Mapping of DSO Projects

A report for the Customer-Led Distribution System Project

Professor Furong Li,

Wangwei Kong, Xinhe Yang, Chi Zhang

Dr. Ran Li

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1. Executive Summary

1.1. Background

The decarbonisation agenda has increased the penetration of low carbon technologies and distributed generation at homes and businesses, creating growing distributed energy resources (DERs) at the edge of the supply system. Through substantially enhanced operational efficiency at the distribution domain, a smart and flexible energy system can turn these DERs into highly valuable assets to improving the utilisation of distribution network and critically the utilisation of distributed energy. This requires a fundamental change to the Distribution Network Operator (DNO) dominated industrial structure to a Distribution System Operator (DSO) dominated structure.

A key step towards a smart and flexible energy system is the creation of vibrate markets at the distribution level, through which, buyers and sellers of DERs can meet at the distribution level to increase horizontal connections, enabling the existing system to absorb growing DERs whilst delivering major value for DERs. It is therefore critically important to create markets that reflect the characteristics of DERs and the needs of the customers and the grid, deliver customised energy products and services to address local energy and network needs.

In the UK, the effort in trialling commercial arrangements to mobilise DERs is largely geared for addressing differing network needs, including thermal, voltage, fault current constraints and frequency responses [1] [2] [3] [4] [5]. As the volume of DERs increase, a point will be reached where network based markets cannot absorb sufficient DERs, nor do they provide sufficient incentives for DERs to thrive and grow. It will be a necessity to introduce energy markets at the distribution level to substantially improve the utilisation of distributed generation, thus creating major value for DERs, and allowing for the existing system to connect growing DERs at substantially reduced time and cost.

There are significant developments around the UK, Europe and the USA, the purpose of this report is to review the latest development in the DSO area across the three regions, identify the key topics, commonalities and differences and inform major gaps for future innovations. We are focusing on the market operation of DSO, including local energy market and network services market. Projects largely fall into two categories, practical demonstration to test the commercial options and feasibility; and thought-leading visionary projects that focus on the conceptual roles and functions of DSO.

In this report, we reviewed 40 projects. There are 16 projects for the UK, including 8 demonstrated projects and 8 visionary projects. EU has 15 projects including 12 demonstrated projects and 3 visionary projects. For the USA, a total number of 9 projects (8 demonstrated projects and 1 visionary projects) had been investigated.

All demonstrated and visionary projects investigate DER behaviours and the system performance from different angles, it is thus essential to develop a systematic approach to be able to categorise DSO activities comprehensively. In this report, we classify the distribution network projects according to three main categories: technical solutions, commercial solutions and the coordination between them, where technical solutions are largely exercised on the distribution network, and commercial solutions are largely exercised

for energy customers. The three categories span from operation to planning time scale. The relationship across the three categories and over operational and planning time horizons is shown in Figure 1. This categorisation has also served as a vehicle to synthesis all projects, develop heat maps and identical critical gaps for the future.

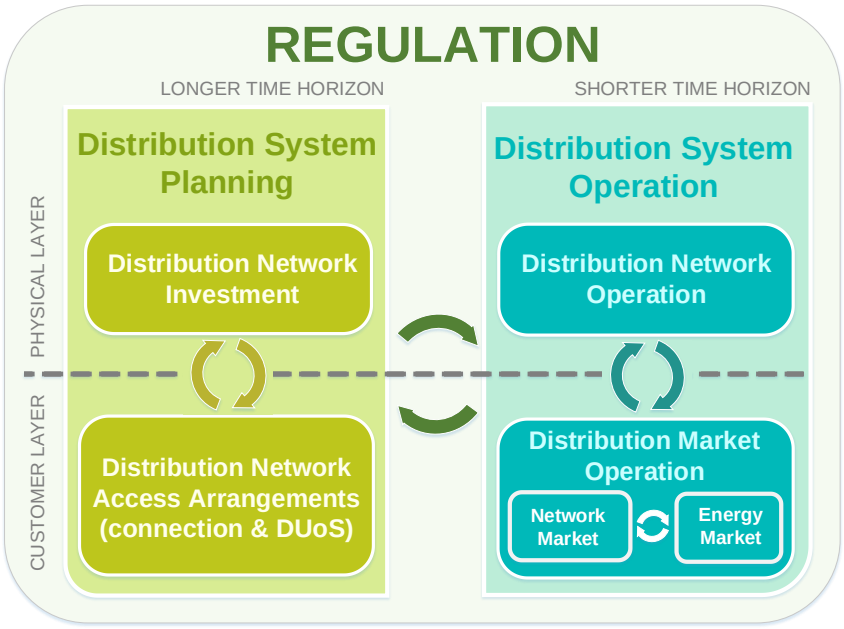


Figure 1. The structure of distribution system management

The main functions related to planning are technical investment and commercial arrangement to influence the location and operation of network users. The investment planning including both traditional and non-traditional investments, such as installing distribution automation. The commercial arrangement includes both the connection agreement and the use of system charge.

The operation consists of network operation and market operation. The network operation is mainly about the technical operation such as the control of voltage, thermal, and security. The market operation can be further classified into network market and energy market. Both markets can be operated in a distributed or centralised fashion, i.e. local market and central market. Central market is well analysed by the majority of the DSO related projects while research on the local market is still a gap to be filled.

Coordination exists among the DSO roles and functions. Four coordination are identified in our project:

- Coordination between the planning and operation;
- Coordination between investment planning and commercial arrangement;
- Coordination between distribution network operation and distribution market operation;
- Coordination between network market and energy market.

The coordination is potentially a vital responsibility of the future DSO. It is also an area of particular interest in this report.

1.2. Assessment of project outcomes

Based on the review of frameworks proposed in other projects, we for the first time define four roles for the future DSO, i.e. distribution network planning, distribution network operation, distribution market operation and coordination. Heat maps are created based on the roles and related functions of the future DSO.

The project reviews are carried out based on two main topics: local energy market and network services market.

The key review points for the local energy market are:

- How the local energy market platform is designed?
- What are the energy products and how they are traded?
- Who is the market operator and corresponding functionalities?
- Cost-benefit analysis of market participants?

The key review points for the network services market are:

- What are the market services and functions?
- How is the market designed and how to procure services?
- Who is the service provider?
- What is the result of cost-benefit analysis?
- What kind of technologies are enabled?

The majority of reviewed projects are focusing on the network services market. It is not hard to find that market for network services has reached a relatively mature level. Limited projects, mainly visionary projects, have focused on local energy markets. The design, build and demonstration of the local energy market is still a gap among the current activity.

1.3. Summary of learning synthesis

Local Energy Market

Limited projects have shown interest in local energy markets. The majority of them in this area are visionary projects, attempting to identify and define the future roles and functions DSO will serve in the markets. Within this area, we have been focused on the market design, the platform, the energy products and their commercialisation, the market operator and cost & benefit analysis.

Key Learnings

- Among the roles and functions defined, the neural market facilitator and the market operator are the most recognised ones. The roles require DSOs to facilitate the development of the local energy market, as the required capabilities can only be satisfied in the DSO position.
- Peer-to-Peer (P2P) -based and agency-based markets are the only two demonstrated market structures in the three regions. Both market structures were proved to be profitable through cost & benefit analysis.

Recommendations

- The commercialisation of the energy products, such as products standardisation, measuring, pricing and penalty require further investigation.
- The cost & benefit analysis is significant for all the market participants. It has a great impact on customer engagement, DNO/DSO revenue stream, distribution network planning and operation. Hence, a comprehensive cost & benefit analysis is required.
- A clear specified operation authority with corresponding functionalities is expected with high effectiveness and scalability.

Markets for Network Services

The majority of projects reviewed are focusing on markets for network services, focusing on the market arrangement and functions, market design and service procurement, service provider, enabling technologies and cost & benefit analysis.

Key Learnings

- Markets for network services is observed as a single-buyer-multi-seller market, as the DSO is the only entity who operates the distribution network and procures network services. Service providers are identified as residential household, distributed generations and third-party franchise.
- The well-recognised function is to offer-non-technology solutions for providing network services, enabling distributed generation, storage techniques and controllable demand through smart ICT infrastructure.
- Cost & benefit analysis was conducted in many demonstration projects. The network services, especially in terms of frequency responses at the transmission level, were proved to be profitable at present.

Recommendations

- Short-time pricing is not recommended for procuring services. The detailed network services provision issues like services measurements and penalty were not illustrated in the reviewed projects.

1.4. Conclusion

The learning from current DSO projects undoubtedly provide a better understanding of the challenges for the networks, requirements for the future DSO roles and the gap of the current projects.

A challenge is arising as the decarbonisation agenda leads to increasing penetration level of DERs. This “moving part” brings great amounts of uncertainty to the system, which makes it rather challenging to forecast both the supply and demand sides’ behaviour. The key resolution to solve this problem is to create distributed vibrate markets. It will provide horizontal connections for buyers and sellers of DERs. In this way, DERs can be absorbed at the distribution level. These distributed vibrate markets are required to reflect the characteristics of DERs and the needs of the market participants, provide customised energy and services to meet the requirements of local energy and network.

This review and synthesis project accomplishes the stage to identify the challenges, the current targeted topics and the remaining gaps and also to inform the further innovation work. In this report, we researched 40 projects that cover three different areas, i.e. UK, EU and USA. We are focusing on the market operation of DSO roles and two topics are included: local energy market and network services market.

Limited projects are focusing on the local energy market. P2P-based and agency-based are the only two demonstration market structures. Further study and demonstration on energy products commercialisation progress and its cost & benefit analysis are still necessary and essential. The majority of the projects researching in this area have been focusing on the roles and functions DSO involving, as visionary projects. The most recognised future DSO roles are the neutral market facilitator and market operator.

We observe a focus on the network services market. The main market functions are recognised as the non-technology solution for network constraints, balancing and investment, while distributed generation, storage technique and controllable demand with advanced ICT provide the possibility to this solution. Similarly, the detailed cost & benefit analysis is significant for DNO/DSO as it has a great impact on the future business model.

We observe an absence on the coordination between the energy market and network services market. The current market runs these two markets independently, which is believed as less efficient but higher-cost. The market integration between the energy market and network services market is necessary, especially at the distribution level. Looking into these two markets together will help to improve the system operation efficiency, lower consumers' costs, and most significantly, it will enable the system to integrate more DERs.

2. Introduction

2.1. Background

The decarbonisation agenda will increase the penetration of low carbon technologies and distributed generation at homes and businesses, creating growing DERs at the edge of the supply system. Through substantially enhanced operational efficiency at the distribution domain, a smart and flexible energy system can turn these DERs into highly valuable assets to increasing the utilisation of distribution network and critically the utilisation of distributed energy. This requires a fundamental change to the DNO dominated industrial structure to a DSO dominated structure.

A key step towards a smart and flexible energy system is the creation of vibrate markets at the distribution level, through which, buyers and sellers of DERs can meet at the distribution level to increase horizontal connections, enabling the existing system to absorb growing DERs whilst delivering major value for DERs. It is therefore critically important to create markets that reflect the characteristics of DERs and the needs of the customers and the grid, deliver customised energy products and services to address local energy and network needs.

In the UK, the effort in trialling commercial arrangements to mobilise DERs is largely geared for addressing differing network needs, including thermal, voltage, fault current constraints and frequency responses [1] [2] [3] [4] [5]. As the volume of DERs increase, a point will be reached where network-based markets cannot absorb sufficient DERs, nor do they provide sufficient incentives for DERs to thrive and grow. It will be a necessity to introduce energy markets at the distribution level to substantially improve the utilisation of distributed generation, thus creating major value for DERs, and allowing for the existing system to connect growing DERs at substantially reduced time and cost.

2.2. The structure of this project

The objectives of this project are to synthesis the current markets at the distribution level including network services market and energy markets, to test the new functionalities of future DSO as the key role in the market operation and network operation. Chapter 3 concludes the learnings of project framework from two comprehensive projects, develops the general framework for categorising DSO projects, and conducts the project mapping; chapter 4 provides a synthesis DSO project review on local energy markets while chapter 5 provides synthesis DSO project review on the local market for network services. Both chapters outline the reviewed projects based on regions (UK, EU and USA) and conclude with key findings at the end of each chapter; chapter 6 identifies the gap of coordination between the local energy market and services market; chapter 7 concludes the overall key learnings; chapter 8 offers the recommendations and conclusion from the perspective of our research team.

3. General Framework for Categorising DSO Projects

3.1. Framework used by Future System Architecture Project [6]

The Future Power System Architecture project [6] drew the conclusion that the 2030 power system will be sophisticated and it requires an entirely new perspective to ensure the secure and effective integration across multiple parties. The project identified thirty-five functions under a group of seven drivers:

- The enhanced need for designed-in flexibility and agility for identifying and responding to changing requirements. The power sector will need to be capable of identifying and responding to material challenges and tipping points as they emerge and new consumer behaviours
- The change in the mix of electricity generation to achieve policy targets, including the use of sources that are weather dependent or confer a low contribution to system stability compared with traditional sources. The rise in renewable electricity generation brings with it technical characteristics that, at large scales, have the potential to reduce the inherent stability and security of the national power system.
- The emerging need for aligned incentives enabling customers to benefit from responding to price signals and the system to operate more efficiently. Customers will be able to save (or earn) money and contribute to decarbonisation while keeping system balancing costs down by becoming active participants in the power sector through their responses to price or control signals, which will often be software automated.
- The emergence of new parties providing new services to customers. The emergence of smart cities, groups of technology users, aggregators and social enterprises will require new modes of interaction with the power system that reflect both the opportunities for their active participation while mitigating the risk that they may create destabilising effects.
- The requirement for active management of network, generation, demand and other services using smart network techniques. The rise of intermittent and distributed generation and new loads such as heat pumps and electric vehicles could be inhibited by network constraints or require costly upgrades unless actively managed by intelligent matching of supply, demand and network capabilities.
- The challenge of managing major events, emergencies and system recovery as the power system becomes increasingly complex and more interactive with its customers. As the power system becomes increasingly complex, decentralised and more interactive with its customers, anticipating, modelling and managing major events will become more challenging. Recovery from prolonged outages will require much more sophisticated coordination to reintroduce load and reconnect distributed generation and storage.
- The emerging need for coordination across energy vectors. A major pillar of UK decarbonisation strategy is the electrification of heat and transport. As the interactions between these markets deepen, some level of coordination will be necessary across electricity, gas, biofuels, petroleum supply and heat networks.

3.2. Framework used by Open Networks Project

The Open Network gave the definition of a DSO: 'A DSO securely operates and develops an active distribution system comprising networks, demand, generation and other flexible DER. As a neutral facilitator of an open and accessible market it will enable competitive access to markets and the optimal use of DER on distribution networks to deliver security, sustainability and affordability in support of whole system optimisation. A DSO enables customers to be both producers and consumers, enabling customer access to networks and markets, customer choice and great customer service.'

ENA also proposed eight functions (shown in Table I) for the DSO and each DSO function includes a set of activities that may be required in the future distribution system.

Table I. DSO eight functions

System Coordination	Operate local and regional areas and coordinate 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 powerflows 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 National Electricity Transmission System Operator (NETSO) 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 NETSO 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 local and regional flexible services. Provide system resilience to very 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.
Service/Market Facilitation	Interface with the NETSO and other network operators to enable the development of distribution capacity products, the creation and operation of local network service 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 Provision	Access services on behalf of others, or provide services to others, where doing so is necessary to maximise whole system efficiency, and protects competition. Use own services to manage other risks on the network and contribute to resilience.
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).

Four roles of future DSO are identified in our project, i.e., distribution network planning, distribution network operation, distribution market operation and coordination. The eight roles of DSO as shown in Table 1 can be emerged into our DSO roles to better present the future functions of DSOs. The re-grouped eight functions are shown in the Figure 2.

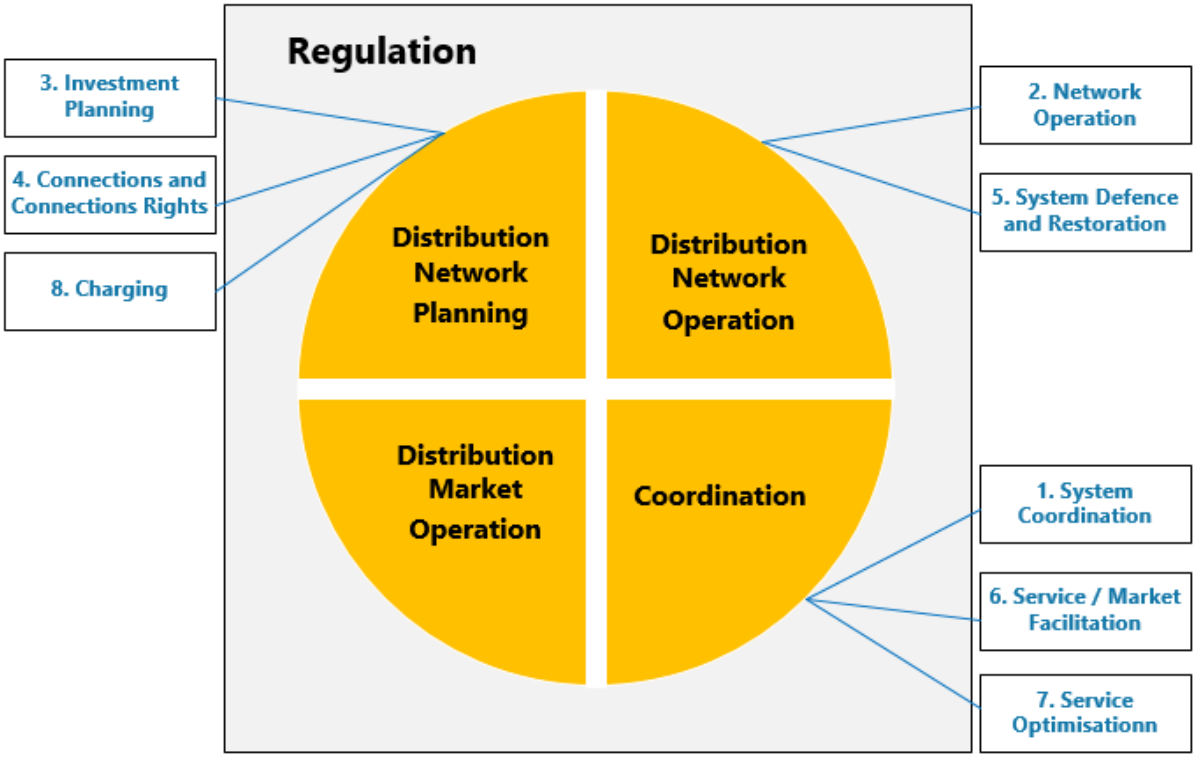


Figure 2. Re-group DSO eight functions into four DSO roles

3.3. Developing a general framework for categorising DSO projects

In order to analyse the roles and functions for the future DSO, the fundamental science of the distribution system need to be clear. The structure of the electrical distribution system which indicating both components and their interactions is shown in Figure 1. Under the guidance of the Regulation, the management of distribution system includes two parts, System Planning and System Operation. There are technical and commercial factors, or physical and customer layer, for both the System Planning and System Operation. In the System Planning, the technical factor should be explained as Investment planning which includes network planning and DER planning. The commercial factor of the System Planning mainly includes the connection planning and system charges. For the System Operation, the technical operation is the Network Operation while the commercial operation is the Market Operation.

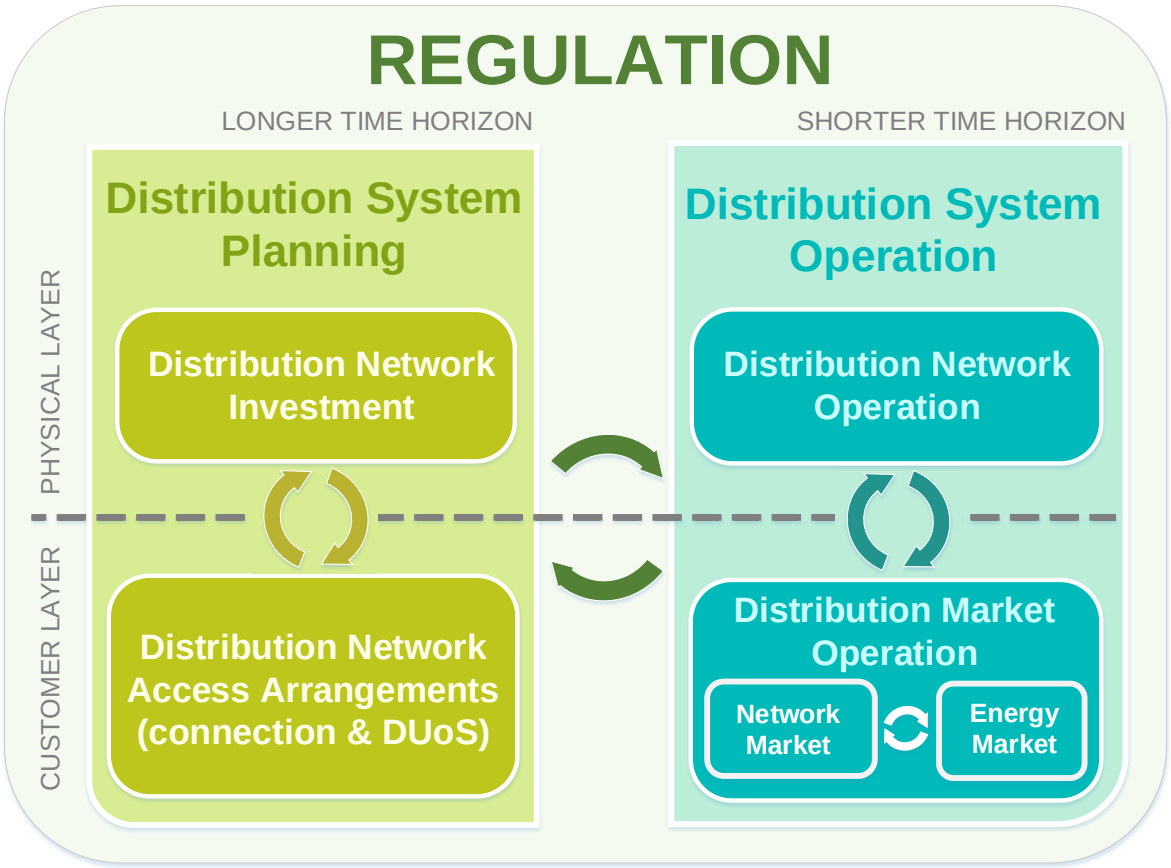


Figure 1. The structure of distribution system management

In this report, we focus on the market operation rather system planning nor network operation. Traditionally, the distribution network market merely means services market that providing ancillary services for balancing the demand and generation. With the growth of distributed generation (e.g. PV, wind) and energy storages (e.g. EVs), a new form of the electricity market is born and it is known as Energy Market. The operation and benefits energy market are discussed by many projects and documents. A major trend is to develop a P2P Market to realise local energy trading. It is worth noting that the energy market should also include central market besides the local market.

The arrows in Figure 1 represent the coordination between each two parts. The highest level of coordination is between the system planning and system operation. The next level of coordination is between the technical operation and commercial operation for both the system planning and system operation. The lowest level coordination is between the two markets of the commercial operation.

3.4. Mapping DSO projects

A total number of fifty projects were reviewed for the project mapping. Different ways of mapping were used because of the nature of the distribution system for the three regions. The heat map of UK's projects is shown in Figure 3. Four roles of future DSO were identified as: distribution network planning, distribution network operation, distribution market operation and coordination. Each role is related to several main functions.

No.	Time	Entity	Roles	Planning					Coordination	Operation								
				Distribution Network Planning						Distribution Network Operation			Coordination	Distribution Market Operation				
			Functions	Investment planning		Coordination	Commercial arrangement			Technical operation			Operation optimization	Network market		Coordination	Energy market	
			Projects	Traditional	Non-traditional		Connection agreement	UoS charge		Voltage	Thermal	Security		Local market	Central market		Local market	Central market
0	2017-2023	NPG	Customer-Led Distribution System															
1	2018-2023	SPD	Fusion															
2	2018-2020	WPD	Electricity Flexibility and Forecasting System															
3	2017-2023	ENA	Open Network Projects															
4	2017-2019	SSEN	Transition															
5	2016-2023	WPD	DSO Transition Strategy															
6	2016-2020	SPD	Evolution															
7	2016.1	SPEN	DSO vision															
8	2016	IET	Future Power System Architecture															
9	2014	UKPN	ANM Connects one of UK's Largest Solar Farms															
10	2013-2017	SPEN	Accelerating Renewable Connection															
11	2013-2015	ENWL	CLASS															
12	2012-2015	UKPN	Flexible Plug and Play															
13	2011-2016	SSEN	Northern Isles New Energy Solutions															
14	2011-2016	SSEN	New Thames Valley Vision															
15	2011-2016	WPD	SoLar Bristol															
16	2011-2015	ENWL	C2C															
17	2011-2014	UKPN	Low Carbon London															
18	2011-2013	WPD	LV Templates															
19	2010-2015	NPG	Customer-Led Network Revolution															
20	-	ENWL	The Vital Role for DNO															
21	-	NPG	ANM Development and Readiness															
22	-	SSEPD	Island DER Integration – Shetland Tidal Array															
	Heat bar																	

Figure 3. Heat map of UK's projects

It can be concluded from the heat map that current projects mainly focus on investigating the distribution network technical operation and the service market. Only 1/4 of the projects mentioned the potential of building an energy market for the distribution system and explained the benefits of the energy market. The 'coolest' areas belong to the Coordination. Two projects talked about the coordination between the network operation and market operation. Only one project touched the coordination between service market and energy market and no project made efforts on the coordination between distribution system planning and distribution system operation.

Therefore, according to the heat map, the gaps for UK's current researching area are:

- The coordination between distribution system planning and distribution system operation.
- The coordination between service market and energy market.
- The coordination between investment planning and commercial planning.
- The coordination between distribution network operation and distribution market operation.
- The building and operating of energy market, including both local and central market.

The CLDS project is listed as number zero in the heat map and it is expected to cover the majority of the gaps.

The heat map of Europe is shown in Figure 4. The horizontal direction is the key challenges the grid is facing in network services and energy aspects. The network needs can be concluded as thermal, voltage and security, while the market needs are from two scales: local and wholesale markets. The vertical direction is the DSO roles and functions in distribution network operation, distribution market operation, and collaborative operations among layers. These functions serve as the solutions to solve the challenges. As can be seen, the majority of projects are focusing on the network services. Limited projects show interests in energy market. And an absence can be observed from the heat map, as the coordination between energy market and network services market. The current market runs the energy market and the network services market independently. It is believed that this market is a less efficient but higher-cost power market. It is worthwhile looking both the energy market and the network services market together, both at transmission and distribution levels, which will improve the system operation efficiency and lower consumers' costs.

DSO Roles	Function Solutions \ Challenges		Network Services			Coordination	Energy	
			Thermal	Voltage	Security		Local	Wholesale
Distribution Network Operation	Active Network Management							
	Network Reconfiguration							
	Active Voltage Regulation							
Distribution Market Operation	Real-time operations							
	Balancing Services							
	Settlement							
Collaborative Operations among Layers	Vertical Coordination	Customer - DSO						
		DSO - TSO						
		Customer - DSO - TSO						
	Horizontal Coordination	DSO - DSO (Network & Market Balanced Operation)						
Heat Bar		0 1	2	3	4	5	6	7

Figure 4. Heat map of EU's projects

The project mapping in Figure 4 is based on the evolution of distribution system with an increasing level of DER. The vertical axis represents the technical instruments along the increasing complexity of technical operations of distribution system network, while the horizontal axis represents the commercial instruments along the increasing complexity of market operations of distribution system market, where the complexity is aligned with the DER level in the system. The mapping result indicates that most projects conduct the research in the DER services for the network (network services market), among which majority projects still focus on using basic ANM in system operation. Very limited projects have been established to discuss and demonstrate the distribution system with both local energy market and advanced ANM technologies, which highlights the leading position of the CLDS project.

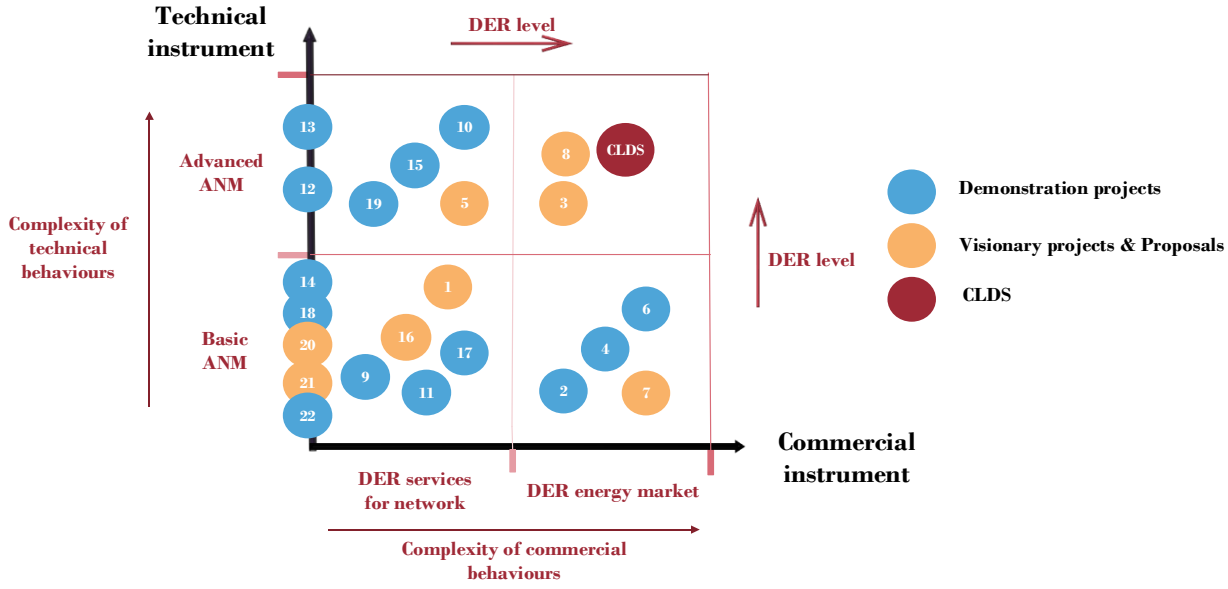


Figure 5. Heat map of USA's projects

4. DSO Project Synthesis in Local Energy Markets

Significant efforts are exercised in improving operational intelligence from the technical operation, this report fills the gap by examining key market development in the distribution sector, both from visionary documents and actual demonstration project.

4.1. Local energy market

Penetration of DER enabling the development of the distribution-level local energy market, where prosumers transformed from traditional consumers, third-party franchises and DER providers with various ownership participate to the local energy trading, The purposes of establishing the local energy market are 1) create financial benefit to all market participants 2) facilitate the integration of DER and 3) provide a non-network solution to tackle distribution network challenges under high DERs level.

Table II. The details of the reviewed projects

Review points: A Cost/benefit analysis of market participants; B Market operators and their funtionality; C Commercialization of energy products; D Local energy market design

Country	Title	Company	Budget	Duration	A	B	C	D
UK	Open Network Projects	ENA	-	2017-2023	✓	✓	✓	✓
	TRANSITION	SSEN	£14.7k	2017-2019	✓	✓	✓	✓
	DSO Transition Strategy	WPD	£125m	2016-2023	✓	✓	✓	
	Future Power System Architecture	ESC & IET	-	2016		✓		
	EVOLUTION	SPD	£6.8m	2016-2020		✓	✓	✓
EU	EvolvDSO	-	€7.9m	2013-2016			✓	
	EDSO	-	-	-			✓	
	CEER	-	-	-			✓	
	P2P-SmartTest	-	€3.9m	2015-2017	✓	✓		✓
USA	Distribution System in a High Distributed Energy Resources Future	-	-	2015	✓	✓	✓	
	CenHub Marketplace	Central Hudson	-	2015	✓		✓	
	CONnectED Homes Platform	ConEdison	-	2015	✓		✓	✓

Each project is introduced by basic description outcomes (if applicable), and followed by key learnings based on four review points. The projects reviewed in this chapter is shown in Table II, where the green shaded means visionary projects.

4.2. Local energy market projects (visionary and demonstration)

4.2.1 Local energy market in the UK

4.2.1.1 Visionary projects

1） Open Networks Project – ENA **[1]**

The Open Networks Project will transform energy networks to support the delivery of the smart grid where all the participants can benefit from competition in the market and reduce energy cost. The project will enable UK's traditional passive local distribution network to change to an active smart platform where new energy technologies can generate energy as well as consume. New services and interactions with other networks will be required since

the local network is going to manage more active generators and consumers. The potential benefits including but not limited to decreasing costs of running the network, providing competition in energy markets and ensuring an intelligent and efficient operation environmental for energy networks.

The project outcomes are introduced:

- Renewable energy generates electricity at different times of day and under different weather conditions. These changes will mean we will be able to store and use more electricity locally in batteries. It will also mean that network companies can connect new technologies more cheaply, by avoiding having to pay to reinforce the grid for example.
- Electric vehicles will not just be re-charged from the network but they will feed electricity back into it. New technology will make it easier for people to buy and sell electricity to and from the grid and businesses will have the chance to take advantage of new services that will help them use energy more intelligently too.
- Our local electricity networks will become a platform that enables the development of new markets for new products, technologies and services across the country that will enable households and businesses greater control over their electricity use by working with service providers to allow that to happen.
- Their relationship with the national transmission network will change, as the lines and responsibilities between local and national networks become more blurred. This Project is about defining that interaction and those responsibilities.

Key learnings:

- This project set a broad vision of DSO mainly focusing on the roles and functions of DSO in future energy network. While in the local energy market, this project specifies that DSO should be equipped with functions of DER investment planning, connection, service/market facilitation, service provision and charging.
- Local electricity network is expected to become a platform to enable the development of new markets for energy products.
- The detail discussion of the local energy market design, product trading, the actual market operator and cost-benefit analysis of various entities have not been mentioned.

2） TRANSITION—SSEN [2]

The objective of TRANSITION is to design, develop and demonstrate a Neutral Market Facilitator Platform to test the operation of the market models being produced by the Open Networks Project. The Platform will enable the transition from DNO to DSO.

TRANSITION aims to:

- accelerate and de-risk the transition from DNO to DSO, reducing uncertainty for customers and industry;
- provide a clear signal to the market that a new platform (or platforms) for market development will be in place and enable the growth of new potentially disruptive market models, products and services;

- inform the appropriateness of competency assumptions for different DSO functions over various timescales;
- develop and demonstrate an NMF Platform including enabling infrastructure, data exchanges and commercial arrangements;
- demonstrate and test potential solutions to inform further development of Open Networks market model options;
- identify cost, risk, and benefits of the market models proposed; and
- consult with a range of stakeholders to ensure the analysis is undertaken from a whole-system perspective.

Key learnings:

- This visionary project defines the role of DSO as a neutral market facilitator and discusses the detailed capabilities, which can be regarded as the prerequisites for DSO to enable the local energy market.
- The local energy market design, commercialisation, market operator definition and participants' business model have not been specified.

3）DSO Transition Strategy—WPD [7]

The DSO transition aims to support the increase of distributed generation to join in the distribution network. The improved functions of DSO will ensure the customers' benefits while providing simple and consistent access to the new markets. A localised visibility platform will be created to show the capacity on the network to support the development of a local energy market. WPD is also committed to providing level playing field access to all customers within territory region so they can participate in energy markets at both the transmission and distribution levels. The DSO will develop flexibility products which customers with controllable demand or generation will be able to provide services. These are likely to be reserve services for real power or voltage control.

Project outcomes:

The functions of DSO that indicated by WPD are:

- develop and maintain an efficient, co-ordinated and economical system of electricity distribution;
- facilitate competition in electricity supply, electricity generation and flexibility services;
- improve the resilience and security of the electricity system at a local level;
- facilitate neutral markets for more efficient whole system outcomes;
- drive competition and efficiency across all aspects of the system; and
- promote innovation, flexibility and non-network solutions.

Key learnings:

- In this project, both local energy market and operational market are discussed, and corresponding roles and functionalities of DSO to ensure new markets are indicated.

- For the local energy market, customers with controllable demand and generation are considered as seller providing reserve services for real power to DSO, while the market operators and trading mechanism have not been studied.
- The cost-benefit analysis of customers is committed but no evidence has supported it yet.

4） Future Power System Architecture [6]

The FPSA project was commissioned by DECC to assist ministers, officials and industry professionals to anticipate these developments and to assess their significance. The project uses systems engineering techniques to examine credible evolutionary pathways and new functionality required. The FPSA project thinks that future power system should be able to provide automated and secure management of demand, generation and other offered energy resources and auxiliary services, including smart appliances, and building and home energy management systems.

Project outcome:

The project has identified thirty-five new or significantly modified functions required to meet 2030 power system objectives. These functions are grouped under seven drivers:

- The flexibility to meet changing but uncertain requirements
- The change in the mix of electricity generation
- The use of incentives to enable customers to benefit and the system to operate more efficiently.
- The emergence of new parties providing new services to customers.
- The active management of networks, generation, storage and demand.
- The recovery from major events or emergencies.
- The emerging need for coordination across energy vectors

Key learnings:

- This project is basically a guideline of the transition to the future power system. Rather than focusing on the distribution system and local energy market, this project use system engineering approach to examine the evolutionary pathways and functionalities of the entire power system, including the context that drive the development of local energy market.
- The detail market design and mechanism are not introduced.

4.2.1.2 Demonstration projects

1） Evolution --SPD [3]

EVOLUTION will end in 2020 and it aims to deliver the UK's first trial of the DSO concept: demonstrating how operating a localised balancing market can reduce customer bills through efficient provision of services and optimised network performance while facilitating cost effective growth in local generation, demand side response and energy storage services. This project will open the balancing market which creates opportunities for more participants as well as reducing system operation costs.

EVOLUTION will improve visibility and controllability to the SO by democratising the balancing services market to a wider group of consumer participants and DER developers. By introducing a neutral market facilitator, a DSO, the cost of Balancing Mechanism participation will be reduced opening the market and local grid management challenges on the distribution network, including the interaction which Active Network Management (ANM) and non-firm connections can be addressed.

Project outcomes:

EVOLUTION will open the balancing market and its income opportunities to significantly more participants whilst reducing system operation costs. The objective of EVOLUTION is to successfully demonstrate how the use of a DSO, as a neutral market facilitator for DER can:

- Offer market access to currently locked out consumers
- Improve overall visibility and control for system operation; and
- Reduce system operation costs throughout GB

Key learnings:

- This project is aiming to evolve DSO into a neutral market facilitator to facilitate the local balancing market which is required by the increasing number of distributed generation. New relationships with customers and TSO will be developed both technically and commercially for the SPD.
- In this project, the marketplace is a novel local balancing market, where DGs, DSR and energy storage are the main resources to provide balancing services.
- DSO is designed as the market operator and responsible for neutral market facilitation.
- Cost and benefit analysis results of local balancing market, which is important to demonstrate the feasibility of the market, are still in progress.

4.2.2 Energy market in EU

4.2.2.1 Visionary project

1） EvolvDSO [8]

EvolvDSO project aims to develop methodologies and tools for new and evolving DSO roles for exploiting the potential of DRES integration in distribution networks. EvolvDSO defined the roles of DSOs based on various future scenarios regarding different DRES penetration levels and technological degrees of freedom. The new tools and methods will encompass a wide array of DSO activities related to planning, operational scheduling, real-time operations and maintenance.

Project outcomes:

Seven roles for future DSO have been identified as followings:

- Distribution Constraints Market Officer: The goal of this role is to select, contract and activate flexibilities that may be used by the Distribution System Optimiser in case of local constraints.

- Neutral Market Facilitator: Administrates the exchange of market information and validates the market participation of market participants from a technical perspective in established[8] markets. Literature has stressed the importance of the neutrality of DSOs during this transition of roles and responsibilities.
- Contributor to System Security: responsible for the exchange of structural data and forecasts along with the TSO. It also manages the operational planning contracts.
- Distribution System Optimiser: Improves the development, operation, and maintenance of the distribution network by managing network constraints, including emergency situations and faults emerging on the distribution network, in a cost-efficient and non-discriminatory manner.
- Data Manager: Ensures metered, network and contractual data procurement, management, and transmission. The role receives, aggregates, validates, processes, analyses, archives and provides data in a cost-efficient and secure way. Also called Information Hub.
- Smart Meter Operator: Defines a clear set of responsibilities to ensure that the implementation, operation, maintenance and decommissioning of the smart meter infrastructure is done in a cost-efficient manner.
- Customer and Other 3rd Parties Relationship Manager: Manages the various contracts and requirements at the distribution system level. Interacts with regulators, authorities and service providers.

Key learnings:

- This visionary project develops methodologies and tools for new and evolving DSO roles, and the specified roles such as neutral market facilitator, data manager and customer and other 3rd parties relationship manager are closed to the expected role of local energy market operator, although there is no clear evidence showing that the DSO will be responsible for local energy market operation.

2） European Distribution System Operators for Smart Grids (EDSO) [9]9]

EDSO suggests 5 priorities for Europe's Grids regarding all the functions DSO expected to serve:

- Engage the customers: Customers acceptance of new technologies towards network management is the key. This will not be possible unless clear financial benefits are offered. As neutral and regulated parties, DSOs are uniquely placed to harness and administer customer data while preserving their privacy and security
- Incentivise Innovation: New ICT tools and smart grids solutions. The current regulation only physically reinforcing the grids. It is no longer fit to deliver on the innovation pace needed. Regulation must enable and encourage DSOs to invest in new ICT tools and smart grids solutions.
- Encourage Active Grid Management: DSO should be allowed to get full access to flexibility services. Enabling the transition to more actively managed local networks should become a policy priority. Regulation should allow DSOs to make use of flexibility services from both local flexibility markets and/or via direct contracts with customers.
- Ensure Fair Allocation of Network Costs: More capacity-based, fair and cost-reflective. Distribution network tariffs should become more capacity-based, ensuring that all grid

users pay fair and cost-reflective rates. Also, DSO regulation should move away from the separate treatment of operating and capital expenditure.

- Strengthen DSO – TSO Cooperation: Related to data, Grid planning and the use of flexibility. Smarter grids require closer cooperation between distribution and transmission at all levels. DSOs should be placed on an equal footing with the TSOs, handling common topics related to data, grid planning and the use of flexibility.

Key learnings

- This project defines priorities for Europe's Grids regarding all the functions that DSO is expected to serve, among which the customer engagement, DSO accessibility to DER services and fair allocation of network cost are key criteria to develop a local energy market.
- The rest of the project content does not introduce the information about market design and trading mechanism.

3） Council of European Energy Regulators (CEER) [10]

There are differences in the number, size and activity profiles of DSOs as well as in the technical nature of distribution networks in Member States. Given this, CEER has concluded that there should be four overriding principles for DSOs. These were largely supported by respondents to the consultation. CEER members will apply these principles in regulating DSOs:

- DSOs must run their businesses in a way which reflects the reasonable expectations of network users and other stakeholders, including new entrants and new business;
- DSOs must act as neutral market facilitators in undertaking core functions;
- DSOs must act in the public interest, taking account of the costs and benefits of different activities;
- Consumers own their data and that this should be safeguarded by DSOs when handling data.

Key learnings:

- This project concludes several overriding principle for DSOs, which comprises the functions that DSO should adopt in the local energy market such as neutral market facilitation, data analysis and cost-benefit analysis of market activities.
- The concrete context about local energy market is barely found.

4.2.2.2 Demonstration projects

1) P2P-SmartTest [11]

P2P-SmartTest project aims to demonstrate a smarter electricity distribution system integrated with advanced ICT, regional markets and innovative business models. It will employ P2P approaches to explore the potential of demand side flexibility and operation of DER and other resources, maintaining power balance, quality and security.

The project includes four demonstration pilots in Spain, Belgium, UK and Finland. The major objective of the test beds is to assess the P2P energy trading scenarios, testing the P2P

platform, evaluating the feasibility of the aggregator algorithm. The project budget is €23,496,142, with €3,496,142 EU contribution.

Project outcomes:

- A P2P trading mechanism is proposed in the project and its impact on smart grid and ICT infrastructures is examined.
- On the smart grid side, the upgrade to a P2P trading environment affects the operation on distribution level greatly and the system will need to be smarter in local levels.
- On the ICT side, obtaining reliable and accurate data is significant to support P2P functionalities.
- The benefits of the proposed P2P platform is quantified as annual savings within the range of 20 -30 € for per member, with only boiler heating optimisation and 30-40 € savings with joint optimisation of boiler heating and wind production. The results show the P2P energy trading is able to balance local demand and generation.
- For the DSO SNA business model, the results show that for the higher security of supply situations, SNA is able to provide more substantial financial rewards to existing DSO entities. Thus affirming the practicalities of the developed SNA business model over current methods in the real-world environment.
- Key learnings:
- This project demonstrated a local energy market in the P2P trading mechanism to promote local generation-demand match up and power quality.
- Demand side flexibility services and DERs operation are taken as energy products offer in the energy market.
- There is no specified market operator in this project, while the main functionality of the operator are souring the information and execute purchase based on bid-offer information.
- Conducted cost and benefit analysis shows evidence of a feasible implementation of the market platform.

4.2.3 Energy market in USA

4.2.3.1 Visionary projects

1) Distribution system in a high distributed energy resources future [12]

Funded by the U.S. Department of Energy (DOE), Berkley Lab launched a visionary study titled as distribution system in a high DER future. The study firstly provided a three-stage framework of the potential evolution of the distribution system based on the extent of DER expansion driven by policy decisions, technology advancements and end-user choices. The DSO development criteria were then derived to evaluate the distribution system development at each stage. Referenced the bulk power system and wholesale market operation, three distribution system operational models were introduced, following by a detailed discussion of evolving distribution system functions of potential models and the evaluation of operational differences in jurisdiction with different policy objectives.

Berkley Lab combined the three-stage evolution and aforementioned evaluation approach to 1) clarify the existing roles and responsibilities of DNOs, suggest potential pathways for the

roles for DSOs; 2) discuss the natural property of future DSO, access the pros and cons of an independent DSO against a distribution utility based DSO.

Project outcomes:

- Distribution energy market is identified in stage 3 where the demand side adopted a high level of DER and multi-party transactions and market operations adopted by the distribution system. This requires regulators to institute changes to allow retail energy transaction across the distribution system, including transactions that are still within a local distribution area (LDA) defined by single T-D interface substation, thus not relying on transmission service.
- Enabling a multi-side market will also require a formal distribution–level market structure to facilitate P2P energy transactions such as an organised residual energy spot market. In addition to local markets within each LDA, end-users may want to transact between LDA using both transmission system and distribution system, which requires coordination between DSOs and TSOs at T-D interfaces.
- At stage 3, the DSO role should evolve to include additional market facilitation services such as financial clearing and settlement.

Key learnings:

- This project proposes a three-stage distribution system evolution map and three potential DSO models. The local energy market is defined to be located at stage three where high DER integration and customer adoption occurs and the market DSO model is adopted.
- P2P residual energy spot market is recommended in the project meanwhile DSO is fully charging of operation of local energy market with the functions including sourcing distributed grid services, optimally dispatch DER provided services and products, creation and operation of local energy market, transaction among DER, and clearing and settlement for the inter-DER transaction.
- However there is no direct discussion about energy product commercialisation and cost-benefit analysis for market participants.

4.2.3.2 Demonstration projects

1) CenHub Marketplace [13]

This project collaborates with the third-party partners to create an engaging, customer driven, web-based, energy exchange of energy products and services that available to customers. For the demonstrated energy exchange, the main functionalities are sourcing the customer and product provider information, comparing and executing the purchase of energy products and services. The exchange recommends a ranked list of customer-personalised energy products and services by analysing the customers' home energy usage data, and conduct the final match-up transaction under customer choices. 7.16% of customers who enter the platform from a link on the utility's website complete their purchase. The product sales in the platform are $41812 at 1st year and estimated to $112.834 at the 8th.

Key learnings:

- In this project, local energy market is designed as a web-based energy exchange agency, the DNO and a third-party enterprise cooperatively operate the market where DNO is responsible for users' data analytics and the third-party enterprise is responsible for the trading transaction.
- Within the marketplace, third party DER providers are the seller while traditional end users participate in the market only as the buyer.
- Cost and benefit analysis has been conducted to demonstrate a profitable market establishment.

2) CONnectED Homes Platform [14, 15]

This project demonstrated a software-based home energy platform for customers' better connection with cost-effective energy efficiency products and services and distributed generation offerings. The local energy market is regarded as a solution to adopt DER.

In additional to being an energy trading platform, local energy market should be equipped with the function that offers personalised energy products and services to customers by advanced data analysis and matches up high quality DER vendors to targeted customers. DSO is in the position that promotes cost-effective energy efficiency products and services at the top of the marketing funnel, where customers look to DSO for advice and information about energy management decision.

Project outcomes:

The Project launched in Q2 2016 to approximately 275,000 customers in Con Edison's Brooklyn and Westchester territories. Customers have access to detailed energy insights online and have received targeted offers in their Home Energy Reports and High Usage Alerts for solar panels, Wi-Fi thermostats, Sealed home services, and the Con Edison Marketplace, as eligible.

Key learnings:

- This project is similar to CenHub Marketplace project, where a software-based energy trading platform is designed. While DNO is the sole operator of market operator here and responsible for users' data analytics, matching up demand and energy products and execute the purchase.
- However there is no clear evidence showing the detail of the energy products exchanged in the market and cost and benefit analysis.

4.3 Discussion and learning

Regional learnings:

In the UK, there are four visionary projects and one demonstrated project conducting research about the local energy market. The related review points were shown in the table at the beginning of the chapter. The energy products were mentioned by all the projects and they appeared to be very similar, i.e. DER, mainly PV, energy storage and EVs, from individual customers in the distribution network. The platform for the local energy market that proposed by the projects are different, Open Networks Project and the DSO Transition

Strategy both aim to create the platform based on the original local electricity network while the TRANSITION project will design a new Neutral Market Facilitator Platform for developing the roles and market rules for the P2P trading. All the projects except the Future Power System Architecture explained that the future DSO would be the future local energy market operator to ensure the market operation and maintenance. As for the Cost-benefit analysis, ENA indicated that the UK could deliver £17-40bn of benefits across the energy system by 2050. SSEN reported that their potential of benefits to be delivered could reach up to £292m for network customers by 2050. All of UK's visionary projects are mainly at the starting point which means the detailed design of the local energy market is still not clear. The actual Cost-benefits analysis can only be accessed after the projects are done. The EVOLUTION project is not building a local energy market, it will open a balancing market which can promote the operation of the energy market. Therefore, it can be seen that the demonstrated project for building a local energy market is still a gap in the UK.

In Europe, limited projects have been focused on the DSOs roles and functions in the local energy market. Some of the organisations and regulators provide guidance and principles for the DSO's transition period. Among them, the most significant change for DSOs is that they are taking the role of market facilitator alongside their traditional role of network service provider. One demonstration project, P2P-SmartTest demonstrated a smarter electricity distribution system, employing P2P approaches to explore the demand side flexibility and optimal operation DER (PV generation). The results of the model have shown economic benefits to consumers and other market participants.

In USA, three projects have studied the local energy market from different aspects. Visionary project from Berkey Lab indicates that DSO should be the local market operator in the local energy market and specifies various functionalities. Two demonstration projects focus on establishing local energy trading platform, and discuss the operational authority of the market platform, where both projects demonstrate the web-based market platform similar to the exchange agency while the operational authority diversifies from DNO operated to DNO-third party operated. Cost-benefit analysis of market operator has been conducted which indicates the market demonstration is profitable.

Synthesis learnings:

Local energy market design has been researched by limited projects in three regions. P2P-based and agency-based market structure are only two currently demonstrated market structures. While the energy products commercialisation progress such as products standardisation, measuring, pricing and penalty has not been illustrated clearly.

Most projects define the new roles and functionalities of DSO in the local energy market, parts of new roles and functionalities require DSOs to enable and facilitate the development of local energy market, the rest roles and functionalities directly indicate that DSO should be the market operator due to that the required capabilities of operating local energy market can be only met in the DSO position. One unique project offers a DSO-third party operated local market demonstration, which indicates the potential of further exploration of market operation authority.

The cost-benefit analysis for customers and market operators are individually conducted by various projects. The analysis is expected to have a critical influence on customer engagement, DNO/DSO revenue stream and distribution network planning & operation. Thus the cost & benefit analysis across entire local energy market including market operators, energy providers and customers need to be discussed and demonstrated comprehensively in reviewed projects.

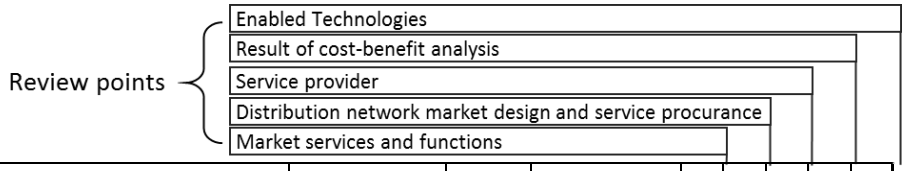
Overall, a local energy market with 1) effective market design: 2) technical and economic neutral commercialisation process; 3) clear specified operation authority with corresponding functionalities; 4) comprehensive cost & benefit analysis is required to be well developed and demonstrated.

5. DSO Project Synthesis in Distribution Market for Network Services

5.1. Network services

Ancillary services are usually proved to the DSO to ensure that generation matches the demand in the distribution network [16]. Traditionally, the ancillary services are provided by central generation from the transmission network. However, as the increasing of DER, the services can now be provided from the distribution network. This is also known as the demand side response (DSR) which is beneficial to both the network and consumers. This section introduces the projects that are researching on the Distribution Network Services Market. Each reviewed project is given a brief introduction with the key learning(s) listed. Discussions that considers five review points are shown at the end of the chapter.

Table III. The details of the reviewed projects



Country	Title	Company	Budget	Duration	F	G	H	I	J
UK	Open Network Projects	ENA	-	2017-2023	✓			✓	
	DSO Transition Strategy	WPD	£125m	2016-2023	✓	✓	✓	✓	
	C2C	ENWL	£1.6m	2011-2015		✓	✓	✓	✓
	The Vital Role for DNO	ENWL	-	-			✓		
	DSO vision	SPEN	-	2016.1	✓		✓		✓
	ANM Connects one of UK's Largest Solar Farms	UKPN	-	2014					✓
	Fusion	SPD	£7.1m	2018-2023	✓	✓	✓	✓	
	New Thames Valley Vision	SSEN	£30m	2011-2016			✓	✓	✓
	Electricity Flexibility and Forecasting System	WPD	£4.3m	2018-2020	✓		✓	✓	✓
	SoLar Bristol	WPD	-	2011-2016	✓		✓		✓
	LV Templates	WPD	-	2011-2013	✓				
	CLASS	ENWL	-	2013-2015	✓		✓	✓	✓
	Customer-Led Network Revolution	NPG	£31m	2010-2015	✓	✓	✓	✓	✓
EU	EvolvDSO	-	€7.9m	2013-2016	✓	✓	✓		
	EDSO	-	-	-		✓			✓
	EcoGrid	-	€21m	2011-2014	✓	✓			
	GRID4EU	-	€55m	2009-2014	✓		✓		✓
	SENSIBLE	-	-	-	✓		✓	✓	✓
	FLEXICIENCY	-	€19.1m	2015-2019	✓	✓	✓	✓	
	SmarterEMC2	-	€13.9m	2015-2017	✓		✓		✓
	SINCRO GRID	-	-	-	✓				✓
	DREAM	-	-	2013-2016	✓	✓	✓		
	RealValue	-	€15.5m	2012-2015	✓				✓
	UPGRID	-	€15.7m	2015-2017	✓	✓	✓		
	REsericeS	-	-	2012-2014	✓				
	SmartNet	-	€12.7m	2016-2018	✓	✓	✓		
USA	Distribution system in a high distributed energy resources future	-	-	2015	✓	✓	✓		
	Fruit Belt Neighborhood Solar	NG	-	2015.8-2017.8	✓		✓	✓	✓
	BNMC Distrbuted System Platform	NG	-	2016-	✓		✓		✓
	Resiliency Demonstration Potsdam	NG	-	2015.7-2017.6	✓		✓		
	Clean Virtual Power Plant	ConEdison	-	2015.6-	✓	✓	✓		✓
	Flexible Interconnect Capacity Solution	NYSEG & RG&E	-	2016.6-2018.4	✓	✓	✓	✓	✓

Each project is introduced by basic description outcomes (if applicable), and followed by key learnings based on four review points. The projects reviewed in this chapter is shown in Table III, where the green shaded means visionary projects.

5.2. Project details

5.2.1 Distribution network services market in UK

5.2.1.1 Visionary projects

1) Open network projects – ENA [1]

The project was described in the previous chapter.

One of the DSO's eight functions is the Service/Market Facilitation. It is indicated that DSO will need to interface with other network operators to enable the development of distribution capacity products, the creation and operation of local network service 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.

Another important function is named Service Provision. This functions is explained as accessing services on behalf of others, or providing services to others, where doing so is necessary to maximise whole system efficiency, and protects competition. Use own services to manage other risks on the network and contribute to resilience.

2) DSO Transition Strategy—WPD [7]

The project is described in the previous section. WPD proposed three market models based on the current model. The four models are defined as:

- Current model is applicable when the distribution network constraints and services have few or even no conflicts in between.
- The GBSO led market model is improved from the current model by enabling all commercial services to be realised using existing mechanism.
- The co-ordinated market model is a sharing procurement model for GBSO and DSOs. To ensure the efficient operation of this model, the market design becomes complicated and the visibility of operations need to be effective.
- The DSO-led market model changes the hierarchy of the commercial frameworks and allows the DSO to coordinate the prioritisation of flexibility services with respect to the constraints on the distribution network.

3) C2C, The Vital Role for DNO – ENW [17]

The C2C project tested and trialled a combination of enhanced automation technology, non-conventional network operational practices, and commercial DSR contracts alongside customer acceptance to such changes.

Key learnings:

- The customer engagement work has shown that there is an appetite in the I&C market for C2C
- The research indicated that contracts would need to be carefully tailored to the needs of individual customers, with a range of customisable contract elements offered to make them as attractive as possible.
- Analysis indicated that an increase in financial reward outweighs all other factors particularly the inconvenience of longer durations. It also proved that increasing the level of payment increases take up by 0.3% for every 1% increase in payment.
- DNO direct engagement was clearly demonstrated as the most effective route to market offering a significantly higher sign-up rate and lower contract cost. In addition, customers valued the strong ongoing relationship with the DNO which reinforced confidence in the Method.

The Vital Role for DNO document suggested that DNOs have a unique role to play as both enablers and participants in creating open markets which enable early adoption and implementation of new technologies and commercial opportunities. DSO will potentially provide services to National Grid to balance the national system and also to network users who may require additional, value adding but non-essential services.

4) DSO vision—SPEN [4]

The DSO vision explained SPEN's view on transition from current DNO role to a full DSO role. The full DSO role is expected to facilitate an open and inclusive balancing services market at the T/D interface. The DSO will also carry out local system balancing, efficiently utilising the Distribution network. SPEN will continue to improve the level of customer service and manage system security in line with their current role as a DNO. The DSO vision project is to ensure that the expansion of DNO to DSO continues to deliver value for money to customers.

Key learnings:

The DSO is then able to use these to:

- reduce network reinforcement
- provide flexibility
- offer balancing services
- provide ancillary services
- encourage demand to match generation

5) ANM Development and Readiness – NPG [18]

The project achieved the goals in both gaining knowledges about ANM, and the implementation of ANM connection solutions. The ANM solution protects the network operating limits from being exceeded by controlling the connection new generation.

5.2.1.2 Demonstration projects

1) FUSION – SPD [19]

The FUSION project demonstrated commoditised local demand side flexibility through a structure market-based framework to address local and national electrical network congestion:

- inform innovative commercial tools to meet evolving customer needs associated with LCT uptake and new connections;
- enable efficiencies from deferred network reinforcement and accelerated customer connections.

FUSION seeks to implement a local competitive, open and structured flexibility market in East Fife, Scotland, as a network management tool to mitigate local network constraints and complement national balancing requirements within the existing regulatory framework. FUSION will develop, implement, and trial the application of the Universal Smart Energy Framework (USEF), and will inform wider policy development around flexibility markets and transition to DSOs through the development of standardised industry specifications, processes, and requirements for transparent information exchange between market participants accessing market-based demand side flexibility.

Key learnings:

FUSION aims to achieve the following objectives:

- Evaluate the feasibility, costs and benefits of implementing a common flexibility market framework based on the open USEF model to manage local distribution network constraints and support wider national network balancing requirements.
- Investigate a range of commercial mechanisms to encourage flexibility from energy consumers' use of multi-vector electrical applications in satisfying overall energy use. Explore the potential for localised demand side flexibility utilisation to accelerate new demand connections to the network that otherwise would require traditional reinforcement.

2) New Thames Valley Vision –SSEN [20]

The NTTV project focused on the Low Voltage (LV) network with the aim to demonstrate how electricity distribution networks can better serve their customers by understanding, anticipating and supporting energy use.

Key learnings:

- The NTVV Project developed and trialled technical solutions, commercial agreements and procedures for network planning and operation. The capabilities on monitoring, modelling and forecasting were developed from this project to better understand the network usage and make decisions on future investments.

3) Electricity Flexibility and Forecasting System, SoLaBRISTOL, LV Network templates – WPD [21] [22] [23]

The Electricity Flexibility and Forecasting System project explores and trials the new system functionality required for DNO transition to DSO, as outlined by the Open Network Projects. The project aims to deliver a practical robust and accurate system capability to ensure DNO can manage the provision of flexibility services that are required for the transition. EFFS will provide a coordination interface to GBSO and enables the configuration and utilisation of multiple different types of optimised distribution orientated services and could potentially allow for wider participation in the balancing market.

Key learnings:

- The benefit of the project will be an available flexibility management system, capable of harnessing multiple services and providing DNOs with the ability to actively manage their networks. This capability will enable the deferment of traditional reinforcement, allowing the use of flexibility in fault restoration and enabling power supplies to be restored more quickly. It will help reduce national balancing costs by managing conflicts with the TSO and will reduce the time necessary to connect new renewable sources of energy to the network.

The SoLa BRISTOL project utilises energy storage technology with variable tariffs and integrated network control to overcome supply and demand limitations at different times of the day. It has utilised direct current in customer premises while having DNO and customers virtually sharing battery storage; this has been proven to benefit both parties.

Key learnings:

- A clear specification is critical and one which identifies a clear lead for each aspect of the project. This encourages ownership and allows for appropriate time and workload to be managed
- Contracts need to include some flexibility for unexpected tasks that emerge during the project lifecycle
- Understanding the type of relationship between partners is vital for project success
- All project members must understand the project and that understanding is not assumed.
- Customer engagement projects do require significant resources.

The LV Network Templates project developed a simple method which allows network planners to accurately estimate the load and voltage at any substation without costly monitoring. The novel “templates” that developed by WPD can give accurate estimations of the types of load and associated voltage profiles at a given substation without the need for costly monitoring.

Key learnings:

- Ten distinct LV Network Templates were successfully identified. These were then assessed for their suitability to incorporate various low carbon technologies
- Analysis of actual LV connected PV installations identified an additional 20% headroom on the existing network, for future connections.
- Voltage tolerance was shown to be within current limits, with greater number above the nominal level than below, thus affording the ability to reduce target voltages at HV,

providing demand and CO2 reduction, savings in customer bills, and additional voltage headroom for LV Distributed Generation

4) CLASS – ENW [24]

The CLASS project proposed a solution that manages peak electricity consumption by controlling voltage with low cost. It was reported that there is a potential to unlock up to 3.3GW of demand response. The results have shown that there are possibilities to enter the frequency and enhanced reactive power markets, prove an alternative, low cost, carbon saving and flexible solution to NG for ancillary services when compared to the existing costly and carbon intensive methods.

Key learnings:

- The technology deployed has successfully demonstrated that it is possible to provide a demand response to reduce demand at peak times.
- Dynamic voltage control has been made possible by the integration of an autonomous substation controller (ASC), developed by Siemens and located at each primary substation in the trial area.
- The trials have shown that DNOs could provide ancillary services for demand reduction during frequency events and reactive power absorption to reduce the high voltage on the NG transmission system during minimum load periods.

5) Customer-Led Network Revolution – NPG [5]

The NPG trialled a range of customer and network flexibility techniques to deliver increased network capacity with minimum cost to customers. CLNR is a smart grid demonstration project developed innovative customer-side technologies (innovative tariffs and load control incentives) and network-side commercial arrangements (including voltage control, real-time thermal rating and storage).

CLNR's trials demonstrated that most domestic customers are inherently flexible and that they contribute less to network peak demand than was previously assumed. NPG now have a greater understanding of the impact of low carbon technologies like solar PV, electric vehicles and micro-CHP, allowing DSO to assess how future network and generation costs could be reduced. CLNR concluded that industrial and commercial (I&C) demand side response is a viable and reliable option, to address future network constraints, both in terms of customer cooperation and post-fault response.

Key learnings:

- Regular domestic customers contribute less to system peak demand than previous assumptions。
- A significant level of naturally occurring diversity was observed in energy practices from home to home and even from day to day within homes. The majority of domestic customers appear inherently flexible.
- Little evidence of customers' new LCT installations creating power quality problems was found.

- Time of use tariffs could deliver value in the next 10 years when delivered in conjunction with energy suppliers, but Industrial & Commercial (I&C) demand side response is fit for business as usual today.

5.2.2 Distribution network services market in EU

5.2.2.1 Visionary projects

1) EvolvDSO [8]

The project description is in the previous chapter. As suggested by EvolvDSO, DSO is expected to contract and activate flexibilities in case of local constraints. Meanwhile, DSO needs to act as a relationship manager to interact with customers, service providers and authorities. And as a distribution system optimiser, DSO is required to improve the operation of the distribution network by managing network constraints in a cost-efficient and non-discriminatory manner. These DSO roles are associated with the functionalities of distribution network services market.

2) EDSO [25]

The project description is in the previous chapter. Among the 5 priorities EDSO suggested, two of them provide guidance on the DSO's functions in distribution network services market, as followings:

Incentivise Innovation: In the part, EDSO suggested that new ICT tools and advanced technologies are the keys to the market. Regulation must ensure DSOs to invest in new ICT tools and smart grids solutions, as related to the 5th review point on enabling technologies.

Encourage Active Grid Management: In this part, EDSO suggested that DSO should be allowed to get full access to flexibility services, which will enable them to optimise local networks and make use of flexibility services, either from local markets or direct contract with customers. Meanwhile, regulation needs to ensure DSOs' priority to enable this transition. This part is related to the 2nd review point on service procurement.

5.2.2.2 Demonstration projects

1) EcoGrid [26]

EcoGrid aims to demonstrate how to involve consumers through the use of market mechanisms and smart control of electricity consumption on a voluntary basis, in balancing an energy system with high level penetration of fluctuating energy sources. A test called the real-time market and home-automation technologies has been conducted. The price signal is updated every 5 minutes to take advantage of flexible electricity demand and DERs. The consumers are able to control and move their electricity consumption to take advantage of low electricity prices. The test was taken in Bornholm, whose share of renewable energy is to 76% in 2025. The total distributed grid with all resources up to 60kV; 28,000 consumers; 268 GWh electricity consumption and heat demand 500 GWh. Distributed RES, including wind power (30MW), CHP (16MW), active demand (under roll-out during the project), photovoltaic (1MW under roll-out during the project) and electric vehicles (under roll-out during the project).

Key learnings:

- The project achieves a five-minute real-time market, which extends the market operation closer to real-time. The EcoGrid Real-time Market will be an integrated part of the current power markets and supports the need for direct control options on a very short timescale.
- Significant peak load reduction was seen: the activation of flexible consumption reduced the total peak load of the participants by 1.2% of the peak load.
- The flexible demand response can be forecasted, resulting in overall improved system efficiency.
- Households, with equipment controlling their heating system to automatically respond price signals, accounted for 87% of the peak load reduction.
- Involving the customers is the key to success. The personalised advice works best.
- Standardised 2nd generation smart grid equipment is necessary.

2) GRID4EU [27]

The project aimed at testing innovative concepts and technologies in real-size environments, to facilitate removing the barriers to the deployment of Smart Grid in Europe. It focused on how DSOs can dynamically manage electricity supply and demand. The project was led by 6 DSOs from Germany, Sweden, Spain, Italy, Czech Republic and France, covered altogether 6 demonstrators in 6 different European countries serving 275,000 consumers.

Key learnings:

- Solutions related to voltage and load control are effective resources to increase network
- Hosting capacity in European distribution grids. The major solutions used in the project include the advanced control of On Load Tap Changer at MV level. Meanwhile, volt-var control of distributed generators in MV grids is a cost-effective way for a smoother DER integration.
- The Scalability and Replicability Analysis performed in GRID4EU indicate that the interaction of DG and demand curves is a significant factor to increase network hosting capacity. It greatly depends on the type of consumers and DT technology, energy storage and flexible demand can help increase network hosting capacity.
- The scale of residential and industrial flexibilities is inherent to the local customer engagement level. The customer engagement level is greatly related to the local context.
- Decreasing the duration of outages is the major driver to increase customer satisfaction. GRID4EU indicated that more automation at MV and LV levels could greatly reduce the fault localisation and restoration time.
- Automation at LV and MV levels can further decrease energy losses, which indicates the planning phase is the significant stage.
- For higher grid resiliency, it is technically feasible to operate the grid in islanding mode more than 4 hours with or without rotating machines, in terms of continuity of supply.
- The telecommunication systems are the important aspect in all smart grid systems. Hence, it is crucial to foster the convergence between electric distribution and communication infrastructures.

3) SENSIBLE [28]

To explore the optimal integration of energy storage with distribution systems and the economic benefits it brings, Project SENSIBLE will implement the demonstration in three sites: Nottingham, Nuremberg and Evora, involving residential and commercial buildings.

Key learnings

- Consumers energy costs (40 houses within the Meadows community in Nottingham) can be reduced by assisting them achieving self-consumption and reduce the energy amount from the grid at peak times.
- Evora demonstration site is aiming at improving DSO at network management and energy efficiency through storage sources, demand side management, home energy management.
- The new control strategy employs load, weather, and electricity price forecasting to optimise the operation of the building storage, controllable loads and generators. The storage sources offer more flexibility to the system. The validation and benefits of the control strategy are demonstrated in the laboratory in Nuremberg.

4) FLEXICIENCY [29]

The four-year project, launched in early 2015, with the aim to address the flexibility and efficiency within the European energy market, focused on consumers and making use of data from smart metering made by DSOs. The project's mission is to create new opportunities for energy business and expand the DSO's market facilitator role for new services. The total budget is €19.1 million, with €13.9 million funded by the EU. Five demonstration sites are in Italy, France, Spain, Sweden, Austria (advanced monitoring, local energy control and flexibility services) based on the provision of "real time" data by DSOs.

Key learnings:

- The FLEXICIENCY will provide a linking platform for different participants to receive/submit data/service requests.
- The services resulting from the proposed technical framework will empower real customers with higher quality and quantity of information on their energy consumptions (and generation in case of prosumers), addressing more efficient energy behaviours and usages such as through advanced energy monitoring and control services.
- Economic assessment of these new services will be proposed and implemented.

5) SmarterEMC2 [30]

The SmarterEMC2 project aims to integrate ICT with the existing power systems.

The vision of the SmarterEMC2 is as followings:

- Create innovative ICT tools that will become part of the infrastructures of the DSOs, the Telco Operators and other independent entities, towards the provision of novel SG services.
- Form a unified ecosystem for the provision of services to all market participants.

- Facilitate the provision of SG services by market actors without extensive CAPEX needs.

To validate the ICT tools, three real-world pilots were implemented in the project in Italy, Greece and Turkey, which demonstrate DER and EVs in a medium sized Micro-grid to assess different strategies, active demand response and virtual power plant for active customer participation in the residential, commercial and industrial sector. The project also includes 3 large-scale lab simulations, which will reveal the ability of the communication networks to support the massive uptake of novel SG services.

Key learnings:

- SmarterEMC2 implements the integration of consumers through demand response services and integration of DG/RES through Virtual Power Plants, taking the Smart Grids Architecture Model (SGAM) as well as the future structure of the Distribution Network.
- The project will evaluate the existing telecommunication infrastructure sufficiency to support the mass-scale business models and Smart Grid services.
- The project will propose the adaption to data models of market-oriented and field-level standards to support the standardisation activities.

6) SINCRO.GRID [31]

The power systems of Croatia and Slovenia have been facing the overvoltage issues. The SINCRO.GRID project employs a fundamental way, integrating advanced technologies to settle short-term operational security problems in Slovenia, Croatia and the whole SEE region.

Key learnings:

The operational security problems have been solved, financial and societal benefits are expected through the following main pillars:

- Compensation devices to ensure the cross-border level voltage stability;
- Advanced dynamic thermal rating (DTR) systems in Slovenian and Croatian transmission grids under extreme weather conditions;
- Storage systems (10 MW batteries) will be employed in Slovenia;
- Distributed renewable generation (DG), 2 MW DG sources (small hydro, biogas) integrated with a short-term forecasting tool at DSO and TSO levels;
- Virtual cross-border control centre (VCBCC), including IT infrastructure and software to optimise RES.

7) DREAM [32]

The DREAM project provides a novel hierarchical management approach of complex electrical power grids, providing new mechanisms for stable and cost-effective integration of distributed renewable energy sources, as well as for enhanced consumer involvement in economic and ecological electricity use. Applying the principles of autonomous agent-based systems to the control and management of the electricity distribution grid allows the system to constantly adjust to current operational conditions and make it robust to exogenous

disturbances. DREAM project has lasted over a duration of 40 months and three key work lines have been carried out:

- A concept and architecture phase, devoted to the establishment of principles and methods to accommodate the functions required to cope with project challenges;
- A design and development phase, devoted to the development of the support system for the new operational characteristics for the distribution grids;
- A validation and demonstration phase, building and operating five sites for test cases in France, Greece, Italy and The Netherlands.

Key learnings:

- Market benefits from empowered consumers and prosumers: an innovative approach using hierarchical principles is employed to connect supply and demand.
- Smarter Distribution Grids: from passive to active smart distribution grids, DREAM aims to implement a semi-autonomous automation system for distribution networks enabling the integration of decentralised energy resources, and makes the grid more resilient to failures.
- Efficient generation from distributed renewable sources: main electric power control is implemented through a zonal approach, maintain the network frequency of transmission networks. Feed-in of power generation, load shedding and use of energy storage devices are implemented at transmission level. Distributed generation is connected at HV environment. The intrinsic control capability made available at distribution network level through the innovative hierarchical paradigm of DREAM, will accommodate for improved real time local balancing of energy demand and provision, thus limiting the request of voltage and frequency regulation capacity at transmission and distribution control level.

8) RealValue [33]

RealValue is a €15.5 million European energy storage project funded by Horizon 2020, the largest Research and Innovation Programme in Europe (€12M funding from the EC). The objective of the project is to demonstrate how local small-scale energy storage, across the whole EU energy system with advanced ICT, could bring benefits to all participants. Physical demonstrations have been implemented in 1250 homes in Ireland, Germany and Latvia together with advanced modelling techniques.

Key learnings:

- Smart Electric Thermal Storage is deployed and replaced the existing electric thermal storage heaters and water tanks. The potential of small-scale storage is considered as an aggregated controllable load.
- To demonstrate its scalability, modelling and virtual simulation are employed to explore the technical and commercial potential at a larger scale in millions of homes. However the results are not available to the public.

9) UPGRID [34]

The project will develop an entirely integrated intelligent system, to implement advanced functionalities on existing technology. Improvement on monitoring and controllability of low voltage (LV) and medium voltage (MV) grids with penetration of DER is expected. Meanwhile, the project aims to enhance the role of DSOs to facilitate and open market for services. The budget is €15.7 million, with €11.9 million funded by the EU.

Four demonstration sites in real user environment are applied in Spain, Portugal, Sweden and Poland to achieve the following objectives:

- Improve the supervision and management ability of MV and LV grid;
- Identify the services provided by DSOs to the retail market: DSM services, smart analytics of load curves, and design of neutral access platform;
- Use of CIM as the reference data model for the project.

Key learnings:

- The project achieves different levels of contributions on the following function objectives proposed by the EEEGI methodology through the four demonstration sites mentioned above:
- C1 Integration of smart customers: through demonstrative workshops in small areas to teach users how to use energy and their possibilities of interaction based on UPGRID developments, participant recruitment is up to 62.82* in Portuguese's demo and active participation of 87.42% in the Spanish demo.
- C2: Integration of DER and new uses, the first step is to improve the LV monitoring and control (advanced cabinets for PV, models to monitor the impact of DER and the incentives for them). Then the network could be adapted to DER necessities and react to unforeseen events.
- C3: Network operations: the performance and impact evaluation for LV Network Management System (NMS) has demonstrated advanced results for LV O&M and end-users. The cost-benefit analysis has shown great benefits with all functions which LV NMS enables.
- C4: Network planning and asset management: the use of data analytics, taking advantage of large amounts of data for monitoring devices to optimise CAPEX. The possibility of performing network reconfiguration provides a solution for loss reduction yielding significant economic benefits to society and the DSO alike.
- C5: Market Design: suggestion for electrical market hub facilitating the interaction between DSOs and customers through market agents.

10) REserviceS [35]

The objective of the REserviceS (Economic grid support from variable renewables) project is to provide a reference basis and policy guidance for future network codes and market design regarding ancillary services from variable renewables.

Key learnings

High shares of variable renewable resources providing energy and supporting the grid can save up to 6% regarding total electricity system costs. Wind and solar photovoltaic (PV) energy can provide GSS frequency and voltage control and hence reduce operation costs.

Creating markets to trade grid support services (GSS) can generate revenue streams for generators, in addition to energy-only markets. GSS is also known as ancillary services and is a significant part of truly integrated Internal Energy Market (IEM) and should be considered as a commodity.

11) SmartNet [36]

The project SmartNet aims to implement the architecture to optimise the interaction between TSOs and DSOs regarding information exchange on monitoring and procuring ancillary services (reserve and balancing, voltage regulation, congestion management). Local ancillary market is supposed to co-exist with the system for balancing and congestion requirements. Different architectures to optimise the interaction between TSOs and DSOs will be compared to manage the purchase of the ancillary services. A simulation platform including three layers (physical network, market and ICT) to simulate three national cases (Italy, Denmark, Spain). The project budget is €12.657.928,00 funded by the European Commission – Horizon 2020.

Key learnings:

The following four questions are expected to answer when the project closed:

- Which ancillary services can be provided for distribution to the whole system?
- How to optimise the TSO-DSO interface: which monitoring and control signals could be exchanged?
- How could the architectures of the real-time markets be revised?
- Which regulatory implications could the above issues have?

5.2.3 Distribution network services market in USA

5.2.3.1 Visionary projects

1) Distribution system in a high distributed energy resources future [12]

Distribution operational market is visible at stage 2, where a moderate level of DER is adopted on demand side and DER integration & optimisation and distribution platform have been developed to support the market. This structure creates the opportunities for DERs to be considered as alternatives to network capital investment or operating expense. The potential types of services include distribution capacity deferral, steady-state voltage management, transient power quality, reliability and resilience, and line loss reduction. Those services need to be well defined, their performance requirements and measurements have to be specified in a technology-neutral manner.

DSOs could procure those services rather than traditional expenditures to meet its statutory requirement for a distribution network, meanwhile boundary question needs to be addressed such as whether DERs can participate in wholesale transmission level market directly or have to go through the DSO which provides the wholesale market interface.

For services compensation, the animation of distribution operational market should consider commercial and operational interest of the buyers and sellers of DER services. It is not clear that a highly granular location and short time-period pricing is appropriate to start developing a market for operational services. It will likely be more tractable and effective to start more simply with substation transformer level or whole feeder pricing and compensation determined by contract.

5.2.3.2 Demonstration projects

1) Fruit Belt Neighbourhood Solar [37]

National Grid (U.S.) worked with partners to launch a demonstration project with two branches testing an in-front-of–the-meter neighbourhood solar model in an underserved, low-to-moderate income (LMI) market as well as a first step distributed services platform (DSP) including dynamic load management.

100 residential solar PV systems were installed on a subset of homes in LMI neighbourhood and comprehensive home energy audit conducted by local contractors. The energy produced by solar PV units was captured in front of the utility meter, aggregated collectively and monetised. Through two-way, wireless communication and data collection between National Grid and individual customer, and collective meters that utilise Volt/VAR Optimization and Conservation Voltage Reduction within demonstration area, the project seeks to reduce distribution losses and achieve voltage optimisation at the individual load point of the 100 PV system sites and along their common feeders.

2) Buffalo Niagara Medical Campus (BNMC) Distributed System Platform [38]

The BNMC is a dynamic mix of health care, life sciences, medical education and private enterprise, consisting of 13 member institutions and close to 100 public and private companies. BNMC is an ideal test bed to conduct distribution level market animation considering the load type, fuel source control capability and automation level. Thus the outcome from BNMC DSP project can be easily scaled up to other regional initiatives.

The project mainly encompassed 1) Development of a valuation model to enable the DSP to meet short-cycle load relief and alleviate forecast electric system challenge to not only achieve a level of resiliency during and other system events that compromise the integrity of the distribution grid and its ability to deliver energy, but also to defer utility infrastructure investment; 2) Testing of a model nodal interface through the creation of Network Operations Center (NOC) at the campus, which serves to optimize and aggregate Campus-based assets by connecting energy supply and demand while providing visibility into each customer-level DER in addition to serving as a nodal for single nodal interface with the DSP.

The detailed capabilities of NOC were tested:

- Market interface that utilises Campus' diverse and flexible assets to monetise its DER inventory through new distribution-level opportunities offered through the DSP and in an enhanced manner at the wholesale level via New York ISO and through its commodity purchases

- Command and control functionality that serves to interface Campus-level command and control capabilities with the DSP's local electric distribution network infrastructure to enable the BNMC's collective portfolio to serve as an asset to the benefit of the electric distribution system
- Optimization platform that maximises economic value through the efficient use of the Campus existing and future portfolio DERs, including co-generation, renewables, storage, alternative fuels, alternative generation, energy efficiency, demand response, and demand management capabilities.

With the NOC in place at the BNM, National Grid will have the ability to test how customers' DER can be informed by forecasted loads, generation availability, and distribution system constraints to create dynamic, forward-looking dispatch schedules that will allow the DSP to accomplish short-cycle load relief.

3) Resiliency Demonstration Potsdam [39, 40]

This project focuses on the development of a business model for a community resilience microgrid and aims to prototype a replicable process for stakeholder and business model development of community microgrids. The project tested the capability of resiliency using DERs in a regional micro-grid during distribution network outage, while optimised the use of DERs to reduce the electricity commodity cost.

4) Clean Virtual Power Plant [41]

Aggregated fleets of solar and storage assets in residential homes are combined as a VPP to provide grid service and resiliency services to customers. Total capacity of demonstrated VPP is 1.9 MW and aggregated energy output is 4 MWh.

For pricing the customer resiliency services, TOU tariffs, critical peak pricing and pre-determined event-driven payments are trialled in the project.

To test the customer willingness to pay for the resiliency services, three pricing frameworks 1) resiliency payment as a percentage of expected solar savings 2) resiliency payment as a percentage of current electric utility bill and 3) resiliency payment as a dollar value has been discussed.

The distribution-level network operational market is not specified in this project, while the projects defined the DSO as a communication and control platform provider to operate the DERs such as VPPs to attending the distribution-level operational market or even transmission-level ancillary services.

5) Flexible Interconnect Capacity Solution [42]

This project tested a new model for interconnecting large-scale controllable DERs to the grid, where 'controllable' encompasses the ability of the DNO to potentially curtail the delivery of electricity generated by a DER to the distribution network.

The ANM impacts on network hosting capacity compared to current interconnecting model is evaluated, and availability of interval loading data on distribution impacts on generation curtailment is evaluated.

Key learnings:

- The connection agreements with DERs include a 2 MW solar photovoltaic (PV) farm and a 450 kW farm waste generator have been signed. The cost of flexible interconnection and benefits from managing network constraints have been analysed.
- This project allows DNO to leverage the distribution network to support a 'platform-as-a-service' business model that generates new revenue streams for DER providers and DNOs, and facilitate DER adoption to participate network operational market.

5.3 Discussion and learning

Regional learnings:

In the UK, there are six visionary and seven demonstrated projects talking about the network service market. The market service provided by the DSO mainly includes enabling DER access or participate in the distribution network. The market service provided by customers (both industrial and commercial) and aggregators is the flexibility service which provides new income streams. Some of the WPD's projects only provide new tariffs as market services. The projects all show weakness in describing the market design and service procurement. The reason could be that these projects are not mainly focusing on developing a network service market. Instead, they are investigating to solve the problems, such as controlling voltage and identify templates for the LV distribution network. Most of the projects shown great performance on reducing cost, the NTVV project indicated that it would enable a reduction of 900 million pounds of network reinforcement. The CLASS project developed a method of controlling voltage which also relates to millions of pounds for saving.

Within Europe, large amounts of projects have been seen demonstrating DSOs' functionalities regarding network services. Such projects explore the roles of DSOs can play in data procurement and provision and the potential of flexibility and balancing services. DSOs also seek synergies with other actors along the supply chain, such as ICT and telecom companies, TSOs, consumers and communities. Amount of projects focus on consumer involvement and attempt to put consumers in a leading position in the market instead of traditional passive customers. And most of the budget has been allocated to functional areas at the distribution level. Electricity customers will be central for realising DER flexibility. The electricity customers are in control of demand side response, and by turning into prosumers they will also have access to generation. The most effective and commonly applied method is through offering appropriate financial incentives. Other key activities, like improving the observability and controllability of LV and MV network, strengthen the coordination between DSOs and TSOs have also been researched in some of the demonstration projects. The unbundling of the network from other services will remain however in order to achieve and utilise the full value of DERs and flexibility, it is foreseen by many that the DSO should take a more active role in the operation of the distribution grid. This will affect the operation of the transmission grid as transmission and distribution are closely coupled.

In the USA, the visionary project defines the local operational market as an alternative to network capital investment or operating expense. The potential types of services are introduced including distribution capacity deferral, steady-state voltage management,

transient power quality, reliability and resilience, and line loss reduction. The potential of local DERs services attending transmission level ancillary market is proposed which requires the discussion of DSO/DNO further functionalities and cooperation with TSO. The demonstration projects test the operational market with various services and product types, such as Volt/VAR optimisation, conservation voltage reduction, demand reduction and resiliency service. The main services providers are observed as residual homes and DGs enabled by PV solar, waste generator, storage and controllable demand. TOU tariff and critical peak pricing are trialled in some of the projects for procuring operational services. While for facilitating and operating the local network service operational market, the detailed functionalities of DSO are specified in most projects.

Synthesis learning

The local network service market/ local operational market is observed to become a single-buyer-multi-seller market, as the DNO/DSO (potentially TSO) is the only entity that acquires network services to operate a sustainable economic and reliable distribution network, while various services provider's types, such as residential household, DGs and third-party franchise, are trialled in a mount of reviewed project.

According to the majority of reviewed project, the main market functions are defined to offer non-technology solutions for network constraints, balancing and investment where various network services are discussed and demonstrated providing successful solutions. The services are mainly enabled by distributed generation, storage technique and controllable demand with smart ICT infrastructure.

For network services procurement, short-time pricing is not recommended while Time-of-Use (ToU) and critical peak pricing (CPP) are demonstrated in some of the projects. The detailed network services provision issues like services measurements and penalty have not been found in all projects.

The comprehensive cost and benefit analysis for DNO/DSO to operate such a market as a non-network instrument is needed to be evaluated with the cost and benefit analysis for DNO/DSO using technical operation, which would result to an important impact on DNO/DSO future business model.

6. DSO Project Synthesis in Coordination between Energy Markets and Network Services Markets

With the increasing penetration of DERs, more uncertainty has been seen in system balancing and operability. The increasing lack of visibility brings challenges to the system.

Network services refer to functions which ensure the balancing, stability and security of the system. As the generation and demand behaviour is becoming more and more challenging to predict, network services have presented their significance in supporting system operability and decreasing capacity margins. Efficient network services ensure the security of supply with the least cost and bring more benefits to the environment as the back-up generation is reduced. For example, in UK, ancillary services include mandatory frequency response, commercial frequency response, reserve and reactive power.

The current market runs the energy market and the network services market independently. It is believed that this market is a less efficient but higher-cost power market. It is worthwhile looking both the energy market and the network services market together, coordinating transmission and distribution levels. This is believed to improve the system operation efficiency and lower consumers' energy costs.

The integration of the energy market and network services market is the process of progressively allowing balancing energy to be drawn from more sources and will help the integration process of renewable energy sources. However, based on the authors' acknowledgement, we haven't seen any projects attempting to implement the market integration. The entirely consistent and convergence is necessary. Hence, this project aims to optimise the coordination between the energy market and network services market, to explore the massive benefits behind it.

7. Summary and Key Learnings

In this report, we researched 40 projects covering 3 representative areas, i.e. UK, EU and USA. There are 16 projects for the UK, including 8 demonstrated projects and 8 visionary projects. EU has 15 projects including 12 demonstrated projects and 3 visionary projects. For the USA, a total number of 9 projects (8 demonstrated projects and one visionary projects.) had been investigated.

The market operation of DSOs is the key focus in this report. Local energy market and network services market are concluded as the major concern of the reviewed projects, while the absence is identified as the coordination between the energy market and network services market.

Key Learnings:

Local Energy Market

Local energy market design has been researched by limited projects in three regions. P2P-based and agency-based market structure are only two currently demonstrated market structures. While the energy products commercialisation progress such as products standardisation, measuring, pricing and penalty has not been illustrated clearly.

Most projects define the new roles and functionalities of DSO in the local energy market, parts of new roles and functionalities require DSOs to enable and facilitate the development of local energy market, the rest roles and functionalities directly indicate that DSO should be the market operator due to that the required capabilities of operating local energy market can be only met in the DSO position. One unique project offers a DSO-third party operated local market demonstration, which indicates the potential of further exploration of market operation authority.

The cost & benefit analysis for customers and market operators are individually conducted by various project. The analysis is expected to have a critical influence on customer engagement, DNO/DSO revenue stream and distribution network planning & operation. Thus the cost & benefit analysis across entire local energy market including market operators, energy providers and customers need to be discussed and demonstrated comprehensively in reviewed projects.

Overall, a local energy market with 1) effective market design: 2) technical and economic neutral commercialisation process; 3) clear specified operation authority with corresponding functionalities; 4) comprehensive cost & benefit analysis is required to be well developed and demonstrated.

Network Services Market

The local network service market/ local operational market is observed to become a single-buyer-multi-seller market, as the DNO/DSO (potentially TSO) is the only entity that acquires network services to operate a sustainable economic and reliable distribution network, while various services provider's types, such as residential household, DGs and third-party franchise, are trialled in a mount of reviewed project.

According to the majority of reviewed project, the main market functions are defined to offer non-technology solution for network constraints, balancing and investment where various network services are discussed and demonstrated providing successful solutions. The services are mainly enabled by distributed generation, storage technique and controllable demand with smart ICT infrastructure.

For network services procurement, short-time pricing is not recommended while Time-of-Use (ToU) and critical peak pricing (CPP) are demonstrated in some of the projects. The detailed network services provision issues like services measurements and penalty have not been found in all projects.

The comprehensive cost and benefit analysis for DNO/DSO to operate such a market as a non-network instrument is needed to be evaluated with the cost and benefit analysis for DNO/DSO using technical operation, which would result to an important impact on DNO/DSO future business model.

8. Recommendation and Conclusions

Recommendation

- The commercialisation progress of the energy products, such as products standardisation, measuring, pricing and penalty has not been illustrated clearly among the projects reviewed.
- The cost & benefit analysis is significant for all the market participants. It has a great impact on customer engagement, DNO/DSO revenue stream, distribution network planning and operation. Hence, a comprehensive cost & benefit analysis is required.
- In the future work in local energy markets, a clear specified operation authority with corresponding functionalities is expected and needs to be demonstrated to prove its effectiveness and scalability.
- As for the service procurement, short-time pricing is not recommended. The detailed network services provision issues like services measurements and penalty were not illustrated in the reviewed projects.
- The current market runs the energy market and the network services market independently. It is believed that this market is a less efficient but higher-cost power market. It is worthwhile looking both the energy market and the network services market together. The integration of the energy market and network services market is the process of progressively allowing balancing energy to be drawn from more sources and will help the integration process of renewable energy sources. However, based on the authors' acknowledgement, there is an absence on this market integration. The entirely consistent and convergence is necessary. Hence, this project aims to optimise the coordination between the energy market and network services market, to explore the massive benefits behind it.

Conclusions

The learning from current DSO projects undoubtedly provide a better understanding of the challenges for the networks, requirements for the future DSO roles and the gap of the current projects.

A challenge is arising as the decarbonisation agenda leads to increasing penetration level of DERs. This "moving part" brings great amounts of uncertainty to the system, which makes it rather challenging to forecast both the supply and demand sides' behaviour. The key resolution to solve this problem is to create distributed vibrate markets. It will provide horizontal connections for buyers and sellers of DERs. In this way, DERs can be absorbed at the distribution level. The distributed vibrate markets are required to reflect the characteristics of DERs and the needs of the market participants, provide customised energy and services to meet the requirements of local energy and network.

This review and synthesis project accomplishes the stage to identify the challenges, the current targeted topics and the remaining gaps and also to inform the further innovation work. In this report, we researched 40 projects that cover three different areas, i.e. UK, EU and USA. We are focusing on the market operation of DSO roles and two topics are included: local energy market and network services market.

Limited projects are focusing on the local energy market. P2P-based and agency-based are the only two demonstration market structures. Further study and demonstration on energy products commercialisation progress and its cost & benefit analysis are still necessary and essential. The majority of the projects researching in this area have been focusing on the roles and functions DSO involving, as visionary projects. The most recognised future DSO roles are the neural market facilitator and market operator.

We observe a focus on the network services market. The main market functions are recognised as the non-technology solution for network constraints, balancing and investment, while distributed generation, storage technique and controllable demand with advanced ICT provide the possibility to this solution. Similarly, the detailed cost & benefit analysis is significant for DNO/DSO as it has a great impact on the future business model.

We observe an absence on the coordination between the energy market and network services market. The current market runs these two markets independently, which is believed as less efficient but higher-cost. The market integration between the energy market and network services market is necessary, especially at the distribution level. Looking these two markets together will help to improve the system operation efficiency, lower consumers' costs, and most significantly, it will enable the system to integrate more DERs.

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