specific standardisation, include photovoltaic power plants, power supply of data and telecom centres, marine vessel applications and electric vehicles.

In the field of public power distribution the use case specific standardisation has always been less intensive than in case of private systems and their equipment. There is no need to change this situation due to adoption of LVDC distribution, but it is relevant to ensure the availability of applicable standards for relevant apparatus (product standards), overall system properties, design of safe equipment (installations), verification of installations and for working safety. At the moment, standards covering some of the above mentioned relevant aspects already exist, but there are also many gaps especially in the contents of the standards. Harshly put, we live and have lived in AC dominated electricity distribution and as the standardization aims at providing guidelines according to the market needs, the present standardization does not consider LVDC distribution thoroughly. The IEC Systems Evaluation Group 4 (SEG4) has been working with the subject the aim being in filling the gaps by considering especially LVDC point of view (IEC, 2016a). In this chapter the status of the existing standardization is reviewed.

In European Union (EU), the Low Voltage Directive (LVD) 2014/35/EU ensures that electrical equipment operating within the voltage range of 50-1000 V a.c. and 75-1500 V d.c. is safe for consumers and environment. (EC 2014/35/EU). The Electromagnetic Compatibility (EMC) Directive 2014/30/EU ensures that electrical and electronic equipment does not cause electromagnetic disturbance or become affected by it (EC 2014/30/EU). The authorities on EU and national levels have prepared and publish the lists of technical standards that give the detailed guidelines for product and equipment design so that the requirements of the directives are fulfilled.

2.1 System and equipment

The two principal characteristics of a distribution system, affecting both the safety and functionality, are the utilised voltage level(s) and the earthing system. Voltage have been divided into two ranges, high voltage and low voltage. The latter includes also the so-called extra low voltage range. In Europe, the voltage bands specified by IEC are followed. Table 2.1 presents the low and extra-low voltage bands according to IEC 61140 (Protection against electric shock - Common aspects for installation and equipment), that nowadays includes the contents of the lately withdrawn standard IEC 60449 (Voltage bands for electrical installations of buildings).

Table 2.1 Low- and extra-low voltage bands (IEC 61140)

Voltage band	a.c.	d.c.
Low voltage (LV)	≤ 1000 V	≤ 1500 V
Extra-low voltage (ELV)	≤ 50 V	≤ 120 V

In addition, boundaries for line voltages are specified as presented in Table 2.2.

Table 2.2 Voltage bands (IEC 60449, IEC 61140)

Earthed systems [VDC]		**Isolated or not effectively earthed systems [VDC]**
Pole to earth	Between poles	Between poles
120≤*U*≤900	120≤*U*≤900	120≤*U*≤900

IEC 60038 lists the rated nominal system voltages, gives recommendations for selecting equipment voltages and also lists equipment voltages for certain systems, and defines operating voltages (utilization voltages). At the moment the standard lacks general definitions for d.c. distribution systems, but gives recommendations for d.c. traction systems and for equipment voltages up to 750 V d.c. Obviously, the definitions are based on electrical systems used in traction. In North America further specifications are also given in ANSI C84.1

In practise the standardization thus allows the use of up to ±750 VDC in bipolar systems and 1500 VDC in unipolar systems. Referring to the preferred voltage levels, one of the questions is whether there is a need to specify certain voltages to be applied in LVDC systems, or, is it sufficient to only limit the band, such as from 120 VDC to 1500 VDC.

Insulation coordination

Insulation coordination is also an important theme which is covered in IEC 60664-1 up to 1500 VDC. However, the tables for rated impulse voltages gives values only for systems having nominal voltage up to 1000 V. The rated impulse voltage values for d.c. systems are supplemented in Annex D of IEC/TR 60664-2-1 to include systems having nominal voltage up to and including 1 500 V. The impulse voltage requirements up to 1500 V d.c. are presented in Table 2.3.

Table 2.3 Impulse voltage ratings according to different standards

Voltage line to neutral derived from nominal voltages a.c. or d.c. up to and including [V]	Rated impulse voltage for equipment for the overvoltage categories [V]				Reference publication
	I	II	III	IV	
50	330	500	800	1 500	IEC 60664-1
100	500	800	1 500	2 500	
150	800	1 500	2 500	4 000	
300	1 500	2 500	4 000	6 000	
600	2 500	4 000	6 000	8 000	
1000	4 000	6 000	8 000	12 000	
1200	5 000	6 000	8 000	12 000	IEC 62497-1
1500	6 000	8 000	10 000	15 000	IEC 60664-2-1

Electromagnetic compatibility (EMC)

From the system perspective the key EMC publications concern the specifications for electromagnetic environment and compatibility levels (design levels for systems). The compatibility levels can be used as guidance for setting limits for disturbance emissions and immunity of equipment by product committees and other relevant bodies. Separate rules apply for different parts of an LVDC network. Basically the requirements can be divided to those that deal with 1) the supply of customer-end installations, 2) public LVDC network and 3) the interface to public medium voltage network. Nevertheless, the system has to be compliant with the existing installations and cannot disturb the operation of other systems, such as ones operating in radio frequencies (RF). In LVDC systems, the EMC-theme is one of the most essential ones as the system is constituted by utilizing the converters.

The compatibility levels for customer-end supply (1) voltage quality requirements are given in EN 50160, that is based on the requirements defined in IEC 61000-3-3 and IEC 61000-2-8. The methods for measuring the supply voltage quality is specified in IEC 61000-4-30. Furthermore, the IEC 61000-2-2 gives limits for low-frequency conducted disturbances and signalling in 50 Hz and 60 Hz a.c. systems with voltage up to 420 V, single-phase or 690 V, three-phase. Considering that the customer-end inverter is a part of the public network, the limits for public low-voltage power supply systems apply in its a.c. output, that is, at the same time the input terminal for the building installation. However, it has to be noted that in case of considered LVDC system, this is not the point of common coupling for the public low-voltage system. In North America respective requirements for compatibility levels are given, for instance, in ANSI C84.1, IEEE 1159, IEEE 519. In an LVDC network, where the customer supply voltage is formed by the customer-end inverters, the requirements for the supply voltage quality can be met and exceeded quite easily.

When considering the DC mains (2), the current EMC standardisation is mostly lacking. From the basic EMC publications relevant parts of the IEC

61000 series include IEC/TR 61000-2-1, IEC 61000-2-2, IEC/TR 61000-2-3, IEC/TR 61000-2-8. All the mentioned standards are written from the perspective of a.c. networks. Furthermore, the standards do not recognise the situation in which the public low voltage network is separated from the customer-end installations and from the supplying medium voltage network with power conditioning converter, that either mitigates or totally prevents propagation of disturbances.

The compatibility levels in interconnection of an LVDC network with an public medium voltage distribution system (3), the limit values for low-frequency conducted disturbances and signalling are defined in IEC 61000-2-12. The standard specifies compatibility levels in the point of common coupling of a public medium voltage network with private installations connected directly or through transformers, or substations feeding public low-voltage distribution systems.

To facilitate the system design, the IEC/TR 60725 describes reference architectures for low-voltage supply systems and their reference impedances in case of supplying residential, commercial and light industrial premises. These apply for conventional a.c. systems, and have been found to describe quite poorly the situation in typical Nordic rural environment. Furthermore, they are not applicable in case of inverter supplied premises. Different approach need to developed for LVDC distribution. In converter-fed systems the question is more of balancing between the active mitigation of disturbances by means of control and filtering and the instantaneous level of interferences.

Considering the application environment, special attention has to be paid on the climatic overvoltages. To enable the design of the overvoltage protection, the IEC/TR 61000-2-14 describes various overvoltage events that are typical for public low and medium voltage networks. Events are categorised with respect to relative magnitude, duration and energy content. Recommendations are given regarding mitigation of the risks of equipment failures.

Guidelines for EM disturbance mitigation

The mitigation of electromagnetic interferences is considered in the documents belonging to the IEC 61000-5 series. The parts -5-1, -5-2, -5-6 give guidelines for mitigating the conducting and radiating interferences by the means of cabling and earthing system design, shielding and screening, and . Aligned guidelines are given in the national SFS 6000-4-44 standard that is based on IEC 60364-4-44,CENELEC HD 60364-4-442, HD 60364-4-443 and HD 60364-4-444. The main problem is, that the mentioned standards do not recognise a d.c. network matching with the considered concept. Furthermore, the scope of the IEC standards is limited to industrial, commercial, and residential environments.

The IEC 61000-5-7 considers protection of sensitive electrical and electronic devices against external electromagnetic interferences. It defines means to evaluate the shielding performance empty mechanical enclosures and is thus aimed to allow manufacturers to select suitable casings for their apparatus. This standard is generic and suits well also for LVDC distribution.

Earthing and safety

From the safety perspective it need to be noticed that the selection of the voltage level is tied to the used earthing system. The selection of the earthing system affects the protection equipment that is discussed in section 2.5. The two main earthing systems are earthed (TN) and earth isolated (IT) systems which have been defined in IEC 60364 and in North America in IEEE 142 and National Electrical Code (NEC). The above mentioned existing standards also enable use of single point earthed system (TT). In addition to the basic earthing system definitions, no further guidelines are given for the selection and design of the earthing system for public LVDC distribution, that is, a clear gap.

The main safety regulations come from the IEC 60364 series which discusses also the DC-related issues. Touch voltages should be limited to 120 VDC in DC systems according to IEC 60364-1 or automatic disconnection of fault need to be applied. The required switch-off-times for the latter are defined in IEC 60364-4-41. In addition, the Finnish national standard SFS 6000-8-801 (additional requirements for public distribution) gives some further guidelines, but the specifications are only defined from the perspective of existing a.c. systems.

In addition, some characterisation of DC short-circuit current calculations are given in IEC 61660 for auxiliary installations such as substation systems etc. For the safety of the system, the principal guidelines exist. The challenges are related to proving of the short-circuit currents for conventional protection devices in customer installations which enforces the dimensioning of the converter according to the maximum current demand. That in turn leads into higher component rating, increased costs and decreased efficiency. If the converter itself could be classified and tested as protection equipment (“relay”), the issue could be resolved more intelligently.

One of the DC specialities is corrosion which may cause premature aging of the materials as a result of stray currents. It is somewhat unknown what is the severity of the issue, in earth isolated or high impedance earthed LVDC systems. However, when considering that 1 A constant d.c. current will corrode about 9 kg of steel within a year, even a small current can cause problems with steel reinforced buildings over long time periods (tens of years). At least in earth isolated system, the total isolation level is being monitored and therefore the operation of the setup is constantly monitored. General guidelines and methods to avoid corrosion are given in EN 50162.

2.2 Installation and assembly

The IEC 60364 series and its European and national versions CLC HD 60364 and SFS 6000 series give the basic definitions for the design and installation of LVDC distribution systems. The standards define the basic structures and applicable earthing systems, and give applicable guidelines for selecting and connecting power cables. Furthermore, generic limits are given for the time of disconnecting supply for fault protection in installations realised with different earthing system alternatives.

The Finnish standard series includes a national part SFS 6000-8-801, that gives further specifications for public low voltage networks. The scope includes both a.c. and d.c. networks with nominal voltage up to and including 1000 V a.c. and 1500 V d.c. The generic definitions are well-applicable for d.c. systems. However, it is preferred to update the standard to give specific definitions for d.c. distribution that take into account the features of converter fed systems and the related additional level of safety. Furthermore, if the guidelines for the fitting personnel are considered, there is certainly a need for respective standardisation.

International standard IEC 60364-6 and its national version SFS 6000-6 deals with the verification of installations. Furthermore, in Finland a further verification inspection has to be conducted for all public distribution systems within a year from the commission (KTMp 517/1996). The procedure is described in national standard SFS 5825. Both of these standards are basically written for a.c. installations, but can be partly applied also for d.c. installations. The adapted procedure for installation verification for public LVDC distribution system is discussed in (Nuutinen et Al., 2012). For the measuring equipment used in inspections, there is the IEC and EN standard series 61557 which ranges up to 1500 VDC.

As the LVDC system may include a battery, relevant guidelines can be found from the standards EN 50272-2 and IEC 62620 that deal with stationary battery installations. Furthermore, as an island network can be realised, guidelines given in IEC/TS 62257 for design, operating and maintaining an LVDC system capable to island operation may be applicable.

The IEEE project P946 “*Recommended Practice for the Design of DC Power Systems for Stationary Applications*” appears promising as it seems to cover all key aspects. However, its applicability to public power distribution especially outside North America will be seen as the project is based on earlier document dealing with auxiliary d.c. installations.

2.3 Network equipment

The use of existing cables with LVDC is basically enabled through the CENELEC harmonization document (HD) HD 603 that apply for the low voltage power cables with rated voltage of 0.6/1 kV. The international IEC 60502-1 does not take into account the d.c. use.

For aerial conductors there are various national standards in different countries. For instance in Finland there is SFS 2200, that is, based on the harmonised European specifications given in CLC HD 626 for overhead distribution cables with rated voltage of 0.6/1 kV. The d.c. use of overhead cables is not recognised by the existing standards, but related work is going on. For the aerial lines using uninsulated wiring and separate insulators, the standard IEC 61325 gives requirements for use with voltages above 1000 VDC.

For the cabinets and more importantly for the assemblies the recently renewed standard series is IEC 61439 including the parts presented in Table 2.4. The series ranges up to 1500 VDC which is promising from LVDC point of view.

Table 2.4. IEC 61439 series

IEC 61439-1	General rules
IEC 61439-2	Power switchgear and controlgear ASSEMBLIES
IEC 61439-3	Distribution boards
IEC 61439-4	ASSEMBLIES for construction sites
IEC 61439-5	ASSEMBLIES for power distribution
IEC 61439-6	Busbar trunking systems
IEC/TR 61439-0	Guidance to specifying ASSEMBLIES

However, the problems may arise as soon as the setup, i.e. the whole assembly is considered. It might be difficult to ensure that the entity is compliant with the parts in itself or with the surroundings. This is especially challenging, as some parts in the assembly may not be considered to be used in the LVDC distribution application.

For the empty enclosures IEC 62208 is a valid standard for indoor and outdoor use, up to 1500 VDC. Correspondingly, for the households and respective installations there is IEC 60670 series.

For the measurement (static meters) for DC usage there is a working draft of IEC 62053-41 which could provide valuable information considering the possibility of using of the converters as measurement devices.

In LVDC systems, transformers are also needed. The cornerstone of transformer standardization is IEC 60076. More particularly, for this type of use IEC 61378-1 with respective references deals with the use of transformers with power electronics, especially in industrial applications.

2.4 Power electronics

As the LVDC distribution system utilises converters, one of the main standardisation themes is related to power electronics and especially to their EMC requirements. With power electronics, the voltage variation and frequency are easily maintained among the limits, which, defined by the standards, are actually somewhat loose. The related key documents from the system perspective were discussed in section 2.1.

For converter designer the relevant question is: what are the limits for emissions and immunity? These are further divided into limits for conducting voltage and current disturbances and limits for radio frequency interferences. The generic rules are given by the IEC 61000-6 series, parts of which the most applicable ones are -6-3 and -6-1 for immunity and emissions of the customer-end inverters and -6-5 for the immunity of the rectifying converter. No applicable generic definitions exist for the emissions caused by the rectifying converter into the medium voltage network.

When considering the low frequency phenomena in customer-end a.c. supply, the compatibility levels defined in EN 50160 and IEEE 519 can be used as design limits for output voltage control engineering. For the harmonics injected into the public electricity network there are two standards, IEC 61000-3-2 and 61000-3-12 that set the limits for the injection. For the conducting disturbances in the range of 0-150 kHz the IEC 61000-6-3 is a sort of a general document if none other exists but is clearly for AC systems point of view.

An applicable guidelines for the design of the rectifying converter are given in the technical specification IEC/TS 62578:2015 "*Power electronics systems and equipment - Operation conditions and characteristics of active infeed converter (AIC) applications including design recommendations for their emission values below 150 kHz*" However, this is not a standard that set limits and gives procedures for compatibility testing, but describes valuable calculation methodologies for system engineering.

In addition, there are product standards by the TC22 and its sub-committee SC22E, such as IEC 61204-3 that sets requirements for the EMC of power supplies up to 1000 VDC, and IEC 62477-1 that defines safety requirements for the stand-alone UPS-systems. The applicability of the given guidelines still need to be further reviewed from DC distribution point of view.

The CISPR 16 series gives comprehensive definitions for compliance testing of devices with respect to the radiating emissions. Further guidance is given in CISPR 18-2 for measuring the emissions in overhead line networks. When considering the embedded communications system of an LVDC network, the emission limits and related tests are defined in CISPR 22. For the communication, in addition to CISPRs, there is national SFS-EN 50065-1 which considers the EMC among the frequency band of 3…148,5 kHz.

Finally, the IEC 61000-4 series gives in overall comprehensive guidelines for laboratory environment compliance testing of the converters.

Outside Europe, other relevant guidelines are also given in UL 1741 for the connection of distributed energy resources (DER) and in Mil-Std-461F for the electromagnetic interferences (EMI).

2.5 Protection equipment

The main standard series concerning the protection equipment is IEC 60947 including the parts listed in Table 2.5. Solid-state-breakers (SSB) are not included. For fuses there is separate IEC 60269-1 standard. For the analysis on “*Effectiveness of residual current devices (RCD) in TT, TN and IT systems*” there is IEC 61557-6 standard. All of the mentioned range up to 1500 VDC.

Table 2.5. IEC 60947 series

IEC 60947-1	General rules
IEC 60947-2	Circuit-breakers
IEC 60947-3	Switches, disconnectors, switch-disconnectors and fuse combination units
IEC 60947-4	Contactors and motor-starters
IEC 60947-5	Control-circuit devices and switching elements
IEC 60947-6	Multiple function equipment
IEC 60947-7	Ancillary equipment

Other important protection devices are insulation monitoring devices (IMD) and surge protective devices (SPD). The respective standards are IEC 61557-8, IEC 61643 and EN 50539-11 all of which follow the LV range definition. The protection category is a good example of relevant standardization, which exists also from LVDC distribution perspective. The reason is that there has been a need for such components and corresponding standardization has been developed which now supports also this DC application. However, despite the standardization the availability of products might decrease along with the greater DC mains voltage levels. It however, is, a temporary problem which resolves itself if sufficient demand arises.

3 Ongoing development work

3.1 IEC activities

The IEC got deeply involved in LVDC standardisation development in 2009, when the standardisation management board (SMB) decided to establish the strategic group 4 (SG4) – LVDC distribution systems up to 1500 V DC – based on the proposal by the Swedish national committee. The term of the SG4 was 5 years (2009-2014). The original scope was wide and ambitious and included addressing the market development, determination of the priorities and directions for standardisation, and to set up a roadmap for systematic LVDC standardisation. As the work progressed, also the goals and abilities to reach them started to narrow and become clearer. Finally in its final report to the SMB, the SG4 recommended two main actions to be taken: 1) establishment of a new systems evaluation group to develop a architecture of the LVDC standardisation work program and 2) standardisation of the nominal voltage used in d.c. installations in data centres and telecom centrals to be selected from the range 380 V ± 20 V.

SEG4

Based on the SG4 recommendations, the SMB set up the systems evaluation group 4 (SEG4) – Low Voltage Direct Current Applications, Distribution and Safety for use in Developed and Developing Economies.

The task of the SEGs is to cover the gap between the emerging technologies and the work of the technical committees in areas requiring systems approach in standardisation development. Unlike the technical committees, the SEGs are open to external experts in the related field. Thus participation does not require one to be appointed by a national committee, but anyone working on the field can apply for membership from the IEC secretariat. In this way the knowledge of the experts working with the newest technologies, and that typically are not involved in standardisation, can be engaged in the standardisation work. The external experts bring new information and perspective that may expedite the work significantly.

The main goal of the SEG4 has been to create a work program for the development of international LVDC standardisation. The SMB defined the scope of the work as follows:

"*The SEG will identify new areas of standardization to be undertaken by the IEC. The SEG will evaluate the usage of LVDC in different integration environments in developed and developing economies with the objective to enhance energy efficiency and to develop new ways to utilize LVDC power. The SEG will actively engage with relevant stakeholders within the IEC and external stakeholders already working in the field of LVDC. Under the active participation of the existing TCs and external stakeholders, the SEG shall:*

- *Evaluate and if necessary define the voltage parameters for LVDC*
- *Evaluate the existing market for LVDC products and applications*

- *Project the future market for LVDC products and applications using information from current studies and simulation models*
- *Define use cases for the integration of DC infrastructure in the different areas (residential, commercial, public, industrial, premises, Renewable Energy, E-Mobility)*
- *Evaluate the future applications for DC*
- *Evaluate the status of safety in LVDC and the appropriate place for further standardization of LVDC safety to be located*
- *Evaluate the advantages and disadvantages of the usage of LVDC (energy efficiency, regulation, and transmission…)*
- *Review the inventory of existing standards and standardization projects inside and outside IEC*
- *Evaluate gaps in standardization by using a use case mapping tool*
- *Define a structure for the coordination of cross TC/SC work in IEC, where required*
- *Monitor TC/SC work in IEC to highlight any overlap of work or potential inconsistencies*
- *Recommend technical work to define the LVDC network and grid*

The SEG shall work in close collaboration with SEG 6 Non-traditional Distribution Networks / Microgrids. The SEG is requested to provide the SMB with its recommendations on an approach to standardization in this area" (IEC 2016a)

The call for members of the SEG4 was published in November 2011 soon after the SMB decision to establish the group and the SEG4 started its work in January 2015. By September 2016, the SEG 4 had reached its main goals and reported its findings to the SMB. In between, six SEG meetings and an international conference were organised. One more SEG 4 meeting has been planned to take place in January 2017, before the group will be disbanded and the recognised further tasks handed over to the other bodies of IEC.

The internal organisation of the SEG 4 comprises six working groups:

- WG1 Current status, Standards and standardization
- WG2 Stakeholder assessment and engagement
- WG3 Market assessment
- WG4 Collection and rationalization of current voltage data
- WG5 Collection and rationalization of LVDC safety data
- WG6 LVDC for electricity access

Work in TCs

Several IEC TCs have started the work to standardise different aspects of LVDC systems. Most of the work has been initiated either as a result of a proposal by a national committee or based on the recommendations of another IEC body. Following paragraphs introduce some of the relevant TC projects.

TC8 (Systems aspects for electrical energy supply) is currently working to standardise operating voltages for d.c. systems. Basically this means updating the IEC 60038 standard. The work was initiated according to the SG4 proposal. The focus has been on voltages applicable in data and telecom centrals, but the overall aim has been to specify general list of primary and secondary operating voltages for all d.c. use cases. Also the table of rated equipment voltages in the IEC 60038 is going to be updated accordingly. (IEC 2016b) Use case specific system standardisation, overlapping the existing ITU-T and ETSI definitions, has not been seen necessary.

TC13 (Electrical energy measurement and control) has started a project on the requirements for d.c. energy meters for the voltage range up to 400 V d.c., IEC 62053-41 (Electricity metering equipment (DC direct current) - Particular requirements - Part 41 - Static meter for active energy (class 0.5 and 1)). The main objective is to standardise the d.c. energy meters for indoor applications, e.g. for measuring the household energy exchange with public network. (IEC 2016c)

SC22E (Stabilized power supplies) is currently finalising new standards (IEC 62909-1 and -2) for grid connected bi-directional AC/DC converters to interface various d.c. applications with a.c. grid in the voltage ranges up to 1000 V a.c. and 1500 V d.c. UPS systems, are not included in the scope. SC22E is also working to update the standards of low-voltage power supply units (PSU) with d.c. output (IEC 61204-series) and supplied from a.c. or d.c. source voltages up to 600 V a.c. or 1 000 V d.c. The scope of this series is limited to PSUs in individual apparatus and component PSUs used as a part of fixed installation or incorporated in other devices. It does not cover devices specified in the publications of other TCs. (IEC 2016d)

TC23 (electrical accessories) is working to standardise plugs and sockets for various use case of LVDC. At the moment the main focuses are aimed on technical specifications for plugs and sockets for data centres and other access controlled areas in power range from 2.6 to 5.2 kW, IEC/TS 62735-2. (IEC 2016e) The work aims to supplement the ITU-T and ETSI 400 V d.c. data and telecommunications centre standards with related electrotechnical product standardisation.

SC23E (Circuit-breakers and similar equipment for household use) has two ongoing projects related with LVDC: IEC 60898-3 (Circuit-breakers for overcurrent protection for household and similar installations- Part 3: Circuit-breakers for d.c. operation) and IEC/TS 63053 (General requirements for residual current operated protective devices for D.C. system) (IEC 2016f)

TC64 (Electrical installations and protection against electric shock) working to update the IEC 60364 series. This work includes also considerations on the rules for d.c. installations. Furthermore, based on the new proposal made by the German national committee, the TC 64 has started to develop the technical specification IEC/TS 61200-1 (Application guide: Residential electrical installation in direct current not intended to be connected to Public Distribution Network). (IEC 2016g)

IEC-BIS LVDC conference

The IEC SEG 4 organised together with the Indian Institute of Technology a two-day international conference on LVDC. The conference was named LVDC- Redefining Electricity. It took place in New Delhi, India, on 26-27 October 2015 and was hosted by BIS. The proceedings are openly available in http://lvdcconference.com/.

The objective of the conference was to highlight applications and use cases of LVDC technology, showcase the practical achievements and the state of the art, and expedite the standards development by bringing together a large number of the key stakeholders. The conference type was an expert seminar, and thus, no open call of papers was published. All the speakers were selected by the organising committee amongst well-known experts in LVDC technology having both academic and industry background.

In total 28 speakers were selected to give their presentations in the six technical sessions. Keynote speeches and synthesis were by 11 speakers, including Mr. Jim Matthews, the Chairman of the IEC SMB, and the secretaries representing the Indian Ministry of Power, Ministry of Consumer Affairs, and the Ministry of New and Renewable Energy. Each WG Convenor acted as the chairman of a technical session. The conference program is presented in Table 3.1 below.

Table 3.1 Main program of the IEC-BIS LVDC conference

26 OCTOBER 2015	
Inaugural Session (6 speakers)	
Technical session 1 (two themes parallel in two rooms):	
Data Centers (4 speakers)	Public Electrical Systems-Last Mile (5 speakers)
Technical session 2 (two themes parallel in two rooms):	
Electrical Equipment (5 speakers)	Private Electrical Networks (4 speakers)
27 OCTOBER 2015	
Morning Key Note speaker Secretary of the Ministry of New and Renewable Energy	
Technical session 3 (two themes parallel in two rooms):	
LVDC for Mobility (Marine vessels, Aircraft, Automobile, EV Charging, Railways) (5 speakers)	Rural Homes / Electricity Access (No Grid Connectivity, Developing Economies) (5 speakers)
Summary session	
Synthesis and major outcomes from the technical sessions presented by the 6 session chairmen and overall conclusions presented by the SEG 4 Convenor	
Conclusions and Next Steps (Presented by Jim Matthews)	

The summary of the main outcomes of the technical sessions pertaining to the state-of-the-art and the development needs of standardisation are presented in Table 3.2 – Table 3.7.

Table 3.2 A1 Data centers.

Present standards and industry practises	Needs to develop standardisation
– use case is well covered in existing telecom standards	– electrical equipment used in d.c. installations – voltage characteristics

Table 3.3 A2 Electrical equipment

Present standards and industry practises	Needs to develop standardisation
– some equipment standards are available for the mature use cases, e.g: o industry o traction and electric road vehicles o data and telecom centres o PV installations	– protection equipment is priority (e.g. RCDs) – nominal operating and equipment voltages and voltage characteristics – use-case specific equipment and product standards – safety requirements for battery energy storage systems with different chemistries – Collaboration between TCs needed

Table 3.4 A3 LVDC for Mobility

Present standards and industry practises	Needs to develop standardisation
– 750/1500 V d.c. traction system is de-facto and well-standardised – ISO and IEC standards exist for electric road vehicles and their charging systems	– voltage standards should be aligned between ISO and IEC – marine and aviation installations

Table 3.5 B1 Public Electrical Systems

Present standards and industry practises	Needs to develop standardisation
– Use case is not directly standardised but there exist several applicable standards written for other use cases – existing rules for installation and system design mostly applicable	– updating existing standards for installation and system design – nominal operating and equipment voltages and voltage characteristics – EMC requirements for converters used as a part of utility grids – power electronics based protection methods – interconnection rules for DER units – inspections – working safety

Table 3.6 B2 Private Electrical Networks

Present standards and industry practises	Needs to develop standardisation
– existing rules for installation and system design mostly applicable – standards for power electronics used within private installations mostly exist	– updating existing standards for installation and system design – nominal operating and equipment voltages and voltage characteristics – electrical equipment used in d.c. installations ○ protection ○ plugs and sockets for residential and tertiary buildings, and for related applications (such as lighting) – updates of product standards for appliances – working safety

Table 3.7 B3 Electricity Access

Present standards and industry practises	Needs to develop standardisation
– some system level standards of a.c. systems for electricity access exist – standards for PV powered stand-alone d.c. systems exist partially and are under development	– system level specifications for design of equipment intended for stand-alone applications – nominal operating and equipment voltages and voltage characteristics for off-grid systems – safety and protection – products for applications, such as solar pumps – storage systems

From the perspective of the SEG4 work, the conference was a success. The conference attracted more than 200 experts, 40% of them coming from outside India. The expert presentations provided novel information of the use cases of LVDC technology and the discussions triggered during the sessions contributed in induction of comprehensive understanding. The main technical outcomes for LVDC standardisation can be summarised as follows:

- LVDC is confirmed to be a transversal technology;
- The key criteria for d.c. voltage are the resulting power capacity and the safety requirements.
- Five levels of voltages are emerging as a basis for further discussions (in 0 V to 1 500 V range);
- The market is moving towards hybrid installation mixing low voltage a.c. and d.c. ;
- Standardisation of related emerging technologies, such as fuel cells, storage, PV and PoE need to be reviewed closely.

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In addition to the standards, it was noticed in almost every session, that governmental regulations play an important role in development of markets. However, agreeing on and standardising the basic properties of LVDC on global level brings major solution the current chicken-or-the-egg problem.

The IEC-BIS LVDC conference was planned to be the first one in an undefined series of upcoming similar events organised by an IEC body working with LVDC standardisation issues in collaboration with liaisons. No official plans have been announced of the second event so far.

3.2 CENELEC activities

CENELEC has not considered necessary to establish its own coordination group to especially deal with the LVDC standardisation issues on European level. Instead, the European experts have been encouraged to participate in the work of the IEC SEG4. The technical committees will deal with the LVDC standardisation issues based on the needs raised by the national committees and in collaboration with the respective IEC committees.

Before the SEG4 started its term, the CENELEC formed an ad-hoc working group on LVDC. The tasks of this group were to define the objectives and the strategy regarding the way European standardization should address LVDC standardization outside the CENELEC Membership, with a first emphasis on India. The group reported to the CENELEC Working Group on Policy. Based on the report of the ad-hoc group, the CENELEC strategy will be to support the development and deployment of IEC standards globally.

3.3 National activities

In many countries industrial consortia or working groups under the national or regional standardisation organisation (SDO) have been established to work with the LVDC standardisation issues important for the local industry. According to the results of the LVDC survey by the IEC SEG 4, such groups exist at least in Canada, China, Germany, India, Italy, Japan, Korea, Netherlands, United Kingdom and USA.

In North America, the main use cases for LVDC distribution has been considered to be found within buildings. The considered applications include office lighting and d.c. power supply of appliances with technologies such as PoE and USB type-C™, data and telecom centres, and residential microgrids. Outside of these main industrial interest areas, lots of work has also been aimed to develop d.c. based solutions for electricity access.

The major players in LVDC standardisation in Asia are coming from Japan, India, South Korea and China. In India the main focus is on electricity access where as in China industrial applications have been first targeted. In Japan and Korea the work has been mainly aimed on electrical installations in buildings, including the data centres, but it has also been lately expanded to include utility networks or settlement-scale microgrids.

The bureau of Indian standards is developing its own national standard for design and installation of off-grid PV powered ELV d.c. microgrids for providing access to electricity. The scope includes both residential and village-scale installations, nominal voltage of which is 48 V d.c. The proposal has been reviewed also by the SEG4 as a possible basis for an IEC standard on the same area. However, for this field there are also other proposals and also existing standards that have to be carefully reviewed before further actions. In addition to SEG 4, at least the IEC TC 64 and TC 82 are currently working on the standardisation of off-grid systems for electricity access.

In Europe the focus is quite evenly distributed between public and private use cases. Following paragraphs introduce some national actions in European countries.

Finland

In Finland, setting up a national mirror committee for the SEG4, or founding another national group focusing solely on LVDC issues, has not been deemed necessary. The work has been channelled through the SK8 (Systems aspects for electrical energy supply). SESKO officers coordinate the work on national level so that relevant issues are dealt in appropriate technical committees.

In addition to SK8, the SK20 (Electrical cables) has been active in the field of LVDC standardisation. The SK20 working group for underground cables was given an assignment to review the standardisation of low-voltage aerial bundled cables (ABC) and underground cables (UGC) from the perspective of d.c. use. The objective was to update the HD603 and HD626 harmonisation documents as a part of their normal maintenance, if considered necessary. The WG discovered a need to standardise d.c. usage for ABCs as a result of the envisaged market development and the known gap in the existing specifications. No technical reasons for omitting the specifications for d.c. use were found in earlier research (Lahti;Kaipia;& Kannus, 2011), (Suntila, 2009), or were known by the experts in the WG. Consequently, the WG has prepared a proposal for the CENELEC TC20 to define use of ABCs in LVDC systems with rated voltage not higher than 1.5 kV between conductors and 0.9 kV from conductors to earth. The proposal is similar with existing definitions given in the HD603 for the XLPE and PVC insulated low-voltage UGCs that are typical for utility installations.

At the same time the WG gave proposal of the connection of the conductors of three-phase ABCs or UGCs, if they are used in d.c. systems. This proposal was also sent to the SK64 (Electrical Installations and Protection Against Electric Shock) to be considered during the next update of the SFS 6000-8-801 (Low-voltage electrical installations. Supplementary requirements for certain installations. Public distribution networks).

By the time of writing this report, the CLC TC20 or SK64 had not made any decisions dealing with the above proposals yet.

Germany

In Germany VDE has set up an expert group to consider standardisation of LVDC. As a result of the work, VDE and DKE published the German standardisation roadmap for LVDC (VDE 2016). Furthermore, the German national mirror committee for TC64 has proposed publication of a technical specification that gives guidelines for design and installation of standalone residential LVDC microgrids.

Netherlands

In the Netherlands, the national committee NEN (Nederlandse Norm) has established a working group for LVDC standardisation under the NEC64 (national mirror committee for TC 64). The group has been writing a new part of LVDC installations into the NEN 1010, that is the national standard for low-voltage electrical installations based on the IEC 60364 series. (NEN, 2016)

United Kingdom

The Institution of Engineering and Technology (IET) has taken the lead in development of the LVDC standardisation in Britain by publishing the Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings. (IET Standards, 2015) Also the British Standards Institution is strongly involved through the IEC and technical committee work.

4 Further development needs

4.1 Identified main gaps

As mentioned above, from the perspective of public LVDC power distribution, there is no major needs to write completely new standards. Many of the standardisation gaps can be fixed with minor updates or additions to the existing standards. The need of new documents is mainly limited to the standards for power electronic converters used in LVDC networks and to EMC standardisation. The main gaps and proposed actions to be taken are described in more detail below.

National standard SFS 6000-8-801 for public low-voltage installations is missing the key definitions for LVDC distribution, and is proposed to be updated with following:

- overview of applicable system structures and equipment
- operating time requirements for fault protection in LVDC networks
- deviations to existing overcurrent protection requirements
- recommended earthing arrangements and earthing system
- guidelines for defining the short-circuit current supply capability of a customer-end converter and the recommended minimum
- coupling of conductors when an a.c. cable (UGC or ABC) is used in an uni- or bipolar LVDC network
- requirements for wire and cable marking

There is need to update the definitions for the procedures of verification (SFS 6000-6, IEC 60364-6) and verification inspection (SFS 5825) of installations. At the moment these standards include guidelines only for the inspections of a.c. installations.

Use of low-voltage power cables in LVDC systems with rated voltage ≤1,5 kV between conductors and ≤0,9 kV from conductors to earth need to be identified in standard IEC 60502-1. The recommended value of the highest system voltage in above use is 1.8 kV. Suitable values can be extracted directly from the CENELEC HD 603.

The electromagnetic environment specification and the compatibility levels for public low-voltage systems (IEC 61000-2-1 and -2), belonging to the basic EMC standards, are recommended to be reviewed and updated to recognise d.c. distribution. At the moment there are definitions given only for a.c. distribution.

Accordingly, based on the changes to the environment definitions, it is recommendable to review the immunity test standards (IEC 61000-4 series) for possible needs for updates.

Simultaneously with the revision of the electromagnetic environment definitions, it is worth to consider updating also the mitigation guidelines given in IEC 61000-5 series to take into account the public d.c. distribution.

Guidelines are especially needed related to mitigation of disturbances within the public d.c. networks and for considering the impacts of the converters to the propagation of interferences between the public and private installations.

A new methodology for evaluating the compliance with the compatibility levels, that is not based on reference impedances of the network but to the properties of the feeding converters, need to developed to enable system design from EMC perspective. These guidelines can be included either in IEC/TR 60725 or be published as a new technical report.

The generic EMC standards (IEC 61000-6 series) need to be updated to take into account the properties of the public LVDC distribution system or supplemented with a new part that defines emission and immunity for apparatus used in public power delivery. The latter option is recommended as more and more power electronic devices are going to be implemented also into the a.c. networks as primary components in near future.

Furthermore, new EMC product standards have to be developed especially for the power electronic converters of LVDC distribution systems. These are clearly complex products used in special environment compared to the conventional use cases of power electronics, and thus, writing a stand-alone standard is justified. Considering the variation in the properties of the application environment of these devices as well as in the used system structures, more than a single set of requirements is needed. Guidelines for selecting and possibly customising the requirements and related test procedures based on the environmental variables is a crucial part of the new EMC product standards. Based on the work to be done with basic and generic EMC standards by the TC 77, the natural starting point for product standards is the definition of the common emission limits for the active devices connected into a public LVDC network. The development of the product standards requires close cooperation between TC22 (especially SC22E and SC22F) and TC77. Considering the application environment, involvement of TC8 is needed.

Guidelines are needed for performing short circuit current calculations of primary d.c. systems supplied from different sources including both self and line commutated rectifiers, batteries, d.c. generators, etc. This could be either a new document or addition into respective standards for a.c. systems: IEC 60909-series and IEC 60865-1

TC8 and TC64 asked to consider preparing a LVDC systems engineering guidelines similar to the IEC TS 61936-2:2015 (Power installations exceeding 1 kV a.c. and 1,5 kV d.c. - Part 2: d.c.) published by TC99 for high voltage systems.

SC121A and TC 64 are invited to consider the definition of requirements for the performance and use of solid-state circuit breakers and preparing relevant amendments to 60947 and 60364 series.

The use of the converters of an LVDC network as back-up protection devices and identification of the related additional level of safety in installation design need to be considered. TC 64 is requested to take necessary actions.

To close the major gap in voltage standardisation, TC8 is invited to carefully review the final report of SEG4 and consult the experts of SEG4 in order to update the IEC 60038 with 4-6 preferred nominal operating voltage bands for d.c. systems, covering the whole low-voltage range. Respectfully, at least following voltages should be added into the table of equipment voltages for d.c. systems: 750, 900, 1300, 1500 V d.c.

Finally, considering the modern active systems with multiple sources and storages, connection and operating codes are needed for the active networks and interconnected equipment to ensure the safe interoperability. These grid codes for LVDC networks should be considered on the lead of TC8 in collaboration with TC82, TC120, TC22 and other committees found relevant during the work.

As a transversal subject for standardisation, an LVDC standards map similar to the existing smart grid standards map (http://smartgridstandardsmap.com/) is recommended to be created. This would greatly help manufacturers, users and vendors in finding the relevant publications.

4.2 Stakeholders

In addition to IEC, ANSI, IEEE and some national committees, such as NEN, VDE and BIS, the associations of equipment manufacturers and the academia are the most active players in LVDC standardisation at the moment. From the industrial scale users, the most active have been the telecom and data centre industry, and the transportation industry. Some activities seem to be going on also in the real estate sector. The electricity distribution companies and the electrical contractors are still rather passive in standardisation. However, it has to mentioned, that several distribution utilities around the world belong to the group of forerunners.

The key stakeholder groups in LVDC standardisation development are:

- IEC, its liaisons, national committees and other standardisation organisations
- Industrial-scale users of the LVDC technology
    - Distribution network operators / electrical utilities (partly represent also the consumers)
    - Electrical contractors (partly represent also the consumers)
    - Builders, real estate (partly represent also the consumers)
    - Transportation industry and related service providers (marine, aerospace, road vehicles, charging systems, etc.)

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- Telecom and data centre operators, builders and related service providers
- 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
- Academia, education and non-academic research institutes
  - Universities and technical colleges
  - Testing and certification institutes and laboratories
- Versatile energy industries associations, such as IEA
- Other national or regional standardization organizations: CENELEC, Emerge, IEEE, IET, etc.
- Development banks and multi-lateral financial and aid institutions, e.g. World Bank, African Development Bank, USAID, etc.
- Governmental bodies and regulatory authorities

The last three mentioned stakeholders are not expected to participate in the technical standardisation work directly, but the decisions related to energy policies and finding of energy related investments will affect strongly to the development of the markets.

Without the help of national committees engagement of the relevant stakeholders to actual standardisation work will be difficult. Many of the companies working with the LVDC technology are small and do not have much of resources to be used for participation to standardisation. Thus, participation to standardisation needs to be made easy and inexpensive for them, e.g. by organising regional workshops in collaboration with universities.

4.3 Standardisation process

Instead of the rather passive ex-post standardisation and waiting for the market winning technologies to emerge, proactive approach and first defining the common rules can speed up both the technology and market development. Based on the common rules, at least some level of compatibility between competing solutions can be ascertained, enabling steady development of the application and growing trust to LVDC technology in general. A good example of this approach can be found from the field of telecommunications, that has decades of experience in agreement of the general technical specifications for new systems in consensus of the industry, governmental authorities, academics before widespread development of the markets. Of course the same practices cannot be directly adapted to standardisation of electrical systems, but they can and should be learned from.

CLIC

Figure 4.1 presents the structure of electrotechnical standardisation from the perspective of LVDC. As mentioned before, on the horizontal systemic level the need of new standards is limited. However, new use-case specific documents are needed to give guidelines for system engineering and equipment design. The use case standards will be on constant development as long as new use cases appear on the markets. On the equipment component levels, the need of completely new standards is again much more limited, if the IEC succeed in coordination of the work. Some special solutions will be specified such as product standards.

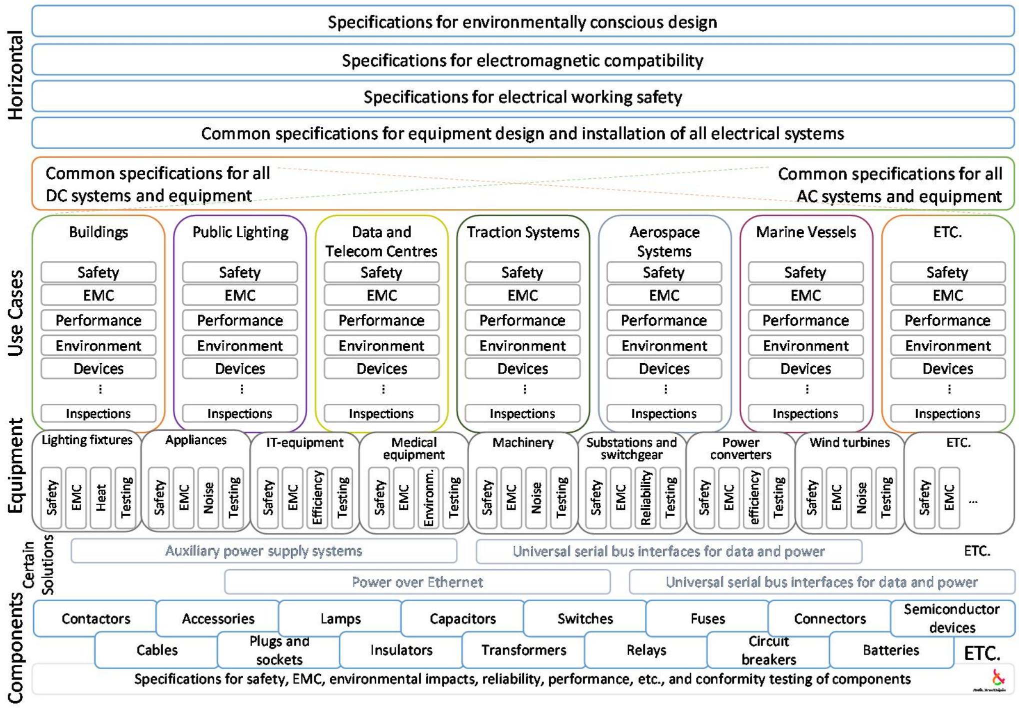

Figure 4.1 Typical structure of electrotechnical standardisation, with example given from the perspective of LVDC.

Considering the standardisation gaps, strong systemic approach is needed for the standardisation. The required process resembles the one developed for coordinating the smart grid standardisation. The key steps in this process are:

1. Establish a body to coordinate the standardisation development work
2. Engage external experts and form internal structure for the group
3. Define formal methodology for collecting and evaluating of use case and market information
4. Assign the following iterative tasks to the coordination group:
    I. collect use case and market information
    II. Evaluate the use case information and compare it with existing standardisation, identify standardisation gaps
    III. Categorise the identified standardisation needs according to the levels presented in Figure 4.1

IV. Delegate the identified standardisation development work to relevant technical committees
V. Nominate of external experts to working groups of relevant TCs as visiting experts to
VI. Evaluate standardisation projects currently worked on by the TC
VII. Coordinate the information exchange between committees
5. Iterate as long as needed

Information of the LVDC use cases has to be collected from the stakeholders as widely as possible. Coordination of this process requires adopting of a well-structured use case collection and mapping methodology. The templates and procedures developed for coordination of the smart grid standardisation provide ready-to-use tools also for the LVDC use case mapping and evaluation. Use case mapping and evaluation provides the basis for coordinating the standardisation of use case specific as well as use-case independent technical details

Performance based and oriented standardisation cannot be efficiently developed only by following market development and standardising one application at a time based on the properties of market winning technology. It would take a long time for the standards to be developed on this way and lead to development of several competing practises that may never be fully harmonised. An example of the inability of harmonisation after establishment of local practises is the plurality in plug and socket standardisation. On the other hand, the use case specific standards and the product standards must be developed based on market development. However, use case specific standardisation can never replace the need to define the general horizontal specifications.

Both the commercialisation of novel solutions for applying d.c. power and the coordinated development of the standardisation of d.c. equipment would benefit from the definition of even elementary common horizontal specifications. Examples of such horizontal specifications are the standardisation of the nominal voltages for equipment as well as defining recommendations for the rated operational voltages. The definition of the high level transversal rules would open the development of markets by solving major part of the chicken-or-the-egg problem nowadays hindering development of the markets.

Examples of questions to be addressed in the development of the common horizontal specifications:

- how to design suitable system architecture for LVDC distribution system for a particular use case?
- what are the needs for system flexibility and expandability?
- what are the common properties of active and passive power systems utilising d.c.?
- what are the characteristic properties of active power system utilising d.c.?

- how to ensure interoperability of resources within an active LVDC system?
- what internal and external power and communications interfaces need to be defined?
- what are the recommended practices for describing the interfaces?
- what are the main parameters defining the properties of the interfaces?
- what are the safe ranges for the values of the parameters of the interfaces?
- what are the systemic issues to be considered in equipment design?
- what are the recommended practices for describing the system properties?
- what are the recommended practises for considering the characteristics of the application environment?
- how the compliance with the requirements and recommended practices are verified?
- how use of LVDC affects the society and energy policies, and vice versa?
- how the terminology need to be developed?
- what are the methods for use case mapping and description?
- what are the KPIs for use case prioritisation?
- what are the KPIs needed in system engineering?
- what is the energy political role of LVDC?
- how LVDC affects the society, and vice versa, how to maximise the positive impacts?

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5 Summary and conclusions

This report presented an analysis of the status of currently available electrotechnical standards and development of the standardisation from the perspective of using low-voltage direct current (LVDC) networks in public power distribution. From the perspective of public power distribution, LVDC is already quite well covered in the standards dealing with installations and basic equipment used in the utility networks.

In addition to the state-of-the-art analysis, the further needs to develop the standardisation were listed and the standardisation processes discussed.

System oriented transversal guidelines and specifications are required to specify the overall framework to guide the development of safe and efficient LVDC systems and related equipment for the applications and use cases of future. The first set of horizontal standards need to be specific enough to provide guidance to the system and equipment developers when no other specifications are available, but at the same time loose enough to allow adaptation of the technical solutions to new use case and environments.

Examples of practical standardisation development needs are:

- Guidelines for selecting suitable voltage and earthing system in different operational environments
- EMC requirements for systems, equipment and devices including immunity, compatibility and emission limits for conductive and radiating interferences, and related procedures for conformity testing
- Applicability of power electronics based protection equipment and identification of the role of converters in protection system
- Interoperability rules for active d.c. systems (i.e. grid codes for generation and loads)
- Standards for special d.c. products that do not exist in a.c. networks
- Electrical working safety regulations and certification of electrical workers

The most important enablers for the development of coherent set LVDC standards are the thorough use case mapping based on a well-defined methodology and system oriented coordination of the technical standardisation work.

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