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LVDC systems -
Part 102: Low-voltage DC electric island power supply systems

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IEC TR 63282-102 has been prepared by IEC technical committee 8: System aspects of electrical energy supply. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
8/1760/DTR	8/1784/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

This document is to be used in conjunction with and as a supplement to IEC TR 63282 up to 1 500 V DC.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63282 series, published under the general title *LVDC systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

– reconfirmed,
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– revised.

INTRODUCTION

The vast majority of global population lives in the developing countries, and a significant portion of the developing countries have no, or poor, access to electricity. According to the United Nations Foundation, there are still around 1,2 billion people who do not have access to electricity and around 1 billion more who depend on unreliable electric networks. Energy access is a complex task in rural areas as most of the villages/hamlets are located at remote and/or hilly terrain. Barriers to energy access include uneconomic grid expansion and high transportation costs for fuel. However, these remote areas are rich in availability of locally available resources such as waste from agricultural field, solar intensity, wind utilization, etc., so how to use local resources to provide electricity supply has become a challenge in remote rural areas.

Electric island LVDC (Low voltage direct current) systems have recently been recognized by a number of stakeholders as an alternative solution for energy access in rural area. Several countries have already shown interest in the development of DC systems in order to improve the quality of their inhabitants' life together with the development of the local economy.

This document defines electric island LVDC systems for rural or remote areas, and on ships which normally operate with no connections to a national grid infrastructure. The purpose of this document is to provide some effective technical information to support the construction of electric island LVDC systems. It provides the unique characteristics of electric island power supply system and the key elements such as optional voltage level, topology and operation control, and provides some cases.

This document harmonizes with IEC TR 63282 for voltage level and power quality, and as a supplement to IEC TR 63282, but the application scenarios are slightly different and the power quality in this document are more prominent because there is no connection to a nation's primary grid.

This document mainly consists of three parts. The first part (Clause 4) gives the characteristics of the system, and describes the characteristics of the power source, load and the power quality of the electric island LVDC systems. These characteristics are designed to inform a number of stakeholders of the information to be aware of when building electric island LVDC systems. The second part (Clause 5) gives the system composition and technical description, and describes the load requirements, power source requirements, protection and operation of the electric island LVDC systems. Finally, five typical cases are given (Clause 6).

1 Scope

The scope of this document is to assess the existing technical requirements (by TC 64, TC 82, SyC LVDC) and close any gaps related to electric island LVDC power supply systems in rural or remote areas without electricity up to a maximum of 1 500 V only. Additionally, it covers the case of LVDC auxiliary power supply systems for ships.

Specific technical items for electric island LVDC systems are explained in this document. Rationale for the proposed voltage level, topology, power quality, etc. are given.

This document gives inputs to several TCs in charge of the standardization of different issues and coordinated by SyC LVDC.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

– IEC Electropedia: available at https://www.electropedia.org/
– ISO Online browsing platform: available at https://www.iso.org/obp

3.1
nominal system voltage
suitable approximate value of voltage used to designate or identify a system

[SOURCE: IEC 60050-601:1985, 601-01-21, modified - The original term "nominal voltage of a system" has been replaced by "nominal system voltage".]

3.2
electric island power supply system
off-grid or isolated power system
system that provides electricity without relying on any utility power grid

Note 1 to entry: It is designed to generate and store electricity using renewable energy sources such as solar panels and wind turbines, combined with energy storage systems like batteries, sometimes associated with a diesel generator. Electric island power supply systems are usually designed for isolated islands or for rural electrification in developing countries.

4 Characteristics of electric island LVDC systems

4.1 General

Power supply of electric island LVDC systems can be achieved with variable renewable sources like photovoltaic (PV) arrays, wind turbines and energy storage units. Consumption of electric island LVDC systems can be derived from a set of electrical equipment such as fans, lighting, mobile phones, etc.

Electric island LVDC system represents a specific scenario within the field of LVDC systems. The power quality phenomena described in IEC TR 63282 are applicable to electric island LVDC power supply systems. Different scenarios and scales exhibit unique features, leading to diverse requirements for power quality.

4.2 Rural or remote areas without access to the grid

Electrification of remote rural regions through national power grids is largely unviable due to both the high infrastructure cost and the limited power generation capacity in many countries.

Generally, rural or remote areas have vast territories with low population density and relatively modest electricity consumption, which are characterized by low energy density. An electric island LVDC system that relies on one or more energy sources in conjunction with a battery and power conversion equipment is a feasible solution.

In terms of power sources, rural or remote areas are basically characterized with abundant renewable energy sources. Technologies such as wind turbines and PV arrays can be utilized in electric island LVDC systems to economically satisfy local energy demands. Generally, the solar power generation ramps up with the sunrise and wanes as the sun sets, while the wind power generation usually peaks at night. Considering that variable renewable sources, like PV arrays and wind turbines, provide intermittent supply, energy storage plays a crucial rule in enhancing flexibility and reliability of the electric island supply systems. The commonly used energy storage in power systems include pump hydro, compressed air, flywheel, as well as lithium-ion batteries, supercapacitors, etc. However, these options are costly and typically designed for large-scale scenarios. For electric island LVDC systems in rural or remote areas, economically viable lead-acid batteries are generally employed as the energy storage components.

In terms of loads, the electricity demand in these regions primarily caters to fundamental living and production necessities. According to the report published by Energy Sector Management Assistance Program (ESMAP), a multi-tier framework is defined for electricity consumption, as shown in Figure 1. Load characteristics in rural or remote areas basically refer to the ESMAP multi-tier framework, ranging from Tier 1 to Tier 3, which pertains to household electricity supply requirements. Most load profiles exhibit morning and evening peaks while more affluent homes also exhibit mid-day peaks. Daytime electricity consumption peaks in the morning, primarily driven by lighting, radios, and other electrical appliances. Nighttime electricity consumption mainly includes lighting, cooking and charger usage. Consequently, there are instances of insufficient power supply and increased electricity demand, leading to potential deviations of the system voltage from its normal operating range.

Electric island LVDC systems in rural or remote areas face limitations of village distribution and topographical factors. The loads tend to be relatively decentralized, resulting in an excessively large radius of electricity supply to cover all households. As the loads increase, low voltage issues arise owing to larger line voltage drop. Phenomenon of voltage fluctuations and deviations will be occasionally caused by the temporal and spatial disparities between the power sources and the loads. A careful consideration on system voltage selection and appropriate voltage level is paramount, which can significantly contribute to the mitigation of such issues. Overall, in remote and rural areas without access to electricity, the primary power quality concerns include voltage deviation, voltage fluctuation, power interruption, and ripple. While prioritizing cost-effectiveness, it is appropriate to consider a reduction in power quality indicators in these scenarios.

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
1. Peak capacity	Power capacity rating[27] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
			Min 12 Wh	Min 200 Wh	Min 1 kWh	Min 3,4 kWh	Min 8,2 kWh
	OR services		Lighting of 1 000 lmhr/ day	Electrical lighting, air circulation, television, and phone charging are possible			
2. Availability (duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
	Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
4. Quality						Voltage problems do not affect the use of desired appliances	
5. Affordability					Cost of a standard consumption package of 365 kWh/year <5 % of household income		
6. Legality						Bill is paid to the utility, prepaid card seller, or authorized representative	
7. Health and safety						Absence of past accidents and perception of high risk in the future	

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Figure 1 - Multi-tier matrix for measuring access to household electricity supply

4.3 LVDC auxiliary power supply system for ships

The auxiliary power supply system for ships is a typical LVDC, which is mainly responsible for supplying power to auxiliary loads on the ship, such as hotel loads. This will be discussed in this document. Noted that the primary power system of ships for the electrical propulsion is not included.

In terms of power sources, a ship's electric power is supplied by generators, fuel cells, energy storage systems, PV arrays and other energy sources having sufficient capacity to support onboard services. The generator is the most commonly used power supply device of the DC ship, and the number and capacity of the generators can be determined according to the hotel load demand. Energy storage can store electric energy when the power consumption is low, and provide power supply for the hotel load when the load demand is high. PV power generation is a clean energy that can be used in combination with generator and energy storage to improve power utilization. The ships can have both a main power supply and an emergency power supply according to the demand of electricity. According to IEC 60092-201, the main electric power supply ensures uninterrupted power to all essential electrical loads for maintaining the ship in normal operational and habitable condition and preservation of the cargo, without relying on the emergency power supply. The emergency power supply is capable of sustaining for a minimum of 6 hours according to IEC 60092-507. The starting current, surge current and fault current are restricted to a level that guarantees the effectiveness of the safety device and meets the voltage drop limits specified by IEC 60092 (all parts).

The loads on a ship can be categorized into two main types: propulsion loads and hotel loads. Hotel loads encompass various elements, including lighting, ventilation, accommodation requirements, and auxiliary systems like small pumps and winches. Their contributions to the overall load are dependent on the shipboard missions. For instance, passenger cruise carriers and survey vessels have significant sensor and operational loads during missions, resulting in a more significant impact from hotel loads on the total power demand. According to IEC 60092-201, loads connected between lines and middle wire are balanced as far as possible within 15 % of the respective loads. According to IEEE Std 45.1™, the capacity of energy storage and on-line generators for redundancy are able to carry on-line uninterruptible and short-term interruptible loads.

The battery can be installed either as a stand-alone unit or in combination with other energy sources as the main electric power supply, while also serving as an emergency power source. When the energy storage is used as an emergency power source, it is capable of carrying emergency loads without charging, while maintaining the storage voltage within [−12 %, +5 %] of its nominal voltage throughout the discharge period. According to IEC 60092-507, the nominal DC voltage tolerance at the battery terminals, within which all the DC equipment is able to operate, is set at ± 10 %. Besides, the important loads of the ships remain functional when subjected to the minimum voltage at the battery terminals.

Overall, the power quality is pretty important to ensure the normal operation of DC ships. IEEE Std 1709 gives certain provisions for medium-voltage DC power systems on ships, mainly focusing on voltage ripple and noise, and according to it, the acceptable rms value of ripple voltage and load induced noise does not exceed 5 % per unit, while further research is needed for the power quality of ships with LVDC power supply.

5 Composition and technical description of electric island LVDC system

5.1 General

Understanding how to utilize an electric island LVDC system implies knowledge of its system composition and technical information, including the power source requirements (refer to Clause A.2 for detail information), load requirements (see Clause A.3), energy storage requirements (see Clause A.4), wiring (see Clause A.5), connectors and sockets (see Clause A.7), voltage level, topology, protection and operation (see Clause A.6 and Clause A.8), design (see Annex B), system installation (see Annex C), etc.

The IEC 62257 series provides comprehensive guidelines for renewable energy and hybrid systems for rural electrification. Some of them are applicable to both AC and DC systems. Specifically:

– IEC TS 62257-4: offers recommendations for system selection and design;
– IEC TS 62257-5: covers protection against electrical hazards;
– IEC TS 62257-7: provides guidance on the use of generators;
– IEC TS 62257-9-4: focuses on integrated systems and user installation;
– IEC TS 62257-9-7: recommends criteria for the selection of inverters;
– IEC TS 62257-9-8: sets requirements for stand-alone renewable energy products with power ratings less than or equal to 350 W.

5.2 Voltage levels

5.2.1 General

Nowadays, LVDC distribution projects covers a wide range of scenarios, such as residential and office buildings, data centres, hospitals, retail establishments, transportation systems, lighting networks, and applications in agriculture or fish farming. Voltage levels are influenced by various factors such as topology, load distribution, supply capacity, insulation, wiring features, control strategies, protection requirements and equipment characteristics. Different commonly used voltage levels can be found in IEC 60038 and IEC TR 63282.

The selection of an appropriate DC bus voltage is made comprehensively, taking into account various influencing factors related to safety, power efficiency, and cost-effectiveness.

5.2.2 Rural or remote areas without access to the grid

For power supply to the rural or remote areas, electric island LVDC systems consisting of PV panels, batteries and loads present a promising solution by closing the access gap as well as featuring lower costs. Typically, these systems are installed on rural housing and village houses, where DC power directly feeds lighting and small DC appliances, or small AC appliances powered by dedicated inverters operating on DC power. The capacity of solar panels ranges from hundreds of Wps to thousands of Wps (Watts-peaks). The DC voltages provided to the loads are generally 5 V USB, 5 V USB-PD to 20 V USB-PD (USB Power Delivery), 12 V, 24 V and 48 V. The actual voltage is determined by the requirements of the system.

For example, if the batteries and the inverter are a long way from the PV array and use a switching type solar controller, then a higher voltage can be required to offset the power lost in the cables. In larger systems, 120 V DC or 240 V DC can be used, but these are not typical household systems. Due to the potentially fatal voltages used, the complexity in electrical designs would be increased, and the resulting system would be more expensive than for systems using voltages below 60 V DC that are not so dangerous.

As a general guideline, the nominal system voltage tends to increase with the total daily energy consumption. For smaller daily loads, a 12 V system voltage is commonly used, while intermediate daily loads are typically accommodated with a 24 V system voltage. For more substantial energy requirements, a 48 V system voltage is commonly used. The Sustainable Energy Industry Association of the Pacific Islands (SEIAPI) suggests that a 24 V system voltage is appropriate for systems with a maximum instantaneous power up to 4 kW, and for higher values of maximum instantaneous power, a 48 V system is used, as shown in Figure 2. Specific technical specifications can be found in IS 16711 and IEC 63318. Additionally, communication cables can provide power up to 70 W (PoE, power over Ethernet).

As for larger scale scenarios, further technical specifications are outlined in IEEE Std 2030.10™.

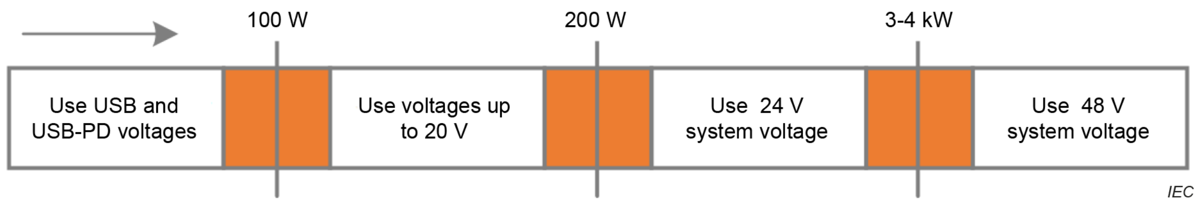

Figure 2 - Guideline to select system voltage

5.2.3 LVDC auxiliary power supply system in a ship

IEC 60092-201 gives typical values of nominal voltages and maximum voltages for common applications of LVDC auxiliary power supply system in a ship, as shown in Table 1.

Table 1 - Voltages for different applications (IEC 60092-201)

Application	Nominal voltages (V)	Maximum voltages (V)
Cooking, heating	110, 220	500
Lighting and socket outlets	24, 110, 220	500
Communication	6, 12, 24, 48, 110, 220	250
Supplies to lifeboats or similar craft	12, 24, 48	55
Instrumentation	24, 48, 110, 220	250

5.3 Topology

5.3.1 General

The electric island DC power supply systems can be applied to both remote areas and ship power supply systems. In this document, the electric island DC power supply systems for remote area are further categorized into two levels: household-level and county-level, based on power capacity.

There is no unified standard for the system topology of DC distribution network. The selection process requires a thorough evaluation of various factors, including the power supply range, power supply capacity, the cost of the DC distribution network, and the choice of insulating switch equipment. At present, there are two basic structures, namely ring topology and radial topology. Different topologies are applied to different scenarios.

5.3.2 Household-level installation

A household installation is a small, interconnected, self-sustaining electrical system. For household-level applications, the ESMAP multi-tier framework can be used as a reference, including use cases from Tier 2 to Tier 5, as shown in Table 2.

Table 2 - Generic requirements for ESMAP tiers and attributes

Attribute	Tier 2	Tier 3	Tier 4	Tier 5
Peak capacity (W or daily Wh)	Min 50 W Min 200 Wh	Min 200 W Min 1,0 kWh	Min 800 W Min 3,4 kWh	Min 2 kW Min 8,2 kWh
Availability	Minimum 4 h per day; Minimum 2 h in the evening	Minimum 8 h per day; Minimum 3 h in the evening	Minimum 16 h per day; Minimum 4 h in the evening	Minimum 23 h per day; Minimum 4 h in the evening
Reliability	Not mentioned	Not mentioned	Moderate impact	little (or no) impact
Quality	Not mentioned	Not mentioned	Moderate impact	little (or no) impact

Configuration of such an individual installation is based on the scale of local loads, economic conditions, environmental factors, etc. A household installation commonly includes loads (sorts of household electric appliances), power sources (such as PV panels, wind turbines, DC generating sets and storage units), and ancillary facilities (such as distribution boards, wiring systems, socket-outlets). As depicted in Figure 3, these installations are considered fundamental building blocks. In islanded mode, a household installation is fed directly from local power sources, which is able to achieve self-balancing.