

TECHNICAL REPORT



Decentralized electrical energy systems roadmap

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TECHNICAL REPORT



Decentralized electrical energy systems roadmap

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

DECENTRALIZED ELECTRICAL ENERGY SYSTEMS ROADMAP

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IEC TR 63410 has been prepared by subcommittee 8B: Decentralized Electrical Energy Systems, of IEC technical committee 8: System aspects for electrical supply. It is a Technical Report.

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

Draft	Report on voting
8B/139/DTR	8B/152/RVDTR

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

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.

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INTRODUCTION

Decentralized Electrical Energy Systems are intended to support the development of safe, secure and reliable systems with decentralized management for electrical energy supply, alternative/complement/precursor to traditional large interconnected and highly centralized systems.

Decentralized electrical energy systems have applications for developing countries (focusing on access to electricity) as well as for developed countries (focusing on higher reliability, black-out recovery and/or services). Interactions within Decentralized (Multi) Energy Systems are also considered.

- Microgrids

A microgrid is an independent system composed of distributed energy resources, which normally connected with main grid with tie-line. Due to the imbalance between supply and load, a microgrid can either connect with main grid or operate independently.

- Non-conventional distribution systems

Non-conventional distribution systems include grid-tied local system, multi-energy local system and DC distribution system.

A grid-tied local system means a group of interconnected loads and distributed energy resources with defined electrical boundaries forming a local electric power system at distribution voltage levels, that is not intended to be disconnected from a wider electric power system.

A multi-energy local system is composed of distributed power networks (such as electrical power supply, gas supply, and cooling/heat supply networks), energy exchange segments (such as CCHP unit, generator, boiler, air conditioner, and heat pump, etc.), distributed energy storage segments (such as electricity storage, heat storage, gas storage, cooling storage, etc.) and users.

One DC distribution system is an electrical power system formed by connecting the DC electrical power supply, DC lines, DC converter stations, DC loads and monitoring systems in the way of direct current, mainly completing DC electrical power distribution and consumption.

- Virtual Power Plants

A Virtual power plant achieves Distributed Energy Resources (DER) aggregation and coordination optimization (such as DG, energy storage systems, controllable load, and electric cars, etc.) through advanced ICT and software systems. It is considered as a special power plant participating in electricity market and power grid operation.

- Decentralized DC distribution system

The decentralized DC distribution system is mostly distributed in the strong demand DC power supply area or in the area of high DC load density, and in the areas where DC power supply and DC load exist simultaneously. The decentralized DC distribution systems are distributed in AC power supply areas. [Source: IEC SC 8B, WG5]

DECENTRALIZED ELECTRICAL ENERGY SYSTEMS ROADMAP

1 Scope

IEC TR 63410, which is a Technical Report, aims to prepare a road map for categorizing Decentralized Electrical Energy Systems and identifying gaps in the existing standards relevant to Decentralized Electrical Energy Systems. The task of IEC Subcommittee 8B is to develop IEC publications enabling the development of secure, reliable and cost-effective systems with decentralized management for electrical energy supply, which are alternative, complementary or precursors to traditional large interconnected and highly centralized systems. This includes but is not limited to AC, DC, AC/DC hybrid decentralized electrical energy system, such as distributed generation, distributed energy storage, dispatchable loads, virtual power plants and electrical energy systems having interaction with multiple types of distributed energy resources.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1 Terms and definitions

3.1.1

microgrid

<in an electric power system>

group of interconnected loads and distributed energy resources with defined electrical boundaries forming a local electric power system at distribution voltage levels, that acts as a single controllable entity and is able to operate in grid-connected and/or island mode

Note 1 to entry: This definition covers both (utility) distribution microgrids and/or customer owned microgrids.

[SOURCE: IEC 60050-617:2009, 617-04-22]

3.1.2

isolated microgrid

group of interconnected loads and distributed energy resources with defined electrical boundaries forming a local electric power system at distribution voltage levels, that cannot be connected to a wider electric power system

Note 1 to entry: Isolated microgrids are usually designed for geographical islands or for rural electrification.

[SOURCE: IEC 60050-617:2009/AMD2:2017, 617-04-23]

3.1.3**black start**

start-up of an electric power system from a blackout through internal energy resources

[SOURCE: IEC 60050-617:2009, 617-04-24]

3.1.4**virtual power plant**

VPP

party or system that realizes aggregation, optimization and control of decentralized generations, energy storage devices and controllable loads, which are not necessarily within the same geographical area, and facilitate the activities in power system operations and electricity market

[SOURCE: IEC TS 63189-1:—¹]

3.1.5**intentional island**

island resulting from planned action(s) of automatic protections, or from deliberate action by the responsible network operator, or both, in order to keep supplying electrical energy to a section of an electric power system

[SOURCE: IEC 60050-617:2009/AMD2:2017, 617-04-17]

3.1.6**prosumer**

network user that consumes and produces electrical energy

[SOURCE: IEC 60050-617:2009, 617-02-16]

3.1.7**aggregator**

party who contracts with a number of other network users (e.g. energy consumers) in order to combine the effect of smaller loads or distributed energy resources for actions such as demand response or for ancillary services

[SOURCE: IEC 60050-617:2009, 617-02-18]

3.1.8**microgrid operator**

party responsible for the safe and reliable operation of a microgrid

[SOURCE: IEC 60050-617:2009, 617-02-19]

3.1.9**microgrid user**

party who supplies electric energy or is supplied with electrical energy through a microgrid

[SOURCE: IEC 60050-617:2009, 617-02-20]

¹ Under preparation. Stage at the time of publication: IEC/PRVDTS 63189-1:2023.

3.2 Abbreviated terms

ADEMS	Aggregator DER Management System
AMI	Advanced Metering Infrastructure
BDEMS	Building DER EMS
BUC	Business Use Cases
CAGR	Compound Annual Growth Rate
CHP	Combined Heat and Power
CIM	Common Information Model
CIS	Customer Information System
CVPP	Commercial VPP
CVR	Conservative Voltage Reduction
DDEMS	DSO DER EMS
DER	Distributed Energy Resources
DERMS	DER Management Systems
DES	Distributed Energy Storage
DMS	Distribution Management System
DOMA	Distribution Operations Model and Analysis
DR	Demand Response
DSCADA	Distribution SCADA System
DSOs	Distribution System Operators
DSPF	Distribution System Power Flow
ECPs	Electrical Connection Points
EPS	Electric Power System
ESPs	Energy Service Providers
ESI	Energy Services Interface
EV	Electric Vehicle
EVEMS	Electric Vehicle EMS
EVSE	Electric Vehicle Supply Equipment
FDEMS	Facility DER Energy Management Systems
GIS	Geographical Information Systems
GOOSE	Generic Object Oriented Substation Event
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEV	International Electrotechnical Vocabulary
ISO	International Organization for Standardization
ISOs	Independent System Operators
LAN	Local Area Network
MDEMS	Microgrid DER EMS
MDMS	Meter Data Management System
NEA	National Energy Administration
OMS	Outage Management Systems

PAS	Publicly Available Specifications
PCC	Point of Common Coupling
PDEMS	Power Plant DER EMS
PPA	Power Purchase Agreements
PV	Photovoltaic System
REP	Retail Energy Providers
RDEMS	Retail DER Energy Management System
RTOs	Regional Transmission Organizations
SGAM	Smart Grid Architecture Model
SyC SE	System Committee Smart Energy
TBLM	Transmission Bus Load Model
TCs	Technical Committees
TSOs	Transmission System Operators
TVPP	Technical VPP
VDEMS	Virtual Power Plant DER EMS
WAN	Wide Area Network

4 Methodology

A System Approach is a holistic, iterative process that helps to deal with complex situations. This document is developed as a means of exchange with the System Committee Smart Energy and other involved Technical Committees (TCs) in order to identify applicable standards and standardization work to be undertaken.

Figure 1 identifies links between TCs and System Committee Smart Energy (SyC SE). Figure 2 illustrates the fields that SC 8B covers and the relationship between work programmes.

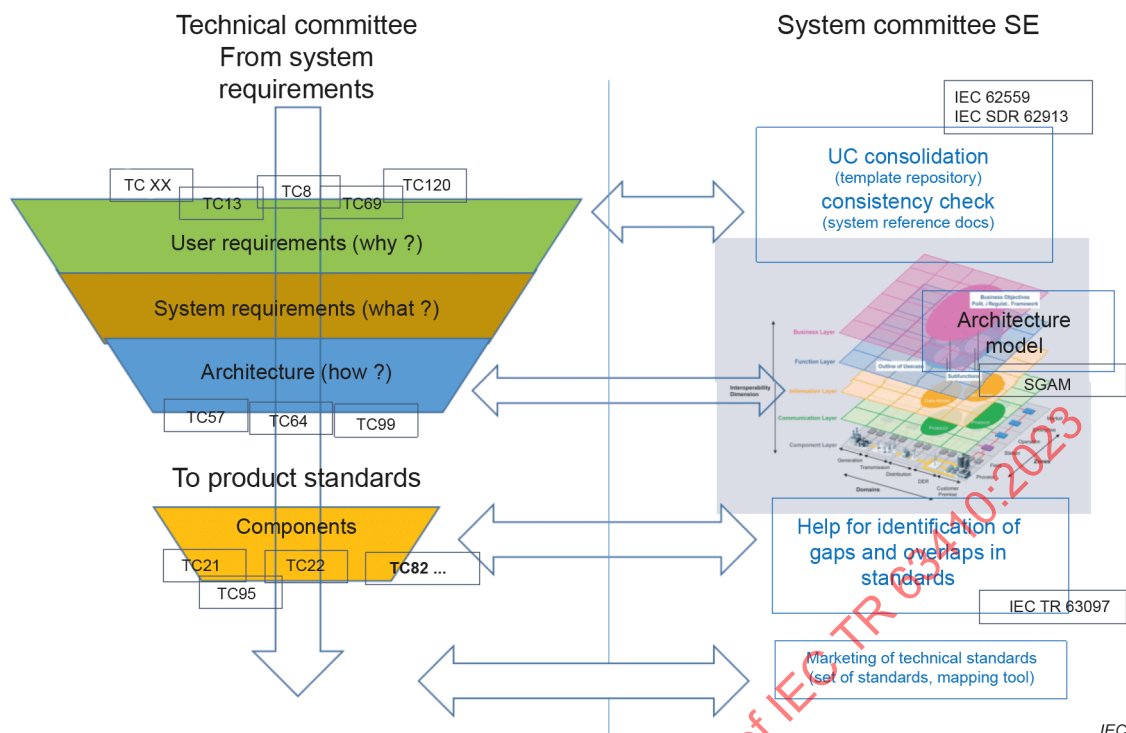


Figure 1 – From system requirements to product standards (TC8 Road map)

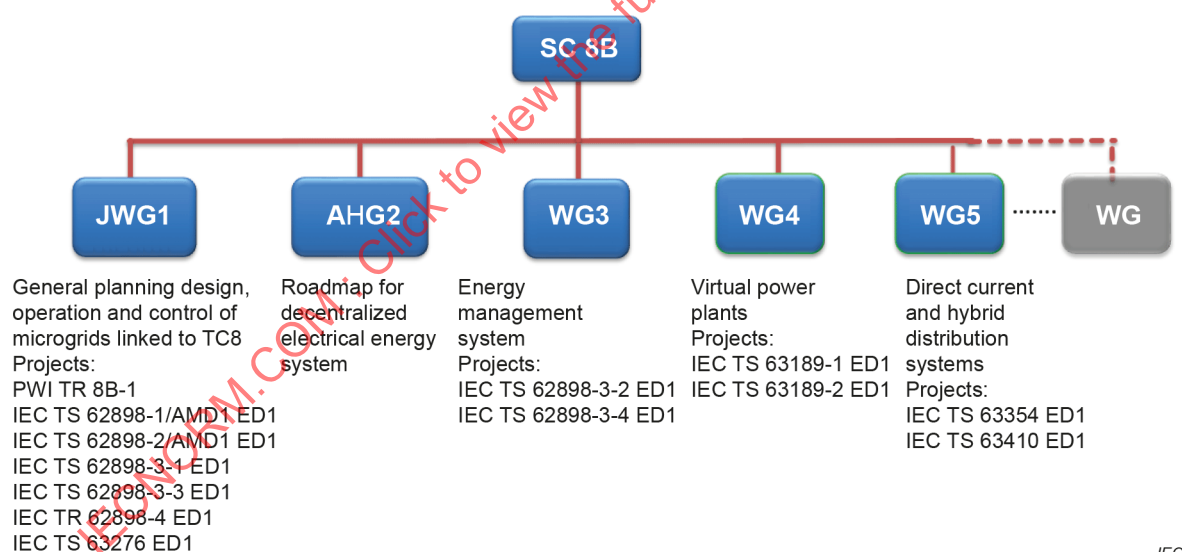


Figure 2 – SC 8B work groups, fields and work programmes

5 Market analysis, market segmentation and business models

5.1 Online survey

5.1.1 General

To support the decentralized electrical energy system standardization strategy development, the IEC SC 8B AHG2 prepared a survey on decentralized electrical energy systems in 2018 and a survey on microgrids in 2020. The survey outcomes are given in 5.1.2 and 5.1.3.

5.1.2 Outcomes from the 2018 survey on decentralized electrical energy systems

1) Participation of government in the non-conventional distribution system development

Non-conventional distribution systems include grid-tied local systems, multi-energy local systems and DC distribution systems. According to the online survey, it can be seen that governments are very supportive. Three of the five non-conventional distribution system projects identified in the survey are government-sponsored and the remaining two projects do not receive any sponsorship fund.

Government support contributes a lot to the non-conventional distribution system's development, and it has a big impact on the near future of the market. Standards are important to guarantee the confidence of investing in new market and technologies; therefore, government may be not willing to support if the standardization work is not sufficient.

2) Drivers and types of non-conventional distribution system projects

According to the survey results, five primary drivers to launch non-conventional distribution system are summarized, which are shown below:

Non-conventional distribution systems play an important part in achieving emission reduction and energy conservation, improving comprehensive utilization efficiency of energy, and cost efficiency in investments and operational cost, etc.

- Improving the acceptance and local consumption of renewable energy generation
- Improving comprehensive utilization efficiency of electricity, heat, gas and other forms of energy
- Solving the problem of electricity use in areas with weak connections to the power grid or geographically isolated islands
- (In some cases) providing higher cost efficiency in investments and operational cost (life cycle assessment) compared to traditional grid solutions
- Saving energy and reducing emissions.

3) Application of decentralized electrical energy systems

Despite of the low response, the information received about five responses covers all common types of projects. Two projects are DER projects, two are DC distribution projects, and the remaining one is a multi-energy local system project.

At present, the specifically designed technologies and equipment for non-conventional distribution systems are not available in this analysis because none of the results received from the five surveys responded to this question.

4) Standards needs for non-conventional distribution systems

The survey is beneficial to identify the satisfaction degree in the current standardization level of non-conventional distribution systems. The collected results are still valuable although the number of responses is limited.

Issues identified include lack of standards on technical requirement of multi-energy local systems, which makes it impossible to identify whether the projects under construction are multi-energy local system. Also, there are few standards in DC distribution. Therefore, it is difficult to develop non-conventional distribution system projects due to the lack of relevant standards. The development status of standards on DER, multi-energy local systems, and DC distribution in these countries are shown respectively in the form of figures.

According to the limited survey results, gaps identified in the non-conventional distribution system standardization include:

- Technical requirements for multi-energy local systems.
- Protection configuration, parameter adjustment of DC distribution network or technical requirements to be met when interconnecting with AC system.
- Materials, installation and tests for LVDC systems.
- System specifications in DC distribution.

5.1.3 Outcomes from the 2020 survey on microgrids

- 1) Microgrid standardization is strongly market driven.

Figure 3 shows the results of the survey.

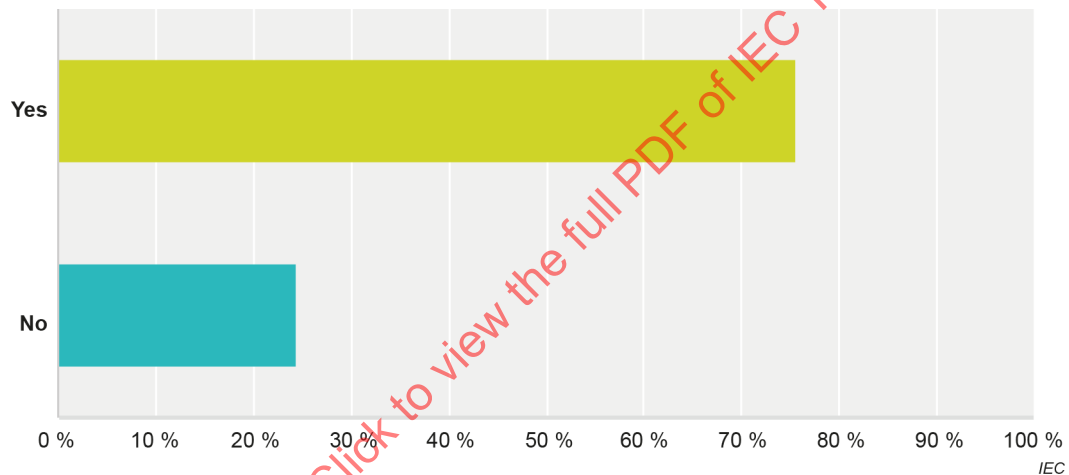


Figure 3 – General view of the microgrids projects implementation in countries

NOTE The data is provided based on personal knowledge from the participants.

Nearly 75 % of the participants already have microgrids in their countries, and according to the very limited resources from the participants, the market has great potential.

Table 1 – Market Status and roadmap to 2020

Country	Current Scale	Roadmap to 2020 (USD)
China	At least 100 projects	China's National Energy Administration (NEA) has released the National Action for the construction of the distribution network (2015-2020) in July 2015, in which a general view for microgrid is to "build one or two microgrid demonstration projects in each province, that installed renewable energy generation should exceed 50 % of the load demand".
Switzerland	1 000 000 USD	10 000 000 USD
Thailand	7 500 000 USD for the 1 st upcoming project	We are working on it. About 3 more projects may be added.
U.S.A	20 000 000 USD to 10 Billion USD	4 to 5 times present level
India		At the COP21 meeting held at Paris, India unveiled its plans to meet 40 % of its installed electric power generation using renewable energy by the year 2030. The slew of measures the country undertook to meet those targets include its proposal to install renewable energy powered Micro and Mini Grids. The proposal is to install a minimum of 10,000 renewable energy using Micro and Mini Grids to achieve 500 MW yield in the next five years.
Israel	We have today in the country some 300 local distribution networks that act as a microgrid but not controlled yet. In the other hand they are already regulated as a microgrid. They are connected to the grid in a single point.	After the pilot we are running in the country we can assume that the government will allow to more entities to aggregate as a microgrid. We can assume that this will give some more 200 additional microgrids: campus, hospitals.
Germany		Over the past ten years, Germany's renewable energy sector has grown more than threefold and the country is now an undisputable leader in renewables in Europe and globally. The current energy mix sees renewables accounting for 50 % of total capacity, with small scale PV at this time representing 15 % and expected to further grow thanks to declining solar costs.
Nigeria	Encourage plan for industrial area microgrids.	

31 out of 62 participants skipped the question "*Please indicate the scale and roadmap up to 2020 of the microgrid market*", which is quite understandable. For an individual expert or stakeholder, it is hard to provide the information of the whole country's market scale and roadmap, even if there is a published roadmap available. The gathered responses are summarized in Table 1. Due to the limits of time and resources, the market scale and roadmap information gathered here is raw, but we can still see from the very general trend that:

- There are many existing microgrids market around the world.
- The market is highly likely to expand and grow.
- There is a political desire to accelerate the development.

2) Microgrids are deployed for much diversified reasons

- Power supply to remote area;
- Utilize renewable energy/manage DER;
- Improve reliability, resilience, power quality and security;
- Reduce transmission losses;
- Encourage demand management;
- Disaster recovery;
- Improve distribution system;
- Verify of new technologies;
- Decrease operations and maintenance costs;
- High penetration RES resiliency.

One of the key features that makes microgrids stand out from the many new technologies is that it is not just suitable for developed economies, but also for emerging economies. From the drivers listed above, we can see that microgrids have been considered as a solution to:

- reach clean energy goals;
- power un-electrified population; and
- elevate grid performance and energy consumption.

Thus they have even greater potentials in future development.

3) Microgrids application and technology innovation have mutually promoted effects

New technologies enable microgrids and application of microgrids triggers R&D of new technologies, which often requires additional work in standardization to realise better development and deployment, as shown in Figure 4.

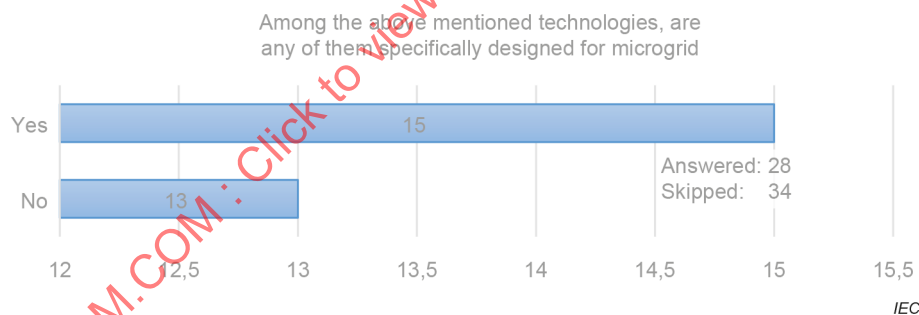
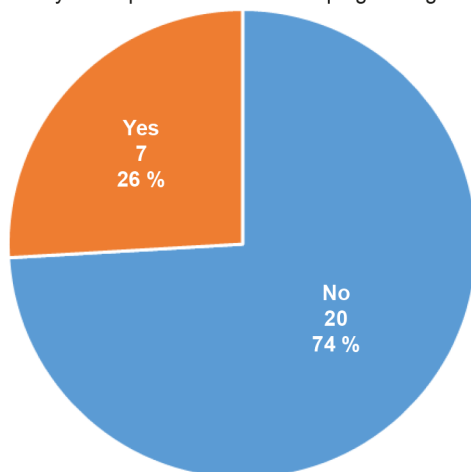


Figure 4 – New technologies developed for microgrids

4) Standardization of the field is in urgent need of improvement, as can be seen in Figure 5.

Q49: Do you find the current international standards meet your requirements for developing microgrids?



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Figure 5 – Standardization satisfaction in the area

The survey also preliminarily identified some specific standards gaps and conflicts; the results are reported in Item 4.1, *Gaps identified for microgrids standardization*, which presents more solid conclusions. However comments such as "We never found the direct microgrid standard yet" may show a general picture of the situation.

5.2 Categories of decentralized electrical energy systems

5.2.1 General

Decentralized electrical energy systems with similar physical compositions but used in different scenarios could be categorized differently, or decentralized electrical energy systems under the same category could be applied to different scenarios. Following is an attempt to categorize decentralized electrical energy systems under the following headings:

- Market assessment/application: market assessment from practical application, i.e. application scenarios sometimes may be easier to assess vs. technical aspects, since it depends on how and for what application a microgrid is designed and used;
- Technical features: decentralized electrical energy systems can be categorized into microgrid, non-conventional distribution systems and virtual power plants according to technical characteristics and/or technical requirements.

5.2.2 Categories based on application scenarios

Categorizing based on application scenarios is one of the most common ways of classification. It is a direct and application-oriented way to categorize. The differences between various categories may be blurred, as one project may fall into the scopes of more than one category. However it could be helpful to have a quick and general view of the scale, application environment, participating roles, and interaction mode of decentralized electrical energy systems.

It is shown in the survey data that for decentralized electrical energy systems currently declared, under construction or already in operation, from the perspective of application scenarios, decentralized electrical energy systems are used in institutional/campus, facility/community/utility, commercial/industrial, remote area and military power supplies that require higher power supply reliability.

Taking microgrids as an example, the following describes the main features of decentralized electrical energy systems applied in different scenarios.

- **Institutional/campus**
Institutional/campus microgrids usually operate in grid-connected mode typically used for municipal building, universities and hospitals. These kinds of microgrids generally have fixed load and thus sufficient consumption ability to avoid constraints from utility prohibitions on transfer of energy services across public right-of-way.
- **Facility/Community/utility**
Facility/Community/utility microgrids refer to microgrids that are designed to be operated in grid-connected or isolated mode, used for community power supply or as initiated by utility. These types of application are based on specific issue or need to provide cost effective solution for electric supply or higher reliability. Most regulators will approve such investments if they are more economical vs. other solutions.
- **Remote system**
Microgrids in remote areas are mainly developed to be operated in islanded mode to provide electricity supply to isolated geographic regions. In this case, the systems are normally of small size and capacity. Applications for mining installations or holiday resorts beyond the service area of the main power grid have been implemented in recent years.
- **Military**
Military microgrids include grid-connected networks for military bases, and islanded networks for forefront operation bases. Higher reliability and safety requirement are the most distinct features of these kinds of microgrids. Distributed renewable energy resources usually play a significant part in this type of microgrid.
- **Commercial/industrial**
Commercial/industrial microgrids are mostly grid-connected networks, used in industrial and commercial areas for higher reliability and safety. These kinds of microgrids have been already developed and matured in application, especially in North America. However, incremental cost and the lack of standard design scenario have limited their development and deployment.

5.2.3 Categories based on technical features

According to technical characteristics and/or technical requirements, decentralized electric energy systems can be divided into microgrid, non-conventional distribution systems and virtual power plants. Among them, microgrids can be divided into non-isolated microgrids and isolated microgrids according to whether they are tied with the main grid or not. Non-conventional distribution systems include multi-energy local systems, grid-tied local systems and DC distribution systems. Virtual power plants can be divided into Technical VPP (TVPP) and Commercial VPP (CVPP).

- **Non-isolated and isolated microgrid**
The non-isolated microgrid can not only be tied to the grid, but also operate independently when the main grid fails or is disconnected from the main network for economic operation. Isolated microgrids only have off-grid operation mode and do not operate in parallel with the main grid.
- **Multi-energy system**
The multi-energy local system is a comprehensive utilization system of multiple energies such as electricity, heat and natural gas, which is located near users. It focuses on coordination and optimization among different energies, but does not emphasize the dominant position of any particular energy. It is mainly composed of power supply networks (such as electrical power supply, gas supply and cooling/heating network), energy exchange links (CCHP unit, generator unit, boiler, air conditioner and heat pump, etc.), energy storage links (such as electricity storage, gas storage, heat storage and cold storage, etc.), terminal

integrated energy supply units (such as microgrid) and a large number of end users. The multi-energy local system has broken the existing mode of separate planning, design and operation of various energy supply systems such as electrical power supply, gas supply and cooling/heat supply, etc. It is an integrated energy production, supply and marketing system that organically coordinates and optimizes the production, transmission, distribution, transformation, storage and consumption of various energies in the process of planning, construction and operation, etc. It can comprehensively and efficiently utilize various energies.

- **Grid-tied system**

The grid-tied local system is mainly characterized by small power sources located near users, such as distributed photovoltaic power generation, which can supply power to nearby power users. More attention is paid to the localization of electricity production and consumption.

- **DC distribution system**

DC distributing systems do not need inverters to convert direct current from generators such as PV cells to alternative currents. Thus from the aspect of DC compatible load and equipment power supply, DC distributing system can be more efficient.

- **VPP**

According to different operation objectives, virtual power plants can be divided into Technical VPP (TVPP) and Commercial VPP (CVPP). TVPP determines the management mode conducive to the safe and stable operation of the power grid from the perspective of system management by combining with the influence of the operation characteristics of the virtual power plants on the local power grid. CVPP formulates optimal power generation plans based on user demand, load forecasting and power generation capacity forecasting and participates in power market transactions from the perspective of market revenue.

5.3 Decentralized electrical energy systems market assessment

5.3.1 Stakeholders identification

Surveys and experiences of representatives from SEG6, SC 8A and SC 8B following major stakeholders have been identified but not limited to:

- Consulting Engineering firms
- Electrical equipment manufacturers
- Equipment vendors
- Users
- Utilities
- Transmission system operators
- System integrators
- Governments
- Car manufacturers
- Railways
- Standard organizations
- Academics
- Consultancies
- Real Estate developers
- Facility operations managers
- Microgrid owners
- Communication infrastructure operators

Moreover, service providers, such as energy-saving service companies, third party in demand response or ancillary service markets, may also be stakeholders depending on the market conditions. In addition, if the microgrids involve multiple kinds of energy, such as gas and heat, they will also bring new players. Considering microgrids' role in disaster recovery and public emergency response, public safety and public transportation may also be relevant.

The variety of stakeholders has diversified the deployment of microgrids and boosted the market, but may cause difficulties in standards development and more importantly in standards adoption. During the survey and general work of SEG 6, we have very easily identified several organizations working on the international level of microgrid standardization, such as IEC TC 8, TC 64, TC 82, SEG 4, SyC Smart Energy, etc. For this topic, WG 3 has performed a more thorough investigation and analysis, and the result is presented in Clause 6 of this document. However even just based on the preliminary identification, potential overlap and conflicts are reasonably expected. Inconsistent standards may split the global market, confuse users and eventually delay the development of microgrids. Therefore, standards developed within a unified platform and with clear guidance are more effective than those developed in/by scattered entities.

5.3.2 Market outlook

Based on the working packages of SEG 6, WG 1 was set up with the goal to assess the current market need and deployment of microgrids, identify the trend and analyse the influential elements. WG 1 adopted the survey approach to collect market information as widely as possible. Unfortunately, the low response to the corresponding questions in the survey failed to provide a quantitative market assessment. However, the group was able to identify a trend of active consideration and wide development in every country participating in the survey. This was similar to the experiences and activities within SEG 6 member countries. The technical development and successful pilot projects have given people more understanding and application of microgrids. Market forecasts from different resources show that there is a market need and confidence in microgrids application around the world, as illustrated by Figure 6 and Figure 7 produced by market research companies at an international level:

NOTE Technavio said worldwide microgrid markets will increase at a compound annual growth rate (CAGR) of nearly 14 % from 2016-2020.

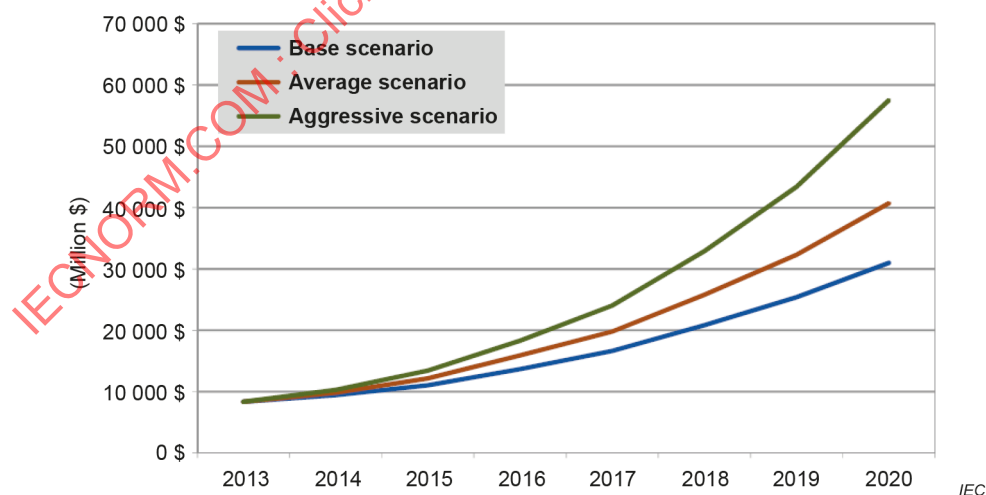


Figure 6 – Total microgrids revenue by forecast scenario, world markets:2013-2020

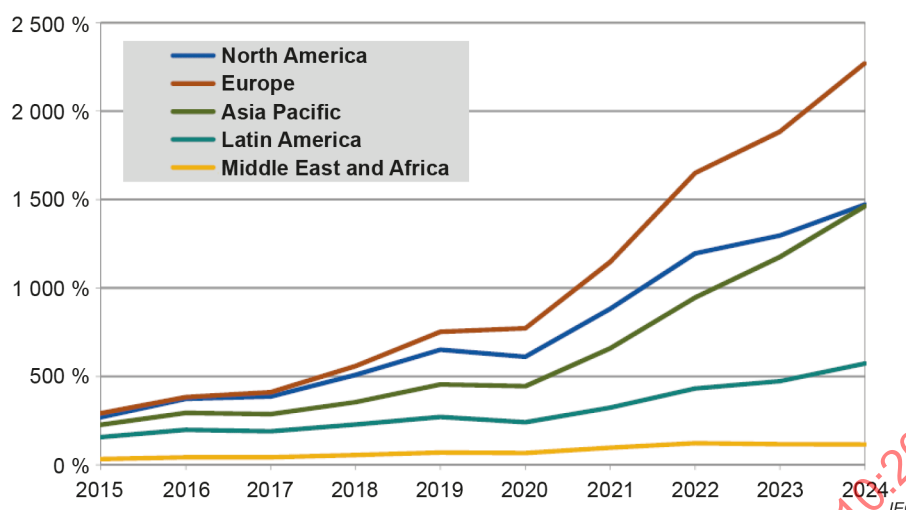


Figure 7 – DER Capacity Installments as a Percentage of New Centralized Generation, Regional Averages: 2015-2024, Source: Navigant Research

Among the many drivers for microgrid development, growing importance of energy self-sufficiency, policy stimulation, increased depletion of fossil energy, cost reduction of renewable energy generation, unexpected changes of energy prices and tariffs and technology innovation are the most influential ones. The proliferation of current and planned deployment of distributed generation, with the ability to better control load and consumption, calls for better optimization of those local energy networks which are becoming more complicated and independent.

The complexity, diversified structures, and lack of standardization of the newly developed microgrids make such deployments complex and expensive, and are quite often still dependent on governmental funding. We estimate, based on market data including our online survey, that the adoption of microgrids will grow fast, and the introduction of the relevant standards will be imperative to support such growth.

Most governments are actively supporting the evolvement of microgrids to support their sustainable development goals, as well as power quality and resiliency. Government funding, and supportive policies still play a major role in driving microgrid deployments. In the market survey, half of the projects are funded, mostly by government agencies. Secondly, the gradual stepping down of the cost of distributed generation is also a massive dynamic for future microgrids development, e.g. the cost of PV generation has dropped 70 % compared to three years ago. Thirdly, the aging grid infrastructure in developed economies, the higher occurrence of extreme weather conditions, disaster threats, and anti-nuclear public sense have put more fuel on the development of microgrids. At last but definitely not least, the advancement and further cost reduction of energy storage technology, covering deficiency of renewable energy resources and enabling more application, will further accelerate the market. Standard control systems and reducing the cost of energy storage systems will play another significant role in reducing the overall cost and effectiveness of the microgrids.

5.4 Market needs and business models for decentralized electrical energy systems

1) Market needs

With the development of distributed local power supply systems such as distributed photovoltaic power generation and distributed wind power generation, as well as microgrid and multi-energy local system, decentralized electric energy systems, as the supplementary form of power supply for large power systems, are increasingly becoming an effective energy supply solution to meet the demand of load growth and reduce environmental pollution.

Microgrids can be implemented in many different environments and can take many forms. Generally speaking, some of the microgrid applications in today's market are as follows:

- Guarantee continuity in load service by islanding: Microgrids are used for higher reliability and continuity of supply by islanding, i.e. by operating it disconnected from the grid during grid faults/outages.
- Electrify remote areas using renewable energy resources: In this application, microgrids are one of the solutions promoting electrification for remote areas and/or islands with integration of renewable energy resources (or distributed energy resources DERs). It may also provide back up for a community with weak transmission or distribution feeders.
- Optimize local resources to provide services to customers inside the microgrid: Microgrids used for providing services to their customers, by optimizing the assets such as energy storage, dispatchable loads and generators. This is beneficial for reduction of energy costs, increase of local energy consumption, decrease of greenhouse gases emissions, etc.
- Optimize local resources to provide services to the grid/disaster preparedness: Community microgrids serve critical facilities such as hospitals, police, grocery stores, pharmacies, emergency shelters, police and fire stations, banks and community cell-phone charging centers, and community communication assets. Such microgrids are also called "town center" or "oasis" microgrids and provide electricity to multiple customers in the face of an emergency (e.g. storms, wind, fire, terrorism) and often cross public rights of way.

Non-conventional distribution systems play an important part in achieving emission reduction and energy conservation, improving comprehensive utilization efficiency of energy, and cost efficiency in investments and operational cost, etc.

- Improving the acceptance and local consumption of renewable energy generation;
- Improving comprehensive utilization efficiency of electricity, heat, gas and other forms of energy;
- Solving the problem of electricity use in areas with weak connections to the power grid or geographically isolated islands;
- Higher cost efficiency in investments and operational cost (life cycle assessment) compared to traditional grid solutions;
- Saving energy and reducing emissions.

Virtual power plants (VPP) can effectively lower the market access threshold of distributed power supply, improve the economic benefits of distributed power supply, reduce the management difficulty of distributed power supply and the influence of power grid, and provide auxiliary services for power grids. VPP can aggregate distributed power sources to stably transmit power to the main grid without reforming the power grid, and can provide fast response auxiliary services, thus becoming an effective method for distributed power sources to join the power market, lowering the market access threshold for distributed power supply and achieving benefit of economies of scale. At the same time, visualization of distributed power supply and coordination, control and optimization of VPP greatly reduce the impact of grid-connection of distributed generation on the main grid, reduce scheduling difficulties caused by the growth of distributed generation, make distribution management more reasonable and orderly, and improve the stability of system operation. Therefore, VPP provide a feasible technical solution for distributed power generation to participate in the power market. On one hand, the VPP provide the best operation mode of distributed power supply to maximize market benefits; on the other hand, the optimization strategy of VPP can meet the requirements of unified scheduling, operation and management of the distribution network and ensure that the parallel nodes of each distributed power sources meet the voltage requirements and power flow constraints of the distribution network.

2) Business models

In terms of the application of microgrids, the key factor at current stage is not experimentation or verification of projects or technology, but to figure out what kind of business model can bring this DER integration platform into a new stage of commercial operation.

Based on online survey and industry reports from some organizations, a number of recognized business models are listed below:

- Facility owner financing and maintenance

Microgrids by definition are for addressing unique needs and/or issues. As a result, microgrid projects that are currently operational adopt this business model, especially utilities, campus or institutional microgrids which comprise a larger market share. Some R&D/pilot projects are also financed by facility owners. To improve efficiency and reduce emissions, asset owners including utilities often replace key assets within microgrids (such as diesel generators, CHP and distribution infrastructures). Once new assets are introduced, a more complex integration is required and any incremental upgrades are borne by the facility owner. Financial benefits gained by efficiency and reliability improvement ultimately reduce operating costs and outweigh expenses incurred by facility owners.

- Utility rate base

Utilities also consider use of microgrids to address customer needs for broader benefits as part of a utility rate based on economic considerations. In most cases, utility owned microgrids that adopt this business model are public or private power providers in rural and/or isolated markets because of overall economic and environmental considerations.

- Vendors and equipment suppliers

Evolution of microgrids provides vendors new opportunity and destination for their products, for example, companies that sell storage devices, smart electricity meters and (most importantly) different types of DG. Nonetheless, companies that are active in the field of microgrids are still establishing cooperative relationships in order to develop and to better integrate these types of components with the network, optimizing and economic leveraging aspect of microgrid. With the increase in such efforts, the business model to deliver cost effective microgrid will evolve.

Some companies sell microgrid hardware (DG, energy storage devices and distribution network components) and software at the same time, thus they can provide most components for microgrids. For example, there is an informal alliance formed by Power Analytics, Viridity Energy and Spirae, which provides microgrid modelling, economic optimization and practical control technology packages. DG is the substantial cost in microgrid projects. If there is gradual and sustained growth in this area, vendors will develop and provide bundled microgrid packages.

- Networking control service agreement

Distributed Generation equipment and hardware is the major portion of investment in the microgrid. However, the integration function of microgrids is the most challenging technical task. Since there are many ways to control and optimize microgrids, this will be the most complex task. What consumers only expect is functional operation of the microgrid, thus vendors providing service agreements that includes acceptance of the microgrid operation risk will be an extremely appealing value proposition.

Some vendors are transferring into this business model similar to plug and play. Since only a small number of microgrids are adopting this business model, it is unsure whether this business model will become mainstream in the future. What is predictable is that more attention will be paid to the open structure of microgrids, plug & play function and seamless networking of different types of renewable energy and energy storage devices, which promote the application of this business model.

- Power purchase agreements (PPA)

PPA is an important concept and business model in the residential and commercial PV market of some countries, such as the US and China. It is expected that PPA will continue to play an important role and business operation method for grid-connected microgrid projects. Upfront cost is not required from consumers. In the PV field, private sectors with abundant capital-owned related equipment and leased generation systems until all tax reduction and accelerated depreciation are maximized. In the microgrid business field, some vendors are promoting microgrid PPA, which is taking on the risk of performance in exchange for capturing future revenue streams from sales of ancillary services.

To ensure such a business model is playing its role, the microgrid control system needs to adopt open structure, reduce additional cost incurred by adding new equipment, and include monitored performance checks. For example, the performance of PPA solar projects is higher than small contract installation projects. Since microgrids are more complicated than simple PV systems, companies that are willing to sign long-term PPA must fully understand the risks and select vendors carefully.

- Operations and maintenance contracts

Among the mainstream microgrids, operations and maintenance contracts that aim to provide the best performance are increasing. Apparently, microgrids in remote areas serving low-income communities will become the largest potential market of this business model. This is due to the lack of skilled labor including licensed engineers and technicians. The weak links of these isolated microgrids are lead-acid batteries malfunction and performance depreciation of solar and wind generators.

With the increased application of PPA in microgrid projects, operation and maintenance will gradually become a crucial part of project operation, as the economic viability of microgrid operation will depend on the actual operation performance of the microgrid projects.

- Pay as you go

The main challenge of microgrid development in developing countries is how to achieve revenue flow to support sustainable business development in the less developed areas. "Pay as you go" for power supply and key infrastructure is gaining popularity. This method is especially suitable for small and remote microgrids in developing countries where it is only required to provide enough power for lightings, computers and mobile phones. The key of this business model is to maintain stable service costs and to be able to terminate services when consumers stop paying. The electricity purchase method is basically the same as any other prepaid services. The only difference is that consumers can gradually invest in their own PV systems.

Although a smart electricity meter may not be mandatory to enable microgrids, it will play a crucial role and can be used to monitor status and calculate real time energy usage of individual consumer within a microgrid. Without reliable monitoring and accurate calculation methods to track actual energy usage, business models of these emerging microgrid markets are not sustainable. Hence, it is believed that smart electricity meters and communication are significant to the operation of rural microgrids under "pay as you go" business model.

5.5 Conceptual approach from DER to microgrid

As stated in IEC 61850-7-420:2021, the conceptual model for DERs shall be recursive, i.e. a DER is composed of DER as shown in Figure 8. In that approach DER encompasses in the same approach generators and controllable loads, by the argument that you may provide a very similar energy system behavior by applying controls to generators and reverse controls to loads. This enables as well to easily consider storage as part of DERs (controllable generator or controllable load).

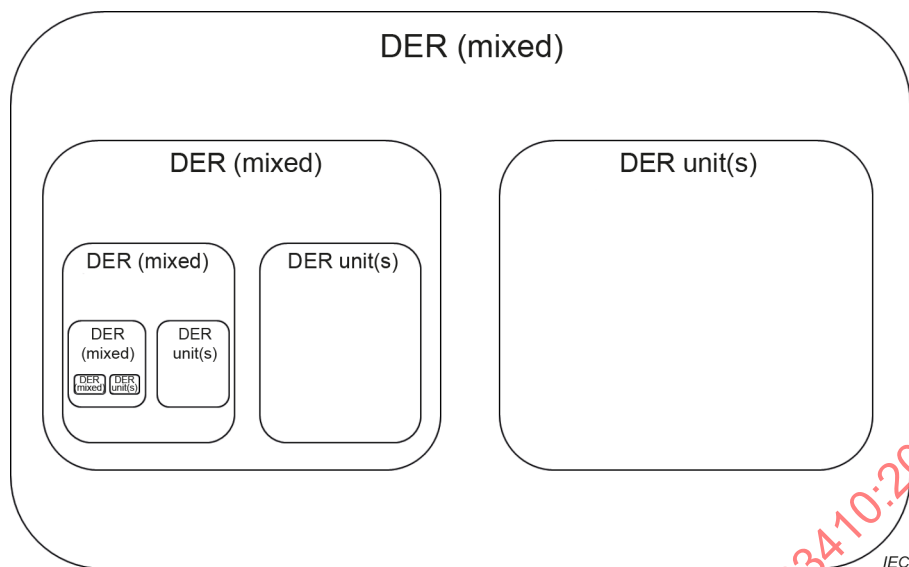


Figure 8 – Recursive conceptual model of DERs

This composition (also called aggregation) can be physical, if the concerned DERs are connected on the same electrical network. However it can also be virtual, and this introduces the concept of VPPs.

Adding to the DER the ability to run in a stand-alone way, i.e. not exchanging any power with an “upper Area network”, transforms the DER into a microgrid.

This leads to this conceptual model for microgrids as shown in Figure 9.

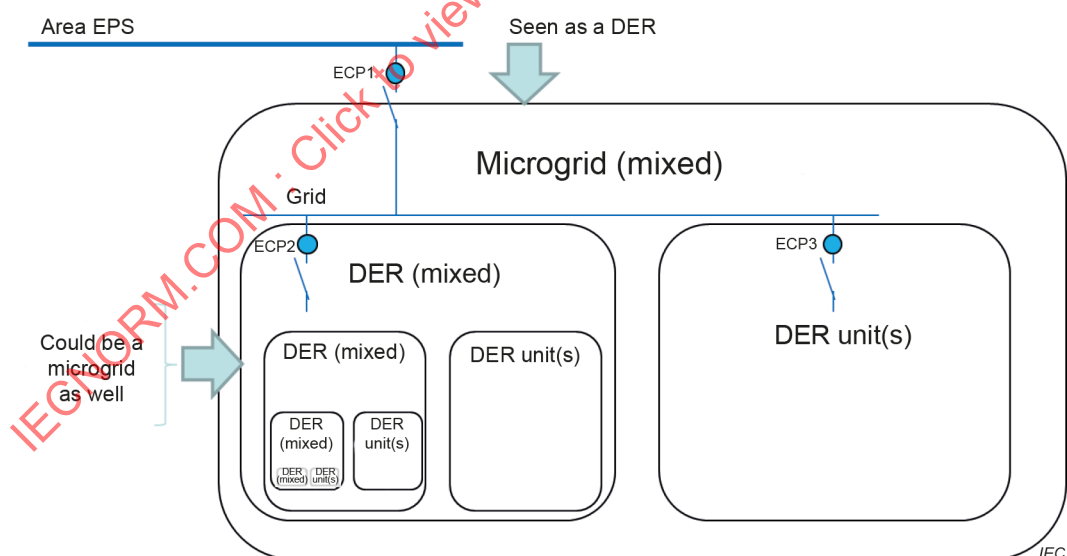


Figure 9 – The conceptual model for microgrids

This conceptual approach helps understanding why DER, microgrids and VPPs are from the exact same family (as far as energy is concerned). Only three prerequisite must be highlighted:

- DERs include any generators and controllable loads, and thus de facto storage;
- Virtual aggregation (i.e. VPP) can be approached very similarly to physical aggregation;
- Microgrids are DERs which have the possibility to run autonomously.

6 Reference architectures, roles and use cases

6.1 Architecture model for DER management (as proposed by SyC SE)

Most DER systems can or must operate autonomously in order to respond rapidly to changing power system conditions and meet power system safety, reliability, and efficiency criteria. At the local level, DER systems must manage their own generation and storage activities autonomously, based on local conditions, pre-established settings, and DER owner preferences. However, communications with utilities, facility energy management systems, and/or retail energy providers can support additional functions and provide updated functional parameters, so that the DERs can participate more effectively in the management of the Area Electric Power System (EPS). But direct control by utilities is not feasible for the thousands if not millions of DER systems connected to the distribution system, so a hierarchical approach is necessary for utilities to interact with most of these widely dispersed DER systems.

In some situations, depending on regional options and regulations, utilities may request or require DER systems to be located at critical electrically important points, while utility assessments of new DER implementations may determine which DER functions could be preferred or even mandatory for providing grid support. For any DER systems to be active participants in grid operations, their operations must be coordinated with other DER systems and with distribution grid equipment such as load tap changers, capacitor banks, and voltage regulators.

Many commercial and industrial customer sites would likely include Facility DER Energy Management Systems (FDEMS) that could modify DER autonomous settings and issue direct commands. The Area EPS operators could interact with these FDEMS occasionally to update settings or broadcast pricing signals and/or emergency commands. In addition, the distribution-level area EPS operators could provide some of the DER benefits to Regional Transmission Organizations (RTOs) and/or Independent System Operators (ISOs) for reliability and market purposes. In some regions, Retail Energy Providers (REPs) or other Energy Service Providers (ESPs) would be responsible for managing groups of DER systems.

Information exchange is critical to accommodate these complex and dynamic power system requirements, and management of these information exchanges needs to be organized and interoperable. Specifically, a hierarchical approach is necessary for the various stakeholders (utilities, aggregators, facilities, markets, and DER system operators) to exchange information. At the local level, DER systems generally manage their own generation and storage activities autonomously based on local conditions, pre-established settings, and DER owner preferences. DER systems can also be active participants in power system operations and must be coordinated with other DER systems and distribution equipment. In addition, the Distribution System Operators (DSOs) must interact with transmission system operators (TSOs), also known as regional transmission organizations (RTOs) and/or independent system operators (ISOs), for reliability and market purposes. In some regions, retail energy providers, aggregators, or other energy service providers are responsible for managing groups of DER systems either through operational actions or market actions.

This hierarchical approach can be described as hybrid combinations of five levels across multiple domains, as illustrated in the five-level hierarchical DER system architecture shown in Figure 10 and described below. The circled numbers identify the various logical information exchanges.

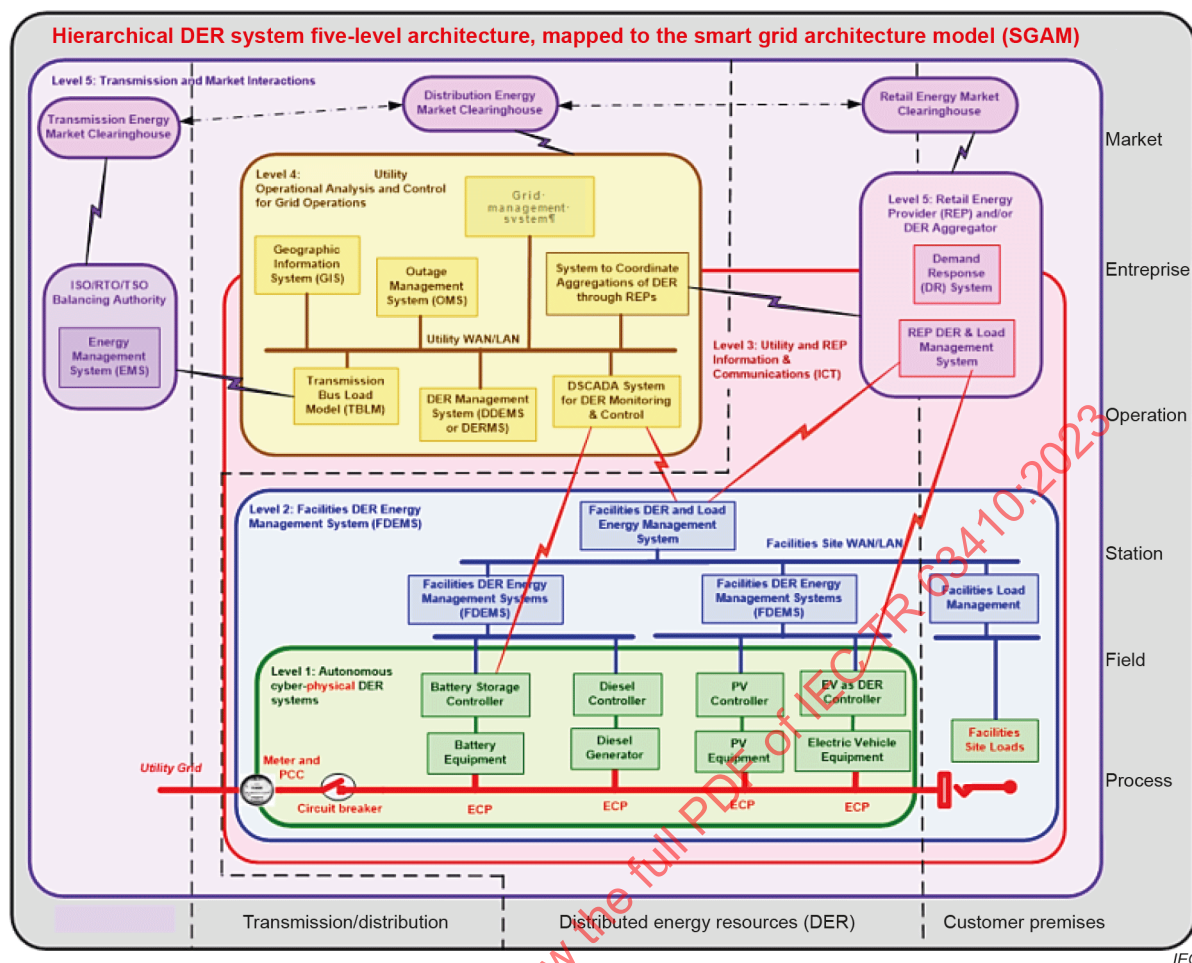


Figure 10 – Example of a hierarchical DER system five-level architecture in SGAM format

- Level 1 DER systems** (green in Figure 10) are the lowest level and include the actual cyber-physical DER systems themselves. These DER systems will be interconnected to local grids at Electrical Connection Points (ECPs) and to the utility grid through the Point of Common Coupling (PCC) (the ECP and the PCC may be the same if the DER is directly grid-connected). These DER systems will usually be operated autonomously. In other words, these DER systems will be running based on local conditions, such as photovoltaic systems operating when the sun is shining, wind turbines operating when the wind is blowing, electric vehicles charging when plugged in by the owner, and diesel generators operating when started up by the customer. This autonomous operation can be modified by DER owner preferences, pre-set parameter, and commands issued by utilities and aggregators. The communication protocols used internally to DER include ModBus, SunSpec Alliance profile for ModBus, and potentially Generic Object Oriented Substation Event (GOOSE). For electric vehicles, IEC 15118 is used between the EV and the charging spot (EVSE).

- 2) **Level 2 facility DER management** (blue in Figure 10) is the next higher level in which a facility DER management system (FDEMS) manages the operation of the Level 1 DER systems. This FDEMS may be managing one or two DER systems in a residential home, but more likely will be managing multiple DER systems in commercial and industrial sites, such as university campuses and shopping malls. Utilities may also use an FDEMS to handle DER systems located at utility sites such as substations or power plant sites. For utilities, FDEMS are viewed as field systems and shown at the Station level of the SGAM; however, from a facility's point of view, they may be seen as enterprises in their own right, and they could then be shown at the Enterprise and Operations levels. The communication protocols used within a facility are most often proprietary but could include IEC 61850, IEEE 2030.5 (SEP2), and Building Automation and Control networks (BACnet).
- 3) **Level 3 third parties:** Aggregators or retail energy providers (red in Figure 10) shows market-based aggregators and retail energy providers (REP) who request or even command DER systems (either through the facility's FDEMS or via aggregator-provided direct communication links) to take specific actions, such as turning on or off, setting or limiting output, providing ancillary services (e.g. volt-VAR control), and other grid management functions. Aggregator DER commands would likely be price-based either to minimize customer costs or to respond to utility requirements for safety and reliability purposes. The combination of third parties (this level) and facilities (Level 2) may have varying configurations, responsibilities, and operational scenarios but, overall, still fundamentally provide the same services. The communication protocols used by aggregators are usually proprietary, but could include Open Automated Demand Response communications specification (OpenADR) for market-based interactions or potentially IEC 61850 or IEEE 2030.5 (SEP2) for technical interactions.
- 4) **Level 4 utility operational grid management** (yellow in Figure 10) applies to utility applications that are needed to determine what requests or commands should be issued to which DER systems. Distribution System Operators (DSOs) must monitor the distribution power system and assess if efficiency or reliability of the power system can be improved by having DER systems modify their operation. This utility assessment involves many utility control center systems, orchestrated by the Distribution Management System (DMS) and including the DER database and management systems (DERMS), Geographical Information Systems (GIS), Transmission Bus Load Model (TBLM), Outage Management Systems (OMS), and Demand Response (DR) systems. Transmission System Operators (TSOs), regional transmission operators (RTOs), or independent system operators (ISOs) may interact directly with larger DER systems and/or may request services for the bulk power system from aggregated DER systems through the DSO or through the REP/aggregators. Once the utility has determined that modified requests or commands should be issued, it will send these either directly to a DER system, indirectly through the FDEMS, or indirectly through the REP/Aggregator. The communication protocols used for direct control of DER systems is either IEEE 1815 (DNP3) or IEC 61850, while indirect interactions through the facility or plant use either IEC 61850 or IEEE 2030.5 (or in the case of wind plants, IEC 61400). The communication protocols used between the DSO and aggregators may be IEC 61850 or IEEE 2030.5. Internal to the DSO, the Common Information Model (CIM) can be used to exchange power system models between applications (IEC 61970) or for messaging between back office systems (IEC 61968). The DSO and TSOs may also exchange information on DER systems using IEC 60870-6 (ICCP).
- 5) **Level 5 market operations** (purple in Figure 10) is the highest level, and it involves the larger energy environment where markets influence which DER systems will provide what services. The TSO markets are typically bid/offer transaction energy markets between individual DER owner/operators and the TSO. At the distribution level, the markets are not yet well-formed, and, over time as they evolve, they may be based on individual contracts, special tariffs, demand response signalling, and/or bid/offer transaction energy markets. The communication protocols used for market operations include OpenADR, IEC 62325, and IEC 62746.

6.2 Actors and Roles (from SyC SE)

Table 2 lists the business roles that have been identified so far by SyC SE. This list is not exhaustive and will be updated as the use cases are drafted.

Table 2 – Business Roles of the domain

Business roles	Definition
Energy generation roles	
DER Owner	Responsible party for overall market and financial decisions and contracts related to DER including microgrid design and operations
DER Operator	Responsible party for operational aspects of the facilities and their DER systems including real time microgrid operations
Flexibility aggregator	A party which aggregates flexibilities for its customers. May activate flexibility sites. Equivalent to Retail Energy Provider (REP) in this document
DER equipment manufacturer	Entity that produces, tests, sells, and implements DER systems
Producer	Party generating electric energy. Additional information: This is a type of Grid User. [SOURCE: based on IEC 60050-617:2009, 617-02-01]
Prosumer	Party both generating and consuming electric energy
Decentralised electricity producer	Electricity producer with generator(s) connected to the distribution grid. Production can be dispatchable and/or non-dispatchable. This is a type of Producer.
Power Plant Operator	Responsible party for operational aspects of a power plant
Power Plant Owner	Responsible party for market and financial decisions and contracts related to a power plant
Utility roles	
Microgrid Operator	Responsible party for operational aspects of a microgrid
Microgrid Owner	Responsible party for market and financial decisions and contracts related to a microgrid
Retail Energy Provider (REP)	Third party managing DER systems based on market information
System operator	A party that operates one or more grids. This term is used when it is not necessary to specify whether distribution or transmission system operator is meant.
Distribution system operator (DSO)	Entity responsible for the planning, operation, maintenance, and the development in given areas of the electricity distribution network (LV, MV, and potentially HV), the quality of electricity supply (power delivery, voltage etc.) and for customer access to energy supply retail market through his system under regulated conditions. Equivalent to MV/LV system operators.
Transmission system operator (TSO)	Entity responsible for the planning, operation, maintenance, and the development in given areas of the electricity transmission network (HV), the quality of electricity supply (frequency and voltage), and access to the bulk market system for DER systems capable of participating Equivalent to HV system operators. According to the Article 2.4 of the Electricity Directive 2009/72/EC (Directive): "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity". Moreover, the TSO is responsible for connection of all grid users at the transmission level and connection of the DSOs within the TSO control area. [SOURCE: EU Commission Task Force for Smart Grids, EG3]

Business roles	Definition
Balancing authority	Entity responsible for balancing generation and load, using frequency management to achieve this responsibility
Customer roles	
Client / customer (of electricity supplier)	A party connected to the grid that contracts for the ability to consume electricity at a metering point.
Consumer	A party connected to the grid that contracts for the ability to consume electricity at a metering point.
Grid user	A party connected to the grid and consuming and/or producing electricity. Grid Users include Consumers, Producers, and Prosumers. Equivalent to Party Connected to the Grid.
Market services roles	
Service provider or energy service provider	Entity providing electricity-related services (such as energy efficiency or communication services).
Bulk power market or transmission market	Entity providing a market for the buying and selling energy and ancillary services to the bulk power system
Distribution market	Entity providing a market for the buying and selling energy and ancillary services to the distribution power system In general, this entity does not exist as a "market" but many energy service providers may provide related capabilities
Demand response market	Entity providing energy prices to consumers and prosumers so that they may change their energy demand based on those prices.
Third party roles	
Meter operator	A party responsible for installing, maintaining, testing, certifying and decommissioning physical meters in compliance with the regulated conditions for contract between ESR and their customers. [SOURCE: ENTSO-E, EFET, and eBIX, 2010]
Metering point administrator	A party responsible for registering the parties linked to the metering points in a Metering Grid Area. He is also responsible for maintaining the Metering Point technical specifications. He is responsible for creating and terminating metering points. [SOURCE: ENTSO-E, EFET, and eBIX, 2014]
Telecommunications operator	Entity that offers telecommunications services.
Electricity Installer	Entity that installs and maintains smart electric systems for industrial, commercial and residential purposes.
Equipment Manufacturer	Entity that produces and sells electrical devices and electricity management devices.

Table 3 lists the system roles that have been identified so far by SyC SE. This list is not exhaustive and will be updated as the use cases are drafted.

Table 3 – System Roles of the domain

System Roles		Definition
Level 0 Electric Power system		
Electric Power System (EPS) (high level)		Facilities that deliver electric power to a load
	Local EPS	An EPS contained entirely within a single premise or group of premises
	Area EPS	An EPS that serves Local EPSs
	Microgrid EPS	A Local EPS that can operate as an island and is operated as a virtual resource to the Area EPS
	DC EPS	A Local EPS that operates direct current
Electrical Point of Connection (ECP)		Point of electrical connection between the DER source or sink of energy and any EPS Each DER unit has an ECP connecting it to its local power system; groups of DER units have an ECP where they interconnect to the power system at a specific site or plant; a group of DER units plus local loads have an ECP where they are interconnected to the utility power system. NOTE For those ECPs between a utility EPS and a plant or site EPS, this point is identical to the point of common coupling (PCC) in the IEEE 1547 "Standard for Interconnecting Distributed Resources with Electric Power Systems".
	Point of Common Coupling (PCC)	The point where a Local EPS is connected to an Area EPS
	PCC Switch	Switch plus its controller at the point of common coupling (PCC) between the Local EPS and the Area EPS
	EPS Switch	Switch plus its controller within an EPS
Synchronizing equipment		Equipment that synchronizes the frequency between two EPSs
Weather System		Meteorological service providing weather system that can affect DER capabilities
Level 1 DER		
Virtual Resource (high level)		A set of one or more energy service resources, including generators, energy storage, controllable load, and ancillary services
Distributed Energy Resource (DER) (high level)		A distributed set of one or more energy service resources, including generators, energy storage, controllable load, and ancillary services
	Renewable DER	DER system whose prime mover energy comes from renewable sources, including water, solar, wind, and biofuels
	Combined Heat and Power (CHP)	DER system whose primary purpose is creation of heat but can also provide electrical energy from the heat creation capability. In some circumstances, electrical energy is the primary purpose with heat as a secondary purpose
	Electric Vehicle (EV)	Automobile which is powered completely or in part by electricity and whose battery can be charged from an EPS
	Electric Vehicle Supply Equipment (EVSE)	
	Photovoltaic system (PV)	
	Fuel cell	
	Wind turbine	

System Roles		Definition
	Hydro plant	
	Gas turbine	
	Biomass plant	
	Wood chip boiler	
	Battery energy storage	
	Pumped water storage	
DER Unit (high level)		Prime mover and converter to and/or from electrical energy, including generators, energy storage, and controllable load
DER Controller (high level)		Controller of DER unit
DER System (high level)		Combined DER controller and DER unit, including generators, energy storage, and controllable load
	Regulating DER System	DER system responsible for frequency and/or voltage regulation. The regulating DER system could be a generator, an energy storage system, or controllable load.
	Non-regulating DER System	DER system not participating in frequency or voltage regulation.
DER Storage Unit (high level)		DER unit that includes energy storage that can be converted to electrical energy
DER Generating Unit (high level)		DER unit that includes generation of electrical energy
DER Controllable Load (high level)		DER that consists primarily of a load that is allowed to be modified based on operating conditions, tariffs, contracts, or other criteria
	Non-Controllable Load	Load that is not allowed to be modified
	Critical Load	Loads within a Local EPS having the highest priority of service. These loads are served at the expense of all other loads.
	Non-Critical Load	Loads within a Local EPS having the lowest priority of service. These loads may be left unserved in favor of critical loads.
Time Synchronization Source		Source of an accurate time signal
DER Protection Function		Safety-related function to prevent harm to personnel, the DER system, and/or other electrical equipment
DER Log		Log of significant events and alarms for use in market settlements, operational analysis, and other audit purposes
DER Meter		Meter that records the energy produced within specified time periods, energy used within specified time periods for DER charging of storage, and demand curves of DER generation and storage over time
Level 2 FDEMS		
DER Management System (DER-MS) (high level)		System that manages the settings and dispatch of DER systems
Facility DER EMS (FDEMS)		System that manages the settings and dispatch of DER systems within a facility. This facility could be a residence, a building, a commercial site, an industrial site, or any other high-level location.
	Microgrid DER EMS (MDEMS)	System that manages the settings and dispatch of DER systems within a microgrid, and that can cause the microgrid to become an island and to reconnect with the Area EPS

System Roles		Definition
	Power Plant DER EMS (PDEMS)	System that manages the settings and dispatch of DER systems within a power plant
	Building DER EMS (BDEMS)	System that manages the settings and dispatch of DER systems within a building
	Virtual Power Plant (VPP) DER EMS (VDEMS)	System that manages the settings and dispatch of DER systems that are enrolled in a virtual power plant
	Electric Vehicle EMS (EVEMS)	System that manages the settings for charging electric vehicles, including as DER systems
	Meter Data Management System (MDMS)	
Electric Vehicle Supply Equipment (EVSE)		
Energy Services Interface (ESI)		
Facility Local Area Network (Facility LAN)		
Level 3 Aggregators		
Aggregator		See definition
	Aggregator DER management system (ADEMS)	
	Retail DER Energy Management System (RDEMS)	System that manages the settings and dispatch of DER systems that have been contracted to be operated by REPs and/or Aggregators
Level 4 DSO and TSO		
Transmission System Operator (TSO)		See definition in Table 6
	TDEMS or TSO EMS	TDEMS is part of the TSO EMS that manages large DER systems or large aggregations of smaller DER systems
Distribution System Operator (DSO)		See definition
	DSO Planner	Planner
	DSO DER EMS (DDEMS)	
Distribution Management System (DMS)		High level term for all applications used for distribution management.
	Distribution Operations Model and Analysis (DOMA)	Topological model of distribution system, including the location and profile characteristics of all distribution equipment and DER systems (individually and/or in aggregate). This model is derived from the geographic model in the GIS, the facilities information (often included in the GIS and/or an asset management database), and the DER profiles (derived from the CIS and DER characteristics database).
	Distribution System Power Flow (DSPF)	Application that determines the power flows of the distribution system, using the DOMA model
	Transmission Bus Load Model (TBLM)	
Geographic Information System (GIS)		Geographic model of the distribution system, including the location and characteristics of all distribution equipment and DER systems (individually and/or in aggregate)

System Roles		Definition
Customer Information System (CIS)		System with customer information, including personal information, billing information, customer profile information, etc.
Outage Management System (OMS)		
Distribution SCADA System (DSCADA)		
Level 5 Market		
Transmission Energy Market (high level)		
	Wholesale Energy Market	
	Balancing Authority (market)	
	Transmission market operator	
Retail Market (high level)		
	Demand Response (DR) System	System providing demand response pricing information for different energy products during different time frames
Demand Response (DR) Pricing Schedule		Schedule provided by REPs, DSOs, TSO, and others to indicate contractual and/or forecast prices for energy and ancillary services during specific time periods
	EV Pricing Program	Special pricing for charging EVs
	V2G DR program	Vehicle to Grid demand response program
Level 6 Communications		
Wide Area Network (WAN)		
	Public Network	
	Advanced Metering Infrastructure (AMI)	
	Cellular system	
	Public Internet	
	Communication Nodes	
Cyber security		
	Password and certificate management	
	Firewalls	
	Key management systems	
	Role-based access control systems	

6.3 Use Cases: Microgrids

6.3.1 General

Presently, several technical committees or research organizations have been involved in the development and application of use cases, such as:

- IEC SyC Smart Energy

- IEC TC8 and its WGs
- CIGRE, CIRED, IEEE
- EDF R&D, EPRI
- Universities

The Business Use Cases (BUC) have been classified based on their need and objectives as follows:

- Guarantee a continuity in load service by islanding
- Electrify remote areas using renewable energy resources
- Optimize local resources to provide service to customers inside microgrids
- Optimize local resources to provide services to the grid / disaster preparedness
- Develop larger energy system by interconnection of isolated microgrids
- Optimize energy supply cost by proper use of local asset within a community-run distribution system

Not all use cases are further introduced in this clause. The use cases using 62559 templates are introduced in IEC 62898-4. This document only keeps the list introducing the environment and types that microgrids are applied. A detailed use case is given below to explain their granularity of the description and the coverage of the information.

6.3.2 Business Use Case A: Microgrid-Guarantee a continuity in load service by islanding referencing IEC 62898-4

This BUC is based on document IEC SyC Smart Energy/32/CD, and is intended to be reviewed to be consistent with IEC TS 62913-2-1, *Generic Smart Grid Requirements – Part 2-1: Grid related Domains*.

1) Name of use case

Use case identification		
ID	Area(s)/Domain(s)/Zone(s)	Name of use case
	Microgrids	Microgrid-Guarantee a continuity in load service by islanding

2) Version management

Version management				
Version No.	Date	Name of author(s)	Changes	Approval status

3) Scope and objectives of use case

Scope and objectives of use case	
Scope	This BUC concerns connected microgrids only (distribution microgrids or facility microgrids). It describes how microgrids can guarantee continuity in load service by islanding, i.e. by operating disconnected from the main grid. This BUC is an entry point for specifying interoperability requirements and associated data models of IEC TR 61850-90-23.
Objective(s)	This BUC reaches several objectives on the services to microgrid users: – Improve reliability of power supply of customers by a) by maintaining supply continuity and/or b) maintaining supply continuity for critical loads – Facilitate maintenance of network assets, by enabling supply continuity to customers during an interruption. – Reduce outage times for the customers within the microgrid. Three kinds of islanding are possible: – Preventive islanding if a supply interruption is planned (e.g. due to maintenance), or a grid outage is expected (storms that could damage overhead lines, damages by third parties, line congestion are non-exhaustive examples). – Automated islanding in case of unplanned grid failure. – Black Start recovery to re-supply loads after grid failure, if the microgrid is technically not capable to automatically island without any black. After starting the islanding, the microgrid will continue to operate in islanding mode as long as the power is not back to normal on the overlay grid. Afterwards, it can reconnect to the grid, and work again in connected mode.
Related technical issues	<u>Operation of Use Case and technical issues:</u> This Use Case can be broken down into four steps, including a total of six scenarios: – Step 1: Before Islanding (scenario 1) – Step 2: Starting the islanding with one of the following scenarios: • Preventive islanding if a supply interruption is planned, or a grid outage is expected (scenario 2) • Automated islanding in case of unplanned grid failure (scenario 3) • Black Start recovery to re-supply loads after grid failure (scenario 4) – Step 3: Maintaining the islanding (scenario 5) – Step 4: Reconnection to the main grid (scenario 6) Scenario 2 is only applicable for planned grid outages, which can be planned maintenance of upstream equipment or anticipation of possible upcoming failure or constraints on the network (storms that could damage overhead lines, line congestion are a few examples). Scenarios 3 and 4 are applicable when an unplanned outage of the main grid occurs. The choice between both scenarios depends on the technical capabilities of the microgrid: automated islanding is better for the clients, as they do not sustain any outage, but is much more technically complicated to achieve, and thus needs more equipment and more investments. The processes before and during the islanding, and for the re-connection to the main grid are the same in every case. <u>Before islanding (scenario 1)</u> When the microgrid is connected to the main grid, in normal operating conditions, the microgrid manager monitors the state of the main grid and of the different generators, storage systems, controllable loads and other flexibilities inside the microgrid to enable islanding if an outage occurs and to assess the possible duration of islanding. Microgrid (storage) might operate only a limited time in islanding mode. This duration should be sent to the DSO, especially for sensitive applications. The microgrid manager informs the MV/LV system operator about the microgrid's possibility to island in real time. For utility microgrids, the MV/LV system operator gives an authorization to island in case of outage (If possible, automatic action will be engaged).

Scope and objectives of use case	
	The microgrid manager also prepares the different generators, storage systems, controllable loads and other flexibilities, so they are in the optimal state to start islanding if necessary, in coordination with the other use cases using them. For example, a certain percentage of a storage system's charge could be reserved to enable islanding, and not be used for other use cases. To prepare a generator, storage system or controllable loads, the microgrid manager can either have direct control, or pass through a system manager (DER operator or EES operator). The preparation and the assessment of the islanding duration takes into account the forecasting of the consumption and production inside the microgrid. In case of critical loads such as hospitals, banks, etc. seamless switches are needed for islanding and the total islanding duration must be defined and guaranteed. <u>Starting the islanding</u> <u>Preventive islanding (scenario 2)</u> The preventive islanding can be triggered by one of the following events: For distribution microgrids, the MV/LV system operator informs the microgrid manager that it should perform a preventive islanding due to: – an operation on the network that will cause a supply interruption in the microgrid area, or – an expected grid failure due to climatic events or constraints on the network. The MV/LV system operator informs the microgrid manager about the starting time and the duration of this event. For facility microgrids, the private network operator can decide to operate a preventive islanding if he receives one of the following information: – The MV/LV system operator informs about an operation on the network that will cause a supply interruption in the facility area; – The MV/LV system operator or a weather forecast provider informs about an expected grid failure due to climatic events; – The MV/LV system operator informs about an expected grid failure due to grid constraints; – The private network operator calculates from market prices that it will be less expensive to island for a given period of time. In coordination with other use cases, the microgrid manager prepares the different generators, storage systems, controllable loads and other flexibilities, so that the system will be able to island during the entire event. For critical applications, periodic tests must be conducted to ensure the readiness of the system. The microgrid manager informs the MV/LV system operator about the microgrid possibility to island. Before the event starting time (real or expected), the microgrid manager takes control of the operation mode of the different generators, storage systems, controllable loads and other flexibilities, and starts the islanding by physically disconnecting the microgrid from the main grid and simultaneously switching the relevant resources to islanding mode. <u>Automated islanding (scenario 3)</u> At a given time, an unplanned outage occurs on the main grid, and is detected by the microgrid manager. If the conditions enable it (for critical loads, this must work 99,999 %) the microgrid manager takes control of the operation mode of the different generators, storage systems, controllable loads and other flexibilities, and starts the islanding by physically disconnecting the microgrid from the main grid and simultaneously switching the relevant resources to islanding mode. The microgrid manager informs the MV/LV system operator about the microgrid islanding state, and the possible duration of the islanding. <u>Black start recovery (scenario 4)</u> At a given time, an unplanned outage occurs on the main grid, and the microgrid is enable to automatically island, and is thus power off. The microgrid manager evaluates the possibility to perform a black start recovery, and informs the MV/LV system operator about it. If a black start is possible, the microgrid manager takes control of the operation mode of the different generators, storage systems, controllable loads and other flexibilities, physically disconnects the microgrid from the main grid and simultaneously switches the relevant resources to islanding mode, and performs a black start by managing the energy sources and the other flexibilities. The microgrid manager assesses the duration that it will be able to maintain islanding, and informs the MV/LV system operator about it. <u>Maintaining the islanding (scenario 5)</u>

Scope and objectives of use case	
	Once the islanding has started, the microgrid operator has control over the different generators, storage systems, controllable loads and other controllable devices in a microgrid. The bus bars on LV level should be divided into non-interruptible (lights), interruptible (heating, cooling, etc.) and interruptible with a time delay (dryer, washing machine). This should ensure enough flexibility through a simple and reliable approach in order to manage them to maintain the islanding for the targeted duration. If it is impossible to maintain all the loads supplied for the total duration, the microgrid manager optimizes the supply time of the loads, taking into account priorities between the loads. The microgrid manager regularly assesses the possible duration of the islanding, and informs the MV/LV system operator about it. This assessment takes into account the forecasting of the consumption and production inside the microgrid. Load priorities should be considered when the microgrid is operation in island mode, e.g. washing is not important action during a blackout. If, due to a lack of production, consumption or flexibility, the islanding becomes impossible to maintain, the microgrid manager safely powers out the microgrid area, or reconnects the microgrid to the main grid when it is possible. <u>Reconnection to the main grid (scenario 6)</u> When the power on the main grid has regained normal operating conditions, the MV/LV system operator informs the microgrid manager that it can reconnect the microgrid. The microgrid manager then manages the different generators, storage systems, controllable loads and other flexibilities to enable a reconnection without perturbation, and physically performs the reconnection. The microgrid manager informs the MV/LV system operator about the reconnection, and gives back the control of the different generators, storage systems, controllable loads and other flexibilities to the other use cases.
Related business case(s)	

6.3.3 Perspectives

The following topics can be addressed in the future:

- Identify the common components of BUC that are or need to be standardized (for example metering issues, power quality and reliability issues, black start recovery, status of grid as producer or consumer could be some components)
- Identify some important specific components in some of the BUC that are not present in the others
- Link each component to existing IEC standards or standards under development
- Identify the ones for which no standard exists or is under development
- Propose generic requirements for the processes (or components) that will need to be considered for standardization

6.4 Use Cases: Non-conventional distribution systems

6.4.1 Grid-tied local systems

The traditional distribution network is a passive network that distributes power and power to users in one direction. The access to distributed generation makes the distribution network an active network with a two-way power flow. At the same time, it also brings technical problems such as voltage fluctuation, relay protection mis operation or refusal. The impact of distributed generation access on distribution network, active distribution network planning, distributed generation grid connection protection and control, active distribution network protection, active distribution network voltage control, active distribution network power quality control, distributed generation scheduling and management are the hot spots of power technology research.

According to the penetration rate of distributed generation in distribution network (the ratio of distributed generation capacity to rated capacity of distribution network) and the technical measures taken, the grid connection technology of distributed generation can be divided into three types: connect and forget, grace access and active network management.

6.4.2 Multi-energy local systems

A multi-energy complementary system is the expansion of traditional distributed energy application and the embodiment of the concept of integration in the field of energy system engineering, which makes the application of distributed energy expand from point to area and from local to system. Specifically, "multi energy complementary distributed energy system" refers to the "regional energy Internet" system that can contain a variety of energy resource inputs and has a variety of output functions and transportation forms. It is not a simple superposition of multiple energy sources, but should make comprehensive and complementary utilization according to the level of different energy grades at the height of the system, and make overall arrangements for the cooperation relationship and conversion use of various energy, so as to achieve the most reasonable energy utilization effect and benefit.

The multi-energy complementary integrated optimization demonstration project mainly has two modes: first, for the end-users' multiple energy needs such as electricity, heat, cooling and gas, adjust measures to local conditions, make overall development and complementary use of traditional and new energy, optimize the layout and build an integrated energy supply infrastructure, through natural gas combined heat, power and cooling, distributed renewable energy and energy intelligent microgrid, realize multi energy collaborative supply and comprehensive cascade utilization of energy; secondly, to make use of the resource combination advantages of large-scale comprehensive energy base, such as wind energy, solar energy, hydropower, coal and natural gas, and promote the construction and operation of wind, water and fire storage multi energy complementary system.

The construction of a multi energy complementary integrated optimization demonstration project is one of the important tasks of building the "Internet plus" smart energy system. It is conducive to improving the coordination of energy supply and demand, promoting clean energy production and consumption, reducing the wind power, abandoning light, abandoning water power and promoting renewable energy consumption. It is an important starting point for improving the comprehensive efficiency of energy system, and for building clean and low carbon, A safe and efficient modern energy system has important practical significance and far-reaching strategic significance.

6.4.3 DC distribution systems

In recent years, with the improvement of public awareness of energy conservation and emission reduction, there are increasingly higher requirements for energy saving and consumption reduction, reliability improvement and power quality of power distribution networks. Clean and flexible distributed energy has been promoted and developed rapidly all over the world, which has changed the power supply composition of power grids. The electricity generated by PV, wind power, fuel cell, biomass energy and other new energy is DC or becomes DC through simple rectification. This electric energy is directly integrated to the DC distribution network to save lots of conversion process and reduce power consumption. Also, there are more and more DC loads such as office electricity usage (computers and office equipment), commercial electricity usage (electric locomotive, elevators, etc.), household electricity usage (DC frequency conversion air conditioner, refrigerator, washing machine, etc.) on the load side. If they adopt a DC power supply, this can greatly improve the energy efficiency and power quality. DC power distribution is not only the best technical solution to solve the problems of renewable energy grid-connection and corridor limitation, but it can also reduce the power loss of the distribution network and the negative impact of distributed energy on the distribution network, and improve the power supply efficiency, reliability and power transfer capability.

In the future, the distribution system will exist in the form of an AC network and a DC network. Therefore, the future regional distribution network must be an open system, which can adapt to the integration of middle and small-scale distributed energy and energy storage systems widely, manage the demand side, and realize the source-grid-load interaction and other requirements by making full use of the DC distribution technology in the transformer region.

From power supplies in residential areas and industrial parks, the interconnection of regions and renewal of city centers with limited space, to the electrification of transportation, as well as the collection of large-scale offshore wind power and power supplies of large-scale data centers, the active application demand is the driver for the development of DC power distribution technology and a DC power distribution network. Typical application scenarios of DC power distribution include electric vehicles, data centers, residential buildings, offshore wind power, industrial parks, multi-microgrid DC interconnection, etc.

6.4.4 Electric vehicles

The development of electric vehicles (PEV) is an important method to improve the energy structure, ensure energy security and develop the low-carbon economy, and electric vehicles will play a significant role in the future. Currently, electric vehicle charging stations mainly rely on AC charging piles. With the development of DC distribution network, DC charging piles and DC distribution network will be the main components of electric vehicle's battery swap station in the future.

However, with the rapid increase in the number of electric vehicles, its influence on the power system especially the MV/LV system becomes more and more significant. Electric vehicles can be considered as a type of random charging load, and the charging power demand is affected by the user's driving habits and battery characteristics. A large number of electric vehicles' integration to households, offices and other areas will influence the local load distribution, and they may be charging in the peak load period during a day. This further increases the load demand of substations or transformer, which can lead to overload in serious cases.

DC power distribution network can be connected to the external AC system through the AC/DC converter, and a multi-terminal LVDC is able to connect to multiple lines or transformers in AC system through multiple converters. It makes full use of available power balance ability between lines or transformers to shift the peak load demand of a single feeder or transformer caused by the increase in the amount of electric vehicle integration, thereby avoiding the overload of lines or transformers. This then provides users with higher running reliability, and solves the electric vehicle integration constraints caused by the existing structure and capacity configuration of the distribution network. Therefore, it improves the ability of electric vehicle integration in power distribution network.

6.5 Use cases: Virtual power plants

The Business Use Cases (BUC) have been classified based on their need and objectives as follows:

- Virtual power plant operation platform and its practice
- Virtual power plant providing comprehensive energy services
- Normal mode of participating in power system operation
- Emergency mode of alleviating power system contingencies
- Participating in peak shaving energy market
- Local energy management and coordinated control of distributed energy resources
- Virtual power plant participating in primary frequency control
- Virtual power plant participating in secondary frequency control
- Virtual power plant participating in voltage regulation

7 Standards identification and gap analysis

7.1 Microgrids

7.1.1 General

The availability of standards will greatly simplify the implementation of microgrids and lower the cost of equipment and controllers. Some identified ongoing standardization activities related to microgrids in IEC are listed in this document. the standardization needs and gaps in microgrids are also discussed.

IEC TS 62898-1, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification*, IEC TS 62898-2, *Microgrids – Part 2: Guidelines for operation*, and IEC TS 62898-3-1, *Microgrids – Part 3-1: technical requirements – protection and dynamic control* have been released. IEC TS 62898-1/AMD1, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification*, IEC TS 62898-2/AMD1, *Microgrids – Part 2: Guidelines for operation*, IEC TS 62898-3-2, *Microgrids – Part 3-2: Technical requirements – Energy management systems*, IEC TS 62898-3-4, *Microgrids – Technical requirements – Monitoring and Control systems*, and IEC TR 62898-4, *Microgrids: Part 4 – Use cases* have been approved. IEC TS 62898-3-3, *Microgrids – Part 3-3: Technical requirements – Self-regulation of dispatchable loads* will be discussed at the next meeting.

Standards that match the unique characteristics of the microgrid are required to allow microgrids to play a larger role in the distribution grid operation and contribute to electricity access in remote rural areas and geographic islands, including coordinated and consistent electrical interconnection standards, communication standards, implementation guidelines, etc.

The interaction between the microgrids embedded in distribution systems and the DSO, particularly in terms of the power purchases and related financial agreements and reciprocal regulatory obligations between the microgrid and the DSO, are often part of Grid Codes enforced by Authorities. Standards that can help demonstrating compliance with the Grid Codes are very useful.

7.1.2 Needs identified for microgrid standardization

Microgrids are not as simple as a mini traditional power grid. Key features distinguishing microgrids from traditional power distribution systems include:

- powered by distributed generation sources including renewable with intermittent and random characteristics, and CHP generators
- active interaction with end user
- the introduction of dynamic load control systems
- the heavy use of power electronics, such as multiple inverters
- the ability to operate as an island system
- multiple operation modes, such as integrated operation, islanding operation, integration/islanding transition, and
- existence of a single point of common connection (for grid-connected microgrids)

One or several features may exist separately in traditional power systems and may not trigger any specific issues. But when a microgrid is developed as a system which embodies all these features together, it generates a unique set of opportunities and risks, which brings higher requirements for various aspects of microgrids, such as planning and design, demand and supply balancing, voltage and frequency control, protection configuration and setting, information and communication planning.

As introduced through the conceptual approach in 7.2, microgrids can easily be considered as “extensions of DERs” with some specific capabilities such as (refer to IEC 57_1999e_DC and 57/2176e/INF) – this de facto includes communication and information models, as well as all steps of the life cycle from planning to specifying to commissioning and design, testing, operation and maintenance):

Connection/disconnection requirements of microgrids to main grid – including coordination with the area EPs (main grid)

- Planning and design
- Protection (during islanding mode otherwise similar to DER)
- “Stand-alone” monitoring and control (as extension to DER management system)
- System performance of microgrids, including the reliability, power quality, etc (as an extension of DER grid tied system)
- Operation (as complement to DER management systems)
- Microgrids black start
- Safety requirements
- Microgrids management, including maintenance, in addition to DER management systems
- Solution for access to electricity in remote or developing areas

7.1.3 Gaps identified for microgrid standardization

Microgrid standardization gaps identified are shown as the following:

- Terminology
- Modelling and simulation (electro-magnetic transient, stability, frequency domain for PQ, etc.)
- System performance indicators for distributed energy systems, including the reliability, power quality, etc.
- Safety requirements
- Connection requirements of microgrids to main grid
- Connection requirements of micro-sources or devices into microgrid
- Commissioning, and conformance & acceptance test (microgrid system as a whole)
- Commission and maintenance
- Tech-economic evaluation
- Standards for evaluating the safety of the system and its components
- Standards and codes addressing the installation of the system
- Criteria for measuring and expressing the performance of the system
- EMC and power quality (already addressed by TC8)
- System performance of electricity supplied by microgrids, including the reliability, power quality, etc.
- Microgrids management, including coordinated operation and control of multiple energy resources, optimal utilization of multi-types energy storage, cost-effective operation of microgrids, demand side management within microgrids, microgrids black start, coordinated operation with main grid, Coordinated operation of multi-microgrids, participation in ancillary service, maintenance, etc.
- Test and evaluation of microgrids
- Solution for access to electricity in remote or developing areas

- DC microgrids
- Guidelines for electrification projects
- Microgrids interconnectivity
- Development of a) simple and small, b) medium size and c) large microgrid based on least cost, efforts and expertise
- Currently, the published microgrids standards: IEC TS 62898-1:2017, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification specifying the planning of new microgrid projects*, IEC TS 62898-2:2018, *Microgrids – Part 2: Guidelines for operation, specifying the operation of microgrids*, IEC TS 62898-3-1:2020, *Microgrids – Part 3-1: Technical requirements – Protection and dynamic control specifying the protection and control methods of microgrids*, have not fully addressed the above mentioned gaps. The undergoing microgrids related projects: IEC TS 62898-1/AMD1, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification*, IEC TS 62898-2/AMD1, *Microgrids – Part 2: Guidelines for operation*, IEC TS 62898-3-2, *Microgrids – Part 3-2: Technical requirements – Energy management systems*, specifying the energy management in microgrids, IEC TS 62898-3-3, *Microgrids – Part 3-3: Technical requirements – Self-regulation of dispatchable loads*, specifying the self-regulation of dispatchable loads in microgrids, IEC TS 62898-3-4, *Microgrids – Technical requirements – Monitoring and control systems*, specifying the monitoring and control in microgrids, and IEC TR 62898-4, *Microgrids: Part 4 – Use cases*, specifying the application of microgrids, also have not fully addressed the above mentioned gaps.

7.2 Non-conventional distribution systems

7.2.1 Needs identified and gap analysis of grid-tied local system

A grid-tied local system is located near users with small installed capacity and local power is consumed locally. It is generally tied to low-voltage distribution networks, such as the system tied to the local distribution network composed of a photovoltaic power generation system installed on the roofs of users and local consumers.

There are two modes of operation for a grid-tied local system. One is that the generated power is consumed by its internal users and the surplus power is not transmitted to the main grid. The other is to transmit the surplus power to the main grid when the power generated is not used up by its internal users. For the former mode, the grid-tied local system is an ordinary power user relative to the main grid, and the user shall not supply power to the main grid. In this mode, the grid-tied local system should meet the grid-tied requirements of the existing users. For the latter mode, the grid-tied local system is a user with power generation capacity relative to the main grid. In this case, it is equivalent to connecting a small power source to the distribution network. Standards need to be specified for the grid-tied local system of this operation mode to standardize and lead the safe and reliable operation of the grid-tied local system.

Although the grid-tied local system also includes power supply and users, the grid-tied local system is different from the microgrid. The main difference between the two is that the grid-tied local system is always tied to the main network and does not have the ability to operate independently from the main network.

The grid-tied local system that transmits power to the public power grid mainly needs the following standards:

- Standard series of technical requirements for access to public power grid. This standard series provides technical requirements for grid-tied local systems that transmit power to public power grids, including power control, voltage and frequency response characteristics, maximum allowable short-circuit current, safety and protection functions, communication protocols, power metering, operation detection and power quality, etc.

- Standard series of characteristic tests. This standard series mainly standardizes the voltage and frequency characteristics, power quality (flicker, harmonic) effects and low voltage ride-through capability test methods of grid-tied local system.
- Standard series of operation control. This standard series mainly specifies the operation mode arrangement, active power/frequency control, reactive power/voltage control and emergency control of grid-tied local system.
- Standard series of information and communication. This standard series specifies the data acquisition, communication interface, communication medium and communication protocol of the grid-tie local system.

7.2.2 Needs identified and gap analysis of multi-energy local system

Multi-energy local system is originated from the research in the field of thermoelectric optimization. In the field of energy, there is a long-term situation of coordination and optimization of different energy forms. For example, CCHP can achieve the purpose of improving fuel utilization efficiency through coordinated optimization of high and low grade heat energy and electrical energy. Ice storage equipment coordinates electrical energy and cold energy (which can also be regarded as a kind of heat energy) to achieve the purpose of peak cutting and valley filling of electrical energy. In essence, CCHP and ice storage equipment belong to the local multi-energy local system.

Although the concept of a multi-energy local system has been considered for a long time and there have been a lot of previous studies, there is still a lack of a unified definition at present.

The multi-energy local system in this document refers to integrated energy production, supply and marketing system formed through organic coordination and optimization of energy generation, transmission and distribution (energy network), conversion, storage and consumption in the process of planning, construction and operation. It is mainly composed of energy supply networks (such as electrical power supply, gas supply and cooling/heating networks), energy exchange links (such as CCHP, generator units, boilers, air conditioners, heat pumps, etc.), energy storage links (such as electricity storage, gas storage, heat storage and cold storage, etc.), terminal integrated energy supply units (such as microgrids) and a large number of end users.

Both the multi-energy local system and the energy Internet pursue the large-scale development of renewable energy and the significant improvement of energy utilization efficiency. Their ultimate purpose is to solve the problems of sustainable energy supply and environmental pollution. However, the two have different focuses with the following significant differences:

- 1) the multi-energy local system focuses on energy systems themselves, while the energy Internet emphasis on the interconnection of energy systems.

As for the energy system itself, with the increasing demand for various types of energy, the coupling between different forms of energy is increasingly close; the independent operation of different energy systems in the past has become increasingly difficult to meet the energy demand of the future society. Jumping out of a single energy system and coordinating and optimizing multiple energy sources at a higher level to meet the increasing energy demands of mankind are the inevitable result of social development. It is the internal driving force for the birth of multi-energy local system. Therefore, a multi-energy local system places more emphasis on coordination and optimization between different energy sources, instead of relying too much on network interconnection and ICT technologies. As even an isolated system with more traditional control methods can achieve the purpose of improving energy efficiency and meeting the diverse needs of users.

The energy Internet can be seen as the product of the penetration of Internet concepts into the energy system or the reconstruction of the energy system. Therefore, it places more emphasis on the interconnection of the energy networks. The goal it pursues includes many features of the current Internet (such as peer-to-peer openness, plug and play, wide distribution, two-way transmission, high intelligence and real-time response, etc.). So it

places special emphasis on the deep integration of the Internet and ICT technologies with the energy system.

- 2) A multi-energy local system does not overemphasize the dominant position of which energy source, while the energy Internet relies more on electrical energy.

A multi-energy local system pursues coordination and optimization among different energy systems. Different energy forms shall assume different roles in different applications, and the dominant energy shall vary with different application scenarios. For the long-distance and large-capacity transmission of energy, the power grid and the natural gas network are often required to complete; at this time, electrical energy and natural gas shall dominate. For energy storage, electrical energy storage, natural gas energy storage or cold/hot energy storage shall be selected according to factors such as capacity and response speed, and the corresponding energy form shall play a leading role. In order to meet users' diversified energy demands such as electricity/cold/heat, there may be various combinations; for example, a single power grid can be used for energy supply, and other required cold and hot energies are obtained by electrical energy conversion. It can also be the power supply mode of electricity+natural gas; electricity/cold/heat demand can come from both electricity and natural gas and can also be mixed energy supply of power+natural gas+heat. Under the three modes, electricity/gas/cold/heat and other energies play different roles, and there is no inevitable dominant energy form.

The goal pursued by the energy Internet determines that the electrical power grid and electrical energy shall play a leading role in it. This is mainly because the electrical power network has the advantages of real-time energy transmission, high degree of automation and plug and play on the user side, while the electrical energy itself has the characteristics of easy transmission, conversion and use. Therefore, using an intelligent electrical power grid as the backbone network or core platform is more conducive to the realization of the goal of energy internet. Rifkin, in his book *The Third Industrial Revolution*, even makes the conclusion that smart power grid + distributed energy is the energy Internet.

In order to realize the organic coordination and optimization of production, transmission and distribution, conversion, storage and consumption of multiple energy sources, the multi-energy local system needs to formulate the following standards, including:

- Terminology,
- Modeling and simulation,
- Coordination, planning and optimal design of multi-energy systems,
- Test, including commissioning and acceptance test, field test, and equipment testing,
- Operation, including energy production forecasting, energy load forecasting, coordinated operation control of various energies and energy management,
- Maintenance,
- Measurement of multi-energy sources,
- Information exchange among various energy systems, including information models and protocols, etc.,
- Evaluation, including efficiency evaluation and technical index evaluation.

7.2.3 Needs identified and gap analysis of DC distribution system

7.2.3.1 General

- 1) Needs for DC distribution system standardization

DC power distribution technology involves the power industry, electrical manufacturing industry, construction and the majority of users. The system is very complicated and related technology is in the rapid development.

The project IEC TS 63354, *Guidelines for the planning and design of the centralized direct current distribution systems*, has been approved.

The urgent need for standardization is to provide technical support and specifications. The standardization of DC power distribution has key needs such as common criteria, plan and design, construction, installation and commissioning, test, operation and maintenance, dispatch and management, technical requirements for equipment and evaluation.

- General terms and definitions of DC distribution technology

With the development of new energy, power and technology, clean and flexible distributed energy has been promoted and developed rapidly all over the world, which promotes the rapid development of the DC power distribution industry. However, DC power distribution technology has changed the structure and operation mode of power distribution system and power consumption. It is urgent to carry out standardization and unification research on DC power distribution system and equipment terms and definitions (DC switch, DC transformer, converter station, other equipment and facilities), electrical graphics and text symbols, as well as naming rules for DC power distribution equipment and system scheduling.

- Planning and design of DC distribution technology

With the development of the economy, the penetration of distributed generation in power distribution networks increases gradually. DC power distribution network advantages become increasingly apparent, and projects keep emerging. However, there is a lack of unified plan and design. There is an urgent need to carry out standardization research on DC distribution voltage level and selection standards, technical guidelines of typical grids, design specifications of power distribution system, power consumption systems, and substations, technical guidance for power supply plans, technical specification of distributed generation integration, technical requirements of electric vehicle charging facilities integration, technical specifications for lightning protection and grounding design. It is necessary to ensure the standardization of the DC power distribution system's development and establishment, which promotes the healthy and orderly development of DC distribution technology and related industries.

- Construction, installation, commissioning and acceptance of the DC power distribution system

With the implantation of DC power distribution projects in succession, their commissioning and acceptance are of great significance for the reliable operation of power distribution network. Therefore, it is necessary to standardize the operation process of the DC power distribution system, construction and installation projects of converter stations, on-site inspections and project quality as soon as possible to ensure the normal operation of DC systems.

- Test specifications of DC power distribution equipment

With the rapid rise of the DC power distribution technology industry, the demand for energy saving and consumption reducing, improving reliability and power quality in DC power distribution network on user side is increasing. There is an urgent need to develop specifications for test methods and requirements of the converter equipment, transformer, circuit breaker, lines and other equipment used in DC distribution, and keep the reliability and safety of the system operation.

- Technical requirements of DC power distribution system operation and maintenance

With the rapid development of the DC power distribution system, it is playing an increasingly important role in power system, and its safe and reliable operation is improving gradually. There is an urgent need to propose clear requirements for operation control technology of the system interconnection between DC power distribution and the AC power grid, system operation control, DC station operation technology, system monitoring functions, grounding technology of system operation, maintenance technology in the case of system equipment's live-line state, on-line monitoring technology, and the system power quality's monitoring technology. It guides the operation and maintenance of DC power distribution system, and improves the reliability and stability of the power system.

- Scheduling management of DC distribution system

With the wide application of information and communication technologies in the power grid, DC power distribution system incorporates into the unified management platform of the power grid gradually. There is an urgent need to standardize the DC power distribution system and its scheduling management operation of the equipment, related technologies on system automation information interaction, system relay protection device configuration and operation management, basic technical requirements for system relay protection and safety automation devices, ensuring operation safety of DC power distribution systems with diversified sources and load types, geographical dispersion, frequent voltage fluctuations under the new generation of smart grid environment.

- **Technical requirements for DC distribution system equipment**

DC power distribution technology is still in its early stage of development, and DC equipment product differentiation is very large. It cannot form a unified market so there is an urgent need to unify the technical requirements of transformer, circuit breaker, isolating switch, converter, cable technology, lightning arrester and other key equipment in DC power distribution system. It will promote the standardization and orderly development of DC power distribution industry, as well as the coordination of related products in technology.

- **Evaluation of DC power distribution systems**

The advantages of DC power distribution system are becoming apparent, but it is the lack of comprehensive assessment data system to provide a basis for planning and construction, operation and maintenance, and energy saving benefits. It is necessary to actively promote standards development on status evaluation technology of DC power distribution equipment, supervision guideline of system technology, system operation index and assessment guideline, system reliability evaluation technology, system economic evaluation guideline, system energy-saving effect evaluation, which provides strong technology and data support for the establishment of a DC system.

2) Gaps identified for DC distribution system

DC distribution system standardization gaps identified are shown as the following:

- Planning and designing DC distribution systems
- Control and protection of DC distribution systems operation
- Commissioning and experimental testing
- Technical requirements for the integration of the sources
- Technical requirements for the integration of the loads

7.2.3.2 Planning and designing of DC distribution systems

The standardization of planning and designing of LVDC/MVDC distribution systems should be accelerated. With the development of the economy, the penetration of distributed generators in distribution systems has gradually increased, and the advantages of LVDC/MVDC distribution systems are more obvious. DC distribution projects are emerging, however, the unified planning and designing are lacking. Thus the research of the selection of DC distribution voltage levels, typical grid technical guidelines, the design specifications of distribution system, converter station, DC line, and lightning protection urgently needs to be carried out to ensure the standardization of the development and construction of LVDC/MVDC distribution systems.

7.2.3.3 Control and protection of DC distribution systems operation

The technical requirements for the control and protection of LVDC/MVDC distribution systems operation should be clarified. As an effective solution for managing the high penetration of renewable energy, LVDC/MVDC distribution systems have been motivated under the circumstances of increasing energy crisis and environmental problems. Thus the operation control, maintenance, management (energy management, optimized operation, multi-sources coordinated control) protection, safe operation guidelines, and operational technical

specifications urgently needs to be carried out to guide the control and protection of LVDC/MVDC distribution systems operation and to improve the reliability and stability of the entire power system.

7.2.3.4 Commissioning and experimental testing

The specifications of commissioning and experimental testing for LVDC/MVDC distribution systems should be improved and unified. With the rapid improvement of the DC distribution technology, higher requirements for energy conservation, reliability and power quality are proposed from the user side. Thus it is urgent to standardize the commissioning, handover, acceptance and detection methods of hybrid distribution systems, converter stations, DC lines, etc. to ensure the safety and reliability of system operation.

7.2.3.5 Technical requirements for the integration of the sources

Due to the randomness and intermittent characteristic of the distributed generations, the difficulty of the operation control of the distribution network is increased. Thus it is urgent to standardize the technical requirements of the integration of energy storage system, fuel cells and other non-renewable energy sources into the LVDC/MVDC distribution systems to meet the demand of large-scale distributed generations access.

7.2.3.6 Technical requirements for the integration of the loads

As higher demand for power quality is proposed and more sensitive and dynamic loads are appearing, higher requirements for the capability of power supply are needed to ensure the safety and reliability of the system operation. Thus it is urgent to standardize the technical requirement of the integration of electric vehicles, DC charging power plants, air conditioners, and other loads into the LVDC/MVDC distribution systems.

7.3 Virtual power plants

7.3.1 Needs identified for virtual power plants standardization

A virtual power plant (VPP) can integrate hundreds or thousands of small power generation or consumption units. These small units are integrated through information communication technology and cooperative control technology. The power supply of each small unit may not be controllable, for example, the output of a distributed photovoltaic power generation unit cannot be controlled. However, due to the existence of cooperative control systems of VPP, through unified monitoring and dispatching, the whole system can be presented as a controllable system to the outside, and can participate in the dispatching of electrical power grid and the competition in electricity market.

The most distinct feature of VPPs from microgrids is that the components of VPPs are not necessarily within the same geographical area, and their scope of aggregation and interaction with the market depends on the communication capability and reliability. VPPs break the physical limits between the power suppliers and users in the traditional power system, and makes the full use of the advanced communication, measurement and control technology to aggregate the different types of distributed generations into a whole to participate in the power grid dispatching operation and electricity market transaction. VPPs require no infrastructure reform, but enable the aggregation of distributed power sources to achieve stable transmission to the public grid and the fast response auxiliary services, which can significantly reduce the impact to the public grid from the integration of distributed generations.

In order to realize flexible control of a large number of power generation or power consumption units and participate in the electricity market and power grid operation as a special power plant, a VPP needs to formulate the following standards:

- Terminology

- Modelling and simulation
- Architecture and functional requirements
- Monitoring and control
- Operation, including coordinated operation with main grid, coordinated operation among multiple VPPs Information and communication related to VPP operation
- Commissioning, and conformance & acceptance test (VPP as a whole)
- System performance of VPP, including the reliability, power quality, etc.
- Participation in ancillary service
- Participation in electricity market
- VPP management, including maintenance, optimal energy management, coordinated operation and control of multiple energy resources, optimal utilization of multi-types energy storage
- Connection requirements of VPP to main grid
- Connection requirements of micro-sources or clients to VPP

7.3.2 Gaps identified for virtual power plants standardization

VPP standardization gaps identified are shown as the following:

- Terminology
- Modelling and simulation
- Monitoring and control
- Operation, including coordinated operation with main grid, coordinated operation among multiple VPPs Information and communication related to VPP operation
- Commissioning, and conformance & acceptance test (VPP as a whole)
- System performance of VPPs, including reliability, power quality, etc.
- Participation in ancillary service
- Participation in electricity market
- VPP management, including maintenance, optimal energy management, coordinated operation and control of multiple energy resources, optimal utilization of multi-types energy storage
- Connection requirements of VPP to main grid
- Connection requirements of micro-sources or clients to VPP

Currently, there are only two undergoing VPP related projects: IEC TS 63189-1, *Virtual Power Plants – Part 1: Architecture and functional requirements* specifying the architecture of virtual power plants and functions required, IEC TS 63189-2, *Virtual Power Plants – Part 2: Use cases* specifying the use cases of virtual power plants.

8 Proposal for future actions to address the standardization needs for decentralized electrical energy systems

8.1 Microgrids

The technical standard system of microgrids mainly includes the following categories: basic general, technical requirements, debugging and acceptance, test and detection, operation and maintenance, and scheduling and management. In the future, the formulation of microgrid technical standards will mainly solve the following problems:

- 1) Guiding principle

The technical conditions and design principles that should be met in the process of grid-connected operation, off-grid operation and off-grid transition are specified. They are based on IEC TS 62898-2:2018, *Microgrids – Part 2: Guidelines for operation*, and the undergoing project: IEC TS 62898-1/AMD1, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification* and more details should be added.

2) Normative design

The planning and design of interconnection between microgrid and distribution network are specified. They are based on IEC TS 62898-1:2017, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification*, IEC TS 62898-2/AMD1, *Microgrids – Part 2: Guidelines for operation*, IEC TS 62898-3-2, and the undergoing project: and more details should be added.

3) Coordinated operation

The technical requirements of power control, system abnormal response, mode conversion and other aspects that should be satisfied under different operation modes of microgrid are specified. They can refer to IEC TS 62898-3-1:2020, *Microgrids – Part 3-1: Technical requirements – Protection and dynamic control*, but emphasize on various operation modes of microgrid.

4) Energy optimization

The energy exchange and dispatching of microgrid are specified. They can refer to the undergoing project IEC TS 62898-3-2, *Microgrids – Part 3-2: Technical requirements – Energy management systems*, but emphasize on the energy optimization.

5) Security assurance

The test conditions, test items and test methods of microgrid interconnection interfaces are specified. The standard system of microgrid mainly formulates the isolated type and off-grid type respectively, and the provisions of grid connection, debugging, acceptance, and test are detailed.

6) Networking voltage design

The designing of microgrid networking voltage considering the microgrid capacity, type of energy resources, and injection current at point of interconnection are specified.

The other undergoing projects, IEC TS 62898-3-3, *Microgrids – Part 3-3: Technical requirements – Self-regulation of dispatchable loads*, specifying the self-regulation of dispatchable loads in microgrids, IEC TS 62898-3-4, *Microgrids – Technical requirements – Monitoring and Control systems*, specifying the monitoring and control in microgrids, and IEC TR 62898-4, *Microgrids: Part 4 – Use cases*, specifying the application of microgrids also have not addressed the above mentioned problems.

8.2 Non-conventional distribution systems

Based on the determination of the design objectives and principles of the non-traditional power system standard system, combined with the characteristics of the distributed energy system, from the energy structure, system construction, key equipment, information exchange and key technologies, the standards in related fields are analysed, and the standard systems and standard planning are put forward.

In the field of non-traditional power system planning, a set of more mature planning methods has been formed in distribution network planning at present. However, the planning objects of the related researches are mostly focused on the source network charge, and few have involved various energy storage configuration methods. In addition, uncertainty analysis, multi-time constant system and multi-energy system reliability analysis still need to be further studied.

In traditional power system control, power system source–network–load–storage longitudinal coordinated control research is leading, but the research of horizontal coordination between multi-energy system control method is still in its infancy. A variety of energy equipment with adjusted speed differences makes it difficult for related coordination, according to the flow

dynamic characteristics and interaction, and then the best time scales with intelligent control method can be put forward.

In terms of intelligent regulation of multi-energy flow, multi-energy complementary coordinated optimal scheduling is the basis of multi-energy system planning and the market interactive game. Through the collaboration of multiple systems, the economic and energy efficiency objectives of non-traditional power systems can be achieved, and the large-scale consumption and efficient energy supply of distributed renewable energy can be promoted.

1) Guiding principles

The attribute range, technical conditions and design principles of non-traditional distribution networks are specified.

2) Normative design

The planning and design of non-traditional distribution networks are specified.

3) Coordinated operation

The technical requirements of power control, system abnormal response, mode conversion, etc. that non-traditional distribution networks should meet under different operation modes are specified.

4) Energy optimization

The energy exchange and dispatching of non-traditional distribution networks are specified. The non-traditional distribution network standard system is similar to the distribution network, but it is more complex and detailed concerning power electronics and operation control.

8.3 Virtual power plants

Virtual power plants, including aggregation, operation and trading, realize energy efficient utilization by controlling multiple types of flexible loads (including energy storage and controllable distributed power supply), which is a method to solve the above problems and also a feasible business model to support the construction of Energy Internet. In the future, VPPs need to focus on several types of technologies and develop relevant standards:

1) Coordinated control

The control objects of VPPs mainly include all kinds of DG, energy storage system, controllable load and electric vehicle. Due to the concept that VPPs emphasize the function and effect of external presentation, it is a key and difficult point for the coordinated control of VPPs to realize the high demand of power output by convergent and diversified DER. The VPP needs to coordinate and control the energy storage system, the distributable generator set, and the controllable load to reasonably cooperate with it, so as to form corresponding standards to ensure the high level of operation.

2) Measurement, control and metering

Intelligent measurement, control and metering technology is an important part of virtual power plant, which is a basis for VPPs to monitor and control DG and controllable loads. VPPs need remote measurement of real-time user information, reasonable management of data, and send it to relevant parties, through the establishment of standards to take reasonable adjustment measures.

3) Information and communication

VPPs adopt bi-directional communication technology, which can receive the current state information of each unit and send control signals to control targets. The communication technologies applied to virtual power plants mainly include internet-based technologies, such as Internet protocol based services, virtual private networks, power line carrier technology and wireless technology, etc. The above information and communication technologies applied to VPPs need corresponding standards.

8.4 DC distribution systems

Distributed DC power distribution involves power generation, power grid, users and other fields. The complexity of the system is prominent, and related technologies are in rapid development. At present, the relevant standards in the field of distributed DC power distribution lack unified planning, coordination and top-level design, so it is difficult to provide effective standards support for the future industrial development. It is suggested that the development of standards can focus on the overall system requirements, planning and design, operation and maintenance, equipment technical requirements, as well as the connection conditions of distributed power supply into DC distribution network and other aspects.

1) Voltage level and grid structure

According to the application environment, power supply size, load capacity and power supply distance, selecting a reasonable voltage level of distributed DC distribution system, and standardizing the grid structure of distributed DC distribution system according to the requirements of application scenarios and power supply reliability.

2) Interconnection of DC system and AC system

As the distributed DC system is distributed in the whole AC power supply area, it needs to be interconnected with the AC system. This part plans and designs different interconnection modes between distributed DC distribution system and AC distribution system according to load, access voltage level, capacity and application scenario, and selects and plans protective grounding and functional grounding of different voltage levels in distributed DC distribution system.

3) DC protection system

The protection configuration principles of system level, area level and equipment level of distributed DC distribution system are specified.

4) Monitoring and communication

The functions of the monitoring system required for the distributed DC distribution system are standardized. They are mainly divided into basic functions and expandable functions. At the same time, requirements are put forward for the communication mode and communication medium required for the corresponding monitoring system.

5) DC power supply and user access

Regulating the requirements of different capacities and types of DC power supply and user access to distributed DC distribution system.

Annex A **(Informative)**

Online survey

A.1 Overview

To support the Decentralized Electrical Energy System standardization strategy development, a survey has been prepared by IEC Subcommittee 8B AHG2. The results will serve as a reference to form the roadmap of Decentralized Electrical Energy Systems standardization.

The purpose of this questionnaire is to learn the current status of technology, project, and standardization on the Decentralized Electrical Energy Systems in the world and identify the gaps for standardization.

This questionnaire is structured in three parts including background information, microgrid, and Non-conventional Distribution Systems.

A.2 Result summary and challenges

A.2.1 Result summary

A.2.1.1 Stakeholders and interests in standardization

The survey has not drawn enough attention from stakeholders (shown in Figure A.1). We only received 5 answers out of 26 countries, which may lead to a non-comprehensive assessment for the global status of microgrids and non-conventional distribution systems. Despite the low response rate, utilities and standard organizations show their interest in standardization.

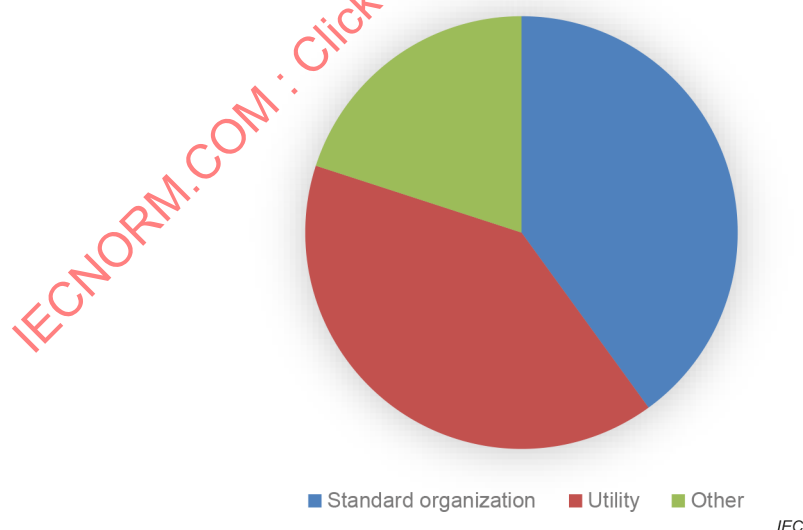


Figure A.1 – Variety of participants

A.2.1.2 Involvement of government in the microgrid development

From the following analysis of the project information collected from the survey, we could see the supportive role of governments (see Figure A.2).

In fact, all of the seven microgrid projects identified in the survey are funded, 71 % of the funding coming from joint funds, and 29 % coming from private funds. Although there is no project sponsored by governments alone in this survey, governments play a key role in joint funding. According to the information of seven projects that are listed in the survey, only one of them is operating without subsidy.

Government support is still a major factor in microgrid development. Considering that the cost of construction and operation of microgrids is significant and cannot be changed dramatically in a short time period, government funding has a decisive influence to the near future of the market. However, comparing to other player in the market, government typically plays a conservative role, and therefore standards are necessary to ensure confidence in investing in this market.

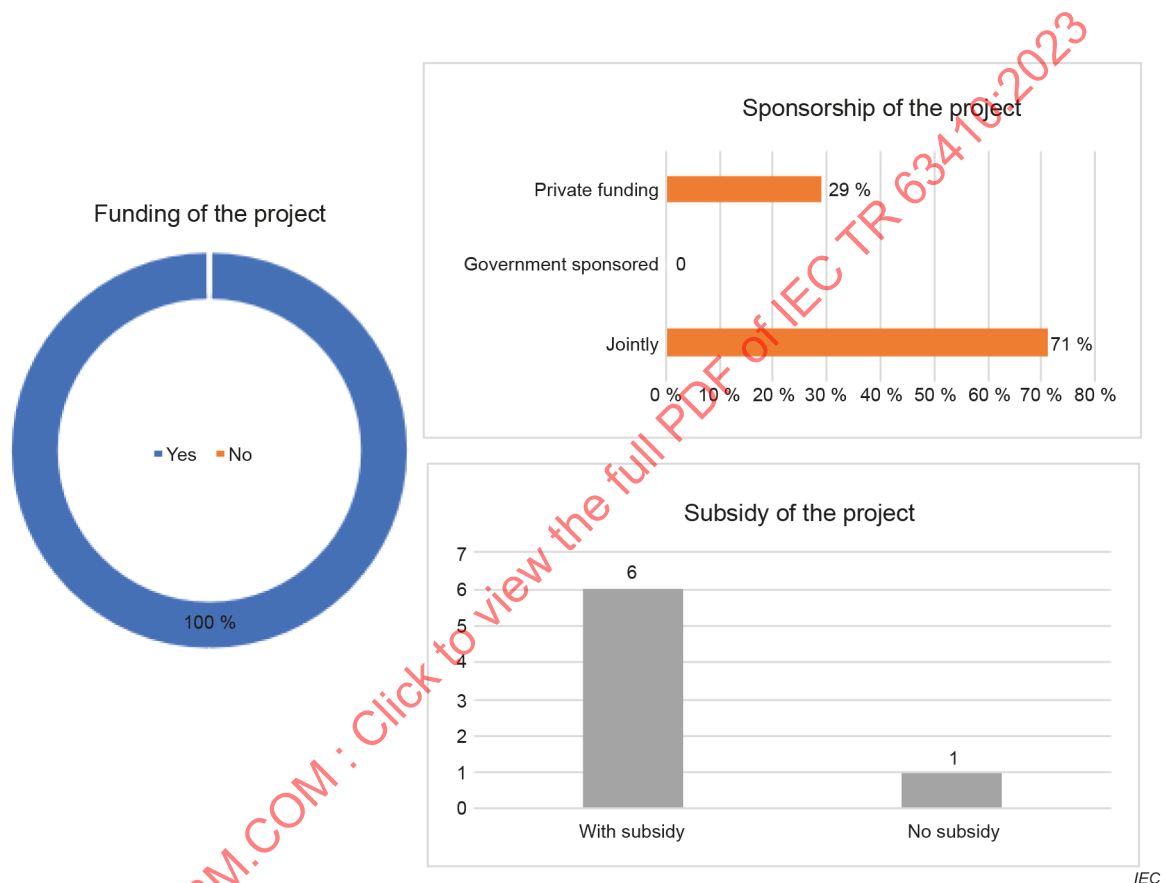


Figure A.2 – Involvement of government in the microgrid development

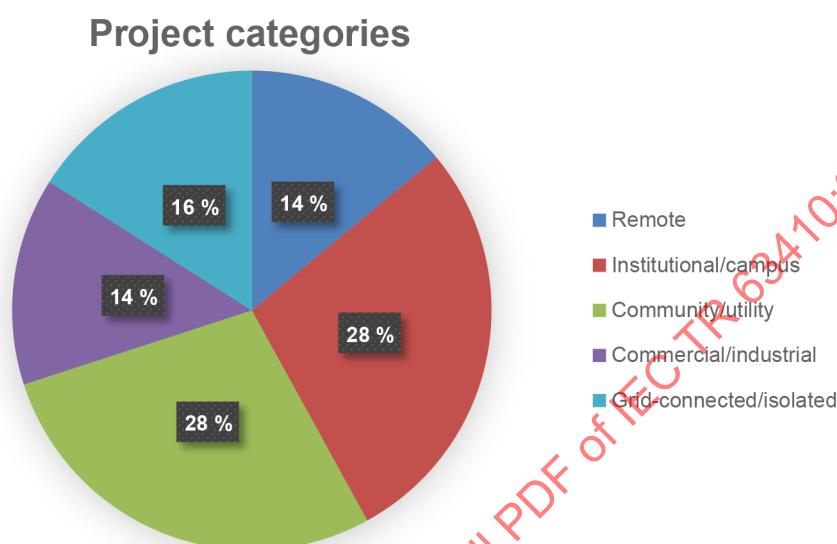
A.2.1.3 Diversity of microgrid projects and requirement of technologies

From the survey, we have summarized seven primary drivers to construct microgrids, which is shown in Figure A.3. Microgrids can play a key role in facilitating achievements of emission reduction and energy conservation, prolonging the life and improving the performance of aging infrastructure, and electrifying remote areas.

- Improving the power reliability and power quality
- Power supply to remote area
- Branding of the energy community
- Decreasing operations cost
- Disaster recovery

- Saving energy and reducing emissions.
- Utilization of renewable energy

Despite the low response, the project information received still covers most of the common types. Among these, projects built in mature grid environment form the majority and trigger the development of new technologies and equipment specifically for microgrids besides a group of existing technologies required. Additional efforts in standardization for new technologies and interoperations between technologies will certainly help it evolve further.



IEC

Figure A.3 – Diversity of microgrid projects and requirement of technologies

The specifically designed technologies for microgrids are shown below:

- Microgrid modelling and simulation
- Microgrid planning and design
- Demand side management in microgrid
- Smart protection
- Integration/islanding transition
- Economic operation and optimal energy management of microgrid
- CCHP/CHP

The specifically designed equipment for microgrids are shown below:

- Microgrid controller
- Microgrid protection device
- Energy storage system

A.2.1.4 Standards needs for microgrids

The survey helps us identify that there is a need to develop standards for microgrids that will facilitate its design and growth as shown in Figure A.4. International standards will also avoid duplication of efforts and conflicts on horizontal requirements in the development of microgrids. This will help seamless integration of microgrid projects with public network system/grid in an

efficient manner. Within the IEC, standards related to microgrids are across many TCs/SCs and for users they can be challenging in their usability and visibility of relevant information.

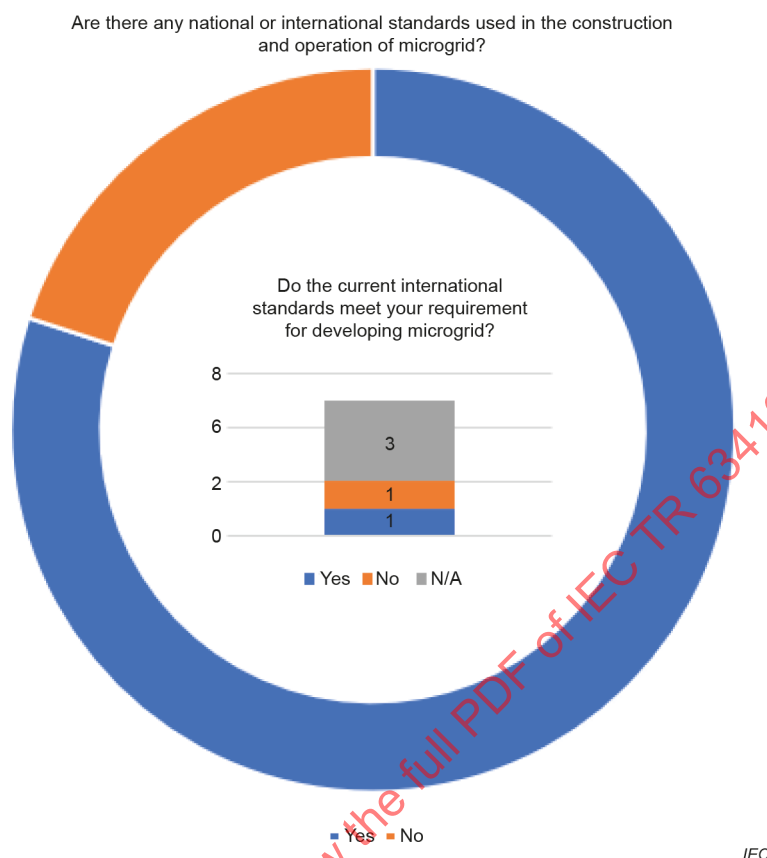


Figure A.4 – Standards needs for microgrids

According to limited survey results, gaps identified in microgrid standardization include:

- Technical requirements that microgrids system should meet
- Integration, and guidance on coordination with private and public system regulation
- Direct current
- Test and evaluation

A.2.1.5 Participation of government in the non-conventional distribution system development

According to the analysis of the project information collected from the survey shown in Figure A.5, it can be seen that governments are very supportive.

Actually, not all of the five non-conventional distribution system projects identified in the survey are funded. Three of them are government-sponsored and the remaining two projects do not receive any sponsorship funding.

Furthermore, two of these projects are operating without subsidy and the other three projects have subsidies.

Government support contributes a lot to the non-conventional distribution system's development, and it has a big impact on the near future of the market. Standards are important

to guarantee the confidence of investing in new market and technologies; therefore, governments may be not willing to process if the standardization work is not enough.

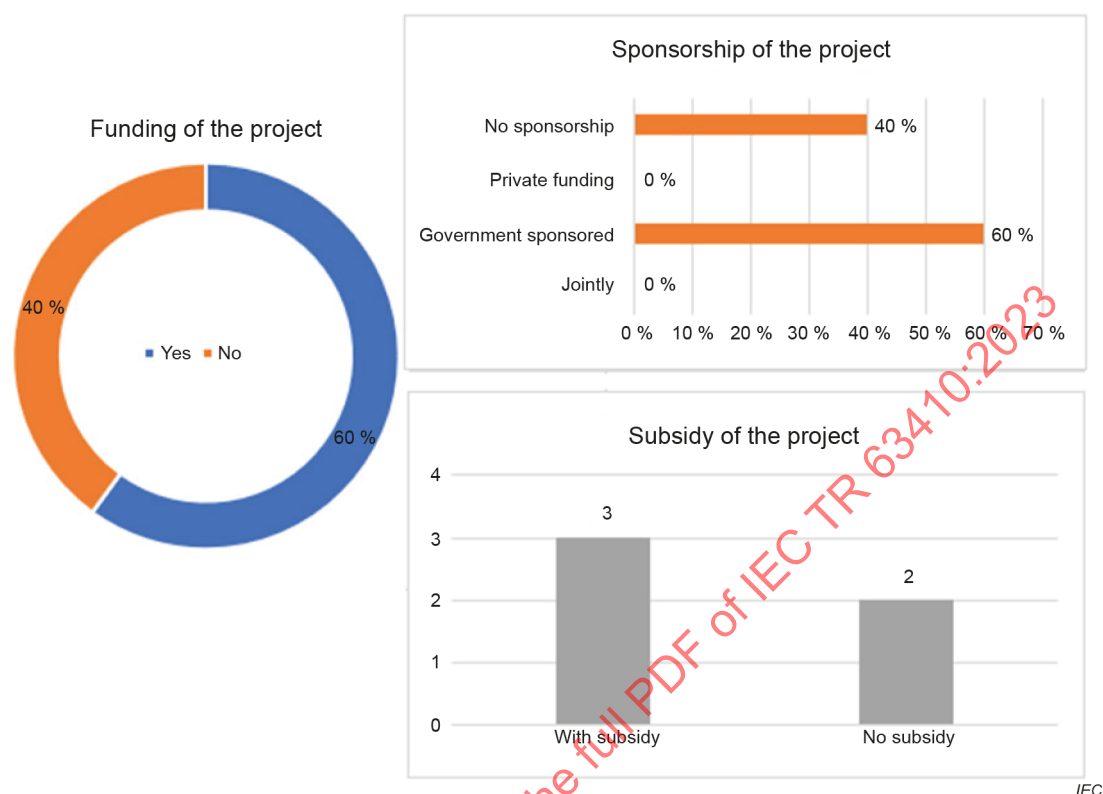


Figure A.5 – Participation of government in the non-conventional distribution system development

A.2.1.6 Drivers and types of non-conventional distribution system projects

According to the survey results, five primary drivers to launch non-conventional distribution system are summarized, which are shown in Figure A.6. Non-conventional distribution systems play an important part in achieving emission reduction and energy conservation, improving comprehensive utilization efficiency of energy, and cost efficiency in investments and operational cost, etc.

- Improving the acceptance and local consumption of renewable energy generation
- Improving comprehensive utilization efficiency of electricity, heat, gas and other forms of energy
- Solving the problem of electricity use in areas with weak connections to the power grid or geographically isolated islands
- Higher cost efficiency in investments and operational cost (life cycle assessment) compared to traditional grid solutions
- Saving energy and reducing emissions.

Despite the low response, the five projects information received cover all common types. Among these, two of them are DER projects, two of them are DC distribution projects, and the remaining one is multi-energy local system project.

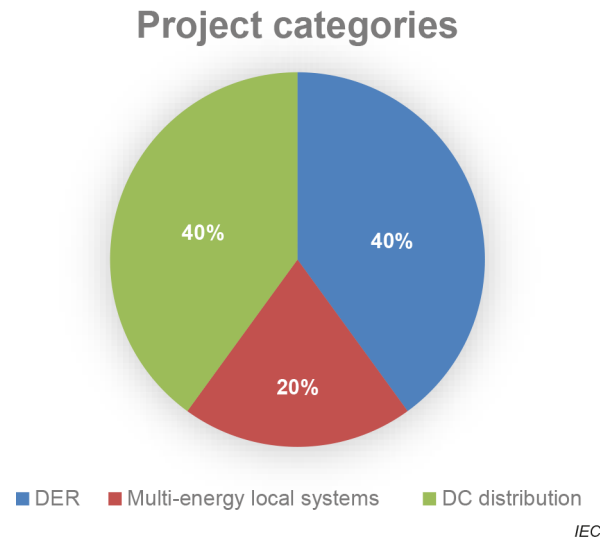


Figure A.6 – Drivers and types of non-conventional distribution system projects

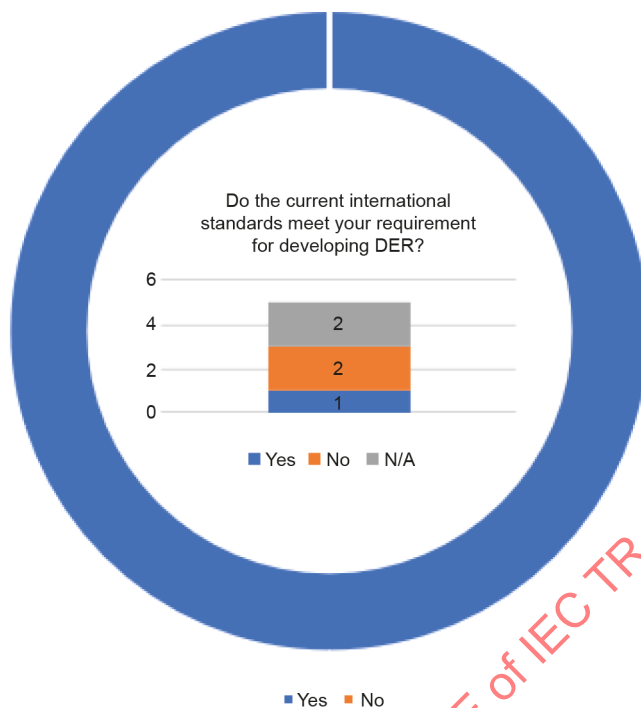
At present, the specifically designed technologies and equipment for non-conventional distribution system are not available in this analysis because none of these five surveys results we receive responded to this question.

A.2.1.7 Standards needs for non-conventional distribution system

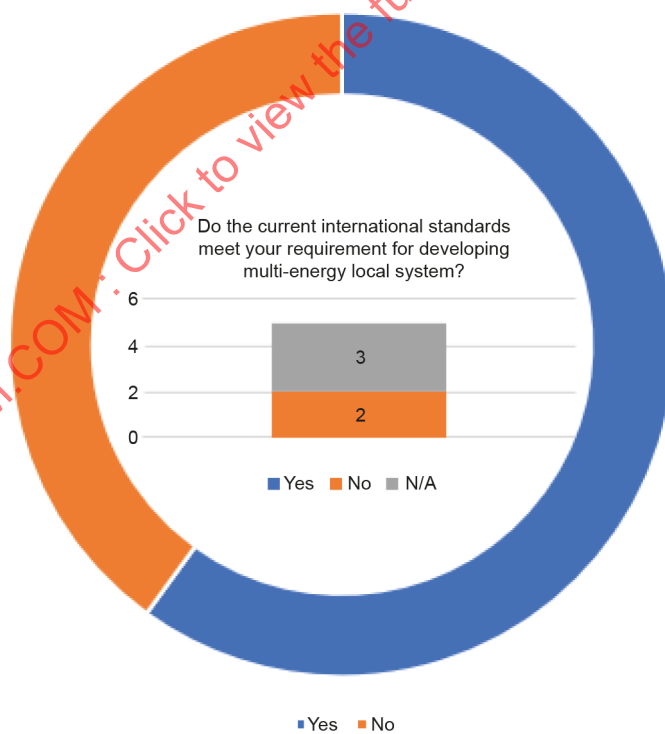
The survey is beneficial to identify the satisfaction degree in the current standardization level of non-conventional distribution system. The collected results are still valuable although the number of responses is limited.

Issues identified include a lack of standards on technical requirement of multi-energy local systems, which makes it impossible to identify whether the projects under construction are multi-energy local system. Also, there are few standards in DC distribution. Therefore, it is difficult to develop non-conventional distribution system projects due to the lack of relevant standards. The development status of standards on DER, multi-energy local systems, and DC distribution in these countries are shown respectively in Figure A.7.

Are there any national or international standards used in the construction and operation of DER?



Are there any national or international standards used in the construction and operation of multi-energy local system?



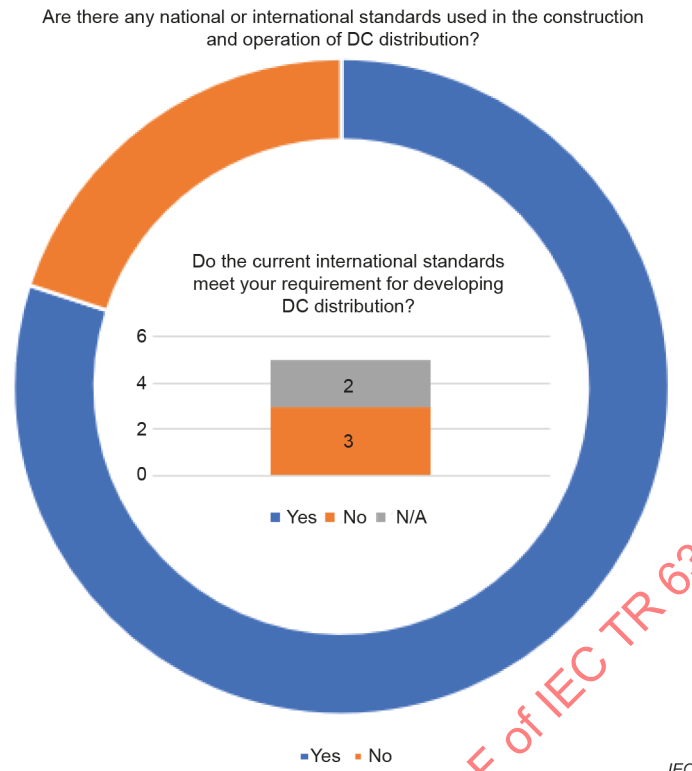


Figure A.7 – Standards needs for non-conventional distribution system

According to the limited survey results, gaps identified in the non-conventional distribution system standardization include:

- Technical requirements for multi-energy local systems
- Protection configuration, parameter adjustment of DC distribution network or technical requirements to be met when interconnecting with AC system
- Materials, installation and tests for LVDC systems
- System specifications in DC distribution

A.2.2 Challenges

The first challenge is how to balance between collecting enough information and keeping the questionnaire short enough to avoid scaring off participants. The question list is shortened to 16 questions, but still we only received answers from five out of 26 countries. Therefore, the low responses lead to a low result confidence.

Secondly, the responses from these five countries do not cover all the questions. Participation status by countries is shown in Figure A.8:

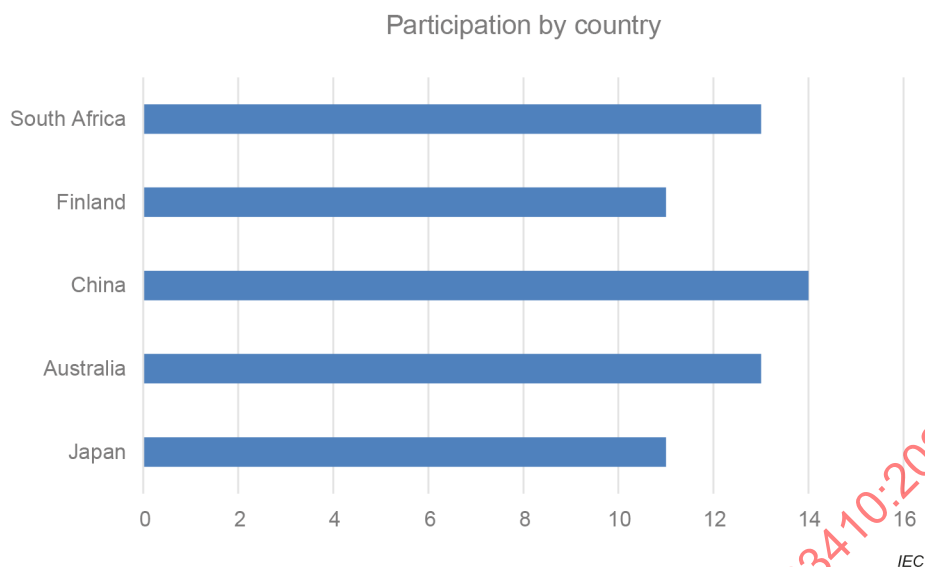


Figure A.8 – Challenges

Thirdly, questions regarding technologies, equipment and standards are mostly open questions. The intention is to avoid any bias and limits caused by the personal knowledge of questionnaire developer but this may also reduce participants' interest in responding, and add the difficulty in analysing and summarizing the results.

A.3 List of the questions

Table A.1 gives a list of the questions in the survey.

Table A.1 – List of the questions

No.	Description	Response	Remarks (if any)
Background information			
1	Which country are you based in?		
2	Which type of business do you represent?	☐ Academic ☐ Engineering firm ☐ Utility ☐ Equipment vendor ☐ Government ☐ Standards Organization ☐ Other:	
Part A-Microgrid			
Market status and marketing roadmap			
3	Are there any microgrid project(s) in your country?	☐ Yes ☐ No	
3a	If No, do you intend to implement such project(s), and for what purpose?	☐ Yes Purpose: ☐ No	

No.	Description	Response	Remarks (if any)			
3b	If Yes, please indicate the scale and roadmap up to 2025 of the microgrid market.	Market scale: roadmap up to 2025:				
3c	Are these microgrid projects funded? If Yes, please indicate the name of the sponsor(s)	☐ Yes Sponsor: ☐ No				
3d	What is the main driver for you/your country to launch microgrid projects?					
Projects and business mode						
4	Please indicate the total number of microgrid projects and corresponding number for each type in your country.	Type	Number			
		A. Commercial/industrial				
		B. Community/utility				
		C. Campus/institutional				
		D. Military				
		E. Remote				
		F. DC				
		G. Grid-connected/isolated				
		H. Other	1. _____ 2. _____ 3. _____			
		Total				
5	Please indicate the name, scale and purpose of typical microgrid projects to your knowledge.		Project1	Project2	Project ...	
		Name				
		Scales (MW)				
		Purpose				
		Type:				
		a) Commercial/industrial b) Community/utility c) Campus/institutional d) Military e) Remote f) DC g) Grid-connected/isolated h) Other				
		Micro-sources				
6.	What are the business modes of these typical microgrid projects?		Project 1	Project 2	Project ...	
		Invested by				
		a) Private b) Government sponsored c) Jointly				
		Operated by				

No.	Description	Response				Remarks (if any)
		Under the regulation of				
		Whether the microgrid project participates in auxiliary market? If yes, please indicate what type/kind of service? For example: peak load shifting, reliability, disaster recovery, demand response, etc.				
		Who are the main stakeholders engaged with the project?				
		Is there any subsidy for the project? a) One-time subsidy for construction b) Subsidy based on power generation c) Feed-in tariff subsidy d) Others (please indicate)				
Technologies and standards						
7	What technologies and equipment are most applicable and/or a concern for you in microgrid projects?	Technologies: Equipment:				
7a	From the technologies and equipment(s) listed above, are there any specifically designed for microgrids?	☐ Yes Please indicate the specifically designed technologies: Please indicate the specifically designed equipment: ☐ No				
7b	Are there any national or international standards used in the construction and operation of microgrid?	☐ Yes Please identify the standards ☐ No				
7c	Do the current international standards meet your requirements for developing microgrids?	☐ Yes Please indicate the international standards ☐ No				
7d	If No, what are the most urgent needs for standard?					
7e	Have you ever experienced any difficulties in microgrid planning, design and operation caused by lack of or conflicting standards? If Yes, please describe.	☐ Yes Description: ☐ No				
Part B: Non-conventional distribution system						

Market status and marketing roadmap																																									
8	Are there any DER (such as distributed PV), multi-energy local systems (such as CCHP), DC distribution projects or any other non-conventional distribution system (convey networks other than AC distribution systems firmly connected to a large interconnected grid) in your country?	☐ Yes ☐ No																																							
8a	If No, do you intend to implement such projects, and for what purpose?	☐ Yes Purpose: ☐ No																																							
8b	If Yes, please indicate the scale and roadmap up to 2025 of the non-conventional distribution system market.	Market scale: roadmap up to 2025:																																							
8c	Are these non-conventional distribution system projects funded? If Yes, please indicate the name of the sponsor(s)	☐ Yes ☐ A. DER Sponsor: ☐ B. multi-energy local systems Sponsor: ☐ C. DC distribution Sponsor: ☐ D. Others _____ Sponsor: ☐ No																																							
8d	What is the main driver for you/your country to launch non-conventional distribution system projects?																																								
Projects and business mode																																									
9	Please indicate the total number of non-conventional distribution system projects and corresponding number for each type in your country.	Type A. DER B. multi-energy local systems C. DC distribution D. Others		Number																																					
		1. _____ 2. _____ 3. _____																																							
		Total																																							
10	Please indicate the name, scale and purpose of typical non-conventional distribution system projects in your country to your knowledge.	<table border="1"> <thead> <tr> <th></th> <th>Project 1</th> <th>Project 2</th> <th>Project ...</th> </tr> </thead> <tbody> <tr> <td>Name</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Scales (MW)</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Purpose</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Type:</td> <td></td> <td></td> <td></td> </tr> <tr> <td>a) DER</td> <td></td> <td></td> <td></td> </tr> <tr> <td>b) multi-energy local systems</td> <td></td> <td></td> <td></td> </tr> <tr> <td>c) DC distribution</td> <td></td> <td></td> <td></td> </tr> <tr> <td>d) Others _____</td> <td></td> <td></td> <td></td> </tr> </tbody> </table>					Project 1	Project 2	Project ...	Name				Scales (MW)				Purpose				Type:				a) DER				b) multi-energy local systems				c) DC distribution				d) Others _____			
	Project 1	Project 2	Project ...																																						
Name																																									
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Purpose																																									
Type:																																									
a) DER																																									
b) multi-energy local systems																																									
c) DC distribution																																									
d) Others _____																																									

		composition of distributed energy				
11	What are the business modes of these typical non-conventional distribution system projects?		Project 1	Project 2	Project ...	
		Invested by				
		a) Private				
		b) Government sponsored				
		c) Jointly				
		Operated by				
		Under the regulation of				
		Whether the non-conventional distribution system project participates in auxiliary market? If yes, please indicate what type/kind of service? For example: peak load shifting, reliability, disaster recovery, demand response, etc.				
		Who are the main stakeholders engaged with the project?				
		Is there any subsidy for the project?				
		a) One time subsidy for construction				
		b) Subsidy based on power generation				
		c) Feed-in tariff subsidy				
		d) Others (please indicate)				
Technologies and standards						
12a	What are the technologies and equipment of most concern for you in DER projects?	Please indicate the technologies:				
		Please indicate the equipment:				
12b	What are the technologies and equipment of most concern for you in multi-energy local systems projects?	Please indicate the technologies:				
		Please indicate the equipment:				
12c	What are the technologies and equipment of most concern for you in DC distribution projects?	Please indicate the technologies:				
		Please indicate the equipment:				

13a	From the technologies listed above, which of them are specifically designed for DER?	☐ Yes Please indicate the specifically designed technologies: Please indicate the specifically designed equipment: ☐ No	
13b	From the technologies listed above, which of them are specifically designed for multi-energy local systems?	☐ Yes Please indicate the specifically designed technologies: Please indicate the specifically designed equipment: ☐ No	
13c	From the technologies listed above, which of them are specifically designed for DC distribution?	☐ Yes Please indicate the specifically designed technologies: Please indicate the specifically designed equipment: ☐ No	
14a	Are there any national or international standards used in the construction and operation of DER?	☐ Yes Please identify the standards ☐ No	
14b	Are there any national or international standards used in the construction and operation of multi-energy local systems?	☐ Yes Please identify the standards ☐ No	
14c	Are there any national or international standards used in the construction and operation of DC distribution?	☐ Yes Please identify the standards ☐ No	
15a	Do the current international standards meet your requirements for developing DER?	☐ Yes Please indicate the international standards ☐ No	
15b	Do the current international standards meet your requirements for developing multi-energy local systems?	☐ Yes Please indicate the international standards ☐ No	
15c	Do the current international standards meet your requirements for developing DC distribution?	☐ Yes Please indicate the international standards ☐ No	
15d	If No, what are the most urgent needs for standard?		

16a	Have you ever met any difficulties in DER construction and operation caused by lack of or conflicting standards? If Yes, please describe.	☐ Yes Description: ☐ No	
16b	Have you ever met any difficulties in multi-energy local systems construction and operation caused by lack of or conflicting standards? If Yes, please describe.	☐ Yes Description: ☐ No	
16c	Have you ever met any difficulties in DC distribution construction and operation caused by lack of or conflicting standards? If Yes, please describe.	☐ Yes Description: ☐ No	

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Annex B (Informative)

Microgrid and its application

B.1 Overview

When DERs (Distributed Energy Resources) are integrated into distribution networks at customer sites, issues arise with respect to reverse power flows, i.e. from user (load) to the grid. The traditional distribution system is designed for power flow from grid to customer, not the two-way flow of power. Since reverse power flow is not controlled by the utilities (let alone the transmission operator), major technical issues arise, such as voltage rise, protection system design, which are further compounded by the intermittency of renewable energy sources due to weather variability.

To solve the above-mentioned problems, a new type of control and management mode is needed to minimize the effects caused to the operation and management of distribution network by DER integration. A promising solution is to combine local DG with in-site loads as a whole within a clearly defined electrical boundary, i.e. non-conventional distribution networks/microgrids, which acts as a single, controllable entity with respect to the grid. In this report, the term "non-conventional distribution network" is intended to convey networks other than AC distribution systems firmly connected to a large interconnected grid.

Microgrids are able to disconnect from the grid in times of disruption, either from inadequate supply during normal times or outages as a result for fault or disasters. During normal operations (e.g., no shortage of generation due to outages), microgrids offer the additional benefit of optimizing supply and demand through comparative pricing and price arbitrage (e.g., buying from the utility when market prices are lower than generation cost in a microgrid and selling to the market when costs in the microgrid are lower than market prices).

The concept of microgrids is developing at a very fast pace across the whole world and with that, the definition of microgrid is also evolving based on learning from the on-going pilot demonstrations and use of it for new applications. According to the feedback of online surveys and industry research reports, although the practice and application of microgrids may vary in each country, microgrids have the following features in general:

- Distinct physical boundary and clear electrical boundary points between public networks;
- Integrated units with the combination of energy storage devices, control devices and protection devices on the basis of distributed generation;
- Close to user terminal loads;
- Connect to distribution network voltage levels;
- Can switch between grid-connected mode and islanded mode.

Research data shows that among identified microgrid projects that are applying, under construction or operating, the supply system, these include AC microgrids, DC microgrids and AC-DC combined microgrids according to the electricity supplied. In terms of application scenarios, there are commercial/industrial microgrids, community/utility microgrids, campus/institutional microgrids, military microgrids and remote microgrids; in terms of connection to main network, there are grid-connected microgrids and isolated microgrids. Grid-connected microgrids can operate in parallel with public network or disconnect from public network and operate independently in case of public network malfunction or economic operation requirements; isolated microgrids can only operate in islanded mode and do not operate in parallel with public networks.

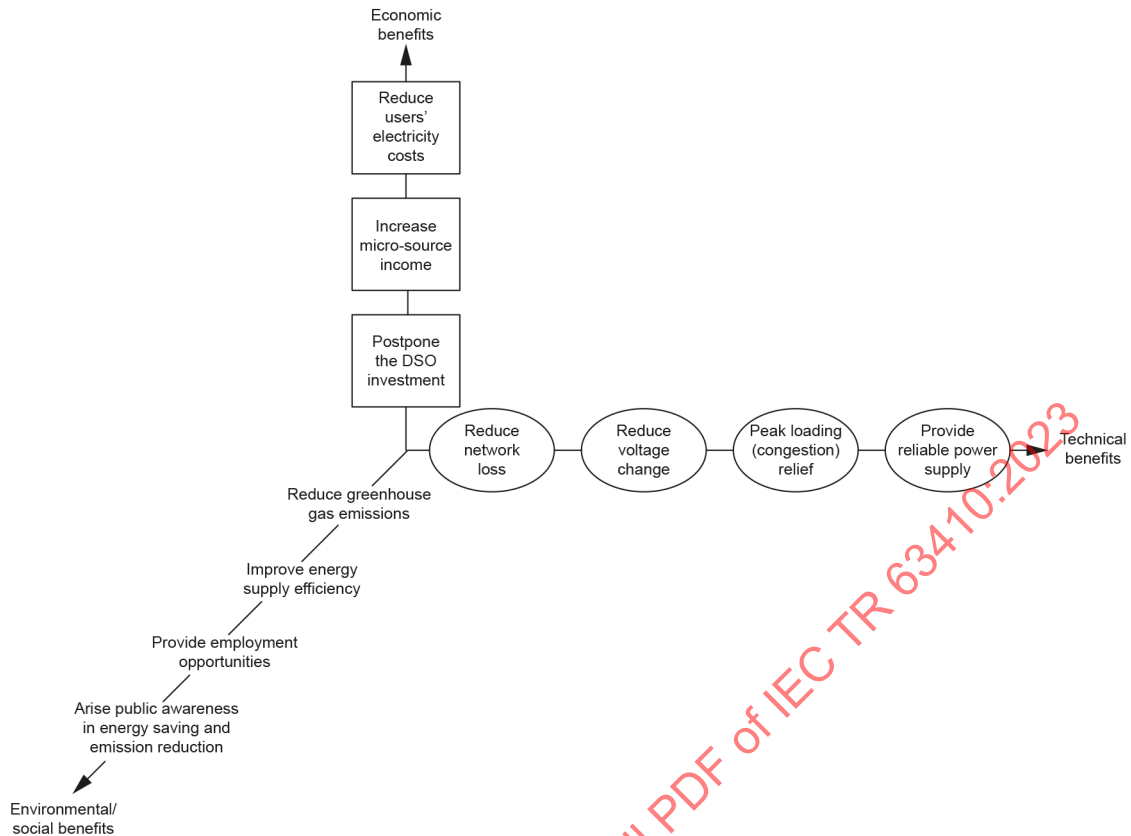
Microgrids integrate distributed generation, load, energy storage device and control devices into a single, controllable and autonomous system. For large grids, microgrids can be seen as a controllable unit of the grid; for customers, microgrids can satisfy their specific demands, such as improving reliability of local power supply and comprehensive utilization of energy by CHP. Generally, when distribution networks fail, microgrids automatically disconnect from the distribution network and operate independently.

In terms of resource allocation, microgrids are optimized based on configuration platforms of distributed energy resources. By configuring energy storage devices and cooperating various distributed generations, microgrids can solve the problems related to the random and intermittent power output of distributed renewable generation such as wind power generation and photovoltaic power generation.

In terms of relationship with distribution networks, microgrids are crucial components of the distribution network. Advance microgrid technology is equipped with almost all features of a smart distribution network: bilateral interaction, self-healing function, flexibility, contribution to continuous power supply, improvement of power quality, assimilation of distributed energy locally, etc. In terms of structure, microgrids are the subsystem of smart distribution networks and they are a significant component of smart distribution network security and natural disaster defense system; in terms of application, microgrids are the implementation carriers of some smart distribution network functions, which satisfies the demand of connecting distributed generation and users' demand on power quality and power supply reliability.

Microgrids can be used to optimize local distributed generation, improve users' power supply reliability and supply remote areas (see business use cases discussed previously). Moreover, microgrids offer a new solution to improve the network's overall anti-disaster ability and post-disaster emergency power supply capacity. Firstly, as a supplementary form of large network, microgrids can be used as standby power to support receiving networks in special occasions (such as earthquake, storms, floods, hurricanes and other incidents). In case of power fluctuation in receiving networks or voltage drop at grid connection points, microgrids can promptly supply active or reactive power to maintain system stability; meanwhile, microgrids can operate independently and quickly disconnect from large public system and form 'isolated microgrids' in order to guarantee uninterrupted power supply for government, hospitals, mines, broadcasts, telecommunication, transport hub and other critical loads inside the microgrid; moreover, building microgrids in different forms and sizes in natural disaster-prone areas provides the function of 'black start' and can quickly recover supply to important customers inside the microgrid after disasters.

Public network operators, DER owner, end users and society or public in a general sense are the stakeholders of microgrid application. Stakeholders may have different benefits from microgrid development and application, but in general they can be summarized as economic benefits, environmental/social benefits and technical benefits, as Figure B.1 shows.



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Figure B.1 – Microgrid benefits

A microgrid could offer the following economic benefits:

- Reduce end users' costs/taxes
- Increase micro-source income within microgrids
- Postpone DSOs investment

A microgrid could offer the following environmental and social benefits:

- Promote the development of renewable energy or low-emission generation, reduce greenhouse gas emissions
- Application of energy efficient technologies, such as combined heat and power generation technology
- Raise public awareness in energy saving and emission reduction

Provide a power supply solution for remote areas or underdeveloped areas

A microgrid could potentially offer the following technical benefits:

- Reduce power loss during transmission;
- Relieve voltage change;
- Shift peak load;
- Provide reliable power supply

To fully realize the benefits of microgrids listed above, a relevant market and regulatory framework shall be established and implemented. Moreover, reasonable planning is required to