# Defining Three Distribution System Scenarios for Microgrid Applications

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# Defining Three Distribution System Scenarios for Microgrid Applications

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***Abstract*— Power systems, especially distribution systems, are undergoing the most drastic overhauls with the growing integration of renewable energy and digitalization. One of the most efficient technological solutions to address the challenges the distribution system faces today, is the formation of microgrids. With heterogeneous driving forces from policy, regulation, system operation, infrastructure developer, aggregator, and end-user, how microgrid will evolve and develop in the future distribution system remains an open question and deserve closer scrutiny. In this paper, a brief state of the art of current microgrid design is introduced considering knowledge and experience from both practitioner and academia. Based on a simple foresight method, three foreseeable scenarios for the future distribution system are depicted. Aspects related to its use cases, energy management system features, and market models will be discussed for each possible scenario. This will shed light on the future research and development of microgrid applications.**

***Keywords*— Distribution system, Foresight, Microgrid planning and operation, State of the art, Standards, Energy Management System, Market model***

## I. Introduction

Power system is experiencing the most drastic changes in history during this revolution of "decarbonization" for its energy resources—with ambitious regulatory goals for ramping the renewable share in the total power generation up to 50%, 30% and 20% by 2030 in Europe, United State, and China respectively as representative examples. The most salient feature is the thrust of the distributed generations, among them the small and medium scaled power generations are gaining popularity in the low voltage and medium voltage level. This change disrupts the traditional structure of the power system which has generation, transmission and distribution systems with clear boundaries and unidirectional power flow in a hierarchical way. Together with the consistent pursuit for the higher level of performance in term of lower cost, higher reliability, etc., all these drivers turn the current power system into an active test field for the latest technologies from information and communication, data science, to materials, and so on, not only for the self-generation facility but also for controllable loads, such as smart home systems, microgrid community and so on. The controllability of the system increases as the complexity escalates.

Distribution system is the place where it has the most drastic changes, as it has been relatively less developed compared with transmission system in terms of new technology adoption and the increasing integration of small and medium distributed power generations. The conventional passive network faces the challenge from the technological perspective like the reverse power flow, the low fault current, the voltage regulation, net metering, and possible overloading of transformers due to surplus generation from distributed generations, and so on, not to mention the regulatory puzzle to the policymaker to design a mechanism to coordinate the development of different aspects. The urgent need is to increase visibility and controllability. With also increasing integration of renewable generation in the transmission network and to compensate for the intermittent supply from these resources, flexibility is needed and is also expected to be provided partly by the distribution system. This reinforces the need for higher controllability either from the supply or consumption in the distribution network.

There two different yet related concepts that are proposed to address the challenges of the distribution system. One is "virtual power plant" which integrates heterogeneous distributed generation resources and controllable load to get a reliable power generation [1], [2] . The "virtual power plant" essentially acts as an aggregator and its main purpose is to enhance the distributed power generation to participate in the legacy electricity market. As most of the work based on this concept is using a centralized solution to coordinate all the resources, it will impose a daunting computation burden to the aggregator controller to fulfill the function. Compared to this, the other concept which is based on the microgrid will be more versatile. As a group of distributed generation and load with clear electrical boundary, the microgrid can either be connected to the grid or be islanded. As the definition of the "grid" in the definition of a microgrid is flexible, the future distribution system can evolve into a large cluster of microgrids or systems of microgrids [3]. This is the other hypothetical future for the distribution system. The total capacity of the microgrid was in 2019 expected to reach to 26,769.0 MW (including planned), with such a number the trend is becoming more evident [4]. Scholars also propose the concept of "supergrid" from the transmission side which enables a large amount of electricity to trade across long distance by aid of deployment of high voltage transmission system such high-voltage direct current (HVDC) systems. The coexistence of a large volume distributed generation with the

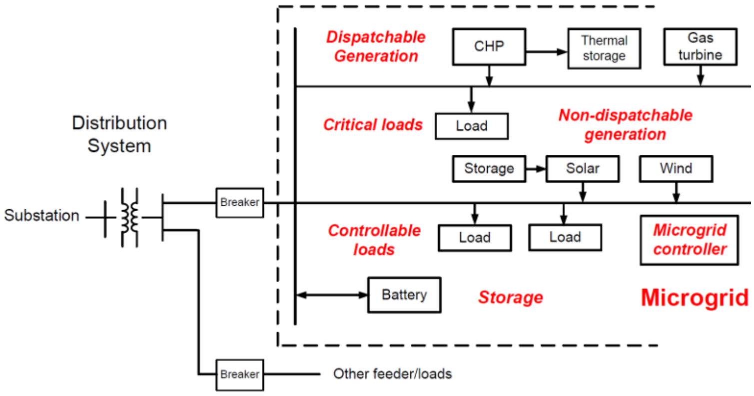


Figure 1. Generic structure and components for a single microgrid

medium ones, determine that the new technology from both the transmission side and the distribution will coexist and need to be coordinated. With the potential to act as an aggregator as a single microgrids or a microgrid cluster, the distribution system based on microgrids will pave the way for the fulfillment of this mega grid paradigm.

Yet considering the sometimes-competing interests of different stakeholders in the distribution system and unbalanced development of facilities from them due to the policy preference, along with other uncertainty from other drivers that are intertwined, such as technology development and social trend and values, how microgrid evolves in this system is indeed not a one-fit-all answer. There are already many versatile microgrid types that suit different use cases. Taking for example that we already know that massive tax cuts will benefit all the industries including renewable industry, yet too low a tax might not make cost-saving from self-generation attractive to the industry electricity user. To cast appropriately the microgrid applications in different scenarios of future distribution system are indeed necessary for prioritizing the techniques that are crucial for microgrid practice and devolvement and thus a certain foresight method is desired to be linked with its research and development.

This paper is organized as follows. Section II provides the state of the art for current microgrid design considering both practitioner and academic knowledge and experience. In Section III, three foreseeable scenarios will be introduced. Their distinct features are discussed in terms of use cases, and Energy Management System (EMS) and electricity market models will be discussed in a representative yet not complete way in the hope of shedding light for the future research and development. Section IV concludes the paper.

## II. Brief State-of-the-Art Microgrid Design

With the maturity of microgrid technology, the process of its standardization is also advanced. The standards often contain the most generic requirements in the topic of interest and therefore is more representative. In this section, the state of the art of microgrid operation and design is introduced based mainly on the standards. Several practical problems that could hinder the microgrid development are enumerated which shows the necessity to put the strategic thinking into practice for microgrid technology development preparing for the future distribution system.

### A. *Microgrid definition*

Generally, microgrid means a group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes. Yet its standardized definition is still evolving with the system becomes more complex and technology becomes more mature.

At the commencement of microgrid technology development, there are none standards to refer to, but some standards that apply also to the distributed generation as well as some local regulations for renewables. Islanding was not allowed in the earlier standards and thus cannot form a real microgrid in this sense; there is, in turn, no requirement for voltage and frequency regulations. With more effort paid on the standardization while witnessing the fast growth of microgrid applications, there are now several standards that specifically apply to microgrid available as listed in Table I [3].

Comparing the newest IEEE P1547 with the one in 2013, several salient changes reflect the changes in the requirements

TABLE I. STANDARDS DEVLOPEMENT FOR MICGRIDS

| Application Areas | Standards that Facilitate Deployment of Microgrids |
|---|---|
| Operation | IEC TS 62898-2 Microgrids Guidelines for Operation [4] |
| | IEEE P1547-REV IEEE Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces [5] |
| | IEEE P2030.7 – Standard for the Specification of Microgrid Controllers [6]* |
| | IEEE P2030.10 - Standard for DC Microgrids for Rural and Remote Electricity |
| Planning | IEC TS 62898-1 Guidelines for microgrid projects planning and specification [7] |
| | IEEE P2030.9 – Recommended Practice for the Planning and Design of the Microgrid (draft-inactive) [8] |
| Testing | IEEE P2030.8 – Standard for the Testing of Microgrid Controllers (draft-inactive) [9] |

a. * this standard is also applied for the planning of the microgrid.

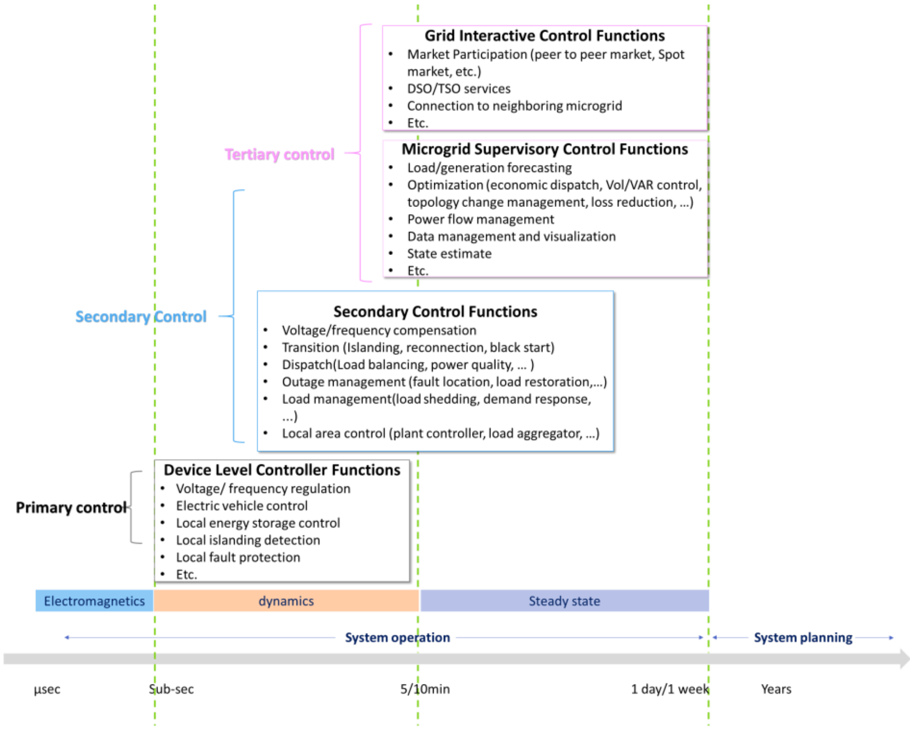


Figure 2. Microgrid control system time frame and action time domain

for the microgrid to interconnect and interoperate with outer grid.

- Islanding is allowed and the requirements are stipulated
- The 10 MW capacity limited when connected to the Point of Connection (POC) is removed
- The requirement should not only be met at Point of Common Coupling (PCC) for the new standard
- Requirement about communication interface is included in the new one and cybersecurity is mentioned.
- More detailed requirement for reactive power support
- Complexity in terms of categorization to address different penetration level is added in the new standard

The new IEEE Std 2030.7-2017 explicitly defined that to be considered as a microgrid, the system must [6]:

- Clearly defined electrical boundaries.
- A control system to manage and dispatch resources as a single controllable entity
- Installed generation capacity that exceeds the critical load; this allows the microgrid to be disconnected from the main grid, i.e., operate as an entity in islanded mode, and supply local loads.

A conceptual illustration of a microgrid is shown in Fig. 1, where the key components of a microgrid needed to make it to work properly include: controllable load, storage, critical load, non-dispatchable generation, dispatchable generation, as well as the interconnection breakers to the upper grid and the controllers.

With new technologies adopted and experiences learned for microgrid implementation, the definition of microgrid and its standardization will continuously change, which make it imperative to keep up with state of the art of this technology and make a foresight based on it.

### *B. Microgrid design-- from operation to planning*

Microgrid, in fact, is a tiny version of a power system. The design of it considering the entire lifecycle is from planning to operation. These two parts are often considered separately as inherited from the practice for the bulk power system. Instead of looking at the detailed state-of-the-art control strategies and design approaches from the literature, we focus on the general process for the design and thus mainly standards are cited here.

The hierarchical control of microgrid considering its unique structural and components features while mimicking the operation large power system has been widely recognized [10][11]. In the architecture of microgrid control systems, different layers are defined according to the different levels of timing criticality. A long-time span microgrid control system time frame and its action domain are illustrated in Fig. 2. Detailed functionalities that a microgrid should fulfil is summarized in different controlled level.

In the design of a microgrid, these operational requirements should also be considered. Based on IEC 62898-1, the general planning and design process can be illustrated as Fig. 3. In this process, after the type of microgrid is chosen and the feasibility analysis, operation requirements should be considered in the planning stage.

### *C. Practical problems for microgrid deployment*

In real life projects, there will be some practical problems from regulation, policy as well as technology that potentially will hinder the development of microgrid [12]. This could include:

- Higher uncertainty of load prediction

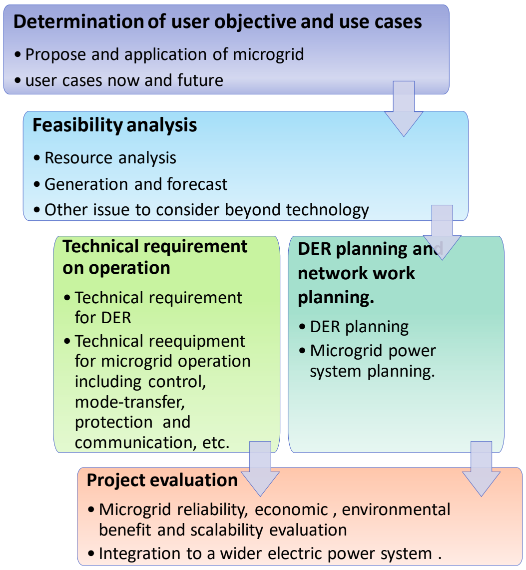


Figure 3. Microgrid planning and design process

- Coordination and co-planning of microgrid and distribution system
- Balancing the interest of multiple stakeholders.
- Regulation and policy uncertainty
- Imperfect performance evaluation system and integrated planning methods
- Data sharing with interconnected system

Therefore, to counteract more efficiently the obstacles which will hinder the future microgrid implementation and most of them come from uncertainty, strategist thinking which will consider multiple possible future scenarios is of paramount importance to be included. With each possible scenario in mind, R&D resources will be appropriately allocated, and necessary countermeasures can be set beforehand.

## III. Foresight for Microgrid in Future Distribution System

Possible counteracting forces from policy maker, local system operator, end customers leave the prospect of microgrid development in the future distribution system more uncertain. A simple foresight method draws the scenarios into a 2*2 matrix considering two most critical uncertainties—the Distribution system operator (DSO) and the customer. Based on this 4-quadrant chart, these three main scenarios for the future distribution system are derived as automatic network, distribution network as backup, and flexible an intelligent power system according to Sintef's Centre for Intelligent Electricity Distribution (CINELDI) [13] (see Fig. 4[14]).

### A. *Three scenarios*

One axis of the quadrant is from passive customers to active ones. By "active" it means that the customer is eager to adopt new technology and to enter novel electricity markets. They are shifting from conventional energy consumers to "producers" using local generation and energy storage. On the contrary, the passive customers just want to consume the energy whenever they need without changing their consumption behaviors and indifferent to new technologies, such as renewable energies and smart homes, as well as new markets. They will not share the responsibility of the distribution system operation. The other axis is from passive DSO to active DSO. Active DSO is more active in adopting new technology, energy storage, sensors, ICT systems which lead the network into a cyber-physical system. This happens due to the possible incentives from the regulation to adopt ICT system and the necessary competency from the personnel. More details about these three scenarios are given in the follow sub-sections.

#### 1) *Automatic network*

In this quadrant, the customer is not as active as the DSO in taking the new technology which leads to the digitalization of the grid. They still take the energy as the product that they consume passively. On the other hand, driven by the regulation, policy, economic benefits and other incentives, the DSO is who build utility-owned microgrid which based on the utility-owned energy storage to facilitate the operation and cooperation of the grid components, defer the would-be investment to cope with higher peak load (such as EV charges at higher power for a short period), increase the quality of energy service for the customers and thus competitiveness, and achieve more efficient utilization of local flexibility. However, the way how electricity is delivered is still the largely same as it is in the traditional power system—from the large power plant, to distribution system and the customers, except very few customers will get part of energy from their own renewable generations. In this scenario, microgrid will be mainly utility-owned microgrid alongside the utility-owned energy storage system. How electricity is sold and bought is also largely the same as it is today in which the energy company will set the price. There could be no well-functioned local market.

#### 2) *Distribution network as backup*

In this quadrant, the customers are leading the DSO in terms of new technology adoption for the digitalization and automation of the power infrastructure. In the customer side, the transport sector will be electrified, energy demand will be increased, and more local generations in term solar, wind energy will be installed, energy storage is readily available in terms of EV and home owned battery packs, and more advanced energy management system for the customer such as smart home controller, energy community controllers will be available. The DSOs adopt not enough new technology invest mainly on the transformers, cables and other traditional components instead of the ICT system, which lead to the consequence that customer will eventually consider the network as conservative and expensive.

For the market, there could be two possible extreme scenarios. One is that there still exists -- the retail market as it does now although less subscribed from the customers, considering the case that only during a certain season when energy self-sustained cannot be committed. The other case is that, as the local market that facilitates the energy exchange through customers themselves will be emerging, and the conventional energy company will be priced out of the market. In this scenario, the self-owned microgrid will be popular and some of them can even be islanded microgrids.

#### 3) *Flexible and intelligent power system*

This scenario is what in line with CINELDI's Vision where both the customer and the grid embrace the

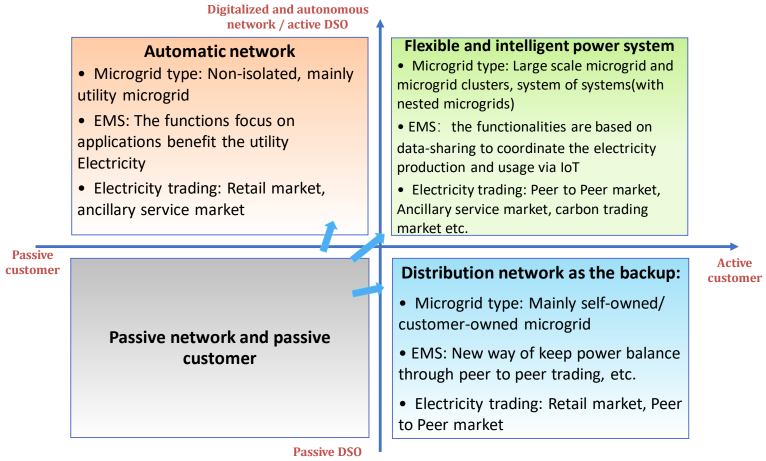


Figure 4. Microgrids in the main scenarios of future distributions system

digitalization and automation. Customers will actively participate in the operation of the grid by employing new technologies to change their consumption and production behaviors, such as smart home platform, smart charger platform, smart energy storage, etc. Microgrid will be proliferating as the local generation will be increased. More real islands will become islanded microgrids. For the grid-connected microgrids, the smooth interaction with the distribution network is facilitated by the adoption of advanced sensors, measuring equipment, control and automation equipment. The entire distribution system will be a system of systems based on microgrids. Radical changes in the market will occur. Local markets that empower the conventional small player will be formed and various kind of commodities, from energy to ancillary service, to carbon emission, will be traded to efficiently allocate the resources.

### *B. The user case emphases and EMS functions in different scenarios*

Although the general objectives of a microgrid are to improve energy efficiency, reduce emission, increase energy security and resilience, improve reliability and enhance the flexibility, specific use cases and hence the corresponding EMS functions are determined by the stakeholder and possible benefits that system could bring to them. To identify the use cases is also the first step in planning a microgrid. Sometimes it is not an easy job, as microgrid is versatile in terms of the functions that it can be fulfilled and each microgrid is unique to meet different requirements and benefits of its stakeholders. Their stakeholders can cover from microgrid end-user/customer, owner, operator, investor, DSO, to DER operator, etc. The ownership of a microgrid can also be complex as it varies and can have more than one owner, such community microgrid. Here we aim to compare the differences in the EMS requirements to match the system with different future scenarios considering the main stakeholders of the representative microgrids, and thus identify the important features and possible challenges of the EMS in these three scenarios.

1) *For automatic network which only the network is comparably more developed in digitalization:* As the microgrids are mainly utility-owned, which are mainly grid-connected, except certain microgrids on the islands or in the rural place. The main use cases will be favoring the need of the DSO who is the operator and the owner of the microgrid, which include but now limited as follows [6]:

a) Minimum requirements: i) Maintain power import/export limits (balancing); ii) Prevent unsafe back feed of the distribution system; iii) Protection coordination—relaying for isolating faults within the microgrid

b) Additional services: i) Aggregated ramp rate control at the POI; ii) Peak demand reduction/maintaining constant load; iii) "Upstream" power quality; iv) Demand response: day-ahead; real-time (automatic demand response); interruptible load, utility event response; v) Voltage regulation at the POI; vi) Phase balancing.

As it can be seen, utility controlled microgrids are supposed to provide regulation services for the entire area owned by the DSO. This includes frequency and voltage regulation, either autonomously or under direct control of the distribution system operator, demand response, spinning reserve, load control, and black start capability for the local distribution grid. Although the architecture of the EMS can be either distributed or centralized, it is more likely that system architecture will be centralized as the DSO is the only owner and operator.

2) *For the case of the system that the distribution network is taken as the backup*: The main use cases for the microgrid will be favoring the interests of the traditional customer who now owns their own private microgrid. Seeing the conventional distribution network as expensive, the use cases, therefore, will mainly target to function as an isolated microgrid. Voltage profile control, frequency control (in island mode), phase imbalance control, and active control of harmonic distortion may be desirable features of EMS for the regulation within the microgrid system area. Higher level functionalities such as optimal dispatch and forecasting are also indispensable. With the reduced dependence on the utility network, the performance requirements of these functions will be more demanding. Depends on the level of interaction among different microgrids and maturity of the local energy market, the EMS will evolve into different architectures --centralized or decentralized.

3) *For the ideal case where the system is flexible and intelligent*, although the ownership is mainly non-utility

TABLE II. MAKRET MODELS FOR DIFFRENT MG-DSO COORDINATION SCHEMES

| Coordination Scheme | MG DSO interaction features | Remarks |
|---|---|---|
| Retail market model | The main commodity in this model is energy. For microgrids, it will purchase energy deficit and sell the surplus (mainly from RES generation, some allow energy from storage to feedback to the grid). For DSO, it will buy energy from the RES from prosumer, mainly for carbon emission reduction. | Already exist. No real involvement of microgrid in terms of network operation responsibility. DSO uses tariff design (fixed pricing, dynamic pricing, capacity subscription, etc. [14].) to incentivize the customer to help to mitigate the network stress |
| Ancillary market model | DSO will purchase ancillary services from microgrids in the form of the contractual agreement or maybe in real-time market, such as voltage regulation, congestion management, etc., to keep the stability and reliability of the network as well as to defer investment on network extension to accommodate more fluctuating renewable generation. | The flexibility achieved by microgrids through energy management (especially from energy storage utilization) can contribute to the ancillary service of required by DSO. It is still a one-sided market. |
| Wholesale market model | Both microgrids and DSO can participate in the wholesale market, especially the spot market, as sellers or buyers. They could compete. | Microgrids participate in the wholesale market within VPP or third parties. Here the wholesale market is integrated with the local market. The wholesale market here is a two-sided market, but the microgrid's participation relies on the third party. |
| P2P market model | There can be little or no evolvement from DSO, the main participants are small players, such as microgrids. Microgrids exchange energy among themselves. This market is a short-term local market, such as intraday or intra-hourly market. | The grid operation is achieved through utilizing local flexibility, the main market players are small players like microgrids or integrators. This is a two-sided short-term local market. |

owned as in the second case, the interaction between neighboring microgrids is increased. The open local market requires the EMS to have more sophisticated functionality on optimization and prediction to fulfill multiple regulation and energy trading objectives. As it is not easy for a single software to cover all the-state-of-the-art algorithms to fulfill specific functionality, the entire EMS will be more likely to evolve into a platform in which various function modules will be interoperating as an ecosystem via the Internet of Things (IoT) and data sharing.

### *C. The market models for future microgrids*

The openness level on market is increased as the digitalization from both the network side and the customer side is deepen. There are several possible market models suitable for different future scenarios. Based on the complexity in terms of implementation, four types of market models are listed related to the local market in the distribution network. The features of interaction between DSO and microgrid are compared and their balancing responsibilities for the distribution network can be summarized as in Table II. The main difference is whether the market is a two-sided market and who share the responsibility of the distribution system operation. In each future scenario, multiple market models can coexist and function at the same time. For example, for the scenario of an automatic network, the main market model that play the role will be the retail market model. There will be very limited room for ancillary market, but this could not be the main stream in a network that customers are reluctant or unable to change their consumption behaviors. In the case of a flexible and intelligent power system, which is the ideal case, it is typical that the multiple market models could find their way as there are technical and regulatory foundations to make it possible in this highly automatic and digitalized system.

## IV. CONCLUSIONS

Three disruptive technologies that are indispensable to achieve the ideal flexible and intelligent distribution system have been highlighted. Despite that, we cannot precisely predict what our power system the future technology will bring us, continuous effort from multiple research communities, will prepare us better for it.

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