TAMPERE UNIVERSITY OF TECHNOLOGY

TEEMU LEPPÄLÄ

BENEFITS RELATED TO DISTRIBUTED ENERGY RESOURCES AND THEIR IMPACT ON NETWORK OPERATIONS

Master of Science Thesis

Prof. Saku Mäkinen has been appointed as the examiner at the Council Meeting of the Faculty of Business and Technology Management on October 5, 2011.

ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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Power distribution networks in Finland are evolving towards smart grids. Distributed energy resources (DER) are one part of these future grids. Distributed energy resources include distributed generation, distributed energy storages and active demand response, which along with smart communication enable more secure and efficient use of distribution networks.

This thesis exists to find out whether DER applications are useful for distribution system operators (DSO) and how ready Finnish DSOs are for DER diffusion. Additionally, DER impact on distribution network operations is discussed. One objective of the thesis is to use Technology acceptance model (TAM) to form a framework and use it to analyze data and answer research questions.

A qualitative research method was used in this thesis. The data was gathered by carrying out four semi-structural interviews and by using secondary data. Four interviewed DSOs included small and large DSOs as well as DSOs having urban and rural network environment. Smart Grids and Energy Markets (SGEM) research program proceedings as well as other material are used as secondary data.

Technologies related to DER are improving and their prices are falling but the biggest challenge is to develop standards and thus enable interoperability of devices. It was found that DER can bring benefits for DSOs but DSOs don't perceive them. Benefits like loss reduction and island operation of DER were considered possible, but DSOs weren't able to perceive monetary benefits. Furthermore, DSOs didn't have much experience of DER which increases DER related perceived complexity. On the other hand, firms are learning about DER and smart grids all the time and changes are not rapid in the industry, which gives DSOs time to adapt. Organizationally, two types of DSOs were found. Large DSOs have resources to do research and gain experience while smaller firms are waiting for ready-made working solutions to appear.

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Suomen sähkönjakeluverkot kehittyvät kohti älyverkkoja. Hajautetut energiaresurssit ovat osa älyverkkoja. Ne sisältävät hajautetun tuotannon, hajautetut energiavarastot ja aktiivisen kuormanohjauksen. Yhdessä tietoliikenneratkaisujen kanssa ne mahdollistavat aikaisempaa turvallisemman ja tehokkaamman jakeluverkkojen käytön. Tämän työn tärkein tutkimuskysymys on: Onko hajautetuista resursseista hyötyä verkkoyhtiölle ja ovatko verkkoyhtiöt valmiita hyödyntämään näitä etuja? Lisäksi tarkastellaan hajautettujen resurssien vaikutusta jakeluverkkojen käyttöön. Työn tavoitteena on myös kehittää Technology Acceptance Modeliin (TAM) perustuva viitekehys, jota käytetään kerätyn tiedon analysointiin.

Työ on luonteeltaan laadullinen tutkimus, jossa on käytetty puolistrukturoituja haastatteluja sekä toissijaista tietoa, jota on kerätty muun muassa SGEM (Smart Grids and Energy Markets) tutkimusohjelmasta. Neljän haastatellun verkkyhtiön joukossa on suuria ja pieniä yhtiöitä joiden hallinnassa on sekä kaupunki- että maaseutuverkkoa.

Työssä havaittiin, että hajautettuihin resursseihin liittyvien teknologioiden hinnat laskevat, jolloin niiden hankkiminen muodostuu aikaisempaa kannattavammaksi. Haasteena on kuitenkin sopivien standardien kehittäminen, joilla varmistetaan laitteiden yhteensopivuus. Hajautetut resurssit voivat tuoda hyötyjä myös verkkoyhtiöille, jotka eivät kuitenkaan tällä hetkellä havaitse niitä. Esimerkiksi siirtohäviöiden pienentäminen ja hajautetun tuotannon käyttäminen saarekkeessa mainittiin mahdollisiksi sovelluskohteiksi, mutta verkkoyhtiöt eivät koe saavansa niistä riittävää rahallista hyötyä. Lisäksi havaittiin, että suurimmillakaan verkkoyhtiöillä ei toistaiseksi ole paljoa kokemusta hajautetuista resursseista, jonka seurauksena yhtiöt kokevat ne monimutkaisiksi. Toisaalta yhtiöiden osaaminen karttuu älyverkkojen kehittyessä ja muutokset ovat tällä toimialalla hitaita, joten muutoksiin ehditään sopeutua. Suurilla yhtiöillä on resursseja tehdä tutkimusta ja kerätä kokemuksia, kun taas pienet yhtiöt tyytyvät odottamaan valmiiden ratkaisujen ilmestymistä markkinoille.

PREFACE

This Master of Science Thesis is carried out in ABB Distribution Automation during autumn 2011 and spring 2012. The thesis is part of Smart Grids and Energy Markets (SGEM) research program. It has taught me a lot about smart grids itself but even more about executing a project that has been the largest so far in my career.

I would like to thank my supervisors M.Sc. Matti Kärenlampi and M.Sc. Ilkka Nikander for giving me an interesting subject and for valuable advice I have received during the process. Furthermore, thanks for my superior and all the colleagues who have supported me during the project. Of course, I also want to thank all the people in DSOs who participated in interviews.

I would also like to thank my examiner professor Saku Mäkinen for providing ideas and advice even on a very detailed level. Finally, I would like to express my gratitude to my family and friends who have encouraged and supported me during this work as well as during my studies that have taken almost two decades.

Tampere, 27.07.2012

Teemu Leppälä

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ABBREVIATIONS AND NOTATION

ADSM	Active Demand Side Management
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
BESS	Battery Energy Storage System
BI	Behavioral Intention
CEO	Chief Executive Officer
CES	Community Energy Storage
DER	Distributed Energy Resources
DMS	Distribution Management System
DR	Demand Response
DRMS	Demand Response Management System
DSO	Distribution System Operator
EBIT	Earnings before Interests and Taxes
EMV	Energiamarkkinavirasto (Energy market authority)
ERP	Enterprise Resource Planning
EV	Electric Vehicle
GPRS	General Packet Radio Service
HRM	Human Resources Management
HV	High Voltage (>110kV)
LOM	Loss of Mains
LV	Low Voltage (<1kV)

MMS	Microgrid Management System
MV	Medium Voltage (1-110kV)
NE	DMS 600 Network Editor
OPC	Ole for Process Control
PEOU	Perceived Ease Of Use
PLC	Power Line Carrier
PU	Perceived Usefulness
PV	Photovoltaic
RFID	Radio Frequency Identification
R&D	Research & Development
SA	DMS 600 Server Application
SCADA	Supervisory Control and Data Acquisition
SGEM	Smart Grids and Energy Markets
TAM	Technology Acceptance Model
TCP/IP	Transmission Control Protocol/Internet Protocol
UPS	Uninterruptible Power Supply
USCRC	United States Corporate Research Center
VPN	Virtual Private Network
VPP	Virtual Power Plant
WACC	Weighted Average Cost of Capital
WS	DMS 600 Workstation
XML	Extensible Markup Language

1. INTRODUCTION

1.1. General background

Traditional power networks are evolving towards smart grids. On a general level ABB (2009) has defined that smart grid is:

- Adaptive, with less reliance on operators, particularly in responding rapidly to changing conditions.
- Predictive, in terms of applying operational data to equipment maintenance practices and even identifying potential outages before they occur.
- Integrated, in terms of real-time communications and control functions.
- Interactive between customers and markets.
- Optimized to maximize reliability, availability, efficiency, and economic performance.
- Secure from attack and naturally occurring disruptions.

One area of smart grids is decentralized or distributed generation which enables shorter distances between loads and production and thus improves system efficiency. In addition to distributed generation, a concept called distributed energy resources (DER) includes energy storages and demand response (DR). All these tools can be used to achieve the abovementioned vision of smart grids.

By definition, many DER units are integrated in distribution level rather than in transmission level. This thesis makes effort to analyze power distribution environment from the distribution system operator’s (DSO’s) point of view. The transition to smart grids has largest impacts on distribution level as DER units are integrated and customers demand for more secure distribution. The old fact is that around 90 % of outages perceived by customers proceed from medium voltage (MV) network (Lakervi & Partanen 2008). Such development creates challenges for DSOs on how to fulfill law requirements and make profitable business at the same time.

Generally, smart grids are considered to be reality after 2020, maybe after 2030. This thesis, however, has shorter time span. While it looks to years from 2030 onwards it deals with current situation and current DSO prerequisites with respect to DER. Such time span of 5-10 years is needed to be able to see what is happening on the market in the near future and thus be able to serve customers better. Basically, this thesis positions itself somewhere between the current DSO environment and current academic research.

1.2. Network management and microgrids

This thesis is made as a part of Finnish national SGEM (Smart Grids and Energy Markets) program. The program is managed by Cleen Oy (Cluster for Energy and Environment) and it is partly funded by Tekes. The other part is funded by participants like universities (e.g. TUT), research centers (e.g. VTT), and corporations like ABB. The SGEM program is going to end in 2014.

More precisely, this thesis is part of SGEM work package 6.6 which is named as "Network management and microgrids". In addition to ABB the package includes cooperatives like VTT, TUT, and NSN. This work package concentrates on management of smart grids and it defines some specifications for microgrids. Integration of microgrids and larger grids is also discussed. This thesis represents the DSO's viewpoint in this discussion.

1.3. Research questions, objectives and limitations

This thesis exists to answer three questions. The first question is what technologies can be used in distributed energy resources in next few years? This is not the most important question, but it is tackled somewhat briefly to determine what DER is about and to evaluate the overall state and potential of these technologies.

The second question is to find out adoption and usefulness of these technologies. This is one of the main questions. What does it require for a DSO to adopt DER technologies? Are they useful for DSOs? Why or why not?

The third question is what effects do DER have on network operations? This is the other main question. How DER could be utilized by DSOs?

One objective of this thesis is to develop a framework and use it to analyze DSO environment and to answer research questions. Another objective is to gain better understanding on how DSOs conceive the future of smart grids in general. This thesis is limited to inspect the situation mainly in Finland. Effects and possibilities discovered in question two are, of course, global but interviews and state of the DSO environment is studied in Finland. This limits the global generalizability of the thesis somewhat. However, with respect to network automation and smart grids Finland is one of the leading countries in the world which can make ideas and experiences valuable to countries (or DSOs) who are developing their networks to a smarter direction.

1.4. Research methodology and structure of the thesis

The research methodology is based on collecting secondary data and on carrying out semi-structured interviews. The goal is to tackle question 2 by developing a theory-based framework and then use it to create specific questions for interviews and to analyze the answers to these questions. The approach is inductive as a theory is developed and it is tested against the real environment. However, proving the theory is not the ultimate goal in this thesis even though it may be useful for future research.

Question three is tackled by scanning secondary data and adopting ideas the author believes to be useful in thesis’ environment. Some ideas and visions regarding DER related impacts and benefits are gathered during the interviews as well. Value related theories are used to analyze the benefits as well as technical aspects.

Part 2 of the thesis introduces the main background theories used. Part 3 combines these theories and the environment of the thesis ending up with the framework used to create and analyze questions. Part 4 describes the research environment and methodology in more detail. Part 5 of the thesis introduces the results and analyzes their meaning. Part 6 deals with conclusions based on results. The reliability, validity and limitations of this study are also evaluated.

2. THEORETICAL BACKGROUND

2.1. Technology adoption

Technology adoption is defined as an individual’s or organization’s decision to make full use of the technology. (Rogers 2003, p. 21) There are several factors influencing the decision whether or not to adopt a new technology. These factors can be divided into three categories: Attributes of an innovation, community effects and network externalities, and characteristics of the potential population. (Narayanan 2001, p. 109.) Originally these factors are considered to model diffusion of an innovation, but they can be utilized in adoption discussion too. For example Vowles et al. (2011) use similar attributes in their study about the adoption of a radical innovation. According to Rogers (2003) there are five general attributes of an innovation:

- Relative advantage is the degree to which an innovation is considered to be better than its rivals. Rogers highlights that what matters is the relative advantage perceived by an adopter, not any objective relative advantage. The greater the relative advantage, the higher the innovation’s rate of adoption.
- Compatibility is the degree to which an innovation is compatible with past experiences and needs of adopters. Rogers mentions compatibility with sociocultural values and beliefs, previously introduced ideas, and needs for the innovation. In more technical point of view, compatibility can also stand for compatibility with existing technologies.
- Complexity is the degree to which an innovation is perceived to be difficult to use. Innovations that are simple to use are adopted easier than innovations that require learning of new skills and procedures.
- Observability is the degree to which an innovation and its effects are perceivable to others. If people are able to see an innovation and its results they are more likely to adopt the innovation themselves.
- Trialability is the degree to which an innovation can be tested and experimented before actual adoption. Giving adopters a possibility to test the innovation on a limited basis makes the actual adoption rate higher. (Rogers 2003, pp. 219-266.)

Community effects and network externalities basically mean that an innovation (and its diffusion) benefits from the community adopting it. This is naturally the case with mobile phones and other communication technologies as innovations require many users to be beneficial for at least someone. However, any innovation can benefit from the adopting community since more information can be gained of the innovation and its attributes, which in turn reduces the risk related to the innovation. (Narayanan 2001, p.

110.) A same sort of community effect was noticed by Woersdorfer & Kaus (2011) when they studied the adoption of solar heating systems in northern Germany. As other members of the community invested in solar heating systems, the likelihood of new members to invest in same systems increased. (Woersdorfer & Kaus 2011.)

Vowles et al. (2011) recognize five different factors defining organizations' enthusiasm to adopt a new (radical) innovation. *Technology opportunism* describes firm's ability to respond to new technology developments. High opportunism leads to easier and faster initiation of the adoption process than low opportunism. (Rogers 2003, p. 420.) *Depth of knowledge resources* describes firm's level of IT expertise. The more expertized people, the easier it is to adopt a new innovation since the needed information can be discovered with less effort. *Innovation related experience* has also an effect on innovation adoption. Naturally, prior experience removes the need for new information seeking and thus makes adoption decisions easier. Also Woersdorfer & Kaus (2011) argue that prior knowledge related to a technology makes it more likely to be adopted. Other *Depth of search* refers to the degree to which a firm gathers information from various sources. Usually innovators are more anxious to search new information which makes them good adopters as well, where laggards are not interested in searching information on new innovations which, in fact, makes them laggards in the first place. Finally there is *influence of champion*, where champion refers to strong personalities in a firm. Having champions behind the new innovation makes the adoption of the innovation more favorable. (Vowles et al. 2011.)

Ghobakhloo et al. (2011) studied small- and medium-sized enterprises and found out that factors influencing the adoption of electronic commerce were perceived relative advantage, perceived compatibility, CEO's innovativeness, support from technology vendors, and competition. The study was carried out by asking 235 managers in manufacturing industry. (Ghobakhloo et al. 2011.) On the other hand, Alam (2009) studied internet adoption in Malaysia by having a questionnaire sampling of 435 small- and medium-sized businesses. He found that factors affecting internet adoption were manager's characteristics, perceived benefits, technological competency, cost of adoption, and organizational culture. (Alam 2009.) They both mention manager's role in the adoption process. This is easy to understand in small businesses where manager's opinion is important in every decision. Alam's cost of adoption has much to do with perceived compatibility mentioned by Ghobakhloo et al. even though actual investment cost are surely a factor in small enterprises especially in less developed countries like Malaysia.

Thiesse et al. (2011) studied the adoption process of RFID (radio frequency identification). They concluded that most important factors were, again, top management support, supply chain forces, costs, and perceived benefits. This brings a new factor to the table. Supply chain forces refer to adoption made by other members in a same supply chain. This factor was found to affect positively to the adoption process.

Thiesse et al. also point out that in the first stages of adoption, technical issues like relative advantage and compatibility are the main concerns of managers, but when the adoption decision is made, organizational and environmental aspects become more and more important. (Thiesse et al. 2011.) A same sort of change in affecting factors was discovered by Waarts et al. (2002) when they studied adoption of ERP or enterprise resource planning software. They found that perceived potential value was influencing more on early adopters than late adopters. Additionally, compatibility with business processes, reliability, and user friendliness were found influencing more on late adopters. (Waarts et al. 2002.)

2.2. Technology acceptance model

The technology acceptance model (TAM) was initially developed with IBM Canada Ltd to evaluate the market potential for multi-media-related PC-applications in mid-1980s. It was broadly introduced by Davis in 1989. (Davis & Venkatesh 1996.) After that, the model has been widely used in information systems field to analyze the adoption of a new innovation. In TAM there are two fundamental determinants called Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) that affect on the adoption decision. Perceived usefulness is defined as: *"the degree to which a person believes that using a particular system would enhance his or her job performance"*. Perceived ease of use in turn is defined as: *"the degree to which a person believes that using a particular system would be free from effort"* (Davis 1989).

Figure 2.2 illustrates this relatively simple model. An individual (or an organization) perceives usefulness and ease-of-use of a given technology. These attributes are strongly affected by external variables such as technology characteristics, training and the nature of the technology implementation process. Venkatesh & Davis (1996) have studied determinants of PEOU. They found that general computer self-efficacy has an impact on perceived ease of use. The actual object usability had an impact only after an individual had had direct experience of the object. PU and PEOU are followed by an attitude towards a new technology. This attitude leads to Behavioral Intention (BI) which finally leads to technology adoption (or rejection). However, the attitude component was removed from the final TAM, since there was empirical evidence that it did not fully mediate to the model. This was due to a finding that in many cases a technology was adopted because of improved efficiency generated by the technology, not because of a positive attitude towards it. (Davis & Venkatesh 1996.) Davis (1989) concludes that perceived usefulness is extremely important for adoption. It is more important than perceived ease of use because people can adopt innovation because of its ability to provide a critically needed functionality despite the difficulties related to the use of the innovation. Thus perceived usefulness shall not be overlooked in designing systems. However, it has to be mentioned that Davis also concludes that PEOU has an effect on PU as the easier the system is to use the less effort is needed to use the system and thus more time can be invested elsewhere. This causality is indicated by an arrow in figure 2.2. (Davis 1989.)

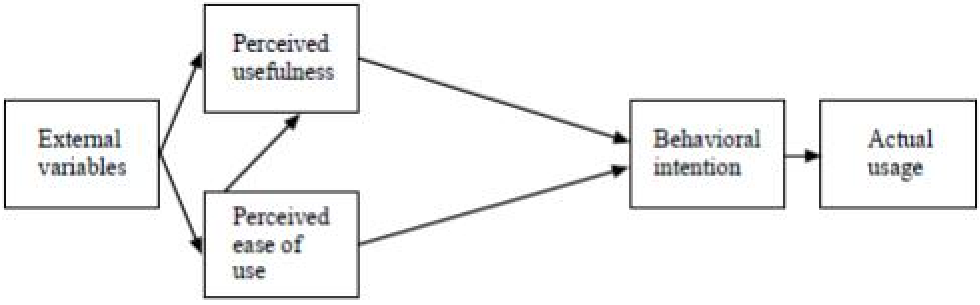

Figure 2.2. *Technology acceptance model. (Modified from Davis & Venkatesh 1996).*

The original TAM uses statistical approach in order to find out PU and PEOU. Informants' opinions are gathered by several questions using a multi-item scale for example from 0 (strongly disagree) to 5 (strongly agree). The original TAM formation included 14 such questions for PU and 14 for PEOU (Davis 1989). Davis & Venkatesh (1996) criticize the model and its reliability by stating that the questionnaire gives different results depending on the grouping of questions i.e. asking PU in one group and PEOU in other gives different results than asking them intermixed. However, the difference wasn't significant and it was suggested that open verbal questions should be grouped in order to reduce confusion. (Davis & Venkatesh 1996.) Many researchers have since then replicated the original model and improved it by including other factors. The model is also tested by many researchers and it's proved to be valid and useful especially in analyzing the adoption of firm-level software innovations. (Adams et al. 1992; Szajna 1994)

Organization itself is not able to form any kind of an attitude or BI, so therefore they are formed by organization's managers and they have to have a clear understanding whether or not the innovation is going to create value for the organization (Pérez Pérez et al. 2004). Wu (2010) states that one important factor influencing the adoption decision is CEO's attitude. Although Davis et al removed the attitude component from the final TAM it still doesn't lead to a contradiction. Managers' attitude is important factor to promote the adoption process, but attitudes of those who really use the innovation are not equally important as they are somewhat forced to use the innovation. This is also the reason why attitude was dropped out from the TAM by Davis. Also Vowles et al (2011) highlight that having organization's strong personalities (champions) behind the new innovation can make it more likely to be adopted. (Wu 2010; Vowles et al. 2011)

2.3. Value creation and value networks

Value is basically something that is worth paying for. Anderson & Narus (1998) define value in business markets as “the worth in monetary terms of the technical, economic, service, and social benefits a customer company receives in exchange for the price it pays for a market offering.” They also suggest that a market offering has two elements: value and price. Thus changing the price does not change the value the offering provides to a customer. Instead, it changes the customer’s incentive to purchase the offering. (Anderson & Narus 1998). Also Porter and Kramer (2011) define value as benefits relative to costs (Porter & Kramer, 2011). In this study, value is connected to TAM via the assumption that received value is very closely connected to perceived usefulness found in TAM. (Davis 1989.)

Grönroos (2008) introduces two types of value: value-in-exchange and value-in-use. Value-in-exchange is basically the value embedded in products and services and it can be obtained quite easily by firms as it is used as a basis of pricing. Value-in-use is more complicated as it is created when the customer uses the product or service. The essential idea is that goods are not bought to keep in storage, but to utilize own skills and other resources in addition to them to create value. Grönroos defines this customer value as follows: “…after they have been assisted by a self-service process (e.g. cooking a meal) or a full-service process (eating out at a restaurant) they are or feel better off than before.” When looking from this point of view, customers are the value creators and firms are to support them by providing resources needed. Grönroos concludes that value-in-use is needed in order to create value-in-exchange in the long run. In shorter periods of time, however, the latter can be obtained alone as some goods or services are sold without them creating enough customer value to be purchased again. (Grönroos 2008.)

Porter (1985) defines value chains as a series of operations where every participating operation contributes to the value provided to the customer. These chains are found in firms where different activities like manufacturing and logistics form one chain. However, the same chain structure is found in larger scale in industries where firms constitute chains to create offerings for the end customers. In this case each firm contributes to the end value by performing its value creating activities. Figure 2.3 illustrates Porter's value chain. Firm infrastructure, Human Resources Management (HRM), R&D or Research and Development, and Procurement are supporting activities and logistics, operations, marketing and service/aftersales are main activities. (Porter 1985, pp. 54-55.)

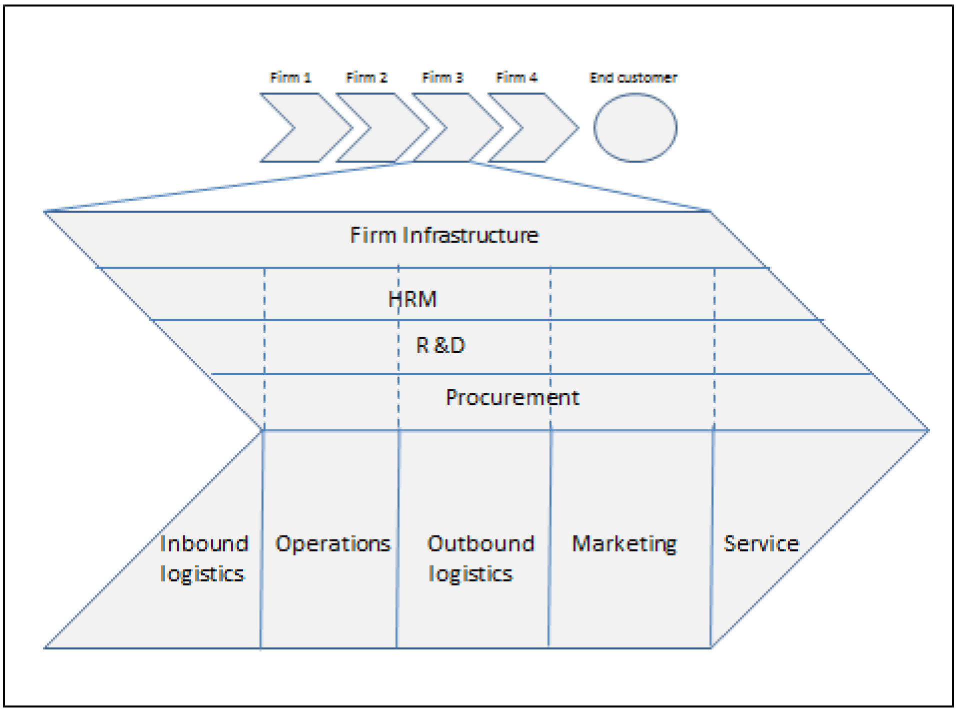

Figure 2.3. *Value chain according to Porter (1985).*

As can be obtained from the figure, main activities are tied to supporting activities as for example HRM is responsible of taking care of people of all main activities. Porter states that along with managing the actual activities, a firm should also put emphasis on managing the links between activities. Porter also argues that there should be a connection between firm's value chain and a customer's value chain. This is because a firm should create as much value as possible for its customer in order to differentiate from its competitors. (Porter 1985, pp. 54-82.)

As products and services are formed as a result of series of operations, the value added to the final outcome within these operations is interesting. Bowman & Ambrosini (2007) suggest that there are five types of firm activities:

- Product creation activities (type 1) are the activities related to manufacturing the product or service itself.
- Value realization activities (type 2) refer to marketing and selling the outputs created in the first type.
- Input procurement activities (type 3) aim to reduce the money paid for suppliers. Raw materials and labor are obviously included in these activities. It is also stated that activities increasing production efficiency and line supervision activities are included as well.
- Capital stock creating activities (type 4) refer to activities that are expected to create value in the future. For example market research, R&D and training are these activities.
- Firm maintenance activities (type 5) are those necessary to keep the business continuing. For instance, tax management and accounting are included in these activities. (Bowman & Ambrosini 2007.)

These five activity types are coupled in different ways i.e. some activities like type 5 can be separated from others without harming value creation but types 1, 2, and 3 should be kept together. Bowman & Ambrosini conclude that a firm might be able to create more value by rearranging these activities. (Bowman & Ambrosini 2007.)

3. POWER DISTRIBUTION BUSINESS

3.1. Traditional value network

In traditional power distribution the value chain can be illustrated like in figure 3.1. Blue arrows indicate the actual power flow and red arrows are to indicate money flow. Power is produced in multiple centralized power stations like Olkiluoto. The physical power flows through transmission (Fingrid Ltd.) and distribution networks to the end customer. The customer pays for the electricity to the retailer, which is decoupled with the distribution company by law. In Finland this law is called Electricity Market Act and it took effect in 1995. Retailer procures the electricity from the energy market, which is called Nord Pool Spot in the Nordic countries. Producers, in turn, sell the electricity to the energy market. Note that this figure illustrates the value chain in the case of small retail consumers and firms. Large industrial customers operate differently by usually procuring the energy directly from the market but they are not in the scope of this thesis.

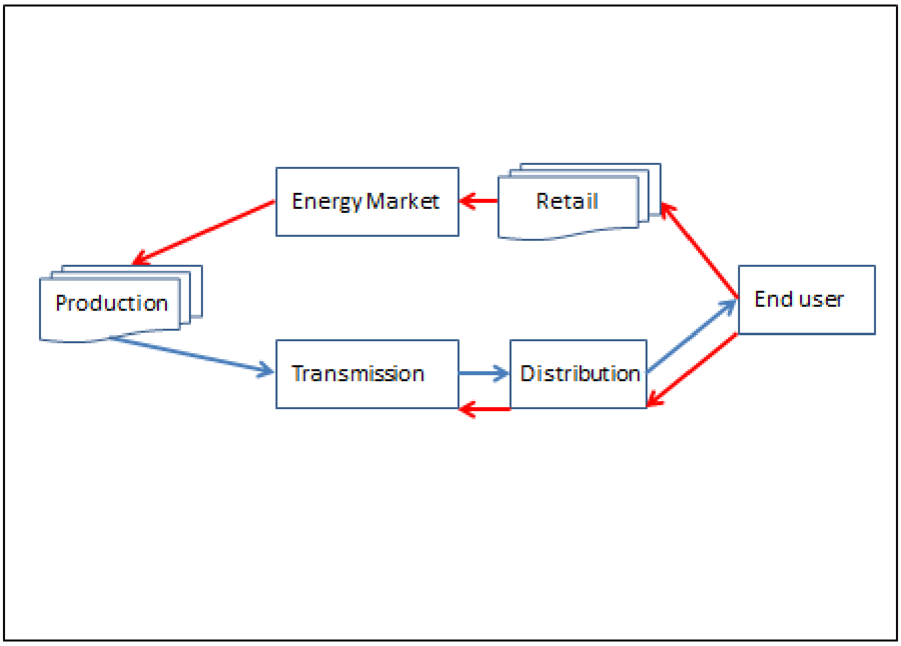

Figure 3.1. *Value network in traditional power distribution.*

As can be obtained, value chain is fairly straightforward and not much can be done to optimize it. Of course, efficiency inside each block can be improved and it has also been the case in recent years. For example DSOs have made continuous improvements to their networks in order to decrease losses or gain better grid reliability which turns in greater profit and improves customer satisfaction at the same time. Note also that only electricity retail business and producer business are open for competition. This is indicated with multiple rectangles in these blocks. As retail business is open for competition, some new firms who have nothing to do with traditional electricity companies have appeared. These firms can provide cheaper electricity to consumers due to their lighter cost structure as they are not stressed by legacy activities like power production or district heating operations, which might be the case with traditional retailer companies.

Here, the value created by a DSO comes from network operations i.e. transferring the energy from primary substations to end customers. Another value creating activity is planning and development of the network. Third value component created by a DSO is based on metering and balance management. DSOs are responsible of arranging metering in a way that actual energy consumption can be measured in customer points. At the time of writing almost all Finnish DSOs are at the end of their job of changing all customer meters to AMR (Automated Meter Reading) devices. A law regarding electricity metering obligates DSOs to change at least 80 % of their metering devices to AMR devices by the end of 2013 (Tuntimittaussuositus 2010). They enable multiple new functions like billing based on actual consumption, and getting more accurate data for network load modeling purposes. Now DSOs are able to monitor LV (low voltage) network’s condition as well but the downside is rapidly increasing amount of data gathered from the network. This so called AMI (Advanced Metering Infrastructure) is the first step toward smart grids.

Balance management, in part, refers to DSOs duty to make sure that all energy consumed in their area is also purchased from the market and correct consumptions are billed. If there was no balance management, it would be possible for a retailer to cheat and charge for more electricity than is procured from the Nordpool spot. This would not be noticed easily as technical electricity distribution doesn’t directly depend on billed electricity. However, cheating would become more difficult and balance management easier as AMR devices provide hourly consumption data for participants.

Figure 3.2 represents these value activities. There are also supporting activities needed to efficiently perform main activities. One of these is an R&D, activity, which search for betters solutions to be used in the main activities. Clouds illustrating network automation and AMI include multiple technologies like metering devices and communication protocols but their connections to DSO's activities are interesting. ABB's role is to supply software and hardware products to DSOs to be used mainly in network automation. Note, that DMS is also used in network planning and in AMI systems where it supports LV (low voltage) network alarms and some on/off type controls.

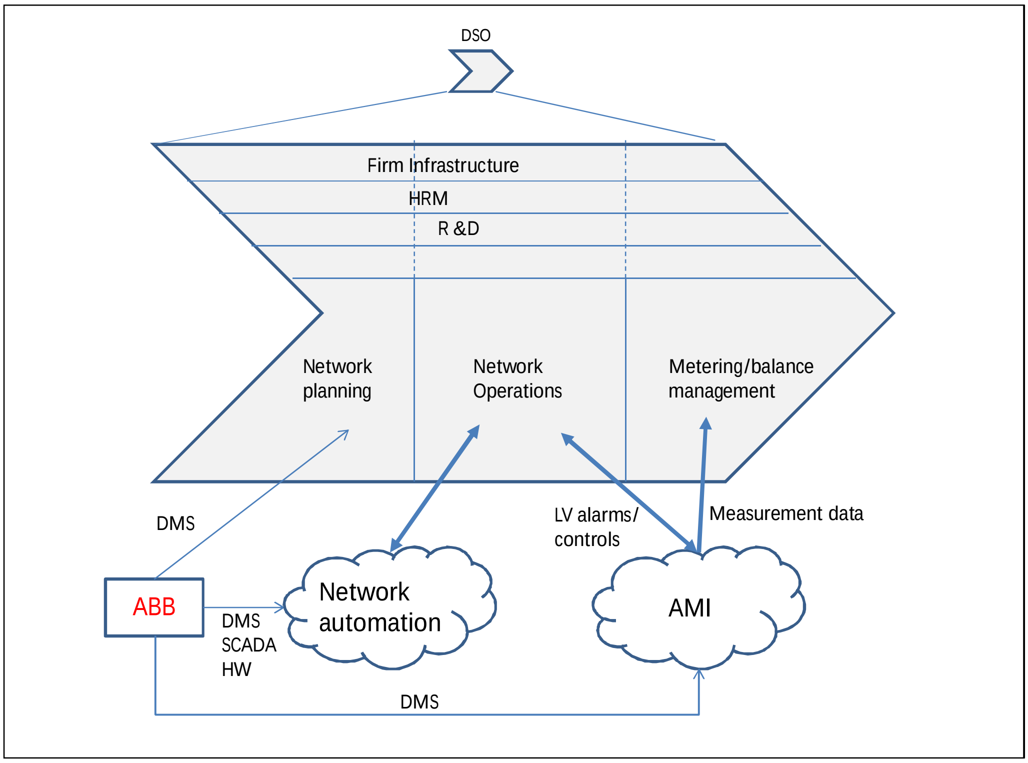

Figure 3.2. *Value activities of a DSO. (Modified from Porter 1985.)*

3.2. Value network in smart grids

When it comes to smart grids, the traditional value chain has to be changed. It is stated that energy markets are going to be reformed within changes related to smart grids. It is going to be similar to what mobile phones and internet did to communication industries. Probably the greatest change is that also end consumers - who were passive and feeding only money into the system - are now able to create some value as well. It is done by interactively participating to energy markets. There are multiple ways of doing this. First the ability to generate own power. Second the ability to store power to energy storages and by this way level down peak demand by supplying power from the storage. Third and maybe the easiest way is to control and regulate their energy consumption for example by heating the house and water only when electricity price is low or when overall energy consumption is low. Moreover, these usually occur in same time since electricity price is based on demand. Of course, the consumer is able to execute all these measures together as well.

Different types of value defined by Grönroos are to be discussed closer here as in smart grid environment the consumer is able to create both types of value. In the case of electricity the Grönroos' definition of customer value is especially appropriate. No one procures electricity for the sake of itself but for its ability to be used in multiple devices as a resource to create value. In this sense, the consumer has always created value-in-use and the DSO has been helping him. In the future the consumer is able to create value-in-exchange as well since he has something to sell to the system.

As can be seen in figure 3.3 there is new player involved in the value creation process. It is usually called Aggregator or virtual power plant (VPP). The main task for this participant is to aggregate and control multiple small-scale energy resources. (Lemström et al. 2005; Rautiainen 2008.) It is needed because small producers are not allowed to operate in Nord Pool Spot (there is power limit and participation fee) and it is likely that they don't even want to. (Valtonen & Honkapuro 2010.)

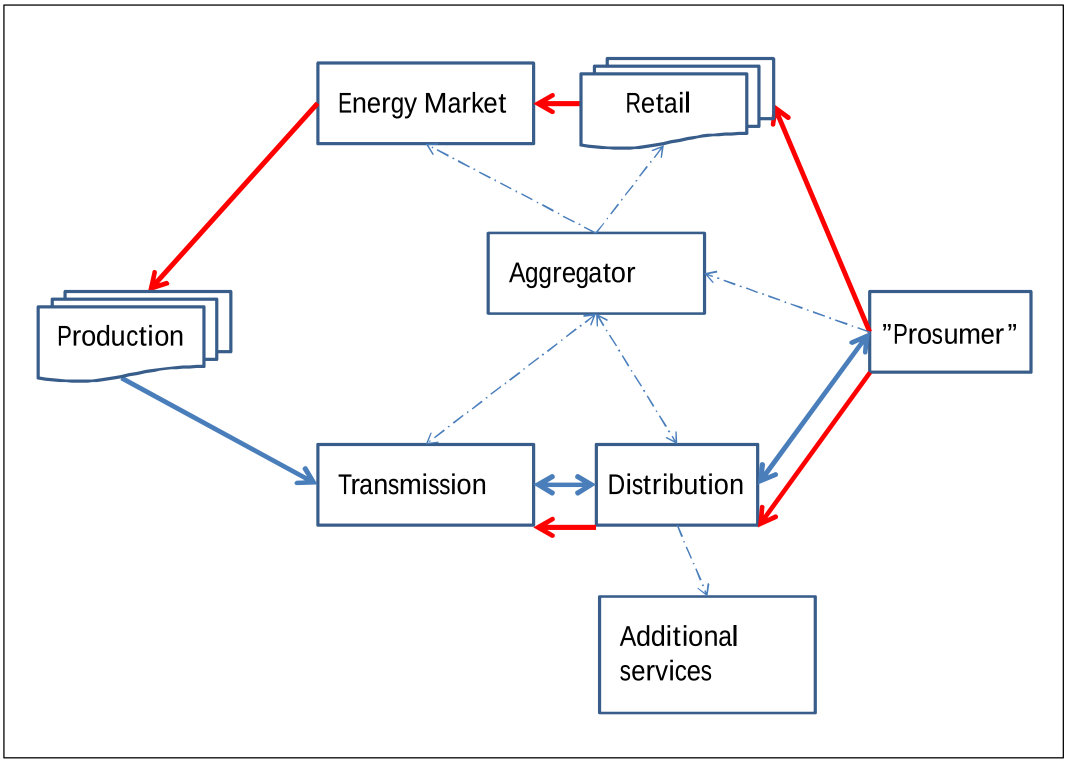

Figure 3.3. *Value network in smart grid environment.*

The aggregator purchases the small production and sells it on the market and is thus capable of gaining the "critical mass" needed to operate efficiently on the market. The aggregator also interacts with distribution companies, since power generated by small producers is transferred through their network. An interaction with the transmission company is also needed for the reason that the aggregator is able to sell production and storage capacity for reserves to be used in frequency control. An aggregator needs a database of all its distributed resources and their attributes. It can also utilize measurement data acquired from third party suppliers. One example is weather data which can be used in load (and production) forecasting. In addition to the database, an aggregator needs reliable communication links to its DER. It is not generally appropriate to build communication from the scratch, but instead utilize incumbent links already established by DSOs and retailers (Valtonen & Honkapuro 2010).

However, there is no aggregator in the market so far. This is mainly due to the fact, that there is not much to aggregate yet and risks are too high for many investors to involve. Obviously, smart grids are going to bring new value to the table and aggregator is probably the one who benefits the most. Consequently, it is likely that some incumbent market operator is going to act as an aggregator at first. (Valtonen & Honkapuro 2010.)

There are several alternatives for aggregation. Firstly a retailing company, since it already has relationships with customers and it already operates on the energy market. To be able to sell small production to the grid, the producer has to have a buyer for the generated electricity. Today, one possible buyer is the retail company so why not in the future in a larger scale as well. Additionally, small-scale production provides an efficient instrument for retailers to be used in procurement portfolio management. Such role is called a retailer-aggregator by Valtonen & Honkapuro (2010). Second alternative is a DSO. It can integrate small production and energy storages to its existing network and thus optimize grid efficiency i.e. postpone network reinforcing investments and share load between feeders. Currently, DSOs are obligated to take the power generated by small plants into the grid and they have to be able to measure power taken from the grid as well as power fed to the grid. Additionally, it is not allowed to net these i.e. subtract power-fed-to-the-grid from the power-consumed-on-site. (Energiateollisuus 2011.) However, under current laws one limitation for a DSO exists: it is not allowed to sell or buy electric energy meaning that it is unable to operate on the energy market (Valtonen & Honkapuro 2010). Third alternative for the aggregator is an energy producer. Small production is usually based on renewable sources and this enables current producers to be “greener” than before by aggregating small production. (Helsingin Energia 2011.) However, in Finland many producers are owned by large industrial companies in order to guarantee low-cost-energy for factories and they do not necessarily benefit from the small production.

There is a so called prosumer in figure 3.3. The prosumer is able to operate both as a consumer and as a producer. Naturally, not all customers are going to be prosumers. One big question is how many are. It is expected that solar photovoltaic systems and wind generators are going to reach grid parity in few years meaning that it is economically feasible to invest in these systems and for instance in Germany this is already happening (Castillo-Cagigal et al. 2011). According to Heiskanen et al (2012) there is some interest in small production in Finland too. However, they conclude that both technology and business processes related to small production should be more developed than they are today for consumers to adopt such systems. (Heiskanen et al. 2012.) The main reason for adoption of photovoltaic systems in Germany is that the German government is heavily supporting PV investments by providing feed in tariffs i.e. guaranteed price for a generated kilowatt hour. According to interviews made by Heiskanen et al. such tariffs would also be appreciated among potential small producers in Finland. (Heiskanen et al. 2012.)

Järventausta et al. (2010) have developed an interface called Interactive Customer Gateway (INCA) to be used between a prosumer and a DSO. INCA can be used to convey measurement signals to DSO or aggregator and control commands from these participants to the prosumer. In laboratory demonstrations there was one computer managing customer's devices i.e. loads, production, and storages. It was also connected to upper level systems like to the DSO's SCADA. Figure 3.4 simplifies the INCA concept. (Järventausta et al. 2010.) Solid lines indicate power flow and dashed line indicates data transfer. Note that power is able to load to both directions between energy storage and INCA and between grid and INCA.

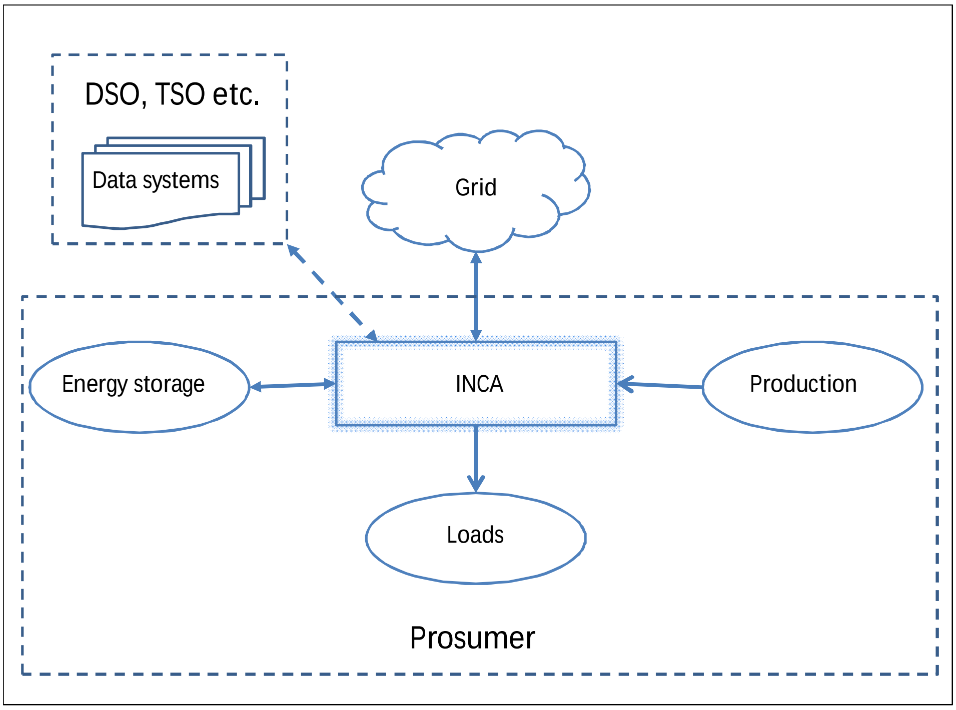

Figure 3.4. *The INCA concept. (Järventausta et al. 2010.)*

There are many open questions related to prosumers. One example is who is going to sell the electricity to the prosumer. Järventausta et al. (2010) suggest that it would be the aggregator (who also buys the production) but in these cases the prosumer's freedom to select its retailer would be compromised. (Järventausta et al. 2010.)

There are also some additional services in the figure 3.3. These can be provided by the DSO or some other participant like the aggregator or the retailer. One of these services could be a possibility to charge an electric vehicle (EV). A change to reduce energy consumption by utilizing demand response (DR) could also be provided as a service. In fact, Fortum Kotinäyttö is one of these applications even though it is not able to control any loads but instead it gives detailed information about home's energy consumption and thus helps to optimize it (Fortum 2011). More sophisticated DR service could be to convey messages through network to customer devices. Another service opportunity is to advice customers in DER related issues as well as in energy consumption issues. Such services are already available today but it would be possible to exploit them more. However, when it comes to energy consumption issues, it would be necessary to decouple DSO-charged-fees from the consumed energy for the counseling to be credible.

In smart grids a DSO can be seen as a market place provider where it enables transactions between participants and takes care of technical conditions related to the network. (EMV 2011b.) This leads us to the key activities of a DSO: Firstly, to operate the network and guarantee pre-agreed conditions for producers and consumers. Secondly, manage the assets committed to the network i.e. optimize LCC (Life Cycle Costs) of equipment and make plans for development. This is indicated with "Network planning" in figure 3.5. It is likely that these activities are still going to maintain their position as key activities whereas many other activities like network construction can be purchased as a service. Metering can be considered as a key activity too even though technical metering and other AMI activities can be outsourced. In these cases, however, the responsibility for the measured data stays with the DSO. (Lakervi & Partanen 2008, pp. 21-22; Tuntimittaussuositus 2010.)

Figure 3.5 illustrates DSO's value activities in smart grid environment. A new activity called "Services" is appeared. It means additional services provided to the customer by a DSO. However, services like transmitting demand response signals can be provided to other market participants like to the aggregator as well. Arrows indicate that control command asked by others (or DSO itself) are sent through DSO's network and/or communication links. Automation related to MV and LV networks are combined to one singe cloud which refers to devices and communications needed. ABB is still providing equipment for network automation and tools for network planning and operations.

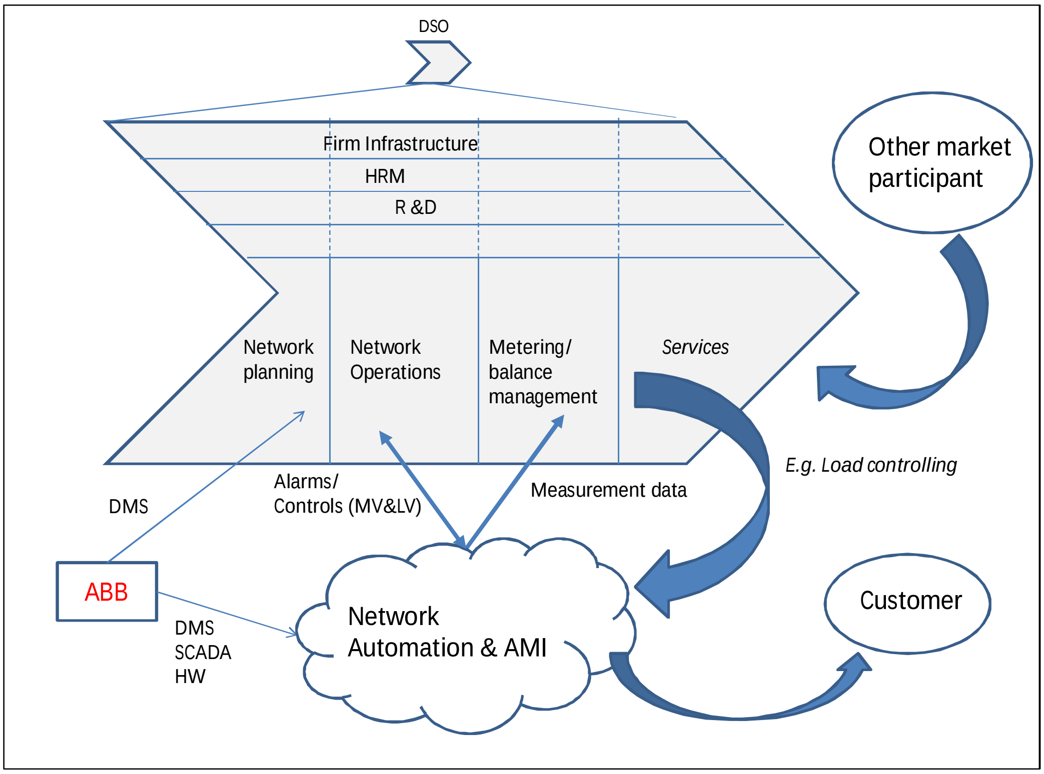

Figure 3.5. *Value activities of a DSO in Smart Grid environment. (Porter 1985.)*

As a result it can be stated that value networks in smart grid approach are more complicated than before. There are many open questions for instance about what kind of business models can be created. These models are not studied in this thesis but an underlying assumption is that DSO provides a platform, which is used by retailers, aggregators, and other players to make business. DSO takes care of physical conditions and intervenes in market actions if it is needed on technical or security basis.

3.3. Technology acceptance model for distribution system operator

Technology acceptance model fitted into power distribution environment is presented in this chapter. The model can be used to study the acceptance process of any participant but here the investigation is limited to the DSO's viewpoint. This is selected because it serves the aim of the thesis. Moreover, the model can be used to analyze any technology but here the emphasis is put on studying DER technologies.

It has to be clarified that DSO is not necessarily the investor in these cases. Especially in the case of distributed generation/small production the DSO is not going to be the investor but is has to be ready and aware if someone else invests. One exception still exist: DSO probably needs some backup power in the future as well and it has to invest in mobile generators (or battery units) that fit to the definition of distributed generation. (IEA Enard 2011.) One objective in this thesis is to find out whether or not DSOs have adequate prerequisites to enter to this new environment. The following framework is developed for this purpose.

Figure 3.6 introduces the TAM applied to the DSO environment. Attributes affecting on PU and PEOU are network, DSO's environment, technology, and DSO's organization. Network refers to DSO's network topology and condition. MV network built to looped configuration accepts DER easier than radial network. Also relatively modern network is easier for DER applications than an old one. Environment refers here to the DSO's business environment. For example relative portions of different customer types can be considered as expectations for DSO may be different among industrial customers than among household consumers. Other significant DSO stakeholders are network automation suppliers and network maintenance partners in cases where network construction and field maintenance are outsourced. Automation suppliers' offerings may constraint technical development of the network due to lack of suitable product features. Network maintenance gets complicated as more equipment is installed and adequate skills are required from maintenance persons. This was also indicated by Heiskanen et al. (2012) as they argue that owners of apartment buildings are not enthusiastic about new technologies as service companies lack skills to maintain them. (Heiskanen et al. 2012, p. 9.)

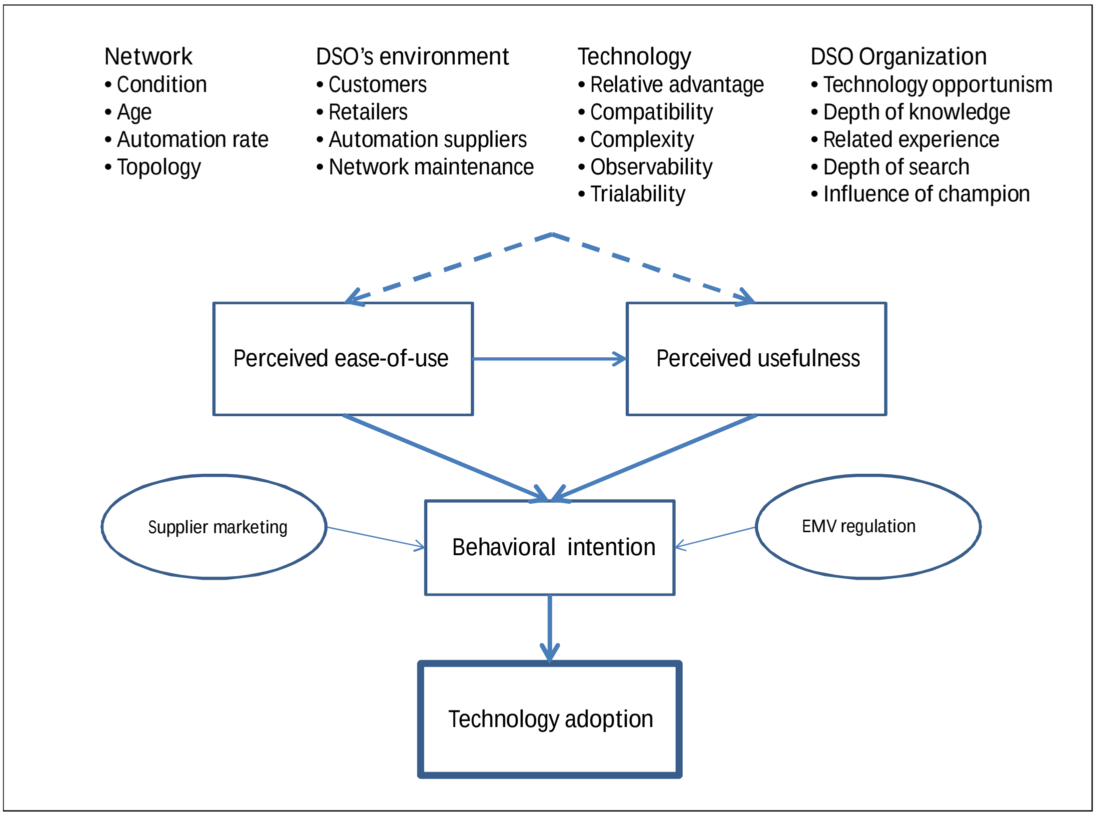

Figure 3.6. *TAM for DSO.*

In case of DER technologies the following topics considering the technology itself are to be discussed.

An issue discussed by Vowles et al. (2011) and Habets et al. (2011) is innovation's radicalness. Vowles et al. found that adopter's perception of innovation radicalness is interesting. They state that radicalness is mainly defined by significant increase in benefits and perception of integrated network where first indicates that radical innovation has notably more benefits than an old solution and the latter indicates that having networks of other users, complementary innovations, and producers available, leads to a higher probability of adoption. (Vowles et al. 2011, p. 1164.) Habets et al. (2011) studied road construction and asphalt equipment in Netherlands and concluded that the more radical the innovation is perceived by the adopter the less eager the firms are to adopt. The study was based on questionnaire asked both the industry experts and companies. They also concluded that firms having more knowledge resources i.e. educated and skillful personnel are generally more interested in innovations. However, they are also better aware of disadvantages introduced by new technologies. (Habets et al. 2011.) Hence, the radicalness of DER related innovations are to be discussed within this thesis.

Relative advantage inside each domain is another issue. For example DSO's geographical environment has an effect on which technologies of distributed generation are the most suitable. Needs and prerequisites are different for a DSO located in northern inland than a DSO located in southern coast. Another level of relative advantage is the comparison between different DER applications: Is it better to invest in energy storages or demand response devices? However, it is possible to invest in many types of technologies as they are not mutually exclusive. The third and the most important level is the relative advantage with respect to conventional grids. The question is: Do DER applications have relative advantage over cabling and increase of network automation? Ghobakhloo et al. (2011) found that perceived relative advantage together with perceived compatibility were the most important things regarding electronic commerce adoption. (Ghobakhloo et al. 2011.)

Compatibility with existing equipment and past experience needs to be evaluated. Generators are known to be efficient and capable of supplying power for customers also under exceptional circumstances but there is no similar experience of storages. Connecting storages to the grid is more complicated since power has to be able to flow in both directions securely. Demand response requires communication between devices which, in turn, has to be based on standards that don't yet fully exist. This leads to a rigorous selection of applied technologies. Rogers mentions compatibility with previously introduced ideas and concludes that all new ideas are compared to existing practices (Rogers 2003, p.249). This may lead to objection of DER technologies as they differ to some extent from earlier solutions. Some new ideas may be required as DER applications are not necessarily needed in DSOs.

Complexity of smart grid systems is obvious. Complexity is, however, reducing all the time as standards are evolving and some procedures can be proved to be better than others. DSO has to live with complexity as DER applications are probably going to appear to networks and DSOs are obligated to ensure their connectivity. How much is the complexity actually increasing? Some DSOs might also see this as an opportunity and are not worried about the increased complexity at all.

Can anyone observe the benefits? What even are the benefits and how they are measured? Usually DSO's customers don't know what is happening in the grid. They only observe the failures so one of the questions is can the number of outages be reduced by using the technology? Another question is whether the DSO is able to reduce its total costs somehow.

In the case of DER, trialability means pilot projects. DER equipment is expensive and it cannot be widely installed for trial. Pilot projects are usually carried out with device vendors and other stakeholders and they are partly funded by government. This makes these projects beneficial for all participants and they are definitely needed in order to gain experience. The important questions are where to pilot and what to pilot since everyone has to have something to give to the pilot project. Good examples of pilot targets are new residential areas and building blocks as well as housing exhibition areas, where a third party investor (constructor) is investing to a new technology and a DSO provides adequate network infrastructure together with metering and communication/control equipment.

PEOU is especially affected by complexity and compatibility of the technology. Device and system vendors like ABB have to play a big role here as their solutions define the usability of the entire system. Moreover, beyond actual devices like generators there is the system management level which requires emphasis on development of network management solutions.

When it comes to organizational issues, the framework developed by Vowles et al. (2011) can be used. Table 1 summarizes the essential topics in this area of interest. However, it has to be noted that changes needed in organizations in order to adopt DER are going to be small if there even are any. Another question is if some organizational adjustments need to be done afterwards in order to operate smart grids efficiently. As a consequence, organizational viewpoint is needed here to chart if DSOs have resources needed to adopt and operate DER applications.

Table 1. *Organizational issues. Modified from Vowles et al. (2011).*

Attribute	Questions
Technology opportunism	- Number of people working with technology - Is there a separate R&D department?
Depth of knowledge resources	- IT expertise - Educational and career background of managers - Number of people in planning
Innovation related experience	- DER related experience in a firm
Depth of search	- Information channels: conferences, pilot projects, cooperation with universities etc. - Number of people available in information seeking
Influence of champion	- Are there champions? Who are they?

As can be obtained from table 1, the number of people interacting with new technology is vital for technology adoption. In DSOs there are multiple operational tasks going on and at least in smaller firms it is possible that there is no time for sensing and analyzing new technologies. Moreover, lack of suitable pilot projects can form barriers for adoption of new technologies as a possibility to gain experience is lost with the missing pilot.

Network externalities and community support i.e. surroundings of the firm have an impact on PEOU. In the smart grid environment the DSO has to interact with many stakeholders like customers and electricity retailers. As a consequence, every participant has to be ready for change in order to create working smart grid environment. This is perhaps the biggest challenge, since neither DSO nor anyone else can operate smart grids alone. Again, pilot projects are important to be able to develop interaction between participants. This is also concluded by Vowles et al. (2011) as they state that three types of networks are required (Vowles et al. 2011.) Perhaps the network of complementing products turns out to be the most important here as network management solutions are needed in order to efficiently incorporate DER.

Supplier marketing has an effect on the decision which supplier's offering to go for. Additionally, suppliers have a messenger's role as they spread information about new technologies and related standards. Probably the adoption decision is based on suppliers' ability to provide working solutions instead of small pieces of equipment. According to Moore (2006) this opinion gets stronger when moving from innovators to early adopters and again to early majority. Innovators are ready to live with uncertainty caused by new technologies and they are prepared for additional configuration work. (Moore 2006, p. 22.)

There is an authority to supervise power transmission and distribution activity, i.e. make sure that DSO's duties are fulfilled and their pricing is reasonable. In Finland the authority is called Energy Market Authority or EMV (Energiamarkkinavirasto). It has defined WACC (weighted average cost of capital) based limits within which the DSOs are allowed to make profit. If the amount of profit is too much, it has to be compensated for the customers by lowering transmission fees. All the DSO's income is based on transmission fees collected from the customers which again, depends on pricing. Thus, without regulation, the DSO could charge as much as it wants. Interestingly, the profit is based on committed capital rather than on revenue, which makes metrics like EBIT look misleading. The capital committed to distribution networks is large compared to annual revenue which leads to high EBIT figures even with a moderate rate of return. Large DSOs in Finland like Fortum and Vattenfall had an EBIT% of around 40 in 2010 which has raised some debate about the appropriateness of the regulation. (Kankare 2012.)

The third supervision period started on first of January 2012 and it ends in 31 December 2015. The main idea for the new period has been to include some incentives to the regulation in order to encourage DSOs to operate in a desired way. An example of this is to allow greater profit for a company who invests in network reliability improving technologies. This improvement is made for example by building underground cable lines and installing network automation devices. The allowed profit gets higher when the number of outages perceived by a customer gets smaller. As a new component, there is going to be an *innovation incentive*, which aims to encourage DSOs for innovative actions. First part of this incentive enables DSOs to deduct research related expenses from EBIT before the final EBIT is calculated. The second part gives DSOs a possibility to deduct five Euros from EBIT per installed AMR device. However, this deduction is possible only for customers having primary fuses smaller than 63A and balance management has to be based on hourly data. Additionally, if balance management was based on hourly data before 1.1.2011, the DSO is not allowed to make the deduction. (EMV 2012.)

Governmental regulation affects BI because it may limit the benefits gained from DER technologies. This could also have been included in DSO’s environment mentioned in attributes affecting PEOU but it requires its own part as it has significant impact and it can be changed without changing the technical and environmental aspects.

4. RESEARCH METHOD AND MATERIAL

4.1. Research method and data

There are two main research methods in this thesis. First one is called semi-structured interview. It is used to gather information on how DSOs see their future when it comes to DER and what prerequisites do they have to adopt DER applications. Four DSOs are interviewed. They are selected in a way that they represent different types of companies. Helen Sähköverkko (hereafter Helen) is large urban DSO in Helsinki city area and it is part of Helsingin Energia corporation. Fortum Distribution is the largest DSO in Finland and it manages urban and rural networks in different parts of Finland and it is part of Fortum Ltd. KENET Oy is a small DSO found in Kokkola region western Finland. It represents small company owned by city of Kokkola. Jyväskylän Energia Siirto (JES) is part of Jyväskylän Energia corporation. It operates on a small urban area in Jyväskylä in central Finland. One reason for selecting these particular companies is that they are ABB's MS Pro customers although Helen doesn't have MS Pro products in use but they may be used in control room in Kalasatama pilot project. These DSOs represent different types of networks and different types of geographical environments as well as business environments.

Interview questions introduced in chapter 4.3 were sent to informants by mail about two weeks prior to actual interviews. This gave them time to find correct answers and find out the required information. The actual interview was carried out in customer's premises at it took 1-2 hours depending on interviewees other ongoing tasks. There were two to four DSO representatives in the meetings and they were mainly representing network operations. In KENET and JES there were also network planners involved.

An alternative method for gathering information from DSOs would have been to carry out a mail survey. Probably it would have been carried out by email or even by a third party service application found in the internet. However, the mail survey was not selected because of the nature of the research. Firstly, there are 87 DSOs in Finland and according to Saunders et al. (2009) the typical respondent rate is around 35 per cent (Saunders et al. 2009, p. 222). This would result in around 20 answers meaning that there is no place for a statistical analysis. Secondly, and more importantly the nature of the research is to find out what are DSOs' current conditions regarding DER applications and these topics are not fully covered with simple yes or no type questions. The author has also heard some rumors that DSO managers are not eager to answer complicated questions asked by mail by some random student as answering would require searching of information and at the same time the managers are not able to see the corresponding benefit.

Second method is exploiting of secondary data which is used to gather information on how DER applications can benefit the DSO. This method is chosen because DER applications have been studied by scholars and firms around the world. Calculations and comparisons have been made in order to find out what are the most important benefits of technologies. A lot of research has also been made in SGEM. Many publications in SGEM are related to DER and they can thus provide some information regarding possible benefits. Another method for searching of benefits would have been simulations which are often used in electricity engineering research. However, the nature of this work is to find common denominators instead of finding absolute solutions for a particular case. Therefore simulations were found to be unsuitable. Furthermore, lots of valid simulations have been carried out in SGEM by VTT for instance.

4.2. Research environment

4.2.1. Distribution network industry

The major difference between distribution network industry and many other conventional industries is that there is no competition in power distribution industry. This natural monopoly of DSOs (and TSO) is economically justified since there is no point to build several parallel networks to perform the same task. The main argument for this is, of course, that distribution networks are expensive to build and to some extent complicated to maintain and use.

The entire chain from a generation plant to a household customer is monopolized. In Finland there is Fingrid Oy to handle national power transmission in voltage levels between 400 kV and 110 kV. These networks are built to withstand storms and other harsh weather conditions. There is also a so called n-1 criterion which means that any device in the network can break down without causing an outage to Fingrid’s customers. There are 12 companies to take care of so called area transmission (usually 110 kV voltage level). And finally, there are 87 DSOs to distribute power to end customers usually with voltage levels of 20 kV and 400 V even though a medium voltage of 10 kV is used for example in downtown Helsinki. (Lakervi & Partanen 2008.) DSOs have duties defined by EMV to maintain and develop their network, transfer power through the network, and attach new consumers and production plants to the network. (EMV 2011.)

4.2.2. Distribution network topology

Conventionally power is generated in centralized power plant and transferred through multiple voltage levels to the end customer. In the case of distribution networks (MV), the system has been simple and hierarchical as well. Power consumed by a household customer is distributed from the primary (HV/MV) substation to the secondary (MV/LV) substation and then to the customer. The essential point is that the MV network is used in radial configuration i.e. there is only one route for power to flow. In the smart grid approach things are done differently. Figure 4.1 illustrates this change in network topology. The core idea in smart grids is to use network in a way that power is able to flow bi-directionally. Production is also distributed to all voltage levels. This means that consumer is able to be a producer and the other way around.

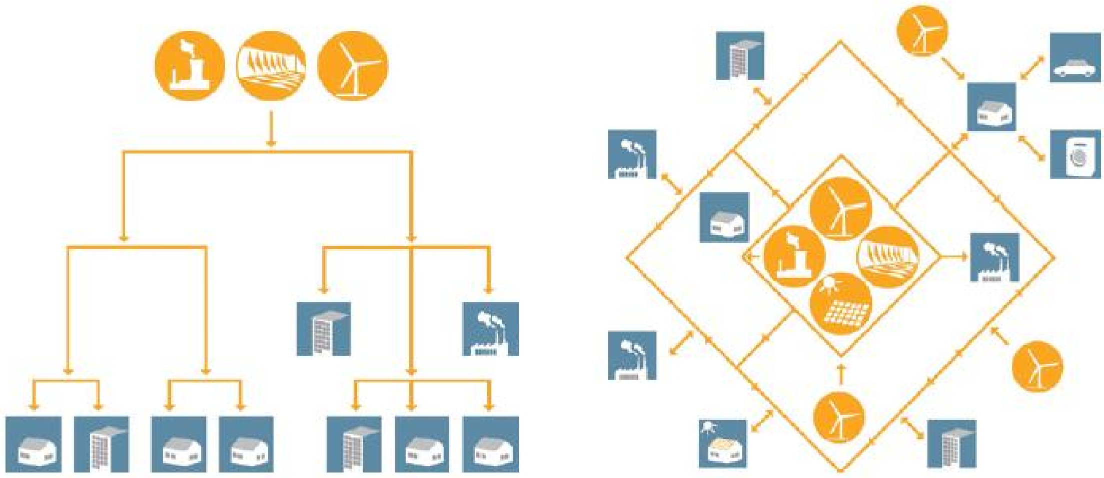

Figure 4.1. *Conventional grid and smart grid (ABB 2009).*

Another aspect related to network topology is that MV networks are used in looped/meshed configuration i.e. there is at least two routes for power to a network node. This makes network management and protection more difficult but on the other hand it improves network reliability. Also LV networks can be used in meshed configuration although it is less likely.

4.2.3. SCADA/DMS

The control and supervision of the distribution network is made by using SCADA and DMS. SCADA or Supervisory Control and Data Acquisition system is used to interact with switching devices and measurements in different parts of the network. It is able to read measurements and control devices remotely. The operation of SCADA requires high reliability as well as secure communication. Some SCADA systems are operated outside the internet in order to guarantee cyber security while some systems can be controlled via Virtual Private Network (VPN). The corresponding product in ABB's portfolio is called MicroSCADA Pro SYS 600. Figure 4.2 illustrates the user interface of SYS 600.

DMS or Distribution Management System is able to combine SCADA information and geographical information to create an intuitive illustration of the state of the network.

DMS interacts also with other systems like Customer Information System (CIS) to locate customers and create customer specific outage reports, and Advanced Metering Infrastructure (AMI) to receive hourly load data and LV network alarms. The main task of DMS is hence to help DSO personnel to manage the network and make informed decisions in network operations.

The corresponding ABB product is called MicroSCADA Pro DMS 600. It is divided into three separate programs called Network Editor (NE), Workstation (WS), and Server Application (SA). NE is used to edit current network data and plan new network. Calculation functions are available to ensure that all necessary technical conditions are met. NE writes data to the database and creates a compressed binary file of the database used by WS instances. WS is the operational tool for DSOs. It shows the network topology overlaid to a geographical map or an aerial photo. It uses colors to show connected lines and unsupplied lines and it informs the user if a switching operation causes a loop or the device is not able to handle the predominant load current. SA in turn is responsible of connection with SCADA. It tracks switching state changes made by SCADA and forwards these changes to WS instances.

DMS 600 is capable of performing the following advanced tasks:

- Calculate and show voltages in different parts of the network
- Calculate load and fault currents
- Locate faults and recommend restoration operations
- Plan switching operations
- Manage LV networks via AMI/AMR
- Analyze load-production balance in islands
- Forecast future network conditions (loads, voltages)

There are many other features in DMS 600 as well and new features are needed in order to be able to control smart grids efficiently.

Figure 4.2 shows the user interface of DMS 600 Workstation.

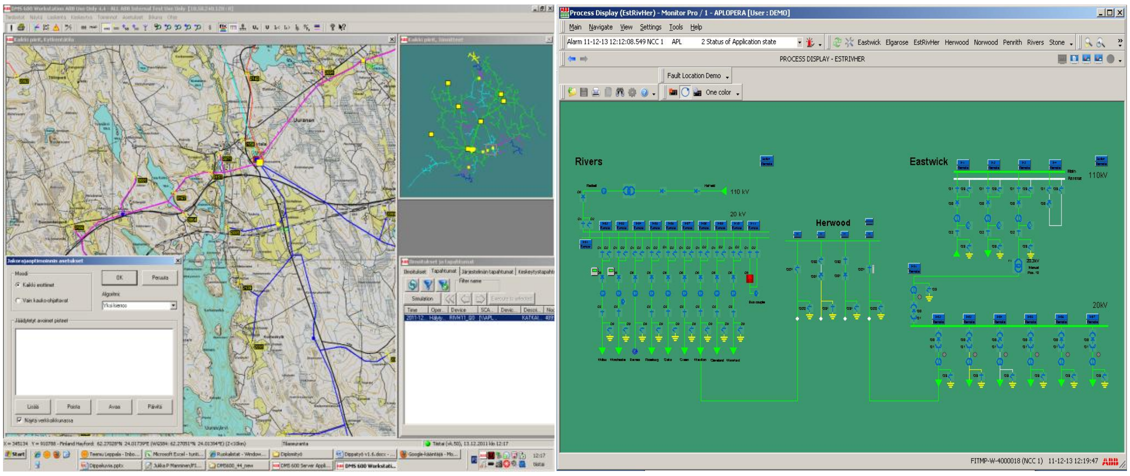

Figure 4.2. *DMS 600 WS and SYS 600 user interfaces.*

Originally DMS was used centralized in the DSO level i.e. one DMS system handled the whole network. This is still the case in many companies. However, current DMS version can be utilized in different network areas within DSO. One control center acts as a main control center and others are called area control centers. The area control centers are able to operate independently in case of a communication line break and changed data can be replicated afterwards.

It is likely that network areas are going to be more common in the future. This is due to increased data transfer between the network and the control center. It is not appropriate to handle all data in one control center and in some cases it may be just impossible.

4.2.4. Distributed generation

Distributed generation can be defined as generation connected to a distribution network (MV or LV) although some distributed generation can be connected to 110 kV network as well. Probably better definition is based on generated power. According to Borbely & Kreider (2001) distributed generation has power output less or equal to 10 MW. It follows from this definition that wind farms with three or more large (5 MW) windmills are no longer distributed generation. Borbely & Kreider also conclude that some wind farms and hydro power plants are not genuine distributed generation as they are dependent on location. (Borbely & Kreider 2001.) Moreover, distributed generation is by definition located next to loads which decreases losses and thus makes power distribution more eco-friendly.

Electricity market act defines small scale production as production with power output less than 2 MVA (Electricity Market Act 386/1995). Small scale production is further divided into four categories by Energiateollisuus.

1. Power plants not connected to a grid. These are usually found in summer cottages etc. and they are not dealt with in this thesis.
2. Power plants as a substitute for distribution network i.e. backup systems. These are found for example in farms.
3. Power plants operating parallel to distribution network while power is not fed to the grid. This type is known as peak shaving.
4. Power plants operating parallel to distribution network and power can be fed (partly or fully) to the grid. (Energiateollisuus 2011.)

Plant categories 2-4 are considered in this thesis as they have or may have an impact on DSO's operations.

There are various technologies available for distributed generation. Diesel engines are widely used in remote areas but renewable fuels are getting more and more popular in this field. Wind and solar power are the most common technologies followed by small-scale hydro and some wave and tide based systems. Combustion based systems are also widely installed at least in Finland where wood and peat are used as fuel.

4.2.5. Energy storages

Traditionally storing electricity in a wider scale has not been sufficient. Instead, energy has been stored in natural or artificial lakes to be transformed to electricity when needed. This method is still important in Finland where more than 16 percent of electricity is generated with hydro power. (Energiateollisuus 2011.) However, in Finland these processes are mainly irreversible meaning that excess electricity cannot be used to pump water to upstream pools. It follows from the poor storage possibilities of electricity that power generation and demand have to be equal all the time.

The classification made for small scale generators is suitable for energy storages as well. In this thesis only storages affecting on DSO's operations are worth taking into consideration which, again, relates to classes 2-4. Utility-class storage requires around 1 MW power capacity and 1MWh storage capacity.

4.2.6. Demand response

Demand response is also called Active Demand Side Management (ADSM) in some publications. It refers to means to control customer loads according to some parameter. One of these parameters is grid frequency which indicates the balance between demand and consumption of the entire grid. Another parameter is electricity spot price which is easier to understand by customers.

There are some issues to be decided in DR. What loads to control since not all consumer loads are going to be controlled. Heating and cooling are probably the most suitable ones. Another issue is related to the level of automation in homes. One way to do DR is to install a smart device which measures or detects changes in control parameters and performs operations according to these changes and pre-programmed rules. These devices can also be located elsewhere and commands are conveyed through the network. This may be easier way as the amount of installed devices is smaller. However, in case of fault or other exceptional network situation the control command has to be given somehow by a DSO. This requires at least an agreement between customer and DSO and a reliable data connection between customer's control unit and DSO's SCADA or DMS. A standard developed for this purpose by CIM User Group of IEC is called IEC 61968-9. It uses CIM (Common Information Model) to define attributes and parameters needed to execute demand response operations. The current model is introduced in 2009 and a newer version is under construction and it is estimated to be released by the end of 2012. (ABB internal document.)

4.3. Questions for customer interviews

The questions introduced in this chapter are used in interviews with DSOs to find out their prerequisites to utilize DER and what are their future expectations. There are four main areas of interest which are also found in theory: network, organization, stakeholders, and technology.

Network

Q1: What is your network's state in terms of cabling rate, average age and automation rate (e.g. remote controlled disconnectors/ all disconnectors)? This question simply sheds some light on network's overall state. Answers can be used to evaluate whether or not the network is ready for DER. As discussed in chapter 3.3 the higher the automation rate, the easier it is to remotely form islands and thus avoid outages. Cabling rate refers to the part of the network that is constructed by using underground cables. High cabling rate is expected to decrease the usefulness of DER as cable enables reliable supply under all circumstances. Additionally, cables can't take loads higher than they're rated for. In cases of power restoration, the cable can even prevent the utilization of DER.

Q2: What are your biggest concerns related to network? For example load levels, reliability etc. This question gives a chance to tell about problems. Answers can be used to evaluate if DER is able to provide solutions. Perceived usefulness regarding DER remains low if it is not able to solve current problems. It is expected that many problems are related to network age and new DER equipment cannot help there. On the other hand, old network can be seen as an opportunity as renewal of old network enables DER to be taken into account.

Q3: Do you have to take DER into consideration when planning networks today? This is to find out if DSOs are already prepared for DER diffusion in planning somehow. Preparation does not necessarily mean that there is actual DER in the network yet. This also tells something about interaction between DSO activities i.e. planning and operations. Porter (1985) states, that effective value creation requires strong links between activities. This question also has a link to question two as renewal of old networks requires planning where DER should be taken into account.

Q4: Are you taking DER into consideration when planning maintenance outages? This is preparation from the operations point of view. One example is a generator in an LV-network, which is able to back-feed the MV network. This question also measures technology opportunism: Are firms ready for technology development?

Organization

Q5: Do your operations/planning personnel have DER related experience? Are you putting some effort on evaluating future technologies? This is to find out how technology oriented the organization is. Amount of innovation related experience as stated by Vowles et al. (2011) is found to be a factor in adoption process. This question may also help DSOs as it gives them a possibility to evaluate their skills and resources. The second part of the question measures firms' depth of search ability. Are they willing to do some research and furthermore, do they have resources to do it.

Q6: How good is your knowledge with respect to smart grid? Is your strategy and management's attitude behind it or against it? The first part measures firms' depth of knowledge resources. The scope is wider as knowledge about smart grids is asked. DER is part of smart grid but if the basic knowledge is lacking, it would be difficult to understand DER. The second part of the question is to chart the overall atmosphere and management's attitude or influence of champion as stated by Vowles et al. (2011), which is found to be very important in the adoption process.

Q7: Does your organization structure support SG environment? Is it likely that you are going to need new vacancies or even departments in the future? Current organization structure of DSOs may not be suitable for new environment because the amount of data collected from the field is larger than before. Probably DSOs are not able to answer this simply because they don't know. However, they might have some idea about their future organization, which can be checked against author's assumptions.

Technology

Q8: Do you have distributed generation/ energy storages in your network? How do you see their development within next five years? This is to find out current state of DER, and DSO's vision of DER diffusion especially on their site. This question can also be used to evaluate DER related experience. The second part answers can be referenced to a smart grid roadmap developed in SGEM (Parkkinen & Järventausta

2012). It is likely that results are quite similar as the roadmap is developed by asking DSO opinions. However, in that study the operations personnel were not in the target group.

Q9: On scale 1-5, how much do you think network complexity is going to increase if there are distributed generation/ energy storages attached? This question measures the increased complexity of networks. Of course, the increased complexity is due to integrated equipment mainly DER. Numerical value of complexity is acquired which is better than verbal answer even though it is not statistically helpful.

Q10: Do you see any advantages/benefits created by DER devices? How about disadvantages/downsides? These questions measure directly whether or not DSOs see some relative advantage of DER over traditional technologies. Benefits are related to perceived usefulness as they would enhance DSO's performance while disadvantages would weaken performance.

Q11: What are the major challenges with respect to DER diffusion? This question is to acquire DSOs' ideas about barriers of diffusion of DER. Price is probably one barrier but it may not be first on the list when looking from the DSO's point of view. Technology complexity and compatibility issues are expected to arise.

Stakeholders

Q12: Can you perform your daily operational/planning routines with current SCADA/DMS tools? This question is to find out DSOs satisfaction to used tools. This question and especially the next one are also to evaluate DSOs' PEOU with respect to smart grids and DER.

Q13: What new requirements for SCADA/DMS in order to fulfill tasks in SG environment? This question evaluates smart grids from control system point of view. Interviewees should think what would be required from the control system in order to manage smart grids efficiently. In this question also, the scope is wider as it covers smart grids as a whole instead of DER. SCADA/DMS features are connected to PEOU of the system as they can dilute complexity perceived by operators.

Q14: Are you involved in pilot projects or in university cooperation? This question is to find out if the interviewed DSO has a possibility to increase its DER related experience somewhere. Theory mentions pilot projects as a good way to gain experience. University cooperation is included because smart grids (and DER) are studied in universities and DSOs are able to get knowledge by cooperating.

Q15: Are your customers interested in distributed resources? This question charts DSO's customers' interest towards DER. It can be easily obtained by a DSO as contract with it is needed to be able to connect small production. The idea behind this question is to see whether potential small producers have already planned production. This information can, again, be used to assess how quickly new product features are needed.

Q16: How is your AMI handled? Is it capable of controlling loads i.e. performing demand response activities? This question is to find out if the installed equipment is capable of conveying control commands and thus enabling demand response operations. This information is needed in order to see whether the interviewed DSOs are technically able to participate in DR.

Q17: How DR will be implemented in the future i.e. who is controlling and via who's equipment? This question requires visioning of future events. Answers can be used to evaluate the current state of DR as well as system readiness. This question should provoke discussion about different DR concepts. DSOs may have different opinions regarding DR activities.

Q18: Do you see new business opportunities for a DSO? Some services perhaps..? This question is designed to find out if DSOs have ideas about new business opportunities. Because the questionnaire is targeted to operations personnel in DSOs it is likely that they don't have business related answers. However, operations personnel probably have an understanding on what is DSOs role in the future. Answers can be referenced to assumptions made in chapter 3.

5. RESULTS

5.1. Available technologies

This chapter introduces available technologies related to DER. All available technologies are not represented here but the following technologies are likely to be used in distributed generation, energy storages, and demand response within next five to ten years. All technology areas are divided to sub levels, where key technologies are evaluated. Additionally, different technologies are looked from the network point of view to see what challenges or possibilities they might bring in.

5.1.1. Distributed generation

5.1.1.1 Wind power

Wind power is based on energy committed to moving air. Wind turbines are used to harness this energy by converting it to rotating motion, which again, is easy to convert to electricity. Due to physics related to energy content of wind, there are two main factors defining the power provided by the mill. Wind speed is the most important one as power output is proportional to the cubic of wind speed. This factor guides mills to be constructed to windy locations like coasts or even to the sea. Another factor is swiping area i.e. the area covered by a turbine rotor during one rotation cycle. The swiping area is proportional to the square of radius i.e. the length of a rotor blade. As a consequence megawatt class wind mills have inevitably to be designed large in size. (Laaksonen & Repo 2003.)

In wind mill layout, the dominant design is established to be horizontal axis and three-bladed rotor placed on the up-wind side of the tower. However, some smaller mills are still using two-bladed rotor as it is easier and cheaper to manufacture even though not as efficient. Additionally, a two-bladed design usually requires higher rotating speed which leads to noise problems. (Wind energy – the facts 2012.)

When it comes to operational solutions found in wind turbines there is no dominant design anymore. Some turbines operate with fixed speed and some are able to operate with various speeds. As the grid frequency is constant 50 Hz in Europe and the frequency of the turbine’s output voltage depends on rotating speed, the machine has to be internally designed to supply correct frequency. A gearbox is used to increase the turbine speed (around 10-25 rpm) to about 1000-1500 rpm required by the generator. This is relatively easy with fixed speed machines as they are connected to the grid only when the speed is appropriate. This, of course, limits the variety of wind conditions under which the turbine is able to operate. This limitation is overtaken by some manufacturers by installing a double-winded generator, which provides for example a four-pole and six-pole machine in a same body and thus a constant output frequency with two different wind speeds. This solution, however, brings more costs and weight to the system. (Laaksonen & Repo 2003.)

An alternative way of supplying constant frequency with varying wind speeds is to use power electronics between the grid and the generator. This solution can provide simple mechanical structure of the turbine, but investment costs of electronics are higher. A permanent magnet generator can be used as well but weight of magnets cause problems. From the grid point of view the electronics are creating harmful harmonics to the grid but on the other hand, fixed speed machines are causing voltage sags when connected as they draw heavy reactive power required by the asynchronous machine. (Laaksonen & Repo 2003.) However, voltage sags can be avoided by using soft start devices and reactive power can be compensated by using capacitor banks even though these produce more costs for the investor.

Table 2 sums up the used alternatives, their controllability, and their impact on a grid. Asynchronous short circuit machine is the traditional solution, where gearbox is needed to have appropriate speed for the generator. As discussed earlier, two different speeds are possible. Neither output voltage nor reactive power can be controlled which basically means that a strong grid is needed. Asynchronous slip ring machine allows variable turbine speed (within some range) as rotor resistance can be controlled via slip rings and thus enable multiple asynchronous speeds without compromising the output frequency. The downside in this solution is its inability to control voltage or reactive power which again leads to strong grid requirement.

Both synchronous machines found in the table are connected to the grid via power electronics where output current is first rectified to DC and then inverted back to AC with grid frequency. In traditional synchronous machine, some DC is required to excite the generator, while permanent magnet solution doesn’t need such arrangement. Both solutions are controllable with respect to voltage and reactive power which enables connection to weaker grids as well.

Table 2. *Wind generators and their specifications. (Modified from Laaksonen & Repo 2003.)*

Generator type	**Gearbox**	**Speed**	**Voltage control**	**Q control**	**Grid requirement**
Asynchronous (short circuit)	Yes	Fixed or variable (one or two)	No	No, Q consumer	Strong
Asynchronous (slip ring)	Yes	Variable	No	No, Q consumer	Strong
Synchronous	Yes or No	Variable	Yes	Yes. Setting cos(f) or setting Q	Strong or Weak
Synchronous (Permanent magnet)	No	Variable	Yes	Yes. Setting cos(f) or setting Q	Strong or Weak

Laaksonen & Repo (2003) argue that wind mills or wind farms generating more than 10 MW are usually connected to 110 kV grid while smaller 5-10 MW mills are connected to 110/20 kV substation using their own feeder. This solution enables more efficient voltage control and easier fault clearance as generator feeder can be simply disconnected. Less than 5 MW mills are connected to the existing MV network by using appropriate transformers and protection devices. (Laaksonen & Repo 2003.)

In smaller (<20 kW) wind mills the solutions discussed above are still applicable. However, the most complicated control solutions are not suitable due to high investment and maintenance costs. These mills are used in stand-alone systems like in boats and in summer cottages but there are also mills used parallel to a distribution network, which are of interest here. These devices always have some power electronics embedded which enable cheaper generator configuration and a possibility to synchronize the system with a local grid. Permanent magnet generators are used as their prices have decreased and reliability has improved. Generally, small wind turbines are developing to the direction of bigger ones with respect to blade materials and internal design. Biggest costs are related to inverters. Little information is available whether or not these inverters can be used to control active power output. This ability would be appreciated by DSOs as can be seen later. (Wind energy – the facts 2011.)

There are also vertical axis designs available for small wind turbines. One manufacturer of such is Quiet Revolution Ltd which provides vertical axis turbine Qr5 to be used in urban environment. The main advantage is, that the turbine doesn't have to be yawed (rotated) towards wind as the design is symmetrical. Additionally, it is especially useful in changing and skewed winds which makes it suitable for urban environment where tall buildings affect wind speed and direction. This particular model is capable of supplying 6.5 kW power to the grid (Quiet Revolution 2011).

Following table 3 sums up the major planning parameters regarding a wind turbine investment. There are two types of turbines analyzed as for them these parameters differ from each other. Some figures for large turbines are taken from TEM (2009), which recommends feed in tariffs for wind power. It has assumed turbines to have output power of 2-5 MVA. Investment cost refers to cost needed to have the mill up and running. The cost is getting smaller as turbine size increases which is due to having about same costs divided for bigger amount of units (kWs). Utilization time refers to the time in which the mill produces its annual energy by running with its maximum power. It is found to be larger for large mills as they are usually located on windy sites and they are higher. Wind is found to be greater in speed and more stable when getting higher above the ground. According to VTT (2011) the average utilization time for Finnish wind turbines was found to be 1650 h/a. It was also stated that year 2010 was not as windy as years before it. (VTT 2011.) Technical lifetime refers to the time the system is expected to operate.

Table 3. *Planning parameters for wind turbines (TEM 2009; VTT 2011; Laaksonen & Repo 2003; Wind energy – the facts 2011)*

	Large wind turbine (>1 MW)	**Small wind turbine (<100 kW)**
Investment cost	900 – 1400 €/kW	2500 – 8000 €/kW
Utilization time	1800 – 2800 h/a (1650 h/a)	1200 – 2500 h/a
Technical lifetime	20 a	15-20 a

As a consequence, wind turbines and wind power is found to be somewhat mature technology. There are multiple commercial solutions available and many technical problems are solved. The technology is evolving incrementally in larger turbines as new technical innovations are developed in order to improve reliability and increase efficiency and thus provide cheaper electricity to the market. In smaller turbines some architectural innovations are more likely to be seen as vertical axis turbines may turn out to be suitable for urban environments. Traditional technologies are also evolving incrementally as better-than-before solutions are found in generators and power electronics design. From the DSO point of view improvements and cost decrease in power electronics are welcomed due to easier grid integration as can be seen from table 2.

European Union has defined environmental goals for 2020. These goals are going to need more wind power in order to be achieved. This, along with national subsidies, is going to create market potential for wind turbines in smaller scale as well.

5.1.1.2 Solar power

Solar power is based on sun radiation arriving to the earth. This solar radiation above earth's atmosphere is around 1377 W/m² which is followed by total irradiation power of about 176,000 TW (Masters 2004, p. 411). In contrast, world's net electricity generation in 2008 was 19,100 TWh (IEA 2011) which means that it would require little more than six and half minutes for the sun to generate this energy! However, it is obvious that this is never going to happen in practice as all solar irradiation cannot be harvested and the efficiency of solar cells is much smaller than 100 % as can be seen later.

PV systems are highly beneficial in distant locations where other power sources are not available. They don't require fuel or maintenance as there are no moving parts. PV systems are lightweight compared for example to combustion engines and they can be easily scaled to supply the required power. However, absence of need of fuel and maintenance are beneficial for grid connected applications as well. Borbely & Kreider (2001) have argued that solar energy is two to five times as expensive as grid power, in locations where the latter is available (Borbely & Kreider 2001 p. 96).

Solar resource and its potential are highly dependent on location. At the equator the so called air mass ratio can be 1 meaning that sun is shining from directly above. Generally the air mass ratio is defined as

$$m = \frac{1}{sin\beta}$$

Where m is air mass ratio and β is sun's height angle i.e. the angle between the sun and the horizon. Thus, getting away from the equator increases the air mass ratio and forces sun rays to travel longer path in the atmosphere which, again has direct implications to the output power of a solar system. (Masters 2004, p. 388-389.) Other factors affecting the PV system efficiency are clouds and cleanliness of the air. It is stated that irradiation levels in southern Finland are almost equal to those in central Europe while fluctuation between winter and summer levels are bigger though (Energiateollisuus 2012). Furthermore, air is cleaner in Finland than in central Europe which improves efficiency of PV systems.

Solar electricity system consists of two main parts: the solar panel used to convert sun radiation to electricity, and batteries or power electronics used to store or feed the electricity to the grid. Additionally, a tracking system may be installed. While creating more costs, it enables better overall efficiency by following the sun on its daily path and rotating the panel accordingly. Moving parts of this system bring in some unreliability and need for maintenance. Some supporting structures, protection devices like fuses, and wiring equipment are also needed in order to have a working solar PV system.

A solar panel consists of smaller units called photovoltaic cells. When a photon from the sun arrives to a photovoltaic cell, it hits to an electron and –if having adequate energy- breaks it free from the atom. After this, an internal electric field of the cell conveys the electron to one direction and the positive atom to the other. When looking from the outside, this movement can be obtained as electric current. (Masters 2004, p. 460-461.) As can be deducted, the more photons (radiation) the more current available whereas the voltage over one cell remains very small. These factors together lead to a design where there are multiple cells in a series forming strings which are again connected in parallel to form arrays. Solar panels are formed by connecting suitable amount of arrays to create useful voltage and current capacity. Of course, panels can and usually will be used to form bigger arrays as well.

Different materials can be used in photovoltaic cells. The most common material is silicon (Si) which is followed by others like Gallium (Ga), Arsenic (As), Cadmium (Ca), and Tellurium (Te). Additionally, there are different technologies available to use silicon. At their best, under laboratory circumstances they are able to reach an efficiency of around 25 % while theoretical maximum being 49.6 %. This efficiency cannot be reached in practice as some photons are always reflecting from the panel surface and some are hitting the conductors needed to carry the current. There is also some resistance in the circuit. The reason for the use of silicon is its price as it is much cheaper than other suitable materials. Another reason is that it is safe for humans while e.g. cadmium is found to be a hazard for human health as well as for the environment. GaAs, in turn, has high efficiency which is not even weakened by temperature (which is the case with silicon) and a lightweight construction. However, it is very expensive which makes it find use only in space applications. (Masters 2004, p. 485-499.)

The other important part in photovoltaic systems is an inverter needed to connect the system to the grid. Batteries and a DC system can also be used and they are quite common in stand-alone systems because they are cheaper and simpler than AC systems. An inverter converts DC provided by the panel to AC required by the grid. The system also takes care of the synchronization with the grid when the solar system is used parallel to a distribution network. There is also one additional task for the power electronics: to adjust the system resistance in a way that the PV panel produces the maximum power available. On the other hand, it is also possible to limit the power output by operating in some other position than in the maximum. From the DSO point of view, this feature would be beneficial as the LV network voltage may arise when too much power is supplied by PV systems. In these cases the DSO would have to curtail the power output and thus ease voltage problems. Kulmala (2008) states that DSOs are not used to do voltage controlling in LV networks. Also DER units are not originally intended to be used in voltage control. (Kulmala 2008, p. 3.) So far, active voltage control in MV networks is based on tap changers located to primary transformers while secondary (MV/LV) transformers only have an off-load tap changer meaning that a maintenance outage is required to be able to adjust LV network voltage (Lakervi & Partanen 2008). When PV and other DG are diffusing, it is possible that active voltage control has to be included in secondary transformers as well.

So far, most of the PV panels are based on thick design. It is likely that in the future thinner panel designs are going to increase their market share. These thin-film cells are easier to manufacture which leads to lower costs per unit. They can also be installed for example to windows or wall materials which would make them suitable for many applications. In 2004, however their efficiency was around 8 % which is not enough for commercial success (Masters 2004, p. 497).

In the PV sector as well as in wind power, the development of power electronics provides less expensive solutions to markets. This combined with the decrease of PV panel prices will lead to grid parity in many European countries within next years.

5.1.1.3 Mini combined heat and power

Mini combined heat and power (CHP) refers to systems where some fuel is used in a combustion process to create heat or shaft power. Electric power can be generated with this heat by circulating hot steam through turbine blades. Shaft power can be used directly to run a generator, which is the case with diesel engines and gas turbines. The excess heat (about 70 % of the input energy) can be used as thermal energy for heating water or buildings. By doing so, 50-60 % of the original energy can be exploited which leads to an overall efficiency of around 90 %. (Borbely & Kreider 2001, p. 272-273.) It also immediately follows that profitability of such plants depends heavily on demand of heat. Thus it may be possible that it’s uneconomic to run mini CHP plants during summer time.

CHP applications have been used for a long time in larger scale to provide heat and power for processes. By this way, the boiler technology and steam circulation technology have developed to be very mature and effective. Many different fuels can be used and hazardous emissions can be avoided by installing advanced filters. In Finland, coal, wood, and peat have been used as fuel in larger scale and it is likely that these are going to be used in smaller scale too. In micro-scale, the easiest way is to burn wood as it does not require dedicated environmental permissions (Helsingin energia 2011). From the PEOU point of view, the logistics needed for fuel and supervision when running are making CHP plant more difficult and costly to use. These problems can be somewhat tackled in farms, where wood is easily available for fuel and supervision is somewhat automatically arranged by residents.

When it comes to grid issues, CHP plants are more versatile than wind or PV applications as they can be easily controlled. Both active- and reactive power can be adjusted with a rotating generator. These plants are also capable of supplying fault currents needed by protection even though it has to be taken into account in network planning. One issue related to CHP plants is whether they are capable of supplying power to an unsupplied network. Such ability is known as black-start capability. It may be complicated as external electricity is needed to excite the generator and to start pumps and other devices. In normal operation, this electricity is taken from the grid, but in black start it is not possible and batteries or a diesel generator is needed instead.

5.1.2. Energy storages

5.1.2.1 Electric vehicle

Generally there are two types of electric vehicles (EV) available. Plug-in hybrid electric vehicle (PHEV) refers to a vehicle where batteries can be charged from the grid but there is also a combustion engine on board. This (usually diesel) engine provides backup power for the vehicle in accelerations and in high speeds. There are different designs where diesel engine is used parallel to electricity system meaning that both are capable of running the vehicle. Series design refers to a design where diesel is only used to generate electricity for batteries or motors. However, for example Toyota Prius is capable of operating in both modes (Toyota 2012). Currently sold Prius is not PHEV as its batteries cannot be loaded. A genuine PHEV version of Prius is stated to be available in summer 2012. (Toyota 2012.) Advantage for PHEV over full electric vehicles is their substantially longer radius and lighter weight as amount of needed batteries is smaller. Additionally, smaller batteries are faster to charge.

Inside an EV, three key technologies or technology areas can be discovered. Firs one is motors that run the vehicle. In PHEVs both electricity and combustion engines are needed, even though the latter does not require further development to be used in electric vehicles. Different types of electric motors are suggested, but the “good old” induction motor may be the best due to its reliability and simplicity which also makes it cheap to manufacture. (Biomeri 2009.)

The second area of technology is batteries. Lithium-ion batteries are mature and widely used technology in portable devices such as laptop computers and mobile phones. They are also used by current PHEV and EV manufacturers due to their advantageous energy density (Wh/kg) and efficiency. For these reasons it is expected that Li-ion is going to be the dominant design in EV batteries resulting in very high demand and thus decreasing prices (EPRI 2010, p. 99.) For example lead-acid battery used in traditional vehicles is not as suitable because of its lower energy density and efficiency. Additionally, lead-acid batteries are heavier than lithium ion batteries. (Tammi 2011.)

The third area of technology is charging. Generally, there are two methods available: Fast and slow charging. In fast charging the vehicle is charged with 3-phase connection and the charging power can be tens or hundreds of kilowatts. Slow charging refers to a single phase connection with a fuse of 16 A resulting in a charging power of 3.6 kW when single phase voltage is assumed to be 230 V. Power-posts used to pre-heat vehicles in winter times can be utilized in slow charging as they are widely available. In addition to used voltage and phase connection, some power electronics are needed. Technologies exist but they are not built to be used in vehicles meaning that they are not designed to withstand dust, moisture, and vibration. In case of fast charging, the charger electronics are located outside the vehicle which makes current electronics suitable while in slow charging the electronics (rectifier and converter) are inside the vehicle. International standards are needed in order to take both methods into account and to design reliable connections. IEC standards 61851 and 62196 are coping with these issues. (Tammi 2011.)

According to a study ordered by Finnish Ministry of employment and the economy and carried out by Biomeri Oy, PHEVs are going to be in use earlier than full EVs. The study has also developed scenarios which describe EV diffusion in Finland. These scenarios are summarized in table 4 which provides relative portions of EVs of new vehicles in 2020 and 2030.

Table 4. *EV diffusion in Finland (Biomeri 2009).*

	Base case		**Fast scenario**		**Slow scenario**	
	PHEV	EV	PHEV	EV	PHEV	EV
2020	10 %	3 %	40 %	6 %	5 %	2 %
2030	50 %	20 %	60 %	40 %	20 %	10 %

As illustrated in table 4, the amount of PHEVs is bigger than that of EVs. This is due to their lower price and a possibility to use conventional fuels which makes them easier to adopt (Biomeri 2009). However, major part of the vehicles in 2020 and 2030 are still conventional vehicles. This is concluded by Tammi (2011) in his master’s thesis where he states that percentages for PHEVs and EVs of all vehicles in 2020 are 2 and 1 respectively. In 2030 these figures are stated to be 15 and 5 for PHEVs and EVs respectively (Tammi 2011 p. 22). Unkuri (2011) in part, has concluded that in the fastest diffusion scenario for EVs, the overall energy demand in Tampere region would increase about 6 %. This should not cause problems with respect to network capacity. (Unkuri 2011 p. 16.)

From the grid point of view the problem is not the overall increase in demand but the time when it occurs. In case the EV is charged in the evening in winter, when the load is highest even without EVs, some MV/LV transformers are going to suffer from overloading. Consequently, the charging should be timed to happen in times, when there is no other load. This would even turn the diffusion of EVs to be a positive thing as the utilization time of the distribution network increases. (Biomeri 2009.)

The ability to use EVs as energy storages in larger scale depends heavily on their diffusion. Järventausta et al. (2010) argue that it would be possible to cut peak power of one MV feeder from 3.6 MW to 2.7 MW by utilizing EVs in peak shaving. However, it is not stated how many EVs there are along the feeder. In addition to the amount of EVs, their limited ability to feed power to the grid would decrease their usability as energy storages in network operations. (Järventausta et al. 2010.)

5.1.2.2 Batteries in larger scale

Batteries can be used as energy storages in larger scale as well. It is done by connecting battery units in series to achieve desired voltage and these strings are connected in parallel to get the desired capacity. Such layout makes battery storages relatively heavy and large, especially when it comes to utility-class storages where a capacity of more than 1 MWh is required. The following technologies among others can be used in battery storages: Lead-acid, lithium-ion, and sodium-sulphur.

There are many applications mainly UPS (Uninterruptible Power Supply) size, where a lead-acid battery is used. A lower energy density of a lead-acid battery is not such an issue here as larger storages can be implemented. Efficiency limits the use of lead-acid somewhat as well as its ability to withstand cyclic use. Lead-acid batteries are used because they are inexpensive. Some more advanced lead batteries are in development. They should have higher efficiency and better durability as well as faster response time. (EPRI 2010, p. 90.)

Lithium-ion batteries found in mobile phones and EVs are also suitable for larger implementations. Efficiency of 85%-90% and long life in cyclic use are their advantage but the cost of the storage in utility size applications is around 1000 €/kWh. (EPRI 2010, p. 107.)

Sodium-Sulphur or NaS batteries are originally developed by Japanese NGK Insulators Ltd and Tokyo Electric Power Co. They sustain cyclic use well but some losses are introduced as the operating temperature of the storage has to be kept around 300 degrees Celsius (ESA 2010). Ready modules of 1 MW/6 MWh for utility-class use are available meaning that the technology is fully commercialized. Round-trip efficiency (i.e. the ratio of charged ac and discharged ac) of NaS batteries is approximately 80%. (EPRI 2010, pp. 91-93.)

In addition to batteries an inverter is needed in order to have AC output for the grid. Like in the case of wind and solar power, the inverter can be used to adjust the output power (both active and reactive) of the storage. This is extremely useful from the DSO perspective as storages can be used to regulate voltage of the MV network. A control device needs to be included in storage unit because it is essential for both economically and technically to be able to control the power flow to and from the storage. The controller may be embedded in the inverter and it is connected via some communication interface to upper level systems such as a microgrid controller or SCADA. ABB provides a system called Battery Energy Storage System (BESS) which includes power electronics required for grid connection and battery units. The electronics of BESS can act like a traditional generator by supplying both active and reactive power. It is also possible to connect other storage technologies like flywheel to control electronics.

It is likely, that battery based energy storages are going to be widely used in utility applications as related technologies such as Li-Ion and advanced lead-acid get mature enough and prices are lowering due to EV diffusion. EPRI (2010) has concluded that in many applications in 2010 storage prices exceeded the received value. In some high value applications like in data centers the received value exceeds costs if a suitable storage technology is chosen. In order to receive high enough value, energy storages should have multi-functional role meaning that storage is used in many applications. (EPRI 2010.) This in turn leads to more complicated contracts between storage owners and other stakeholders.

5.1.2.3 Other storage types

One of the most mature technologies related to energy storages is pumped hydro. It generates electricity just like conventional hydro plants but during off-peak demand electricity can be used to pump water to the upper reservoir. Such plant requires large enough height difference and a suitable location for upper reservoir. Environmental effects are to be taken into account and permits are needed. Efficiency of such plants is around 80 % and operating time around 50 years. (EPRI 2010, p. 84-86.) However, it is economical to build large pumped hydro plants because of high investment costs which easily rule them out of the scope of DSOs. Additionally, suitable height differences are rare in Finland. For these reasons, pumped hydro plants are not considered further in this thesis.

One proposed technology is to compress air into a tank during off-peak demand. The tank can be everything from a pipe system to a mine cavern. According to Crowe (2011) there are only two projects in the world where an underground cavern is used as storage and the plant sizes are much more than 10 MW, which is considered as a limit for DER. Smaller man-made tanks instead, might turn out to be suitable for compressed air based storages. (Crowe 2011.) According to EPRI (2010) the aboveground applications are more expensive on dollars per kilowatt-hour basis but they are smaller and thus suitable for DSO environments as well. As turbine development of such plants goes further, some plants are going to be seen in the US. (EPRI 2010, p. 87.)

Another proposed technology which has been demonstrated and to some extent commercialized is a flywheel where energy is stored into a rotating mass. Such storage responds very quickly (in around 4 milliseconds) and has efficiency of 93 %. So far, small units have been implemented mainly for UPS purposes. Larger installations are going to be seen within 3-5 years. (EPRI 2010, p. 97.)

There is a super capacitor where relatively large amount of electricity is stored into a capacitor to be used quickly. It is useful in smoothing transients and as UPS applications. A super capacitor has limited storage capacity and it is expensive but it sustains thousands of charge-discharge cycles and has large energy density. In 10 years, some nano-material based capacitors might be developed. (EPRI 2010.)

One form of energy storages are heat based storages like warm (or cold) water and room air. Unlike EVs and batteries these storages do not preserve electricity but energy in other form. This is followed by the fact that the preserved energy cannot be transformed back to electricity meaning that it is not possible to feed electricity to the grid from these devices. Additionally, this idea is not new but it is used in Finland for a long time by heating houses at night time and for not so long time by heating water with solar thermal systems.

Thus these storages are easy to implement and they are found in every household, they can be used immediately as energy storages. The idea is to “charge” these storages when the overall demand of electricity is low and thus reduce peak loads. From the consumer point of view these storages are invisible as they are “discharging” them without thinking about it. Another good thing is that in these cases the electricity is already used to create value and short interruption in power supply is not harmful. This type of energy storage is tightly connected to demand response because it can be modeled as load. Furthermore, EVs can be first seen as such unidirectional storage because it is likely that in the first phase, electricity is not fed to the grid from EVs (Parkkinen & Järventausta 2012).

5.1.3. Demand response

As stated earlier, demand response or demand side management refers to loads’ ability to adjust according to production or locally according to supply capacity. It is important to notice that demand response is not equivalent to energy saving. DR only makes loads less volatile while total consumption remains the same. The DR concept requires at least loads suitable for control and switching devices to disconnect these loads. Loads suitable for DR are such that their disconnection (or connection) cannot be noticed by a consumer. Room heating, water heating, refrigerator, air conditioning (heat pump) and EV charger for example are suitable for DR while consumer electronics, sauna, and lightning are not. Moreover, an alternator can be used. It switches off heating when a sauna stove is switched on and thus reduces the total power drawn from the grid.

A problem related to DR is the control of the loads, not finding suitable ones. A model where controlling is carried out locally is relatively easy to implement as some device observes a control parameter like spot price and makes switching operations accordingly. This device would also take care of local energy production and storages and thus manage a sort of microgrid which makes this device essential when it comes to microgrid issues. This sort of device is called an E-box by Kanchev et al. (2011). A ThereGate provided by There Corporation is another example of such device. The box is connected to upper level systems in order to take commands from a centralized energy management system (EMS) controlled by the aggregator for instance. (Kanchev et al. 2011, p. 2.) The device would also take other factors like room temperature into account when performing control logics. Ventyx Ltd. provides a software called DRMS (Demand Response Management System) to be used in DR controls. They have installed a pilot system to Baltimore G&E in the US. The system enables controlling of three different loads: room heating, water heating, and air conditioning. The controls can be carried out separately from each other.

To be useful for a customer, there should be a real-time pricing based on spot price available (Dang 2009). Another problem related to local control is the system's inability to see the entity. If there are DSM capable home automation devices in many households and they are all programmed to increase load when the spot price is low, the result would be grid overloading. Not necessarily the whole grid but the local LV grid and the feeding transformer. The third problem is that such method is reactive meaning that only past or current information is used in controls. The vision of smart grid includes the ability to plan and optimize production and consumption before-hand according to external parameters like outside temperature, rain, and planned maintenance of centralized plants in order to reduce emissions and save energy.

To be able to tackle the problems related to local control it is proposed that a centralized control should be used. This means that some participant, most likely the aggregator should manage the entity and send control commands to home automation devices. In order to do this, a communication link between the load controller and the home automation is needed. Different technologies on different levels are available first of which is the public internet (Wang et al. 2011). It is widely diffused and it can be safely assumed that it is present in locations willing to participate in DR. In this case the controller sends a message to the home automation device, which carries out switching operations. Note that a DSO is not involved in this control chain by any means. The pro side is that the logic can be used everywhere as DSO and its technology selections are not affecting. It has to be remembered that retail business is open for competition and contracts between a retailer and a customer shall not depend on DSO; for example customers in Helsinki and in Jyväskylä should have same possibilities to participate in DR. The con side in part is that overloading of a local distribution network is still possible unless the local DSO validates the control scheme somehow. Cyber security issues related to internet communication are also to be taken into account (Wang et al. 2011). Despite some problems this type of communication in DR has a chance to materialize as it is easier to implement especially when considering the fact that electricity retailers and customer lead users are usually more agile than DSOs. If customers are really interested in DR, the additional investment related to equipment should not be a problem. Of course, customers should be properly informed about long (and short) term costs and benefits of DR as indicated by Åhlman (2012).

The other high level communication technology available is the one used for reading the measurements (Wang et al. 2011). The actual communication to AMR devices can be executed via multiple technologies like 3G, GPRS (General Packet Radio Service), PLC (Power Line Carrier), or TCP/IP (Transmission Control Protocol/Internet Protocol). As communication to meters already exists, it would be natural to use AMR devices to carry out switching operations or at least to provide a platform for DSM equipment. Plain AMR devices’ ability to control multiple loads or load groups may be limited which advocates the platform architecture. This control method would utilize DSOs’ devices and communications which again enable DSOs to validate control commands and thus prevent overloading problems. The cons here are that DR depends on a DSO and it is also stated that the system’s ability to transfer data quickly enough would not be adequate. Especially in GPRS networks the capacity depends on other traffic (Kenet Oy 2012; Valtonen & Honkapuro 2010).

The centralized control also requires dynamic tariffs for consumers as otherwise it would be difficult to obtain monetary savings. However, the problem is how to determine the real effect of DR by tracking hourly data. The smaller measured value may as well be caused by a consumer and not the DR. Or even worse, part of the saving is caused by DR and the rest is caused by a consumer even without him knowing it. It comes down to metering resolution. One reading per hour might not be enough but one reading per minute could be better. However, such arrangement would produce 60 times more measurements. According to Heiskanen et al. (2012) many consumers don’t want tariffs based on spot price as it may sporadically compromise them to very high prices. Moreover, they feel that they don’t have measures to hedge against these risks like the bigger players do. (Heiskanen et al. 2012.) For these reasons, the customer could only make a contract with the retailer in which he pays for minimizing his electricity bill. Of course, the price of the contract itself should not be more than a difference between the traditional way and the value of the optimally consumed energy because otherwise it would not be beneficial for the customer.

A concept for DSM introduced by Helsingin Energia consists of three layers. The lowest layer includes controls like daytime/nighttime control which already exists. These controls are made by a DSO in case there is no other agreement. The second layer includes controls made by a retailer. These are based on contracts between a retailer and a customer. In these controls the retailer optimizes customer's consumption by sending a load profile for the next 24 hours. The control scheme is validated by a DSO and sent through their network and devices. The third and highest layer is for abnormal conditions. A DSO or a TSO can override all lower level commands by executing controls based on technical conditions. For example in a case of power shortage a TSO obligates DSOs to do load shedding in order to maintain transmission system's stability. Additionally, a DSO is capable of controlling loads in order to prevent overload of its equipment. Note that these measures are not needed during normal operations as the DSO validates the load profile and intervenes in this phase if technical conditions are not met. Furthermore, there should be some marginal capacity left for estimation errors as otherwise problems would occur in case the actual load is larger than expected. Such arrangement somewhat weakens the overall efficiency but on the other hand it enables DSOs to avoid congestions which would lead to compensations. The highest control level may be needed in a fault situation when the network configuration has to be changed and pre agreed conditions don't apply anymore. (Helsingin Energia 2012.) This type of control architecture is tested successfully by HELEN and VTT. (Koponen & Seppälä 2012.)

Concepts presented above are applicable to household consumers. For larger entities like industrial customers the DR concept is different as they procure their electricity professionally and they are capable of optimizing their consumption themselves. They can even sell their consumption to a TSO to be used in frequency control where the smallest block is 10 MW. However, these parties are still interested in solutions that set them free from reading measurements and turning switches manually, which again, leads to a possibility to provide DR as a service.

Generally speaking all the technologies needed to implement DR are available. Challenges are to find the most suitable ones and develop standards to ensure interoperability of devices. One example is IEC 61968-9 standard which defines XML messages to be used in load control. The standard does not define any technology to be used in physical transfer of the message. This enables it to be used in multiple environments as the used technologies may vary. It would be rational to exploit installed base of devices as much as possible to avoid large investments and thus attract shareholders to participate. Business models and legislation are also in a need of further development. At the time of writing, promising pilot projects like Kalasatama in Helsinki are ongoing and they are probably able to answer DR related questions.

5.1.4. Microgrids

Microgrids are grids located to a relatively small geographic area. For example a grid supplied by a single secondary (MV/LV) substation can be considered as a microgrid. However, traditional and passive low voltage network is not microgrid as a microgrid contains small production and/or energy storage capacity and some intelligence which is usually called microgrid controller or MMS (Microgrid Management System). (Laaksonen et al 2011.) Thus microgrids are capable of producing at least part of their consumed energy and they are able to optimize their own production and consumption. Additionally, microgrids should be able to operate in an island mode in case the connection to the distribution grid is lost. However, islanding causes problems as it is rarely the case that load and production inside the microgrid are equal at the time of islanding. The idea of microgrid is newer than the idea of DER. At first, DER was intended to be integrated into MV and LV grids and all controls were made by DSO control center. However, if there are many DER units attached it is easier to control them by having a hierarchical system, where all levels make local decisions and appear as loads or generators to the level above them.

The basic model of microgrid is presented in figure 5.1. In this example the microgrid is considered to be formed inside an LV grid. However, it is possible and that real microgrids have MV network involved as well. (Laaksonen et al 2011.) It seems logical to form a hierarchical structure where intelligence is distributed to all levels and decisions are made locally in each level. This reduces the need of data transfer between levels. In this model, the home automation device is capable of controlling resources under it like for example minimizing the energy consumption according to its own intelligence or according to external signals. Microgrid controller in turn, is able to control resources inside the microgrid meaning that it utilizes its embedded intelligence to optimize energy consumption of the microgrid. It communicates with home automation devices and with generation and CES (Community Energy Storage) controllers.

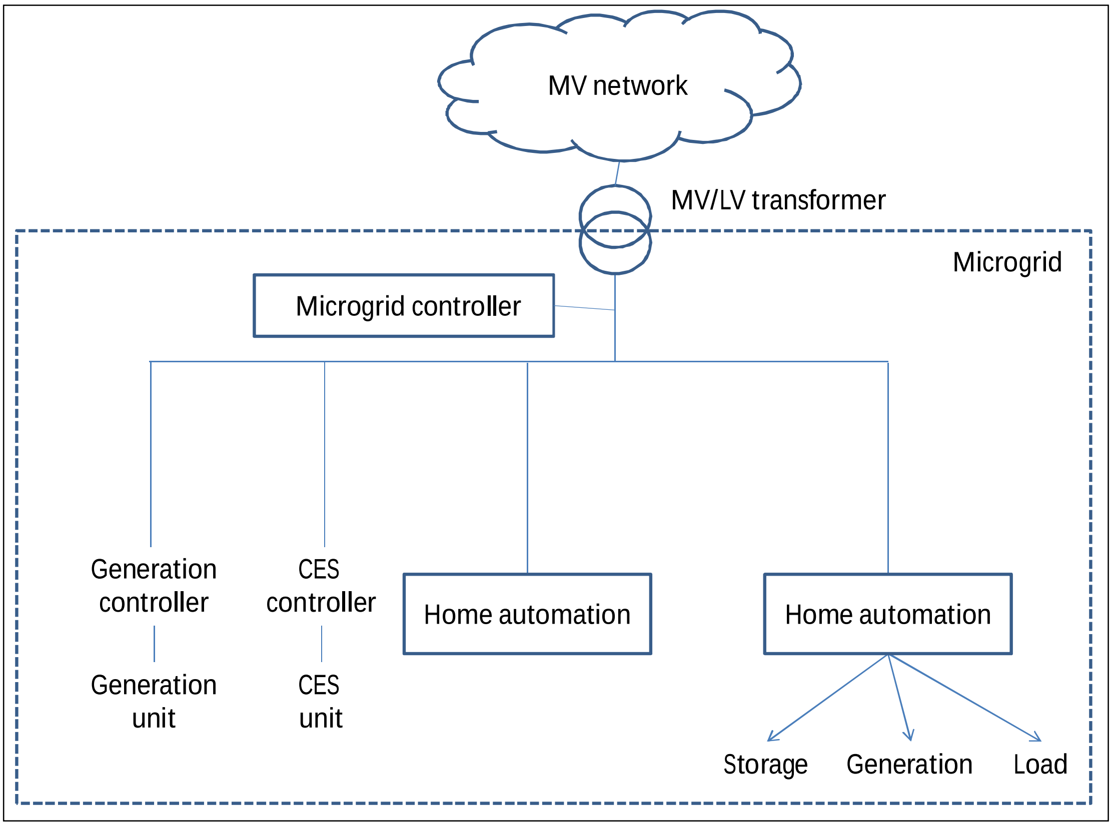

Figure 5.1. *An example of a microgrid.*

The CES concept is developed by ABB USCRC (United States Corporate Research Center). It includes energy storage with a capacity of around one megawatt located near secondary substation on LV side. It can be utilized in applications discussed later even though they are mainly designed to support the LV network. University of Vaasa has studied such storages and simulated their behavior. They found out that the best location for CES is near the transformer as also suggested by the USCRC. From there, the storage is also capable of supporting voltage in MV network. (Laaksonen et al. 2011.)

From the DSO point of view, the interesting part is the interface between the microgrid and the MV network. In ideal situation the microgrid controller communicates with SCADA via some interface like OPC and, depending on under or overproduction of the microgrid, SCADA/DMS sees the microgrid as a load or as a generator respectively. For example in a case of line overloading the DSO gives microgrid instructions to draw n kilowatts from the MV network. The microgrid controller takes adequate measures to fulfill the task by running production, discharging batteries and shedding low priority loads. Another question is how microgrids fit together with aggregation. The additional piece of equipment between the controllable DER unit and the aggregator might be in contradiction with each other. This thesis is not trying to answer this question. In SGEM consortium Nokia Siemens Networks and VTT have studied microgrid controllers and their requirements. Different possibilities for microgrid operation and simulations can be found for example in Pasonen (2010). On the other hand, the microgrid concept is quite similar to INCA developed by Järventausta et al. (2010). Some of the ideas can be copied to microgrid environment. Also ABB's USCRC is about to start a project regarding microgrid controller. Such development enables ABB's product portfolio to cover whole distribution network automation also in smart grid environment.

Speaking of which, there is some way to go until microgrids are reality at least in Finland. For the overlap period between a traditional passive grid and a smart grid SCADA/DMS have to be capable of communicating directly with home automation devices and maybe with generators and CES units attached to an LV network. Such interface already exists: AMI can be used to convey signals as discussed in demand response chapter. Moreover, even if there is a microgrid controller between DMS and home automation, the AMI is still needed to fetch measurement values.

5.2. Interview results and discussion

This chapter goes through answers received from the interviews question by question. At the end of each question and domain (e.g. network) there is a short discussion about the answers.

5.2.1. Network

Q1: What is your network's state in terms of cabling rate, average age and automation rate (e.g. remote controlled disconnectors/ all disconnectors)? Cabling rate of MV network was 37 % in KENET and 80 % in JES. Fortum distribution had a cabling rate of 11 % while in cities of Espoo and Joensuu it was 58 %. The highest cabling rate was found in Helsinki, where it was 99.5 %. Rate of automation measured by remote controlled switching devices' per all switches was found to be less than ten per cent in Kokkola and about 10 % in Jyväskylä and in Helsinki. The amount of remote controlled switches is increasing at a speed of around 5 percentage unit per year. Fortum announces that the amount of remote disconnectors is increasing with the annual speed of around 80 pieces. Worth mentioning is the fact that the network in downtown Jyväskylä is tightly looped with circuit breakers as border switches which improves remote operation of the network.

All DSOs agreed that cabling rate is going to increase in the future which is due to increasing customer demands as well as pressure set by government. Cabling is expensive and it takes time to renew old networks by using cables. It may not be profitable to build backup connections by using cables as they cost more and they would not be needed that much in the first place. DER can definitely be connected to cable networks if only cables are dimensioned accordingly. Increasing automation rate is good for DER utilization as it allows fast forming of islands. DSOs see it primarily as a way to reduce outage times because it enables fast connection of backup feeders. Due to this benefit, the rate of automation i.e. the amount of remote controlled switches in the MV network is increasing. Another question is if fast islanding requires more sophisticated automation than is currently installed.

Q2: What are your biggest concerns related to network? In companies having rural network like KENET and Fortum the biggest problems related to network were its age and condition. Also Helen has old cables that should be replaced with new ones which would decrease the overall age of network. Future challenges in all companies include the renewal of old networks in a way that is profitable to DSOs. MV cabling should be scaled up but current regulation doesn't provide incentive to do so even though it is expected to change. On the other hand, in Jyväskylä the biggest concern was mentioned to be a breakdown of a switch station. Overall condition of the network was not an issue for them. Additionally, problems related to earth fault currents introduced by extensive cabling were mentioned as well as challenge to detect a fault from a cable. MV networks in Kokkola and Jyväskylä were compensated meaning that the neutral point of a secondary winding of a primary transformer is connected to earth through a compensation coil. Such arrangement reduces earth fault currents as they are capacitive while the compensation coil produces inductive current (Lakervi & Partanen 2008). In Helsinki, there is currently one compensated primary substation but compensation is going to get wider. As a result, earth fault will not cause relay tripping but only an alarm. Another challenge indicated by Helen is protection of cables against excavators. There have been many cases where an excavator has accidentally harmed MV cables.

Generally, DER cannot solve issues related to old and deteriorated network: renewal investments are needed sooner or later. In cases of equipment breakdown, DER could be helpful by providing backup power. On the other hand, such issues are reported by urban DSOs where wider utilization of DG and storages is more difficult. Additionally, urban houses are usually heated by district heating which disables possibility to apply DR to electrical heating.

Q3: Do you have to take DER into consideration when planning networks today? In Kokkola, Jyväskylä, and Helsinki distributed resources are not widely taken into account when planning networks. Feeders are designed according to highest possible load. In Kokkola there is a convention that generators with output power higher than 2 MVA are connected directly to a primary substation. When it comes to protection issues, distributed resources are taken into account when necessary. Planning of protection is also said to require some planning. Fortum in turn, takes distributed generation into account in network planning. The challenge is how to dimension networks in a case there are multiple project proposals but only few of them are ever going to materialize. Common practice has been that the feeder is dimensioned according to the first or known producers and later joiners are to pay the reinforcement if it is needed. However, electricity market act prohibits DSOs for charging the reinforcement costs from small producers (<2 MVA). (Electricity Market Act (396/1995) 14b§.)

There are many things to take into account in network planning. DER is one of them and probably the best overall solution is achieved by tight cooperation between network operations and planning because decisions made in planning have an effect on operations.

Q4: Are you taking DER into consideration when planning maintenance outages? Hospitals and other known DER locations as well as DSO's own backup generators are taken into account as their specifications and controls are known. Farms having backup generators are taken into account if the existence of a generator is known somehow. However, this issue requires more attention in the future as backup generators and other types of DER diffuse. Especially backup generators are likely to increase their role as storms have taught people to prepare. So far, generation located to an LV network is not taken into account as a resource in MV side in Kokkola. It is only made sure that it is safe for personnel to operate. Fortum takes mobile generators one step further by calculating whether it is economical to utilize generator or leave customers with an outage. Such feature may be included in DMS in the future.

Generally MV networks in Finland are constructed in years between 1960 and 1970 meaning that many components are more than 40 years old. This is the case especially in rural areas as further reinforcements have not been needed since. In urban areas the situation is, averagely speaking, better as cities are expanded since 1960's and networks are constructed accordingly. Interview results somewhat support this assumption as network condition is found to be an issue especially in rural areas while there are some problems in Helsinki as well. Such problems were not encountered in JES which is located purely on urban area and the city is much younger than the city of Helsinki.

Smaller DSOs indicated that DER is not needed in power restoration as traditional backup connections are available due to looped network topology. Fortum and Helen, in part, saw DER as a backup possible. It was assumed that looped topology makes DER supplied islands easier to form, which is arguably the case, but DSOs did not see it that way. This is probably due to their point of view, which is based on today's situation. DG can be used in rural areas in some cases but it will not solve the deterioration issue. Tightly looped network and increasing automation would help DER utilization in cities but lack of space limits the diffusion of bigger DG units.

5.2.2. Organization

Q5: Do your operations/planning personnel have DER related experience? Are you putting some effort on evaluating future technologies? DSOs have some experience related to distributed resources. However, it is mainly limited to backup generators and on the coast, to wind mills. Some investment of time has to be put on evaluating and planning future technologies as DSOs will suffer from wrong decisions for 40 years!

For instance in Jyväskylä there is a project visioning future grids as well as housing exhibition is taking place in 2014.

Here, also bigger companies have more knowledge and better possibilities to acquire experience. For example in Fortum network operators are involved in network planning and they know what solutions are appearing in the future. Additionally, there is more DER related knowledge in Fortum Sweden. They are heavily investing in evaluating future technologies and their meaning in operations. Also Helen has put effort in technology evaluation. They have R&D projects where operational personnel are also involved. They have also tested price-based demand response with VTT. This project has given DR related experience which others don't have.

Q6: How good is your knowledge with respect to smart grid? Is your strategy and management's attitude behind it or against it? When it comes to knowledge and attitudes, it is found that generally, the atmosphere in the industry is pro smart grids. However, the reliability of this study might somewhat limit this assumption as only few DSOs are interviewed. It seems that people in DSOs are interested in future grids and DER applications but their prerequisites to do something vary. In larger companies like Fortum and Helen smart grids are written in strategy meaning that adequate resources should be available. In some companies though, the strategy formation was ongoing and it was not yet clear what needs to be done and when with respect to smart grids. It was also found out that in smaller organizations the *influence of champion* (see chapter 2.1) was immediate and activities were directed according to champion's (CEO's) interests. However, the problem in smaller companies is the lack of resources as current ongoing tasks take all time available. This reflects also to people's knowledge as there is no time to search for information or train people. It is also suggested that some resistance for change is found in every DSO which might in some cases limit the desire for further information seeking. Fortum has solved the information seeking issue by having a dedicated unit for new businesses which takes these tasks away from operations and planning. They evaluate and develop new business opportunities while network operations people concentrate on current situation.

Q7: Does your organization structure support SG environment? Is it likely that you are going to need new vacancies or even departments in the future? It was assumed to be difficult to answer this question but DSOs were still able to figure out something. They agreed that some changes are needed and probably more personnel resources are needed in the future. Especially IT and automation knowledge was emphasized rather than traditional power system expertise. In Fortum, it was stated that new vacancies may be needed to be able to handle information and alarms coming from LV network via AMI. There was also some discussion about different traits of DSOs. It was stated that some DSOs are active in changing both the environment and the organization while others are just following the leaders' example on both frontiers. Basically, this is about technology strategies as there are leaders and followers even though in this case leaders can never defeat followers. Reasons for selected strategies are somewhere else than in competition. Helen indicated that the amount of resources can even be reduced as automation systems handle their tasks. However, this depends on selected strategy as some activities like AMI can be outsourced and it doesn't have effect on DSO organization. On the other hand, manual switching operations earlier made by mechanics are now carried out by control center. The possibility to reduce resources is also suggested by EMV (2011b) even though it highlights that personnel should be trained better than before.

From the organizational point of view it seems that DSOs are divided into two groups. First one includes those who have clear strategic goals and adequate resources to pursuit those goals. They have the leader's role in the industry. They actively search for new information and experiences. The second group consists of those whose strategies are not so clearly defined with respect to DER and their resources are more limited than of those in the other group. These companies are somewhat forced to take the follower's role. It is generally believed in DSOs that more resources are needed in smart grid environment. Chapter 3.2 suggests some new businesses for DSOs and it assumes that new people may be needed to run these businesses while interviewed DSOs believe that new resources are needed in network operations. On the other hand (at least in bigger companies) the interviewees represented operations and they were thus unable to comment company level HR issues.

5.2.3. Technology

Q8: Do you have distributed generation/ energy storages in your network? How do you see their development within next five years? There are wind turbines in KENET's and Fortum's networks and in Jyväskylä there is one solar generator and one gas turbine located in a sewage treatment plant. Jyväskylän Energia consolidated corporation also has its own micro-hydro plant. AMR devices enable load controlling or demand response applications but current communication systems do not necessarily do so. At least in JES there has been discussion about controlling some loads via AMI but plans were not yet materialized. Additionally the control of street lightning has been planned as well as monitoring and controlling of heating or cooling of substation buildings. Helen has implemented demand response possibilities which have been piloted along with VTT (Koponen & Seppälä 2012).

According to DSOs it is likely that some DER applications are going to get more common in next five years. They believe that more wind turbines are going to be constructed in coastal areas and maybe some solar panels are going to appear in residential areas especially if they can be efficiently integrated in windows. However, five or ten years are considered to be quite short time and radical changes are not likely to take place even though it is likely that speed of development is increasing in the industry. Small production (or micro production) owned by private households is increasing in many distribution networks in other countries. German solar power is one example of this development. Such a rapid diffusion of DG is not expected in Finland.

Q9: On scale 1-5, how much do you think network complexity is going to increase if there are distributed generation/ energy storages attached? With respect to network complexity it was suggested that complexity would increase for the amount of 2-3 at a scale from zero to five. Respondents found it hard to answer as it was difficult to determine what to put in the other end of the scale when current state is in the other. When comparing current state and smart grids of 2030 the value would be 5 but DSOs decided that the comparison should be made to something that is 5-10 years away. They also agreed that changes are going to happen with relatively slow pace and their know-how is going to develop at the same time along with the environment. Furthermore, some DER related ideas can be copied from central-Europe. Of course, the author is to blame for the unclear phrasing of the question.

Q10: Do you see any advantages/benefits created by DER devices? How about disadvantages/downsides? In case of DER technology the DSOs see some advantages introduced by DER. They mention loss reduction as the most beneficial application of DER followed by peak shaving and more sophisticated load shedding introduced by demand response. This would mean something like from five to ten amperes for each customer which is enough for a refrigerator and illumination. (JES 2012.) Helen indicates that losses are not a problem in Helsinki due to relatively short distances. They also suggested frequency support from storages even though it would require significant amount of storage capacity. DSOs see DER supplied islands quite distant in the future even though Fortum and Helen considered it as a possibility at least during planned maintenance operations. In KENET they found EVs and their possibilities as energy storages closer than widespread island operation of DER.

On a more general level it was stated that benefits of DER for DSOs (or for some other participant) are not currently clear enough. This is mainly due to electricity price as monetary savings brought by demand response stay moderate as well as the money acquired by storing electricity and selling it during high demand. The latter is however based more on the low volatility of the spot price rather than on the price value itself. It seems that for DSOs relative advantage of DER over traditional solutions remains quite low as they don’t perceive any significant advantages. There are definitely benefits but they are difficult for a DSO to exploit as it would require investments made by others and contracts with these participants.

On the disadvantage side it was mentioned that DER can even make outages longer than before as many possible feeding points have to be checked before starting the actual work. On the other hand, customers can use their own systems and thus avoid outages. Also network planning and protection get more complicated as many feeding points exist and fault currents increase. Helen suggested that increased fault currents are not a problem as many DG and storage units are so small that they won't significantly change prevailing conditions. JES also pointed out that documentation and management of network related data gets more and more important.

All these issues are somewhat in relation to the increase of overall complexity of networks. One interesting point for DSOs is that currently TSO consumption fees i.e. fees paid for TSO by DSOs are based on consumption in DSO area as well as on the energy transferred through TSO/DSO interface. However, production units smaller than 1 MVA are left outside the measurement meaning that energy produced by them is not strained by TSO consumption fees. (Fingrid 2012; Lemström et al. 2005.) It was concluded in question 10 that there are not much advantages for DSOs but on the other hand there are not many disadvantages weakening DSO performance.

Q11: What are the major challenges with respect to DER diffusion? For the biggest challenges related to DER attachment and diffusion DSOs mentioned simply the challenge to manage the entity especially during abnormal situation. Additionally, more stakeholders are participating in network related activities and someone has to take care of equipment integrated to networks. It is likely that the maintenance of micro-production is outsourced to a service provider and the owner does not take care of it. The point is that DSOs should set tight limits on what kind of devices are connected to the network in order to guarantee that devices are working as they should. Limits written to agreements can be referenced in the case of poor maintenance, which again forces investors to take care of their equipment somehow.

From technology point of view the DSOs don't see relative advantage of DER to be substantial. They want to see clear advantages that can be measured in money. As assumed, DSOs were worried about increasing complexity and compatibility of devices but they believe that compatibility issues along with increased complexity can be handled in the long run. However, they indicated that this depends on network management tools as they play a big role in defining the PEOU of DER systems. As discussed earlier, large companies are likely to continue developing suitable methods for DER integration and smaller companies are to follow when best practices are found. Small DSOs are also interested in purchasing a ready-made solution instead of independent devices.

5.2.4. Stakeholders

Q12: Can you perform your daily operational/planning routines with current SCADA/DMS tools? For this question the answers were simply yes. However, some defect reports were announced but luckily newer DMS versions should solve most of these issues. In Fortum where there are multiple systems in use, it will be challenging to maintain good interoperability of these systems in the future. Currently Helen has not

ABB’s network management products in use as they have network information system and DMS provided by Tekla Ltd. and SCADA provided by General Electric Ltd.

Q13: What new requirements for SCADA/DMS in order to fulfill tasks in SG environment? The following DER related requirements or improvement proposals were suggested by DSOs.

- SCADA/DMS should automatically isolate fault according to fault detectors
- DMS should advice the user more or use embedded intelligence to figure out what to do and what operations to avoid. This is however, easy to say but much more difficult to implement.
- DMS should alert about backup generators (or other voltage sources) on a faulted zone.
- Measurement values fetched from secondary substations to be listed. Also load levels with respect to transformer size should be taken into account.
- Measurement values should be visible on DMS screen all the time.
- Schematic presentation of the network which should be easy to modify.

It can be seen that many issues are in a close connection with current state of the network. This was, of course, predictable as DSOs see things from their operational perspective and many of the interviewed persons worked in operations. However, these proposals are valuable to ABB distribution automation as its mission is to serve customers today, in the future, and in everything between these two. This means that in order to make profitable network automation business it is necessary to balance somewhere between academic visions provided by communities like SGEM and real world found in DSOs. This ends up with phenomena called technology push and market pull. Technology push provided by academic research and internal R&D are needed to pursue longer term goals i.e. smart grids of 2030 while market pull obtained by asking customer opinions is needed to sell products in the near future. No one is interested in paying extra for a feature that is needed in 2030.

Q14: Are you involved in pilot projects or in university cooperation? KENET and JES are not currently involved in any pilot projects. Jyväskylä housing exhibition 2014 however, is going to provide some sort of a pilot. Fortum in turn, is basically involved in every pilot project in this field. Fortum is involved in SGEM and they also have cooperation with Finland’s leading universities like TUT, LUT, and Aalto. Helen has its own pilot project in Kalasatama. They are also involved in SGEM and they make cooperation with Aalto -university which is also located in Helsinki.

These answers show that bigger DSOs have pilot projects and cooperation which enable them to gain new experience and deepen their knowledge resources. Small DSOs instead don’t have such possibilities, which again is probably due to resources as cooperation requires effort in order to be fertile.

Q15: Are your customers interested in distributed resources? In KENET region some customers have been interested in investing in distributed generation. So far, none of these projects have been executed or at least, the DSO does not know about them. They also pointed out that sellers of micro production have activated which again may increase customer calls in near future. In Fortum, there have also been many questions about distributed generation, namely wind power. They believed that many of these questionnaires have been made in pre-studies in order to evaluate project profitability rather than in real closed projects. Also Helen has received some enquiries regarding DER.

Despite enquiries there have not been many active projects. This indicates that DER investors are careful about making investment decisions which is probably due to unclear profitability and regulation. As mentioned by DSOs, government subsidies are needed for DG to diffuse. In this sense, there is no acute hurry to get advanced DER related features to the market even though having these ready at the time of exploding demand (if there is one) would create remarkable competitive advantage.

Q16: How is your AMI handled? Is it capable of controlling loads i.e. performing demand response activities? In JES there is GPRS connection to AMR devices. They have also utilized AMI in LV network management. As indicated earlier, the devices are capable of load controlling but other parts of the system may set some limitations. In KENET and Fortum there is a GPRS connection to AMR concentrators which are installed to LV networks. Connection between the concentrator and meters is carried out via PLC. LV network management features are not yet utilized in these companies. In Fortum, there are switching devices included in AMR devices which provide a possibility to disconnect particular customers from the network. Helen has built a system where one master meter communicates with upper levels via 3G/GPRS and slave meters communicate with masters. This makes sense in Helsinki, where majority of houses are apartment houses. There is a point to point connection to detached houses in Helsinki area. All Helen’s customers can be controlled via AMI as there is also a switching device included in meters. They also stated that all the meters are installed by the end of 2012.

With respect to demand response, Helsingin Energia consortium is clearly ahead of others. DSO provides technology to control customer loads and retailer makes business on this platform. If the architecture is found to be working, it has chances to become a dominant design of demand response.

Q17: How DR will be implemented in the future i.e. who is controlling and via who’s equipment? It was assumed that also this question would be difficult for DSOs. It was also turned out to be the case. Helen introduced the DR concept discussed in 5.1.3 which is more advanced than those of others’. DSOs agreed that some type of demand response is needed in a case of EVs to avoid network reinforcements. It was also stated that DSOs are not very interested in controlling loads because they don’t perceive any benefit. The exception is national power shortage, when TSO gives orders for DSOs to shed loads. Additionally, bigger customers manage their consumption themselves and there is no reason for a DSO to intervene. This could be the case with microgrids as well. DSOs are not interested in what happens inside the microgrid. On a wider perspective, DSOs don’t see any rapid change taking place very soon. One reason is mentioned to be current electricity price which is low and it does not thus encourage people to save electricity. However, it was stated that new tariffs which enable savings are likely to appear. For example customers who are satisfied with lower level of service may receive some savings.

Q18: Do you see new business opportunities for a DSO? Some services perhaps..?
Generally DSOs don’t see any major business opportunities lying ahead. They believe that they could be more active in services but again, it would be difficult to make service business profitable. Fortum indicated that a DSO could sell generation management as a service to wind park owners for instance. In Sweden there is couple of such agreements. Furthermore, current legislation limits DSO’s business opportunities. There is common understanding that DSO operates as a platform provider for markets. This is well in line with earlier assumptions as such development is logical. It makes DSO’s job easier as the amount of needed technologies gets smaller and many of them are already available. There is probably a need to redefine borders of liabilities as smart grids develop. For example, to what extent is the DSO responsible for network conditions inside a microgrid? However, a DSO could provide microgrid management as a service. Such questions are relevant around 2020 though.

As a result, it seems that there is some interest in DER in DSOs but available resources limit information seeking and thus keeps depth of knowledge somewhat shallow. In smaller firms, there is no experience of DER except of that received from windmills. Additionally, lack of pilot projects makes it more difficult to gain some experience. In small DSOs it seems that influence of champion is significant and thus, in order to get small firms to the level big ones, some information sharing and consultation should be given to business managers of firms. In large DSOs though, the situation is just the opposite. They have resources to do R&D, they participate in pilot projects, and they have cooperation with universities which help them to gain experience and knowledge.

On a general level economical viewpoints and governmental regulation and subsidies play a major role in DER diffusion. It was stated by many DSOs that current regulation doesn’t encourage people (or firms) to invest in DG. The regulation, in turn, is not in DSO’s or in investor’s hand which means that both participants are waiting for decisions to come out. The regulation is, after all, developing to a right direction as incentives for investments and innovations are included. However, lot of uncertainty is perceived by DSOs which is mainly due to relatively short (4 year) supervision periods of the regulator. Lifetimes of network investments are far longer than that. Additionally, current regulation limits the profitability of widespread MV cabling which would be needed to hedge against harsh weather conditions accelerated by climate change.

5.3. DER consequences for a network operator

This chapter is based on second data collection as well as on customer interviews. New possible service businesses and value creating activities are also discussed. The chapter is divided into two subchapters dealing with normal and abnormal conditions. Normal condition refers to a situation where the distribution system works as planned and all the components operate as they should. Abnormal conditions, in turn, refer to a situation where some equipment is broken and network operation deviates from the pre-planned case. This sort of division may be valuable when approaching from the DSO’s point of view. During normal operation it is likely that economic incentive or market force is guiding operations while during abnormal situation the technical aspect steps in. According to an assumption made earlier, a DSO takes care of the technical conditions and may thus be more interested in abnormal situations.

5.3.1. Normal conditions

The first case where DER can be beneficial for a DSO is when DER units are used to reduce loads of primary transformers or feeders. It is done by supplying some of the loads from distributed generators or storages. It is even possible to replace a primary transformer by supplying its loads from DER units or from other transformers. As a consequence, there is a possibility to decrease system losses as power is flowing shorter distance than before. In distant locations the use of DER also enables smaller voltage drops and higher overall utilization of network capacity. Some limitations for DER usability are set by DER specifications and cable ratings since adequate power may not be available or it cannot be transferred. (Dragicevic et al. 2010; Haesen et al. 2009; Lemström et al. 2005.) In this case the DER are able to generate value also for a DSO meaning that it would be interested in supporting such projects. For the investor of the DER this would appear in smaller transfer fees charged by a DSO. On the other hand DSO could own energy storages to be used in decreasing voltage problems in case the voltage measured at the customer point doesn’t meet quality standards. (Mäki 2012, p. 28.) If better than average voltage is desired, the customer should pay the storage because otherwise the vast majority of customers would pay for the benefit received by a few customers. This is not in line with a principle found in accounting that costs should be carried by the one who causes them.

To be able to manage systems including DER, they need to be carefully documented to DSO’s systems. Basic data of generators and storages need to be available in DMS. Also load and production curves should be available to be able to calculate load profiles of feeders. DSOs are also able to monitor load levels of secondary substations by installing AMR devices to these locations. In case of fault, the fault current fed by DER should be taken into account. DMS 600 already includes such feature.

There is a possibility to postpone or even avoid network reinforcement investment by utilizing DER (Haesen et al. 2009). It follows from the previous chapter since line loading can be limited to a suitable level. This is done by supplying the increased demand from DG or from storages loaded during low demand. Demand response can be utilized here too as, unlike wind or solar generators, it is always available. In this case also, the additional value can be perceived by a DSO even though it is not as easy as in the first case. Haesen et al. (2009) argue that there should be adequate amount of DER integrated in networks in order to perceive such advantage. (Haesen et al. 2009.)

On the other hand, lines still have to be designed to take fault currents generated by DER which may weaken the saving potential. In addition to fault currents, DSOs are eager to have strong enough lines to be able to supply the load even if the DER unit is faulted or otherwise unable to supply. According to discussions with DSOs, this benefit of DER is not going to be realized in Finland in near future (Kenet Oy 2012; JES 2012). Additionally, for this benefit to be realized for a DSO, an investor for DER is needed as well as suitable network configuration. IEA (2011) argues that if there is a local generation unit and the area is operated in an intended island, there is no possibility for a consumer to freely select his energy provider. This again, is in a contradiction with current energy market laws. (IEA Enard 2011, p. 21.) To handle this effect of DER in DMS, the load flow calculations carried out in network planning mode should take DER into account.

In the future, there is going to be a need for an EV loading station. Such station can be based on energy storage. Fast EV loading requires large amount of energy to be charged in a short period of time. In order to make the charging of multiple EVs fast enough, a connection to MV network is required. As a consequence this creates sharp peak loads to the network every time an EV is loaded. These peaks can be avoided by using large (MWh class) energy storage which is charged with moderate power when feeder demand and electricity price are low. This could be one of the additional services provided by DSO even though it is not allowed to sell any electricity. A general model of the storage is needed in DMS to be able to calculate feeder currents and voltages during the storage operation. Alternative way of finding out the needed information is to apply measurement values fetched via SCADA. Cooperation between a DSO, an energy retailer, and a possible station operator is needed in order to operate the storage efficiently.

Energy storages can be used to level down the fluctuating output of PV and wind generation. (Mäki 2012.) Also IEA Enard (2011) argues that this application can help to sell generation units when there is balancing storage attached. Crowe (2011) sees huge market potential for energy storages in this application. Especially, when it comes to micro production where prosumers are the investors, the package including generator and storage might be highly appreciated. Instead of curtailing PV output, the excess power could be used to charge energy storage and thus prevent voltage rise in LV network during peak production. Heiskanen et al. (2012) argue that potential small scale producers are interested in working solutions provided as a service rather than individual devices. (Heiskanen et al. 2012.) A generator-storage package appears to a DSO as a steady supplier which can be compared to conventional generator. Such predictable production is valuable for a DSO as for instance voltage level near generator remains constant but the benefit is even greater for the generation owner (or the aggregator) who sells the energy because the output of the system can be precisely predicted.

Larger energy storages can also be utilized in frequency control. There should be at least 10 MW available within 15 minutes in order to participate to frequency control (Fingrid 2011). This amount of storage capacity can be achieved by using aggregation of small-scale storages. AES has implemented a storage unit of 12 MW to be used in frequency control in Northern Chile mining area. The storage can be used to support the system frequency until necessary generators are started. (AES 2012.) Since power system frequency is a global quantity there is no direct benefit for the local DSO from this application. The case can even be the opposite as explained in the next paragraph.

The frequency of a grid decreases when the amount of load is greater than that of production. In normal conditions, the discrepancy is usually compensated by increasing the production of hydro plants. In an abnormal situation where for instance a large nuclear plant drops off from the grid some power reserves have to be started. In these cases – instead of starting expensive gas turbine reserves – energy storages can be used to supply at least part of the missing power. In a distribution level this would mean heavy currents drawn from storage units ending up with increasing voltages in MV network. Such incident would be difficult from the DSO’s viewpoint. However, demand response can be utilized in frequency control as well. Instead of supplying more power to the grid from generators or storages, the load can be curtailed by disconnecting lower priority loads. This is in line with one of the basic assumptions of the smart grid that loads should follow generation. (ABB 2009.) In case of a high frequency (production exceeds load), the situation would be easier as storages can be gently charged which decreases the frequency. Now, storages would only appear as loads for DSOs. As a conclusion, it would be practical to combine energy storages and demand response in normal operations as also suggested by IEA Enard (2011).

5.3.2. Abnormal conditions

The first DER application for abnormal conditions is that DER supports power restoration i.e. helps to maintain acceptable network conditions in fault situations. There is island version and non-island version developed for SGEM, where non-island version is easier to execute. Especially network maintenance operations can be planned to utilize DER and by doing so, minimize the outage area. The value is created by avoiding outages and thus outage costs. The avoided cost is money for a DSO because smaller amount of outages lead to higher allowed profit, which again makes investment calculations possible. The cost of outage is defined in a survey made by Honkapuro et al. (2007). The survey was based on a large questionnaire asking the perceived harm of an outage. (Honkapuro et al. 2007.) It should be highlighted that the monetary value given by the following equation doesn't mean real money, but the value of the harm caused by an outage. The cost depends on customer type and the length of the outage. The monetary value of an outage is calculated by using the following equation:

$$C = \sum_{j \in J} \sum_{i \in I} \lambda_{zone}(A_i + B_i t_j) P_{ij} n_{ij}$$

Where λ refers to a sum of network component failures in the zone of inspection, A and B are factors defined for each customer group and they are found for example in Honkapuro et al. (2007), t is outage duration, n_{ij} is the number of customers of group i at load point j, and P_{ij} is average power of customer group i at load point j. (Antikainen et al. 2009.)

As can be obtained, the cost of an outage in a specific zone can be reduced either by decreasing λ or by shortening t. The first one can be done for example by using underground cables and the latter can be affected by installing network automation enabling faster disconnection of the faulted zone. Furthermore, the time of an outage varies depending on where the customer is located. Some customers are having an outage with the length of reconnection while some perceive the powerless time required to repair the fault. Increasing the amount of network automation enables reconnection times for more customers and thus prevents longer interruptions and related costs. In addition to network automation, DER is able to reduce the outage time by supplying loads "behind" the fault.

In addition to outage costs discussed above, the DSO is obligated to pay compensation to its customers for outages lasting more than 12 hours. In practice, this means paying back a part of annual transfer fees charged by the DSO. However, an upper limit exists: currently the maximum amount of compensation is 700 euros. (Electricity Market Act 27 f §.) After Hannu and Tapani storms in December 2011 there has been discussion about raising the compensation limit. Naturally, DSOs would not be delighted about such decisions. Moreover, EMV suggests that limits regarding outage lengths are going to be changed. For example in urban areas the time after which the compensation steps in is going to be reduced to three hours from the current 12 hours. (EMV 2011b.) However, such development requires changes in current energy market laws, which again takes time. It is likely that such tightening of compensation limits are not going to be seen before 2020.

Antikainen et al. (2009) found that even locating DG to the most advantageous point of the test (MV) network was not very feasible from the economic point of view (Antikainen et al. 2009). Furthermore, investments in DER alone are not enough but investments are also needed in network automation and control systems to be able to form such islands remotely and within relatively short time. However, using DG to supply a single low voltage network would be a working solution (Antikainen et al. 2009). The scenario created in SGEM suggests that DER equipment is owned by private firms or farms and systems are designed to supply only the farm's load in island situation. Under current market circumstances, only this type of design is feasible for DER owners since there is no standard way to sell power to others. As a result, only the surplus power is available for "traditional" consumers. This somewhat limits DER usability in power restoration especially when complicated contracts are needed between the DSO, the DER owner, and the aggregator. There are also some other considerations like Loss of Mains or LOM protection, which is definitely needed to prevent unintended island operation and to enable successful auto-reclosing operations. (Kauhaniemi et al. 2011.)

Another application is the one where energy storage and a generator are used as a backup system. This system falls into category 3 defined in chapter 4.2.4 as the storage has to be connected parallel to the distribution network for it to be charged. IEA Enard 2011.) The aim is to supply power from the storage unit until the generator is started and synchronized. In shorter interruptions the generator is not needed at all which creates savings in fuel costs. The storage also enables uninterruptible supply, which is important for example for computers. Furthermore, if maximum power of the generator is exceeded, the storage is able to supply the surplus power. These island systems can be considered as an insurance against power outages in malls, office buildings, and industrial blocks. DSO has to be aware of these systems to be able to operate network securely. In practice, a switch disconnecting the backup system from the distribution network is required and DSO personnel have to be able to see the air gap between the systems. In these systems too, the protection which disconnects the storage during auto-reclosings should be installed.

The DSO can also utilize backup generators in low voltage networks to provide power supply for customers during MV network maintenance and why not in longer fault interruptions as well. This possibility is widely utilized at least in Jyväskylä (JES, 2012). Sometimes the generator is used to supply multiple LV networks by transferring the power through an MV network. Such installation forms an island manually and currently it needs to be supervised on site as there is no working earth fault protection. (JES 2012.) In a larger scale too, the lack of background network in MV islands and microgrids makes earth fault protection complicated as fault currents are too small to be detected but large enough to create hazardous touch voltages.

If there is no storage attached, the system falls in class 2 defined in chapter 4.2.4 meaning that it is a genuine backup system not intended to supply power to the grid. These solutions are found in rural areas where tractor-operated generators are widely used in cattle farms to provide power for milking and storing of milk. In these cases too, a switch disconnecting the farm from the distribution network is required, and luckily, they are widely installed. It separates the farm from the distribution network and thus enables an island operation without compromising the occupational safety of field groups repairing network faults. However, in these cases too, the DSO should be aware of such equipment to be able to ensure the safety of personnel. Furthermore, a short interruption will occur when connecting the farm back to the distribution network since there is no equipment for synchronizing and the connection has to be made via an outage.

Security issues in fault situations lead us to a wider problem recognized by DSOs: There may be many possible feeding points which need to be opened, locked and earthed before starting to repair the actual fault. This would even result in longer interruptions than before as DSO personnel need to take additional precautions. In addition to isolating the fault point, the configuration needs to be restored after the fault, which takes even more time. All the interviewed DSOs agreed that safety of personnel comes before savings in outage costs. DMS systems were found to be important in indicating where to look for possible feeding points. This issue should be addressed in DMS development.

Higher amount of DER introduces higher than before fault currents in cases where a rotating machine is connected directly to the system. Contrary to popular belief, DER connection made through power converters doesn’t introduce high fault currents. The maximum current can be as small as 1.2 times the nominal current which is not adequate for over current protection. Most DER devices are and will be connected via power electronics which requires revised plans for network protection especially in island situations. It would be possible to use distance –protection in converter fed islands which again, is expensive. With respect to rotating machines at least feeder protection at primary substation has to be checked as the fault current supplied by DER can blind the feeder protection. Moreover, wrong (healthy) feeder may be disconnected unless the protection takes current direction into account. (Kauhaniemi et al. 2011.) Protection issues are not in the scope of this thesis and they are not considered further but they should definitely be taken into account in network planning. The additional work related to protection planning was considered as a challenge or disadvantage by JES. In any case, some investments are needed to ensure secure operation of networks which again sets pressures to raise transmission prices to cover the costs (Lakervi & Partanen 2008).

It is quite clear that none of these benefits alone makes DER a good investment. More of these activities need to be performed together which is also indicated by EPRI

(2010). They found frequency regulation, backup systems, and systems for grid support and investment deferral to be the most profitable energy storage applications when measured by present value of projects. However, highest values are received when storages are used on transmission level rather than on distribution level. (EPRI 2010, p. 31.)

There is definitely some value available also for DSOs in DER applications. So far, the additional value is hard to perceive as visible benefits are smaller than disadvantages. In short term, it is likely that DER projects cost more than they benefit but on the other hand, that is the case with every R&D intensive project. This value is basically received as smaller costs in network operations.

New additional value that can be used to run new businesses is even harder to find. For DSOs it seems that conveying command controls for demand side management and for storages and DGs as well could be the best area for new business opportunities. When taking into account the possibility that customer billing evolves towards one-point system, which means that electricity retailer is the connection point to a customer and both energy and transfer are billed with one invoice, there are smaller chances for DSOs to operate as advisors. However, such systems are not yet utilized and it is suggested that DSOs could still be contacted in network issues. Moreover, if management of microgrids is given to a third party, it is likely that a DSO and its expertize are needed to run such systems. On the other hand, why to search for new business opportunities as current business can be adjusted to yield as much as needed and even more.

5.4. Future requirements

This chapter discusses about the requirements needed to exploit the abovementioned features of DER. Something about communications, interfaces, etc. and especially what is DSO’s role in this development.

To be able to manage DER integration and networks including DER some features are needed in distribution management system. Features already found in DMS 600 are not mentioned. Following issues are briefly covered.

- Component model and user interface for energy storage
- Model for microgrid
- User interface for load shedding via AMI
- Validation process for running scheme
- Extended generator model including backup symbols

Model for energy storages is needed to be able to manage storages attached to MV network. Interface including storage attributes like maximum power input and output is needed. These values can be used to find out the worst case. Probably some control interface is needed for the DSO to be able to disconnect the storage. Measurement values fetched by SCADA are needed to monitor power flow.

Model for microgrid is more challenging as it is not clear what kind of systems they actually are. At first, some borders or background symbol for microgrid for DSO to know where it is. Connection to microgrid controller has to be established somehow. In case the microgrid controller takes care of islanding in fault situations, it should be pre-defined what loads and customers are going to be within the island. Another possibility is to continuously monitor loads and production and iterate islanding plans accordingly.

A user interface allowing DSO operator to select LV networks, feeders, or other areas where load shedding is done is needed. However, this requires that unimportant loads that can be shed are connected to a group that can be controlled via AMR device's on/off switch which again requires pre-defined load priority. If priorities need to be changed on the run, some more sophisticated home automation is needed.

Validation process of DER running scheme is probably done in estimation. Loads and productions of units are needed in some form, after which the estimation calculation is run. DMS reports of problematic areas and can recommend some correction. On the other hand, such capacity check could be carried out by the aggregator. This approach would separate market operations and technical operations from each other more clearly. Such arrangement would require DSOs network model to be exported from DMS to aggregator's systems. However, DSOs may not be willing to do that since network data is tightly connected to their core business. Moreover, one aggregator is probably operating on wide area and it would need network data of multiple DSOs.

Current generator model needs to be extended to cover different types of generators. A symbol can differentiate wind generators and solar generators for instance. At least a symbol is also needed for customer sites having backup generation. Additionally, some specifications can be included too. The following table aggregates generator classes introduced by Energiateollisuus and their possible operating modes. Cross indicates a mode that is intended while P stands for a mode that is possible but not necessarily desired. Idle refers to a situation where resources are connected in parallel to a distribution network but there is no active power flow in or out.

Table 5. *DER classification and operating modes.*

		P out	P in	Island/Microgrid	Idle
Class 1 “Stand alone”	Generator			X	
	Storage			X	
Class 2 “Backup”	Generator	P		X	
	Storage	P	X	X	P
Class 3 “Peak shaving”	Generator	P		P	P
	Storage	P	X	P	P
Class 4 “Power source”	Generator	X		P	
	Storage	X	X	P	X

From the DSO and DMS point of view the modes indicated with P are interesting as they should be taken into account in order to promote safety.

6. CONCLUSIONS

6.1. General summary and discussion

Three main areas have been studied in this thesis: technologies used in DER, DSO prerequisites and possibilities to have DER in their network, and DER implications to network operations on the distribution level.

With respect to DER related technology, the overall development is likely to be incremental as small or moderate performance improvements are seen on sub levels. Better designs for PV panels and improvements in battery technologies are probably the most significant issues. In demand response, there are many alternative technologies available in many levels but the real problem is in standards and common procedures rather than in technologies. Furthermore, benefits and liabilities for different participants are still unclear which creates some barriers for adoption and diffusion.

It seems that wind power is increasing in coastal areas. It does not have that large implications for DSOs as wind parks are connected to transmission level and individual units are likely to have their own feeders. Some voltage and protection issues are likely to occur though. On the other hand, micro-scale wind turbines connected to LV network are probably seen within 10 years. This might cause some voltage problems while congestion problems are not likely according to DSOs. Wide diffusion of class 4 PV systems is not expected by interviewed DSOs but some such plants are probably going to be seen. In central Europe though, these small-scale PV systems already cause some voltage problems in LV networks and these issues are increasing in the future. From the PV owner point of view, energy storages would be a better solution than curtailment of PV output carried out by a DSO.

TAM suggests that perceived usefulness is a key to technology adoption. The problem is that DER can be useful as indicated by literature and research but DSOs don’t perceive it to be. Reasons for this are found in antecedents of PU. One factor reducing PU is the fact that DER cannot help in the most urgent network related issue i.e. age and deterioration. Cabling is found to be the solution for this problem especially when more weatherproof network is appreciated. This again, whittles away the relative advantage of DER over cabling which is also a factor for PU. Generally, PU is closely connected to perceived value as also suggested by Davis (1989). The difficulty to perceive concrete measurable value from DER related operations is the most important reason for reduced PU received by DSOs. They mentioned loss reduction as the biggest advantage or source of excess value from the operational point of view. Independent islands and their ability to reduce outages were considered to be far in the future. Additionally, DSOs highlighted that direct monetary benefits should be clearer than today for DSOs and other participants to involve. Such benefit has links to electricity price and to compensations DSOs are obligated to pay for outages. Compensation fees are expected to rise during next 5 to 10 years which makes for example backup generators more valuable. It is more difficult to say anything about electricity price. There will be pressures to hike up transfer rates because of renewal investments.

TAM also suggests that PU can be affected through PEOU as easy-to-use systems are useful and valuable because they release effort to be put elsewhere. Some new technologies are compatible with current technologies while some are not. For example small amount of generation and energy storages are relatively easy to integrate in networks. On the demand response side the amount of possible technologies make compatibility more difficult although a well designed AMI system would enable DSOs to utilize meters in DR easily. As a result, the biggest concern is related to increased complexity of distribution systems which, in turn, decreases perceived ease of use by DSOs.

It was found by Venkatesh & Davis (1996) that perceived ease of use is strongly affected by individual’s computer self-efficacy. Of course, their study was about computer systems as many TAM related studies are. But on the other hand, computer systems can be considered to be one of the key elements in future smart grids because system management and increasing amount of controls are made remotely by computers. Due to extensive use of SCADA and DMS systems in Finnish DSOs it can be assumed that general computer self-efficacy is on a good level in DSO operations. Venkatesh & Davis (1996) conclude that hands-on experience is important for PEOU. In this sense the lack of relevant DER related experience in all Finnish DSOs significantly reduces PEOU. Observations made in DSOs and especially in Fortum and Helen support assumptions of theory as they believed that the more they get experience the less complex they find new technologies.

From the organizational point of view it was found that there are two types of DSOs. Large companies actively participate in pilot projects and invest in DER and smart grids related R&D while small companies take follower’s role and act only when obligated by law or when suitable services are provided. Such polarization is not about willingness or attitude of network people but about resources. This leads to a fact that pro DER attitude is required in business managerial level in order to have DER (or smart grids in general) written in corporate strategy and thus enable adequate resources. Resources enable searching of information and even some experimental projects which, again, pave the way for greater perceived ease of use and thus smaller barriers for adoption. On the other hand, some market pull would be needed as well. For example higher volatility of electricity price would probably accelerate people’s interest in DER applications.

While currently DSOs don't see many benefits or relative advantages, the literature and academic research reveal that there are benefits available. DER can be beneficial in normal operation as well as in abnormal operation or fault situation. Many DER applications are related to backup solutions like to microgrid islands which should be able to improve voltage quality especially during fault situations. For DSOs this would appear as smaller outage costs and even as avoided compensation fees. Also higher utilization of feeders via energy storages and demand response are able to create excess value for DSOs when corresponding technologies evolve and barriers like overall system complexity are reduced. From this point of view the future of DER also in Finland looks brighter than it looks based on mere interviews.

What does this all mean then? DER has not yet widely diffused in Finland which means that neither DSOs and retailers nor potential prosumers and regulators have much experience about DER. Retailers are developing new electricity products and services but they need DSOs and customers to involve while these are waiting for a regulator to take the initiative and prices of DER to fall. Solutions suitable for Finnish environment are going to be developed through academic research and pilot projects but it takes time before these are fully operational.

This study doesn't reveal any ground breaking results related to DER integration. It however manages to answer research questions. Technologies are scanned mainly for background purposes. Technologies used in sub levels of DG and storages are not necessarily relevant for DSOs. DR and microgrid technologies instead are more important. Questions two and three were found to be connected together as utilization of technologies depend on their usefulness. Factors for usefulness and ways for utilization were found. Research objectives regarding TAM –based framework were reached even though the framework could have been better in terms of depth of theory.

6.2. Reliability and validity of the study

When it comes to reliability the concern is whether results are reliable. If someone else carried out the interviews with the same questions he would probably get similar answers. However, the answers are tightly related to the time of the study which means that in couple of years the answers would deviate from answers received in this study. Answers would be slightly different if there were different persons answering but due to consistency between answers of different firms it is likely that answers within a same firm would have been similar with each other. Observer error and observer bias can be considered low because there has been only one observer in the study.

In validity the concern is whether the used meter measures the right thing. There are many types of validity which are assessed here. External validity refers to generalizability of findings. Internal validity is the extent to which the study measures what it is intended to measure. Content validity measures whether the questions cover the desired topic. Predictive validity refers to the extent to which findings can be used to predict respondents' future behavior.

Regarding external validity, the question is whether or not the interviewed DSOs represent all Finnish DSOs or are results generalizable to other DSOs. On a general level the results represent the industry relatively well. Changes in environment affect equally all DSOs. Technology and organizational issues, again, cannot be generalized because from this viewpoint DSOs are different. It is obvious, that results cannot be generalized outside the population i.e. Finnish DSOs. Having more DSOs in interviews would have increased the external validity of the study but on the other hand, it may have been that the number of new issues or viewpoints wouldn't have increased correspondingly. Interviewees represent different types of companies as well as different areas which gave different viewpoints to the subject. As discussed in chapter 4 the structured interview gave better understanding of what is happening in the DSO environment that a mail questionnaire would have done. This deeper understanding improves reliability of the study.

In internal validity it comes down to the used framework. Is it suitable for its purpose? The original TAM uses questionnaire and statistical approach rather than qualitative approach. Moreover, it is designed to model the adoption of firm-level systems and the modeled firm also makes the investment which makes adoption critical for investment profitability. In this study, the object of adoption is not affecting the whole company in a way a computer system would have done and what is more, the actual adoption decision is made by some other participant. However, the TAM provides a structure for a framework to analyze different attributes affecting the adoption and relations between these attributes. This again enables the analysis of the state of affairs in the firms and in the industry. Deeper theory development would have provided better framework, easier question phrasing, and more effective analysis of collected data.

Content validity is concerned whether the questions presented in 4.3 actually ask the right thing. Some questions could have been configured better in order to put them better in line with the theory but on the other hand questions were designed also to get some ideas what to improve in the current product. In this sense, the needs of ABB overtook the needs of theory which is negative for the study but positive for the work right after the study. Additionally, some questions were unclear which resulted in difficulties to answer them. In these situations, however, the very method of collecting data turned out to be valuable as the meaning of a question could be clarified by the interviewer.

Predictive validity is concerned whether it is possible to predict future based on the study. It was found that studied firms are in a position where they are waiting for investors and regulators to make decisions. Thus it turns out to be difficult to predict future actions because it is not directly in the hands of interviewees.

6.3. Limitations and future research

Globally, this thesis has one major limitation and it is that the thesis concentrates on Finland. The DSO environment, energy market, and governmental regulation are country sensitive and it follows that all the ideas cannot be used everywhere. Another limitation is that this study doesn't provide any practical numbers or other advice about how to integrate DER or how to best utilize them in business. It only lists possibilities and their strengths and weaknesses. One topic of future research would be to concentrate on some of the solutions described in this thesis and calculate its profitability in more detail although it would be difficult due to numerous assumptions required. Such research would attract some interest in DSOs as well. It would also be interesting to carry out the same interviews for instance in DSOs in Europe or in the US and discover whether the environments differ from each other. Such research would also give more comprehensive understanding of the current state of smart grids and DER integration.

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