Electricity Market Structure, Market Design and DSO Implications

A report for the Customer-Led Distribution System Project

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1. Executive Summary

1.1 Background

The UK's decarbonisation agenda has increased significantly the penetration of low carbon technologies and distributed energy resources (DER) at the periphery of the electricity supply system. By enhancing the operational efficiency of the distribution network, a smart and flexible energy system can exploit flexible DER so that they become an alternative to expensive network investment. It could also facilitate the consumption of locally produced renewable energy by local demand and thus reduce the uncertainties and complexities that arise throughout the system from such intermittent generation.

A key stage in the development of a smart and flexible energy system is the establishment of effective and efficient markets at the distribution level that will provide a platform for participants to be appropriately rewarded for their contributions to a low carbon energy economy. Well-functioning local markets should enable buyers and sellers of the power produced by DER to trade at the distribution level and thus enable the existing system to accommodate the growing number of DER and deliver a satisfactory return for these investments. An important step is therefore to create efficient markets that can deliver products and services that meet the needs of customers and reflect the characteristics of the DER.

There are growing numbers of initiatives in GB to trial market solutions that could provide an alternative to the traditional method of electricity supply. At present these are mainly limited to providing incentives to DER to help resolve network problems. However, as the number of DER increase a point will be reached where network capacity services markets cannot absorb the additional DER without significant network reinforcement and investment. Nor do they provide a sufficient incentive for DER to thrive and grow. As shown in our modelling results[1,2], the benefits for DER from energy markets are on average 26 times higher than that from network capacity services markets. Introducing energy markets at the distribution level would substantially improve the utilisation of distributed generation and thus create additional value for DER. They would also allow the existing system to connect a growing number of DER at a reduced cost, and in a timely manner.

The purpose of this report is to provide initial thinking on how greater customer participation can improve the efficiency of the whole system by extending the commercial development of the distribution system from ancillary services markets to energy markets. In undertaking this, the report addresses the following three key questions:

i) What should be the new market structures in the distribution system?
ii) What are the options for introducing energy markets to the distribution system?
iii) What are the implications for the roles and functions of the distribution system operator (DSO)?

[1] Value Creation by Local Energy Markets
[2] Benefit Assessment from Introducing Local Energy Markets

1.2 Key Learnings

The key learnings of the report are organised into the sections of Future Market Structure, Energy Market Options, and the High Level Implications for the Roles and Functions of the DSO

As distributed generation and flexible loads increase, the industrial structure of the electricity supply system and its markets will need to adapt to keep up with an increasing quantum of dispersed generation. Market mechanisms will be needed that extend from the transmission system to the distribution level in order to optimise the distributed energy resources. As more DERs connect to the system, capacity markets, energy markets and ancillary services markets will all be necessary to ensure a reliable, efficient and secure distribution system which has a lesser dependency on the transmission system. Therefore, significant problems can be addressed within the distribution system which reduces the burden of the transmission system. A comprehensive market design would enable the coordination of resources so as to deliver these criteria for the overall system.

A local energy market with time scales of day-ahead, intra-day and real-time will be a major component of a new electricity supply infrastructure. Its introduction will correspond to the three development stages of the market structure: central-control dominated structure, regional-control dominated structure, community-control dominated structure. As this evolution proceeds, it may be appropriate to evolve the scope of the responsibilities undertaken by the DSO to deliver the optimum outcome across multiple objectives and stakeholders. Further work is required to assess the optimal scope for DSO at each stage of this evolution.

<u>Future Market Structure</u>

The existing national electricity market that functions at a notional point on the transmission system is well-developed and ensures effective energy supply and reliable network operation from centralised generation. However, the growth of energy resources in the distribution system (DERs, for example), offers the prospect of future demands being met by local energy supplies, with distributed resources providing a range of ancillary services for both transmission and distribution networks. The current market structure does not provide a capability for DERs to provide these services. In contemplating a future market structure, our main focus has been to investigate the relationships between energy and other markets - such as network capacity services - and the connection and use of the system charges. We have proposed a structured approach that connects all market components in a single diagram. This provides a systematic overview of all markets in the supply chain illustrating their responsibilities and relationships with the technical operation.

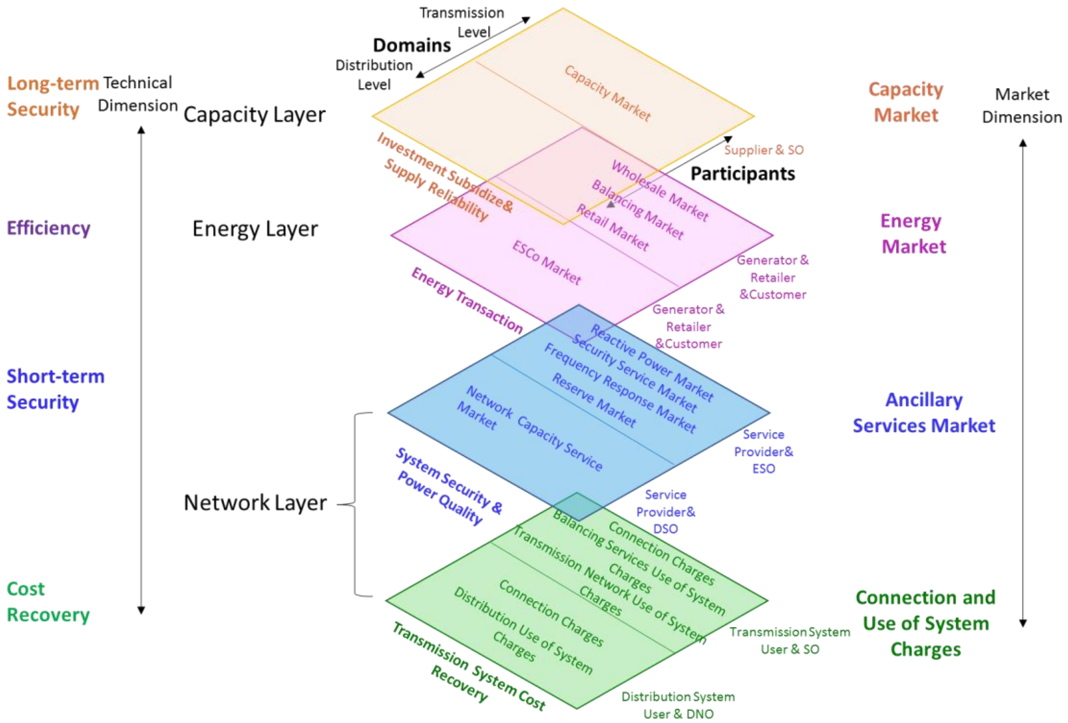
Figure 1 (a) uses this approach to illustrate the current market structure in the UK transmission and distribution systems. The figure is organised as three layers; a long-term capacity planning layer, an energy trading layer, and a network operation layer. Four market dimensions represent the existing markets in the UK in each of these three layers. Each market dimension is divided into two domains indicating its appearance at the transmission and distribution systems [1-10].

It is apparent that the bulk of the existing market operations are transmission oriented. The capacity market is designed to ensure that sufficient transmission connected generation will secure national demand. The energy market predominantly trades in a wholesale market between generators and suppliers with suppliers retailing to final consumers in the secondary retail market, which provides users with their affordable energy supplies. A balancing market supports the clearing process of the wholesale market but without the access of distributed system resources. An ancillary services market allow larger generators and service providers to offer various products so that the reliability of the system at the transmission level can be guaranteed. Contrastingly, there is a limited development of these market arrangements at the distribution level. Where they do exist they are closed bilateral commercial arrangements between customers and distribution network operators (DNOs) or energy service companies (ESCos), rather than part of a liquid competitive market structure.

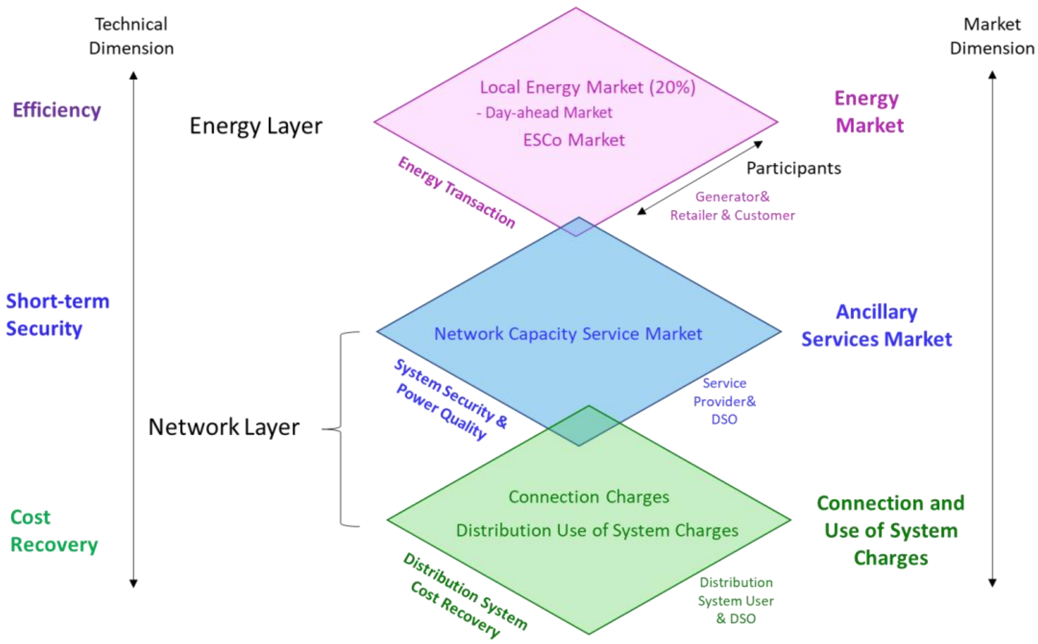
Figure 1 (b) (c) and (d) suggest three future market structures for distribution systems that would correspond to the three identified industrial structures. In the centralised industrial structure, demand is met mainly by generation connected to the main interconnected transmission system and only a small proportion of demand is met from local DER. To enable the local matching of supply and demand a local energy market is available for day-ahead energy trading. A local ancillary services market could assume some of the responsibilities of the transmission ancillary services market so as to maintain distribution network reliability (for example by providing reactive power).

In the regional-control dominated industrial structure, resources located on the transmission and distribution systems take equal responsibility for supplying load. This increases the importance and capabilities of local markets compared to the case in the centralised industrial structure. The further penetration of DER introduces a more dynamic local energy market such as might operate intra-day or for the local balancing of supply and demand, thus sharing the burden of the transmission balancing market at the T-D interface. With sufficient DERs, the ancillary services market also becomes capable of providing both transmission and distribution networks with reliability and security services.

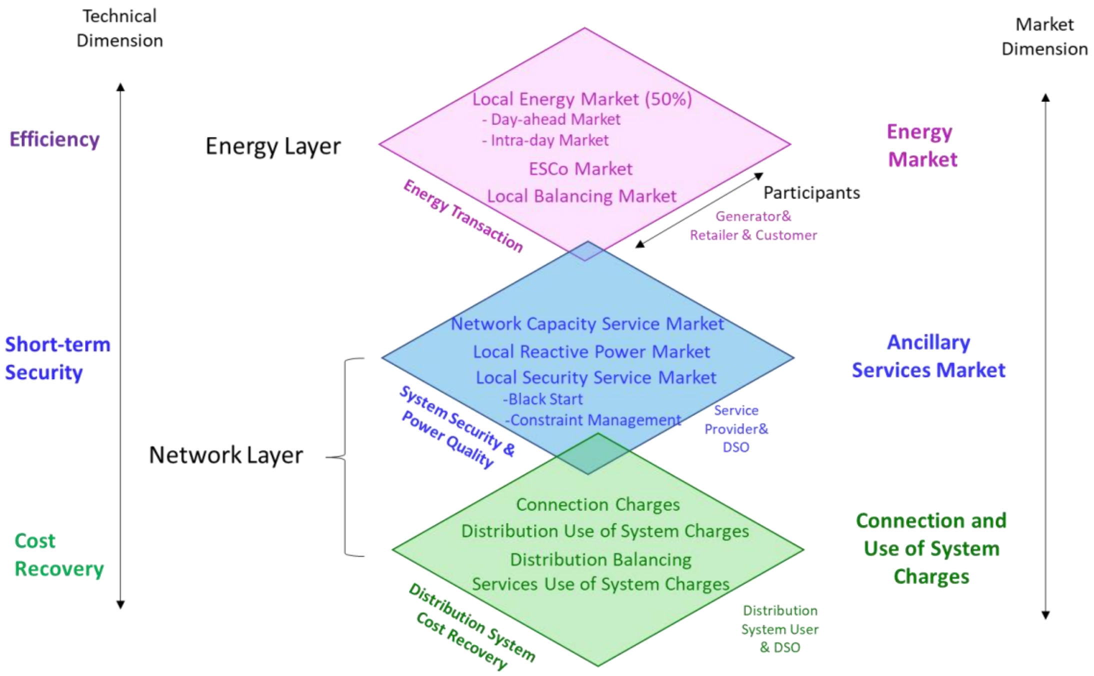
In the community-control dominated industrial structure, where the majority of energy demands are met by local supplies, the local market structure mimics the transmission system markets, but is entirely operated by decentralised communities. The local markets operate to ensure the whole system functions in a cost-effective, reliable and secure manner.



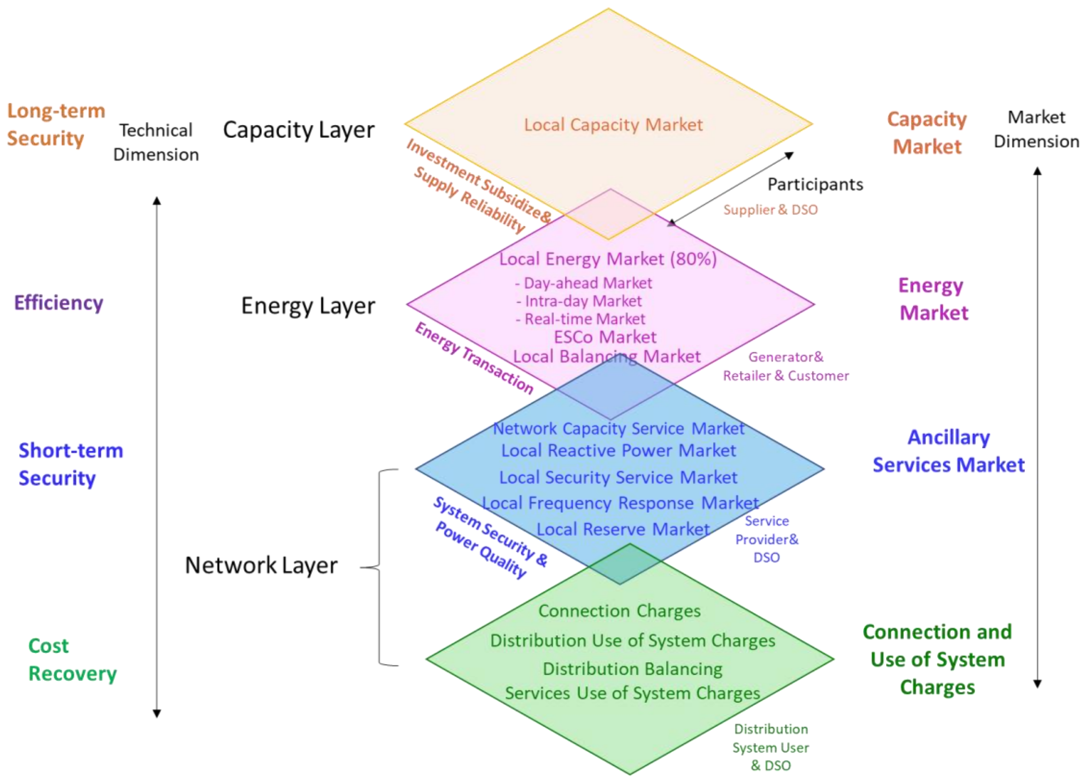
(a) The Market Structure in Current UK Electricity System



(b) Central-control Dominated Market Structure in Distribution System



(c) Regional-control Dominated Market Structure in Distribution System



(d) Community-control dominated Market Structure in Distribution System

Figure 1: Electricity Market Structures in the Current UK Electricity System and Future Distribution System

In summary, this work has presented an overview of the current market structures in both the transmission and distribution systems, and the three suggested future industrial structures. The industrial structures evolve from a centralised structure through a regional-control dominated structure to a community-control dominated structure. This evolution follows an increasing availability and capability of DER, and illustrates the devolution of the responsibility for securing electricity supply from markets based at the transmission level to markets at the distribution system level.

Energy Market Options and Efficiency Assessment

An increasing penetration of distributed generation within the distribution networks offers the prospect of local matching of energy demand and supply, with implications for the reliability and security of the power system operation as a whole. The emergence of smart and flexible loads creates the prospect for electricity demand transitioning from a passive to an active pattern. As this evolution occurs some responsibilities need to be transferred from the transmission system to the distribution system. Because some distributed resources exhibit different characteristics, the markets at the distribution level cannot directly duplicate those at the transmission level. Instead new market options are needed that can facilitate the participation of these distributed resources.

The energy market is a critical component of the future distribution system. It has therefore been selected as the vehicle for investigating the market options appropriate to the different industry structures. From the perspective of time-scale, the day-ahead, intra-day and real-time markets will evolve gradually at the distribution system level with the three development stages of the system structure. Different horizon options for these markets could satisfy the different requirements of participants. A market with a long-time horizon for transactions could provide information for making investment decisions, whereas shorter transactional horizons could provide better forecasts in operational time-scales.

Any new market arrangement needs to be considered from the perspectives of reliability, efficiency and security of the distribution system. The effectiveness of market options can be assessed using the criteria of trading volume, trading price, and the energy residual. As indicated by our study, an appropriate option could better match a flexible load with intermittent generation, or facilitate local power balancing and thus reduce the export of intermittent DG to the wider grid.

Figure 2 demonstrates a possible transition for the future market structures in the distribution system. The transition pathway indicates that as the degrees of decentralisation, decarbonisation and digitalisation increase, the responsibility of electricity market devolves from the transmission system to the distribution system. In the Figure 2, the green layer represents the connection and use of system charges which recovers the network investment costs. The blue layer represents the ancillary service market which ensures the short-term security of the distribution system. The pink layer represents the energy market which improves the energy cost-efficiency. The yellow layer represents the capacity market which ensures the long-term security of the distribution system.

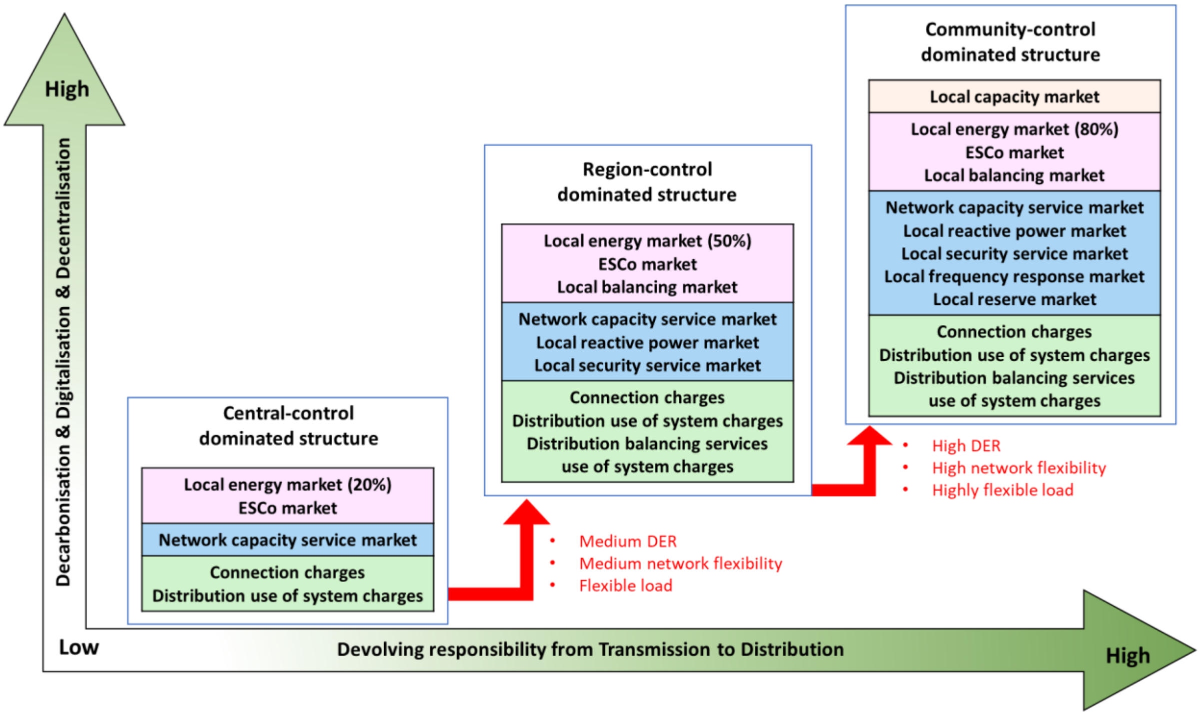


Figure 2: The transition of future market structures of the distribution system

High-level Implications for the DSO's Roles and Functions

The introduction of a local energy market as an adjunct to an ancillary services market at the distribution system in order to improve local energy balancing would fundamentally change the roles and functions of distribution network operators. Building on the model used by the Open Network Project, we have classified the 8 DSO functions in 4 roles: distribution network planning, distribution network operation, distribution market operation, and their overall coordination. We have further expanded the definition of coordination into three categories:

i) Coordination between the ancillary service market and the local energy market,
ii) Coordination between distribution network operation and distribution market operation,
iii) Coordination between distribution network planning and distribution market operation.

The minimum and maximum involvement DSO scenarios are used to illustrate how the distribution system operation activities required under each market structure could be assigned to different players. Maximum involvement requires the DSO to take control of all four roles, indicating that the DNO takes emerging roles and transforms to the DSO. For the minimum involvement the DSO as an independent entity only takes responsibility for coordination, the remaining activities in the distribution system are discharged by the DNO or third parties.

The required activities for distribution system operation at different evolution stages of the distribution system are identified and listed in Table 1. How responsibility for these activities should be allocated to different players is still to be determined, including whether the DSO includes traditional DNO activities (ie whether the DNO becomes the DSO) or whether the

DSO operates alongside the DNO, and the role of 3rd parties in operating markets. Further work is needed to assess the impact of the penetration levels of distributed energy resources, the extent of market refinement, and structures of the distribution system and what this means it terms of the most appropriate scope of DSO as structures evolve.

Table 1. Key distribution system operation activities present under different industrial structures, indicating the minimum/maximum options for DSO involvement

Key activities and responsible parties for distribution system operation: DNO, DSO or 3rd party		**Central-control dominated industrial structure** Min DSO	/ Max DSO	**Regional-control dominated industrial structure** Min DSO	/ Max DSO	**Community-control dominated industrial structure** Min DSO	/ Max DSO
Network planning	Forecast long-term demand and DERs.	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Network planning	Assess network investment and reinforcement	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Network planning	Consider DERs contribution in capacity planning					DNO	/ DSO
Network operation	Forecast short-term output of DERs	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Network operation	Identify network constraints	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Network operation	Formulate timely restoration plans	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Energy market	Manage energy transaction mechanism between regions or communities within the distribution system.			3rdP	/ DSO	3rdP	/ DSO
Energy market	Enable settlement and monitor contracted energy product delivery	3rdP	/ DSO	3rdP	/ DSO	3rdP	/ DSO
Energy market	Operate local balancing market to ensure whole system balancing			3rdP	/ DSO	3rdP	/ DSO
Energy market	Manages day-ahead energy trading at the distribution level	3rdP	/ DSO	3rdP	/ DSO	3rdP	/ DSO
Energy market	Manages intra-day energy trading at the distribution level			3rdP	/ DSO	3rdP	/ DSO
Energy market	Manages real-time energy trading at the distribution level					3rdP	/ DSO
Ancillary service market	Manages services transaction mechanism	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Ancillary service market	Procure network capacity services	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Ancillary service market	Procure reactive power services			DNO	/ DSO	DNO	/ DSO
Ancillary service market	Procure security services			DNO	/ DSO	DNO	/ DSO
Ancillary service market	Procure frequency response services					DNO	/ DSO
Ancillary service market	Procure reserve services					DNO	/ DSO
Ancillary service market	Enables settlement and monitor contracted service product delivery.	DNO	/ DSO	DNO	/ DSO	DNO	/ DSO
Coordination	Neutrally facilitate DER participation in distribution level and national markets	DSO	/ DSO	DSO	/ DSO	DSO	/ DSO
Coordination	Coordinate distribution level and national energy markets	DSO	/ DSO	DSO	/ DSO	DSO	/ DSO
Coordination	Coordinate distribution level energy market and ancillary service market			DSO	/ DSO	DSO	/ DSO
Coordination	Coordinate distribution network operation and market operation.			DSO	/ DSO	DSO	/ DSO
Coordination	Coordinate distribution network planning and integrated network & market operation.					DSO	/ DSO

2. Introduction

2.1 Background

The decarbonisation agenda has increased and will continue to increase the penetration of low carbon technologies and distributed energy resources (DER) at the periphery of the electricity supply chain. By enhancing the operational efficiency of the distribution network, a smart and flexible energy system can convert DER into high value assets which can improve the utilisation of the distribution network, and the utilisation of the DER. A key step towards this smart and flexible energy system is the establishment of liquid markets at the distribution level through which buyers and sellers of the energy produced by DER can trade locally and thus enable the existing system to accommodate a larger number of DER as well as providing advantage to them. It is therefore important to create an efficient energy market capable of reflecting the characteristics of the DER, and meet the needs of customers by delivering customised energy products and services that address the requirements of both.

This report focuses on the introduction of energy markets at the distribution level. Three key issues are investigated:

i) What are the relationships between energy markets and the wider system markets, i.e., the ancillary services market and the connection and use of system charges?
ii) What are the options for introducing energy markets to the distribution system?
iii) What are the implications for the roles and functions of the DSO?

The report is organised in three sections: future market structure, possible energy market options, and high-level implications for the roles and functions of the DSO.

i) Future market structure: a layered and structured approach is proposed to connect all of the market components in a single diagram. This will provide a systematic view of all markets in the supply chain and illuminate the scope of their responsibilities and relationships with the technical operation of the system. This approach is used to benchmark the current market structure, and then explore future market structures under different industrial system structures, namely: a central-control dominated structure; a regional-control dominated structure; and a community-control dominated structure as presented in the report "Future Industrial Structure of Distribution Sector".

ii) Energy market options. Different options for energy markets in the distribution system are proposed, and the products, their timescales and marketplaces in which they are traded investigated. The option for the products traded could be a single energy product, or differentiated energy products with differing degrees of flexibility or stochastics (continuity of output). For trading timescales, the market options vary depending upon their time resolution, such as a day-ahead market, an intra-day market and a real-time market. The appropriate conditions that would benefit the DER most would determine the form of the trading marketplace.

iii) High-level implications to the roles and functions of DSO: The future roles of a DSO under differing market structures are investigated so as to indicate how a DNO might transform to a DSO. We considered two extremes; the maximum and minimum involvement of the DSO in the distribution market. In the maximum involvement scenario, the DSO would be responsible for all market and network operations and network investment. In the minimum role scenario, the DSO focuses only on market coordination.

2.2 Report Structure

This report is organized as follows:

- Chapter 3 provides a literature review of the GB electricity market structure and discusses future electricity market structures under different industrial systems.
- Chapter 4 presents a number of options for introducing energy markets to the distribution system, and assesses the relative merit of each market option from a quantitative perspective.
- Chapter 5 summarises the high-level implications for DSO roles and functions.
- Chapter 6 concludes the overall key learnings of the report.

3. Market Structure

3.1 Current Market Structure

3.1.1 Background

Previously the market designs for electricity supply have been based on the concept of centralised generation and passive demand. Centralised power producers connected to a transmission network supply most of the energy needed to meet the demand of consumers. A wholesale market enables energy to be traded between those generators and energy suppliers across the country. Retail markets direct the energy from supplier to the end user. A capacity market, balancing mechanism and ancillary services markets are designed to provide incentives for larger generators to ensure the security and reliability of the system.

Recent technological developments coupled to government policies for climate change require a low-carbon transition of the electricity supply industry. Integration of large-scale renewable generation with distributed generation located behind smart meters, and smarter loads forces a transformation of the distribution system. Compared to the traditional passive distribution network, a future distribution network will become more active. Rapidly increasing numbers of DERs increase the complexity of the operation and planning of the distribution network. The prospect for the local matching of electricity production and consumption creates a new dimension for the operation of the distribution system. In the future design of the commercial arrangements for the distribution system it will be essential to devise market structures that can optimise the functioning of DER and enable the DNO to meet their network obligations.

In the UK and EU efforts at trialling commercial arrangements have been overwhelmingly focussed on DER having incentives to provide local ancillary services and address network operational issues. For example:

- The **FUSION** project demonstrates commoditised local demand side flexibility through a structured market-based framework to address local and national electrical network congestion [1].
- The **CLASS** project proposes a solution to manage electricity consumption in peak period by controlling system voltage [2].
- The **SENSIBLE** project explores the optimal integration of energy storage in distribution systems and aims at improving DSO in network management [3].
- The **FLEXICIENCY** project aims to provide new opportunities for energy business and to expand DSO’s market facilitator role for new services [4].

Trialled commercial arrangements have the potential to manage network conflicts for the DNO. However with a growth in the number of DER it will be necessary to introduce energy markets at the distribution level that can both improve the utilisation of DER and avoid expensive network investments. This will deliver value for both DNO and DER.

The remainder of this chapter focuses on the energy-related markets. A market structure covering the entire supply chain is proposed as a benchmark. Three structures for a future electricity market in the distribution system are also proposed. These correspond to the three structures previously suggested for a future industrial structure for electricity supply.

3.1.2 Current Electricity Market Structure in the UK

The electricity supply chain consists of four principal components: electricity generation, the transmission network, the distribution network and suppliers to the end user. The objective of the electricity supply chain is to provide economically efficient and reliable supplies of electricity for consumers. Under the centralised model, this objective is achieved by means of a number of different kinds of markets. Energy markets across different time scales collaborate to balance demand and supply at minimum cost. The ancillary services market is managed by the transmission system operator (TSO). It aims to maintain the security and quality of the electricity supply across the system. Connection and use of system charges are designed to recover the network investment cost of augmenting network capacity and connecting new users. A capacity market ensures there is sufficient generation to meet demand in the longer-term.

Energy-related Markets

Energy-related markets include a wholesale market, a balancing mechanism and retail markets. The wholesale and balancing markets are run at the transmission level in GB.

The wholesale market is where electricity supply and demand are broadly matched. Generators trade with retailers or sometimes directly with customers [5]. Different models or trading methods might be used in diverse markets. Transactions in the GB wholesale market take place bilaterally, or through an exchange, whereas in Australia the National Electricity Market (NEM) is under the pool model where all parties sell to, or buy from a Pool.

In GB the balancing mechanism provides a facility for matching electricity supply and demand on a minute by minute basis. Any mismatch between supply and demand in the power system is eliminated in the balancing mechanism or through the purchase of ancillary services by National Grid Electricity Transmission (NGET), which acts as the 'residual balancer'.

The balancing mechanism is one of the tools used by the TSO to balance supply and demand close to real-time. It allows the acceptance of offers (generation increase and demand reductions) and bids (generation reductions and demand increases) at very short notice. The market participants whose generation or consumption deviates from the contracted amount are subject to an imbalance price, which is determined predominantly by the bids and offers in the balancing mechanism. The imbalance price acts as an incentive for generators to meet their contracted obligations in the wholesale market, so as to minimise the need for residual balancing [5].

The retail market provides a platform for electricity transactions where consumers purchase electricity from suppliers. Suppliers purchase electricity from the wholesale market then sell it to consumers in the retail market. They play an important role in the retail market, including retail price settlement and the measurement of energy delivered. From 1998 the retail market has been fully competitive enabling consumers to shop around for their supplier. This helps keep pressure on prices, and promotes innovation in products and services [6].

The only energy-related market at the distribution level is being trialled by Cornwall Local Energy Market, operated by Centrica's Distributed Energy and Power Business. This trial seeks to optimise local resources under the current local grid capacity by setting up a local transaction platform for distributed generation, flexible demand, and storage. In its initial stage, the market aims to solve the heavy grid congestion that persists in Cornwall as the result of the large capacity of renewable generation installed, and the limited export capacity of the local grid. The cost of establishing a local energy market could be significantly less than the cost of traditional network reinforcement [7, 8].

Ancillary Service Markets

Ancillary service markets provide transaction platforms for various ancillary services, which ensure the security and quality of electricity supply. In GB, ancillary services in transmission system including frequency response services, reactive power services, reserve services and system security services [9]. These services are generally procured through market-based mechanisms. Ancillary services are separated into mandatory system ancillary services obligated by the Grid Code, and commercial ancillary services described in the Connection and Use of System Code (CUSC). Ancillary services that are mandatory for large generating units, can also be provided by other facilities [10].

Since 1990 the system operator (SO) has managed the stability of the GB electricity system largely by procuring services via bilateral contracts and tenders. For energy-based products, such as frequency response, the contracting process has moved from bilateral contracts to tendered services. Location based services (congestion and black start) are agreed on a bilateral basis because there is an insufficient volume for the process to be competitive [11].

Some ancillary services consist of several subtypes to meet the service objective. For example frequency response service has three subtypes in the GB power system; these are Mandatory Frequency Response (MFR), the Firm Frequency Response (FFR), and the Enhanced Frequency Response (EFR) [12].

- MFR is a mandatory automatic response service obligated by the Grid Code for all large generators connected to the transmission system. It obliges generators to adjust their power output in response to frequency deviations. MFR covers primary, secondary and high frequency response. Generators may also provide other frequency response services so long as the Grid Code obligation is met. The payment mechanism for MFR is described in the CUSC [13].

- FFR is procured to cover the same incidents as MFR. It is open to any provider, including Balancing Mechanism (BM) or non-BM units that are capable of delivering a minimum of 1MW of response. The frequency response in the FFR service includes the dynamic primary, secondary and high frequency responses as well as the static secondary frequency response triggered by target frequencies. FFR is procured by way of a monthly tender [14].

- EFR is an automatic dynamic service targeted at BM and non-BM units that are capable of delivering a minimum of 1MW and a maximum of 50MW of response within one second following a frequency excursion. A monthly tender process is conducted for EFR [15].

The SO ensures that the frequency response services available are sufficient for all possible frequency excursions that might follow conceivable events. This ensures the stable and reliable operation of the GB transmission system.

Connection and Use of System Charges

Connection and use of system charges are aimed at recovering the capital, operating and maintenance costs of a transmission or distribution system. The essential idea is that system users are subject to charges depending on their use of the infrastructure system to transport electricity from generation points to consumption points [16].

Connection and use of system charges consist of three parts at the transmission level [17, 18]:

- **Connection charge:** Connection charge recovers the cost of providing and maintaining the assets required for the sole use of a party to connect to the transmission system. The charge is paid by directly connected loads, generators, and distribution networks.

- **Transmission Network Use of System (TNUoS) Charge:** The TNUoS charge recovers the building, operation and maintenance cost of electricity transmission assets, which is shared (or potentially shared) by generators and demand through their supplier. Generators are charged according to their transmission entry capacity (TEC), and suppliers are charged based on the peak demand of their customers.

- **Balancing Services Use of System (BSUoS) charge:** The BSUoS charge relates to the costs of balancing supply and demand, and the purchase of ancillary services to secure the system. It is calculated on a daily basis as a flat commodity rate and applied uniformly to generators, and demand users via their suppliers.

Connection and use of system charges consist of two parts at the distribution level [19]:

- **Connection Charge**: Connection Charges at the distribution level recover the costs of the connection between the customer and the distribution network. The basis of the charge is outlined in the Connection Agreement between the licensed DNO and the customer.

- **Distribution Use of System (DUoS) charge:** The DUoS charge recovers the costs of investment, operation, and maintenance of the distribution network. It is an ongoing charge invoiced monthly by the DNO to a customer's supplier. Two charging methodologies are currently in use to calculate the DUoS tariff depending on how a customer is connected to the network. The Common Distribution Charging Methodology (CDCM) is used to calculate charges for users connected to the LV and HV distribution networks. The EHV Distribution Charging Methodology (EDCM) is used to calculate the charges to users connected to the EHV levels of the distribution network. The methodologies are incorporated in the Distribution Connection and Use of System Agreement (DCUSA) which governs the contractual relationship between the DNO and users of the distribution networks.

Capacity Market

The capacity market is intended to help secure the system in the longer term by encouraging a sufficiency of generating capacity to be installed or retained to meet the forecast of peak demand. Capacity providers are offered a fixed payment by the National Grid. In return, these capacity providers are obligated to provide the contracted capacity in periods of system stress. The capacity market provides a steady and predictable revenue stream in the four years ahead of the delivery year so as to cover the investment cost, and thus promote investment in future capacity. Penalties apply if the required capacity fails to be delivered when needed. The capacity market operates alongside the electricity market and the existing National Grid contracts [20, 21].

The capacity market in GB takes place at the transmission level. There is no local capacity market at the distribution level.

3.1.3 Electricity Market Benchmark

To describe the entire supply chain of the electricity supply system in a single diagram, a layered and structured approach is proposed that integrates all the market components. The diagram is arranged in three layers that range from a long-term capacity planning layer down to a short-term energy trading and network operation layers. Four dimensions representing each of the existing electricity markets in GB are awarded to each layer. Each market dimension is divided into two domains indicating its relevance for the transmission and distribution levels.

This approach is used to benchmark the current electricity markets, and explore future market structures under differing electricity industrial structures; namely the central-control dominated industrial structure, the regional-control dominated industrial structure and the community-control dominated industrial structure that were presented in our “Future Industrial Structure of Distribution Sector” report. The market structure of the existing GB industrial structure is illustrated in Figure 3 [22-31].

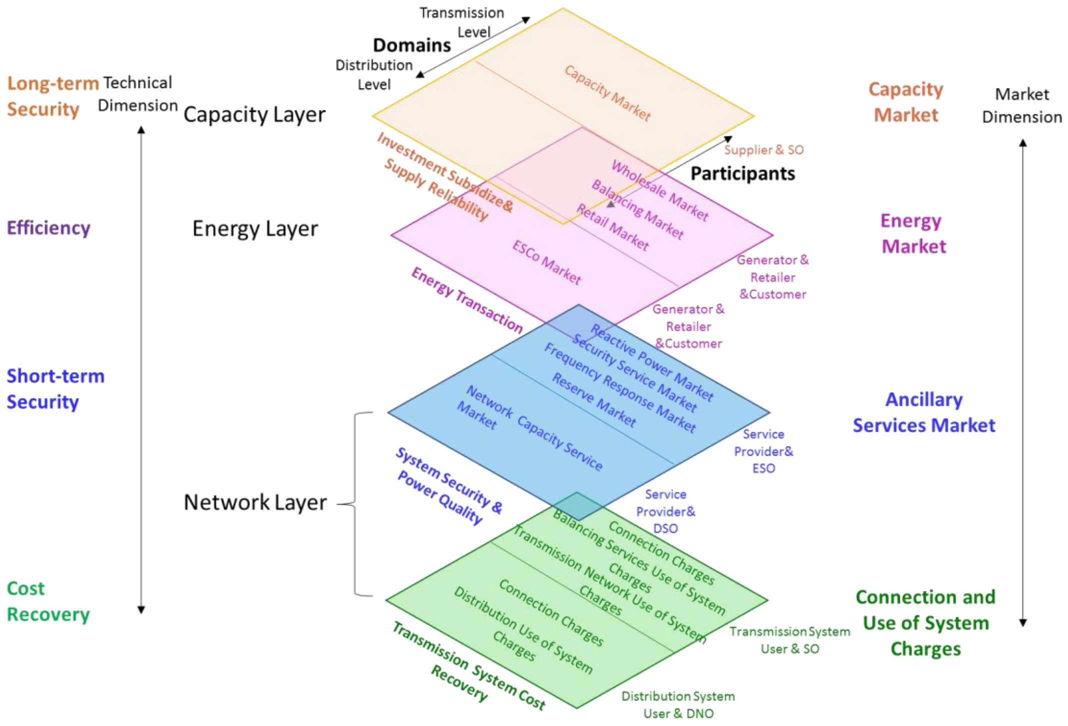


Figure 3. The Market Structure in Current UK Electricity System

3.2 Future Market Structure

The structure of electricity markets corresponds to the industrial structure adopted by the electricity system, which depends on the development state of DERs with the majority of change being in the distribution system where most DERs will be connected.. The exploration of future electricity market structures in this report therefore focuses on market structures in the distribution system.

3.2.1 Future Market Structure under the Central-control Industrial structure

The central-control industrial structure is the least devolved of the three models considered in this report and is the closest to the structure in place today, and in scale it could be similar to current DNOs' licence areas. In this structure the bulk of power is supplied by transmission connected resources. The future electricity market structure in the distribution system under the central-control industrial structure is shown below:

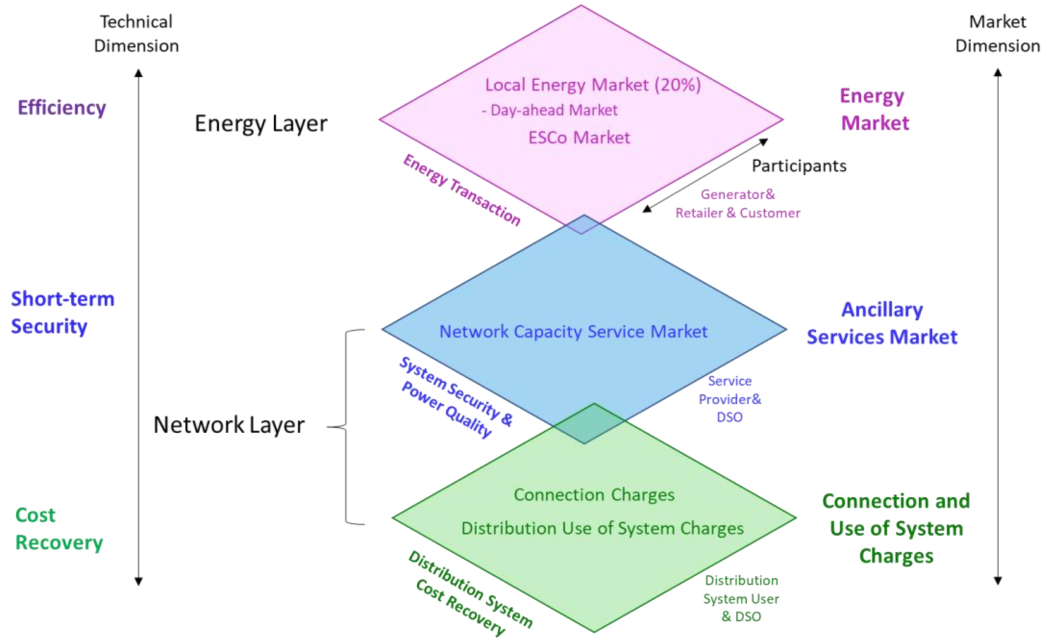


Figure 4: Central-control Market Structure in Distribution System

Future Energy Related Markets

At the distribution level in this model, local energy markets are operate independently of the transmission wholesale market, as energy trading is concluded locally. Only a day-ahead market is introduced in this stage. The market split between transmission and distribution levels allows local markets to design transaction mechanisms that meet local requirements of loads and supplies. Local markets enable consumers purchasing energy mainly from local energy suppliers that may reduce consumer bills and improve energy cost-efficiency.

Future Ancillary Service Market

The network capacity market is the only ancillary service market operated at the distribution level under the central-control dominated market structure. Other ancillary services remain on the transmission network level. They will move downstream gradually from the transmission to distribution networks along with the development of industrial structure.

Future Connection and Use of System Market

In recovering the costs of operating, maintaining and reinforcing the distribution network, the future connection and use of system charges would remain largely unchanged. However, the functioning of the energy-related markets would modify local generation and demand profiles, and ultimately change the requirements for network access. At this stage some modification to these charges would be implemented to reflect this change.

Future Capacity Market

Under this industrial structure the longer-term security of energy supply is expected to be maintained through national capacity market.

3.2.2 Future Market Structure under the Regional-control Dominant Industrial structure

A similar proportion of energy is supplied from producers connected to the transmission system and connected to the distribution system, placing an equal significance on both national markets and distribution level markets. DERs have increased capability to enhance the range of responsibilities that can be met by regional markets at the distribution system level, with one or more regional zones within distribution licence areas

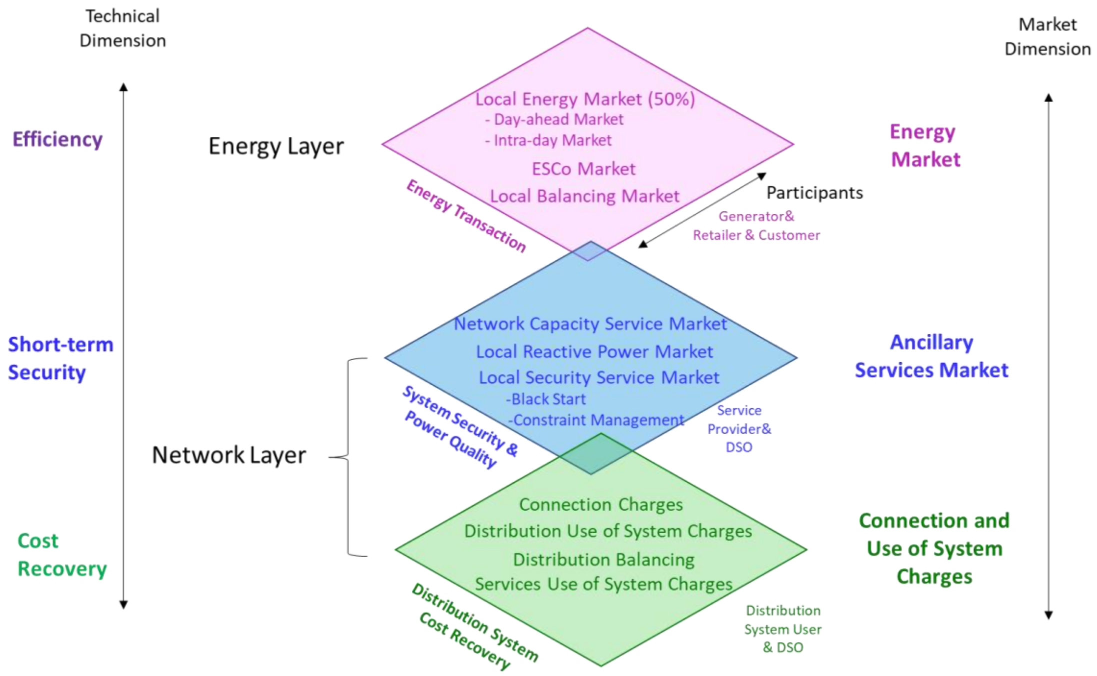


Figure 5. Regional-control Dominated Market Structure in Distribution System

Future Energy-Related Markets

Transmission-level markets are still needed alongside distribution-level energy markets to meet customers' energy needs. However, the distribution system now has more autonomy over its energy markets, because the distribution system is able to provide for a greater proportion of its customer energy needs through D-connected generation. For the energy market, half of transactions occur in the local energy market at the distribution level, and the local balancing market takes around 30% of balancing actions as DER bring more flexibility to the market, with the remainder of the balancing actions being at the transmission system level. Both intra-day market and day-ahead market are introduced. The level of activity in local markets would also tend to increase with the growth in the production and consumption of energy.

Future Ancillary Service Market

For ancillary services, the distribution system now takes the responsibility for both reactive power services and a part of the system security services (black start and transmission constraint management) under the regional-control dominated industrial structure. More network constraints are resolved locally through the network capacity services market without having to resort to calling on national ancillary services. Under the regional-control dominant industrial structure local ancillary service markets take more responsibilities compared to under the Central-control Industrial structure.

Future Connection and Use of System Charges

The future connection and use of system charges remain similar in the subtypes (connection charges and distribution use of system charges) and continue to recover the costs of the network. The increased proportion of local energy-related markets is likely to further impact network access, and lead to more modifications in the charging rules.

3.2.3 Future Market Structure under the Community-control Dominated Industrial structure

Communities have full capability to meet their energy needs, and the dependence on the central supply is substantially reduced. The scale of community-control dominated structure varies from street levels to city levels.

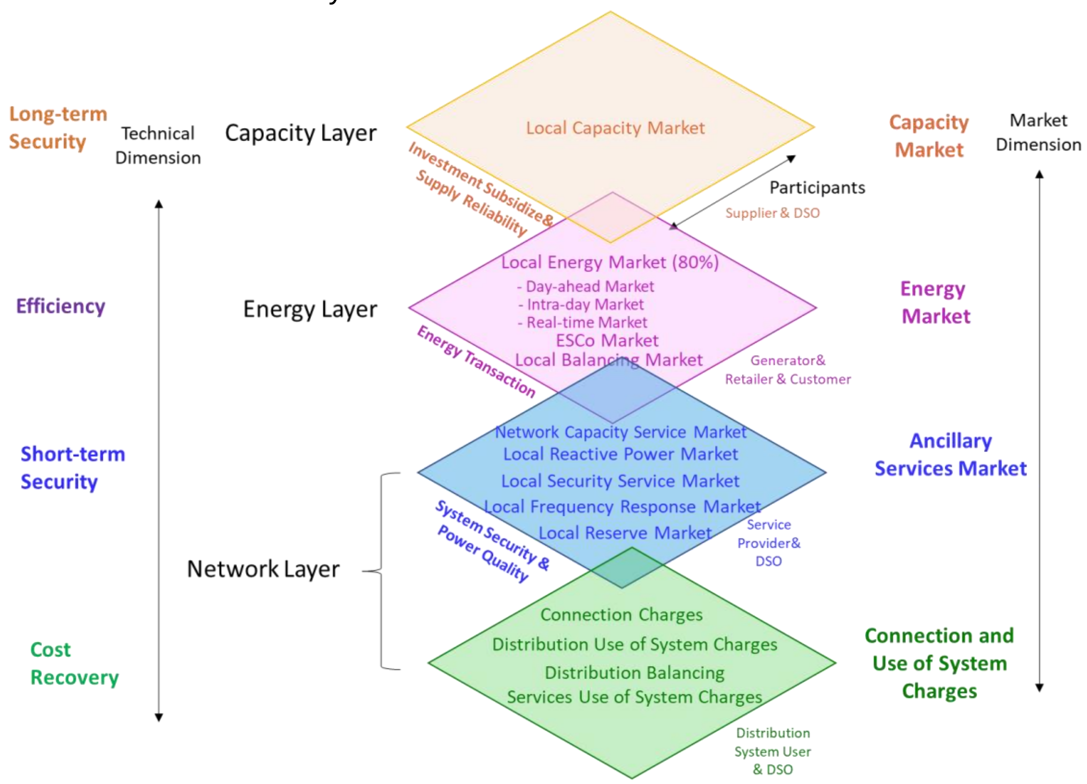


Figure 6: Community-control Dominated Market Structure in future Distribution System

Future Energy Related Markets

In terms of the energy market both wholesale and retail trades and their settlement are concluded at the community level. Energy trading markets in the timescales of day-ahead, intra-day and real time are all introduced to satisfy dynamic transactions needed. The local energy market would meet around 80% of load while the rest of load is still supplied by traditional energy suppliers through the central market.

Future Ancillary Service Market

For the provision of ancillary services, a local ancillary services market has full functionality which is symmetrical with the traditional ancillary market at the transmission level. It is capable of providing reactive power services, security services, reserve, and frequency response as well as network capacity services. Transmission connected generation is still available to provide frequency response services that can offset the large scale of intermittent renewable DER in the distribution system. The devolving responsibility for frequency response to distribution level is because DERs can also provide frequency response.

Future Connection and Use of System Charges

As a consequence of the majority of balancing services being provided by local balancing units, the connection and use of system charges should now incorporate the balancing use of system charge as an additional charging component.

Future Capacity Market

The participants in a future capacity market in this industrial system structure are now DER instead of transmission connected generation. Capacity planning for DER replaces the importance of capacity planning for generation on the transmission system in order to ensure energy supply security in the longer term.

3.3 High-level transition pathways for future Market Structure of the distribution system

Figure 2 demonstrates a possible transition for the future market structures in the distribution system. The transition pathway indicates that as the degrees of decentralisation, decarbonisation and digitalisation increase, the responsibility for the operation of electricity markets increasingly devolves from the transmission system to the distribution system. In the Figure 2, the green layer represents the connection and use of system charges which recovers the network investment costs. The blue layer represents the ancillary service market which ensures the short-term security of the distribution system. The pink layer represents the energy markets which improve the energy cost-efficiency. The yellow layer represents the capacity market which ensures the long-term security of the distribution system.

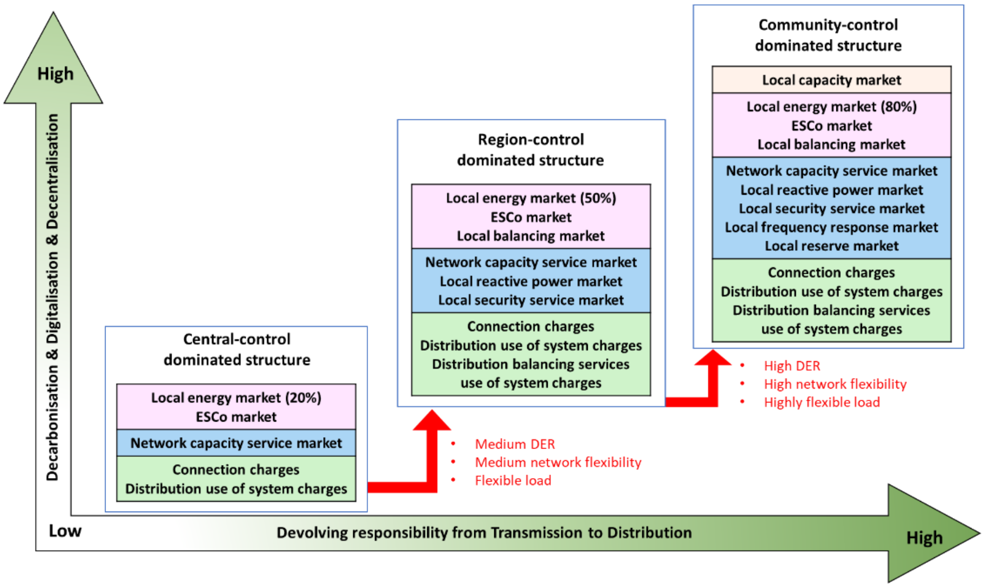


Figure 2: The transition of future market structures of the distribution system

4. Market Options and their Assessment

4.1 Background

An increase in the quantum of distributed generation and flexible load on the distribution network has the potential to transform users from passive to active roles and then participate in the distribution system operation [33-35]. Some functions may be replicated or extended from the transmission system to the distribution system. Distributed resources exhibiting a wide range of diverse characteristics and also diverse loadings/profiles at different locations on the distribution system may render markets at the transmission level unsuitable for the distribution system. Markets at the distribution system level should also have cognisance of the characteristics of both energy producers and demand. New options should therefore be considered for the design of markets at the distribution system level.

These market options need to be considered from the perspectives of reliability, efficiency and security to support the introduction of distribution system operation functions. Any market design should be based on the product to be traded and the trading mechanism. The marketplace should be appropriate for what is traded, and how and where it is traded. In this chapter we investigate the market options for energy markets in the distribution system. The effectiveness of an energy market design should be assessed by the criteria of the trading volume, price, and uncertainty.

4.2 Market Options

4.2.1 Options for Products to Trade

In the wholesale market prices are differentiated by the difference in reliability of generation from traditional controllable generators and from renewable energy generators whose output is uncertain and intermittent. The quality of products traded on distribution systems can be divided into reliable energy (energy that can be delivered according to a forecast that has high reliability) and differentiated energy (energy that is unreliable, and might for example depend on weather conditions).

There are many types of distributed generation connected to the distribution system. Some will be controllable generation, for example diesel engines and combined heat and power (CHP) plants that can provide reliable energy supplies and balance system power fluctuation in real-time operation [36]. Some renewable energy generation, for example photo-voltaic and wind generation will be less predictable and less controllable since their output is dependent on weather conditions.

At the distribution system level, the product traded could be either uniform energy or differentiated energy with different reliability levels. Uniform energy product means that within a local market, the participants trade energy under the same model, regardless of the any differences in the degree of uncertainty in generation or the degree of flexibility in the customer's load [37]. This has the advantage of making the market operation simple. However, its disadvantage is that price cannot reflect the quality of the energy product.

The option of differentiated energy products provides an opportunity for different market strategies and prices to be offered for different energy products. For example, the energy of controllable generators is utilised to supply the demand of traditional load and paid at a higher price. The differentiated energy is utilised by demand that is flexible and can tolerate certain uncertainty in the supply. Thus, its traded price is lower than that from controllable generation. The energy quality on a sunny day and a cloudy day will also be different.

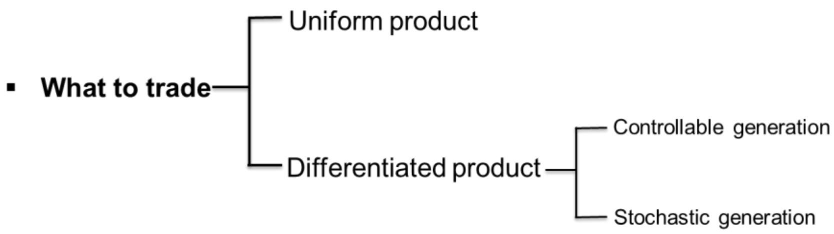


Figure 7: Looking at the energy to trade from perspectives of product

4.2.2 Options for Time Scales to Trade

From the perspective of the length of the market cycle, the existing electricity markets cover day-ahead trades, intra-day trades and real-time trades [38, 39]. 'Time resolution' refers to the time intervals of the transaction. It will vary for markets in different regions or countries. The day-ahead market is open and cleared once a day with a time resolution of 1 hour or 30 minutes, namely 24 or 48 steps of transactions are executed in each trade. Intra-day markets can be open every 6 hours or 4 hours with a time resolution of 30 minutes. The real-time market is open every 15 or 5 minutes with only one transaction executed in each trade.

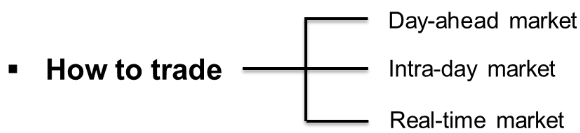


Figure 8: Energy trade can be performed at different time windows

Traditionally electricity markets have been designed based on a fixed length of cycle and time resolution. For example, the cycle of the day-ahead market is one day and the time resolution is 1 hour or 30 min. However, at the distribution system level energy products will be different from those in the traditional wholesale market. Generator characteristics will be different, and there will be diversity in flexible loads that have different working times and working cycles.

Consequently, in the future a dynamic time period may be more suitable so that the time period can be varied over time to satisfy these differing requirements. For example, some loads that can be turned on and off frequently are suitable for a market with a short time resolution so as to balance system real-time power fluctuation. Some loads that need to work continuously will prefer a market with longer time resolution. Drawing on this consideration the concept of a product driven market is proposed. The outputs of PV and wind power depend greatly on the weather. Sometimes, their output can rise or fall suddenly. The market needs to be capable of dealing with this variation.

4.2.3 Options for Marketplaces to Trade

The energy can be traded in the central market or local market depending on the penetration level of DERs. For example, when the penetration level is low, it is difficult to achieve the power balance within a small area. It is more efficient to balance the energy supply and demand in the central market. When the penetration is high, it is a complex problem to balance numerous distributed generation and loads. In this condition, it becomes more practicable to balance energy supply and demand effectively within a local market.

Consequently, in the central-control dominated market with a low penetration level of PV and EV, a small proportion e.g. 20% of energy is balanced in the local market. In the regional-control dominated market with a medium penetration level of PV and EV, a medium proportion e.g. 50% of energy is balanced in the local market. In the community-control dominated market with a high penetration level of PV and EV, a high proportion e.g. 80% of energy is balanced in the local market.

In summary, a different set of market arrangements should be established depending on the PV and EV penetration levels.

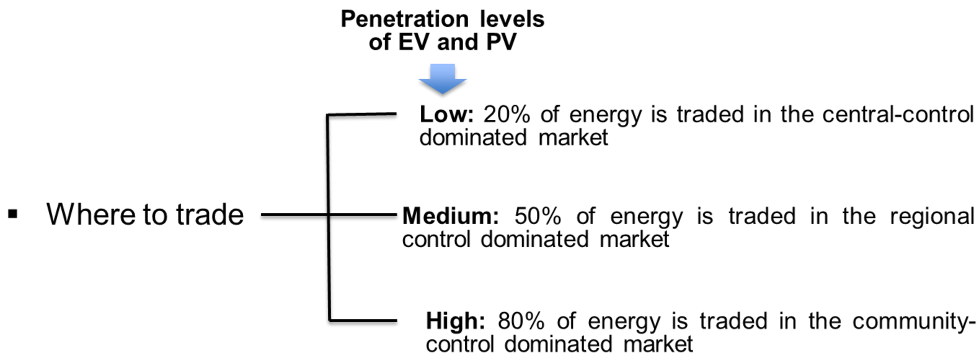


Figure 9: Where to trade

4.3 Assessment for Market Option

Performance of market options is quantitatively assessed in terms of trading volume, trading price. These dimensions are used to assess the effectiveness of different market options, and provide a reference for the selection among the different market options.

Table 2. Quantitative indicators for market

Category	Indicators
Quantitative	Trading volume Trading price Energy residual

The impact of the options of time scales to trade on the market results is assessed in this section. The simulations are conducted on a test case that contains a solar PV generator and 9 flexible loads. Based on the feed-in-tariff rates in GB [40], the utility grid buy-back price is assumed to be 4p/kWh. The average domestic electricity price in GB for period

January to June 2018 is 16.18 pence/kWh [41] which is set as the sell-out price of the utility grid. The average of the buy-back and sell-out prices of the utility grid is set as the trading price in the local market. Relevant results are listed in Table 2.

In day-ahead market 72.12% of PV energy is consumed directly by flexible loads on the basis that PV can sell its electricity directly to loads in the local market. The PV residual power is sold to the utility grid at the price of 4 pence/kWh, the average of PV price is 8.39 pence/kWh. The average price for flexible loads purchasing electricity is 12.89 pence/kWh.

As an assessment of the time scale to trade options, the operation of the market in different time scales are simulated for comparison. The results of a day-ahead market, one hour-ahead intra-day market, and a 5-min real-time market are compared in Table 3 and Figure 10. In the intra-day market more accurate information can be obtained compared with day-ahead market. As a result the electricity trading volume increases in intra-day market, which raises the average price of PV by 5.84% and reduces the average price of flexible loads by 2.79%.

In the real-time market electricity trading is carried out every 5 minutes and thus based on the real-time data of PV output which will be more accurate than the intra-day data. Consequently, local trading volume is increased, which raises the average price of PV by 14.67% and reduces the average price of flexible loads by 7.14% compared to the intra-day market.

Table 3. Market results under different time scales

	Average price of PV, pence/kWh	**Average price of flexible load**, pence/kWh	**Trading volume,** kWh	**PV residual,** kWh / %
Day-ahead market	8.39	12.89	9.26	3.58 / 27.88%
Intra-day market	8.88	12.52	10.29	2.54 / 19.82%
Real-time market	9.62	11.96	11.85	0.99 / 7.69%

Figure 10 shows that the residual PV power feeding back to the utility grid is much reduced. In real-time market, majority of PV energy is consumed in the local market. PV residual need to be balanced by the utility grid is 7.69%. PV residual in day-ahead and intra-day market are 27.88% and 19.82%, respectively.

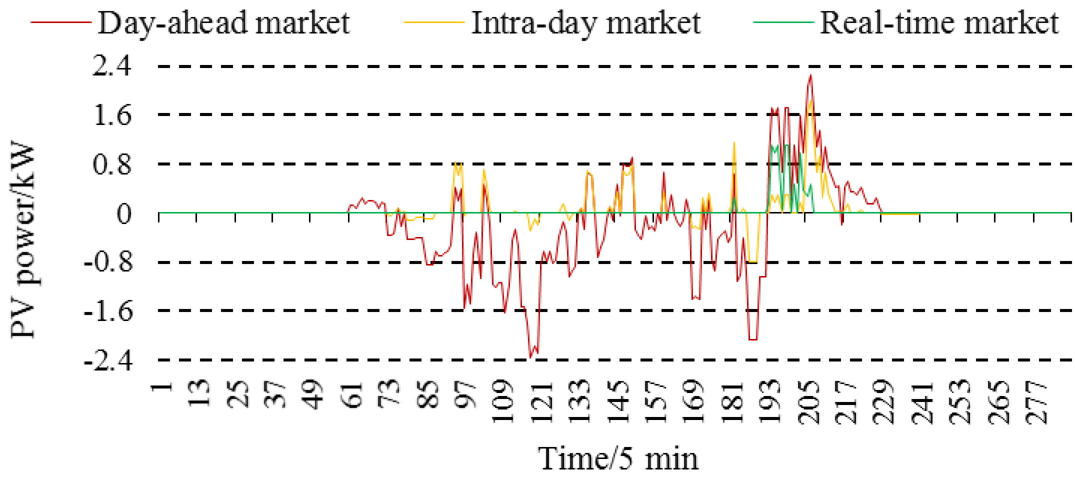


Figure 10: PV residual under market scenarios of different time scales

In summary, unlike the traditional market that trades uniform energy, energy in the local market will be divided into different categories based on the uncertainty degrees and traded in different time scales.

In the central-control dominated market structure, as the penetration level of DERs is low and around 20% of energy is needed to be traded locally, day-ahead market is enough to achieve this target. In the regional-control dominated market structure, around 50% of energy is needed to be traded locally. Thus, intra-day market is introduced. In the community-control dominated market structure, majority of energy is needed to be traded locally. Real-time market which is verified of great effectiveness for local energy trading is suitable to the community-control dominated market structure.

Real-time market could maximize the transactions of uncertain generation with flexible loads and promote the local power balance. The fundamental reason is that the shorter term of the market, the more accurate forecast power of PV (uncertain generation) can be obtained.

5. High-level Implications for the role of a DSO

5.1 Background

To support a stable and effective transition from DNO to DSO, we have discussed the future roles and responsibilities of the DSO under different market structures at the distribution system. Three proposed market structures indicate the evolution of distribution system with the increasing population of DERs. The scenario-based analysis will inform existing DNOs so that they can develop the corresponding functions that are needed at each evolution stage or fundamentally change their scopes of business in the future. The traditional role of the DNO is limited to maintaining the security and reliability of the network through investment, reinforcement, and the network's operation. Introducing energy markets at the distribution level creates emerging market-related roles and functions for the DSO which could either be added to the traditional activities of the DNO or be assigned to a separate organisation. The ENA's Open Networks project has worked with industry stakeholders in outlining the key functional requirements that would be needed by a DSO. 8 high level functions have been identified. These are listed in Table 4 [41-51].

Table 4. Eight Functions of a DSO

Functions	Detail description
System Coordination	Operate local and regional areas and co-ordinate energy and power transfers with other networks and systems to enable whole system planning, operation and optimisation across different timescales. System coordination could include local actions to support thermal, voltage and frequency management across networks, including actions to minimise losses, manage constraints and provide capability.
Network Operation	Operate the electricity distribution network to maintain a safe and secure system. Ensure that network power flows remain within limits and that the network operates within acceptable voltage limits. Ensure that the network remains secure against credible events such as circuit trips and generation loss. Identify and manage current and future risks. Coordinate and collaborate with the GBSO to manage potential conflicts to support whole system optimisation. Respond to Customer needs.
Investment Planning	Identify capacity requirements on the distribution network and secure the most efficient means of capacity provision to Customers. Coordinate with the GBSO and Transmission Owners to identify whole system options. These would include commercial DER options as well as distribution network investment.
Connections & Connection Rights	Provide fair and cost-effective distribution network access that includes a range of connection options that meet customer requirements and system needs efficiently.
System Defence and Restoration	Enhance whole system security through the provision of flexible services. Provide system resilience to low probability but high consequence events using risk-based approaches. Provide the means to re-establish the wider synchronous area in the event of widespread disruption.
Services/Market Facilitation	Interface with the GBSO and other network operators to enable the development of distribution capacity products, the creation and operation of local network services markets and to enable DER access/ participation in wider services for whole system optimisation. Facilitate local and national markets to access and settle services through auctions and other market arrangements for whole system efficiency. Ensure these arrangements are fair and transparent. Provide information and control system infrastructure to facilitate local and national markets and service provision.
Service Optimisation	Ensure system needs can be efficiently met across all timescales by identifying network requirements, understanding the limitations of network assets and providing network access for additional flexibility services from smart solutions and DER services. Ensure whole system optimisation and resilience through the optimal selection of flexibility services.
Charging	Sets Distribution Use of System prices for local network. Determines Point of Connection. Determines connections charges and informs of transmission reinforcement charges (if applicable). Consideration to Exit Charging (dependent on size, variations and apportionment).

5.2 Categorising future DSO roles

ENA identified the functions of a DSO assuming the transition of the DSO is accomplished in one step. As the matter of fact, considering the evolution of distribution system the ENA high level functions cannot reflect fully the necessary functions required of a DSO at the different stages in this evolution. Accordingly so as to facilitate a smooth transition from DNO to DSO and interpret the implications for a DSO under different market structures, we have first classified the future functions of the DSO into 4 roles: distribution network planning, distribution network operation, distribution market operation and the coordination, and allocated the eight functions to each of role. These are shown in Figure 11.

Distribution network planning is responsible for network investment planning, connections and connection rights and charging arrangements. Distribution network operation takes responsibility for network operation and the defence and restoration of the system. Coordination is in charge of system coordination, service/market facilitation and service optimization.

Compared to the distribution network planning and operation roles of the DNO, the DSO must be innovative in its management of the distribution system and the emerging markets. These innovations should embrace corresponding market operations and their coordination. The increased complexity of the distribution network with its attendant markets has led us to further expand the current coordination between transmission and distribution operations. We now consider the broader implications for coordination between:

i) the distribution markets, i.e.: the ancillary services market and the energy market
ii) distribution network operation and distribution market operation
iii) distribution network planning and distribution network operation

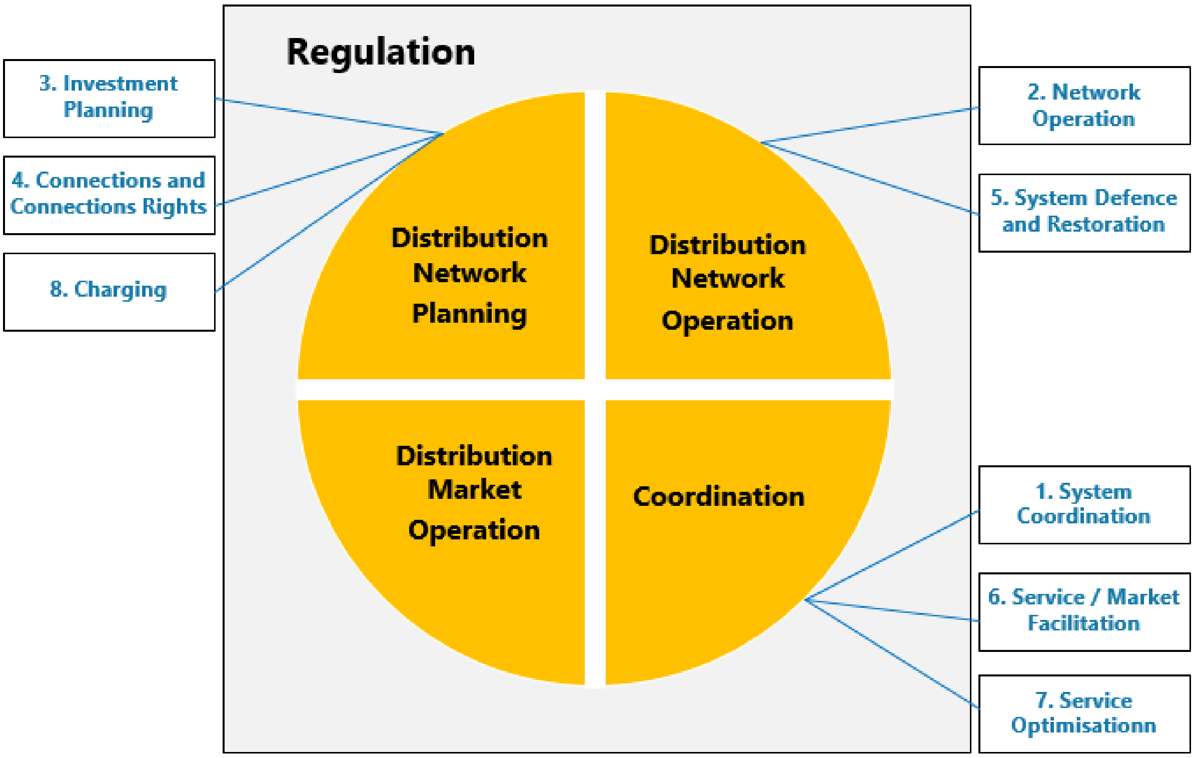


Figure 11: Re-group DSO Eight Functions into Four DSO Roles

The implications for the DSO are different under different market structures since the DSO could undertake one or more of the responsibilities from the four DSO roles identified. In evaluating the implications for the DSO under different market structures we have considered the two potential extremes of a maximum and minimum DSO involvement. Maximum involvement requires the DSO to take control of all four roles, indicating that the DNO takes emerging roles and transforms to the DSO. For the minimum involvement the DSO as an independent entity only takes responsibility for coordination, the remaining activities in the distribution system are discharged by DNO. The three distribution industrial structures representing the different evolution stage of the distribution system are used to evaluate the detailed roles and functions of a DSO under the two extreme scenarios.

5.3 DSO under the Central-control Dominated Industrial structure

In the centralised industrial structure, the total system capacity requirement is met by the electricity system operator (ESO). The majority of power supplies come from transmission connected generation. National markets at the transmission level comprise most of the market activity, including energy trading, system energy balancing, and transmission ancillary services. At the distribution system level, markets for energy trading and network capacity services would primarily be for the purpose of facilitating DER connection and output within specific parts of the distribution system.

Under the centralised industrial structure energy suppliers purchase energy from both the local energy market and the national wholesale market and resell it to customers through the retail market. Individual customers are also able to seek their energy supplies directly from the local energy market. Local energy has a cheaper price, because if it is consumed locally, the very significant cost of integrating distributed generation into the grid is reduced or removed. The costs of integrating the DG into the national system and which could be avoided are: distribution system costs for exporting the DG energy to other distribution areas or to the transmission system boundary; balancing costs at the boundary which includes the costs of inefficiently flexing central generation in response to intermittent DERs; and transmission system costs for making the energy available throughout whole system ie on the national market. This is a genuine cost reduction from a reduction in the scale of the central generation plant, transmission and distribution networks and their operations when flexibilities are aligned with DGs, and which benefits all parties who buy or sell energy. This price differential does not represent these network users avoiding network charges or taxes/levies at the expense of other customers.

With flexible price settlement, the local energy market enables customers to more buy energy from intermittent sources which have an inherently lower value, and as the energy is sourced more locally the losses are also lower. All of these factors reduce the cost to customers of differentiated energy from local intermittent sources compared to buying reliable energy from the national market.

However, the limited population of DER means that the bulk of energy supplies come from the transmission system; i.e. the local energy market could only be operated as an adjunct to the national wholesale market. The settlement of the local energy market affects the net demand submitted to the wholesale market and the balancing behaviour of the ESO. In terms of the local ancillary services market, DER with limited availability are only able to provide basic network capacity services to ensure sufficient network capacity within the distribution system. Although it provides network companies with a solution to operating the distribution network without additional network investment, it would also be unable to compete with the importance of the transmission network investment and operation in its influence on the operation of the distribution network. Distribution network planning and network operation are still viewed as the principal solution for to resolving network constraints.

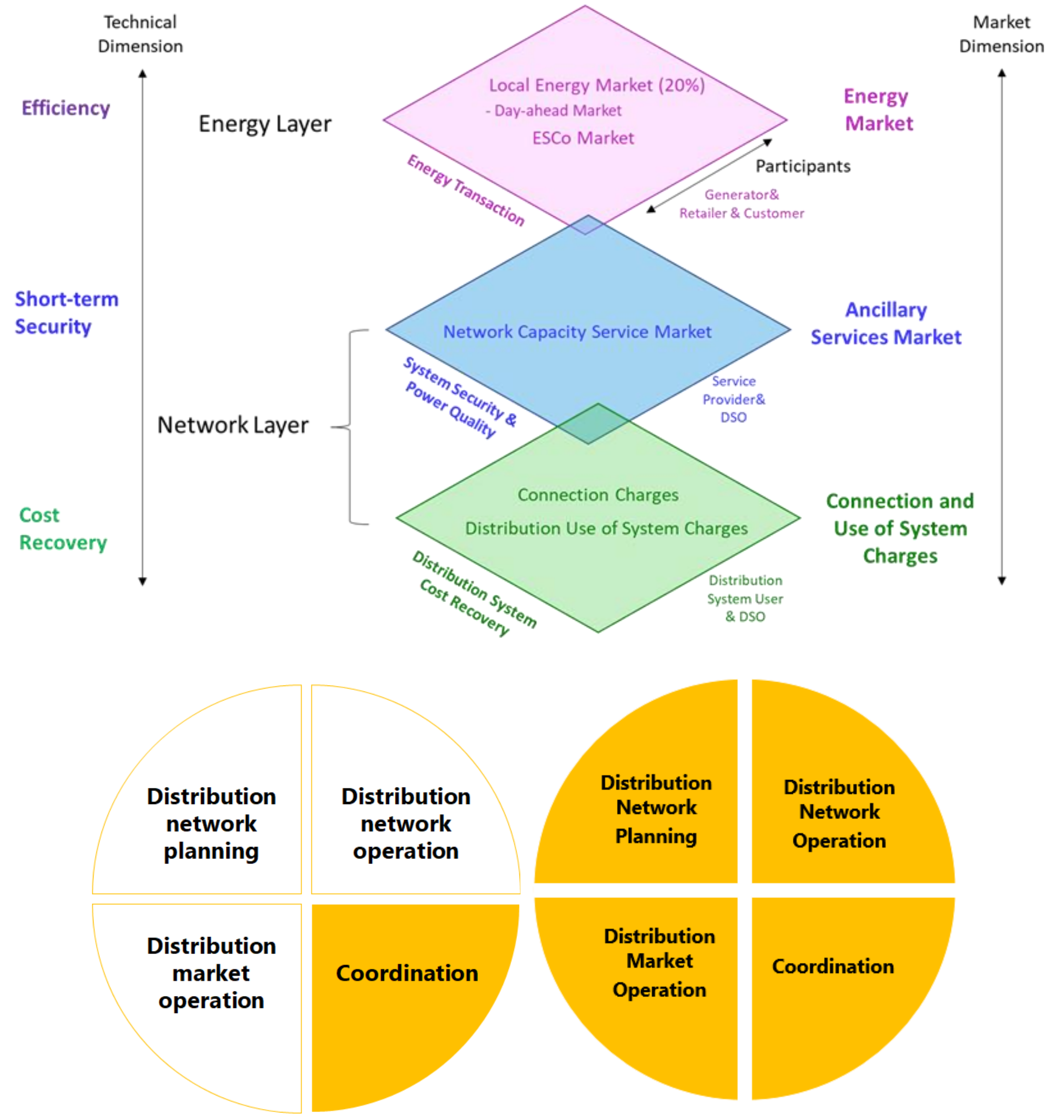


Figure 12: Minimum (left) and maximum (right) Involvement of DSO- Central-control Dominated Industrial Structure

The minimum involvement of the DSO shown in Figure 12 indicates that the DSO is responsible only for coordination. Considering that there is only limited DER availability in the local network capacity service market and that the DSO is not responsible for distribution network operation, the coordination the DSO exercises here only refers to the coordination between the basic local ancillary service market and local energy markets. In this the DSO must function as a neutral market facilitator, managing the detail of customer data and ensuring data privacy. By providing market information for both the ancillary service market and the energy market, DSO can facilitate market decisions of both consumer and DER enabling them to maximise their benefit. The DSO, working in conjunction with the distribution market operators, reduces the conflict between the ancillary services market and the energy market.

The maximum involvement of the DSO assumes it taking responsibility for all the roles of an existing DNO, namely network planning and network operation, and the emerging roles of market operator and coordination. In addition, the DSO would be responsible for the operation of both the local energy market and the ancillary service market. Due to the small scale of DER on the system, the local energy market and ancillary services market would rarely conflict with the operation of the network. The role of system coordination therefore still focuses on coordinating the energy market and ancillary service markets within the distribution system so as to mobilise the efficient use of DER.

The activities that are required for distribution system operation in the centralised structure are set out in Table 6, with an indication of how these could be assigned to different parties under the scenarios of minimum DSO involvement and of maximum DSO involvement.

Table 5: Responsibility for distribution system operation activities under central-control dominated industrial structure

	Key activities for distribution system operation	Minimum DSO involvement	Maximum DSO involvement
Network planning	Forecast long-term demand and DERs.	DNO	DSO
	Assess network investment and reinforcement	DNO	DSO
	Consider DERs contribution in capacity planning	n/a	n/a
Network operation	Forecast short-term output of DERs	DNO	DSO
	Identify network constraints	DNO	DSO
	Formulate timely restoration plans	DNO	DSO
Energy market	Manage energy transaction mechanism between regions or communities within the distribution system.	n/a	n/a
	Enable settlement and monitor contracted energy product delivery	Third party	DSO
	Operate local balancing market to ensure whole system balancing	n/a	n/a
	Manages day-ahead energy trading at the distribution level	Third party	DSO
	Manages intra-day energy trading at the distribution level	n/a	n/a
	Manages real-time energy trading at the distribution level	n/a	n/a
Ancillary service market	Manages services transaction mechanism	DNO	DSO
	Procure network capacity services	DNO	DSO
	Procure reactive power services	n/a	n/a
	Procure security services	n/a	n/a
	Procure frequency response services	n/a	n/a
	Procure reserve services	n/a	n/a
	Enables settlement and monitor contracted service product delivery.	DNO	DSO
Coordination	Neutrally facilitate DER participation in distribution level and national markets	DSO	DSO
	Coordinate distribution level and national energy markets	DSO	DSO
	Coordinate distribution level energy market and ancillary service market	n/a	n/a
	Coordinate distribution network operation and market operation.	n/a	n/a
	Coordinate distribution network planning and integrated network & market operation.	n/a	n/a

5.4 DSO under the Regional-control Dominated Industrial structure

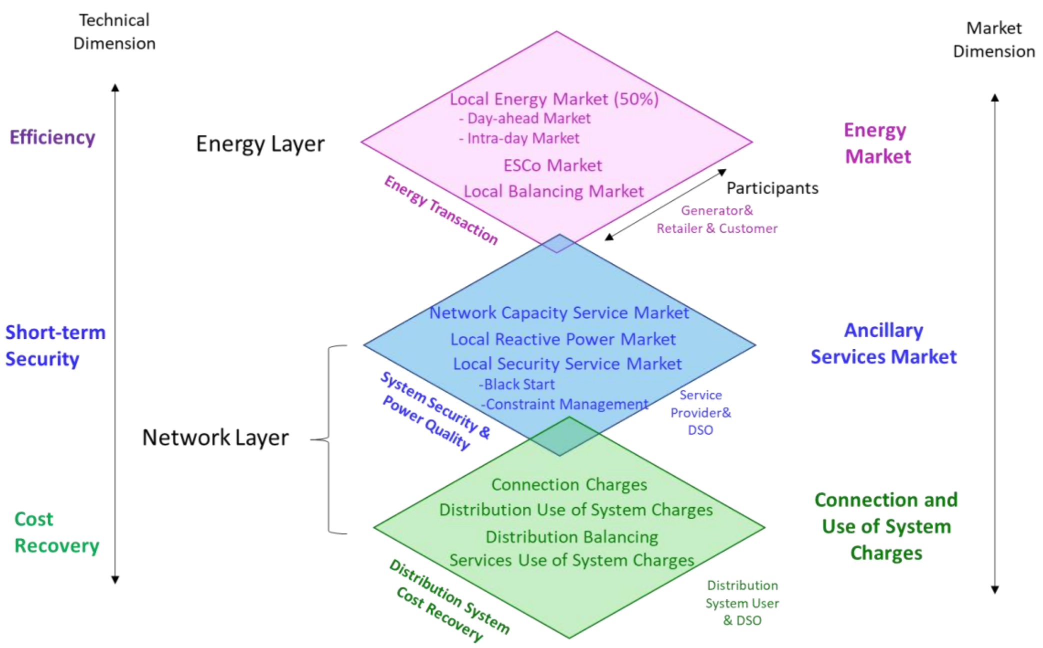
Under this industrial structure the distribution system continues to function as autonomous component of the whole transmission and distribution system. Total system capacity requirements are still met by the national ESO, but demand within each region is met by regional DER and transmission connected generators equally.

More dynamic and variable market activities are expected in the distribution system facilitating an increasing number of DERs. The addition of intra-day energy trading, balancing and the trading of a larger range of ancillary services products marks a significant shift in the operation of the network since the distribution system is now functioning as a quasi-micro grid.

The growing importance of these market activities requires dynamic operation of the market. Active management of the network will need to take account of fluctuations in renewable generation output, the requirement for ancillary services at both the distribution and transmission levels, and the prospect of increased variability in customer demand. A key consideration in this respect will be the creation of one or more regional zones within the distribution licence area, with DERs participating their own regional markets and so contributing to the provision of continuous and economic supplies to the consumers. Increasingly, enhanced automatic voltage control (EAVC) assets located at the extremities of the network to provide for safe regulation of the system may also be needed.

Interaction with the ESO in this structure is likely to be based around the provision of reserve services to prevent distribution zone blackouts. Due to the relative independence of the distribution system in this configuration, the nature of the transmission-distribution boundary is likely to be significantly different from that seen in the existing DNO framework. Some degree of active network reconfiguration within the transmission system is likely to be required in order to recognise the benefits of a more active distribution network.

As shown in Figure 13, the minimum involvement of DSO is where it would be responsible only for coordination. The coordination in this case covers the interaction between the regional energy market and the regional ancillary services market, and the coordination between the distribution network operation and distribution market operation. The DSO would become the neutral market facilitator and coordinator. The DSO would have access to market participant data and provide transparent market information for all participants, thus creating a liberal environment for regional participants to enter both regional ancillary service markets and regional energy markets. The DSO should also be able to exchange market decisions with each market operator and network operator, and so facilitate their dynamic responses. It would also seek to reduce the transactional conflicts and network constraints that might otherwise result from activity in the markets.



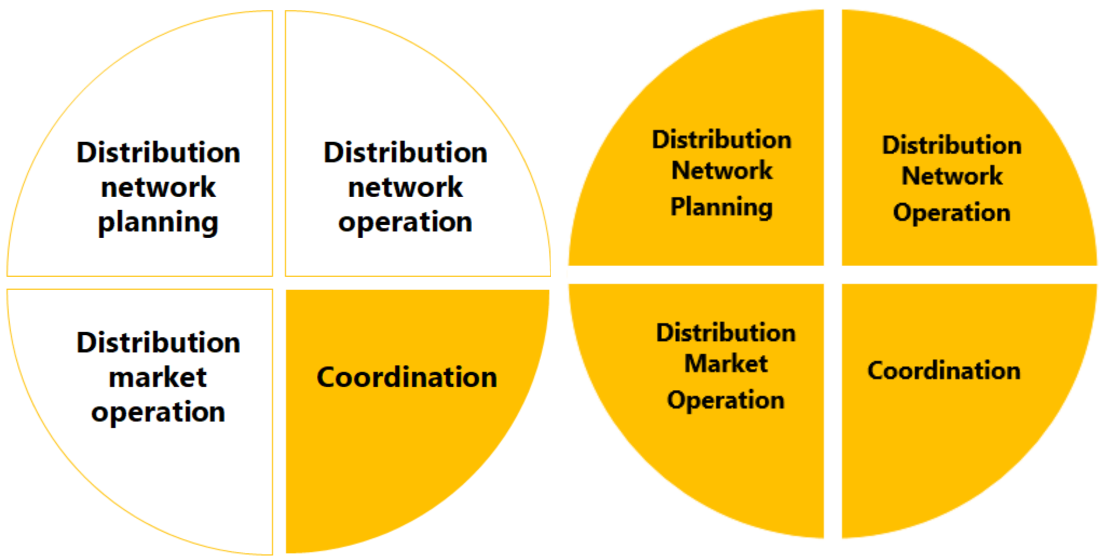


Figure 13: Minimum (left) and maximum (right) Involvement of DSO- - Regional-control Dominated Industrial Structure

Figure 13 depicts the DSO's maximum involvement to encompass all four basic roles. Compared to the maximum involvement in the centralised industrial structure, the regional-control dominated industrial structure significantly increases the complexity of being the market operator since it must now operate multi-layer, multi-type and multi-timescale regional energy and ancillary markets. From the comparison with the minimum involvement, the DSO in this case would be responsible for all aspects of the regional system. The DSO should be able to satisfy the energy trading needs whilst ensuring the reliability of the regional network. This would necessitate the DSO to optimise the actions of DERs across various markets and would require further coordination between the network operation and market operation.

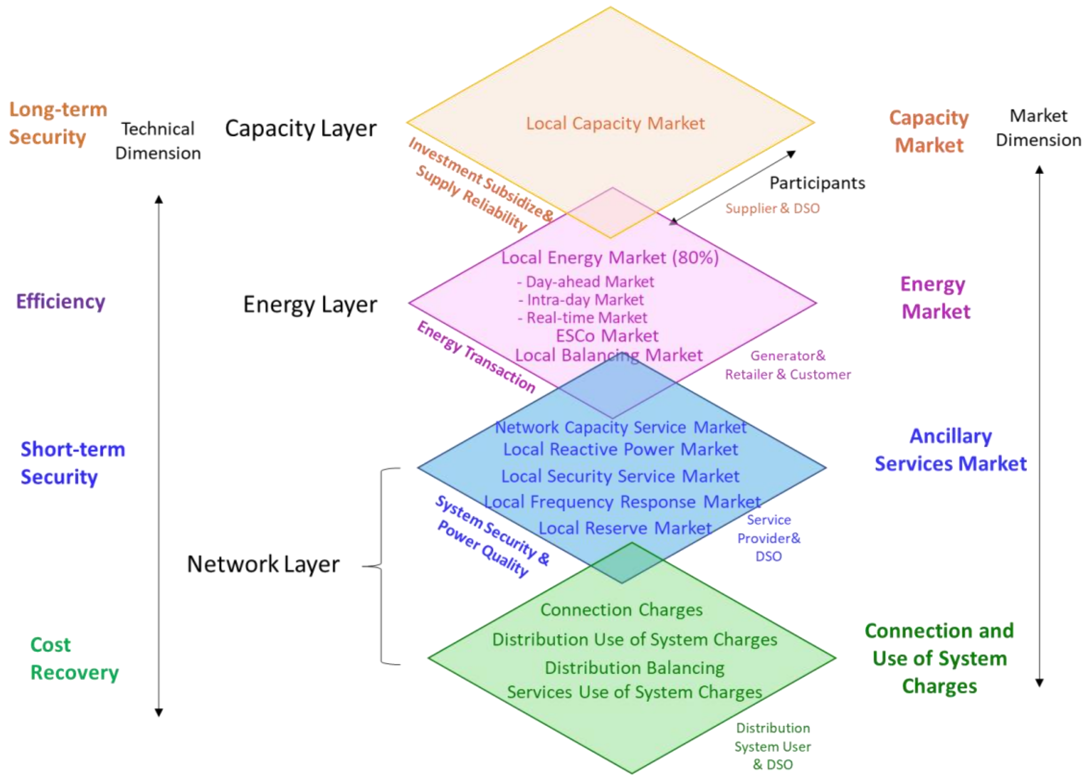
Table 6: Responsibility for distribution system operation activities under regional-control dominated industrial structure

	Key activities for distribution system operation	Minimum DSO involvement	Maximum DSO involvement
Network planning	Forecast long-term demand and DERs.	DNO	DSO
	Assess network investment and reinforcement	DNO	DSO
	Consider DERs contribution in capacity planning	n/a	n/a
Network operation	Forecast short-term output of DERs	DNO	DSO
	Identify network constraints	DNO	DSO
	Formulate timely restoration plans	DNO	DSO
Energy market	Manage energy transaction mechanism between regions within the distribution system.	Third party	DSO
	Enable settlement and monitor contracted energy product delivery	Third party	DSO
	Operate local balancing market to ensure whole system balancing	Third party	DSO
	Manages day-ahead energy trading at the distribution level	Third party	DSO
	Manages intra-day energy trading at the distribution level	Third party	DSO
	Manages real-time energy trading at the distribution level	n/a	n/a
Ancillary service market	Manages services transaction mechanism	DNO	DSO
	Procure network capacity services	DNO	DSO
	Procure reactive power services	DNO	DSO
	Procure security services	DNO	DSO
	Procure frequency response services	n/a	n/a
	Procure reserve services	n/a	n/a
	Enables settlement and monitor contracted service product delivery.	DNO	DSO
Coordination	Neutrally facilitate DER participation in distribution level and national markets	DSO	DSO
	Coordinate distribution level and national energy markets	DSO	DSO
	Coordinate distribution level energy market and ancillary service market	DSO	DSO
	Coordinate distribution network operation and market operation.	DSO	DSO
	Coordinate distribution network planning and integrated network & market operation.	n/a	n/a

5.5 DSO under the Community-control Dominated structure

Under the community-control dominated industrial structure the distribution system operates essentially as a largely independent electricity system, where local DER can satisfy most local demand. The transmission connected generation supplies only a small proportion of the energy market and plays a limited role in providing capacity and ancillary services that ensure system security and reliability. Transmission connected generation is still important in maintaining system frequency and meeting potential shortfalls due to the lack of variable output from renewable generation connected to the distribution system. The bulk of energy transactions and transfers are completed locally within or across communities, and the distribution system becomes largely responsible for its own balancing, ancillary service provision, and generation capacity planning.

Under the community-control dominated industrial structure, local capacity markets replace the traditional capacity market at transmission system level and assume responsibility for ensuring the whole system energy supply security by mobilising local DERs. Highly dynamic local energy markets include day-ahead, intra-day and real-time markets that provide a playing field for DERs and customers to create a cost-efficient energy supply system. A fully functioning local ancillary services market served by a sufficiency of DERs ensures the reliability and security of electricity supply. The local frequency response market is an intermediate market, organising the market participants connected to the D level to participate in the national frequency response market. The local balancing market delivers most energy balancing actions from distributed resources, with generators connected to the transmission system contributing to this market and complementing the actions of local intermittent renewables. The corresponding local Balancing Service Use of System (BSUoS) charges would be applied to users in the balancing market, which do not exist in the central dominant and regional-control dominated market structures.



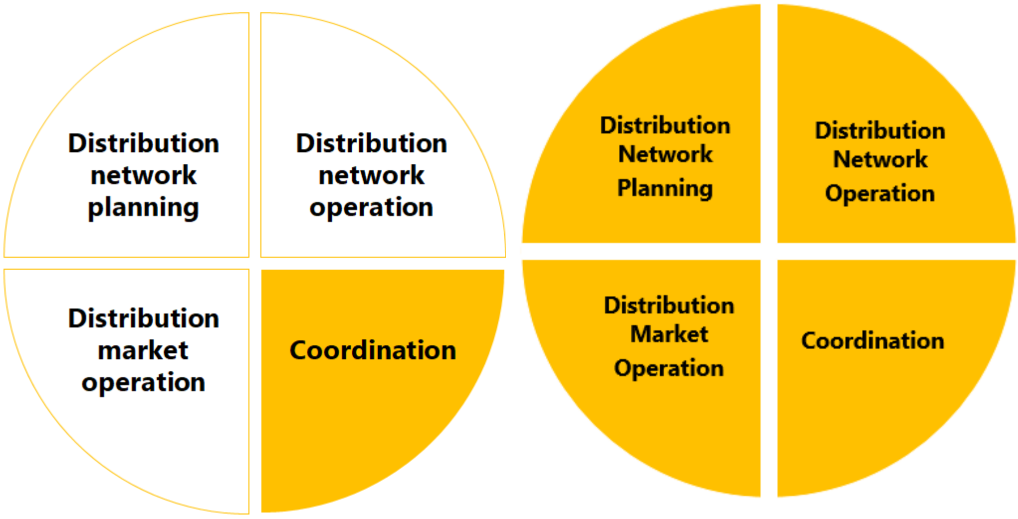


Figure 14: Minimum (left) and maximum (right) Involvement of DSO- Community-control Dominated Industrial Structure

Taking the responsibility solely for coordination, the minimum involvement of the DSO under the community-control dominated industrial structure provides neutral market facilitation and coordination. Apart from the higher market share of DER on the distribution system, and the emergence of more dynamic energy markets and various ancillary service markets, the main difference for the distribution system is that the capacity market is now entirely devolved from transmission to distribution. This indicates that the distribution system is now fully functional in ensuring the affordability, reliability and security across the whole system. As the neutral market facilitator, the DSO is responsible for providing a liberal market environment capability across all community market activities that facilitates DER participation. As markets coordinator, the DSO is required to access and coordinate market results across all markets. It would inform each market operator about potential conflicts and provide an optimal market solution for them to maximize a whole-system benefit under the operational constraints of the network.

As in the previous industrial structures the maximum DSO involvement contains four roles. The most significant distinction here is that the degree to which non-market based network operations (such as ANM) would be called upon would depend on the number of different services and the volume of trades in the ancillary services market. The market operations thus affect the type and extent of DSO network operations. In planning its network the DSO would also be able to rely on the various markets as an alternative to network investment and reinforcement, thus reducing the need to invest in network capacity. Coordination in this maximum involvement role requires the DSO to undertake wide-ranging coordination: coordinate a planning and network operations; coordinating market operation and network operation; and coordinating different markets.

Table 7: Responsibility for distribution system operation activities under community-control dominated industrial structure

	Key activities for distribution system operation	Minimum DSO involvement	Maximum DSO involvement
Network planning	Forecast long-term demand and DERs.	DNO	DSO
	Assess network investment and reinforcement	DNO	DSO
	Consider DERs contribution in capacity planning	DNO	DSO
Network operation	Forecast short-term output of DERs	DNO	DSO
	Identify network constraints	DNO	DSO
	Formulate timely restoration plans	DNO	DSO
Energy market	Manage energy transaction mechanism between communities within the distribution system.	Third party	DSO
	Enable settlement and monitor contracted energy product delivery	Third party	DSO
	Operate local balancing market to ensure whole system balancing	Third party	DSO
	Manages day-ahead energy trading at the distribution level	Third party	DSO
	Manages intra-day energy trading at the distribution level	Third party	DSO
	Manages real-time energy trading at the distribution level	Third party	DSO
Ancillary service market	Manages services transaction mechanism	DNO	DSO
	Procure network capacity services	DNO	DSO
	Procure reactive power services	DNO	DSO
	Procure security services	DNO	DSO
	Procure frequency response services	DNO	DSO
	Procure reserve services	DNO	DSO
	Enables settlement and monitor contracted service product delivery.	DNO	DSO
Coordination	Neutrally facilitate DER participation in distribution level and national markets	DSO	DSO
	Coordinate distribution level and national energy markets	DSO	DSO
	Coordinate distribution level energy market and ancillary service market	DSO	DSO
	Coordinate distribution network operation and market operation.	DSO	DSO
	Coordinate distribution network planning and integrated network & market operation.	DSO	DSO

5.6 Considerations for scope of DSO involvement

DERs penetration level and market activity are two key factors to identify the scope of distribution system operation activities required and options for how these can be delivered in different market structures as the industry evolves.

Under the centralised industrial structure, DER penetration is limited and market activities only include the day-ahead energy market and network capacity services in the ancillary market. Those emerging market operation functions and corresponding coordination functions could be delivered by extending the responsibilities of the existing DNOs. Therefore, a DSO in this market structure may be considered as an evolved DNO that takes, on a role in emerging markets to satisfy local system needs while continuing to fulfil its existing responsibility for network planning and operation. An alternative arrangement that would deliver all distribution system operation activities required at this stage of evolution would be a reduced scope DSO, responsible for solely for coordination and working alongside the existing DNO with responsibility for network planning, network operation and ancillary services market operation, and a 3rd party responsible for energy market operation.

Under the regional-control dominated industrial structure, the DER penetration is considerable and market activities become more various and dynamic. The energy market includes both day-ahead and real-time trading, meanwhile, the local balancing activity appears. For the ancillary service market, besides network capacity service, operators procure more comprehensive services in the market, e.g. reactive power service and security services. The coordination in this structure emphasises the coordination between the energy market and ancillary service market, and the coordination between the network operation and market operations since the market operations are now able to affect the network operation.

Under the community-control dominated industrial structure with a high DERs penetration, the distribution system is operated with a high degree of independence from the operation of the transmission system and market activities are highly dynamic. It is likely there would be numerous virtual or physical communities under a particular distribution network. Each community may be operated by one independent market operator although it is possible that one market operator could manage several community markets. Irrespective of how the community markets and their operation interact, the neutrality of the DSO is an essential ingredient for maintaining market competitiveness, fairness and transparency so that the market functions efficiently across all communities.

As the industry evolves from the centralised to regional to community structures, the scale and complexity of some the activities of distribution system operation increase. How responsibility for these activities should be allocated to different players is still to be determined, including whether the DSO includes traditional DNO activities (ie whether the DNO becomes the DSO) or whether the DSO operates alongside the DNO, and the role of 3rd parties in operating markets. Further work is needed to assess the impact of the penetration levels of distributed energy resources, the extent of market refinement, and structures of the distribution system and what this means it terms of the most appropriate scope of DSO as structures evolve.

6. Conclusions and Key Learnings

6.1 Conclusions

The advent of distributed energy resources and flexible loads are a driver for the development of local markets in a future distribution system. The future electricity market structure, market design and implications for the role of a DSO have been investigated and discussed in this report. The study has been conducted in three parts:

i) A new market structure at the distribution system level

A growth in DER connected to the distribution system argues for the introduction of energy and ancillary services markets at the distribution level that can optimise the use of DER, provide incentives for growth in renewable generation, and avoid costly network investment by the network operator. These could create significant value for the key stakeholders making use of the distribution system. This work presents a layered and structured diagram that summarises the functions and products of the current electricity markets, and provides a systematic foundation for investigating the impact of future market structures.

ii) Options for introducing energy markets to the distribution system

We introduced the market options suited to the characteristics of DER on a distribution system. Market options involve the trading time scale and product type. Simulation results verify that the real-time market with small time increments in its transactions outperforms the day-ahead market and intra-day market because it can obtain more accurate information about PV output. It can increase the trading volume in the local market, and lead to a rise in the average selling price of PV, whilst reducing the average purchasing price of flexible loads.

iii) A DSO's future roles and functions

The increased penetration of DER and the reform of the future electricity industrial structure will profoundly change the ways a DNO plans and operates its distribution network. This will call for a transformation of the DNO to become a DSO. The roles of the DSO under scenarios of maximum and minimum involvement in the distribution system are investigated. Minimum involvement regards DSO and DNO as separated entities and requires the DSO only to take responsibility for coordination but with different implications depending on the scale of market operations i.e. whether the markets operate at the centralised distribution level, or regional or community level. As energy market, ancillary service markets and capacity market are established at the distribution level the roles of the DSO expand to management of the various markets, and their coordination. The maximum involvement of the DSO encompasses four basic roles: network planning, network operation, market operation and coordination. The coordination expands into interactions between 1) various markets 2) network operation and market operation and 3) network planning and network operation.

6.2 Key Learnings

Three future market structures for the distribution system have been identified depending upon the extent to which DER become established. These structures are central-control dominated market structure, regional-control dominated market structure and community-control dominated structure. The proposed evolution from central-control dominated market structure to community-control dominated structure indicates an increasing independency and functionality of these distribution markets. There will need to be a greater reliance on these market arrangements to ensure affordability, reliability and security of the whole system. This will devolve the responsibility of the national markets to a local level.

The energy products traded are classified into uniform energy regardless of their reliability level and differentiated energy (i.e., energy that has different reliability levels). Real-time markets are demonstrated as offering the best option for obtaining a lower cost for flexible loads, through a larger volume of energy matched and traded locally. Options for the marketplaces for trading local energy and local ancillary services depend on the proportion and characteristic of the DERs within each distribution network. These need further investigation.

The most appropriate future role and functions of the DSO will depend upon the future market structures and will affect the role and functions of other parties too. Further work is needed to assess impact of the penetration levels of distributed energy resources, the extent of market refinement, and structures of the distribution system on the most appropriate scope of DSO under each market structure.

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