



BSI Standards Publication

Decentralized electrical energy systems roadmap

National foreword

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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

FOREWORD

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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.

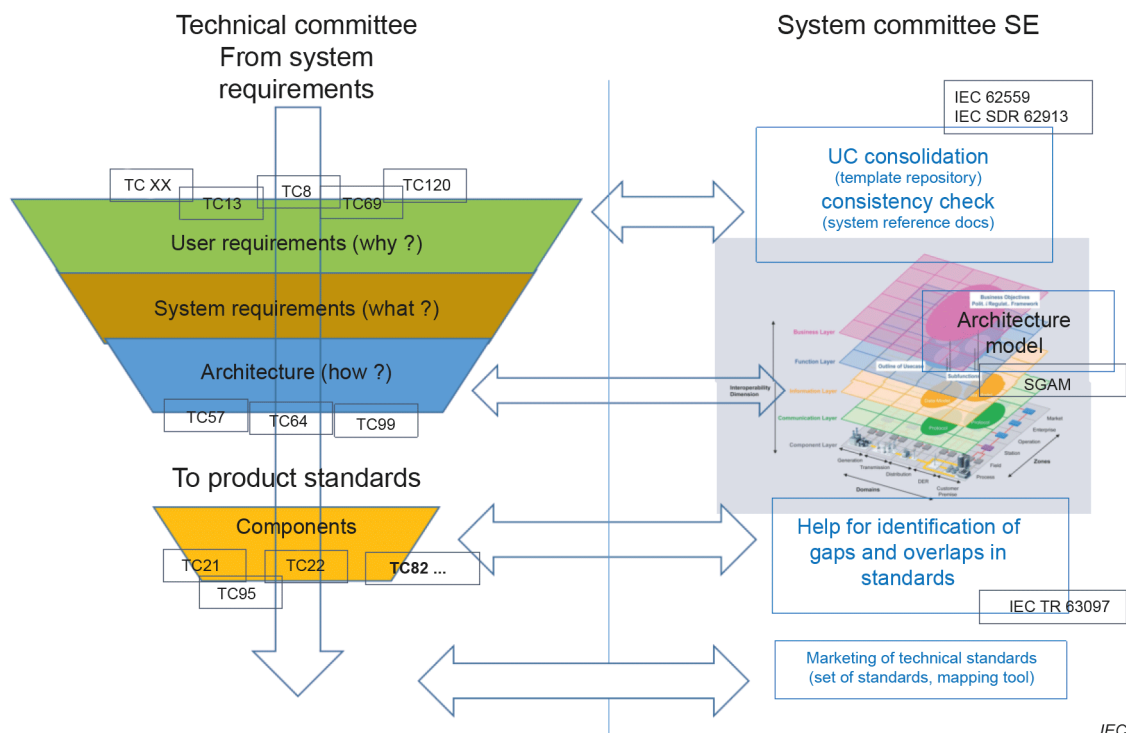


Figure 1 – From system requirements to product standards (TC8 Road map)

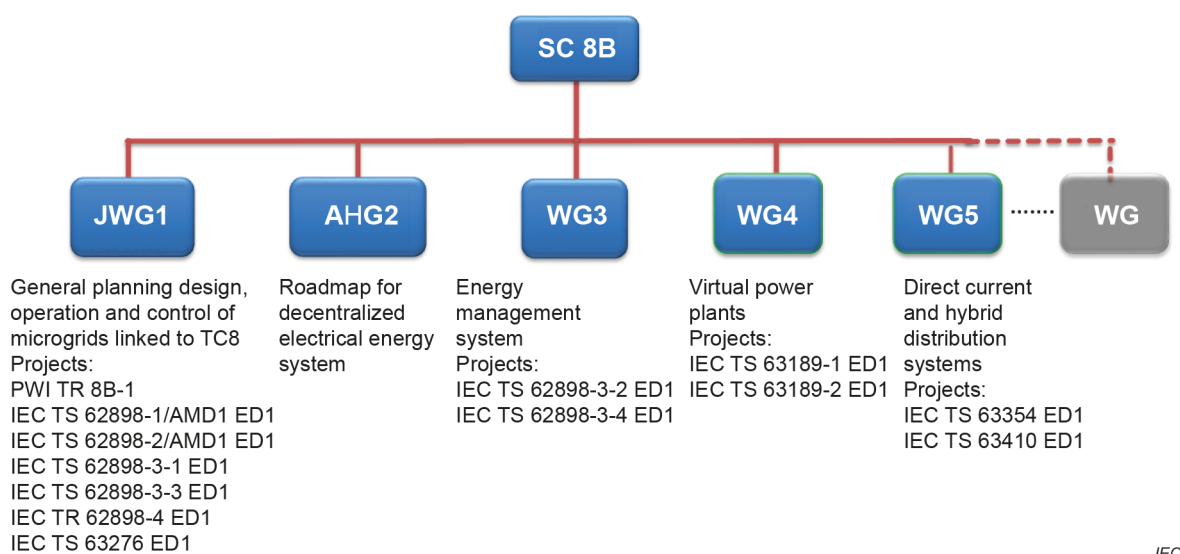


Figure 2 – SC 8B work groups, fields and work programmes

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.

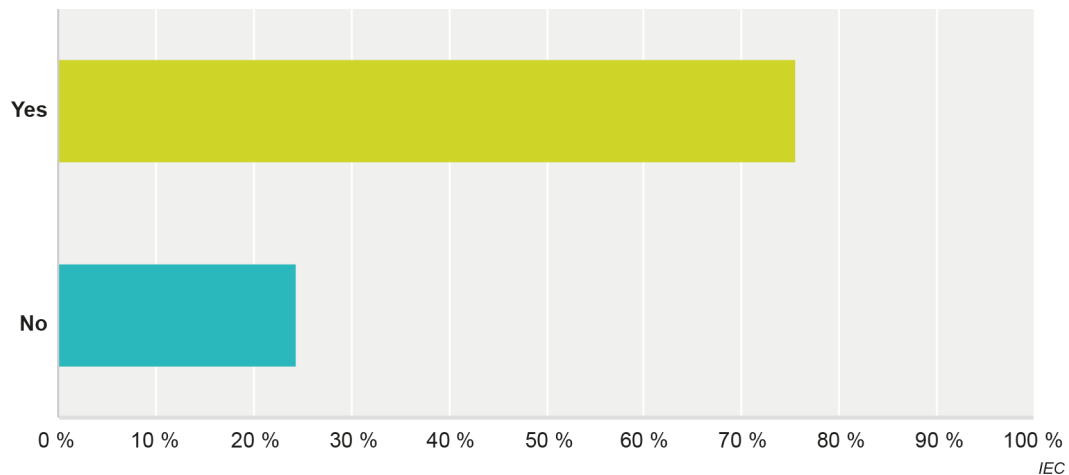


Figure 3 – General view of the microgrids projects implementation in countries

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 stands 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.

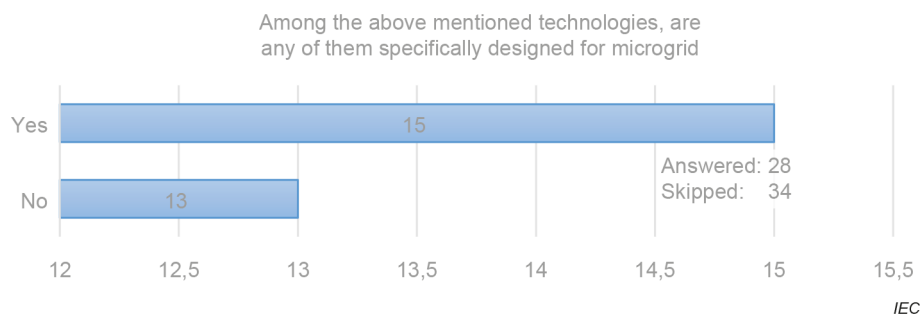


Figure 4 – New technologies developed for microgrids

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?

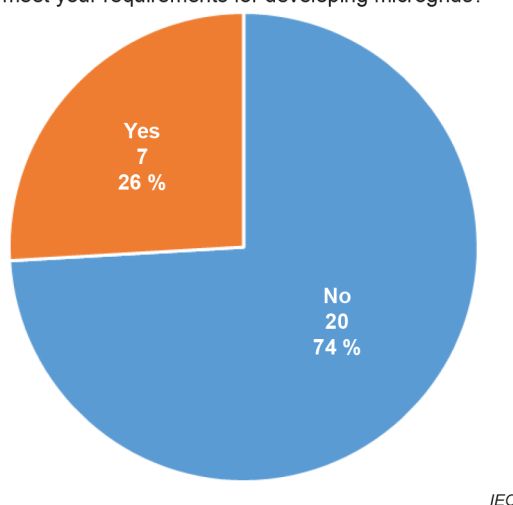


Figure 5 – Standardization satisfaction in the area

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.

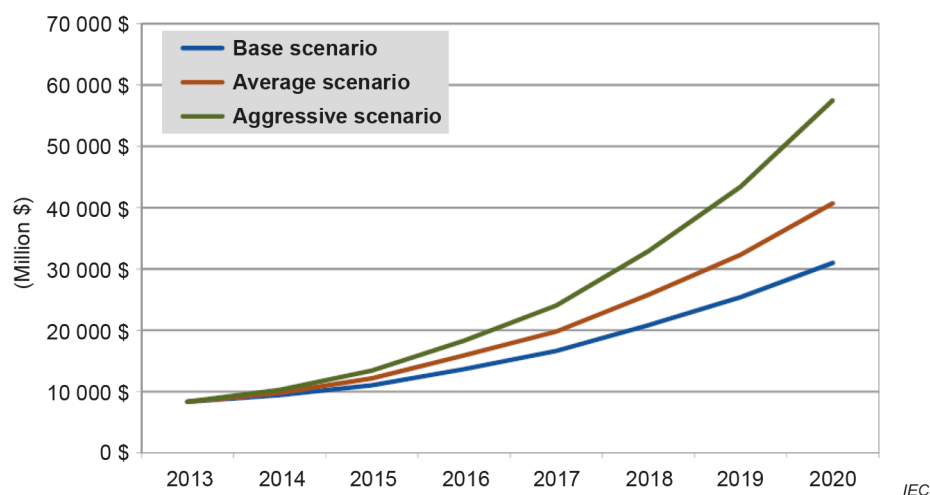


Figure 6 – Total microgrids revenue by forecast scenario, world markets:2013-2020

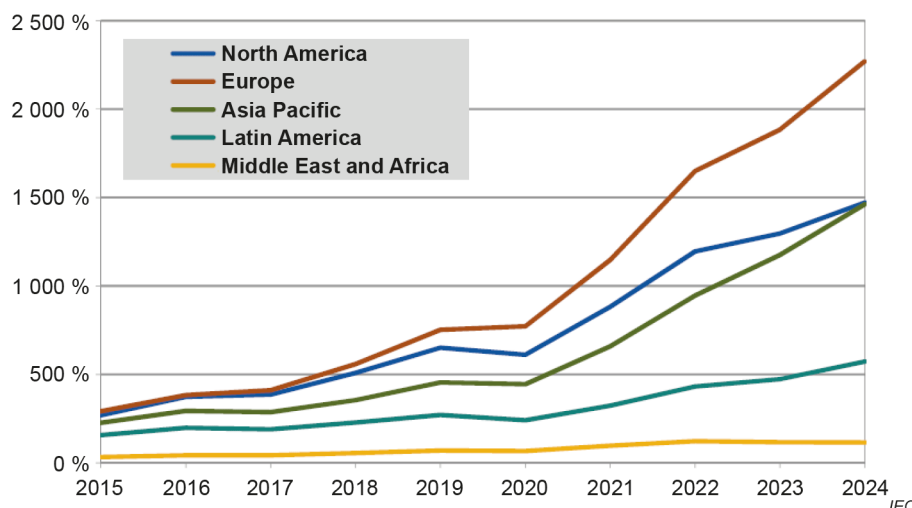


Figure 7 – DER Capacity Installments as a Percentage of New Centralized Generation, Regional Averages: 2015-2024, Source: Navigant Research

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).