SMB/6555/SBP

STRATEGIC BUSINESS PLAN (SBP)

IEC/TC or SC:	Secretariat:	Date:
SyC LVDC	**IEC CO**	**2018-06-29**

PREAMBLE:

1. This SBP is published to show direction of work in the SyC LVDC. However, the SBP will be updated as soon as information from SMB AhG80 is available and incorporated.
2. A document provided by the FR NC "Low Voltage Direct Current Electrical Distribution ~ Draft roadmap proposals" is annexed to this version of the SBP. The document is under review in SyC LVDC AhG3 and the output will be incorporated in the following versions of the SBP.

A. State title and scope of SyC

Low Voltage Direct Current and Low Voltage Direct Current for Electricity Access

The Scope of the SyC LVDC is:

- Standardization in the field of Low Voltage Direct Current (hereinafter referred to as LVDC) in order to provide systems level standardization, coordination and guidance in the areas of LVDC and LVDC for Electricity Access.
- To widely consult within the IEC community and the broader stakeholder community to provide overall systems level value, support and guidance to the TCs and other standards development groups, both inside and outside the IEC.
- To bring urgency to development of standards for Electricity Access enabling inclusive development of all communities.

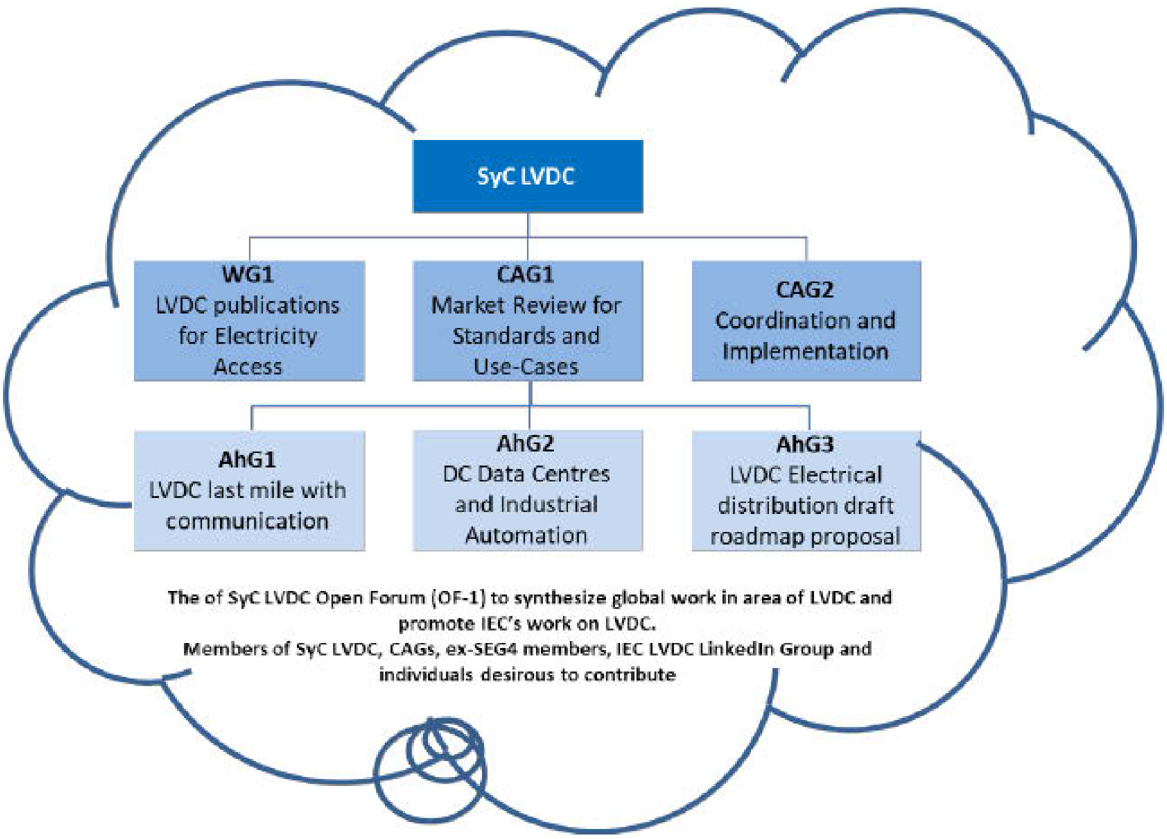
Implementation of LVDC is a relatively new topic and requires urgent standardization. As work proceeds, it may be pertinent to review the scope and activities of LVDC, but SyC LVDC does not presently anticipate any change in its scope.

Several TCs will have interest in the work that SyC LVDC will do in the domain of LVDC. A relevant list of TCs is as follows:

Committee	Description
TC 8	Systems aspects for electrical energy supply
TC22	Power electronic systems and equipment
SC 23B	Plugs, socket-outlets and switches
SC 23E	Circuit-breakers and similar equipment for household use
TC 25	Quantities and units
TC 34	Lamps and related equipment
SC 34A	Lamps
SC 34C	Auxiliaries for lamps
SC 34D	Luminaires
SC 36A	Insulated bushings
TC 38	Instrument transformers

TC 42	High-voltage and high-current test techniques
TC 59	Performance of household and similar electrical appliances
TC 61	Safety of household and similar electrical appliances
TC 64	Electrical Installations and Protection Against Electric Shock
TC 77	Electromagnetic compatibility
TC 82	Solar photovoltaic energy systems
TC 100	Audio, video and multimedia systems and equipment
TC 108	Safety of electronic equipment within the field of audio/video, information technology and communication technology
TC 109	Insulation co-ordination for low-voltage equipment
TC 112	Evaluation and qualification of electrical insulating materials and systems
TC 120	Electrical Energy Storage (EES) Systems
TC 121	Switchgear and controlgear and their assemblies for low voltage
SC 121A	Low-voltage switchgear and controlgear
SC 121B	Low-voltage switchgear and controlgear assemblies
SyC Smart Energy	Systems Committee on Smart Energy
ACEE	Advisory Committee on Energy Efficiency

B. Management Structure of the SyC



The work of SyC LVDC is managed through its secretariat which includes Vimal Mahendru (Chair), Gennaro Ruggiero (Secretary) and Sandrine Gosselin (Administrative Assistant to the Secretary).

The Terms of Reference for various groups:

Terms of reference for CAG 1: Market Review for Standards and Use-Cases

To provide recommendations about the following matters:

- Scan and review external environment and industry for the need for standardization
- Highlight areas for future cooperation with external stakeholders
- Promote IEC's LVDC standardization work and standards
- List, map and prioritize use cases
- Participate to define Program of Work (PoW) and Strategic Business Plan (SBP)

Meetings of the CAG1 are chaired by the SyC LVDC Chair.

Terms of reference for CAG 2: Coordination and Implementation

To provide recommendations about the following matters:

- Coordinate between TCs/SCs and other groups in IEC
- Review and highlight overlap of work
- Support work of the SyC
- Coordinate maintenance of existing publications
- Provide input to Maintenance Teams of existing standards to harmonize voltages
- Participate to define the Program of Work (PoW) and Strategic Business Plan (SBP)

Meetings of the CAG2 are chaired by the SyC LVDC Chair.

Terms of reference for WG 1: LVDC publications for Electricity Access

- Federate specifications and standardization work on Electricity Access
- Develop systems level publications for electricity access
- Engage and coordinate with TCs to embed Electricity Access provisions in existing publications
- Engage electricity access practitioners to seek ground level experiences and expectations

Meetings of the WG1 are chaired by the Convener-WG1. Presently, the convener of WG1 is Mr Rajeev Sharma (IN).

Terms of reference for AhG1 "LVDC last mile with communication"

Additionally, the SyC LVDC has created an ad hoc group AhG1 **"LVDC last mile with communication**". The AhG1 will evaluate and review applications such as street fixtures, public installations, EV charging and charging infrastructure, and community micro-grids operating on LVDC.

The AhG1 shall meet under convenorship of Harry Stokman (NL)

Interim Report (Jan 2018), Final Report (Jan 2019)

Terms of reference for AhG2 "DC Data Centres and Industrial Automation"

The scope of the AhG2 is to:

1. Define the use-case and requirements for DC Data Centres and Industrial Automation

2. Agglomerate stakeholders and market needs

3. Evaluate and advise if any system level work is required, and how this might be achieved

Terms of reference for AhG3 "LVDC Electrical distribution draft roadmap proposal"

The scope of the AhG3 is to:

1. Analyze and build consensus on Low Voltage Direct Current Electrical Distribution Draft roadmap proposals" (FRNC Green paper #2)

2. Propose a way forward

Terms of reference for LVDC Open Forum and LVDC Standardizers Forum

The SEG4 did a great job of bringing together global experts to contribute to its work. In carrying forward the interest and good work of these experts, the SMB agreed to the SyC LVDC proposal to form the Open Forum to be initially federated with all SEG4 experts. The Open Forum would also include all registered experts of the SyC LVDC. Work of the Open Forum is to promote, share and discuss ideas about LVDC and provide meaningful inputs to SyC LVDC".

The LVDC Standardizers Forum has been set up to bring together standardizers from across the world, to harmonize and build one set of standards covering LVDC.

C. Business Environment

In recent decades, with the advent of electronics, devices we use have changed to work with direct current (DC): multimedia and mobile equipment, LED lighting, IT equipment, electric vehicles, etc. More recently, washing machines, refrigerators, fans, heating/cooling systems have also adopted electric motors powered by DC sources, 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, direct current has also become a widely recognised form of charging/discharging energy. This exceptional convergence of technological developments 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 alternating current (AC) in developed economies. In most use cases, the main drivers for the use of DC arise from the expectation of economic benefits (reduced infrastructure and operation costs), improved technical performance and exploitation of renewable energy sources. In developing economies, DC brings the opportunity for a drastic living improvement to 1.1 billion[1] people on the planet that do not have access to electricity.

A very large number of stakeholders are involved: industrial-scale users of the 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 have been telecom, data centers and transportation. The electricity distribution companies and the electrical contractors, who are beginning to explore LVDC use cases and to develop a standardization perspective, are invited to actively participate in the standardization work. LVDC standardization work requires specific expertise and the IEC community will have to reach out to related industrial associations and consortia.

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

[1] IEA, Energy Access Outlook 2017,

electricity supplied to each market. The main classes of use case established are: energy access; renewables and energy storage; data centers, commercial, industrial and domestic buildings; electric mobility; power over Ethernet and USB, LED lighting and signaling, including public areas; and the "last mile" of the public power distribution network.

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 for a given energy is selected, 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. Under certain conditions a threshold of 120V is globally agreed to be the limit under which direct current is considered safe. For protection against electric shock, IEC 61140 shall be applied to define the voltage threshold.

The LVDC safety principles are known and related standards can be applied for product requirements. Standardization work should be considered concerning over-voltage protection, power quality, protective devices (e.g. RCDs for electric shock or AFDDs for arcing), device coordination and selection, wiring rules, and islanded installations. In the whole process of development of this report, there was total unanimity among all experts that regardless of use-case, LVDC must not be less safe than AC.is today.

Regarding existing product standards, there is a need for publications concerning 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.

Direct current has some differences compared with alternating current, namely voltages, plugs and sockets, and the effects on the human body. These will require to be addressed differently.

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 thirty IEC Technical Committees (TCs), are involved 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.

LVDC for Electricity Access

Electricity Access is not a yes/no concept but 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.

Among developing economies there is an urgent need for standards enabling Electricity Access for 48V ELVDC Systems in Tier-2 and Tier 3 of the ESMAP[2] multi-tier framework, including standards enabling compatibility specifically for appliances such as desert coolers, fans, LED lighting, domestic kitchen appliances such as mixers, grinders etc., small TV sets, mobile phone chargers, plugs and sockets, wires and cables.
For other tiers of the ESMAP[1]framework, i.e. Tier 1, 4 and 5, other voltages may be used, as deemed appropriate.

D. MARKET DEMAND

IEC SyC LVDC Standards are likely to have a very wide audience. This is because the very nature of LVDC is parallel to LVAC which has been around for about 130 years. Deep interest in LVDC and demand for LVDC standards are likely to arise from the following groups:

- Policy makers and regulators working toward enabling electricity access for all. This particularly resonates with developing economies.
- Regulators trying to move away from fossil fuels and enable green energy policies
- Industry

[2] ESMAP: https://www.esmap.org/

- Consumers
- Testing laboratories
- Conformity Assessment bodies

E. Trends in Technology and in the Market

There are three major trends which are impacting demand for LVDC standardization;

1. **Proliferation of electronics and communication into everything**: In the last 30 years, electronics have entered every form of electricity consumption. By most estimates about 80% of electricity is now consumed directly through devices using electronic circuitry, i.e. direct current. As a result, the consumption of current has almost entirely moved to direct current and away from alternating current.
2. **Power generation is moving from centralized to distributed, and from fossil fuel to renewable**: With the sharp lowering of prices of solar PV modules, the proliferation of solar PV for power generation is quite visible. At the same time, the cost of storage batteries has also come down. This is an added incentive to look at renewables as a source of energy, rather than simply the polluting fossil fuel plants.
3. **Regulators and policy makers' push**: Regulators and policy makers are now increasingly conscious of their responsibility to ensure sustainable development. Hence, policy makers are pushing for reducing carbon footprints and pollution. At the same time, there is demand to bring affordable, clean 24x7 electricity to all (1.1 billion people without electricity today). This is encouraging policy makers and regulators to push for new standards which enable such sustainable development.

All of the above are encouraging development of LVDC standardization.

F. Systems approach aspects (Reference - AC/33/2013)

Yes, the Systems Committee-LVDC will require the Systems Approach. The systems approach will involve multiple TCs, SCs and perhaps some other committees as well. SyC LVDC will work jointly with TC8/WG9.

IEC SyC LVDC does not expect a new SEG or a SG to be formed for the purpose of deploying the systems approach by SyC LVDC.

Yes, there are certain other SDOs working in parallel to SyC LVDC. The objective of SyC LVDC is to include them in discussions leading to LVDC standardization. .

G. Conformity Assessment

The publications may be used for IECEE and IECRE.

H. Horizontal issues

These issues will be addressed in the standards. Wherever relevant standards exist, these will be referenced.

I. 3-5 Year Projected Strategic Objectives, Actions, Target Dates

Strategic Objectives 3-5 years	Actions to support the strategic objectives	Target Date(s) to complete the actions
Develop and publish LVDC standards for Electricity Access	Formation of WG1 to commence working on these standards	June 2019

LOW-VOLTAGE DIRECT CURRENT ELECTRICAL DISTRIBUTION
Draft roadmap proposals

CONTENT

LOW-VOLTAGE DIRECT CURRENT ELECTRICAL DISTRIBUTION
Draft roadmap proposals

1 Introduction

Draft roadmap proposals for low-voltage DC electrical distribution are enumerated in this document. The proposals outlined hereafter are surely not comprehensive but are meant to help guiding the feature coordinated collective work on these topics.

IEC's technical committees cited hereafter (TC 8, TC 22, TC23, TC 34, TC 64, TC 69, TC 77, TC 82, TC 109, TC 121 *etc.*) should be asked for support, advice, and integration of the results in their own standards. Almost all subjects need to be co-worked between several groups.

LVDC lacks of legacy, field experience, good practices and for some matters, detailed standards and design rules. Physics are not similar to AC. DC facts are simply different.

Installation general characteristics like rating, voltage bands for safe interoperability and earthing systems are basic issues for the LVDC and require careful study. Up to date the earthing system in some DC electrical installations was a question of technical – economic optimum for the DC source and not a safety question. But an earthing system is not a consequence it is a design requirement for safety and operation. Corrosion must be considered, not only for operation constraints but for safety also.

Any electrical installation design uses rules and models for calculation. There is work to do for defining the equivalent network models and analysis tools for DC electrical installations. There exist several types of DC, time constants may anything smaller than the infinite. Power electronic converters are part of the installation, batteries also. All these must be integrated together with their particularities and requirements for installations receiving non-advised to DC dangers personas.

Compatibility issues with upstream or downstream AC or DC electrical installations are non-negligible. Galvanic separation should be mandatory.

The delivered power quality must be of concern in DC electrical installations. This topic impacts the technical-economic equilibrium of the installation. Correction stages for efficient power transfer mean supplementary power electronic components. The energy reserve naturally does not exist or is very expensive (batteries, capacitors, over-sizing *etc.*). This is mandatory for load commutation and installation further evolution.

Protection concepts and safety related problems as well as electromagnetic compatibility notions need a deep review and update. All DC current physiological effects on the human body are to be considered. Fire risks are enhanced as DC arcs do not self-extinguish. Overvoltage phenomena must be quantified.

DC specific equipment requirements must be co-worked with concerned experts working groups. Conductors and insulation level withstand to DC electrical field and transients are equally important.

Capacitors, electronics and electro-chemicals will be ever-present for different functional reasons. This goes with complexity when coming to verification, maintenance, lifetime and sustainability. Going with the cited complexity, verification and maintenance become mandatory not only for operation but for safety. Installation lifetime lowers; replacements and sustainability turn out to be a problem to solve.

A lot of interrogations are addressed, answers should come from a deep state of art, collective work, reviews and updates.

2 Scope

The following roadmap proposals cover distribution rules for low voltage DC (LVDC and voltage < 1500Vdc).

3 Status and objectives

The content of this document is dedicated to LVDC and LVDC for access to energy.

Designing for safety remains vital as it is in the case of AC supply installations. The same safety level as in AC shall be required, keeping in mind that unskilled people may be in contact with the electrical installation.

All listed work items require a deep state of the art including existing international standards at IEC level.

In some industry fields DC applications exist for a long time now (submarines, auxiliary supply panels for power plants, telecoms, aluminium industry). Presentations and reviews of previous work, field experience and any good practice knowledge should be done. Collective work of several experts' groups is required.

4 General characteristics

4.1 Rated power of the supply and rated current

Characteristics of the DC source and power supply and its consequences on the installation design, erection, operation, maintenance, economics and lifetime must be addressed.

4.2 Voltage bands for safe interoperability

A common first voltage band is the rated voltage for the power transfer in normal operation. Plus, and minus variations shall be defined to consider typical DC sources variations like battery floating or photovoltaic panels output voltage variations.

In the event of a fault on a DC electrical installation a breaking device (breaker, fuse *etc.*) must develop a limitation voltage greater than the DC source delivered voltage. This is due to the physical characteristic of the DC current, this is the way to reverse its slope and bring it down to zero. The faster the current limitation is wanted, the higher the limitation voltage will be. The longer the time delay, the higher the energy sustained by the limiting device will be.

One consequence is: the overcurrent limiter's developed voltage must be endured by all equipment connected to the DC bus including the loads. If not the equipment's insulation may be broken and the equipment destroyed.

An example: limitation is done by the action of an ultra-fast fuse for semiconductor. For a DC electrical network rated at 350V, while operating at 400V an ultra-fast fuse develops around 1100V of overvoltage. This voltage level must be withstood by the entire installation connected to the same DC bus.

The compromise and the technological limits must be searched between the overcurrent limiter's energy withstand capacity and the overvoltage withstand capacity of the rest of the equipment. Cost and overall economics may be the judges.

Furthermore, switching devices while opened do not have to clamp the climbing of the voltage developed by overcurrent limiting devices. The protection and switching devices must stand in the same operating voltage band, superior to the rated voltage band.

For instance, the clamping voltage of an overvoltage limitation device connected to DC electrical network is too low and forbids (by clamping) the developing of the limiting voltage of an overcurrent limiter in the event of a fault. The overcurrent limiting device is destroyed by the high-energy level (which cannot be withstood) and the fault current is not extinguished.

Therefore, the second consequence is the need of a voltage band dedicated to overvoltage limitation devices. This band must be higher than the band of the protection and switching devices and much higher than the rated voltage.

The coordination between electrical distribution devices and other equipment (*e.g.* coordination between an overcurrent limiting device and the overvoltage suppressor of a converter or the insulation coordination of the installation in case of a current limiter operation) must be studied.

DC electrical installation consequently needs three voltage bands for ensuring the safe interoperability:

- rated voltage for normal operation (power transmission from one point of the installation to another),
- operating voltage band for protection and switching devices
- overvoltage suppression devices voltage band for transient overvoltage protection

These three voltage bands are needed for an accurate interoperability of all equipment in a DC electrical installation.

The requirement is not just for a functional interoperability but for safety interoperability also. Consequence is not only dysfunctionality but dangerous installation.

Are there any other voltage clamping devices than the known overvoltage suppressors? Is there any possible oscillation or even clamping created by the “all over positioned” capacitors? Experts from the working groups of TC 8 (Systems aspects for electrical energy supply - in charge of the horizontal standard called IEC standard voltages and other standards on power quality), TC 109 (Insulation co-ordination for low voltage equipment), TC 64 (Electrical installations and protection against electric shock), TC 77 (Electromagnetic compatibility), TC22 (Power electronic systems and equipment), TC 121 (Switchgear and controlgear and their assemblies for low voltage), TC 23 (Electrical accessories) and TC 32 (Fuses) should be asked for support and advice on these issues and for implementation in technical standards.

4.3 Earthing systems and conductors’ arrangements

Earthing system’s choice is vital for the safe operation and for service continuity in any electrical distribution installation.

Active conductors, protection conductor and protective bonding conductors should have specific arrangements for LVDC electrical installations depending on the scope of each application.

Source earthing system, protection conductor and protective bonding arrangements must consider corrosion.

Earthing electrodes, their constitution, sizing, maintainability, verification and life time must be carefully considered.

An earthing system is critical for the safe operation of an installation and for service continuity.

Safety requirements should prevail on technical – economic compromise criteria decided by the design of the power electronic converter as a source for example.

For instance, a converter input or output EMC (Electromagnetic Compatibility) filter design’s cost is very linked to the presence of a middle point. Is this middle point “useful” for the installation? Why?

Photovoltaic panels may be technologically different. Some require earthing the positive polarity to avoid corrosion, some others require earthing the negative polarity to stabilize voltage reference to avoid leakage and efficiency losses.

In mixed AC and DC electrical installations, the AC earthing system is well known. Should it be kept in the DC part of the installation? Then converters as a switches’ matrix will connect for example the positive polarity either at the phases (one by one) or even at the neutral depending on the converter's technology. Galvanic separation becomes in this case mandatory for people and goods safety. This will have a non-negligible economic impact on the installation.

Furthermore, let us remind that in AC installation there exists always a non-dangerous conductor. This may be the neutral conductor when neutral is grounded or the phases and the neutral in case of isolated earthing system. If there is no galvanic separation between AC and DC, then DC electrical installation will always have two dangerous conductors. Galvanic separation is therefore mandatory.

Earthing systems are tightly linked to the protection devices technical features. For instance, a second fault on a DC isolated from earth installation requires full capability of the breaking device to develop a limiting voltage superior to the source's delivered full voltage on each connected polarity.

When and why should polarities or the middle point by grounded? Should the earthing be direct or through a high value impedance? When should the installation be isolated from earth? Should it be allowed not to break the middle point or the negative return path? What safety considerations must be reviewed?

What are the impacts on monitoring and eventual communication networks?

Experts from the TC 64 working groups (*e.g.* IEC60364-1, IEC60364-4-41, IEC60364-4-42, IEC60364-4-43) and TC22 (Power electronic systems and equipment), TC 82 (Solar photovoltaic energy systems) should be asked for support and advice on these issues and for implementation in technical standards.

4.4 Equivalent models and methods for analysis and calculation

This item exposes issues related to the equivalent model of a DC electrical network and the way to analyse its fundamentals for sizing and operation (steady-state, load variation dynamics, short-circuit current, overload *etc.*).

4.4.1 Equivalent network models

The AC systems sources have a general structure of representation as voltage source and a R-L (Resistor-Inductor) impedance (called Thévenin equivalent circuit). Furthermore, this system has a 1^{st} order response (in the domain of Laplace). And this fits well almost all network elements and their equivalent models (source generators, motors, transformers, lines and conductors).

Modelling a DC electrical installation is complex and real waveforms, in case of a fault for instance, are essential for the entire life-cycle of the installation.

DC systems sources have different types of representation depending on their type. Batteries may be represented as voltage and R-L impedance as AC sources do. PV panels have an elliptic characteristic voltage depending on the current. Converters have a rectangular voltage - current characteristic and have a second order response (in the domain of Laplace). This kind of second order behaviour means instability and oscillating transients (resonance and overvoltage factors). Regarding overvoltage, high efficiency source means low resistance and thus no dumping effect.

DC electrical installation time constants may be anything smaller than infinite. The voltage period as the well-known 20ms of a 50Hz power system does no longer exist as a network parameter. Direct current may be anything having an average value different from zero (see Figure 1).

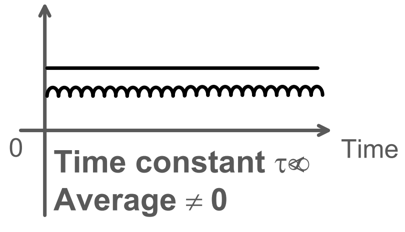


Figure 1 : Time constant in DC electrical networks

Another example, in AC systems we generally know the voltage, the R/X ratio and the short-circuit capacity at a point of the network. This information is enough to build the Thévenin equivalent of this electrical network as voltage, R and L. What are the rules for representing a source like a power electronics converter of a random rated voltage and a limited short-circuit capacity?

These representations must become reasonably well known. An effort for manufacturers of these systems must be required to provide complete data of their systems (short circuit, overload, overvoltage behaviour and limitations).

Steady state calculation of the installation, system response to load variations, dynamics and transient behaviour in fault situation are based on the above considerations.

Moreover, power converters may have different internal structures and associated operating modes. Those operating in the first quadrant (positive current and positive voltage) should be forbidden as the voltage is not properly manged and the efficiency is poor.

Concerning circuit equivalent impedances, capacitors spread all over the installation must be considered. These capacitors are present in the circuit for example for voltage stabilization and control, for power source supply flexibility and for loads internal bus equilibrium.

The presence of these capacitors all over the installation is unknown in AC installation where disconnection is enough to guarantee the lack of dangerous voltage on the separated part of the network.

Experts from TC 73 (Short-circuit currents), TC22 (Power electronic systems and equipment), TC77 (Electromagnetic compatibility), and TC 64 (Electrical installations and protection against electric shock) should be asked for support and advice on these issues and for implementation in technical standards.

4.4.2 Methods for calculation and analysis

Short-circuit calculation methods (at any point of the installation) must use the above clearly defined equivalent models for the LVDC electrical installation.

The up to date state of the art contains some guiding for these calculations like short-circuit current calculation for DC auxiliary installations in power plants and substations covered by the IEC 61660-1 standard. Some DC power system models exist also for HVDC (High Voltage Direct Current) studies (*e.g.* software like EMTPDC, RTDS).

But is it appropriate for DC electrical installations in dwellings, commercial and industrial buildings? Is it kept in mind that the sources, the loads, the safety and service continuity needed in these applications are not the same? How can be obtained equivalent standards as the IEC 61660-1, IEC 61660-2 and IEC 61660-3 for electrical distribution in DC for building applications?

Experts from TC 73 (Short-circuit currents), TC22 (Power electronic systems and equipment), TC77 (Electromagnetic compatibility), and TC 64 (Electrical installations and protection against electric shock) should be asked for support and advice on these issues and for implementation in technical standards.

4.5 Compatibility

Compatibility with other DC or AC installations, interactions, influences and interoperability needs further analysis.

Insulations levels, separation and upstream connection to an AC distribution or a DC distribution system must be studied as this has impact on the earthing system and the safety measures.

For instance, if no galvanic separation is existing and AC distribution upstream connection is present then the continuity of the earthing system must be kept (see also paragraph 4.3).

Experts from TC 64 (Electrical installations and protection against electric shock), TC22 (Power electronic systems and equipment) and TC77 (Electromagnetic compatibility), should be asked for support and advice on these issues and for implementation in technical standards.

4.6 Quality of the power supplied

4.6.1 Power quality

The quality of the energy supplied by a source is related to the quality of the delivered voltage and its capabilities of maintaining a certain quality level. Correction measures may be required at load side if the withdrawn current is too distorted.

An electrical distribution is meant to satisfy the load demand and to deliver the required energy at a technical – economic optimum or equilibrium.

Optimized installation is obtained as a compromise: sizing-losses-efficiency. The best point for this compromise corresponds to the lowest current transmitted to the load with the lowest level of losses. For this to happen the current and the voltage must have the same shape (as it is the case today in AC distribution when the power factor equals 1). So, whatever the voltage shape, to acquire best efficiency, current must follow the same pattern (see also paragraph 5.6).

The above rule (same shape for voltage and current) should apply to constant DC or any kind of pulsed or distorted DC. If the voltage is distorted, then the current must be equally deformed.

On the other hand, direct current means average value other than zero and thus spectral richness undefined.

Fourier theorem states that any distorted waveform can be decomposed into harmonic components. Any voltage or current can be expressed as the sum of the average value (d.c. component), the fundamental plus other harmonic orders. So $v = V_0 + V_1 + V_2 + V_3 \ldots$, $V_0 = average\ value\ of\ v$, $V_1 = fundamental$, $V_2 = order\ two\ harmonic$. Same goes for current. So $i = I_0 + I_1 + I_2 + I_3 \ldots$, $I_0 = average\ value\ of\ i$, $I_1 = fundamental$, $I_2 = order\ two\ harmonic$. Generally, power is defined as $P = \frac{1}{T}\int v(t)i(t)dt$ (1) and $Losses = factor \times Irms^2$. Fourier states that $I_{rms}^2 = \sum I_k^2$ (2) all terms being positive.

From (1) it is understood that all v and i terms that do not have the same harmonic order do not contribute to this integral. This means that in the DC case, v being constant, which means $v = V_0 = average\ value\ of\ v$, only $I_0 = average\ value\ of\ i$ will contribute to the power transfer.

To minimize losses from (2) results that all terms must equal zero except I_0. So, for constant voltage, current must be constant.

But power switching electronic converters potentially absorb a rectangular current depending on the switching frequency of the "chopper". For a rectangular current, $\frac{I_{average}^2}{I_{rms}^2} = 1/\sqrt{(\alpha)}$, α being the switching duty cycle, $I_{average}^2$ is the minimum rms line current and I_{rms}^2 is the line current while chopping.

All these considerations allow the introduction of a term called DC power factor. $PF_{DC} = \frac{1}{\sqrt{\alpha}}$ which equals 1 only if $\alpha = 1$, this happening only if I (the current) is constant.

Rich of spectrum current means also cable sections proportional to $\frac{1}{\sqrt{\alpha}}$, α being the duty cycle of the supplying power electronic converter. Corollary the cable section will have to be oversized and thus more expensive.

So, DC electrical installation also needs "DC power factor correction stages". These devices are power electronic converters that absorb, say a constant current whatever the power converter duty cycle (or, put in another way, whatever the "transformation" ratio).

These power converters called "Power Factor DC correctors" could be boost converters. But boost converters have special starting procedures and will necessarily need a second conversion stage to regulate the output voltage. This fits perfectly the well-known AC power factor correction plus power electronic conversion stage.

Another classical technical solution consists in putting an input LC filter for EMC reasons and for smoothing the current. These passive components will act as a "current smoother" to correct as much as possible the current waveform, the goal being to match the constant value.

All these cost money, sizing, reliability and impacts on the power electronic converter's regulation system. Middlebrook studied related stability issues giving one self-sufficient stability condition but needs careful analysis for DC electrical distribution.

However, DC electrical installation requires constant current absorption and precise regulation systems for the power electronic converters. Input and output voltages at converter level being different, the task seems complex and this is where the DC power factor correction makes all its sense (small duty cycle meaning DC power factor corrector >> 1).

Efficient DC power transmission from an installation point to another, from the DC source or DC power converter to the load or input of another power converter goes with this requirement: constant voltage means constant current.

Loads that absorb pulsed current (like LED lamps dimmers) should thus be equipped with DC power factor correction input stages. And this should have a non-negligible impact on the cost and the economics of the installation.

Another aspect of the voltage and current quality is related to safety in DC electrical installations.

Today, most of safety matters already covering DC electrical installations consider either DC ripple free (perfect constant) either 10% ripple. These points, including assumed physiological effects on the human body as well as other effects than the electric shock should be considered (see also paragraph 5).

What are the quality parameters of the supplied power by a DC source in a DC electrical installation? What should be the filtering requirements and the impacts on the technical and economic equilibrium of the source and load design? What about impacts on the safety aspects of the overall design?

Experts from TC 8 (System aspects of energy supply), TC 64 (Electrical installations and protection against electric shock), TC22 (Power electronic systems and equipment) and TC77 (Electromagnetic compatibility), should be asked for support and advice on these issues and for implementation in technical standards.

4.6.2 Energy reserve

Flexibility of the supply is easy to obtain when a source has generating capacities or reserves far greater than the load demand.

DC sources have limited power, over sizing is very expensive. To answer load demands flexibility is still needed. The DC power system stability relies also on these reserves (see also paragraph 4.6.1).

What are the available reserves of a DC electrical installation? The answer could be: mainly capacitors, batteries or oversized converters. Each one may have technical advantages or drawbacks and costs (see also paragraph 7).

Experts from TC 8 (System aspects of energy supply), TC 64 (Electrical installations and protection against electric shock), TC22 (Power electronic systems and equipment) and TC77 (Electromagnetic compatibility), should be asked for support and advice on these issues and for implementation in technical standards.

5 Protection for safety

Measures for safety may not be compatible either with the technical – economic perfect compromise of the power electronic source converter or with the installation functional requirements (see also paragraph 4.3). This statement must be seriously evaluated in DC electrical installations in all kind of buildings receiving "DC dangers non-advised" people.

5.1 Protection against electric shock

Regarding protection for safety, all DC current physiological effects on the human body must be considered. Does DC polarize fluids, how are reacting the human and livestock blood and skin when submitted to a direct current? What chemical or electrochemical reactions appear in this situation? What should be the dangerous offsets? There was a reported deadly accident in a hospital that occurred at very low DC voltage (about 10V), in special conditions and nevertheless requiring further comprehension of physical and electrochemical phenomena.

DC current physiological effects are not that well known (not as ones' AC are for a long time now) and feature works at MT4 (maintenance team 4 within TC 64) will have to consider these issues.

Depending on the earthing system and the voltage level, the use of residual current devices for people protection shall be mandatory.

The earthing system performances shall be characterized and corrosion's impact on the variability of the earthing impedance value shall be considered for the sizing of these residual current devices.

The TC64 experts (in charge of IEC60364-4-41 and at MT4) should be asked for support and advice regarding DC electrical installations specific characteristics and consequences on present rules.

5.2 Protection against fire

Arc fault protection function should be mandatory in DC electrical installation.

Fire risks should be evaluated for each kind of application depending on the voltage level and the vehiculated power.

In normal operating mode, commutation arcs shall be also considered. In addition to industrial process optimization the car industry still works with 12Vdc for arcing reasons.

The TC64 experts (in charge of IEC60364-4-42) should be asked for support and advice regarding DC electrical installations specific characteristics and consequences on present rules.

5.3 Protection against overcurrent

Overload and short-circuit protection should be revaluated.

What are the thermal effects due to overloads? How shall be characterized the short-circuit situation in a DC electrical installation? What are the impacts on the installation's sizing and design? What are the tools for sizing?

The TC64 experts (in charge of IEC60364-4-43), TC22 (Power electronic systems and equipment) should be asked for support and advice regarding DC electrical installations specific characteristics and consequences on present rules.

5.4 Protection against voltage variations and electromagnetic compatibility

5.4.1 Voltage variations

What are the situations generating overvoltage in a DC electrical installation depending on its upstream connection (to an AC distribution system, stand-alone on batteries or another local source)? Atmospheric phenomena, switching overvoltage and overcurrent limiting devices operating overvoltage should be analysed.

Overvoltage classes (known as Over Voltage Category (OVC) in AC distribution today) should be defined also for DC electrical installations with no connection to AC power distribution. These notions are fundamental for design.

Overvoltage limitation must be coherent with the insulation coordination and should be designed rationally to keep interoperability of all devices and equipment (see also paragraph 4.2).

Some insulation coordination for DC voltages and overvoltage withstand concepts are covered by the IEC 60664-1. Hypotheses are done in this standard like "a pure DC voltage stress" for the equipment, no ripple is considered. This may be very difficultly true in a full DC electrical installation. It will depend on the power quality delivered by the DC power source supply and on the loads polluting characteristics (see also paragraph 4.6).

The withstand characteristics of the solid insulations must be stated and the standard test reviewed.

The TC64 experts (in charge of IEC60364-4-44), TC22 (Power electronic systems and equipment), TC77 (Electromagnetic compatibility) and TC109 (Insulation co-ordination for low voltage equipment) should be asked for support and advice on these items.

5.4.2 Electromagnetic compatibility

What should be the electromagnetic compatibility (EMC) requirements for DC source power electronic converter in the context of a DC electrical installation (interconnected or not to an AC upstream power distribution system)? What happens in case of interconnection of several devices?

At load side, there should be no reason not to apply for example class A and B equivalent fitting curves from updated product specific standards (see IEC 61000-3-2).

IEC standards from the 61000 series define the electromagnetic environment for electrical systems.

However, it should be noted that there is work to do to understand and define the EMC bands for specific DC electrical installation.

The perfect direct voltage is dreamland. Filtering DC voltage is not an easy task for specialists.

For instance, study the LED lighting case. If no proper filtering and no correction of rejected perturbations, lamp dimmers working at 1kHz of switching frequency will induce overlapping the 1kHz on the existing DC (eventually not ripple free). Imagine the disorder for 1000 square meters of lamps like that in a commercial building. Another example is the electric car charging station. Let us assume it switches at 3kHz. This frequency will overlap the DC existing supply and imagine the dysfunction of the loads having input converters designed and regulators tuned at something ideally clean like a pure DC supply.

Experts in charge of TC22 (Power electronic systems and equipment), TC77 (Electromagnetic compatibility), TC109 (Insulation co-ordination for low voltage equipment) and TC64 (Electrical installations and protection against electric shock) should be asked for support and advice regarding the requirements of DC electrical installations with or without an AC power distribution connexion.

6 Equipment selection and erection

What are the rules for suitable equipment and its integration?

What is the state of the art of the efforts done by manufacturers and standardization bodies for appropriate DC electrical installation equipment? This concerns switching, breaking, making, disconnection, monitoring devices, power electronic converters. How should this small world learn to live with each other?

The power electronic converter replaces the transformer in a DC electrical installation. The energy no longer transforms but converts. Going from a voltage level to another, up or down, is not only a matter of available technology but a matter of cost. Efficiency will be expensive. A proper converter with filtering components and some energy reserve is not an easy task for the design engineer. The compromise could be on the cost (including the efficiency) or on the quality, the life time and the safety. Where should be the optimum in this equation, any case would be allowed?

Experts from dedicated standards must be asked for advice on the power electronic converters specific features for DC electrical installation and vice versa.

Depending on the scope of the electrical installation its needs in terms of devices could be different. What exactly are the needs in terms of protection and commutation functions, operation and monitoring for a DC electrical installation?

Specific characteristics for example mandatory non-polarized breakers in double fed electrical distributions, discharge systems for switch-disconnectors, arc fault protection devices for photovoltaic installations must be listed and analysed (and this list is not exhaustive).

In an isolated from earth (floating) earthing system, in a DC electrical installation, in the event of a second fault any breaking device must be able to develop a breaking voltage greater than the voltage of the supply. If not the installation is dangerous (see also paragraph 4.2).

What is the conductors' carrying capacity (ampacity), cross section and allowable voltage drop for DC electrical installations? This will surely depend also on the DC power quality. Are there any specific rules? Submarines, telecoms and other traditional DC applications have specific design for the conductors. In photovoltaic installation, the aging cables and their connectors represent a big issue and the first origin for fires.

How is acting the DC electrical field on the dielectric strength of the cable's insulation? Is retrofit possible, an AC cable can be used for DC electrical installation, is there any derating? How will be conductor marking managed?

DC specific issue is the conductor's polarity. Designers, field operators and installers need help for the identification of the negative, positive and eventual middle point conductors. Switching or mixing among them is unsafe and may be destroying for the equipment.

Precise DC specific equipment and accessories standards need at least a very detailed mapping.

Experts from each device standard committee together with the installation standard committee (TC64) should coordinate to search for eventual updates of standard requirements for DC electrical installation equipment.

For instance, experts from TC 64 (Electrical installation and protection against electric shock - in charge of IEC 60364-5-53 and other IEC 60364 series), TC 77 (Electromagnetic compatibility), TC22 (Power electronic systems and equipment), TC 121 (Switchgear and controlgear and their assemblies for low voltage), TC 85 (Measuring equipment for electrical and electromagnetic quantities), TC 23 (Electrical accessories) committees should be asked for support advice on these issues and for implementation in technical standards.

7 Verification, maintenance, lifetime and sustainability

DC electrical installations have specific technologies and constituents: electrochemical technologies like batteries, capacitors, fuel cells *etc.*; electronics like diodes, transistors, printed circuit boards *etc.*; materials like silicon, SiC, polymer separators, electrolytes. Most of these components have high safety and environment negative impacts. Thus, regular verification and maintenance of the installation is vital.

Furthermore, some of these components have low life time. For example, capacitors, depending on the technical and economic compromise, the operating modes and the current and voltage perturbations exposure may last from in average 3 to 15 years. Today, a good quality power electronic converter for solar panels for instance must be changed in average every 7 to 10 years and is guaranteed for 5 years.

Installation's lifetime may be low thus its sustainability should be defined. Thoughtful thinking about how shall be done the replacement and recycling of all these components is needed. This goes especially for dwellings and commercial buildings.

At installation level, safety precautions shall be taken for maintenance and any other case needing power supply off. DC electrical installation are inherently equipped with capacitors, all over (at source and load side and even spread as energy tampons to stabilize the system and give flexibility to the supply). This implies discharge requirements at both sides of an open circuit to insure there is no risk to contact dangerous voltage on both sides of the installation.

Careful treatment is needed for conductors marking to avoid mixing polarities between them.

Earthing for safety should be mandatory for maintenance and verification purpose. For example, the photovoltaic panels should be earthed close to their output for any intervention on the cabling system or for firemen.

Periodic verification and maintenance should be mandatory not only for functional reasons but for safety reasons first.

Experts from TC 64 (Electrical installations and protection against electric shock), TC22 (Power electronic systems and equipment) and TC77 (Electromagnetic compatibility), should be asked for support and advice on these issues and for implementation in technical standards.

8 Requirements for special applications – access to energy

What are the specific characteristics and the needs of these installations?

For people safety, the specific local climate shall be considered. In any case or even if the installation is SELV it shall be considered that in wet conditions 48Vdc may be deadly. Children are the most vulnerable (see also paragraph 5).

Experts from TC64 should be asked for support and advice for further electrical installation rules and protection against physiological effects of the DC current.

9 Synthesis of recommended work packages and associated liaisons with the standardization experts from IEC's technical committees

Subject	Experts committee to be asked for support and advice	
Installation general characteristics	TC 8	Systems aspects for electrical energy supply
	TC 64	Electrical installations and protection against electric shock
	TC 22	Power electronic systems and equipment
	TC 109	Insulation co-ordination for low voltage equipment
	TC 77	Electromagnetic compatibility
	TC 121	Switchgear and controlgear and their assemblies for low voltage
	TC 32	Fuses
	TC 82	Solar photovoltaic energy systems
	TC 73	Short-circuit currents
Protection for safety	TC 64	Electrical installations and protection against electric shock
	TC 22	Power electronic systems and equipment
	TC 77	Electromagnetic compatibility
	TC 109	Insulation co-ordination for low voltage equipment
Equipment selection and installation erection	TC 64	Electrical installations and protection against electric shock
	TC 22	Power electronic systems and equipment
	TC 23	Electrical accessories
	TC 69	Electric road vehicles and electric industrial trucks
	TC 77	Electromagnetic compatibility
	TC 121	Switchgear and controlgear and their assemblies for low

		voltage
	TC 32	Fuses
	TC 85	Measuring equipment for electrical and electromagnetic quantities
	TC 23	Electrical accessories
	TC 109	Insulation co-ordination for low voltage equipment
	CISPR	International special committee on radio interference
Verification, maintenance, life time and sustainability	TC 64	Electrical installations and protection against electric shock
	TC 22	Power electronic systems and equipment
	TC 77	Electromagnetic compatibility
	CISPR	International special committee on radio interference
Requirements for special applications	TC 64	Electrical installations and protection against electric shock

10 Bibliography

IEC 60364 series *Low-voltage electrical installations and protection against electric shock*

IEC 61000 series *Electromagnetic Compatibility*

TC 22's publications (Power electronic systems and equipment)

IEC 61660 series Short-circuit currents

IEC 61660-1 *Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 1 Calculation of Short-circuit currents*

IEC 61660-2 *Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 2 Calculation of effects*

IEC 61660-3 *Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 3 Examples of calculations*

IEC 60664 *series Insulation coordination for equipment within low-voltage systems*

IEC 61140 Protection against electric shock – Common aspects for installation and equipment

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