TAMPERE UNIVERSITY OF TECHNOLOGY

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EVALUATING SMART GRID DEVELOPMENT FOR INCENTIVE REGULATION

Master of Science Thesis

Examiner: Professor Pertti Järventausta
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ABSTRACT

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European Union accepted a new climate- and energy package in 2008. As a consequence of the new and quite challenging strategy the whole electricity industry has to evolve, concerning also electricity distribution sector, especially as the role of electricity as an energy carrier increases. At the same time the expectations of the society as well as a single customer increase towards electricity supply, voltage quality and the whole network service. Smart Grids can integrate the existing network infrastructure with advanced automation and ICT- technology enabling more efficient and flexible use of the network by opening up new possibilities for additional services. For this reason, a need for the development of "smart" solutions and their introduction increase continuously. DSOs are in a crucial role concerning the development of the network infrastructure.

Network business is a regional monopoly business sector which is regulated by authorities. As the operation environment changes also the regulation model need to be developed into a right direction. The model should allow DSOs to have such economic conditions, that the grid development with "smart" solutions becomes possible which is a prerequisite in order to reach the political targets as well. Significance of the directing signals of regulation and potential incentives are crucial from Smart Grid perspective. This has to be taken into account when developing the future regulation models.

The aim of this thesis is to analyze the "smartness" of electricity distribution networks from different perspectives. The recognition of the most important "smart" solutions is a prerequisite when evaluating the level of "smartness" in a network. Therefore the focus is on analyzing the benefits of "smart" solutions by reflecting them with the ultimate objectives of Smart Grids (EU 20/20/20 targets). Based on analyzes carried out during the work, there has been developed an approach for determining the level of "smartness" in a network. The approach includes the most important aspects of "smartness" suitable to be used especially in the Nordic countries.

The approach has been applied in practice by performing a case study of Vattenfall's distribution networks in Finland and in Sweden. Based on analyzes carried out during the work, the most important challenges concerning future development have been identified and discussed. In addition, consideration of ways to ensure the development of network business into a right direction has been made. As an enabler for Smart Grid development there is a regulation model, which takes into account the needed innovative solutions by providing advanced incentives for the DSOs to overcome the increasing challenges. Potential incentives related to "smart" solutions and Smart Grids have been discussed briefly in the work. Review of how the approach created to evaluate the level of "smartness" could be used in the future regulation models on a larger scale, is however left for further research proposal.

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Euroopan Unioni hyväksyi vuonna 2008 uuden ilmasto- ja energiastrategian. Uuden ja varsin haasteellisen strategian seurauksena myös sähköverkkoliiketoiminnan on kehitettävä, erityisesti sähköenergian roolin merkityksen kasvaessa yhä tärkeämmäksi. Samalla yhteiskunnan ja yksittäisen asiakkaan odotukset sähkön toimitusvarmuutta, laatua sekä verkkopalvelutoimintaa kohtaan kasvavat jatkuvasti. Älykäs sähköverkko kykenee yhdistämään perinteisen verkkoinfrastruktuurin kehittyneeseen automaatioteknologiaan sekä ICT- teknologiaan mahdollistamalla verkon entistä tehokkaamman ja joustavamman käytön avaten samalla mahdollisuuksia uusille palveluille. Tästä syystä tarve äkykkäiden ratkaisuiden kehittämiselle ja käyttöönotolle kasvaa jatkuvasti. Verkkoyhtiöiden rooli älykkäiden verkkojen kehityksessä on ratkaisevassa asemassa.

Verkkoliiketoiminta on säänneltyä, alueellista monopolitoimintaa jota valvotaan viranomaisten toimesta. Toimintaympäristön muuttuessa on myös verkkoliiketoiminnan valvontamallin kehitettävä oikeaan suuntaan siten, että se mahdollistaa verkkoyhtiöille taloudelliset edellytykset kehittää verkkoa älykkäillä ratkaisuilla, joita voidaan pitää edellytyksenä myös poliittisten tavoitteiden saavuttamiselle. Viranomaisvalvonnan ohjausvaikutusten ja mahdollisten kannustimien kohdistumisen merkitys tulee kasvamaan älykkäiden verkkojen kehityksen kannalta. Tämä on huomioitava myös tulevaisuuden valvontamallien kehityksessä.

Tämän työn tavoitteena on analysoida sähkönjakeluverkon älykkyyttä erilaisista näkökulmista. Tärkeimpien älykkäiden ratkaisuiden tunnistaminen on edellytys verkon älykkyyden arvioinnille, joten työssä on keskitytty tarkastelemaan älykkäiden ratkaisuiden tuomia hyötyjä ja sitä miten ratkaisut tukevat perimmäisten tavoitteiden saavuttamista (Euroopan Unionin asettamat 20/20/20 tavoitteet). Työssä suoritettujen tarkasteluiden pohjalta on kehitetty lähestymistapa verkon älykkyyden arvioinnille huomioiden tärkeimmät verkon älykkyyden näkökulmat, jotka soveltuvat käytettäväksi erityisesti Pohjoismaissa.

Verkon älykkyyden määrittämiseksi luotua lähestymistapaa on sovellettu käytäntöön suorittamalla case-tutkimus liittyen Vattenfallin jakeluverkkotoimintaan Suomessa ja Ruotsissa. Tutkimustulosten pohjalta on analysoitu merkittävimpiä haasteita tulevaisuuden kehityksen kannalta ja pohdittu keinoja, joilla voitaisiin taata oikeansuuntainen kehitys verkkoliiketoiminnan kannalta. Älykkäiden verkkojen kehityksen edellytyksenä on valvontamalli, joka huomioi tarvittavat innovatiiviset ratkaisut verkon kehittämisessä. Potentiaalisten kannustimien kehittämistä liittyen älykkäisiin ratkaisuihin on myös pohdittu työssä lyhyesti. Tarkastelut liittyen siihen miten älykkyyden arviointia voitaisiin hyödyntää laajemmin tulevaisuuden valvontamalleissa on kuitenkin jätetty mahdolliseksi jatkotutkimuskohteeksi.

PREFACE

This Master of Science Thesis was carried out in Vattenfall Verkko Oy and Vattenfall Eldistribution AB as a part of Smart Grids and Energy Markets (SGEM) project during spring and summer 2011.

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Thank you all!

Tampere, Finland
October 2011

Joni Parkkinen

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ABBREVIATIONS AND NOTATION

AMI	Advanced Metering Infrastructure
AMM	Automated Meter Management
AMR	Automated Meter Reading
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital Expenses
CEER	Council of European Energy Regulators
COSEM	Companion Specification for Energy Metering
DEA	Data Envelopment Analysis
DER	Distributed Energy Resources
DG	Distributed Generation
DLMS	Device Language Message Specification
DLR	Dynamic Line Rating
DMS	Distribution Management System
DNO	Distribution network operator
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DSP	Demand Side Participation
EC	European Commission
EC TF	European Commission Task Force
EEGI	European Electricity Grid Initiative
EMI	Energy Market Inspectorate
ERGEG	European Regulators Group for Electricity and Gas
EU	European Union
Ex-ante	A term that refers to future events, such as future returns
Ex-post	A term that refers to actual events, such as actual returns
GIS	Geographical Information Systems
GPRS	General Packet Radio Service
HV	High Voltage
ICT	Information and Communication Technology
INCA	Interactive Customer Gateway
IVR	Interactive Voice Response
KPI	Key Performance Indicator
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
MDMS	Meter Data Management System
MV	Medium Voltage
NIS	Network Information Service
NPAM	Network Performance Assessment Model
OPEX	Operational Expenses

PLC	Power Line Communication
PQ	Power Quality
P2P	Point to Point, Peer to Peer
RD&D	Research, Development and Demonstration
R&D	Research and Development
RES	Renewable Energy Source
ROR	Rate of Return
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SDEA	Stochastic Data Envelopment Analysis
SFA	Stochastic Frontier Analysis
SG	Smart Grid
THD	Total Harmonic Distortion
TOTEX	Total Expenses
VFS	Vattenfall Eldistribution AB Sweden
VFV	Vattenfall Verkko Oy Finland
VPP	Virtual Power Plant
WACC	Weighted Average Cost of Capital

1 INTRODUCTION

The role of electricity as an energy carrier is becoming more and more important in the future. The amount of devices and systems which are depending strongly on electricity is increasing rapidly all over the world. In Europe, the total consumption of electricity is increasing continuously and it has been estimated that the total yearly increase in consumption is going to accelerate rapidly over the next decades. At the same time, the consumer expectations for the quality and security of electricity supply and distribution are getting higher and higher.

Vattenfall is Europe's fifth largest producer of electricity and the largest producer of heat. Vattenfall is a large international company and at the moment it operates in many countries in Europe, such as Sweden, Netherlands, Germany, United Kingdom, Denmark, Poland and Finland. The parent company, Vattenfall AB is completely owned by the Swedish state. In Sweden, Vattenfall Eldistribution AB takes care of the electricity distribution within Vattenfall. In Finland, the corresponding distribution network operator is called Vattenfall Verkko Oy. This thesis work is done for Vattenfall Verkko Oy and the main focus is on Vattenfall's distribution network business in Finland and in Sweden.

European Union accepted a new climate- and energy package on December 2008. The legislation package is called as 20/20/20 targets. This legislation states that all the countries inside European Union must reduce their greenhouse gas emissions by 20 %, compared with the levels of the year 1990. New electricity production methods, which are using renewable energy sources, should be implemented. The target is that 20 % of total generation is produced by renewable energy sources. The energy package also states, that energy efficiency should be increased by 20 %. All these targets should be achieved by the year 2020. (Ympäristö, 2010; ERGEG, 2009) It is clear, that the new legislation package is ambitious and in order to accomplish these challenging objectives some new and innovative solutions must be implemented. These ambitious targets and actions that have to be done to accomplish them are introduced in Chapter 2 in more detail.

The whole business environment of electricity distribution has undergone some dramatic changes over the past decades. Electricity distribution is considered as a natural monopoly which is a regulated business environment under regulation of authorities and different legislative guidelines. Economic regulation has been introduced to support the legislative requirements and its objective is to steer the operation of the companies into a desired direction. Nevertheless, the biggest challenge of regulation is to stay along with the development of electricity distribution business. At the moment, most of the suggestions concerning the changes that should be implemented in regulation come from the European level. This is a straight consequence of the fact that the whole legislation in EU countries is on the way towards uniform European legislation. Especially nowadays, on the way towards smart solutions and the concept of a Smart Grid there is an increasing need for "smart-regulation" as well. This means that the current regulation of electricity distribution business should focus and adapt so that it takes into account also the operational environment of the companies, which is quite challenging because of the aging network, instead of just end-user prices and distribution reliability. Chapter 2 describes shortly the current regulation models most commonly used in Europe and the major deficiencies that the current models have. Regulatory incentives from the Smart Grid point of view are also discussed in this work, the discussion is a part of the chapter concerning smart regulation and it is presented in Chapter 7. The study is made by considering different ways to measure the smartness of a network and the benefits of the smartness; the aim is to identify the most important keystones in order to develop and adapt more incentives to the regulation models in the future in order to accelerate the evolution of the networks towards the next generation, Smart Grids.

The concept of Smart Grids refers to a network system, which is able to effectively satisfy all the new requirements and functions of a future network system by using advanced ICT-communication technologies. The traditional electricity distribution network is a passive network that delivers electricity from the generation point to the consumption point. In future, the network system has to be changed to an active network, which is able to intelligently integrate the actions of all the users connected to it – generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supply. The network must be able to adapt small-scale distributed generation and enable two-way power flow inside the grid. It has to be able to support all new functions of the electricity market in order to make the operation of the network and electricity market more efficient and flexible. The concept of a Smart Grid is introduced in Chapter 3 and the characteristics of an intelligent network and the new functionalities that it is able to offer are discussed in more detail. The study is focused on the technical and service perspectives from a Smart Grid development point of view.

The development concerning smart solutions and Smart Grids has already started around the world but the current situation between different countries in Europe varies quite strongly. In the Nordic countries like Finland and Sweden the legislative regulations concerning large scale implementation of advanced metering devices has made the adaption of new services and functionalities possible while in some European countries the development is still at the starting point. When discussing Smart Grids, the technology that is needed already exists. The biggest challenge today is a lack of consistent standards and regulations for smart solutions.

Setting up an exact definition for "smartness" of a network is a very complicated matter. Nevertheless, it is a vital issue in order to be able to measure and further estimate the current development level in a network. In order to be able to adapt new legislation, including new regulatory incentives and standards to accelerate the development concerning Smart Grids and smart solutions, it is important that the benefits and effects of smartness in a network are identified precisely. These benefits and effects of smartness in a network are discussed in Chapter 4 and in relation to that, ways to measure the "smartness" in a network are examined and demonstrated in Chapter 5 by creating a special approach to be able to evaluate the level of "smartness" in a network. As a basis for the evaluation and analysis of the "smartness" in a network there are used some key performance indicators (KPIs) suggested by ERGEG (European Regulators Group for Electricity and Gas) and EC TF (European Commission Task Force) introduced in Chapter 4. (ERGEG, 2010; EG, 2011) These suggested KPIs are expanded in this work in order to have more specific results. The study is concentrated to consider the most adequate manners to be used in the Nordic countries, especially in Finland and in Sweden.

The main focus of this thesis work is to analyze different aspects of "smartness" in a network. Based on the studies performed through the work, the objective is to create an Excel –based measuring application, which could be used in the evaluation of the "smartness". In the final part of the thesis, there are case studies of how the "measuring tool" could be used in the review of Vattenfall's distribution networks in Finland and in Sweden. The idea is that the case studies are performed by using the measuring tool created during this work; the measuring tool is also presented in this work in *appendices 2-14*. Aim is also, that the measuring tool contains the most important aspects of "smartness" in a network which can be evaluated at the moment. The analysis and results of the case studies for the level of "smartness" are presented in Chapter 6. A deeper analysis of how the measuring application and the results that the application gives, could be used in future's regulation models is however left for further research proposal. Nevertheless, there is also some discussion concerning this matter presented in Chapter 7. The conclusions of this thesis work are presented in Chapter 8.

2 REGULATION OF DISTRIBUTION BUSINESS AND OPERATIONAL ENVIRONMENT ANALYSIS

The focus in this work is on discussing the regulation concerning Smart Grids and smart investments from the electricity distribution industry point of view in Europe and in Nordic countries. The whole business environment of the electricity distribution industry has undergone some dramatic changes over the past decades. Electricity distribution, which is considered as natural monopoly, is a regulated business environment under regulation of authorities and different legislative guidelines. Countries in EU have introduced different kind of economical regulation methods and models to suit their needs and monitor the operation of DSOs. The biggest challenge of regulation is to stay along with the development of electricity distribution business. Especially nowadays, on the way towards smart solutions and the concept of Smart Grids there is a need for suitable regulation as well. The biggest problem at the moment is that there is a lack of relevant regulatory incentives to enable the DSOs, which have a major role and responsibility in distribution network development, to make decisive investments in Smart Grid solutions to accelerate the evolution of the networks. This chapter will define what is meant by regulation in this work and demonstrate how the regulation is implemented in the electricity distribution business. The basic theories of the most commonly used regulation models in Europe are presented shortly in this chapter and there are also short descriptions of the regulation models in Finland and in Sweden.

Energy consumption is increasing all over the world, also in Europe. The role and necessity of electricity are becoming more and more important in the future. The amount of systems and devices that are strongly depending on electricity is increasing rapidly. Also rising customer requirements and expectations concerning the quality of supply and reliability of electricity distribution must be taken into account when designing and creating an intelligent future network system. A guideline for new and clear energy policy in Europe was redefined to fulfill the needed targets. European Union (EU) accepted a new climate- and energy package on December 2008. At this chapter there are presented some objectives and preconditions for the development of the future network operation environment.

2.1 Role of electricity in Europe

European energy policy will be facing enormous challenges in the future. The policy has committed to achieve substantial reductions in greenhouse gas emissions, while at the same time ensure a secure and efficient supply of energy at a reasonable cost to the economy. From the conclusion of EURELECTRIC survey, The Role of Electricity: "Only a European energy policy based strongly on demand-side energy efficiency, active development of all low carbon supply sources and active exploitation of the synergy between low-carbon electricity supply and efficient electro-technologies - especially in the heating, cooling and transport sectors - will ensure the transition to a low-carbon economy while contributing to both the security of Europe's energy supply and the competitiveness of the economy". (EURELECTRIC 2007, p10)

Electricity has the potential to respond to the main guidelines of European energy policy. It has a vital and prescriptive role in the reduction of greenhouse gases, while helping to lower oil and gas dependency. In order to be able to seize the opportunity, there was a need for a distinct energy policy pathway, which was implemented by European Union at the end of the year 2008. (EURELECTRIC, 2007) The continuing economic growth of European Union and the increasing attractiveness of electricity as an energy carrier will cause the consumption of electricity to increase. Therefore it is necessary to develop an efficiently working distribution network which is able to accommodate to compensate the increasing consumption of electricity by reducing losses in the grid and making the use of the network more flexible enabling new services, for example. In order to achieve this there should be a sensible regulation system as well. (Hänninen K, 2011) Below there is a Figure 2.1 that figures the increasing consumption of electricity in European Union. The picture is based on historic data (Eurostat) and estimates (European commission).

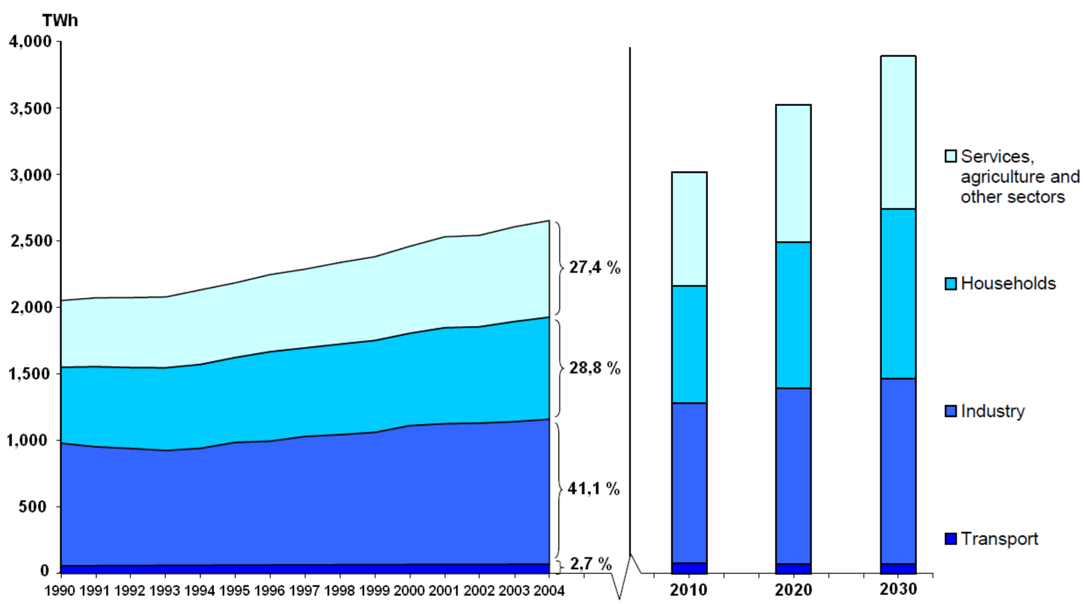


Figure 2.1, *Statistics and estimations of the increasing electricity consumption in Europe. (EEA, 2010 applied)*

2.2 Implementing economic regulation in the electricity distribution industry

Formerly, electricity distribution business was a part of utility bundled with generation and sale. After the restructuring process in Europe between 1980 and 1990, the generation and sale of electricity were opened up to competition (Finland in the 1995). In Sweden the discussions about deregulation started in the late 1980s. A first step in the process was the corporatization of the Swedish state-owned utility Vattenfall AB in 1992. The deregulatory process culminated with the new Electricity Law, which entered into force in 1996. Nevertheless, in electricity transmission and distribution business, free competition is rarely seen as a formidable option when regarding from a technical or economic perspective. As a consequence, the transmission and distribution of electricity are considered as natural monopolies, which have to be regulated by authorities. (Honkapuro, 2008) Below there is a Figure 2.2 that describes a typical structure electricity business sector after the process of restructuring was made.

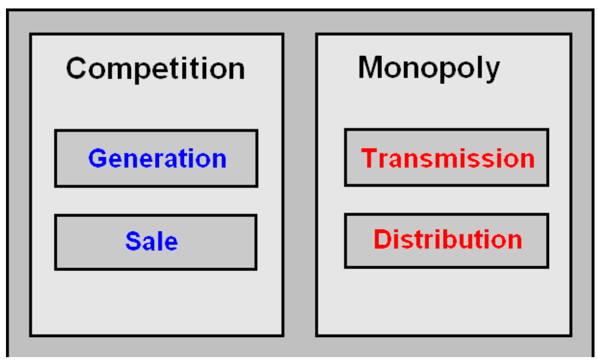


Figure 2.2, *Typical structure of the power supply sector in Europe, after the restructuring process in the 80s and 90s.*

Nowadays, network activities like the distribution of water and electricity are considered as natural monopolies. When discussing the electricity distribution business, the legislation and different acts set some requirements to distribution companies. In addition to the legislation, there is also regulation. The rules of regulation are designed to control the conduct of those to whom it applies. Regulation has an intention to support the legislative requirements and make the whole business sector operation more favorable to all the stakeholders. Usually, regulations are enforced by a regulatory agency formed or mandated to carry out the purpose or provisions of legislation. Regulations can be adapted in many industries and the principles can vary considerably depending on what industry is in question. A guiding principle for all economic activity in the society, especially in the Europe and other western parts of the world, it is the market. (GAIA, 2010)

In the field of electricity distribution, the monopoly is comprised by the existence of a single service supplier to each customer. There is no substitute for service provider and low price elasticity. There are also economic and legislative barriers to enter the market. In addition, the desire to induce productivity and efficiency there may be non-economic excuses to apply regulations on a network industry. Objectives like public safety and continuity of supply are examples of these. (GAIA, 2010)

From the DSOs point of view, two types of regulation have to be defined; these are technical- and economical regulation. Technical regulation assigns the technical rules for the operation and building of the power system including safety issues and different kind of standards concerning voltage limits, for example. At this thesis, the objective is to study and focus mostly the economic regulation. Economic regulation has the main goal to prevent the misuse of the monopoly position. This means that regulation ensures that the companies do not overcharge their customers. Regulation also ensures that the service quality (the whole quality of power distribution) is at an acceptable level. (Viljainen, 2005; Honkapuro, 2008)

Economic regulation has an intension to balance the relatively controversial desires of all the stakeholders (customers, asset owners, distribution companies, society). Customers mainly admire reasonable prices and good level of supply. Society is mainly interested about the development of the network infrastructure and of course reasonable pricing and the level of supply quality as well. Asset owners are expecting some return on the invested capital while distribution companies wish to ensure a stable business environment and possibility to gather sufficient profit to be able to operate and develop the network. These varying expectations cause challenges to the regulatory authorities. (Honkapuro, 2008)

Regulators objective is to maximize social welfare and it is clear that reduction of costs is a societal priority as well as trade-off between consumer and industry interests. The companies under regulation can sometimes see as objectives to increase revenues, which are in addition to financial profits. Availability and access to the information can be seen as main issues in the field of regulation. However, in most cases the information is not symmetrically divided between the regulator and the companies under regulation. Therefore introduction of a fair working regulation model is challenging, since the interests of all stakeholders should be taken into account. (GAIA, 2010)

2.3 Regulation models in Europe

There are different ways to classify the economical regulation models. Regulation models can be divided into traditional profit regulation and incentive regulation. Incentive regulation refers to a regulation model where the regulator applies a certain price decision to the regulated companies. The companies can benefit from profit increases that result from the pricing reductions. Instead of the term incentive regulation is also used the term performance based regulation around the world, especially in the US. The division is also made into cost-recovery, fixed price, yardstick, auctions and technical-norm regulation models, where a fixed price model represents the price cap and revenue cap regulation and cost-recovery model represents the profit regulation, for example. Typically, the described economic regulation models do not occur as such; the most common is a combination of different models. The theory of profit, revenue cap, price cap, yardstick and menu of contracts regulation models are analyzed shortly at this chapter. (Honkapuro, 2008; Viljainen, 2005) It is notable that without adjustments, none of these models introduced below, do not support the investments on Smart Grids from a DSO's point of view remarkably. See *Appendix 1* for more detailed information about European member states regulation models.

2.3.1 Profit regulation model

The idea of profit regulation (rate of return regulation) is that companies are allowed to earn revenue that is enough to satisfy the typical operational and depreciation costs as well as some return on the invested capital. (Honkapuro, 2008) This is shown in equation 2.3.1.1 below.

$$RR_{x,t} = OPEX_{x,t} + DE_{x,t} + T_{x,t} + (RB_x * ROR)_t \qquad (2.3.1.1)$$

$RR_{x,t}$,	required revenue of the company x in year t
$OPEX_{x,t}$,	operational expenses of the company x in year t
$DE_{x,t}$,	depreciation expenses of the company x in year t
$T_{x,t}$,	tax expenses of the company x in year t
RB_x,	rate base of the company x
ROR,	rate of return

Profit regulation is a simple and quite light-handed form of economic regulation. Because the earnings of companies are tied to the values of their asset bases, this regulation model encourages companies to oversized investments in the network. The method is therefore criticized for directing companies to even over optimal reliability levels. There are no guarantees that network investments always go hand in hand with the quality of supply, although it is commonly perceived as that. It is hard to prove that the investments can increase the reliability the most. (Honkapuro, 2008)

The directing signals of the profit regulation do not meet one of the primary aims of the restructuring process, because the regulation model suffers from the lack of efficiency incentives. This is why a regulation model like profit regulation as such, cannot be seen as an attractive option to be used in long term perspective in the electricity industry, especially when observing the EU energy targets. However, by efficiency benchmarking the directing signals of profit regulation method can be improved. In Finland, the efficiency benchmarking is used to set efficiency requirement for the operational costs of the companies. By doing this, one of the disadvantages of profit regulation can be overcome. Nevertheless, this approach does not affect the incentives of overcapitalization. In some cases, the method can make the situation even worse when companies begin for instance book the operational costs as investments in unclear situations. (Honkapuro, 2008; Viljainen, 2005)

2.3.2 Revenue cap and price cap regulation models

Revenue cap regulation is based on defining the allowed revenue for a company. (Honkapuro, 2008) This is shown in the equation 2.3.2.1 below.

$$R_{x,t} = \left(R_{x,t-1} + CGA_x * \Delta Cust_x\right) * (1 + RPI - X_x) \pm Z_x \qquad (2.3.2.1)$$

$R_{x,t}$, allowed revenue of the company x in year t

CGA_x, customer growth adjustment factor (€/customer) of the company x

$\Delta Cust_x$, change in the number of customers of the company x

RPI, retail price index

X_x, efficiency factor of the company x

Z_x, correction factor for events beyond management control for the company x

The fundamental sentiment of the revenue and price regulation is quite the same. This can be determined from the equations of the regulation models. Also the directing signals of the models are mainly similar. As a difference, it has to be remarked that with the revenue cap regulation model there are no incentives for increasing the amount of delivered energy since there is revenue instead of prices. (Honkapuro, 2008)

The idea of price cap regulation is to determine a price ceiling, which is based on the retail price index and the efficiency factor X. (Honkapuro, 2008) This is shown in the equation (2.3.2.2) below.

$$P_{x,t} = P_{x,t-1} * (1 + RPI - X_x) \pm Z_x \qquad (2.3.2.2)$$

$P_{x,t}$, price ceiling of the company x in year t

RPI, retail price index

X_x, efficiency factor of the company x

Z_x, correction factor for events beyond management control for the company x

Determined price cap ($P_{x,t}$) represents the index of different tariffs of the company being regulated. Cost based regulation is typically used for setting the initial price ceiling in the model. However, price cap regulation can typically be implemented after the regulator has collected some information of the typical costs of the industry by using profit regulation at first. (Honkapuro, 2008)

Price cap regulation, as well as revenue cap regulation provides companies efficiency incentives. Prices of the company are separated from the costs of it. Regulated company can retain the efficiency achievements during the regulatory period. Even if there are strong incentives for improving efficiency in the price regulation, an acceptable sharing of the efficiency gains among the company and the customers has to be specified. Practically, this means the selection of the factor X in the equation. The factor X is a mechanism by which customers receive benefits from the expected productivity growth of the companies. With regulation model like this there are some risks if utilities tend to raise their profits by blundering quality issues. Therefore the regulation of the quality of supply is of particular importance always when economic regulation focuses on the prices instead of the profits. The price cap regulation has also been criticized for encouraging companies to increase their sales and therefore providing incongruent inducements against programs of energy efficiency. As a consequence of the price cap, also the large scale investments which are needed in near future place remarkable challenges for the DSOs to overcome. (Viljainen, 2005; Honkapuro, 2008)

2.3.3 Yardstick regulation model

The idea of yardstick regulation is to compare the regulated companies with each other. The allowed incomes can be determined based on the performance of the companies in question. Main elements of the cost-based regulation are defined below in the equation (2.3.3.1). (Honkapuro, 2008)

$$P_{x,t} = \alpha_x C_{x,t} + (1 - \alpha_x) \sum_{j=1}^{K} (f_j C_{j,t}) \tag{2.3.3.1}$$

$P_{x,t}$, overall price cap for the company x in year t

α_x, share of company's own cost information for the company x

$C_{x,t}$, cost of the company x in year t

f_j, weight for the peer group company j in year t

$C_{j,t}$, cost for the peer group company j in year t

K, number of companies in the peer group

This regulation method (yardstick) can be used to introduce indirect competition between the companies which are operating in various geographical positions. Even the method serves companies incentives to cut their costs, there is a risk that companies begin to cut their costs by neglecting quality issues. This can be avoided by including quality in the performance benchmarking as well. This kind of approach can be really close to the real market based competition, because the price is not the only question, but also the whole service quality matters as well as the competition between the different companies. (Honkapuro, 2008)

The yardstick regulation decreases the asymmetry of the information among the companies and the regulator. This is because the regulator can estimate the appropriate cost levels of the companies by contrasting them against each other. Nevertheless, it is important to take into account the differences between the operational environments of the different companies in the comparisons. These must be taken into account to minimize the risks, which are related to the cost variations that are caused by the differences in factors like climate, population density, geography etc. Practically, the yardstick regulation can be implemented in connection with other methods like the price cap regulation (price adjustments). (Honkapuro, 2008; Viljainen, 2005)

2.3.4 Menu of contracts

So far, the introduced regulation models are classical schemes. In the reality, it is really hard to choose one of the classical models and then be able to live with it. The main idea of using a menu of contracts is to be able to avoid the one-size-fits-all thinking pattern. Menu of contracts allows in principle multiple regulations that the DSOs are able to choose from. In addition, having terminated a given class of regulation the DSO is allowed to have a different variant of it like lower or higher base level with smaller or larger catch-up requirements. (GAIA, 2010)

Other purpose of using a menu of contracts is to adapt to the different local circumstances, this is because it is not always relevant to aim at the same quality levels in different DSOs that are operating in dissimilar environments with differing marginal costs and benefits. Also, the use of this regulation method could be a way to protect the DSOs against modeling uncertainty. If the capital costs can be measured in two ways, and both methods have merits and harmful aspects, there can be two models created. The DSOs can be evaluated by a best-of-two approach and the DSO chooses the method that puts it in the best possible light. There are also differences between the ownerships of the companies; this means also that there are differences between the financial targets as well. Therefore a menu of contracts could be an attractive option from owner's perspective. (GAIA, 2010) Nevertheless, in Finland and Sweden where the number of DSOs is large, the use of this regulation method would be very demanding and heavy to realize.

2.4 Regulation in Finland

In Finland, electricity market was de-regulated in 1995 and development of economic regulation model started soon after this. The regulation of network companies is based on the electricity market act (386/1995). The Finnish electricity market act has been changed in many occasions and some specific additions have been made in order to update the law to meet today's requirements. Also the new third EU directive (2009) concerning electricity market requires development of the regulation model and Finnish electricity market act. (EMV, 2007; Honkapuro et al., 2010)

The economic regulation model in Finland has always been based on defining reasonable rate of return in relation to operating capital and with WACC-model (weighted average cost of capital) defined reasonable level of return. The basic principle of the model used in Finland has remained the same; nevertheless the model has been developed remarkably since the first introduction. The regulation was ex-post until 2005, but a significant change took place in 2005, when a transition to a partly ex-ante regulation model with three year regulation period was introduced. (EMV, 2007; Honkapuro et al., 2010)

The second regulation period, with duration of four years, started in 2008. As new elements in the model there was introduced a company specific efficiency improvement target (based on DEA- and SFA –models) with a general efficiency target (efficiency incentive). The second model also takes into account quality of electricity, or more precisely outage costs in economic regulation (quality incentive). Nowadays in Finland, there is a hybrid (combination) ex-ante model which consists of revenue-cap and rate of return (profit) models. (EMV, 2007) Below there is a Figure 2.3 of the Finnish economic regulation model which introduces the basic principles used in the model.

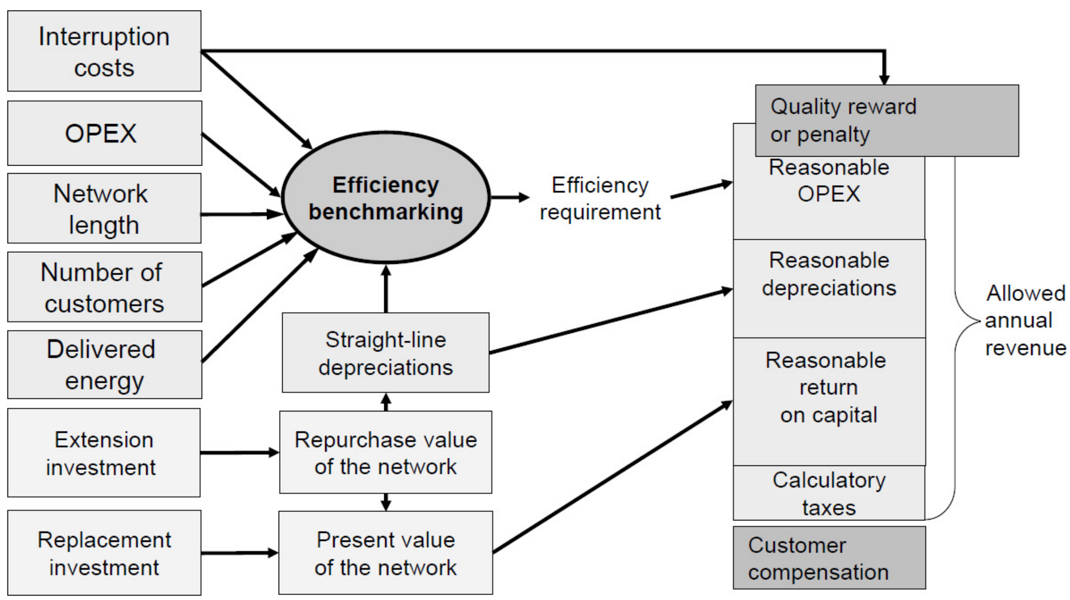


Figure 2.3, *Finnish economic regulation model, overall chart. (Honkapuro, 2009)*

The third regulation period starts at the beginning of 2012. The new model will include "innovation incentive", which aims to incentivize the DSOs to promote new innovative technical and functional solutions in network management. Up to 0,5 % of differentiated income based annual revenue can be treated as R&D costs. The introduction of AMR meters, which are measuring consumption on hourly-basis which is needed for hour-based balance settlement, causes additional costs for the DSOs. The DSOs will be compensated with 5 EUR/ AMR meter (under 63 A) as a part of the "innovation incentive". The current quality incentive will be adjusted to a more rewarding / penalizing direction in a way that the effect is ±20 % to the allowed reasonable rate of return, which clearly increases possible return but also the risks remarkably. As a new method to the model, there will be a so called "investment incentive". The method has been created to incentivize the DSOs to invest in network development and to guarantee continuous development of network business sector in a sufficient way. The "investment incentive" method will be developed during the third regulation period in a way that it will be fully implemented to the regulation model at the beginning of fourth regulation period. Also other methods in the regulation will be developed continuously during the third regulation period. There are also other changes in the new model (2012- 2015), which are discussed later in this work. (EMV, 2011)

2.5 Regulation in Sweden

In Sweden, electricity market was de-regulated in 1996 and a unique regulatory tool was introduced in 2003. The regulation model at the regulation period 2003-2007 was an ex-post Network Performance Assessment Model (NPAM). At the moment, over regulation period 2008-2011, there is a light-handed regulation model in Sweden. The aim of the model is to enable a smooth transition to the next regulation period and therefore it can be seen as an "intermediate regulation model". (Wallnerström et al. 2010)

In Sweden, the focus is at the moment on the new ex-ante regulation model that will be introduced at the beginning of 2012. The transition is partly a consequence of criticism that the different stakeholders have shown towards the NPAM -model, but on the other hand a strong driver is also EU directive (EC 96/92, EC 2003/54) concerning implementation of ex-ante regulation models inside European Union. Because of this transition period, this thesis focuses on the new ex-ante regulation model which will be introduced in Sweden. The new model includes general efficiency requirement and quality correction methods and return is calculated by WACC. The new Swedish model contains a lot of similarities compared to the model used in Finland (second regulation period). There is a Figure 2.4 below about the new economic regulation model that will be implemented in Sweden from the beginning of 2012. (Wallnerström et al. 2010)

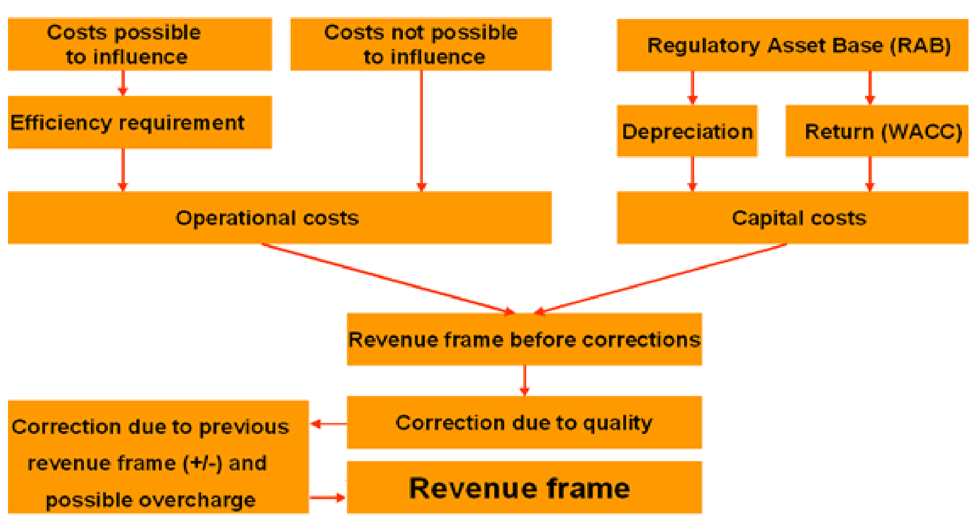


Figure 2.4, *Chart of the new ex-ante regulation model in Sweden from the beginning of year 2012. (VF, 2011)*

2.6 Operational environment and need for smart solutions in the networks

Legislation is one of the external drivers for electricity network evolution, but it is not a direct one. The legislation includes electricity supply demands and the targets concerning environmental issues (climate demands). Another, direct driver for network evolution and innovation is the needs of network users. European Union legislation puts pressure towards the EU member states, which are obligated to change their own policies to achieve the environmental targets committed. The direct drivers, which are formed by the needs of the network users, will be different in different countries. This is because every member state is free to adapt different policies to achieve their commitments. For example, the directive concerning automated metering devices says that the member states are free to leave the meters completely without installing, if the cost-benefit analysis shows that it is not a viable alternative. From Smart Grid perspective this is a problematic issue. (ERGEG, 2009)

The European Union legislation package for climate- and energy issues, named as the 20/20/20 targets was introduced earlier at the Chapter 1. It is the most important legislative driver for Smart Grids. In other words, the main drivers set by the legislation are sustainability, the security of supply and competitiveness. (Ympäristö, 2010; ERGEG, 2009) The means that must be completed to accomplish the legislative challenges, lead to the direct drivers which are very interesting from a technical perspective. The direct drivers reflect the need for Smart Grids. These drivers include the following (ERGEG, 2009):

- Large-scale renewable energy sources including intermittent generation
- Distributed generation including small-scale renewable energy sources
- Active end-user participation
- Energy market integration and accessibility of the market
- Improved operational security and flexibility

These means and the interest that the identified operations imply as drivers for Smart Grids are analyzed below:

Large-scale renewable energy sources will have the biggest effect on the transmission networks. New smart solutions are required to be developed and the technologies should be cost effective. Renewable energy sources are normally far from load centers which makes the effective connection of the RES even more important. Also, the intermitted character that most of the RES technology has makes the monitoring and balancing of the transmission and regional (high voltage distribution) networks more challenging. (ERGEG, 2009)

The distributed generation (smaller-scale) will affect mainly the distribution network. The connection of generation to the distribution network has a lot of unfavorable consequences. The network operator is responsible for the reliability and quality of the supply. If the requisitions of network users cannot be filled when DG is connected to the grid, some investments need to be done by the DSOs. (ERGEG, 2009)

The active end-user participation is the primary aspect in energy efficiency and demand response. The possibilities of active participation depend essentially on the metering system and its functionalities. In the future, network users cannot only act as consumers, but also as producers whenever they are able to generate energy to the grid. As a target there is a need to increase the amount of efficient, renewable energy that could be integrated in the electricity distribution network. (ERGEG, 2009)

Market integration across national borders and the active participation of network users favor competitiveness and it is based on the development of network technologies and market functionalities. A more integrated market will need intelligent solutions to the network to be able to operate correctly. Improved operational security has an aim to improve the quality and the security of electricity supply by monitoring power flows and power system state continuously. Networks flexibility and ability to acculturate the changing network environment is going to be a substantial matter in future. (ERGEG, 2009)

Below there is a Figure 2.5 that describes the differences between a traditional network and a future network. The picture shows the actions that need to be taken to accomplish a much more complicated and flexible function of the future network. These actions can be seen as drivers for Smart Grids and as keystones for the evolution of the electricity networks.

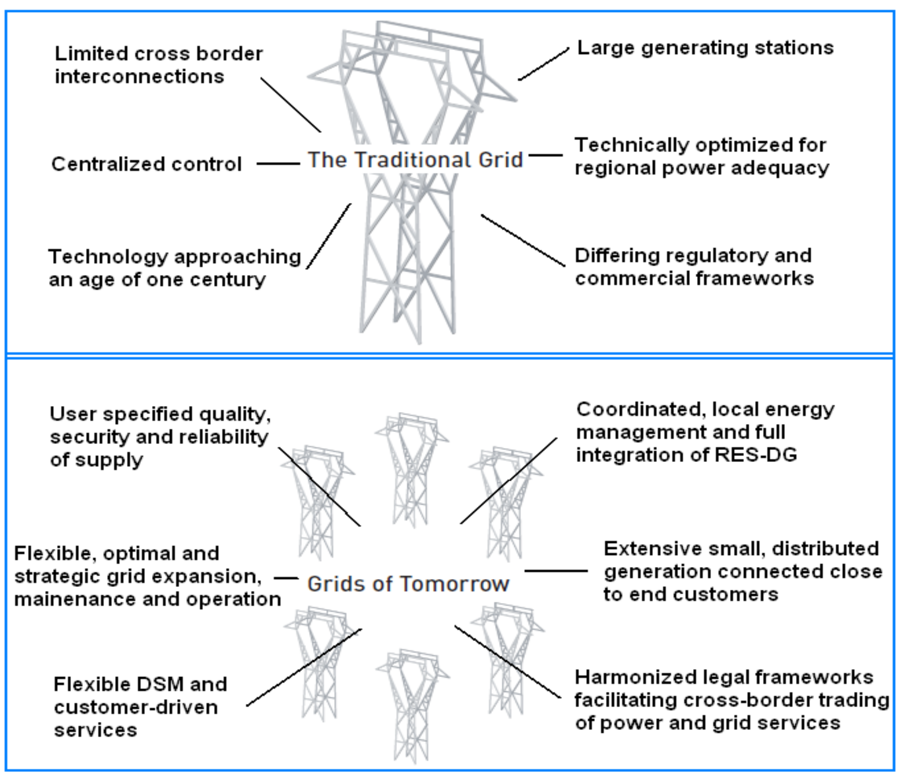


Figure 2.5, *Vision of future network, differences between a traditional grid and a grid of tomorrow. (EC, 2006 applied)*

2.7 Summary

One of the biggest challenges is the wish to increase the level of active end-user participation in the function of the electricity market. The wish is that customers can interact with the market by making actively choices concerning their own energy usage. Customers may also act as producers always when possible by generating energy to own use and to the market. A new term called "prosumer" has been created to determine a customer who can act as a consumer as well as a producer. Demand side management creates more flexibility to the grid and customers play the most important role in it. Penetration of distributed generation (DG), both large and small-scale units to the MV and LV networks is a vital issue. DG can reduce losses when correctly positioned, mostly because it can decrease the average distribution distance and the usage of the grid gets more optimized. Nevertheless, the effect can also be opposite and therefore it is important to plan and manage the network usage correctly. DG also reduces carbon emissions because most of the energy is produced by renewable energy sources like solar panels and wind energy. The total benefit that a future's intelligent network can offer is formed by considering all the aspects that are involved together, not just a certain benefit that is achieved. Because of this, the regulation model needed in the future will have to be holistic and incentivizing towards Smart Grid solutions.

It is clear, that especially in Finland there are new incentives at the regulation model for regulation period 2012- 2015. On the other hand the effects of these incentives are quite hard to predict and therefore a kind of uncertain situation makes the DSOs business environment unpredictable which is not good for any regulated industries. Also in Sweden, there will be naturally a lot of chances when moving towards a completely new model in 2012. This creates a lot of possibilities, but also unpredictability and risks. It is notable, that Sweden will transfer to a model much more similar with the current Finnish model for second and third regulation period.

Smart Grids are about planning, operating and maintaining, expanding and building the new electricity networks of the future in a way which will help to meet the EU's energy and climate objectives. The "smartness" of a grid is on a vital role in order to be able to make the use of technologies and solutions better, to intelligently control generation (low-carbon production), to plan and run existing electricity grids better and to enable new energy efficiency improvements and optional energy services.

3 SMART GRIDS

The concept of a Smart Grid refers to a network that can effectively satisfy the increasing expectations that are focused towards the evolution of traditional networks in the future. The definition and vision of Smart Grids is very complicated and multidimensional issue. At the moment, there is no worldwide (international) definition for the concept of a Smart Grid. The concept can be determined to include distribution and transmission networks, but the most common way is to regard just the distribution network. This work is focused on studying the operation of the distribution networks, concerning Smart Grid solutions. At this chapter there is discussion about the definition of a Smart Grid and the main functionalities that the concept is able to offer. Advanced metering is a vital part of the future's network environment and this chapter analyses the influence and the role of the advanced metering devices. The meters act as enablers to many of the important functionalities and services which are introduced in this chapter. Advanced ICT communication infrastructure has an important role in future networks and most of the applications and functionalities are depending on it. This chapter also discusses the implementation of advanced communication infrastructure and data management systems. The development towards more intelligent networks increases the importance of low-voltage network automation, which has traditionally been quite insignificant. This chapter aims to create an overall picture of Smart Grids without forgetting any of the most important parts of the concept. Later in this work, all these different aspects and solutions that increase the level of "smartness" in a network are discussed in more detail, from the perspective of how the level of smart development can be evaluated.

3.1 Definition of Smart Grids

Around the world there are many definitions for Smart Grids that include huge amount of characteristics. Sometimes the characteristics can be unequal with each other, depending on the point of view. For instance the Smart Grid European Technology Platform defines a Smart Grid as an "electricity network that can intelligently integrate the actions of all the users connected to it – generators, consumers and those that do both, in order to efficiently deliver sustainable economic and secure electricity supply". (Smartgrids, 2011) So far, the traditional electricity network has generally been described simply by the main technology used in it and by the most common electrical and technical statistics. The aim of the latest analysis concerning Smart Grid definition is that the concept of a Smart Grid is attempted to perceive more as a wide-ranging system, than only a network. (Sarvaranta, 2010) Below there is a Figure 3.1 about one vision of a Smart Grid concept.

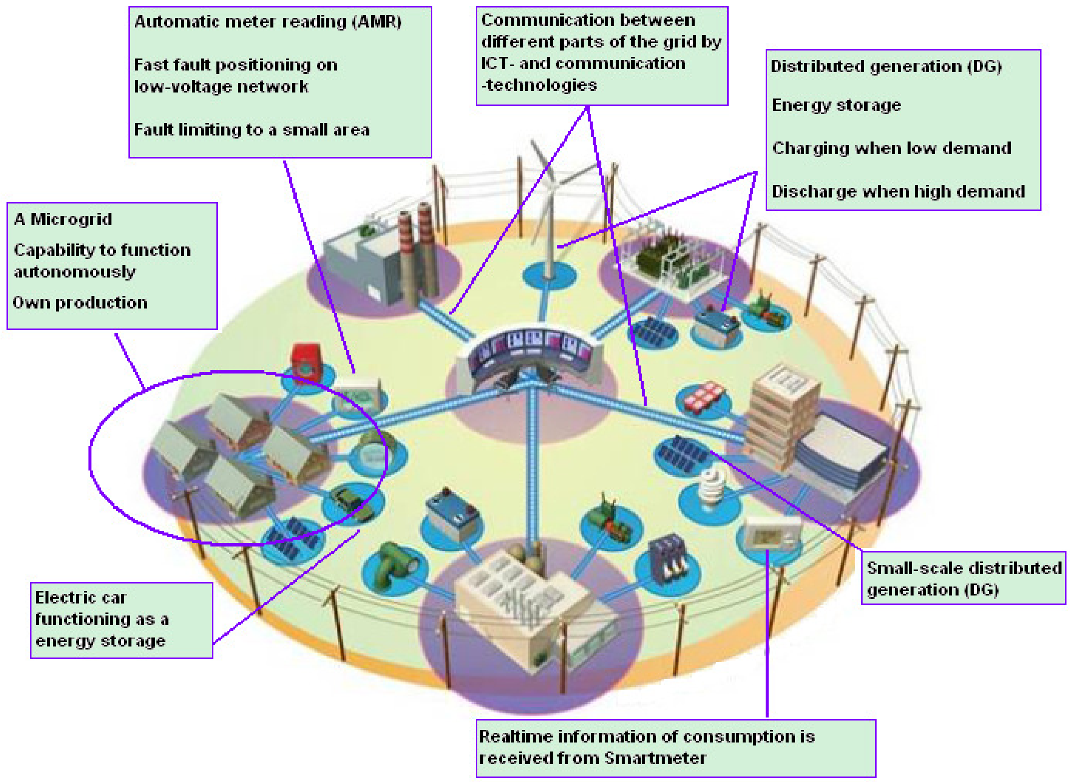


Figure 3.1, *Vision of the Smart Grid concept. (EPRI, 2011 applied)*

A Smart Grid system integrates the existing traditional electric power technology with the latest technology and technology under development by using automation and ICT-technologies. At this work, the concept of a Smart Grid is defined as:

A Smart distribution network is a distribution network that is able to satisfy all the future needs of every party. A network, which features like effectiveness, controllability, reliability and flexibility are improved by using automation, information and communication technologies. A network, that enables consumers to actively participate in the operation of the electricity market via two-way communication. Smart Grid has high capability to handle the power of the increasing amount of distributed generation (DG) produced by renewable energy sources in the future and it is able to attach new energy storages to the grid. A Smart Grid offers new services to the customers and handles the increasing complexity of the network in an efficient way. A future network has self-healing nature and fault ride through features among DG production in order to handle fault situations in an efficient way so that a more secure, sustainable and competitive use of the distribution network can be achieved. Smart Grid is an enabler for future's integrated, flexible and efficient electricity market. (ERGEG, 2010; Sarvaranta, 2010)

3.2 Low voltage network automation

Electricity distribution network automation has traditionally been focused almost completely to the medium voltage (MV) distribution network, while low voltage (LV) network automation has got less attention. This is not because of technological reasons; the question rather is that LV automation's importance and impact on the distribution reliability is relatively small in comparison with MV automation. Also economic terms form a barrier to the large-scale installations of automation solutions, especially to the public LV networks. This far, the existing automation solutions in LV networks have been used to improve the overall performance of the network and the implementations has been only case-specific. (Löf, 2009)

In future, the importance of LV automation is increasing rapidly. This is due to increasing voltage quality performance requirements and the increasing penetration of DG production in the LV network. Large amount of DG in LV network causes a need to replace the commonly used fuse protection method in LV networks with relays and circuit breakers in order to protect the network against short circuits and over currents. The intermittent DG production and installations of heavy motor loads, like heat pumps at a customer points, can cause voltage quality problems to occur more often. Therefore more power electronic based solutions and network automation has to be introduced to manage the voltage level fluctuation. Level of LV automation is also going to be increased because of the introduction of advanced meters (AMI, advanced metering infrastructure). The AMI system can be seen as network automation as well, because it covers the smart metering devices at customer points and MV/LV distribution substation monitoring, for example. AMI system characteristics and functionalities are discussed in more detail in the next section. Below there is a Figure 3.2 that describes the new functionalities to support the LV network management by implementing automation solutions in the LV network. AMI and LV network automation support the functionalities of network operation management like network state and fault management. Better controllability and monitoring of the network loads and DG production, where enhanced detection of voltage deviations and asymmetries are good examples of these improvements. Fault management can be improved by the better detection and location of faults, this leads to better safety from customer perspective when harmful ground faults can be detected, for example. Power quality monitoring and network planning can be improved by AMI and network automation, this is due to improved load modeling and network voltage monitoring, for example. (Löf, 2009)

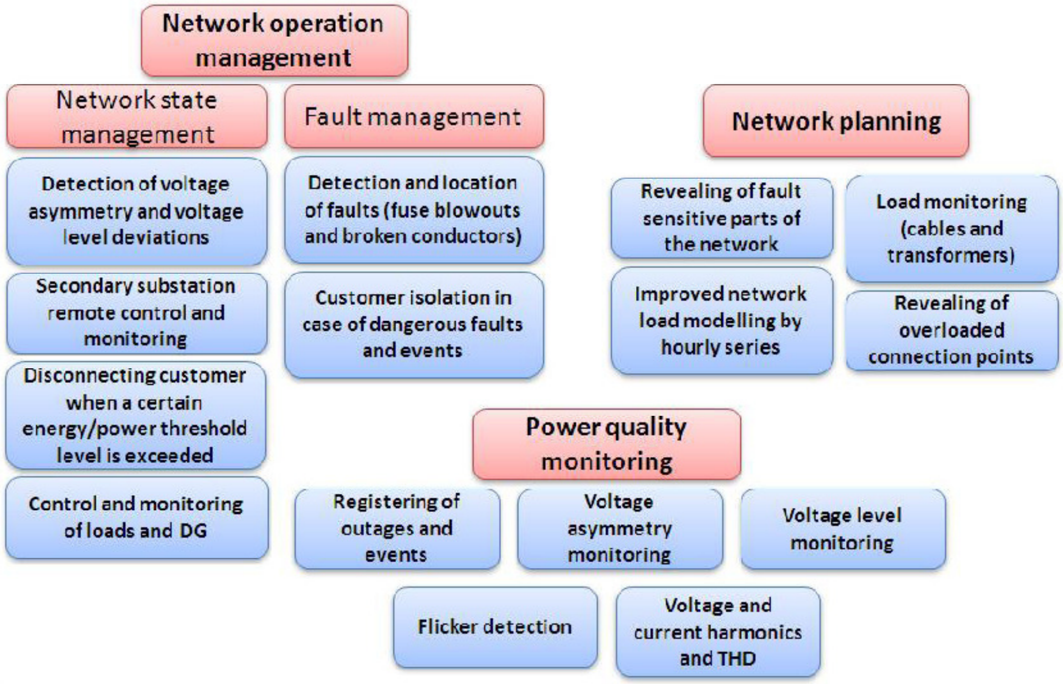


Figure 3.2, *Enhanced low voltage network management. Low voltage network automation and communication solutions enable new functionalities to support LV network management. (Löf, 2011)*

3.3 Advanced metering infrastructure and automatic meter reading

Advanced metering infrastructure (AMI) includes the meter device and other technical devices. It includes IT and communication infrastructures which are connecting a meter with a customer and a meter with the meter-control center. The meter-control center operates meters remotely and co-operates with the data management system. Advanced metering infrastructure conceives the whole system behind the actual remote readable meter (AMR, automatic meter reading). The whole infrastructure forms the main specifications and features that the system is able to offer. At this chapter, there is an analysis of the AMI system and the influence that the advanced metering can bring to the evolution of networks towards the concept of a Smart Grid. (ERGEG, 2007) AMR system which has ICT -technology that uses cellular and broadband connections or PLC based connections to gather data from customers via metering collector, is one example of AMI. Because of the technology that is used, especially the metering collector, it is not possible to have exact real-time information about the status of the meter at the customer point with this kind of solution. Although the meter device itself is remote readable and the consumption is measured hourly, the communication system function makes it impossible to have real-time data from a meter. The reason is that the meter sends the measured data to the collector which sends the data to control-center. This means that it is not possible to take a straight contact (control-center to a metering device) to an individual meter from the meter control-center in order to check the status of the meter in real time, for example concerning fault situations. More advanced AMI systems use point-to-point connections, which enables real-time communication.

Traditionally, metering has been divided into three categories: permanent, temporary and disturbance metering and each of these have their own methods and purposes. Permanently located energy meters are the traditional meters which are measuring energy consumption at the customer point. Temporary and disturbance metering are designed for special cases like power quality metering and fault analysis. (Kujala, 2009)

Automated meter reading (AMR) is one of the most vital issues in the energy distribution industry at the moment, because automated energy and power quality metering is an essential part of the business. These advanced meters enclose not only traditional energy metering but also versatile amount of resources to inspect power quality at the customer point. The increasing amount of metering data makes the data transfer, handling and storing more complicated and there must be new ways to execute these challenges. The target is that in the future all network users are being measured both remotely and automatically. Below there is a Figure 3.3 of AMR meter location in the network. (Kujala, 2009)

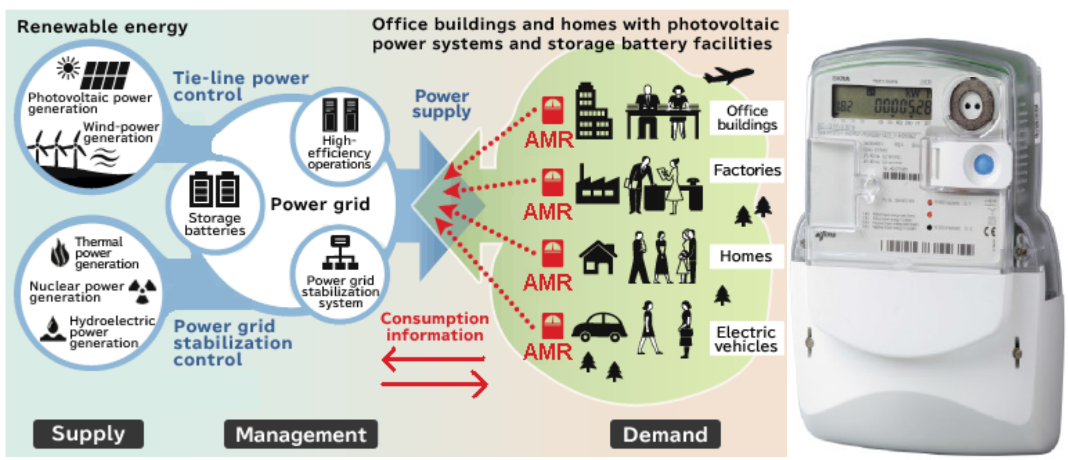


Figure 3.3, *AMR meters in the network. Metering device Iskraemeco MT372, used by Vattenfall Verkko Oy, for example. (Hitachi, 2011 applied; MT372, 2011)*

The AMI system is required to be an open architecture system and most of the advanced meters are built with modular structure. This enables transformability that is required from the meter reading system in the future. Below there is an illustrating Figure 3.4 of how the smart meters are estimated to generalize in Europe over the next few years. As the picture shows, the implementation of the AMR meters is at the acceleration point and the amount of the meters installed is going to be raised rapidly over the next few years. This rapid increase can be explained by legislative requirements in national level set by many of the member states in Europe and the pressure comes mostly from EU level, but also some voluntary introductions of AMR meters have appeared.

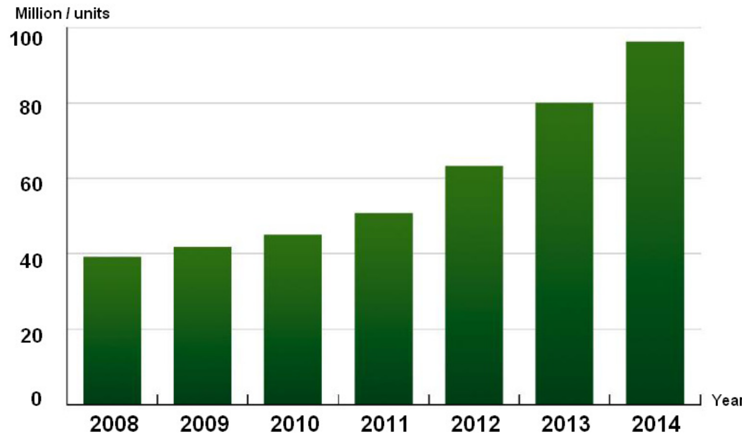


Figure 3.4, *Estimation of smart meter generalization in Europe between years 2008 – 2014. (Löf, 2009 applied)*

3.3.1 Energy consumption measurement

Features of for example Iscraemeco MT372, Echelon IEC CT and other modern AMR meters are comprehensive. Both active- and reactive power can be measured in one or two directions. Measures can be done in single- and three- phase networks. Energy consumption is measured in watt-hours and represented on the meter display in kilowatt-hours. There can be programmed multiple different tariffs to the meters and the selection of a specific tariff can be done by sending signals to the meter remotely. In the future, it becomes very important to be able to measure power flows in two directions when the amount of distributed generation increases within the distribution network. There can be defined multiple different load profiles to the meters. Also the length of the measuring period can be programmed, the options are for example 5, 15, 30, 60 minutes or one day. Special events, like power failures and device disturbances, under and over voltages and outages are stored in the database when they occur during a capture period. The meter stores measured values with time stamps to the database, as an example. (MT372-laitetiedot, 2005; Keränen, 2009)

3.3.2 Customer service

The most significant development in customer service is that AMR meters can offer the actual consumption of energy instead of estimations which makes the billing more exact. Also many other improvements in customer service are enabled by using AMR meters. The ability of remote reading simplifies the processes of changing house ownerships and energy suppliers. The simple process of changing the energy supplier is notable development, especially from the perspective of proper functioning of the deregulated electricity market. For distribution companies, this brings savings by reducing the need for manpower. (Karkkulainen, 2005; Vähäuski, 2008)

The AMR system improves customer service also during power outages, because more detailed data is available concerning the cause and length of the interruption. This is important especially with low voltage faults. Also the locating of faults becomes more accurate and effective; this means that the average interruption time experienced by network customers becomes shorter. New services like informing customers automatically about faults in the network is made possible by AMR meters. In future, also services like customer's opportunity to remotely control of own loads can be implemented. This can be for example remote steering of electric vehicle charging via SMS message. (Karkkulainen, 2005; Koponen, 2007)

3.3.3 Power quality

Traditionally, the power quality measurements are done by specific measuring devices in primary substations and other vital points of the network. At customer point, the quality measurements are traditionally carried out only if there is a special need to measure the quality of supply. Measurements have usually been done by temporary measurement devices for example if a customer has made a complaint of the voltage quality. AMR meters have the capability to integrate power quality metering. With new AMR meters it is possible to convert power quality measurements into a continuous process that covers the whole LV distribution network. (Matikainen, 2004)

By using continuous quality measurement, it is possible to facilitate the locating of the problematic parts of the grid. This also reduces the costs that the use of a traditional power quality indicator at the end-user point (temporary power quality metering device) and the assembly of it are causing in case of a customer power quality complaint and the following investigation process. The possible deviations on the quality can be detected much faster and in the best case the problems can be solved even before the customer notices the divergence in the quality, in cases of proactive power quality monitoring and quality improvements. Other power quality problems like origins of total harmonic distortion (THD) can be found easier. Amount of reactive power can also be measured and customers could be obligated to pay for reactive power or either provide the power as compensator towards the network. (Matikainen, 2004; Kujala, 2009)

3.3.4 Disconnection unit and energy limits

Advanced AMR meters are built with a modular structure which makes the use of the devices more flexible towards different purposes. This means also that most of today's advanced metering devices are capable to connect a disconnection unit or a load steering relay, which are basically normal control relays, to the meters in order to achieve new functionalities. By using a disconnection unit or load steering relay, it is possible to set energy and power limits to the meters. When a threshold value is defined, the consumption of the customer can be limited by disconnecting a part of the customers load from the grid, or by making the customer even completely disconnected from the network when a specific threshold value is exceeded. The functionality can be implemented remotely or by setting the values locally straight to the meter. If a customer has been disconnected, the reconnection can be done manually when the consumption level has been corrected back under the threshold level. (MT372, 2011; Vähäuski, 2008)

The switching device can also be used automatically, when a zero conductor fault occurs to improve the safety of the network system. In other words, the disconnection unit can be seen as a protective device disconnecting the customer in dangerous fault situations. Zero conductor faults have traditionally been problematic to detect, but an AMR meter monitors the voltage asymmetry and the sum of phase currents. The disconnection unit also makes it possible to remotely disconnect a customer from the operator center, if there are unpaid electricity bills. (MT372, 2011)

3.3.5 Demand response

Term demand side management describes the measures taken by energy companies or other authorities in order to affect the consumption of energy. The term demand response represents the ability of energy consumers to react the varying prices on the electricity market or other signals by changing their own consumption of electricity. (Keränen, 2009)

The most important objective of the demand response is to reduce the total consumption of energy during certain moment. This is possible because it is sure that all the energy spent at a certain moment is not essential. Heating load can be shifted to another point of time if necessary, for example. The aim is to lead towards flexibility in electricity consumption. The sector of industry has lots of adaptable loads, so the capacity of the demand response is remarkable. AMR meters measure the hour-specific consumptions in the network using a two-way communication which is a basic precondition for the demand response to be implemented. (Keränen, 2009) Below there is a Figure 3.5 about how the demand response impacts to the peak demand in a way which is beneficial because the difference between normal demand and peak demand is smaller and a part of the load can be shifted to a more favorable period of time. In other words, implementing DR on a large scale has lots of benefits that can be achieved like critical peak demand reduction and overall decrease of the fluctuation of the demand curve.

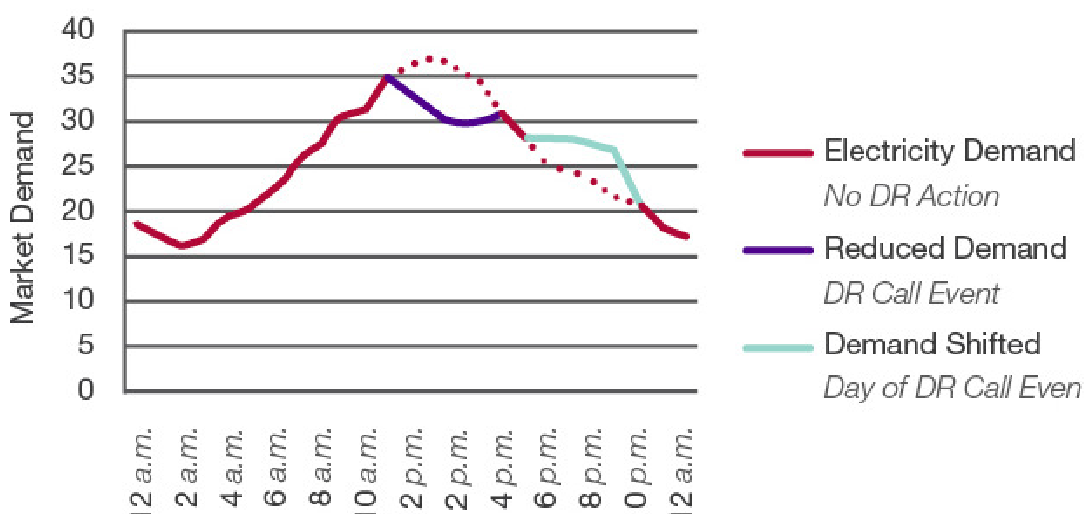


Figure 3.5, *Effect of DR to peak demand and demand shift feature. (NAPP, 2011)*

Pricing and different tariffs are the incentives in order to have an influence on the behavior of consumers. Different methods of realizing the demand response are time-of-use pricing (different tariffs) and direct load management. Direct load management requires an agreement between the customer and an external party that is able to steer consensual amount of customer loads like the DSOs for example. The deregulated electricity market causes some problems with the load management, because the benefits and expenses of load management are not always directed at the same parties. European parliament gave a directive 2006/32/EC, concerning energy services and energy end-use efficiency on April 2006. The purpose of the directive is to create possibilities for the demand side to upgrade energy efficiency. (Vähäuski, 2008; Directive 2006/32/EC)

Demand side management and the demand response can also be seen as a part of increasing amount of distributed generation (DG) in the network. The amount of DG is going to be remarkably larger in the future, than today. This means that the automation and network operation is going to be even much more important in the future because these smaller units of generation around the network are replacing traditional centralized greater units of generation. The problem that occurs is voltage variation, and it could be avoided by using coordinated voltage control. Coordinated voltage control requires reliable state estimation which can be reached by availing AMR data. Majority of DG production is challenging to estimate and therefore it is important to be able to measure, control and optimize both supplied and consumed energy in the network. (Vähäuski, 2008; Repo, 2008) Other challenge concerning small-scale DG units is the management of the production in the electricity market. The concept of a virtual power plant (VPP) has been developed, in order to manage several small-scale production units as one entirety. The concept of VPP became possible after the introduction of AMR meters, as the meters provide energy measurements in two directions. (Vähäuski, 2008)

3.4 Data management

Electricity distribution companies are generally becoming more and more dependent on data management systems. Especially as a result of an expanding number of real-time metering points (AMR meters) and advanced network automation in distribution networks. The real-time network status information to be processed and analyzed by the DSOs is increasing rapidly. GIS-based network data systems, SCADA, and distribution management system (DMS) are becoming more and more important in monitoring and controlling the automated network system. On the other hand, the current development is setting up a road for all kind of service providers, specialized for example in the collection and analysis of the data that becomes available. Also at the same time new competence requirements are set up for the DSOs. As a conclusion, the network operation will develop into a strategically important process, concerning the management and sharing of network data. (Lassila, 2009)

MDMS (Meter Data Management System) is a system which collects and saves information like consumption data, power quality related data and data related to power outages, for example. By using a MDMS system it is possible to improve the data usage offered by the existing AMR devices. Eventually this leads to a better efficiency of the processes exploiting the real-time information. MDMS is also able to calculate and verify that the quality of data is at an acceptable level, which is important when the amount of data increases remarkably and possibilities for different kind of data errors occur more often. At the moment, there is a program concerning MDMS usage within Vattenfall, both in Finland and in Sweden, for example. It is clear, that the role and significance of MDMS is becoming more and more important in the future. (Siemens, 2009)

Highly advanced (or digitalized using ICT communication) medium- and low voltage networks are requiring special tools to be used, such as DMS, QMS and MDMS. The end-customer service is a part of the normal fault management and the role of information service becomes important, especially towards the energy authorities regarding the reimbursement proceeding. The DSOs will increasingly depend on large network databases and the maximum use of the capacity in the future. Below there is a Figure 3.6 which shows the importance of the databases in advanced communication infrastructure. Large and effective databases support many of the new ways of how the network data is managed and exploited in the network operation. The picture illustrates how the integration between different network applications can be carried out. (Lassila, 2009)

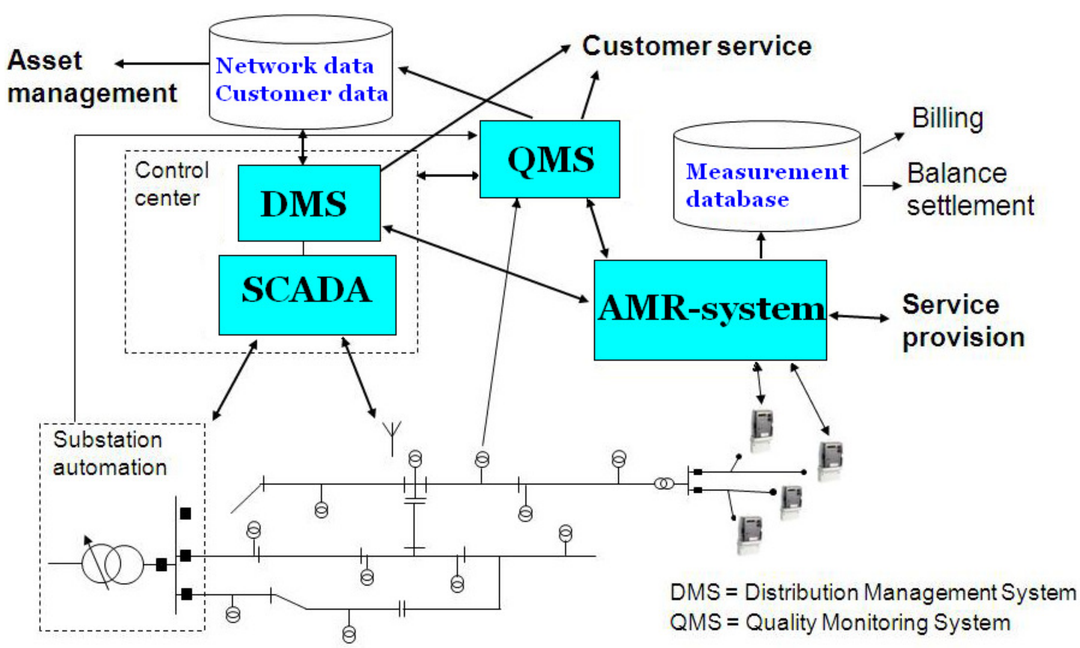


Figure 3.6, *This picture shows the communication routes between different network applications. The importance of the databases used in the network information management is increasing in future; this can be seen from the picture as well. (Järventausta, 2008 applied)*

3.5 Microgrid

A microgrid can be defined as a part of Smart Grids and it is in most cases defined as low voltage electric network that is able to function autonomously as an island when needed. Also high voltage microgrids can be used in many cases, but generally the discussion is concerning LV networks. Capability to island operation is based on small-scale production inside the microgrid which can satisfy the consumption of the grid so that the production and consumption inside the grid are in balance. Most of the components in a microgrid are similar with the Smart Grids, but there are no large scale centralized production units at all. A microgrid is designed so that the grid is flexible and able to adapt to alternating operation situations, especially during faults. The most important characteristic and benefit that can be achieved by realizing microgrid is to be able to use island operation in a controlled manner to decrease outage times in fault situations. (Siemens, 2009)

In normal operating situation, a microgrid is normally connected to the rest of the grid around it. The idea is that when a network fault occurs, the grid transfers to an autonomous island operation, and the area of the network where the fault is affecting can be restricted. The island operation requirement demands that there is enough production to serve the loads in the grid in long run but in short time periods the loads can be served from energy storage devices or other controllable capacity inside the grid (EVs in the future, for example). Adequate control capacity is also needed to ensure a stable function of the grid when demand and production are not facing enough. (Siemens, 2009; Repo, 2007)

Protection of a microgrid is challenging, as short circuit currents varies and are often quite small. Nevertheless, because of the short distances differential relays are suitable to be used and communication between the relays is cheap to realize. The quality of voltage is challenging to ensure because the network is often quite weak, therefore the stability control of the grid must be more active in comparison with larger grids. Highly advanced level of low voltage automation can be seen as a precondition for microgrids to be introduced. The state of the grid must be completely monitored and under control in order to achieve a controlled transition from normal grid operation to a microgrid operation. (Repo, 2007)

3.6 Interactive customer gateway

The next step from AMI towards even more intelligent entity, which utilizes all the features described earlier in this work, is an interactive customer gateway. The gateway is a logical interface between the electricity consumer’s active devices, networks access point active devices, property automation, communication network, external actors and the local controlling system. The interface is one of the most important functionalities of an active distribution network. The features of an active customer gateway enable the functional needs of grid owners (DSOs), customers and suppliers. (INCA, 2010)

Electricity market parties can consider the interactive interface as a meeting point. It converts consumer consumption devices and small scale renewable energy source production to active recourses in system management and the electricity market. At the system level, this means for example new adjustment capacity and at the distribution level, for example a possibility to control the power distribution also during faults. It enables new electricity business possibilities and risk management methods, better service quality and efficiency by optimizing energy expenses. The adaption of the interactive gateway between the market and customers supports the increase of a local small-scale production in the network from a consumer perspective. The interface can adapt many helpful network management and protection functions and metering which makes the small-scale production agreeable from distribution system perspective. (INCA, 2010) Below there is a simplified Figure 3.7 of the INCA–concept. As the picture shows, INCA is a gateway between the distribution grid and all the important parts of the future network like small- and large scale generation, energy storages, different types of loads (controllable/ non-controllable) and the important real-time information exchange between market players, to enable better function of the electricity market.

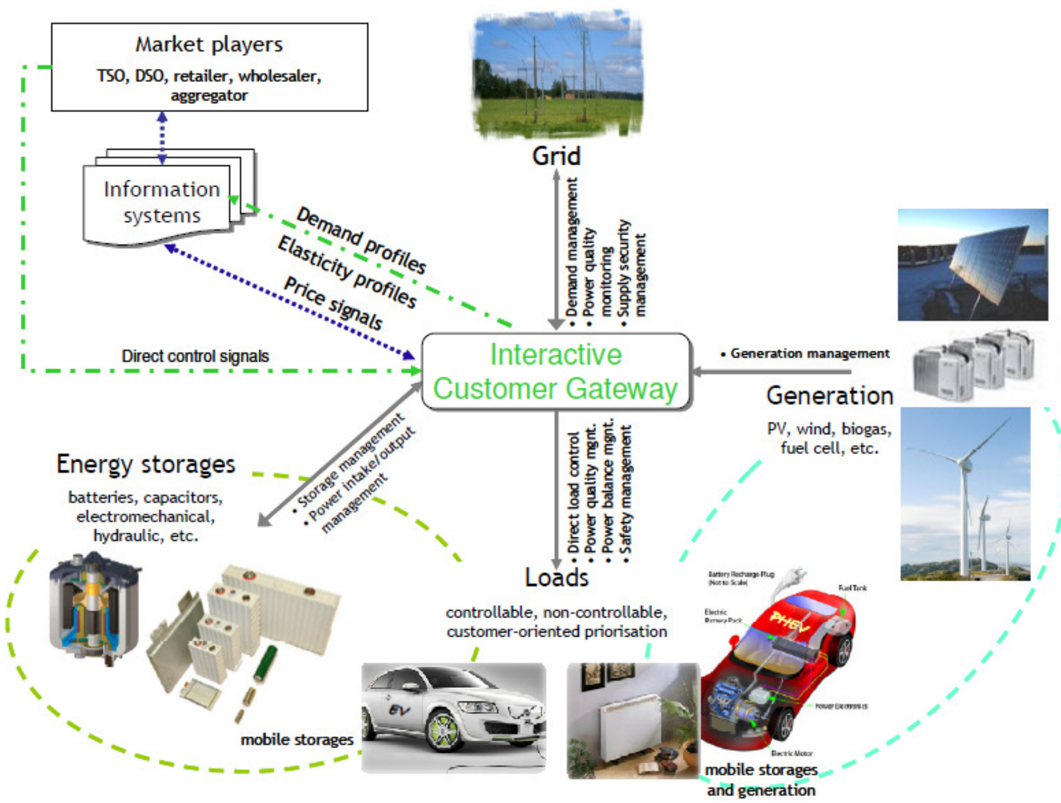


Figure 3.7, Interactive customer gateway, principles. (INCA, 2010)

3.7 Smart Grids in Europe

The role of European Union (EU) as a decision-maker in national policy issues is getting increasingly significant all the time. The European Commission has stated that in order to reach the 2020 targets, it is important to continuously develop the electric networks. There are many directives that have been regulated concerning the features and functionalities of devices that can be perceived as smart solutions. Some discussion about a Smart Grid –directive has also been exposed, but it is unlikely at the moment that it is going to progress in the next few years. (Sihvonen-Punkka, 2010; Hänninen K, 2011) Nevertheless, it is notable that even European Union is quite powerless when concerning certain national level legislative decisions at the moment. This means that national ministries and regulatory agencies have great responsibilities in order to affect to the development of the electricity networks in EU member states.

The EU Commission Task Force for Smart Grids was founded the year 2009 as an objective to discuss shared European needs concerning Smart Grids. As a president of the work group is the commission and as members there are the European energy regulators, transmission network operators, distribution network operators and technology suppliers. There are also three separated specialist groups acting under the steering group. The goal is to devise a common vision of Smart Grids, the implementation of the grids in cooperation with other actors and identify strategic decisions and recommendations concerning regulatory aspects (policy, scenarios, criterion about finance and functionalities). A strategic roadmap about Smart Grids and meter implementation at the European inner market of electricity is also under discussion. The guideline of the work group task is focused on period 2010- 2020. (EG3, 2011; Sihvonen-Punkka, 2010)

From the perspective of the European distribution network operators, the development of a Smart Grid is a clear step to the future. The present network is predominantly at a point where it is achieving the end of its life cycle. The old electricity network base is under a restructure process and investments are needed anyway. From the perspective of DSOs, the utilization of the demand side management and creation of an attractive tariff system in order to intensify the system operation is on a vital role and a challenging part of the development. Also the development of a Smart Grid is driven by an increasing need for flexibility, optimization of operations and benefits as well as regulation and investments in the network as an example. (EURELECTRIC, 2009)

The European Strategic Energy Technology Plan (SET-Plan) has established a roadmap to accelerate and develop the deployment of low-carbon and economic technologies. The main challenge is to integrate innovative technologies with the existing technologies in the electricity systems and to validate the performance of the innovations in real operating conditions. A main focus of the program is the electricity system innovation, rather than technology innovation. The validated solutions are automatically enablers to all the other technology initiatives like solar and wind technologies. The commission has a conception that DSOs in Europe must be in a leading role in the Research, Development and Demonstration (RD&D) projects, because it is vital to test the validated innovations in real networks. The commission states also that there is currently a challenge with the sufficient incentives to launch large scale RD&D projects, since the network business is regulated and the tariffs are defined by regulatory authorities. (EEGI, 2010)

The current distribution networks in Europe are designed for one-way power flows. The power flows from a large scale centralized power plant to the customer at the other end of the network. This method is forced to be changed, in order to adapt enough DG production to the network around Europe, which forces more flexibility and capacity from the grid including two-way power flow. The current investments in RD&D are insufficient to support the changes appropriately and the projects must be accelerated in order to reach the climate goals of European Union. It is notable, that traditional solutions could in theory be able to solve many of the current challenges. The integration of new distributed renewable production could be solved by building new lines and substations, for example. Smart Grid approach would instead bring advanced ICT- solutions in the network to allow a higher penetration of renewable production connected to the existing lines and substations. In this case, the traditional approach would bring a solution, but it would be a lot more expensive than the Smart Grid approach. This does not mean that the traditional infrastructure is no longer needed with the Smart Grid solution, but it means that the “smart” approach is looking for the most efficient way to meet the new challenges and will be less expensive in the long run. Nevertheless, it has to be remembered that a smart solution is not always the most cost effective, because the situation depends on multiple issues in the operating environment. (EEGI, 2010)

One important point is that the current tariff structures in Europe, would allow financing the reinforcement of the lines in the example above but not the deployment of the “smart” solution. The European Electricity Grid Initiative program (EEGI) has been established to defeat the barriers that exist, these are technological, RD&D, market failures and distortions and public barriers. It leans on the Third Energy Package presented by European Parliament and the Council in July 2009. The energy package with other legislation provides Europe an appropriate regulatory framework for adapting a network that has a lower carbon footprint. (EEGI, 2010)

3.8 Smart Grid research in Nordic countries

The Finnish government has contributed the establishing of new non-profit organizations which aim is to concentrate to the development of new solutions. In Finland, CLEEN Ltd is operating as the energy and environment strategic centre for science, technology and innovation. The industry, research institutes and universities are working together in order to develop globally competitive technology and service products. The development is based on common vision and strategic research agenda defined by the centre's owners, companies and research institutes. The expected benefits are to ensure the development of world leading know-how and to accomplish international cooperation with best talent. One of the CLEEN Ltd's on-going research programs is Smart Grids and Energy Markets (SGEM), which is the most remarkable Smart Grid research programme in Finland today. The aim of the research consortium is to develop worldwide solutions for smart grids, which can be implemented and tested in real-life demonstrations in Finnish R&D infrastructure environment. CLEEN Ltd was founded in year

2008 and the program has totally 44 major stakeholders, including 28 corporate actors and 16 research institutes and universities. (CLEEN, 2011)

In Sweden, there are also some RD&D pilot projects concerning Smart Grids and smart solutions. One of the most remarkable projects has planned to be implemented in Stockholm, the capital of Sweden. This urban area pilot in Stockholm Royal Seaport has an aim to make the seaport area fossil free by 2030. The focus areas of the pilot project are making the end-usage of energy more efficient, support environmental effective transports and use local recycling as a part of lifestyle. These goals are aimed to be achieved by using new technology solutions and business models. New market rules are also implemented in order to change the traditional role of customers. Active houses and demand response, distributed generation and PHEV (plug-in hybrid electric vehicle) integration, energy storages and smart substations are planned to be implemented with high capacity communication infrastructure. This large scale pilot is planned to be executed by the main applicants Fortum, ABB, KTH (Royal Institute of Technology) with other associated partners. The building of the demonstration area has started in the year 2010 and it should be finished in year 2025. (Stockholm Royal Seaport, 2011)

Another remarkable and unique full scale integrated demonstration and R&D project is “Smart Grid Gotland”. Gotland is a large island at the eastern coast of Sweden. Gotland has totally around 60 000 inhabitants. This pilot aims to give information on reliability in a Smart Grid context – also market and technical aspects will be tested and verified. Gotland is an excellent test site because there are 100% of the smart meters already installed. There is also large amount of existing wind power production and large amount of additional wind planned and the existing grid needs upgrading anyway. The project will be executed in a partnership between DSO, supplier and academia to integrate state of the art knowledge and new technology. Commercial tests of extended customer participation on the electricity market and new use of electricity including electric vehicle integration are the main aspects to focus. The project is well in line with European climate initiatives with over 30 % of wind power production and over 15 % of e-mobility in the year 2030. The main applicants of this project are Vattenfall and ABB. (Energinyheter, 2010)

3.9 Summary

This chapter defines Smart Grids and the most important functionalities as well as technical solutions related to Smart Grids. Smart Grids can enable better market function and supports the achievement of the objectives set by EU. An important part of the development is also new services offered to network users.

Role of research and development (R&D) and demonstration projects is vital from Smart Grid development perspective as a need for new and innovative solutions increases. In the Nordic countries like Finland and Sweden, R&D projects related to Smart Grids and solutions are at high level which is important concerning the current and also future development of the network infrastructure.

4 BENEFITS OF SMART SOLUTIONS IN A NETWORK OPERATION

Awareness about the importance of future's electricity networks is increasing among European policymakers. To be able to design the legislation and policy in a direction which assists on the way to increase the amount of smart solutions in the grids, guided by adequate regulation, policymakers must be aware of the characteristics of "smartness" and the methodology that could be used in the evaluation of the "smartness" in a network. Policymakers must be able to give right incentives to encourage smart investments, it is also important that the investments improve all aspects of Smart Grids and stakeholders involved. Benefits of the development should be beneficial to all parties and at the same time support the ultimate objectives of the Smart Grids. (ERGEG, 2010; EG3, 2011)

"Smartness" of a network is always seen differently from different perspectives of the network users like an individual customer, the whole society, the DSOs that are operating in environments of a different kind (rural areas and cities) and suppliers, for example. As a consequence, also the benefits achieved by intelligent solutions are focused towards different stakeholder in the electricity supply chain. At this chapter, there is an analysis of the benefits that can be achieved by adding more intelligence in the network. The analyses in this chapter are based on the suggestions made by European Regulators Group for Electricity and Gas (ERGEG) and European Commission Task Force for Smart Grids (EC TF). The analyses in this chapter are also based on the desired objectives of Smart Grid development and the objectives are eminently universal at European level, but also local conditions play an important role as the maturity levels differ quite strongly between different nations. Many of the benefits can be approached or achieved by the actions taken by the DSOs in the electricity supply chain. This chapter discusses also the role of the DSOs in the development process towards the ultimate objectives of the Smart Grid concept.

4.1 Use of key performance indicators

A Performance Indicator or Key Performance Indicator is a special term in all kind of industry and business environment to measure the performance in comparison with the desired objectives. KPIs are commonly used by organizations to evaluate their success or the success of a particular activity in which it is engaged. Sometimes success is defined in terms of making progress toward strategic goals, but often, success is simply the repeated achievement of some level of operational goal, for example. Accordingly, choosing the right KPIs is reliant upon having a good understanding of what is important to the organization or when dealing with Smart Grids to the society. What is important depends on the desired objectives or categories which are measuring the performance. KPIs for different objectives or target benefits can be completely different with each other, for example. Because of the need to develop a good understanding of what is important, performance indicator selection is often closely associated with the use of various techniques to assess the present state of the business and its key activities. These assessments often lead to the identification of potential improvements and as a consequence, performance indicators are routinely associated with "performance improvement" initiatives. (Fizz- Gibbon, 1990)

By formulating a set of key performance indicators (KPIs) and applying those to the electricity network, the progress of Smart Grid development can be measured or at least evaluated within relatively good accuracy. (Dupont, 2010) The evaluation can be started from the defined characteristics of Smart Grids, which are introduced in Chapter 3 (the main benefits of Smart Grids). Then a versatile amount of specific KPIs can be constructed. The next section gives an overview of the different KPIs specified to assess Smart Grid development. Each characteristic or target benefit consists out of several categories to which different KPIs are assigned.

4.2 Performance indicators suggested by ERGEG and EC TF for Smart Grids

One of ERGEG's (European Regulators' Group for Electricity and Gas) and EC TF for Smart Grids (EU Commission Task Force for Smart Grids) key principles for good regulation in the electricity sector is a user centric approach, which concentrates on the outputs of the regulated entity and the effects of a given activity or service instead of the inputs. In other words, the regulation of outputs can be made by direct regulation, for example by setting minimum requirements for certain parameters or by incentive regulation which provides rewards and penalties related to a specific criterion. An incentive regulation model fits quite well with the new Electricity Directive 2009/72/EC established by the European Parliament and the Council of the European Union on 13 July 2009. Regulation of outputs requires the predefined definitions of performance indicators and common targets as well, especially from DSO point of view. Clear measurement rules are very important in this case to make it possible to quantify and verify such targets. These performance targets must be precisely related to the desirable objectives and it is vital that the external effects, which are outside the control of network operators, are cleansed of. The indicators must be benchmarked at international or at least at national level. Benchmarking should be done before the adoption of the indicators in order to define the forthcoming performance targets in future regulation models. The idea in incentive regulation is that the regulated entities are either rewarded or penalized in case of over- or underperform with respect to the targets appointed. (ERGEG, 2009; EG3, 2011)

A regulatory approach that promotes improvements in the performance of electricity grids requires the quantification of the effects and benefits of “smartness” in a network by appropriate indicators (KPIs). In order to put this approach in practice, the most important key effects and benefits will have to be precisely identified according to specific metrics. A proposed set of the main effects and some potential parameters related to them are introduced next (ERGEG, EC TF). Measurements or evaluations concerning the “smartness” may be extracted and eventually adopted in use from the indicators below. However, it is noticeable to safeguard a complete regulation and reasonable rate of return in long-term, to avoid cases of semi-optimization for some of the indicators. It is notable, that the indicators that will be the most suitable for be used in Europe will vary from country to country quite significantly; this is mostly a consequence of the different maturity levels in different countries of Europe in relation to Smart Grids. (ERGEG, 2009; EG3, 2011) The proposed effects, benefits and indicators are introduced in the next sections at this chapter.

4.2.1 Sustainable development

Increased sustainability is one of the main objectives and it can be achieved by lowering the carbon emissions formed in the whole electricity supply chain. Reduction of carbon emissions is one of the main aspects in the European energy- and climate package. Nevertheless, from a DSO’s point of view it is clear that the straight influence can be just partial, because the amount of the emissions depends strongly on the generation structure and market situation. Energy efficiency is one of the most cost-effective ways of reducing greenhouse gas emissions. Smart solutions can reduce the need for costly new generation and distribution capacity by cutting energy usage and peak demand in number of direct and indirect ways and the DSOs have a key role by implementing the new technology in the network. The environmental impact of electricity grid infrastructure can be considered as a straight indicator from a DSO’s point of view; however it is quite challenging to measure the impact precisely. Reduction of accidents and risks associated to generation technologies and network maintenance and construction, can be considered as increased sustainability, for example when dealing with the maintenance and building work of new lines and cables or when connecting new generators to the network. (ERGEG, 2010; EG3, 2011)

A quantified reduction of carbon emissions is considered as a main KPI. Defining and measuring of the KPI could be done by considering the ratio between reliably available RES generation and peak demand. The overall share of energy produced by renewable energy sources is also one of the KPIs because the integration of low-carbon generation technologies that use RES or primary energy more efficiently contributes to meet the sustainability objective. Smart solutions can help to effectively integrate the low carbon production and dynamically manage the mismatch between intermittent renewable (for example wind-energy) and consumer demand. (ERGEG, 2010) DSOs are in a key role when dealing with these KPIs. Even if a DSO cannot directly impact the amount of carbon emissions or to the RES-DG factor remarkably, there is many indirect ways how the impact can be quite considerable. These are for example adaptability for DG production, demand response, energy efficiency services, losses and networks life-cycle costs. Reuse of the materials used in the network components is also one example of sustainability. (EG3, 2011) Below, at the Table 4.1, there are the potential KPIs suggested at European level.

Table 4.1, *Increased sustainability. (ERGEG, 2010; EG3, 2011)*

Benefit that is achieved	Key performance indicators (KPIs) of "smartness" in a network
Increased sustainability	• *Quantified reduction of carbon emissions*
	• *Environmental impact of electricity distribution infrastructure*
	• *Quantified reduction of accidents and risks associated with distribution technologies*

4.2.2 Sufficient capacity of distribution grids

The capacity of the distribution network depends on the physically installed lines and wires, but also of the controllability of the network operation has significant effects on it. In future, the ability to connect considerable amount of distributed RES production to the grid is also essential. (ERGEG, 2010)

The "hosting capacity" approach has been developed to quantify the impact of the increasing level of distributed generation by renewable energy sources in the distribution network ("DER hosting capacity"). The basis of this method is to clearly understand the technical requirements that a customer places on the system and the requirements that the system operator can place on singular customers to be able to guarantee a reliable and secure operation of the system. The "DER hosting capacity" is the maximum penetration of DER, for which the whole power system can still operate satisfactorily. (Bollen, 2006)

The factor can be evaluated by voltage stability or by frequency stability without forgetting protection issues, for example. Hosting capacity can be determined by comparing a performance index with the limit of it. The index for performance can be calculated as a function of the level of DER penetration. DER penetration level can be increased by making investments to the grid, which means that the hosting capacity performance increases. The hosting capacity is determined at the point, where the performance index becomes the same as the limit of it. Examples of these investments to increase the penetration level are larger cross-sections of lines and cables or additional HV/MV transformers. (Bollen, 2006) One possible way to increase the amount of hosting capacity is also to make investments to the network in a way that the controllability and monitoring of the network becomes more advanced. This can be achieved by using remote controlled automation solutions with advanced sensors of a different kind, for example. Hosting capacity can be increased also by using "static" voltage adjustment or by using “active” management of voltage. See Figure 4.1 below, where the hosting capacity is calculated in different investment scenarios.

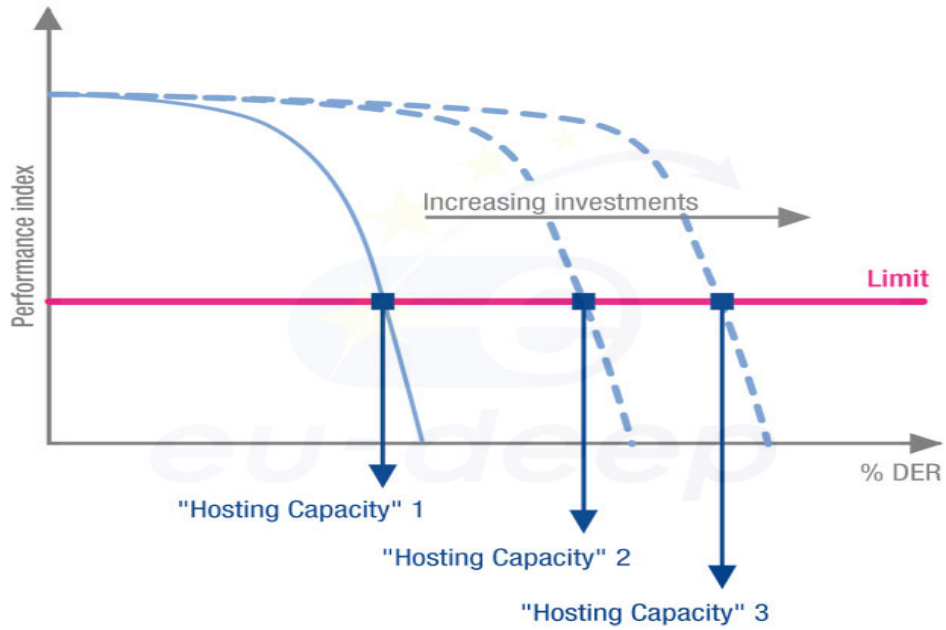


Figure 4.1, *Determining the “DER hosting capacity”. (EUDEEP, 2008)*

Most of the existing distribution networks are developed by using the “fit and forget” principle, which presents the margins that can be securely exploited with a significant proportion of DER. “Hosting capacity” is a function of the type of interaction that is considered. The most important parameters that are related to system loading and voltage control must be considered, such as the coincidence of demand and generation, the homogeneity of the HV/MV substation feeders in terms of location of load and generation and the voltage control margins. Voltage control can be implemented mainly following these two options: limiting the risk of flow inversion along feeders, which limits also the penetration, or by implementing active management for the voltage control settings. (EUDEEP, 2008)

The simplest voltage adjustment method uses the existing margins in urban and semi-urban distribution networks. Operation voltage must be adjusted in order to make more room for DER. Nevertheless, if provided voltage margins are sufficient, active voltage control is not required in that case. This allows to extend the traditional “fit & forget” principle. The extension of the “fit & forget” principle is based on the reinterpretation of network design criteria. As voltage drops along feeders the voltage set point is traditionally adjusted near to the upper limit, so that the highest possible voltage permits a reduction of the losses in the system. In the presence of local DER generation and in cases of irregular location of load and generation along the feeders, the occurring voltage profiles can increase and decrease along the various feeders depending on the coincidence between load and generation. Existing margins can be used to allow the coexistence of load and generation dominated feeders. The reference voltage must be adjusted downwards and the “fit and forget” approach can be expanded. This supposes a sufficient regularity in terms of behavior of the load and generation customers. All other things being equal, this increases the losses in the network due to the lower mean operating voltage, which is not desired. (EUDEEP, 2008)

An active management method can be implemented in case if the voltage control margins are not wide enough and if load and generation functions present suitable properties. Solutions are more complex in these cases because they depend on network characteristics in terms of homogeneity between feeders, or on shapes for loads and generation functions. Behavior facing micro-CHP production or photovoltaic (PV) production should be totally different between each other considering the northern part of Europe, for example. In the first case (CHP), very little or no voltage margin exists but feeders are homogeneous. This means that it is possible to adjust the supply voltage as a function of network loading. In the second case (PV), little or no voltage margin exists and feeders can be non-homogeneous compared with each other. In this case, the peak generation and peak consumption do not normally occur during the same period of time. It is possible to keep the voltage within range by adjusting the voltage set point in the HV/MV substation. The controlled voltage is systematically adjusted as a function of the operating conditions that can be sensed in the primary substation. This is mainly relevant to rural area networks. (EUDEEP, 2008; Repo 2006)

The calculations for hosting capacity should be repeated for every different appearance in power-system operation and design; this is because the hosting capacity from voltage perspective is different from the frequency point of view, for example. Even when regarding just one phenomenon, the hosting capacity is not a fixed value. It depends also on system parameters like the network structure, DER unit type, the kind of load and even climate parameters (solar and wind power). These facts make the estimation of hosting capacity quite challenging. (Bollen, 2006)

An alternative way to connect DG to the network is a so called "flexible" interconnection contract. (Repo, 2006) It means that generation curtailment (executed simply by voltage relays) is applied in order to avoid over-voltages at the DG connection point (wind turbine etc). This kind of approach is optional in case if the reinforcement of the network is too expensive in comparison with the benefits achieved. The method is only suitable in cases, where the situations when the generation curtailment must be used due to over voltages are relatively rare. This is because the use of the curtailment may mean the waste of RES production which is not a desired objective. Basically, the costs of network strengthening should be higher than the lost profit of energy not produced during the repayment period. Especially concerning wind power production, the stochastic nature and low capacity factor makes this idea attractive to maximize the utilization of wind energy resources and network capability simultaneously. The flexible interconnection may benefit both network and production companies by allowing a higher penetration of DG with less network investments. One target of distribution business is also to achieve an optimized use of the capital and assets of an individual DSO and flexible interconnection approach can be helpful to meet this objective. (ERGEG, 2010; Repo, 2006) The KPIs for adequate grid capacity are introduced at the Table 4.2 below.

Table 4.2, *Capacity of distribution grid. (ERGEG, 2010; EG3, 2011)*

Benefit that is achieved	Key performance indicators (KPIs) of "smart-ness" in a network
Sufficient capacity of distribution grids	• *Hosting capacity for distributed energy resources in distribution grids ("DER hosting capacity")*
	• *Installed energy production not withdrawn from renewable energy sources due to congestion and / or security risks*
	• *An optimized use of capital and assets*

4.2.3 Consistent grid access of all users

A uniform grid connection to network users of all kind is a precondition for the energy markets to develop (internal energy market in Europe, for example). This means that all actors connected to the grid should have equal possibilities to act as a consumer, generator or both at the same time. The aim of the indicators presented beneath, is to support new and innovative market models and grid charges (tariffs) for network users of a different kind to be able to participate in the markets in a reasonable way. Also by ensuring a uniform treatment for all type of network users, regardless of their geographical location and other differences is important in order to achieve consistent grid access. The time that it takes from a DSO to connect a new user to the network should be reasonable; also the level of connection charges and grid tariffs should be and remain at a reasonable level. New innovative methods to calculate the tariffs should be implemented in the future; the aim is that a consumer can choose the most beneficial tariff structure depending on the consumption pattern. The optimization of new equipment is also important in order to achieve as effective approach to network connection issues in relation to the resulting benefits. (ERGEG, 2010) Below, at the Table 4.3, there are the potential KPIs suggested at European level.

Table 4.3, *Grid access. (ERGEG, 2010; EG3, 2011)*

Benefit that is achieved	Key performance indicators (KPIs) of "smart-ness" in a network
Consistent grid access of all users	• *Time to connect a new user*
	• *Connection charges for generators, consumers and those that do both, innovative methods to calculate*
	• *Grid tariffs for generators, consumers and those that do both, innovative methods to calculate and define*
	• *Optimization of new equipment design resulting in best ratio of cost / benefit*

4.2.4 Advanced security and quality of supply

One aim of the Smart Grid concept is to achieve a better security and a quality of supply. The first two KPIs introduced at the table below, are equally relevant from the sustainability point of view as well as from the security and quality of supply perspective. Higher share of RES production increases sustainability which is a fact, but it can also influence the networks production –demand balance in case of intermitted RES production. The management of intermitted production is more challenging which can make the power system stability performance worse. Power system stability affects the security and the quality of supply directly. (ERGEG, 2010)

The satisfaction of network users, which are receiving additional services, can have some indirect effects on the quality of service if their expectations are not fulfilled enough. The level of the grid performance has an effect through electricity quality issues, frequency and duration of interruptions and outages must be considered as an indicator anyway when inspecting the quality of supply. DSOs role is remarkable within security and quality issues, but also the whole generation structure has an effect to voltage quality. Penetration of RES-DG production makes the fault protection of the network more complicated and the DSOs must be able to adapt the network to the new requirements, for example. Ratio between reliably available generation capacity and peak demand has to be high enough also in the future, when the amount of intermittent generation capacity increases. (ERGEG, 2010; EG3, 2011) Below, at the Table 4.4, there are the potential KPIs suggested at European level.

Table 4.4, *Security and quality of supply. (ERGEG, 2010; EG3, 2011)*

Benefit that is achieved	Key performance indicators (KPIs) of "smartness" in a network
Advanced security and quality of supply	• *Ratio between reliably available generation capacity and peak demand*
	• *Share of electrical energy produced by renewable energy sources (RES), RES-DG Factor*
	• *Measured satisfaction of grid users with the "network" services they receive*
	• *Power system stability*
	• *Duration and frequency of interruptions / customer*
	• *Voltage quality performance of electricity grid (e.g. voltage dips, voltage and frequency disturbances)*

4.2.5 Upgraded efficiency and quality of service

The efficiency of the network can be increased in future because implementing DR on a large scale can have significant effects on efficiency performance, and DSOs are in a key role by implementing the needed technology for DR. Demand side participation could be measured by collecting the number of customers that has chosen tariffs which have specific demand response profiles (for example high and progressive prices for peak-load hours or seasonal time-of-use characteristics). (ERGEG, 2010) By optimizing the network usage, DSOs are able to decrease the level of losses in the network. This can be achieved by using advanced network control systems, where the actual real-time network status can be used in calculations instead of estimations. The KPIs for efficiency and grid operation are introduced at the Table 4.5 below.

Table 4.5, *Efficiency and service quality. (ERGEG, 2010; EG3, 2011)*

Benefit that is achieved	Key performance indicators (KPIs) of "smartness" in a network
Upgraded efficiency and grid operation	• *Level of losses in distribution networks (absolute or percentage)*
	• *Ratio between minimum and maximum electricity demand within a defined period of time (e.g. One day, one week)*
	• *Percentage utilization (i.e. average loading) of electricity network elements*
	• *Demand side participation in electricity markets and in energy efficiency measures*
	• *Actual availability of network capacity with respect to its standard value*

4.2.6 Upgraded consumer awareness and market participation

Consumer awareness and market participation can be upgraded by using the information provided by advanced meters and advanced data management systems, which is a responsibility of the DSOs to be implemented. Note that the KPIs at the Table 4.6 below are partly overlapping with the efficiency and grid operation parameters. Demand side participation and different pricing models play a significant role in the future electricity market, for this reason these indicators have been lifted separately into an own category as well. Consumers that are aware of their own consumption in real-time through advanced meter information are able to have savings by using different pricing models and by participating in the demand response. Improved energy efficiency is one of the goals set by European energy policy for year 2020. Optional pricing models for customers can enable savings in electricity and level off the average critical peak demand duration, for example by using time-shift for some loads. All these actions have significant effect on energy efficiency as customer participation can be increased. DSOs role is again remarkable when discussing this aspect. (ERGEG, 2010) Below, at the Table 4.6, there are the potential KPIs suggested at European level.

Table 4.6, *Consumer awareness and market participation. (ERGEG, 2010; EG3, 2011)*

Benefit that is achieved	Key performance indicators (KPIs) of "smart-ness" in a network
Upgraded consumer awareness and participation in the market by new players	• *Demand side participation in electricity markets and in energy efficiency measures*
	• *Percentage of consumers on time-of-use / critical peak / real time dynamic pricing*
	• *Measured modifications of electricity consumption patterns after new pricing schemes*
	• *Percentage of users available to behave as interruptible load*
	• *Percentage of load demand participating in market-like schemes for demand flexibility*
	• *Percentage participation of users connected to lower voltage levels to ancillary services*

4.3 Summary

The KPIs introduced at this chapter are based on the suggestions made by ERGEG and EC TF for Smart Grids. Many of the KPIs are depending on several stakeholders in the electricity supply chain. The focus of this work is to analyze the level of Smart Grid development from distribution system operator's point of view. It is clear, that the role of DSOs is quite remarkable even when considering all the KPIs introduced earlier. Nevertheless, there are also few exceptions among the KPIs to which DSOs cannot affect directly or even indirectly.

At this work, the target is mainly use KPIs which are potentially influenced by the DSOs. Therefore the aim is to select indicators to which the DSO's own efforts can affect and to which the DSOs can be seen as enablers from the development and performance point of view. Chapter 5 analyzes the potential KPIs to be used in the evaluation process. Some of the KPIs are based on the suggestions made on the European level and some of them are tailored to suit the network business environment in the Nordic countries. There are also some completely new indicators which can be perceived as well compatible to be used in the Nordic countries.

5 EVALUATING THE SMARTNESS IN A NETWORK

The “smartness” of a network is a very complicated characteristic to measure and it can be deliberated from many different perspectives. The amount of automation in the network can be considered as “smartness” from one perspective. On the other hand is it more important that the quality and reliability of the electricity delivery is at high level despite the fact if there is automation or not? Controllability of the network can be seen as “smartness” in a network as well, because controllability can increase the capacity of the network without increasing the amount of “copper and iron”. In some cases, it can also be a smart solution to build or renew a network by using traditional methods rather than new, innovative methods with complex technology, as the result will be similar eventually. Another possible way to measure the “smartness” is determining the percentage part of customers among AMR meters in a certain grid or by determining the features of the AMR meters used in the same grid. The perception of “smartness” depends on the point of view.

At this chapter there is an analysis of different ways to measure the “smartness” of a network and some key indicators that could be used in the more specific evaluation, especially in the Nordic countries in order to develop the current regulation methods into a direction that would be more favorable towards the smart investments. This issue is crucial at the moment as well as in near future. All of the following categories include an alternating amount of “key performance indicators”. Some of the indicators are similar with the KPIs suggested by ERGEG and EC TF, but there is also versatile amount of new indicators to expand the research base. This is because the aim is to create an approach that observes as comprehensive selection of KPIs as possible in order to achieve holistic results concerning the current development. When considering the scope of this thesis it became clear during the work that compilation of highly detailed definitions for the different levels of development, concerning the KPIs used in the “evaluation tool” was not meaningful. Instead, a more general approach to define the different levels was chosen. This also means that there is a need to accomplish a more accurate definition for the KPIs in future, in order to have more specific results. The categories below are arranged in a specific way so, that first there are some aspects that can be considered as enablers (or inputs) for “smartness” and then there are some consequences (or outputs) of the smart development. The enablers are introduced in section 5.2 and the consequences are introduced in section 5.3. Below, there is a Figure 5.1 that describes the approach which is used at this thesis in the evaluation process for “smartness” in a network. The division between inputs and outputs can be seen from the Figure 5.1 above.

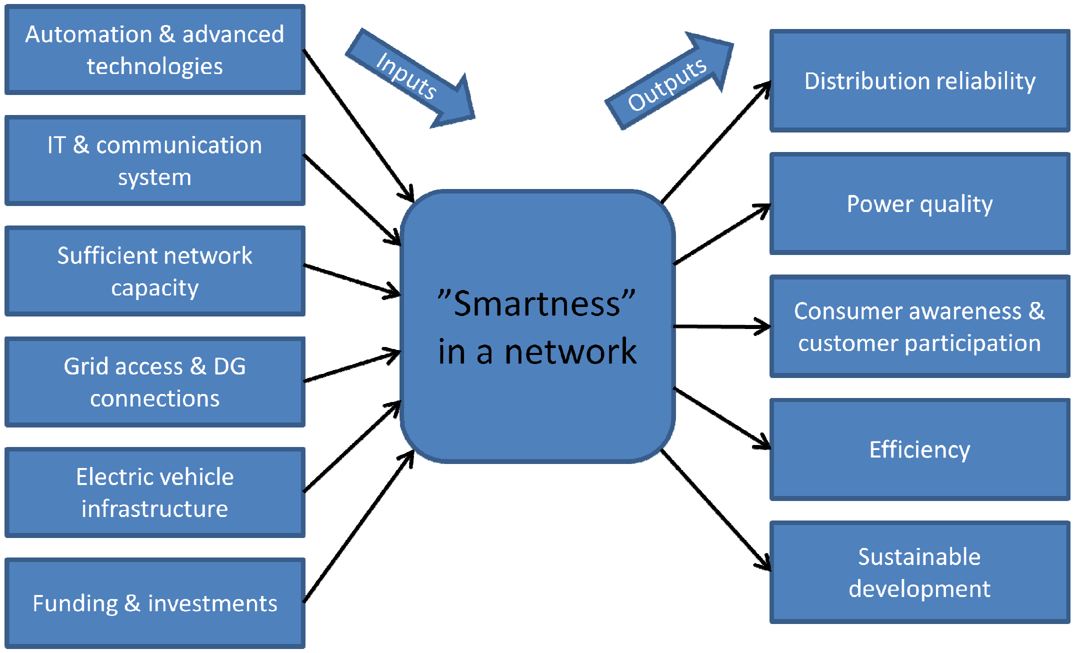


Figure 5.1, *This picture describes how the division between enablers (inputs) and consequences (outputs) can be seen. This is the approach used in this thesis in order to evaluate the level of intelligence in a network.*

5.1 Necessity to evaluate the smartness

At the moment, the situation concerning Smart Grid development and investments is unfair because the costs and resulting benefits are divided asymmetrically between the different stakeholders in the electricity supply chain. Most of the investments in Smart Grids fall largely on the DSOs, while the benefits are largely pointed to other parties (society, electricity system, customers, generators, suppliers etc.) This fact is not taken into account by the current regulation models. Because the current regulatory incentives are not sufficient to incentivize the DSOs to invest in smart solutions and demonstrations, the regulation should be changed in some way. One possible action is to create ways to measure the "smartness" of a network and "smartness" of new investments. The regulation can then be adjusted so, that it is more favorable towards the Smart Grid investments, which are in a key position when considering the achievement of the ultimate goals of the future's network system, referring for example to the European energy- and climate package. (Hänninen K, 2011) Progress in the development of the characteristics concerning Smart Grids can be assessed by several key performance indicators (KPIs). By using KPIs, it is possible to evaluate the current status of Smart Grids and the development of the grids in past and in the future. (Dupont, 2010; ERGEG, 2010)

5.2 Inputs for "smart" development

There are six different categories below, which can all be perceived as enablers for Smart Grid development. The enablers (or inputs) are mainly consisting of technological aspects, which are kind of preconditions for many of the Smart Grid functionalities to be implemented, for example new services. Also financing and funding of the Smart Grid investments and R&D programs can be categorized into enablers, because different financing methods are also a preconditions and a vital part of the development. In other words, by making investments to the network technology and automation the function of the grid becomes more flexible and efficient, possibilities for new innovative services open up and the management, operation and monitoring of the network becomes closer towards the functionalities of a Smart Grid. The consequences of the technological development and new financing options are the outputs of the Smart Grid development; the outputs are introduced in the section 5.3, also at this chapter.

5.2.1 Network automation and advanced technologies

Network automation and advanced technologies can be seen as an enabler from Smart Grid perspective. This is because network automation and the technology used in it, has many consequences to network operation like better controllability and reliability, enhanced fault locating and fault management. Advanced technologies are supporting new services that can be offered to customers for example via advanced metering devices. In Nordic countries like Finland and Sweden, the level of automation is at high level, especially in MV networks. New technologies have been introduced in the past few years. Almost all network functions are today based on the control centre applications which are because of that, a very important part of network operation. Nevertheless, when assessing the development purely from a Smart Grid point of view, the most important precondition and enabler for new innovative services is the introduction of advanced metering devices. By measuring the level of automation and advanced technologies used in the network, it is possible to assess the development level of one perspective concerning the "smartness" in a network. The specific KPIs for network automation and advanced technologies are introduced in the Table 5.1 below. See *Appendix 3* for more information of how the KPIs at the Table 5.1 are implemented to use in the "evaluation tool".

Table 5.1, *KPIs related to network automation and advanced technologies.*

Key Performance Indicators
1. *Supervisory control system (SCADA etc.) connection points (data elements) available, shared by the number of primary substations, secondary substations and monitored / controllable grid elements.*
2. *Primary substations that are equipped with advanced relays like microprocessor relays/ feeder managers (terminal relays) and integrated with the supervisory control system. Share of all primary substations.*
3. *Grid elements that can be remotely monitored in real-time, share of all grid elements.*
4. *Grid elements that can be remotely controlled in real-time, share of all grid elements.*
5. *Total demand served by advanced meters (AMR-meters) which are capable to monitor and communicate remotely. Share of all network users.*
6. *Advanced meter device features corresponding the European directives / standards / recommendations. Level of functionalities.*
7. *Automated meter readings, data transfer frequency supporting different network services. Level of transfer frequency.*
8. *Network operating systems. Applications exploiting the "real-time" data provided by advanced meters. Level of real-time data exploitation.*
9. *Automated MV fault identification (locating) / grid reconfiguration during outages. Level of effective fault management capability.*

The first KPI (1) at the Table 5.1 tells the amount of available points of the control system (SCADA etc.) in comparison with the amount of primary substations, secondary substations and monitored / controllable grid elements. It describes the DSO's capability to monitor and control the distribution network in a sufficient way. Monitoring and controlling the network will be even more crucial in the future, when the amount of DG, LV automation and other solutions depending on high control capability of the network, increase rapidly.

KPI (2) at the Table 5.1 is measuring the level of automation at primary substation level, which describes the DSO's capability to remotely monitor and control the primary substations in the network. Automated solutions at the primary substation level are going to be important in future, as the amount of DG production increases. The role of advanced fault management methods and active voltage control becomes more important and in order to achieve this it is vital to achieve a high integration rate between different network control systems. The KPI measures if there are sophisticated relays and technology at the primary substation level integrated with the supervisory control system.

The KPI (3) at the Table 5.1 is measuring the amount of grid elements that are remotely monitored in real time by the DSO. It is vital, that a large number of grid elements can be monitored in real time both in MV and LV networks in future. A more accurate network state estimation by automated and remotely monitored solutions is needed. This can be achieved by implementing new sensors into the network and integrating them with the control systems, for example.

The KPI (4) at the Table 5.1 is measuring the amount of grid elements, which can be remotely controlled in real-time by the DSO. The ability to remotely control network elements from the control center is important. This ability can effect positively on many things in network operation like capability to transfer into microgrid operation and the fault management process in general by allowing fast network reconfiguration during outages which shortens the average outage time experienced by network customers.

Fifth KPI (5) at the Table 5.1 is measuring the amount of end-users that are equipped with advanced metering devices (AMR, automatic meter reading) which are capable to two-way communication. Introduction of AMR meters has been perceived as one of the most important preconditions to Smart Grid development. Advanced meters, or at least the information that the meters can offer enables many ancillary services in distribution business and electricity market, which are very important in future as the role of different kind of additional and innovative network services increase. Specific billing based on real consumption measurement, demand response, real-time pricing and smart tariffs are examples of these.

In order to establish a common internal electricity market in Europe, there has to be uniform recommendations concerning advanced meters, for example. Some recommendations have been introduced at European level. National recommendations have also been introduced in various countries and the functionalities of the meters, which are seen as the most important have been described. This KPI (6) at the Table 5.1 is measuring the features, that the AMR meters installed, are capable to offer compared with the international and national standards and recommendations.

The next KPI (7) at the Table 5.1 is measuring the level of automated meter data transfer frequency, for example hourly data transfer versus monthly data transfer. Many new services related to DSM are depending on "real-time" information offered by advanced metering devices in a sufficient frequency. Network state management and consumption measurements supporting DR can achieve better accuracy when the frequency of the meter reading is high enough. It is commonly recommended that the meter readings should be done within a minimum of one hour interval, but it has to be also recognized that the data transfer should be done also with a sufficient frequency. In order to achieve all the possible benefits from hourly based meter readings, the data should also be transferred hourly, this is challenging because of the large amount of information.

This KPI (8) at the Table 5.1 is measuring the number of network operating system applications, which exploit the real-time information provided by advanced meters. The data exploitation has a crucial role in future, in order to support new services and better network state management. Both the DSO's internal and external processes can benefit from "real-time" data utilization. Fault management process and billing system, for example.

The last KPI (9) number nine at the Table 5.1 is measuring the network's (DSO's) ability to identify medium voltage network fault location and type, ability to automated reconfiguration of the grid connections in order to limit the faulted area to a minimum in size or number of customers. DSO's capability to realize fast fault management by utilizing the integration between controllable grid elements, advanced relays and network management systems is evaluated.

5.2.2 IT & communication system

Sophisticated IT systems integrated with each other by effective and reliable communication infrastructure based on two-way data transfer can be seen as an important building block of Smart Grid development. The communication channels enable the information exchange between different parts of the network, especially in network monitoring and controlling processes, but also many new services will be enabled by adequate communication channels. Performance of the communication infrastructure has to be reliable and effective, especially in the future when the amount of data and information increases remarkably. At the same time it has to be secured, that no private data of a customer is available for third party or other actors involved, if the data is not needed there for service or other reasons and no contracts has been made. Real-time data exploitation and management in order to support effectively the electricity market operations is vital. A uniform European communication system is a precondition and enabler for the European wide internal electricity market to be implemented in future. An advanced information system helps DSOs to execute the external and also the internal processes of the company. Many of the DSOs internal processes can benefit remarkably of the real-time information, for example network state management which can reach to LV level as well if the AMR data can be exploited. The specific KPIs for ICT infrastructure technology are introduced in the Table 5.2 below. See *Appendix 4* for more information of how the KPIs at the Table 5.2 below are implemented to use in the "evaluation tool".

Table 5.2, *KPIs related to IT and communication systems.*

Key Performance Indicators
1. Performance of communication channels towards the different grid elements (availability, bandwidth, response time). Level of performance.
2. Communication standards and protocols, compliance with European and international methods. Level of compliance.
3. Communication methods supporting different network operations, performance level of real time data exploitation.
4. Real-time data information exploitation to support the DSO's internal processes. Level of performance.
5. Integration level between different IT-applications related to network control and management. Level of integration.
6. Two-way communication. Enabled alerts, remote control and layouts, reading logs, coupling status remote monitoring. Performance level.
7. Customer information security / quality of the information. Level of information security and reliability.

The KPI (1) at the Table 5.2 describes the capacity of communication infrastructure. How well does the communication network between different parts of the network manage to satisfy the need for information exchange related to network operation. It is important that the availability of the communication channel is continuous and the performance of the communication infrastructure is at high level. This means that the bandwidth is high enough to transfer the increasing amount of data in order to achieve an active network management and monitoring in real time.

The KPI (2) at the Table 5.2 is measuring the compliance of the communication standards and protocols with European and national standards. At the moment, it is vital to create a communication system that uses common communication protocols and fits the recommended standards in order to create a uniform infrastructure in the future. Information exchange between different DSOs and market actors is crucial and benefits all the stakeholders, but especially the electricity markets to develop and integrate new innovative services. Universal communication system is an important building block of Smart Grids and this KPI is measuring its compliance at international level.

KPI (3) at the Table 5.2 is measuring how well the communication infrastructure is supporting different operations of the network management. In order to achieve a flexible and efficient management of the network, it is crucial to exploit the real-time data in the network operation. Communication infrastructure should be able to offer network management systems like SCADA and DMS the needed information. This KPI measures also if the communication methods support the network management systems which are important in day-to-day operation. The KPI (4) at Table 5.2 is measuring how well the DSO exploits the real-time information of the network state and operation to support the versatile amount of internal processes of the company. Real-time information from the meters can be used in LV level network state calculation and fault management processes.

The KPI (5) at Table 5.2 measures the level of DSO's integration between different network control systems. Supervisory control system and other systems related to network monitoring and management. The KPI (6) is measuring the ability for two-way communication which enables many of the important functionalities of AMR devices and network control processes. It is important to measure the consumption in two ways in future when the amount of DG increases in the network. LV network automation is also an important matter and it needs to be supported by two-way communication.

KPI (7) at Table 5.2 is measuring the security of individual customer related data, third party access and other risks related to data management and utilization. Privacy policy sets many limits to customer related data availability and companies must use protected transmission methods in order to protect network user's privacy. This KPI measures data privacy and security issues and estimates the performance of the companies in order to achieve secure and protected communication between the stakeholders involved. Also the quality of the information must be sufficient.

5.2.3 Capacity of the electricity distribution network

Network capacity is an important aspect. The physical distribution grid capacity must be adequate to avoid harmful congestion risks and problems related to it. It is also important to ensure continuous production by distributed generation. Hosting capacity for DG is therefore an important factor in future, especially when the amount of RES-DG production in distribution network increases. The optimized use of the assets is important from economic perspective; this can be achieved by using smart technology to control the network operation and by implementing flexible interconnection policies for different generation methods, for example. By using smart solutions to support the network control system, it is possible to avoid expensive reinforcements, in cases where the benefit achieved as a consequence of the increased physical capacity of the network is relatively low.

Especially in the past, but also nowadays it is still a common way to fit the network that is under maintenance or construction project in a way, that focuses only to the maximum injection of power (worst case scenario) in order to avoid harmful congestion risks. This causes many times relatively large investments to the network, even in cases where the utilization rate of the line rarely achieves the maximum rate. In the future, new innovative ways to calculate the optimized line capacities will be implemented. These methods can for example take into account dynamic line ratings for overhead lines connecting large scale DG units to the network or the use of special generation curtailments. Dynamic line rating approach could be useful, when connecting large onshore wind power plants to network, because wind power plants are built in areas with high wind conditions, which increases the effect of dynamic line rating. Nevertheless, the approach relates more to high voltage transmission network. The specific KPIs for network capacity are introduced in the Table 5.3 below. See *Appendix 5* for more information of how the KPIs at the Table 5.3 below are implemented to use in the "evaluation tool"

Table 5.3, *KPIs related to network capacity.*

Key Performance Indicators
1. Physically installed distribution grid capacity. Maximum injection of power and maximum demand, performance level to avoid congestion risks.
2. Hosting capacity for distributed generation produced by renewable energy sources ("RES-DG hosting capacity") in distribution network. Level of DG interconnection capacity.
3. Ensuring continuous production by distributed generation, flexible interconnection policy, voltage adjustment, protection methods. Performance of connection methods.
4. Average HV/MV transformer capacity factor and adequacy of the capacity. Performance level of transformer capacity.
5. Optimized use of assets. Uniformity of DSO's distribution stability curve. Uniformity level.

The first KPI (1) at the Table 5.3 is measuring the physical grid capacity. How well does the grid capacity answer to the situations of high demand and high injection of power to the grid. In some cases the congestion situations can be very harmful to the network operation and stability as well as to the function of electricity market. Therefore the problematic areas inside the network have to be identified. Physical grid capacity has to be high enough, but congestion risks can also be avoided by controlling the network, the production and the consumption in it with a flexible and advanced way.

The KPI (2) at the Table 5.3 is vital at the moment. It measures the networks capability to connect DG production to the grid. It can be evaluated by voltage / frequency stability, for example. It is however quite challenging to measure the hosting capacity of a network precisely because hosting capacity is a local variable. Therefore it has to be calculated repeatedly in all the different points of the network. Nevertheless, hosting capacity of a network can be increased by making reinforcements to the grid or by using smart approaches like network automation which improves the controllability and flexibility of the network or by using advanced voltage control methods. Performance related to hosting capacity is evaluated in general terms.

The KPI (3) at the Table 5.3 is measuring the actions done to ensure continuous production of DG units interconnected to the grid. Protection of the network is going to be facing new challenges when power starts to flow in two ways in the network. Voltage control has an important role, especially in weak networks in order to ensure continuous DG production. This KPI is vital, because it is not desired that energy produced by renewable energy sources has to be withdrawn from the network because of some reasons that are related to the distribution network capacity and operation.

KPI (4) at Table 5.3 is measuring the adequacy of HV/MV transformer capacity in distribution network. The capacity should be high enough to satisfy the demand with no congestion risks. In cases of fault situations it is also important that there is some spare capacity when reconfigurations to the network connections are needed in order to limit the faulted area to a minimum. KPI (5) at Table 5.3 monitors the DSO's stability curve flatness in order to accomplish an optimized use of assets. Steady stability curve can be used as an indicator for the usage of the network. It tells quite well how the network is operating and if the grid is strong enough to satisfy the demand expectations.

5.2.4 Grid access and connection of distributed generation

Uniform grid access policy for all kind of network users is important. The geographical location, the type of customer and other differences between grid users should not affect the interconnection procedure. Interconnection policy should be equal all over the DSO’s territory and the time that it takes from a DSO to connect a new user to the network should be reasonable. Connection charges and distribution tariffs should be on an adequate level. New advanced tariff calculation methods for different kind of users should be implemented and DG production at customer point and other parts of the network should be as easy as possible to interconnect to the grid. The specific KPIs for grid access and connections for new users are introduced in the Table 5.4 below. See *Appen-*

dix 6 for more information of how the KPIs at the Table 5.4 are implemented to use in the “evaluation tool”.

Table 5.4, *KPIs related to grid access and DG connections.*

Key Performance Indicators
1. Time to connect a new user within a reasonable timeframe. Performance level to realize new connections to the network.
2. Uniformity of grid connections. Non-discriminative grid access for all customers. Performance to realize non-discriminative operation.
3. DSO's connection charges for generators, consumers and those that do both. Whether the fees are at an acceptable level compared to average charges.
4. Grid tariffs for generators, consumers and those that do both. Tariff calculation methods and whether the tariffs are at an acceptable level compared to average tariffs.
5. DSO's standards and procedure concerning distributed resource interconnection policy. Performance level of the process.

The KPI (1) at Table 5.4 is measuring the average time that it takes from DSO to connect a new user to the grid from the time when a new electricity connection is ordered. Like in most service based business sectors it is desired that the quality of service is at high level. As a part of the service quality there is always performance. Time to connect a new user within a reasonable time is an objective. The geographical location makes this challenging to be a non-discriminative part of the service. The KPI (2) at Table 5.4 is measuring if there is a non-discriminative access to network regardless of the geographical location or type of customer, from DSO's point of view. In order to achieve a non-discriminatory service the connection should be arranged and the time should be reasonable for all kind of customers.

The KPI (3) at Table 5.4 monitors if the connection charges are justified and at acceptable level. How many different charges there are for different type of users and production devices, for example RES-DG units. How the charges are defined and estimated and if the treatment of different kind of users is uniform. The KPI (4) at Table 5.4 monitors the tariff calculation methods and measures if the tariffs are at an acceptable level. Is there new innovative calculation methods implemented for customers to choose from. The aim of new calculation methods is to create possibilities for consumers to optimize the tariff structure with their consumption patterns in order to have savings in distribution costs.

The KPI (5) at Table 5.4 is measuring how well the DSO's DG interconnection policy is equal to European legislative directives. European Union objective is to increase the amount of RES-DG production in the distribution network; this can be achieved if the connection policy corresponds with the guiding legislative principles and recommendations. It is also vital to have common rules and policies at European level between different stakeholders in the electricity supply chain like TSOs, DSOs, manufacturers and electricity production companies without forgetting the policy concerning private, small-scale DG units that has to become uniform in the future.

5.2.5 Electric vehicle infrastructure development

In future, it becomes important to implement a charging infrastructure for EVs. Networks ability to connect EVs is measured in this category and the effort that a DSO puts towards the development of an advanced infrastructure is evaluated. When EVs become widespread, also versatile opportunities to exploit them to support the network operation could be implemented by the DSOs. EVs could be used as temporary energy storages for example, but also challenges are formed when dealing with huge amount of new type of load in the network. DSOs capability to realize load leveling and technology utilization is measured to determine the development concerning EV infrastructure. The specific KPIs for EV infrastructure development are introduced in the Table 5.5 below. See *Appendix 7* for more information of how the KPIs at the Table 5.5 below are implemented to use in the “evaluation tool”.

Table 5.5, *KPIs related to electric vehicles.*

Key Performance Indicators
1. Hosting capacity for / of electric vehicles (EVs). Performance level to interconnect EVs to the distribution network.
2. Evaluation of the DSO's effort to contribute the development of EV charging infrastructure. Performance level.
3. DSO's opportunity to realize load leveling of EV charging, advanced meter data management and utilization to help this effort, performance.

The KPI (1) at the Table 5.5 is measuring the DSO's network capability to connect EVs. Hosting capacity for electric vehicles can be partly compared with the DG hosting capacity at section 5.2.2. Nevertheless, there are also some differences because EVs can be considered typically as loads but also as energy storages which means that there can be power flowing into two directions depending on usage. When EVs become more common, also the total load increases remarkably which puts new challenges towards the network. Advanced operation of the network and investments in control centers will be needed to cope with an increasing share of RES DG being connected to the distribution grid and with more unpredictable loads such as EVs. DSOs will need advanced systems and control solutions to be able to face the challenges of the future. (EURELECTRIC, 2011) This KPI measures the impact of EVs to the network and the capability of the network to handle new type of load.

The KPI (2) at Table 5.5 is measuring the development of EV charging infrastructure which becomes an important aspect, especially in the future. By measuring DSO's effort to contribute the development of EV charging infrastructure and the current development already achieved, the level of charging infrastructure development can be estimated. A need for the development within this category varies quite strongly between city and rural area networks at the moment. In other words, it has to be acknowledged if the use of this KPI is justified within the network under review. The KPI (3) at Table 5.5 is measuring the technical requirements of DSOs to connect and manage high amount of EV load in the future. New technology utilization can help the effort to manage these new loads, information offered by advanced meter devices can be vital in order to accomplish load leveling and other actions. This KPI measures if the DSO is able to realize load leveling.

5.2.6 Funding and investments for smart solutions

In different situations, different funding options for smart solutions are possible. In general, the investment costs in electricity grids are covered by grid tariffs. These include among others the use of system charges, access charges and connection charges for example. A precondition for the recognition of costs concerning smart solutions is, that the costs relate directly to a real and specific purpose and to a specific solution or service which is deployed in the grid. Regardless of a specific tariff structure and grid costs, it is essential that the grid users understand the system which must be transparent, cost effective, justifiable and non-discriminatory. The costs emerging from the introduction of new services or solutions in the network like DG interconnection, bi-directional protection and optimized grid expansion in order to support new grid user's needs are today mainly paid by the actor which requires those new services and which is the main beneficiary of them. In the European context, a number of different public funding options are in place. These are ranging from EU funding, national governments funding or a combination of public-private partnerships. The level of scrutiny given to publicly funded options should be relatively higher than that given to private funding options. Public subsidy should only be used, when it is clear that industry will not make investments otherwise or when benefit to the society justifies such an approach. The type of funding to be used will also depend on the stage when it is needed, the R&D phase, the pilot project phase or the market introduction phase. (EG 3, 2011) This section discusses about DSOs funding methods and creates an overall picture of it, but this section cannot straightly be perceived as "smartness" of a network. Nevertheless, an overview of different funding strategies concerning network investments is made. Also different kind of ownerships and sizes of the DSOs makes this aspect quite hard to be comparable between the DSOs. It is not appropriate to evaluate the KPIs related to funding and investments on the scale from one to five (1-5) like the study is performed with the other categories in this work. Instead, there are tailored measurement options (three different options) for each KPI in this category. The specific KPIs for funding options and investments concerning Smart Grids and solutions are introduced at the Table 5.6 below. See *Appendix 8* for more information of how the KPIs at the Table 5.6 are implemented to use in the "evaluation tool".

Table 5.6, *KPIs related to funding and investments.*

Key Performance Indicators
1. Selective grid development and innovation funding (tariff structure). Level of selectivity concerning network development and funding.
2. Amount of DSO's total revenue invested for developing network efficiency. Performance level in comparison with regulative / legislative requirements.
3. Investment incentives coupled with obligations and rewards / penalties in regulation. Is the current level of incentives appropriate from DSO's Smart Grid development perspective.
4. Amount of Smart Grid investments financed by external funding. Level of external funding options.
5. R&D programs and funding. Performance level of R&D and demonstration project activity.
6. Total amount of revenue relative to the allowed return. Performance level of revenue / network development.

The KPI (1) at the Table 5.6 measures if the DSO’s funding method is selective in a way that the grid tariffs are related directly to a real and specific purpose. This is important from innovation perspective and by having a specified goal for new solutions the costs relate directly to the deployment of Smart Grid functionalities which can foster the whole development of Smart Grids. It is also vital that regardless of a specific grid tariffs, it is essential that the grid users understand the funding system which must be first of all transparent, cost reflective, justifiable and non-discriminatory. (EG3, 2011)

The KPI (2) at Table 5.6 is measuring how the DSO invests to energy efficiency development. How high is the share of revenue that is invested in energy efficiency improvements during a funding period of one year. Legislation sets certain minimum requirements for energy efficiency improvements during a regulation period and the minimum requirements vary between different countries. This KPI evaluates the DSO’s contribution in overall energy efficiency as a part of electricity supply chain and the performance level in relation to legislative requirements.

KPI (3) at Table 5.6 measures the investment incentives DSO possibly receives to fund Smart Grid investments like an incentive for voltage quality. The KPI (4) at Table 5.6 is measuring the share of DSO's Smart Grid investments possibly covered by external funding options. At the moment, the DSOs are in a quite challenging situation because most of the investments fall largely on them, even if other stakeholders can also benefit of the investments quite a lot. In future, it is clear that also rates, subsidies and external funding options will be an important part of the Smart Grid development at least concerning demonstration and pilot projects.

The KPI (5) at Table 5.6 is measuring the level of Research & Development programs. How does the funding for R&D programs be formed and how high is the R&D investment level. The development of Smart Grids is at a critical point at the moment because large scale investments are needed to replace the aging network anyway. R&D programs can offer important information of new solutions and real-life demonstration programs can act as enablers for accelerated development. Because of this all kind of R&D programs are important from development point of view. This KPI is measuring the level of R&D programs and the investments targeted at the programs.

The KPI (6) at Table 5.6 is measuring the ratio between the DSO's total revenue and allowed rate of return. Electricity distribution is a regulated business sector and companies can earn predefined and reasonable rate of return for capital invested to the network (also depending on regulation method). The level of revenue also depends of the company's ownership and strategy. The ownership of a company can influence the level of return taken, for example municipality owned companies may not take the entire allowed return because of tax reasons. The mechanism is that even with relatively low network tariffs a municipality owned company can reach quite good incomes by having tax incomes in addition to tariff incomes in a way which makes the overall business quite profitable. (Matikainen, 2011; Hänninen M, 2011) Some companies make large investments to the network and therefore even the highest allowed return cannot cover the investments entirely, even in a longer period of time. This KPI is measuring the level of revenue in relation to allowed rate of return.

5.3 Outputs of "smart" development

Next there are five different categories concerning the outputs of the development. The outputs are mainly consisting of different kind of services and functionalities. Naturally, there are also the aspects concerning distribution reliability and power quality. Sustainable development is a consequence of both the inputs and the outputs because the advanced technology in the network enables new energy efficiency services which increase sustainability, for example. It is important to understand that the outputs are formed as a result of different actions taken in the grid development, also the aspects discussed earlier at the section 5.2 at this chapter (inputs). The outputs below are also quite directly related to the ultimate objectives of Smart Grids. By having attention to this fact, it is easier to understand that the regulation of outputs is a very effective regulation method compared with regulation related purely to technical issues. Next there is discussion about the different categories for the outputs of the development.

5.3.1 Electricity distribution network reliability

Reliability of electricity distribution is more and more important as the amount of electricity depending devices and systems increases. Also customer expectations for reliability increase all the time. A future Smart Grid should be safe and reliable; therefore by measuring the reliability indices (SAIDI, SAIFI, CAIDI, MAIFI) it is possible to evaluate the reliability of the network operation, which can be seen as "smartness" as well. Because DSOs are typically different compared with each other, it is vital that also the reliability indices are defined specifically by the type of a DSO in question, city-, urban- or rural -area DSOs, for example. This is because the operation environment between a city area DSO and a rural area DSO can be completely different in comparison with each other. Especially in the future, a capability to island operation (microgrid) will be essential mostly because of increased amount of DG production, which enables a microgrid operation when fault situations occur in the network. This feature enables the DSOs to limit the number of customers, which are influenced by the interruption to a minimum. This enhances the performance of a DSO in relation to reliability indices, for example. The specific KPIs for electricity distribution reliability are introduced in the Table 5.7 below. See *Appendix 9* for more information of how the KPIs at the Table 5.7 are implemented to use in the "evaluation tool".

Table 5.7, *KPIs related to distribution reliability.*

Key Performance Indicators
1. SAIDI, overall performance in city, urban and rural areas. Measured by taking into account supply criterion in different residential areas.
2. SAIFI. DSO's performance level.
3. CAIDI. DSO's performance level.
4. MAIFI, overall performance in city, urban and rural areas. Measured by taking into account supply criterion in different residential areas.
5. Amount of cabling in the DSO's MV distribution network. Cabling level.
6. Share of high impedance grounded networks among DSO's MV distribution lines. Level of compensated networks.
7. Interruption costs. Costs reflecting the inconvenience experienced by network customers as a consequence of distribution disturbances.
8. Power system stability. Stability performance of the distribution network.
9. Microgrids, DSO's effort to implement controlled island operation. Level of research, development and demonstration activity.

SAIDI (System Average Interruption Duration Index). The KPI (1) at the Table 5.7 is commonly used as a reliability indicator. SAIDI is the average outage duration for each customer served. SAIDI is in unit of time, hours / year. Because the operation environment between different DSOs is quite variable, the performance in city area, urban area and in rural area networks is measured. In "city" area networks, it can be defined, that high performance level is achieved when the total interruption time during one calendar year is less than 60 minutes. Respectively for "urban" area networks, it can be defined, that high performance level is achieved when the total interruption time during one calendar year is less than 180 minutes. For "rural" area networks the limit for high performance level is less than 360 minutes of total interruption time during year. (SER, 2010)

SAIFI (System Average Interruption Frequency Index). The KPI (2) at the Table 5.7 measures also networks reliability. It is the average number of interruptions that a customer experiences. Unit is a number of interruptions per customer / year. DSO's performance in reliability is evaluated by measuring the interruption frequency on the distribution network. CAIDI (Customer Average Interruption Duration Index). This KPI (3) at Table 5.7 is related to SAIDI and SAIFI. It can be calculated as ratio SAI-

DI/SAIFI. CAIDI gives the average outage duration that customer can experience, hours / year. DSO's performance related to more specific reliability details is measured by using CAIDI.

MAIFI (Momentary Average Interruption Frequency Index). The KPI (4) at Table 5.7 measures the total number of outages less than 3 minutes in duration per total number of customers. Unit is interruptions (< 3min) per customer / year. Because the operation environment between different DSOs is quite variable, the performance in city area, urban area and in rural area networks is measured. In “city” area networks, it can be defined, that high performance level is achieved when there are no short interruptions during a calendar year. Respectively for “urban” area networks, it can be defined, that high performance level is achieved when there are less than 10 pieces of short interruptions during calendar year. For “rural” area networks the limit for high performance level is less than 60 pieces of short interruptions during year. This KPI measures the amount of short interruptions as a part of reliability reviews. (SER, 2010)

The KPI (5) at Table 5.7 is measuring the development of large scale cabling concerning medium voltage distribution networks when creating weatherproof network system which is able to tolerate natural phenomena like storms and thunders. This KPI is not comparable with all DSOs because operational environment varies quite strongly between pure city and pure rural area networks. In the evaluation, at least the type of the DSO (rural, urban, city or a combination of these) has to be taken into account. Present day orientation among the DSOs in the Nordic countries is to create strategies which aim to achieve a high level of cabling at the MV and LV levels. By measuring the current situation, it is possible to evaluate DSO’s progress in order to achieve a weatherproof distribution network.

The KPI (6) at Table 5.7 is measuring the share of high impedance grounded MV networks (compensated networks) in comparison with the whole medium voltage distribution network in the DSO's territory. By using high impedance grounded networks, it is possible to enhance the network reliability when considering earth faults, because a compensated network limits the current in earth fault situation and can extinguish itself with a higher probability than an unearthed network. On the other hand, by using compensated networks, the detection of earth faults becomes more challenging; sophisticated and more sensitive indication is needed. One advantage that can also be achieved by impedance grounding is decrease concerning the amount of short interruptions and intermittent earth faults.

The KPI (7) at Table 5.7 is measuring the average distribution reliability in form of interruption costs. By determining the average interruption costs, the impact of interruptions in electricity supply towards network users can be evaluated. Interruptions are causing expenses also towards network companies in form of fault repair costs. It can be stated that interruption costs are quite strongly related to the traditional reliability indicators presented earlier in this section. Today, the significance of interruption costs has increased as a part of economic regulation model in Finland and the impact will become important also in other parts of Europe in the future.

This KPI (8) at Table 5.7 is measuring the stability of the distribution grid operation. DSO's performance in network stability controlling is evaluated. Power system stability should be at high level, even in future when the share of intermittent RES production increases in the HV and LV distribution networks. This KPI is evaluating the average network stability performance. The KPI (9) at Table 5.7 is measuring the contribution of the DSO to implement active microgrid operation in the network. Referring to part of the grid, which is able to operate as controlled island in order to increase reliability. This KPI measures the level of projects, research programs and other activity of the DSO in order to implement microgrid operation in the future. For example pilot projects in co-operation with other utilities.

5.3.2 Power quality

This section measures the level of power quality, or rather voltage quality to be precise. The quality of delivered power is usually defined by the quality of voltage waveform; this is because it is impossible to control the currents drawn by customer loads. Voltage quality depends on not only the DSO, but also in certain respects of producers and customers. Generally, voltage quality covers a range of different kind of factors, including interruptions, but in this work the review concerning interruptions is dealt separately in section 5.3.1 (Electricity distribution network reliability, presented earlier.) This section and the KPIs below focus on DSO’s voltage quality performance evaluation from the network and its operation point of view. There are several standards concerning voltage quality criteria, but in the end the quality is directly or indirectly determined by the ability of customer equipment to work and perform properly. An active and working way to measure the quality is therefore to incorporate the impact of the quality (or lack of the quality) at the customer point. Different kind of end-users can have different kind of needs for the voltage quality and therefore it is wise to allow various power quality related contracts for customers to choose from, especially in the future. (CEER, 2008) The specific KPIs related to the power quality performance of the distribution network are introduced in the Table 5.8 below. See *Appendix 10* for more information of how the KPIs at the Table 5.8 are implemented to use in the “evaluation tool”.

Table 5.8, *KPIs related to voltage quality performance.*

Key Performance Indicators
1. Range of different voltage qualities to contract.
2. Customer complaints related to voltage quality issues (excluding outages). Performance level of power quality improvements based on complaints.
3. Voltage quality performance of electricity distribution network (compared to standards like EN- 50160 etc.).
4. Proactive improvement of power (voltage) quality in the network. DSO's performance to enhance power quality continuously.

The KPI (1) at the Table 5.8 is measuring the selection of different voltage levels that can be contracted with the DSO. Different customers are able to choose different ranges of voltages according to power quality requirement. This kind of approach could be useful for network users with sensitive loads and devices in the network. When concerning legislation and more precisely the standard related to power quality EN-50160, it is clear that the requirements of the standard are quite indicative. By offering contracts to customers for better voltage quality, the DSOs can answer better to customer expectations in cases of high voltage quality dependence. This kind of approach could be valuable for corporate customers, for example. This KPI evaluates the DSO's service performance related to power quality contracts.

KPI (2) at Table 5.8 is measuring the power quality service performance of the DSO from customer perspective. It takes into account the customer complaints related to power quality issues. By measuring the amount of customer complaints, it is possible to evaluate the performance of the power quality service in general. Also by evaluating the performance of the DSO to increase the power quality in case of a complaint can be seen as a vital issue when defining the level for this KPI. Improving the quality can be seen as a part of good network service.

The KPI (3) at Table 5.8 tells the performance of the distribution grid from a technical point of view considering power quality. How well does the network manage to achieve a high quality of voltage in the electricity distribution according to international standards, in this case the standard EN-50160. By comparing voltage quality in the network with the standard EN-50160, an overall performance of the distribution network can be evaluated in relation to voltage quality requirements. This KPI could possibly be even more useful when investigating a specific part of the network and for example comparing the results with other network parts. Nevertheless, when considering the whole network, an average performance can be evaluated.

The KPI (4) at Table 5.8 is measuring if there are proactive methods to improve the voltage quality performance of the network based on DSO's quality measurements. Proactive quality improvements can be seen as a vital issue, especially when customer expectations towards network services increase all the time and the amount of intermittent generation devices increase rapidly. DSO's possibility to monitor the voltage quality also at customer point at LV level increase remarkably when new "smart meters" are introduced. This KPI evaluates if the DSO exploit the information in order to increase the level of proactive quality improvements.

5.3.3 Consumer awareness and market participation

End-user participation and overall awareness of distribution system operation and energy efficiency services, is one of the main objectives to achieve. This participation can increase the level of DG production and reduce the total consumption and lower the peak demand, which are all contribution to support sustainable development and energy efficiency. Demand side management and the demand response can be achieved by the technology that already exists, advanced metering devices. By introducing new tariff options and real-time pricing methods, consumers can be able to monitor and lower their own electricity consumption. End-users can also act as producers by generating and selling electricity towards the grid or by cutting their own consumption in order to have savings in electricity bills. This category and the KPIs in it are measuring the level of development which is related to consumer awareness and participation in grid operation and electricity market. The specific KPIs for enhanced consumer awareness and market participation are introduced in the Table 5.9 below. See *Appendix 11* for more information of how the KPIs at the Table 5.9 are implemented to use in the "evaluation tool".

Table 5.9, *KPIs related to consumer awareness and market participation.*

Key Performance Indicators
1. Number of different tariff options available to end-user offered by the DSO (opportunities to choose from). The level of different options.
2. Time-of-use tariffs (ToU), fraction of customers served by the DSO. Level of ToU tariffs in use.
3. Fraction of consumers contributing in demand side management (DSM) in DSO's territory.
4. Electricity supplier change process. DSO as enabler for the process. Duration of the process etc. Performance level.
5. Ratio between consumers and "prosumers", share of customers acting as consumers and producers.
6. Measured satisfaction of network users with the network services they receive.
7. Planned interruptions, DSO's performance on informing the customers inside the interruption area.
8. Customer promises that the DSO offers. Level of the promises from customer perspective.

The KPI (1) at the Table 5.9 is measuring the amount of options that a customer has, when choosing different tariff options in order to have savings in electricity bill. It depends of the consumers load profile, which kind of tariff structure is the most beneficial to be used. If the DSO offers different kind of tariff options to end-users, the end-user can choose the most beneficial tariff and achieve savings in electricity bill by using the electricity in a more advanced way, for example heating a household during night-time when the demand is lower, when also the tariff is lower. This KPI measures the amount of different tariff options offered to the network users by the DSO.

The KPI (2) at Table 5.9 is measuring the possibilities that a customer has in order to adapt ToU pricing tariffs. It also measures the share of customers that have chosen ToU schemes if possible. Time-of-Use tariff is a tariff structure that steers the consumption towards low demand time periods by price signals. When demand is high (peak demand), the distribution tariff is higher and when demand is low (off-peak) the tariff is lower. By using electricity during off-peak periods, the network user can achieve savings in electricity bill. Also the total demand profile becomes flatter, which is beneficial for the DSOs. DSOs are in a key position in creating new tariff structures and the introduction of AMR meters open up new possibilities, for example ToU tariffs based on hourly consumption measurements. This KPI measures the use of ToU tariffs in the electricity distribution.

The KPI (3) at Table 5.9 is measuring the amount of consumers / customers that are contributing in DSM. In other words, share of customers which are applying demand response (DR). At the moment, the contribution is still at relatively low level, but in the future DR will become an important part of energy efficiency services among the LV network users. DR can also be implemented in many ways, for example by using price signals or certain limits for consumption and demand or by direct load control by the DSOs. This KPI measures the DR participation of network users and it will be more important in the near future when DR becomes more general.

The KPI (4) at Table 5.9 is measuring the DSO’s performance related to electricity supplier change process when a customer wishes to change the supplier at the deregulated electricity market. Electricity sales are a part of competitive business and customer can choose the electricity supplier freely, unlike the distribution company. In order to achieve a well functioning supplier change procedure from customer’s perspective, also the DSOs must be well prepared to the change process and information exchange with the new supplier. This KPI measures the DSO’s performance related to supplier change process from customer perspective.

The KPI (5) at Table 5.9 is measuring the policy related to "prosumers" among the DSO's network users. A term “prosumer” means a network customer that can act as a normal consumer but also as a producer always when possible. Especially in the near future, the share of prosumers is going to increase as a consequence of the introduction of small-scale DG units in the network. By measuring the DSOs policy related to “prosumers” it is possible to evaluate the contribution in energy efficiency and customer participation. DSOs should be able to welcome all the DG units to the network and the connection process should be uniform and effective. This KPI measures the policy and the performance of the process.

The KPI (6) at the Table 5.9 is measuring the satisfaction of network users with network services that they receive. Distribution business is nowadays mainly customer oriented and therefore the satisfaction of customers, consumers and producers is vital. By measuring the customer satisfaction related to network services, the overall performance of the DSO can be evaluated. Also new services that are based on ICT-communication in the network should be reliable, for example load management and energy efficiency services. This KPI is very important as the role of the DSOs has changed more to customer service companies, instead of just distribution companies.

The KPI (7) at Table 5.9 is measuring the DSO's effort on informing customers, which connection point is inside a planned interruption area in the network. It is important that network customers are correctly informed about planned interruptions in the distribution of electricity. This can be seen as a part of customer service and in order to reach high customer satisfaction it is important to inform the customers correctly. DSO's performance related to informing is evaluated.

The KPI (8) at Table 5.9 represents the development concerning customer promises. It measures the level and amount of different customer promises offered by the DSO. In a way towards more customer oriented electricity distribution environment, it is important to improve the performance by offering customer promises which a customer can rely on. Customer promises can improve the satisfaction of network users, but also improve the performance of the company's internal processes and ensure a continuous development of the business sector. This KPI measures the level of customer promises in relation to minimum requirements that come from legislation and regulation.

5.3.4 Efficiency of electricity distribution and electricity market

Enhanced energy efficiency is one of the main objectives of Smart Grids. Better efficiency can be achieved by using smart solutions in the network; this is mostly because of new services provided for network customers. New services, which are able to create savings in customer's consumption, are for example demand response and other additional services. DSOs are in a key position to implement these new services, but also consumer interest is vital. Advanced meters installed by the DSOs can offer customers more acknowledge of their own consumption and enhance their contribution in energy efficiency actions. The optimal use of the existing network and advanced operation and control technologies can lower the average losses in the distribution business and reach better efficiency as well. Local generation methods, like DG, can be helpful when optimizing the network usage. This section is measuring the level of efficiency related actions. The specific KPIs for the energy efficiency performance of the distribution network operation and electricity market services are introduced in the Table 5.10 below. See *Appendix 12* for more information of how the KPIs at the Table 5.10 are implemented to use in the "evaluation tool".

Table 5.10, *KPIs related to efficiency of electricity distribution and electricity market.*

Key Performance Indicators
1. *Electrical losses in distribution network (technical losses), share of total energy distributed. DSO's performance to reach high energy efficiency.*
2. *Electricity produced by small-scale distributed generation in order to cut down energy bills and consumption. DSO's capability to allow deployment of the required hardware.*
3. *Additional energy efficiency services offered to the customers by the DSO. Level of different services.*
4. *Share of total energy that a consumer is able to save with ancillary energy services. Level of possible savings.*
5. *Demand side participation in electricity markets and in energy efficiency measures. Level of participation.*

The KPI (1) at the Table 5.10 is measuring the losses (technical) in distribution network. How efficient is the operation of the DSO and is there any kind of actions done in order to decrease the level of electrical losses in the distribution network. By measuring the level of losses it can be evaluated what is the DSO's performance in general energy efficiency. Better efficiency can be reached by advanced use of the network assets.

The KPI (2) at Table 5.10 evaluates the DSO's capability to effectively allow customers to connect small-scale production devices in the distribution network. The devices can be for example small wind power generators at household environment. By evaluating the DSO's connection policy and performance of the connection process, the level of contribution in increased energy efficiency, through implementation of DG, can be measured. Also efficient market functioning can be improved by introducing small-scale producers and their participation in the electricity market.

The KPI (3) at Table 5.10 is measuring the amount of additional / optional energy efficiency services provided by the DSO in order to improve overall energy efficiency. Especially in the future, the role of different kind of efficiency services is going to increase. At European level there is also a lot of discussion about efficiency and services related to it. By measuring DSOs additional services the contribution can be evaluated. Nevertheless, the role of different stakeholders concerning energy efficiency services is quite unclear at the moment, at least in the Nordic countries.

The KPI (4) at Table 5.10 is measuring how much a customer is able to save by using energy efficiency services provided by DSO. What is the level that can be saved in general. This KPI is quite challenging to implement in the evaluation tool, because the amount of different services is still at quite low level. The importance of this KPI will become increasingly important in the future. At the moment, the evaluation of the performance level can be carried out just in an indicative form by considering the effects of consumer consumption monitoring and possible special tariff structures used.

The KPI (5) at Table 5.10 is relevant for efficiency, but it can be just partially influenced by the DSO. This KPI measures the DSO's effort as an enabler for DSP as a consequence of implementing the enabling technology. The evaluation can also take into account the share of network users, which behavior is potentially modified by implementing new technology and innovative solutions in the network.

5.3.5 Sustainable development of the distribution system

Sustainability can be enhanced by lowering carbon emissions and the environmental impact that the electricity distribution network infrastructure causes. This is one of the main objectives of Smart Grids, based on the EU's climate targets. RES-DG production in the distribution grid can also contribute to reaching this target by cutting CO_2 emissions. Also the quantified reduction of accidents and risks related to network operation and maintenance is a way to enhance sustainable development. From a DSO's perspective, this can be achieved by continuously educating the persons working with network maintenance, construction and development. Safety training is also an important way to improve safety in this business sector. This section is measuring the level of sustainable development in the distribution industry operations. The specific KPIs for enhanced sustainable development performance are introduced in the Table 5.11 below. See *Appendix 13* for more information of how the KPIs at the Table 5.11 are implemented to use in the “evaluation tool”.

Table 5.11, *KPIs related to sustainable development.*

Key Performance Indicators
1. *Quantified reduction of carbon emissions. DSO's performance to achieve reductions in carbon emissions, directly or indirectly.*
2. *Environmental impact of electricity distribution infrastructure.*
3. *Quantified reduction of accidents and risks associated in grid operation, maintenance, building and development.*
4. *RES -DG factor, share of electrical energy produced by renewable energy sources.*
5. *Informing of carbon free energy sources and energy efficiency services.*

The KPI (1) at the Table 5.11 measures the Smart Grid development from sustainability point of view. DSOs are only partially able to influence the emissions arising from electricity production and distribution, because the emissions depend mostly on the generation structure and the market situation. But when considering day-to-day network operation, there are many ways to reduce carbon emissions. Employees working with issues related to management, development and maintenance of the network can be geographically located in completely different places. In these cases it is possible to reduce carbon emissions caused by traffic related to physical meetings in some location that need to be arranged. The physical meetings can be replaced by using advanced video meeting (video conferencing) technology, for example. Also by centralizing day-to-day network operation related functions it is possible to enhance the internal processes and avoid unnecessary travelling that causes emissions.

The KPI (2) at the Table 5.11 measures the impact that the construction, maintenance and deconstruction of the electricity network appoints to environment during its lifecycle. The direct impact is quite challenging to be measured, but it is possible to evaluate the processes of the DSO from environment perspective. By evaluating the level of how well the environmental issues are taken into account and what kind of studies there are carried out related to environmental impacts it is possible to obtain an estimate of the environmental impacts of the network during its life-cycle.

The KPI (3) at Table 5.11 evaluates the DSO's operation, planning and education of employees in order to avoid accidents and risks which are related to sustainability and safety issues. Continuous company’s internal education of employees is nowadays important aspect in every business sector, also in distribution business. By maintaining employee’s know-how and awareness of safety factors, it is possible to decrease the amount of accidents and near-miss situations related to network maintenance, operation and construction.

The KPI (4) at Table 5.11 is related to reduction of emissions by using and introducing new RES equipments. The performance level describes the share of carbon free production methods. This KPI cannot be directly influenced by the DSO, but the policy related to RES installations affects the level indirectly and by evaluating the share of RES the DSO’s contribution can be also evaluated.

The KPI (5) at Table 5.11 measures the level of DSO's information sharing concerning new energy efficiency services and carbon free production methods. The network customers need to be informed correctly about new services and “green” production methods in order to be able to influence sustainable development. Nevertheless, the role of DSOs concerning the information sharing of production methods is quite unclear.

5.4 Summary

At this chapter, more specific KPIs have been introduced and the approach for measuring the “smartness” in a network has been described. The KPIs related to the different categories were defined in general terms. The reason for the general definitions is that the aim is to evaluate the current development in Vattenfall’s networks in Finland and in Sweden. Different kind of long term strategies, maturity levels and starting points between the companies makes it really challenging to accomplish a very specific definition for the development levels, as the aim is to make a comparison and a general view of the current development.

The KPIs have been tailored in a way that they are more suitable to be used in Nordic countries, as well as in a way that they can be more affected by the actions taken by the DSOs (possibilities to influence). At Chapter 6 there is a case study, where the approach presented in this chapter and the KPIs have been used when evaluating the current development in Vattenfall’s networks in Finland and in Sweden. See *Appendices 2-14* for more information about the evaluation tool. *Appendix 2* presents the general instructions for how to use the application and *Appendix 14* shows how the overall results of the application are presented.

6 CASE STUDY OF VATTENFALL'S DISTRIBUTION NETWORKS

This chapter contains case studies concerning the level of "smartness" in Vattenfall's networks in Finland and in Sweden. The evaluations for the "smartness" are based on the evaluation tool, created and introduced earlier in this work. More specific discussion, definitions and analyzes related to the "evaluation tool" can be seen at Chapter 5 in this work and *appendices 2 –14*.

The objective of the case studies is to create a vision of the current development level concerning Vattenfall's distribution networks in Finland and in Sweden. The results of these case studies could be used to support the generation of more incentive regulation models in the future in order to accelerate Smart Grid development into a right direction. As an important part of these case studies, there are interviews with experts from different aspects concerning the "smartness" in a network and regulation of electricity distribution business. These case studies are carried out by dealing with the entire network at company's territories in Finland and in Sweden. In these case studies, Vattenfall Verkko Oy in Finland is referred as VFV and respectively Vattenfall Eldistribution AB in Sweden is referred as VFS (Vattenfall Sweden).

The analyzes and discussion carried through the case studies as well as the results of these case studies are based on the knowledge of the author of this thesis. It means that the results can be seen more as indicative values to describe the current development in Vattenfall's networks. On the other hand, the purpose of these case studies is also to demonstrate in practice the approach created to evaluate the "smartness" in a network.

6.1 Operating environment within Vattenfall's territory in Nordic countries

When discussing in general, it can be said that Vattenfall's operational environment in Finland and in Sweden is quite similar when compared with each other. In both countries, the network environment differs quite significantly depending on the geographical location. The reason is that in both countries there are "city- area" networks, but also remarkable amount of "urban" and "rural- area" networks in the company's territory. This is a fact that has to be taken into account when evaluating the level of "smartness". Especially the different maturity level between city- and rural- area networks concerning the smart solutions is quite relevant. This means that when considering the entire network in the evaluation, including both city- and rural- area networks, the results of the case studies represent the average development level in the company's networks.

Nevertheless, this kind of case study could be made also by considering just a part of the network, for example a city- area network. In this case, the results for the development levels would probably be higher. When conducting the studies, it is important to keep in mind that there are also remarkable differences between the networks in Finland and in Sweden. It has to be recognized, that the size of the companies is quite different, because in Sweden there are over twice as many network customers than in Finland and also the total length of the network is remarkably larger which makes the network management and operation even more challenging. In Sweden there are also more different voltage levels in the distribution network than in Finland, making the technical structure of the networks quite different.

In general, Vattenfall experiences Smart Grids as a platform that can handle bi-directional power flows as well as information sharing between all actors in electricity markets. As a network that can function as market platform for renewable energy sources, distributed generation and storage technologies, e-mobility and demand side participation. Vattenfall recognizes that all actors along the value chain have important parts and roles, but especially the DSOs are in a key position to enable the further development of Smart Grids.

6.2 Smart Grids in Nordic countries

In Nordic countries like Finland and Sweden, the level of development concerning automation and advanced technology is at high level. Nevertheless, snowy winters and forested terrain with long distances between production and consumption sets challenges for the distribution of electricity. Network automation and advanced fault management systems are on a vital role in Nordic countries in order to be able to decrease the average outage time experienced by network users. Most faults, which are causing interruptions to electricity delivery, happen in the electricity distribution network. The problems are mainly concentrating on the rural area networks and on the urban area networks, which are typically constructed by using overhead lines at the moment. The city areas are mainly built with an underground cabling already, which is the reason why city area networks have much lower interruption durations and frequencies. This is the reason why for example Vattenfall, both in Finland and in Sweden, has adopted a strategy where most of the network that is built or under maintenance is nowadays constructed by using underground gables, even in rural areas.

However, it is important to remember that different DSOs have totally different starting points because of their sizes vary a lot and also the operation environment can be quite different. As a consequence the strategies between separate DSOs can vary a lot. In Europe, Finland and Sweden are at the top of the development concerning advanced meters. Both countries have set legislative targets and requirements for AMR meters. In Finland, legislation (measuring regulation, March 2009) requires that 80 % of all households should be within remote metering by the year 2014. The new legislation also determined that all customers with fuses greater than 63 amperes should be equipped with an AMR meters immediately. It is notable, that some DSOs have already installed meters to all customers connected to network in Finland, for example Vattenfall Verkko Oy. At the beginning of 2009 about one million customer sites were equipped with a remotely readable meter in Finland and the changeover has been relatively quick because in 2010 the amount was around 1,5 million. (Tekniikka & Talous, 2009) In Sweden, 100 % roll-out has already been reached by Governments legislative requirements. As for example, Norway has taken more moderate line with implementing AMR meters and it has expressed that it will observe the development in other countries first, before making large scale roll-out itself. Now also Norway has defined a timetable for the roll-out and specific minimum requirements for the metering devices.

6.2.1 Vattenfall in Finland

In Finland, the geographical location (climate conditions such as cold and snowy winters), long distances and highly forested terrain sets high challenges for the distribution system. Therefore in Finland, the level of automation and ICT- technology used among the distribution companies in network control and operation is at a relatively high level. This has been taken into account in long term network planning and in creating a fast working fault management via different (monitoring room) implements like SCADA, NIS and DMS which have been taken into use already in the 70's and 80's. Some automated solutions like remote controlled disconnectors have also been introduced already in the 80's and the development has been continuous. (Järventausta, 2011)

Vattenfall Verkko Oy owns over 60 000 kilometers of electricity network and about 390 000 customers in Finland. As an example, VFV has made a decision that all new lines and conductors under renovation are installed as underground cables instead of overhead lines, which is a part of the company's strategy in creating a weatherproof network system which is a challenging task in Finland's snowy and forested terrain. Over the past few years, the weather conditions have also been challenging because there has been many powerful storms like Asta (July 2010) and Veera (August 2010). Nowadays most of the Finnish distribution networks are being installed as underground cables, because also most of other DSOs in Finland have adopted the strategy of weatherproof networks, but nevertheless there are also exceptions. An automated operating system of the distribution network is one of the main reasons, how the good quality of supply is obtained in Finland. Remarkable impact was shown in the decrease of annual outage times of customers after the automation was taken into use in the 80's and 90's. During the past decade, a lot of new solutions have been taken into use by the Finnish distribution companies such as light primary substations (110/20 kV) within VFV and pole mounted reclosers. (Järventausta, 2011) Below there is a Figure 6.1 about the influence that the installation of automation has gained to the Finnish distribution system, especially concerning the average annual outage time in hours experienced by individual distribution network customer in Finland. Vattenfall Verkko Oy is one of the Finnish distribution companies, which has been well presented in the development of new and innovative solutions in the field of electricity distribution technology.

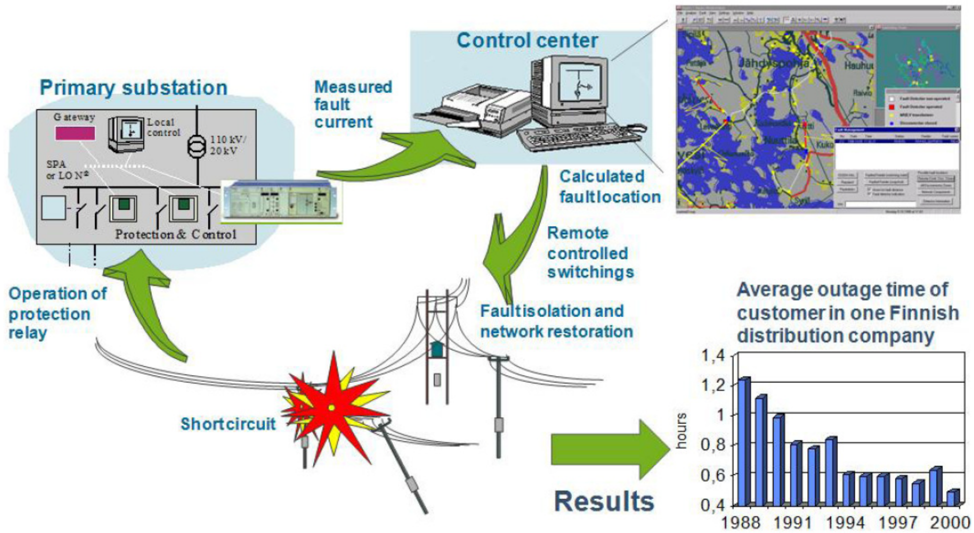


Figure 6.1, *Automated fault management in Finnish distribution network. (Järventausta, 2011)*

The most significant step towards the next generation of distribution networks in Finland is the introduction of AMR metering on a large scale. In Finland, VFV was the first company that made a large scale roll-out of AMR meters between the years 2006–2008, after small-scale pilot projects between the years 2003–2005. The AMR- meters can offer many useful functions for distribution companies, such as the alarms of network faults, power quality monitoring, customer service, load control and customer specific hourly consumption information which is helpful in billing calculations making it accurate. AMR meters and the information that the meters can offer, enable the whole network management system to function better and more efficient. This is important for the energy saving aim that has been a topic over the past few years. AMI has a vital role in the future, especially concerning Smart Grid solutions. (Järventausta, 2011)

6.2.2 Vattenfall in Sweden

The Swedish electricity distribution network consists of total 515 000 kilometers of conductors. The distribution grid consists of 33 000 kilometers of regional lines (high-voltage distribution) and 482 000 kilometers of local lines. Total amount of the local lines is divided into underground cables which share is 297 000 kilometers, and to overhead lines which share is 195 000 kilometers. The share of Vattenfall AB's network in Sweden is about 115 000 kilometers, which is a remarkable amount of network. Vattenfall Eldistribution AB has over 850 000 network customers in Sweden.

In Sweden, the government placed a law in the year 2003, which requires that all electricity meters must be read once a month by the halfway of the year 2009. Because of this, the Swedish companies have quite early implemented remote readable meters. Nowadays all the meters are remote readable and Sweden became one of the first European nations to achieve 100 percent penetration following this regulation driven roll-out of automated meters in 2009. (Vattenfall internet) Nevertheless, the legislation did not take a stand to what kind of functionalities there should be with the metering devices. This is problematic, because as a consequence some of the meters installed in Sweden today are only capable to one-way communication and all of the meters are not capable to hour based measuring and demand response, for example.

Sweden is also making progress towards its ambitious goal of installing 30 terawatt hours (TWh) of wind power production capacity by the year 2020. To be able to balance this remarkable shift towards more intermittent production by renewable energy sources, Sweden's energy market regulation agency (Energy Market Inspectorate, EMI) claims that by installing the new distributed wind power plants geographically widely across the country will be the best solution. This approach should help Swedish power system operators (TSO, DSOs) better integrate and manage large amount of wind power production while also taking advantage of demand response through the installed advanced meters possibly in the future. This decision concerning wind power, places challenges for Vattenfall's distribution network in Sweden. Because of the large amount of wind power, there must be enough network capacity to interconnect the production units to the network.

A great part of the Swedish households have been already equipped for price-based DR. Most of the smart meters installed across Sweden can gather data hourly and the appropriate ICT-communication technology to transfer the data already exists. Therefore, the deployment of price-based DR in Sweden is now depending on current regulation, at the moment there is lack of enabling regulations. In order to capture all the benefits of DR and to be able to manage micro-generation and private energy production, the meters must record and transmit the data more frequently. In the year 2010, the Ministry of Enterprise, Energy and Communication in Sweden announced that the Swedish government is considering a change of how often electricity companies record usage and read the meters. Unlike the monthly readings, hourly readings would help Swedish consumers better understand how the energy demand causes the end-user electricity price to fluctuate. Recent studies made in Sweden (Bartusch, 2010) indicated that DR is successful with Swedish consumers because the network customers in Sweden seem to be active and willing to impact to their energy consumption. The study shows that consumers, which are able to access hourly data, did take actions to substantially lower their electricity bills. In addition, dynamic pricing mechanisms such as time-of-use rates will be playing an important role in realizing the full scope of DR benefits in Sweden. (Carrasco, 2010)

In Nordic countries like Sweden and Finland, the snowy winters and forested terrain sets challenges to the reliability of electricity distribution. Like in Finland, also in Sweden there have been strong storms during the last decade. Many of the Swedish DSOs have implemented a strategy to build a weatherproof distribution system in order to reduce outage time duration in the electricity distribution sector. Among other DSOs, over the past few years VFS has invested a lot in the distribution grid by creating a more weatherproof network. This has been achieved by changing overhead lines into underground cables and by using advanced automation solutions. (Vattenfall, 2011)

6.3 Analyzing the “smartness” in Vattenfall’s networks in Finland and Sweden

At this section there are analyzes for the “smartness” in a network by using the Excel-based evaluation tool. The evaluation of the development level is divided into different categories which are presented earlier in this work at Chapter 5. Each of the following sections contains a varying number of “key performance indicators” upon which the assessment of the level of “smartness” is based on. The aim is to evaluate the current level of development. It is also possible to use this kind of approach in another way. By setting some specific target values (milestones) for the KPIs in the future, it is possible to evaluate the progress towards the ultimate objectives which will be a useful method in the future. More specific description of the approach used in these case studies is presented at Chapter 5.

6.3.1 Automation and advanced technologies

In Finland, VFV has invested a lot to different applications and solutions in order to create a basis for further development. VFV has high level of automation and advanced technologies in the network. SCADA system (Netcontrol “Netcon 3000”), is highly integrated to support network activities at primary substation level and today most of the primary substations are equipped with advanced relay technology by using microprocessor based relays and feeder managers (terminal relays), which are connected to supervisory control system. Examination concerning the share of highly advanced relays at primary substation level shows, that more than 50% of the installed relays are highly advanced at VFV’s network (VAMP feeder managers, microprocessor relays). Nevertheless, most of the other relays are also programmable and quite sophisticated, even they cannot be perceived as highly advanced because of the continuous development of technology. The share of purely static relays is at the moment less than 15%.

SCADA system is connected to all primary substations, remotely controlled components and monitored grid elements. Secondary substations, MV/LV transformers, are not connected to the SCADA within VFV. Nevertheless, monitoring of LV network has become possible after the introduction of AMR meters in LV level. In the VFV’s network there are also a high number of remotely monitored and controllable grid elements which can be controlled in “real-time” from the control centre supported by different network operating applications and communication channels. Between years 2006 – 2009, VFV has installed over 1250 pieces of remote controlled disconnectors and switching devices, so that the total amount has been tripled which is a significant step from control and fault clearance perspective. The company has totally almost 9500 pieces of disconnectors in the network and the share of remote controlled disconnectors and switching devices is at the moment over 27 %. The amount of strategically located remote controllable disconnectors is around 2600 pieces.

VFV uses AMR metering devices, manufactured by a Slovenian company Iscraemeco and model MT372 is being used in Finland. The metering device consists of build-in GSM/GPRS modem and possibility for an external antenna for communication. Both GSM and optical interference are supported by DLMS/COSEM (Device Language Message Specification/Companion Specification for Energy Metering) which is an application layer message specification designed to support messaging on a computer integrated environment. The meter software can easily be upgraded remotely or locally. MT372 also comprises a possibility to connect a switching device to it and VFV has installed the unit to a part of the meters, when seen necessary. (Kujala, 2009; DLMS, 2011) All network customers are equipped with AMR meters capable to two-way communication and the other features of the meters are corresponding well the European and national level recommendations.

The amount of different network operating applications inside VFV, which are exploiting the "real-time" data provided by advanced meters, is quite versatile. DMS (distribution management system), NIS (network information system), GIS (geographic information system), QMS (quality monitoring system) and customer service applications are all supported by AMR data. Tekla Xpower DMS-AMR system can be considered as one of the most important system level integrations and it enables LV network monitoring, control and enhanced LV outage management, which has traditionally not been possible. Other systems like NIS and GIS are also integrated to Tekla Xpower system. Below there is a Figure 6.2 about information flow within VFV.

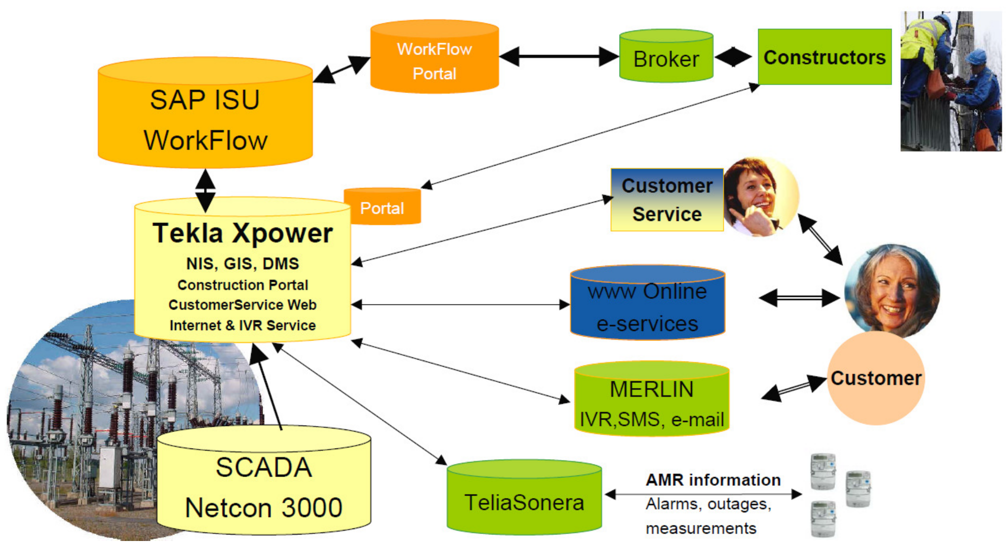


Figure 6.2, *Information flow and integration within VFV systems in Finland. (Myllymäki, 2009)*

Fault management system is quite sophisticated, MV network faults can be identified by type and the system also calculates an estimate about the location at the feeder, this makes the fault management process more effective as the faulted area can be limited effectively with remote controlled technologies. LV network faults can be indicated by AMR meters. As a result, the average outage time caused by faults has decreased clearly because of the development. Vattenfall Verkko Oy has introduced new services, for example by using internet or SMS messages to inform customers automatically about outages. This amenity decreases the work of customer service as customers are informed about the interruptions of supply before they make a call to the customer service. There is a Figure 6.3 below that presents the results.

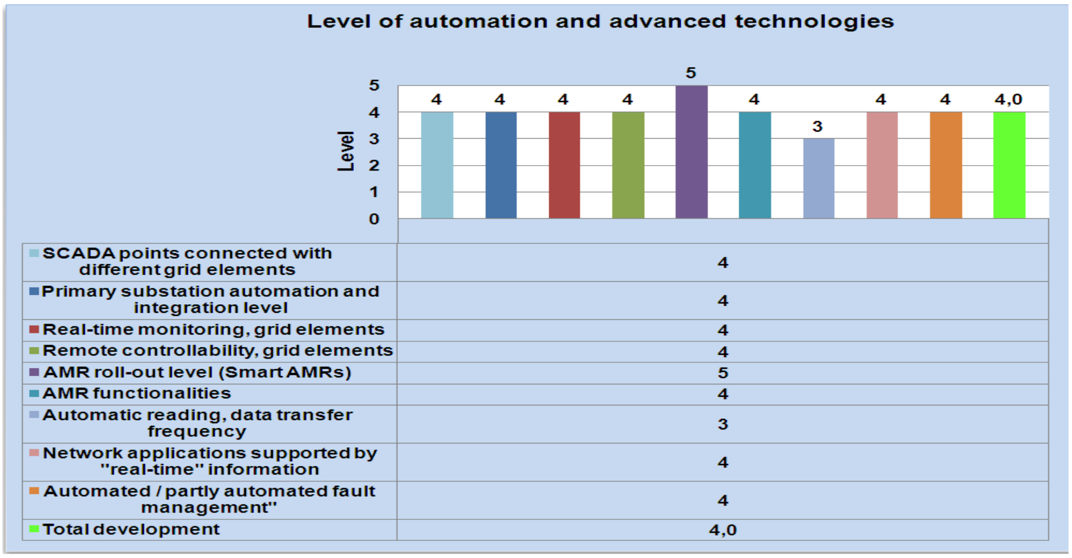


Figure 6.3, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In Sweden, within Vattenfall a system called ENMAC is used. Distribution management system ENMAC is provided by General Electric (GE) and it includes many different subsystems. The whole system is a modular and flexible client-server architecture comprising a number of collaborative software applications such as SCADA, DMS and graphical user interface. (Carlefalk, 2011)

VFS's SCADA system is connected to all primary substations and remotely monitored and controllable grid elements like disconnectors in the field. Nevertheless, the share of monitored and controllable grid elements is at the moment relatively low. It can be estimated, that roughly 10% of all grid elements can be controlled remotely, referring to remotely controlled reclosers, disconnectors and switches. (Carlefalk, 2011) The SCADA system is not at the moment connected to secondary substations (MV/LV substations), but the objective is to create a communication channel there as well, because the controlling and monitoring of all substations is seen evident in the future. Like in Finland, VFS has installed also new relay technology to the network. These are mainly microprocessor based advanced relays integrated to the SCADA system at primary substation level, nevertheless all the benefits and information given by these relays are not exploited at the moment. Also quite a lot electromechanical relays are still used in the older substations; the reason is that there is not a need to renew them because they are working well. A future vision is to show that a digital substation (fully integrated smart substation), based on standard IEC- 61850, can achieve high level of reliability, compared with traditional substations. (Söderström, 2011)

At the moment, in Sweden there are three different types (different generations) of AMR meters installed at the VFS region. Some of the meters are not capable to two-way communication, for example. It can be said, that at the moment the share of metering devices, which are capable to two-way communication and can be defined as "smart" meters is about 70 percent of all the meters installed at Vattenfall's network in Sweden. About 30% of the meters installed in VFS's network are not capable to two-way communication and therefore the functionality concerning DR does not exist, as an example. Nevertheless, all network customers are equipped with an AMR meter, but there are some differences between the functionalities of the meters and European level recommendations concerning especially the "first generation" meters, for example. See *appendix 15* for more information about the functionalities of the different generation meters. The information given by the advanced metering devices supports the different processes of VFS, examples of these are fault management and customer service. (Garpetun, 2011)

Automated fault indication has developed quite a lot, because the type of the fault can be identified. Nevertheless, the location of the fault is not recognized at the moment in Sweden. A challenging thing is relatively low short-circuit currents at high impedance grounded MV networks. The system recognizes the faulted feeder, but the location at the feeder is unknown. Also grid reconfiguration during fault situation is relatively rare. More advanced technology should be implemented in the network to achieve this. The data from the advanced meters is transferred daily into the database, both in Finland and in Sweden. In order to achieve full benefit of AMR meters, the data should be transferred more frequently, like hourly in order to execute more effective services and full-scale DR, for example. (Garpetun, 2011; Söderström, 2011) There is a Figure 6.4 below that presents the results.

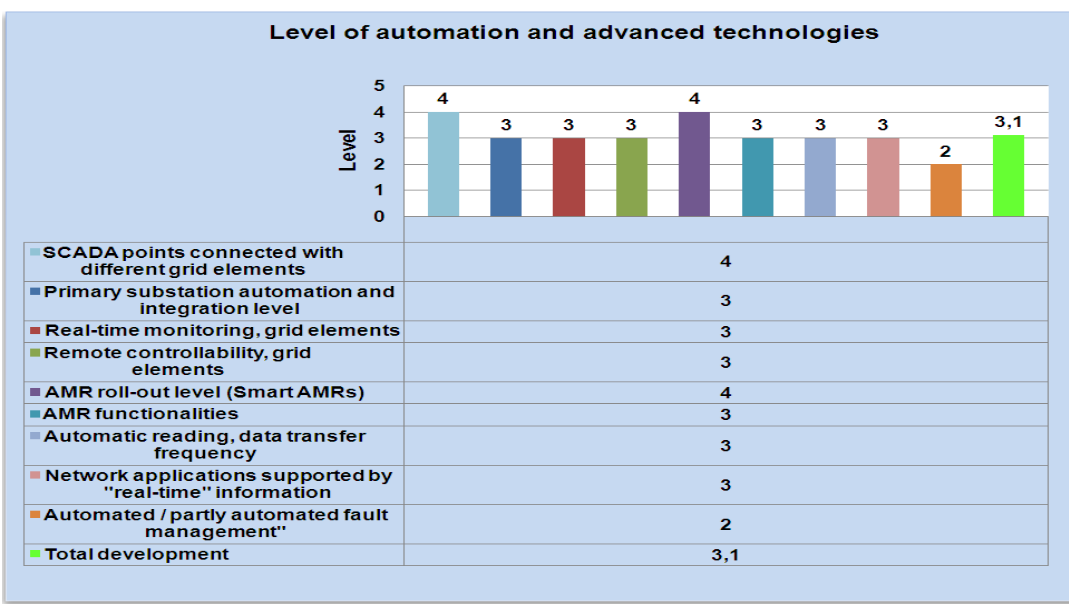


Figure 6.4, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.2 IT & communication system

In Finland, VFV made a large scale AMR roll-out to almost all of its 390000 customers between the years 2006 -2008. ICT communication between different grid elements was executed in cooperation with TeliaSonera Finland and other ICT-specialists. The communication system is highly advanced and it uses an open TCP/IP interface (protocol IEC 60870-5-104) to have connectivity to wireless communication technologies like GPRS and 3G, $450\ MHz$ wireless wideband and satellite network which is not depending on national network infrastructure (also providing duplicated backup). There is also fixed lines (optical fiber) between the most important parts of the network, referring to SCADA connections. The AMR meters use a point to point (p2p) connection (connection between AMR meters and the meter control centre), which enables real-time information about the state of the meter by connecting it straight to the meter control center. The use of IEC-104 protocol makes the infrastructure well compatible with European standards and recommendations. (Vattenfall- intranet, 2011)

The infrastructure connects the control centre applications to the substations and remotely controlled switches, reclosers and other advanced technologies in the network. AMR meters are connected straight to the control centre applications, DMS, measurement database and customer service applications, by using GPRS (p2p) connection in most cases. This advanced solution improves the monitoring, controlling and network state management by allowing an efficient and secure data exchange between different parts of the network and control center applications. Nevertheless, some problems with the quality of the information occur from time to time. This is mostly a consequence of incorrect information from AMR meters (connection problems, false alarms). Also customer service is improved by utilizing real-time information. Especially the AMR-DMS integration makes the management of the LV network possible. This is a significant step towards advanced monitoring and controlling of LV networks which has not traditionally been possible. (Vattenfall –intranet, 2011) Below there is a Figure 6.5 about VFV's (in cooperation with TeliaSonera Finland etc.) solution for communication infrastructure.

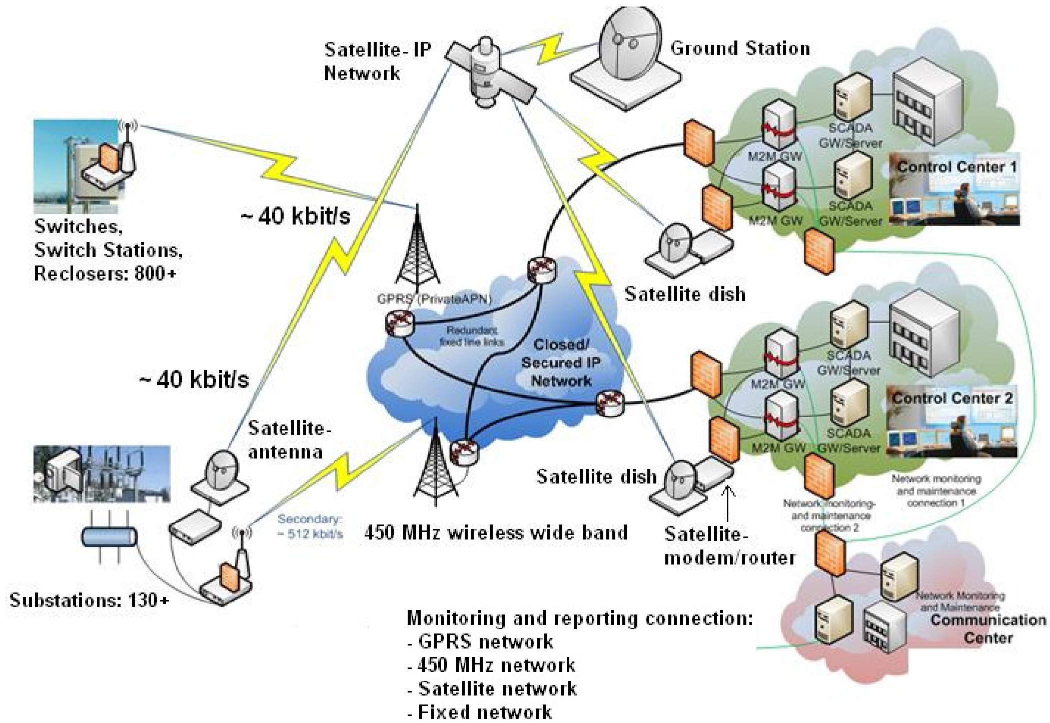


Figure 6.5, *Simplified function of Vattenfall Verkko Oy communication infrastructure. (Vattenfall –intranet, 2011, applied)*

VFV has introduced many new applications over the last decade. Network information system between 2000-2002 (TeklaXpower), network control and monitoring system between 2002-2005 (Netcon 3000), customer information system between 2004-2006 (SAP), phone system in 2006 (MERLIN), AMR management between 2003-2008 (TeliaSonera) and field communication network between 2009-2011, for example. VFV also uses Visimind, which means that all primary substations, overhead regional lines and overhead MV lines are 3D photographed completely every 5 year interval (1 gap year, second year 25%, third year 25%, fourth year 25%, fifth year 25%) and stored in database in order to support maintenance management.

Two-way communication in the field enables coupling status monitoring and control, alerts from different grid elements and even the LV network status can be monitored. This makes it easier to maintain network stability and it makes possible the reconfiguration of network connections if needed. Customer information security, provided by the AMR meters can be seen quite safe. On the other hand the quality of the information could be better. This means that there should be advanced algorithms to calculate and filter the errors, which occur from time to time, away from the information flow. There is a Figure 6.6 below that presents the results.

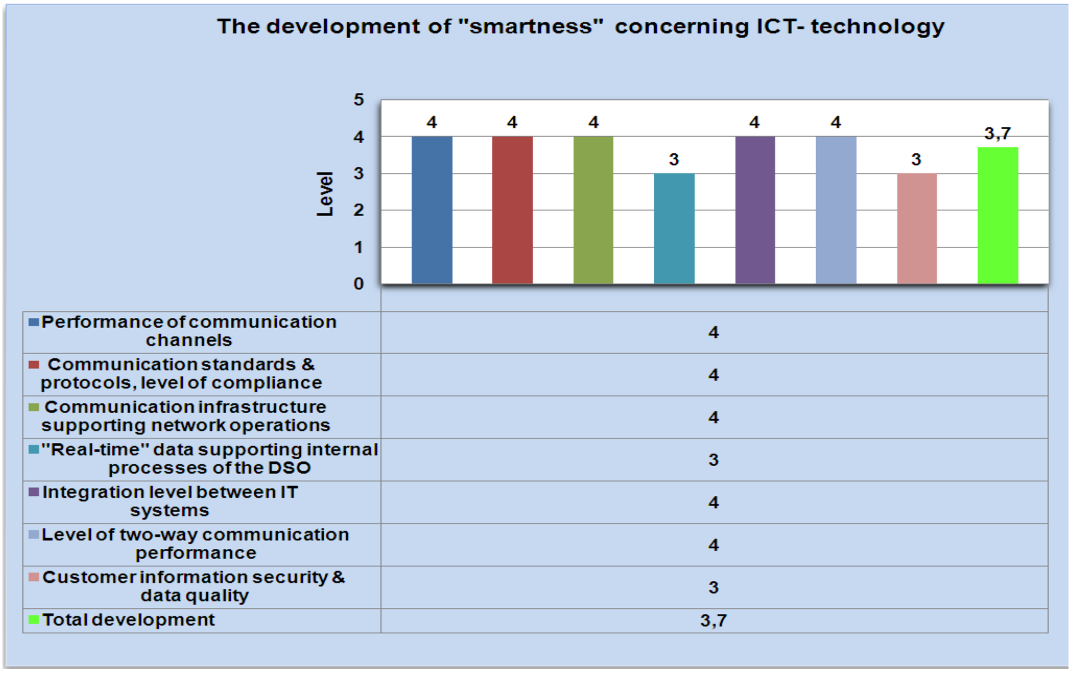


Figure 6.6, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In Sweden, VFS's communication infrastructure is implemented with many different communication technologies. Predominant communication method is PLC (power line communication), but there is also optical fibers, GPRS and wireless mesh networks. The metering communication is carried out mainly with PLC technology, combined with cellular backhaul. This kind of solution is used with the third generation AMR meters (70% of all remote readable meters). The earlier deployments (AMR 1 and AMR 2) are using a mixed communication technologies including PLC, RF mesh network, GSM technology from meter to data concentrator in conjunction with GSM backhaul. Performance of the communication infrastructure is good, even some problems can be found with the quality of the information provided by PLC technology. (Garpetun, 2011)

VFS's communication infrastructure (AMR 3) is built in cooperation with Echelon NES and Telvent, both external service providers. Telvent's Titanium communication uses PLC and TPC/IP connections (GSM, GPRS, MV-PLC) with protocols ANSI/EIA-709 CENELEC A-Band and public or private WAN or TCP/IP. This makes the system well compatible with European and national level standards and protocols. This communication infrastructure supports well different network operations. Only some problems can be found concerning the PLC data quality, which complicates the data usage in case there are differences on the information/data between different systems. The internal processes of the company are supported well with the real-time data provided by the communication system. Customer service can be improved remarkably by the real-time information, including low voltage fault management, for example. Also customer safety can be improved when zero conductor faults can be identified remotely. The communication method makes the customer information security quite well, even the reliability of the information is not high enough at the moment. (Garpetun, 2011)

SCADA, DMS, NIS-GIS-system as well as outage management system are separated from each other which mean that there is no automated integration between the different systems. Nevertheless, there is a manual integration between different systems which makes the level of integration sufficient. On the other hand this means that there is a lot of handwork, caused by the manual integration concerning day-to-day network operation. The biggest problem, in order to execute an automated integration, is that VFS receives the different applications from external vendors. This leads to a situation where the integration is challenging to execute, because VFS is the company in between the different application vendors and does not have enough knowledge about how the integration could be carried out. Other challenging thing is also data quality, which has to be improved first. In other words, same type of data in different applications must match each other. At the moment VFS aims to create a stronger partnership with the application vendors, which have the knowledge of the systems, in order to execute the integrations for VFS in near future. The aim of VFS is to reach high level of integration and as few systems as possible in future. (Carlefalk, 2011) There is a Figure 6.7 below that presents the results.

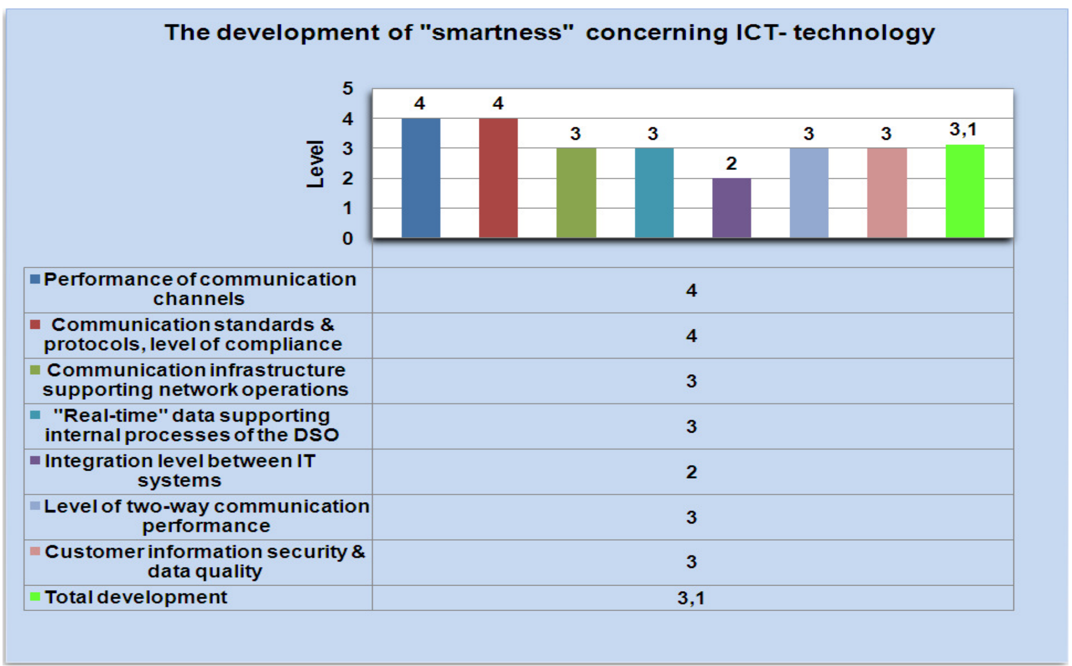


Figure 6.7, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.3 Sufficient capacity of the network

Capacity of distribution network depends on multiple issues when evaluating the whole power transfer capability. It can be measured by considering the average physical distribution network capacity which includes the installed lines, wires and cables and capacity of the installed HV/MV transformers. An important factor is also efficient use of the network, which can be achieved by advanced monitoring and control systems. "RES-DG hosting capacity" describes the network's ability to connect distributed generation units to the network. It is important that the hosting capacity is at an adequate level in future and it can be increased by making investments in a way that the capacity of the network increases. By optimizing the use of the installed assets, the recovery can be maximized. At the moment, it is almost impossible to reach highly optimized use of the assets, because there are huge amount of DG production planned in both countries which has to be taken into account. This means that there is no sense to try to optimize the use of the network completely at the moment, without taking into account the long term planning of the network asset management. By introducing flexible interconnection policy for DG in the future, the level of optimization could be increased remarkably. On the other hand this could lead to a situation, where the production by RES-DG would need to be limited which is not desirable.

Vattenfall's network in Finland has enough physical grid capacity and in normal operating situation, the capacity of the network is good, even during the highest demand in cold winter days. Some problems may occur with high demand, during reimbursement situations, when a feeder under maintenance is replaced temporarily with another feeder or when a primary substation is under maintenance. In general, also the transformer capacity is really high. In addition, during the recent years, VFV has built a number of "light" primary substations to the network, which has increased the transformer capacity and the network capacity in overall remarkably. In normal situation, none of the transformers are being used even near the upper limit of the capacity at the primary substations. It can be said, that when comparing the whole transformer capacity in the network with the highest demand, an average transformer load is under 50 % of total capacity.

In Sweden the situation is quite similar compared with Finland. The capacity of lines and cables of VFS is high enough to satisfy the future needs and increasing demand. Transformer capacity in general is good, nevertheless in some parts of the network, the transformers and lines need to be changed or have already been changed because of increased loading (demand) which is a part of normal development of the network. (Nilsson, 2011) Many of these cases are also related to power quality issues, rather than capacity issues. In general these situations are related to MV/LV transformers in an urban environment. (Lehtonen, 2011) It must also be remembered, that in VFS's operating area, there are twice as many customers compared with VFV. Sweden has remarkable amount of planned wind power production compared with Finland. It is clear, that these plans and their implementation places huge demands for the network and in order to handle the produced power, the network will face a need for reinforcements. This affects mostly the higher voltage level distribution.

However, there are some areas in the network, both in Finland and in Sweden, where the physical capacity will have to be increased in the future. This is mostly a consequence of increased demand in those areas and large scale plans for distributed generation, especially concerning wind power projects, which are planned to be connected to the network. It can be said, that in normal operating situation a congestion risk is at the moment relatively low, both in Finland and in Sweden.

"RES-DG hosting capacity" in Vattenfall's networks in Finland and in Sweden is at good level. When discussing about low voltage (small-scale) devices, in most parts of the network the impact of the devices is not seen as a threat from capacity perspective. Rather the increasing complexity of protection and other factors play a more significant role. When talking about larger-scale production units and plants at higher voltage levels, the impact is more significant. In these cases, the network often needs reinforcements according to the planned amount of generation capacity in a specific area. Many parts of the network are also strong enough to interconnect remarkable amount of generation, without doing any reinforcements. This is a consequence of strategic long-term planning of the network. (Nilsson, 2011) There is Figure 6.8 below about the results for Finland.

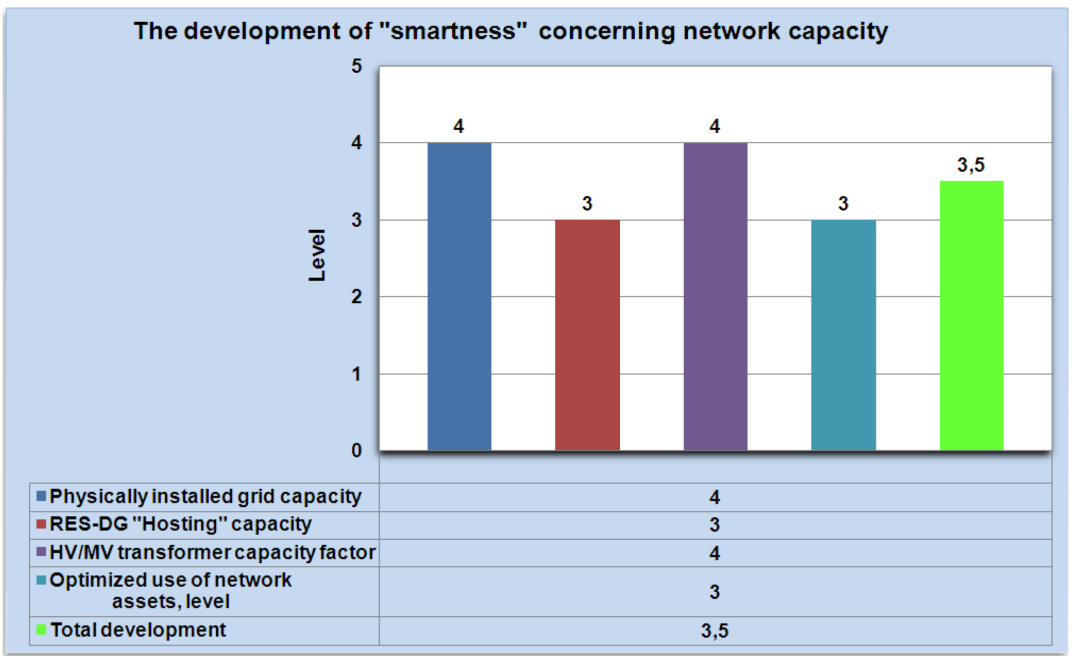
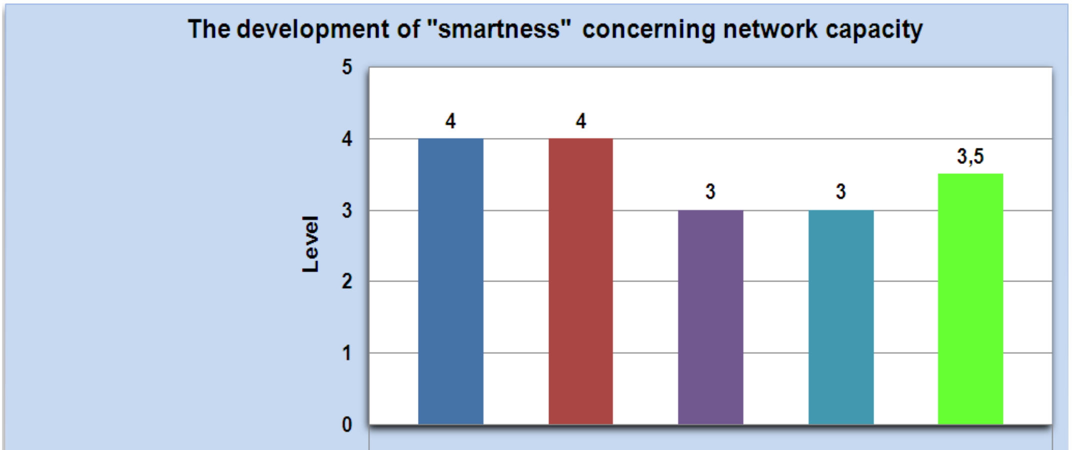


Figure 6.8, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In comparison with Finland, VFS has the same total development, but there can be found some differences concerning the results. For example the "hosting capacity" can be seen slightly higher in Sweden when considering the network structure including transformers and lines. On the other hand when considering just transformer capacity, the study shows that in Finland the average transformer load is relative lower. It must be also remembered that the sizes of the networks are entirely different. Below, there is a Figure 6.9 about the results for network capacity within Vattenfall Sweden.



Physically installed grid capacity	4
RES-DG "Hosting" capacity	4
HV/MV transformer capacity factor	3
Optimized use of network assets, level	3
Total development	3,5

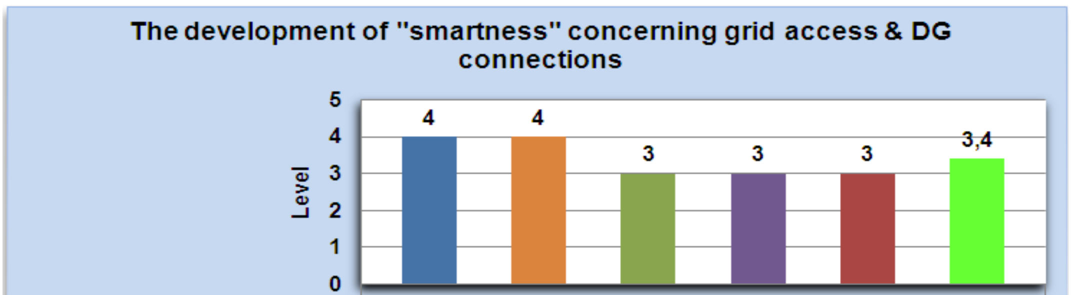
Figure 6.9, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.4 Grid access & DG connections

Access to network, especially concerning RES-DG resources, is at the moment one of the most important factors that need to be taken into account from DSO's perspective. Processes concerning grid access and interconnection of DG units to the network reflect quite straightly the current desires to be able to cut down carbon emissions and DSOs are in key position to make this possible.

In Finland, VFV has a uniform process to connect a new user to the network. As a consequence the time to connect a new user is relatively short. VFV has made a customer promise to connect a new user within a reasonable timeframe, as agreed, which has driven the company's internal process to a more effective direction. Therefore the performance can be seen advanced and delays in the agreed schedule are very rare. In Finland, the DSOs are obliged to threat customers and electricity suppliers uniformly and there is a provision at the electricity market act. It is notable, that the procedure in EU varies quite substantially. VFV follows a principle of non-discriminative operation. This means that same type of customers have same tariffs, regardless of geographical location at the network area. Also all suppliers are given the same information, with no discrimination. VFV also gives a report of the performed activities to ensure a non-discriminative operation regularly.

VFV's connection charges for new customers, as well as grid tariffs are at an acceptable level. There are uniform connection charges and fees for LV customers in three different residential zones and HV customers have connection charges for residential (zoned) and non-residential (non-zoned) areas. The tariffs can be calculated with different methods and customers can make the decision regarding to their own needs. Small scale DG units can be handled like normal connections, so that the connection procedure can be seen as standard connection point. Larger production units are dealt individually and VFV calculates the connection costs based on the needed equipment, connection cable/line and work. Then customer receives an offer within agreed time. The calculations are based on the unit prices given by the regulatory authority. It is clear, that a customer can supply the production to the VFV's network, if there is more energy produced than consumed in customer's connection point (prosumer). Nevertheless, even the operation is at good level, some new calculation methods could be adopted, both in tariff and connection charge calculation in the future in order to support the generalization of DG. There is a Figure 6.10 below that presents the results.



Time to connect a new user, performance	4
Uniformity of grid connections	4
DSO's connection charges	3
DSO's tariffs	3
DSO's DG connection policy, performance	3
Total development	3,4

Figure 6.10, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In Sweden, within VFS there are typically no problems with the connection times. The process concerning new connection points is advanced and effective. Also VFS has made a customer promise for new connections and if the process is delayed, the customer will be compensated. An average connection time is around 6 weeks onwards. There is also a provision of uniform treatment of network customers and electricity suppliers set by the legislation. The uniformity is followed and reported; customers are getting the same kind of service in every situation. (Nilsson, 2011)

The connection charges and network tariffs are at good level. VFS calculates connection charges and fees for customers over 63 amperes individually, respectively customers with main fuses under 63 amperes have uniform and fixed connection fees. There are also different tariff calculation methods for different customer needs and types. The tariffs are separated between two different residential areas, network area north and network area south. In Sweden the tariff selection is very comprehensive from customer's perspective. (Nilsson, 2011)

VFS handles micro-scale production (under 63 amps) as a normal connection point and a customer is compensated for the production towards the network according to service contract. There is a standard cost for connection fee, based on the size of the production unit. Small-scale units (fewer than 1500 kW) have also own tariffs also depending on the size of the unit. Both micro and small- scale production tariffs are divided into north and south areas in Sweden. Large-scale production units (over 1500 kW) are dealt with individually and the process is more complicated and therefore it also takes more time to connect the units to the network. In general, VFS has defined different types of connections related to DG very well and therefore the path to increase the amount of DG devices in the network is supported well. (Vattenfall-Internet) There is a Figure 6.11 below that presents the results.

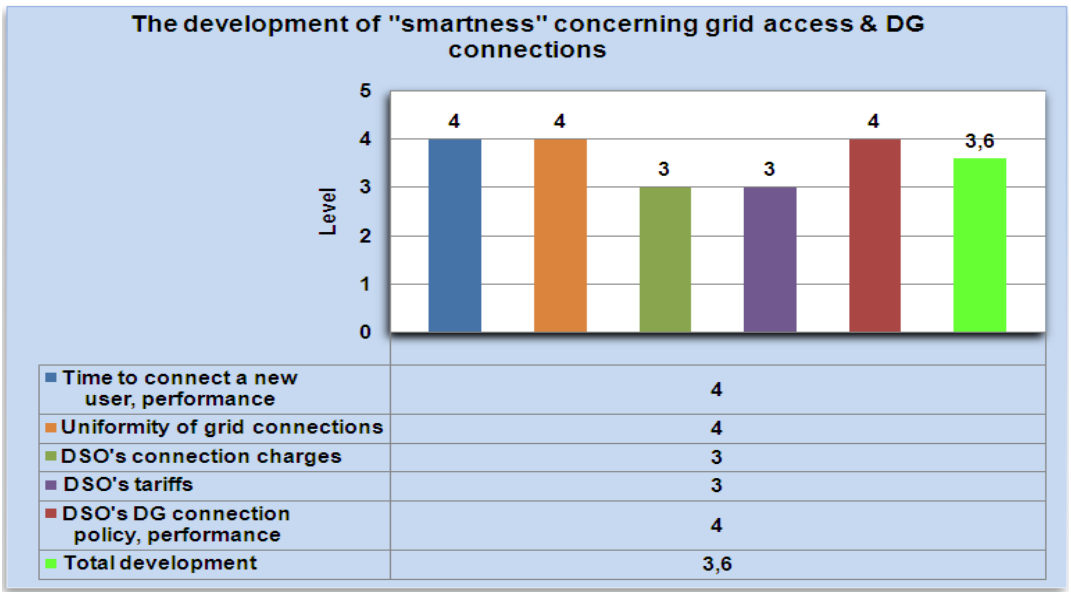


Figure 6.11, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.5 EV infrastructure

Electric vehicles are one of the most important enablers to increase sustainable development by reducing carbon emissions caused by transportation both in private and public sector. DSOs are in a key position, with manufacturers and national legislators, to enable the proliferation of EVs by developing a comprehensive charging infrastructure in their network areas. The network effects caused by EVs have been studied both in Finland and in Sweden and the research continues. The results show that there must be enough physical network capacity as well as intelligent charging methods in the future. Most of the research programs and studies, where Vattenfall is involved are currently being done in Sweden.

In Nordic countries, in this case Sweden and Finland there are huge amount of car parking places equipped with engine pre-heater poles already. As Vattenfall Sweden recognizes, the situation concerning EV charging has nearly the same impact towards the network as the pre-heating of car engines in wintertime. When considering the hosting capacity for DG in VFS's network (section 7.7.3, advanced level) which describes the network capacity, in addition to the existing engine pre-heater poles, the hosting capacity for / of EVs can be seen advanced in Sweden. Also the development concerning charging infrastructure can be seen as advanced, because there are studies being done in VFS in order to be able to retrofit the existing poles (pre-heating poles) to EV charging poles by new technology in near future. In Finland, the hosting capacity for DG is evaluated to be at good level (section 7.3.3), therefore when considering the existing infrastructure for engine pre-heating, the hosting capacity for / of EVs can be seen as good. In Finland, there is also a possibility to retrofit the existing poles in future and therefore the development of the EV charging infrastructure can be seen as good, even the research is not necessarily at sufficient level today.

When the amount of EVs becomes remarkable in the future, the existing network with the current infrastructure (designed originally for engine pre-heating) and new charging points will not be able to tolerate the effects caused by the charging load. In this case new, innovative and intelligent charging methods will have to be introduced. For example, one-phase charging, quick chargers or a combination of these are not desired charging methods from the network perspective. (Nilsson, 2011) Instead, the charging should be controlled and steered towards low-demand periods, night times for example as the total charging load becomes significant. Within Vattenfall, this could be achieved by demand based price signals in Finland and in Sweden, for example. The reason is that the existing AMR meters are capable to remote control of customer loads, both in Finland and in Sweden. Also customer-oriented charging could be steered by introducing real-time pricing signals. At the moment, the development however is not sufficient for large-scale introduction of these methods. (Nilsson, 2011) There are Figures 6.12 and 6.13 below, which present the results for Finland and Sweden.

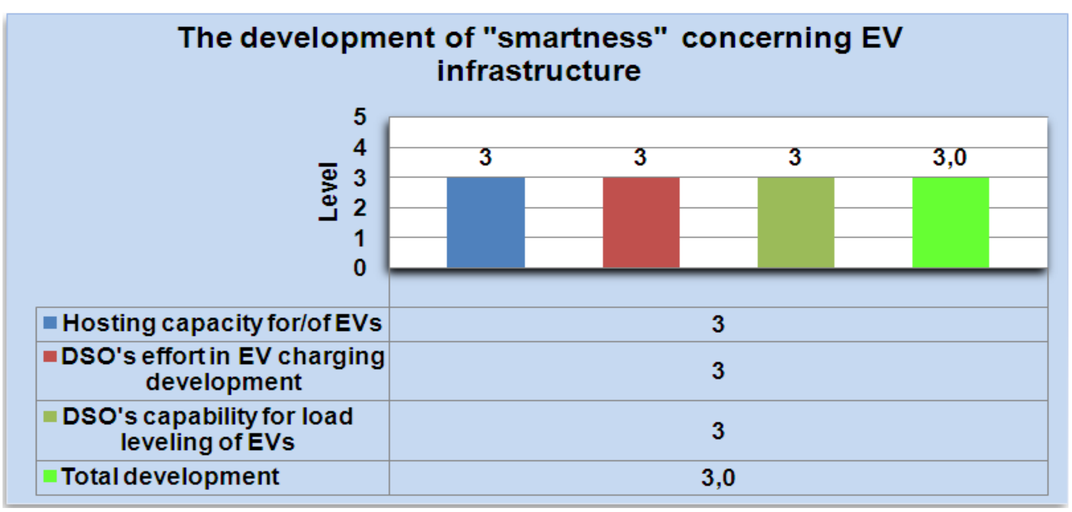


Figure 6.12, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In Finland, the development concerning EV charging infrastructure is lower than in Sweden. This can be seen from the results presented in this section because most of the research programs within Vattenfall are carried out in Sweden at the moment.

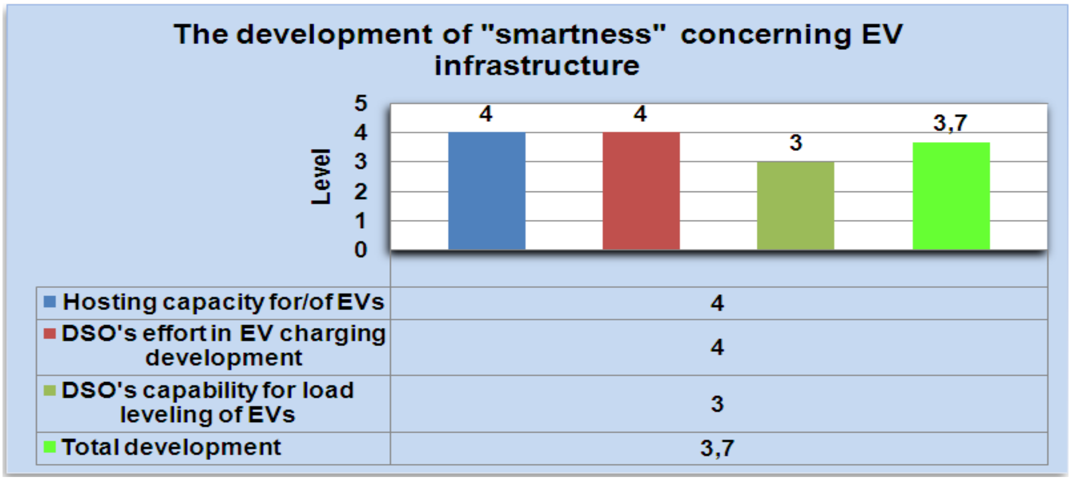


Figure 6.13, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.6 Funding & investments

In this case study, different kind of funding methods concerning network investments are reviewed in general. Issues related to funding and investments are quite complex and therefore this section creates an overview of the situation today. It is not appropriate to evaluate the KPIs related to funding and investments on the scale from one to five (1-5) like the study is performed with the other categories in this work. Instead, there are tailored measurement options (three different options) for each KPI in this category. The KPIs are tailored in a way, that they describe the DSO's policy related to funding and investments.

In Finland and Sweden, the level of selective grid development is quite low; the reason is legislation in both of the countries that requires a non-discriminative tariff structure. In practice this means that similar type of network customers should have similar tariffs structures. It is therefore not possible to develop the network selectively in a way, that certain tariffs relate directly to a specific purpose to develop a specific part of the network. The selectiveness of grid development can nevertheless be seen in a different way, because as a consequence of strategic planning the network is being developed focusing on the most important parts of the network and the process is continuous. Based on systematical analyzes and plans carried out by considering short and long term perspectives, the most critical parts of the network can be identified and eventually handled.

The amount of revenue invested in enhanced efficiency on annual base, is naturally in line with legislative requirements both in Finland and in Sweden. Nevertheless, the requirements are different in these countries. In Finland the requirement consist of general requirement 2,06 % and individual requirement based on average DEA and SFA. In Sweden, there is a general requirement of 1 % /year, from 2010 for costs possible to influence. In Finland, the level of research and development programs within VFV are at relatively high level, there has been and there is many pilot projects going on and new innovative solutions has been developed. The funding of R&D projects comes mainly from network tariffs and the level of external funding options is low. Nevertheless, some of the projects are partly funded by external actors. The new regulation model in Finland, with innovation incentive will support and increase the level further. Nevertheless, standards and new incentives for smart solutions are needed to ensure holistic development on the field of distribution business.

The new economic regulation model in Sweden, from the beginning of 2012, defines a fairly high total revenue frame, which is seen as best part of the new regulation model. (Watne, 2011) Also AMR base price is increased, but wish is to have more incentives for Smart Grid investments in future. At the moment, VFS can cover a part of Smart Grid investments also by external funding but the level is quite low. R&D programs are covered totally as costs and it can be said that the level of R&D activity is relatively low, nevertheless when compared with other DSOs the level is somewhere between (medium level). Total profit in relation to regulated allowed return is at reasonable level, definitely not the maximum. (Johansson, 2011)

Neither of the companies VFV or VFS, is not currently taking the maximum profit allowed by the economic regulation. It can be said that the profit taken is currently at reasonable level. On the other hand this means that the network tariffs, within both of the companies are reasonable. Some pressure for price increases will become also in future because there are major investments becoming as a consequence of the aging network and need for smart solutions in the network. Investments should be made to motivate price increases. There is a Table 6.1 below that presents the results.

Table 6.1, *Funding and investments, evaluation of Vattenfall Finland and Sweden.*

KPI	Options	Finland	Sweden
Selective grid development and innovation funding (tariff structure). Level of selectivity concerning network development and funding.	High Selectivity (3) Partly Selective (2) No Selectivity (1)	2	2
Amount of DSO's total revenue invested for developing network efficiency. Performance level in comparison with regulative / legislative requirements.	High performance (3) In line with legislation (2) Low performance (1)	2	2
Investment incentives coupled with obligations and rewards / penalties in regulation. Is the current level of incentives appropriate from DSO's smart grid development perspective.	High level (3) Appropriate level (2) Low level (1)	1	1
Amount of smart grid research and investments financed by external funding. Level of external funding options.	High external funding (3) Partly external funding (2) low external funding (1)	2	2
R&D programs and funding. Performance level of DSO's R&D and demonstration project activity.	High R&D activity level (3) Medium R&D activity level (2) Low R&D activity level (1)	3	2
Total amount of revenue invested in network development. Performance level of revenue / network development.	High level (3) Reasonable level (2) Low level (1)	3	2

6.3.7 Distribution reliability

In this case study, reliability indicators SAIDI and MAIFI are taken into account by using “supply criterion” in different residential areas. (SER; 2010) The method has been developed in Finland by the industry itself in order to increase distribution reliability by taking into account customer needs as well as needs of the society and different residential areas. In Finland, VFV increases and has increased distribution reliability by building new primary substations, which shortens the average cable length. Also urban and rural area distribution becomes differentiated from each other, so that urban areas are not affected by faults in rural areas and the amount of voltage dips decreases as feeders divide into multiple substations. The distribution reliability has also been increased by investing on substation and network automation and by carrying out enhanced maintenance and animal protection. Today, also many maintenance related works are planned to be performed without causing an interruption to electricity delivery whenever it is possible. The share of these “voltage works” is increasing all the time as new techniques are being developed. At the same time, VFV has developed a construction method for weatherproof networks. This means that all pole mounted distribution transformers, which are sensitive to weather conditions, are replaced with kiosk -type transformers in future. All low-voltage wires from secondary substations to properties are built with underground cables and also medium-voltage network is built with cabling, even in rural areas. The strategy is concerning construction works related to renovation and building of new network. Below there is a Table 6.2 that shows the impact of investments and operational activities on reliability and operational costs.

Table 6.2, *Customer level impacts of investments on reliability and OPEX, where an arrow up means increase and arrow down means decrease. (Honkapuro, 2008)*

	Customer level impacts			
	Long interruptions			
	Number	Duration	Short interruptions	OPEX
Network topology				
New primary substations	↘↘	↘	↘	↘
New MV lines (to short line length / breaker)	↘	↘	↘	↗
Back-up lines	↘	↘↘	-	↗
Network components				
Replacing overhead lines with underground or coated cables	↘↘	-	↘↘	↘↘
Surge arresters	-	-	↘↘	-
Earth fault current compensation	↘	-	↘↘	-
Network automation				
Remote-controlled disconnectors	-	↘↘	-	↘
Fault location system	-	↘↘	-	↘
Operation and maintenance				
Forestry work	↘	-	↘↘	↗
Network building and maintenance under operation (voltage works)	↘↘	↘↘	-	↗

At the moment, the level of cabling in VFV’s medium voltage network (20kV) is around 8 % and in low voltage network around 31 %. A long term target for reliability indicator SAIDI is under 100 min/a. Powerful storms in year 2010 as well as snowy winters have distorted the statistics quite strongly. At the moment within VFV’s network in Finland SAIDI can be evaluated to be 150 min/a when excluding recent extraordinary natural phenomenon. According to supply criterion, the current development level can be estimated to be quite good when the effects of resent natural phenomenon are limited of from the review and the different residential areas are taken into account. Statistics show that during year 2011, about 86 % of the total network meet well the requirements according to “supply criterion”. On the other hand, year 2010 was much more challenging because of the great storms and just 40 % of the network could reach the requirements. VFV also uses high impedance grounded (compensated) networks in MV level distribution grid. Today, many parts of the networks have been changed to use compensated grounding and the objective is to achieve fully compensated MV network in the future. At the moment, the share of compensated MV network is approximately 70 %. The share of compensated overhead lines is currently 67 % and the share of compensated cables is 68 %. There is a Figure 6.14 below that presents the results.

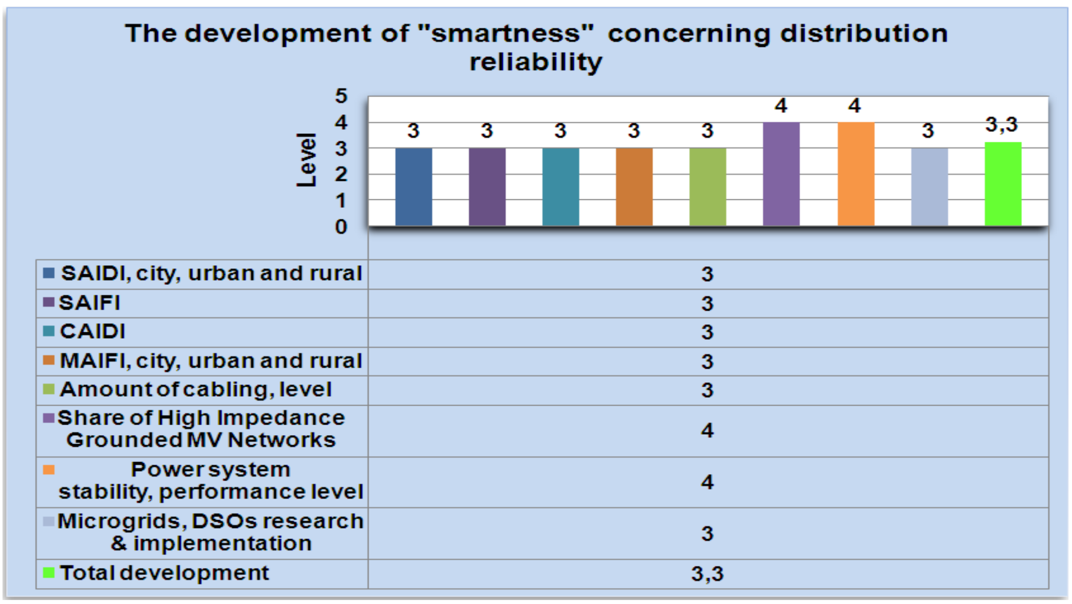


Figure 6.14, *Results for Vattenfall’s distribution business in Finland based on the author’s analysis and knowledge.*

In Sweden, VFS has invested a lot to large scale cabling. In year 2003 VFS started a program as an objective to isolate and change to underground cables 60 % of the company’s MV networks in heavily forested terrains. There is a plan to introduce a new target for the program in year 2015. (Fritz, 2011) Over the past few years, totally over 11 000 kilometers of cable has been installed by Vattenfall AB in Sweden.

VFS has increased the level of cabling in the network and currently there are plans concerning network automation in order to improve the reliability of the network. At the moment, VFS has a target: SAIDI 165 min/a for year 2011. A long term target for reliability indicator SAIDI is under 100 min/a, which is the same target as VFV has. The long term target will be achieved by continuing the program with cabling which has already advanced quite remarkably and by introducing new network automation, remotely controlled disconnectors and reclosers, for example. (Fritz, 2011) VFS has quite different network structure, especially concerning MV networks, when compared with the network of VFV in Finland. One great difference is that there are much more different voltage levels in the MV network. In Sweden, all the lines from 70 kV to lower voltages are high impedance grounded networks. (Eng, 2011) There is a Figure 6.15 below that presents the results.

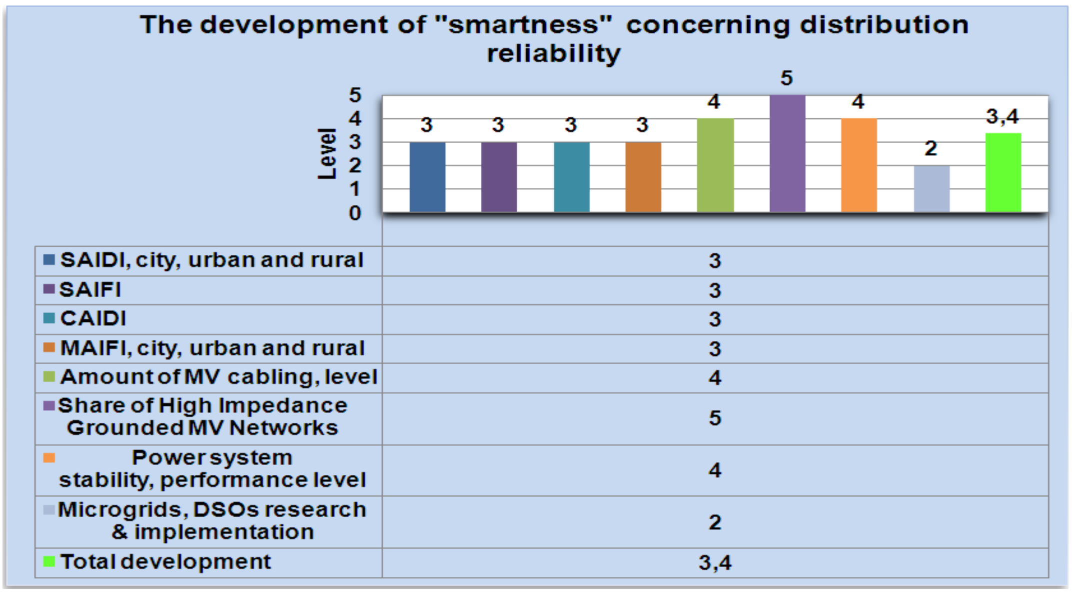


Figure 6.15, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.8 Power quality

In Finland, within VFV it is not possible to make a contract for a certain power (voltage) quality at the moment. Naturally, legislation (standard EN-50160) determines the minimum requirements for voltage quality performance. In case a customer has very sensitive loads and equipment (for example in a hospital etc.), it is possible to discuss and make a contract concerning improved voltage quality. This means that the contracts can be made only case by case, because there is no selection of different voltage qualities offered at the service agreement.

Within VFV's network, Iskraemeco MT372 meters measure U_{rms} values in every three phases. Voltage dips are represented as percentages of U_{rms} nominal value. The daily peak and minimum values of phase voltages are also measured and recorded. Voltage asymmetry is monitored by comparing measured voltages and the average voltages of all three phases. If the difference gets too high (limit value crosses), the meter sends an alarm signal. It is important to define two threshold levels to the meter correctly. It means when the voltage on one-phase rises, the upper threshold level must be set up high enough so that it is only exceeded in zero faults and an alarm is sent. If the upper and lower threshold limit is exceeded at the same time, the system sends an alarm about asymmetrical voltage situation. These monitoring features are significant from power quality perspective.

The voltage quality performance of the VFV's distribution network is advanced. VFV has increased the amount of primary substations and the share of high impedance grounded networks. This has decreased the amount of voltage dips and flickering remarkably. As a consequence, voltage quality complaints are therefore relatively rare and customers are mainly satisfied to the quality they receive. Nevertheless, if a customer complaint is made related to quality issues, there is a systematic method how the quality is being improved within a reasonable period of time, effectively. VFV realizes also proactive voltage quality improvements by utilizing the continuous power quality measurements at the customer connection points. Based on the measurements, critical parts of the network from voltage quality perspective can be identified. This creates an opportunity for VFV to accomplish power quality improvements, even before a network customer recognizes voltage deviations and makes a complaint. This type of activity is very important from customer service as well as service quality point of view. There is a Figure 6.16 below that presents the results.

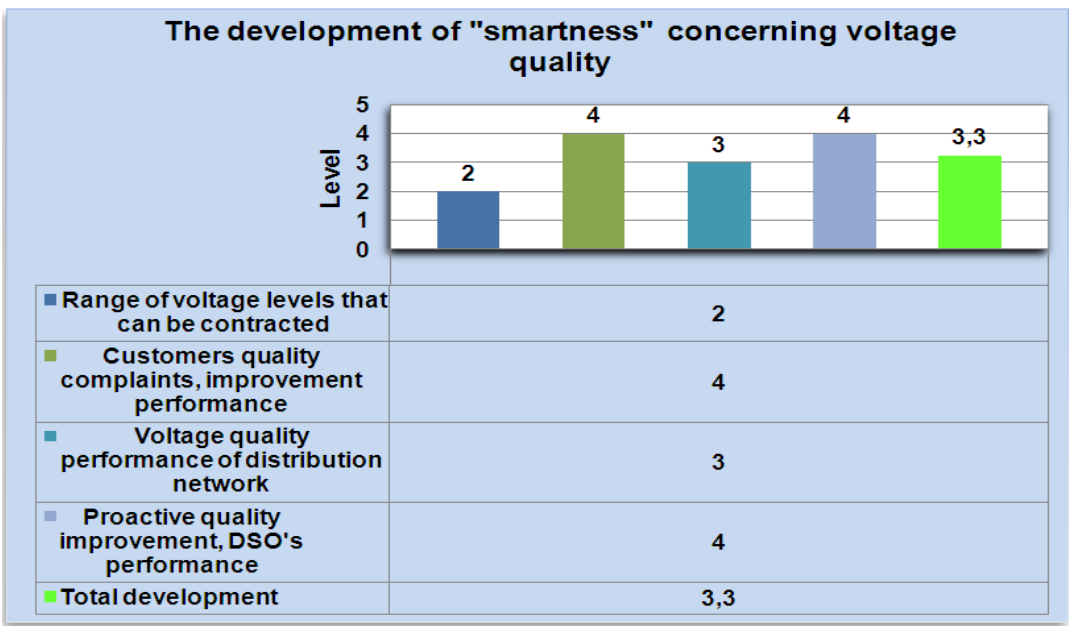


Figure 6.16, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In Sweden, within VFS the situation concerning different voltage quality contracts is similar to that in Finland. There is no ready selection of different voltages, but in individual cases a contract can be made for better voltage quality that the standard EN-50160 requires based on customer's needs (very sensitive loads). In these cases, the contract is made by having direct contact and negotiations with the customer about the different requirements for voltage quality. These individual contracts are mainly done with bigger customers at HV level. (Eng, 2011)

Within VFS, there are three types of AMR meters installed. Only the latest, third generation is able to monitor voltage deviations in three phases like over/under voltages, voltage asymmetry, zero faults, daily peak and minimum voltages etc. 70 % of meters installed are capable to do this, so the quality monitoring is not fully comprehensive in LV network at the moment. (Garpetun, 2011) The power quality performance is in general advanced both in high and low voltage levels. In some network areas, especially in the northern Sweden, there still are some problems with the power quality because of long distances and sparsely populated area in combination with relatively old network structure. (Lehtonen, 2011)

Customer complaints related to quality issues are relatively rare also in Sweden. All the lines from 70kV down are high impedance grounded. At the low voltage level, where the complaints are more common, there is a standard process to handle the quality improvements. Customer service takes the complaint and sends the information to power quality department where analyzes are carried out and the decision concerning the follow-up procedure is chosen. This makes the process effective and comprehensive. At high voltage level the complaints are rare, approximately 15 to 20 pieces per year. Therefore there is no standard process; instead there is a straight customer contact and discussion about the voltage quality. Within VFS, the level of proactive quality improvements is currently quite low. There are some cases where improvements are carried out based on the AMR quality monitoring, but mainly the quality improvements are carried out based on customer complaints. (Eng, 2011; Lehtonen, 2011) There is a Figure 6.17 below that presents the results.

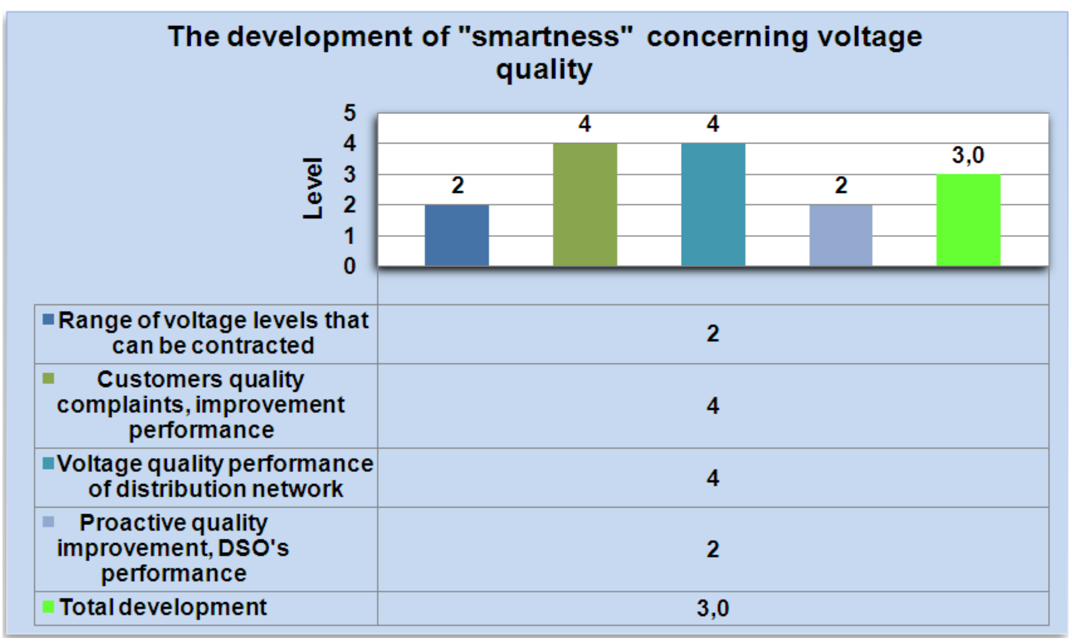


Figure 6.17, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.9 Consumer awareness & customer participation

Vattenfall Verkko Oy distinguishes many different tariffs like general, night-time and seasonal electricity, which are fuse based tariffs for customers to choose from. There are also totally four different demand based tariffs to be chosen. Also the demand based tariffs are divided into general (fixed price) and seasonally variable price tariffs. Two of the demand based tariffs are for customers which are connected to MV (20kV) distribution network. In addition there are also tariffs for temporary connections. These seasonal electricity tariffs mentioned before, can be seen as ToU (time-of-use) tariffs, because there are different tariffs for day and night time as well as for specific months during a year. The share of network customers using seasonal and night time tariff structures is at the moment approximately 20% of all network customers. Real time pricing tariffs are being used among large network customers and in the future this kind of tariff can also be offered to smaller customers, alternatively also the ToU method can be developed into a more specific direction on hourly basis, for example.

Within VFV, the supplier change process has been made as simple as possible; even it is quite complicated due to many stakeholders involved. Nevertheless, from customer's perspective it is quite simple. The performance of the process is advanced and VFV offers customers a promise that the change will be accomplished without delay; otherwise the network operator is obligated to compensate the customer as agreed.

Consumer awareness is also maintained by informing customers about new services and possible interruptions concerning the delivery of electricity, both planned interruptions and interruptions caused by faults. Within VFV the customer is informed, in case of a planned interruption by a letter. The information can also be seen at web-based applications and possibly via SMS message (if the service is activated by customer). VFV has introduced a set of customer promises in order to increase customer satisfaction. See *appendix 16* for more information about Vattenfall's customer (service) promises in Finland and in Sweden, which are in general quite advanced in both countries when compared with legislative or regulatory requirements. These customer promises introduced also serve as company's internal drivers for the processes to be constantly developed and eventually increase the overall customer satisfaction as Table 6.3 below shows.

Table 6.3, *Satisfaction of network users with the network service they receive within Vattenfall distribution in different countries (scale 0-100). (Vattenfall CSR, 2010)*

Customer satisfaction (PR5)

Customer Satisfaction Index (CSI)	B2C		B2B			
			SME		Large	
	2010	2009	2010	2009	2010	2009
Distribution						
Sweden	67	68	61	63	65	66
Finland	69	67	62	63	65	67
Germany	72	72	65	66	71	68
Poland	76	76	65	64	66	67

Customer satisfaction, measured by PR5 indicator towards Vattenfall's distribution business and service has increased during long-term monitoring which was set as a target for the companies earlier, especially in Finland and Sweden. The challenging weather conditions and events during the last couple of years have influenced the rising trend and the improvement regressed between 2009 -2010 as the Table 6.3 shows. The level is currently good, but the aim is to increase the satisfaction index in the future by improving the quality of service further and by introducing new promises and services for customers. There is a Figure 6.18 below that presents the results for VFV.

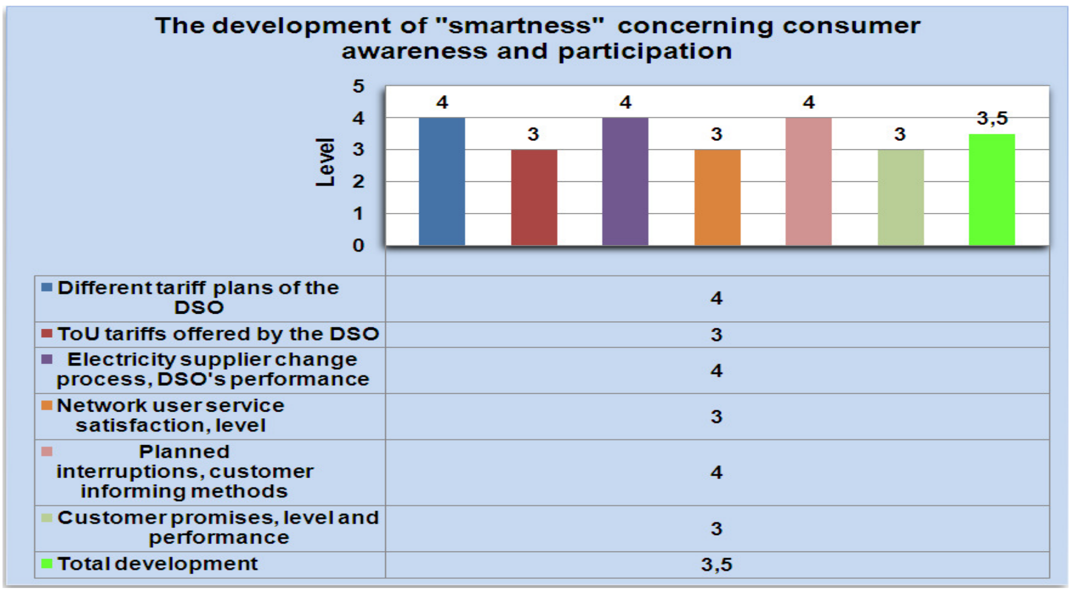


Figure 6.18, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

VFS has divided the local network into two different tariff areas, north and south. At the north area the network tariffs are slightly higher compared with the southern area. This can be explained by lower population density and long distribution distances. There are fuse based tariffs, which can be used with a fixed price or a season based tariff structure. The season based option takes into account the average demand during year and there is pre-defined time periods for high demand and low demand. During the high demand period the tariff is higher and during low demand it is lower. There are also four different demand based tariffs, two for HV connections and two for LV connections. In addition there is a special tariff structure designed for interruptible electric boilers, both in HV and LV levels. There are also predefined tariffs for temporary connections. For the higher voltage level connections there are separated tariffs in VFS's network (regional networks in Sweden). The tariffs have been separated in three different network areas at regional network. The connections can be made from 10kV to 130kV and each of them corresponds to separate tariff. (Nilsson, 2011) The development concerning tariffs in Sweden focuses at the moment on demand based tariff structures. (Watne, 2011)

The season based tariffs in Sweden can be seen partially as ToU tariffs, but completely comprehensive ToU tariff does not exist. A pilot project concerning complete ToU structure has been completed for 90 000 customers in VFS, which is about 10% of all network customers. Larger customers in Sweden are using real-time pricing tariffs quite generally. (Watne, 2011) Customers in Sweden are free to choose the electricity supplier and VFS makes the supplier change process as easy as possible from customer perspective. There is also a customer promise that the process will be completed with no delays, otherwise customer will be automatically compensated. The process has been developed and it is nowadays effective and advanced. Also in Sweden the network customers are informed about planned interruptions by a letter week before the actual outage. The planned outages can be seen also on the internet from web-based applications. Information about outages caused by faults will also be given to customers via web, SMS, email and by IVR. (Solmar, 2011)

VFS has introduced a set of customer promises, like in Finland. The promises are comprehensive and possible compensation is given to customers automatically. See *appendix 16* for information about Vattenfall's customer (service) promises in Finland and in Sweden. Customer satisfaction is being measured annually and the development has been good so far as the customer satisfaction has reached good level, see Table 6.3 above. The aim is also to increase the satisfaction further in the future by implementing new services and by introducing new customer promises. (Solmar, 2011) There is a Figure 6.19 below that presents the results for VFS.

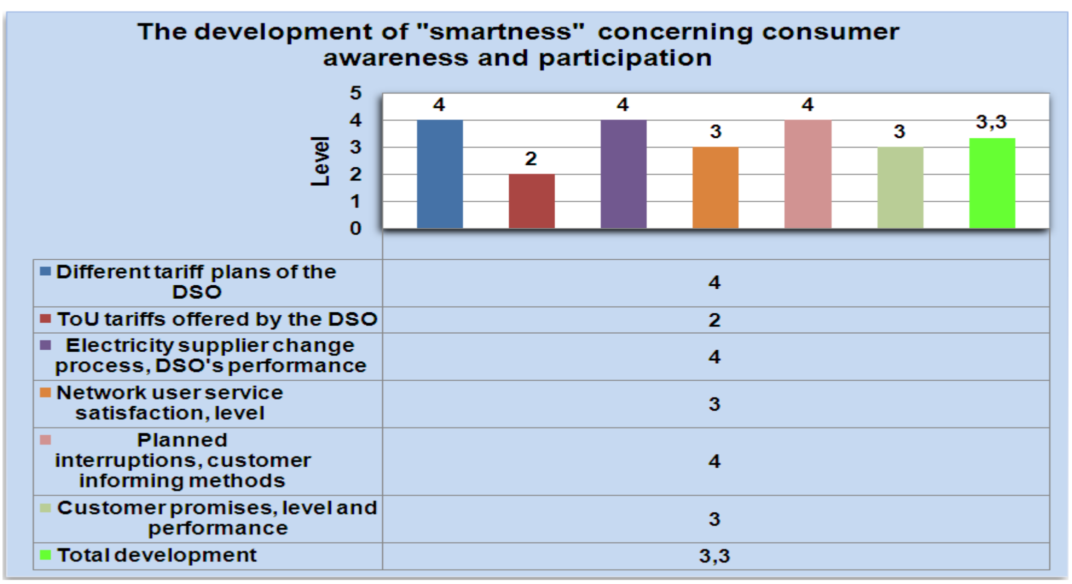


Figure 6.19, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

6.3.10 Efficiency

Electrical losses resulting from the electricity distribution within VFV in Finland, are currently at very low level and therefore the efficiency performance is advanced. Nevertheless, the share of these technical losses could still be reduced from the current level by using the network in more advanced way, for example. The share of electrical losses within VFV is at remarkably low level in comparison with the average level of losses in the EU, concerning electricity distribution. It is notable, that in Finland the share of losses is also in general at really low level.

Energy efficiency can also be increased by introducing small-scale DG in the network. DSO's role is remarkable as enabler for the implementation. VFV has good knowledge and possibilities to help customers to introduce DG production by adding the needed technical equipment to the network. The installed AMRs are capable to measure power flow in two directions including reactive power. Therefore a small-scale DG unit can be treated as normal load in the network.

VFV offers energy efficiency services to the network customers. The most important service is customer's opportunity to monitor previous day consumption on hourly basis from a web-based application. The service improves customer's opportunities to identify the most critical consumption of devices used in the household. It has been studied that this type of service gives incentives for customers to improve energy efficiency and reduce consumption. Also the different tariff structures introduced earlier can be seen partly as efficiency services in case the steering influence can be detected. At the moment, there is also a pilot project in progress involving VFV and external service provider. The project aims to study the use of a so called "service relay" at customer's household. In future, this kind of "service relay" can be highly significant from energy efficiency perspective and it is important that the AMR meters installed at customer points are capable to communicate with external relay technology as well. (Kauppinen, 2011) It is notable, that the roles of different stakeholders are still quite unclear concerning efficiency services and therefore extensive cooperation is important. There is a Figure 6.20 below that presents the results.

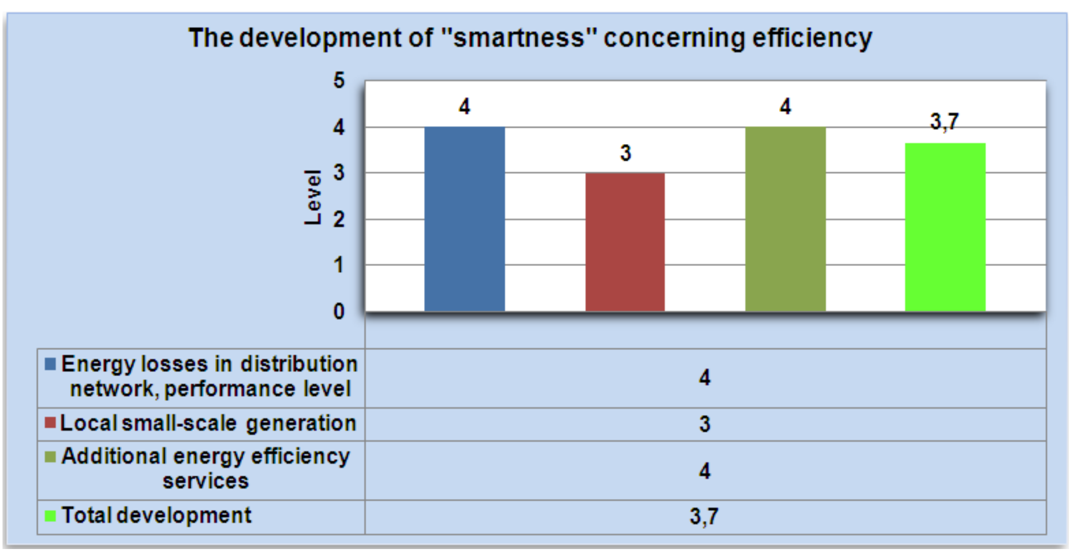


Figure 6.20, *Results for Vattenfall's distribution business in Finland based on the author's analysis and knowledge.*

In Sweden, the share of losses within VFS is a little bit higher compared with the share in Finland. Most significant reduction of losses could be achieved by introducing advanced network control methods, especially concerning MV distribution. In Sweden there are also many different voltage levels in use within VFS. As a consequence, the voltage level needs to be changed through many transformers in the distribution network and because of that the share of especially iron losses increase remarkably. Also long distribution distances (long feeders) increase the level of copper losses. The performance concerning level of losses is nevertheless good, but there is quite a lot room for improvements. (Fritz, 2011)

DG connection policy in Sweden is advanced. VFS connects DG units to the network and can treat small-scale DG like normal loads (< 63 A devices). AMRs are capable to measure consumption as well as production and VFS also compensates electricity produced towards the grid according to tariffs in service contract and in addition also the reduction of losses is compensated to the customer. VFS offers the know-how of what needs to be done in order to accomplish the new connections of DG units (especially larger units). Micro-scale production, small-scale production and larger units are divided into separate processes making the treatment effective for all types of customers, pure producers as well as "prosumers". (Nilsson, 2011)

Within VFS, the amount of additional energy efficiency services for customers is quite low. At the moment, the customers can monitor their consumption on monthly basis. One objective is to develop the system into a direction, that the consumption could be monitored on hourly or daily basis in the future. (Nilsson, 2011) The roles of different stakeholders concerning efficiency services are unclear at the moment in Sweden. Larger customers have hourly pricing within VFS and in the future also smaller customers can have ToU pricing and real-time pricing possibility which can lead to enhanced energy efficiency. There is a Figure 6.21 below that presents the results.

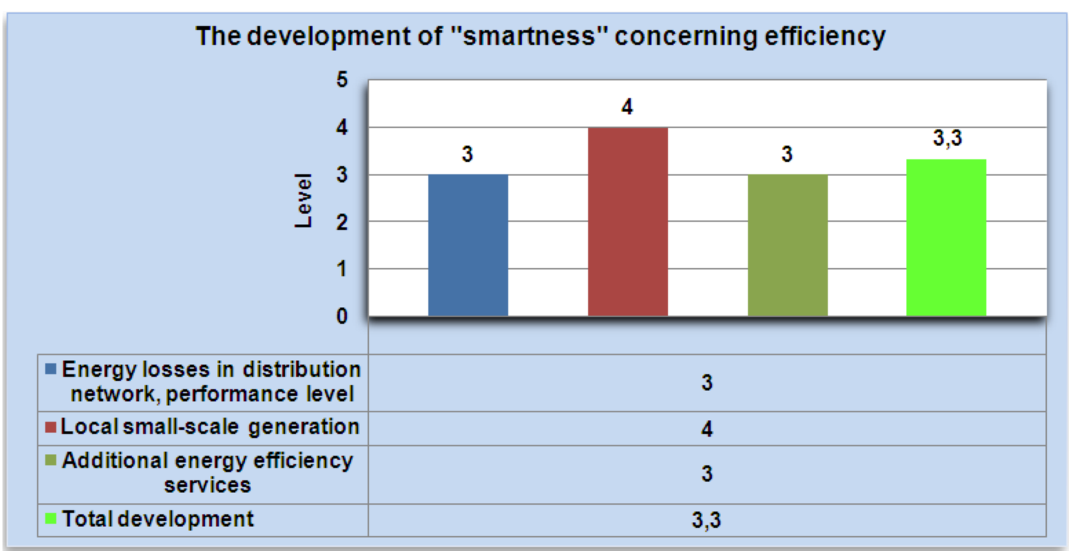


Figure 6.21, *Results for Vattenfall's distribution business in Sweden based on the author's analysis and knowledge.*

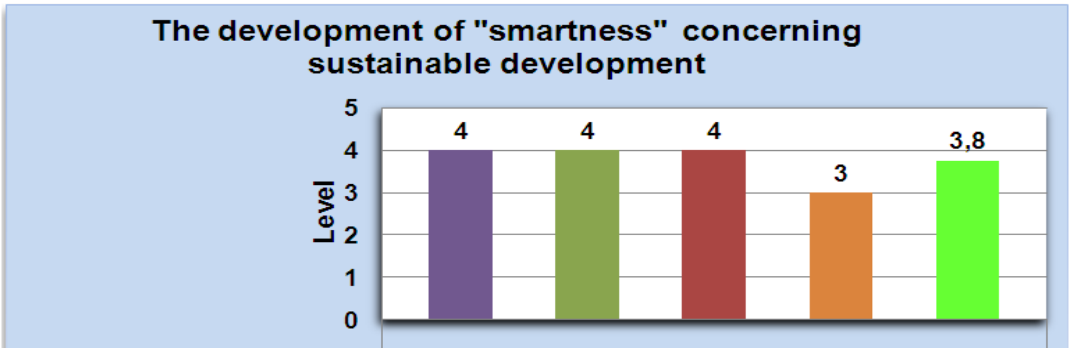
6.3.11 Sustainable development

Vattenfall has committed to produce energy to the society in a sustainable and responsible way. The energy solutions, to which Vattenfall is investing, are supporting sustainable development from the perspective of the society. Vattenfall aims to use modern, economic and environmentally effective solutions and technologies in energy generation and distribution of electricity. Most of Vattenfall's operations are regulated by world-wide, European Union's and national legislative issues and rules. Vattenfall also invests in R&D in order to increase energy efficiency in operations and to increase competitiveness with renewable and low carbon energy sources. Structured and systematic approach from the perspective of environment and sustainability requires defining goals and requirements and also monitoring the performance, which is the current practice in Vattenfall. These issues mentioned above are also taken into account when making contracts with suppliers, subcontractors and other business partners. Vattenfall also encourages network customers to use energy efficiently in order to decrease the environmental impact. (Vattenfall, internet)

Transmission and distribution networks are ensuring that electricity is available always and everywhere. Vattenfall has also invested a lot in distribution loss reduction. Old overhead lines are replaced with underground cables, also new technology is introduced to enhance network monitoring and locating of problems, for example. See *appendix 17* for information about how a range of external and internal stakeholders rated the importance of Vattenfall's sustainable and responsible behavior divided into different aspects concerning the operation. (Vattenfall, 2009)

Both in Finland and in Sweden, environmental issues are taken into account within Vattenfall when planning, maintaining and building of new network. A thorough environmental report is always done in accordance with the legislation. Environmental impact of the network infrastructure is evaluated and planning of the new networks and replacement investments are carried out in a way which decreases the impact. The networks are mostly nowadays placed roadside or as underground cables (taking into account landscaping), which decreases the impact towards forests as well as the impact on the landscape (visual impact). At the same time the reliability of distribution increases.

When dealing with carbon emissions, it is clear that distribution of electricity can affect the emissions mostly indirectly. Vattenfall exploits video conferencing technology, both in Finland and in Sweden, in order to avoid unnecessary travelling and some decrease in the amount of network losses has achieved. Especially in Finland the share of losses is low. Information about carbon free energy sources and new energy efficiency services (own consumption monitoring, for example) is offered to the customer that helps to decrease the emissions by using low-carbon generation technology and by reducing consumption. Safety is one of Vattenfall's core values and by constant education of employees, contractors and other parties has lead to a safe working environment. The amount of accident and risks related to network operation has decreased remarkably because of the good level of knowledge based on continuous education and information sharing. Vattenfall has also concentrated its activities in both countries, in Finland there is one office where most of the operations are carried out. Also in Sweden the operation is concentrated as new offices have been introduced. Nevertheless, there is some potential to increase the performance concerning the KPIs in this category in the future. Because of the provisions and objectives concerning the whole organization, in this case especially Vattenfall Distribution Nordic, the results for Vattenfall's distribution business in Finland and in Sweden are similar from sustainability perspective. (Vattenfall, 2009) The results are presented at the Figure 6.22 below, for both Finland and Sweden.



Quantified reduction of carbon emissions	4
Environmental impact of distribution network	4
Accidents and risks in day-to-day grid operation	4
Information sharing (new services, carbon free production)	3
Total development	3,8

***Figure 6.22,** Results for Vattenfall's distribution businesses in Finland and in Sweden based on the author's analysis and knowledge.*

6.4 Summary

This chapter comprises a case study of Vattenfall's distribution networks as an objective to evaluate the level of Smart Grid development. See *appendix 14* for more information about the results of the evaluations. *Appendix 14* comprises combined results for the different categories evaluated during the case studies in order to easily compare the development levels of the different aspects with each other.

As the case study shows, the current development level within Vattenfall's distribution networks in Finland and in Sweden is at relatively good level. This is a consequence of long-term strategy of the company. Nevertheless, by introducing new incentives in the regulation models the development could be accelerated. In addition, it has to be also noted that the analysis and results presented in this chapter are based on author's own opinions and understanding and therefore cannot be used in any other context without further explanation.

The most significant indicators that could be used in the evaluation and can be potentially determined can be found based on the analysis. Below there are the KPIs, which seem to be the most suitable to be used at the moment:

- *Total demand served by advanced meters (AMR-meters) which are capable to monitor and communicate remotely. Share of all network users.*
- *Communication methods supporting different network operations, performance.*
- *Average HV/MV transformer capacity factor and adequacy of the capacity. Performance level of transformer capacity.*
- *Time to connect a new user within a reasonable timeframe. Performance level to realize new connections to the network.*
- *SAIDI, overall performance in city, urban and rural areas. Measured by taking into account supply criterion in different residential areas.*
- *Interruption costs. Costs reflecting the inconvenience experienced by network customers as a consequence of distribution disturbances.*
- *Electricity supplier change process. DSO as enabler for the process. Duration of the process etc. Performance level.*
- *Electrical losses in distribution network (technical losses), share of total energy distributed. DSO's performance to reach high energy efficiency.*
- *Quantified reduction of accidents and risks associated with grid operation, maintenance and construction.*

7 SMART REGULATION AND INCENTIVES FOR SMART GRIDS

This chapter discusses the possible development of economic regulation in the future, especially how the incentive regulation models can be adjusted in order to enable accelerated development of Smart Grids through implementing incentives for Smart Grid investments. The basic theory of economic regulation is introduced in Chapter 2 and therefore this chapter focuses on analyzing the potential incentives based on the results of the case studies and other discussion performed through the work.

The role of regulation and the methods being used are analyzed and possible suggestions of what would need to be changed as a consequence of the changing environment. It is vital to adapt to the situation and enable future development by overcoming the most crucial challenges. The most important incentives are identified and the methods how they could be implemented are discussed briefly.

7.1 Smart regulation

The changing environment, different roles and responsibilities in energy sector and challenging climate- and energy objectives set by European Union are the main aspects of developing the whole business environment. Smart solutions and Smart Grids are one of the key implements on the way towards a new evolution of the business. In order to execute and accelerate the development and use of these vital utilities, there is a need for applicable regulation on the sector of distribution and transmission networks. The regulation in Europe has to become uniform and such that it contributes the development and deployment of Smart Grid solutions in order to achieve the desired objectives within a reasonable timeframe. European DSOs are in a key position in the development of the electricity networks, but there is a need for enabling smart regulation as well. (EG3, 2011)

As a baseline for appropriate regulation there is a stable framework in a long term. Reasonable rate of return for efficient network investments, especially cost effective smart solutions should be encouraged from regulatory perspective. There should be a consideration and a deeper analyze of the decoupling between DSOs profits and the amount of electricity that the companies are delivering, taking into account the specific KPIs in the performance–based incentive regulation model. Incentives for DSOs to improve efficiency of the network and to create a better market integration and security of supply should be considered. From society point of view, it is crucial to find ways to incentivize network companies to pursue innovative solutions, which are beneficial to all stakeholders. (EG3, 2011)

By implementing regulation of outputs, by incentives or minimum requirements, there becomes a mechanism to ensure the value of the money paid by network users as well as to investigate some metrics for the quantification of the most essential output effects. It is important to assist the mechanisms and solutions that favor consumer awareness and participation in order to open up new market opportunities through actions of the market participants. One way is to improve the commitment between grid operators and network users. By evaluating the costs and possible benefits of demonstration projects for each stakeholder involved and by giving advices to decision makers based on societal cost benefit assessment, the development of Smart Grids can be accelerated. (EG3, 2011)

The participation of the European electricity regulators in Smart Grid discussion and cooperation activities with all the stakeholders is a fundamental issue. Especially an active cooperation with standardization organizations, device manufacturers and DSOs in European and national level is important. This is essential for example in order to achieve interoperability of Smart Grid devices and systems, to clarify protocols and standards for information management and data exchange. Continuous exchange of expertise and dissemination of results from demonstration projects at European level is important, for example the pilot projects in Sweden and in Finland, which have already been introduced earlier in this study in order to acquire the best regulatory practices as soon as possible. (EG3, 2011)

7.1.1 Performance benchmarking in economic regulation

In order to fulfill the objectives concerning the efficiency improvements, increasing demand for quality of supply as well as security and service quality, regulators can include incentive schemes to regulatory frameworks. To provide companies with incentives, performance benchmarking is in many cases included in the regulatory framework. As a consequence of such an approach, the outcomes of the regulation depend on the actual performance of the company. The benchmarking also tends to reshape the directing signals of the economic regulation. (Honkapuro, 2008) Because electricity distribution is a capital-intensive business sector with long asset life-times, the network investments have long lasting, both technical as well as economical effects. In addition, a non-interrupted and cost efficient electricity distribution is a vital, almost self-evident element in the modern society. Due to this, it is important to ensure that economic regulation directs companies to design their networks and organizational structures so that the total socio-economic welfare is maximized. (Honkapuro, 2008)

Socio-economic welfare can be maximized, when there is a right kind of methodology to include the input parameters in the benchmarking process. Most suitable way seems to be to combine the inputs as one parameter, measured as monetary quantities. In other words, when all the parameters can be taken into account in the same way in the efficiency benchmarking, the following incentive effects are well in line with the objectives of smart solutions which is to minimize the total costs. The main outputs of the benchmarking can be considered to be the quantity and quality of the delivered energy or on the other hand maximum demand and quality. It can be also concluded that usually in an input-oriented benchmarking model, the incentives for increasing the outputs are slighter than decreasing the inputs. It is also vital from benchmarking point of view that both input and output parameters are taken into account by considering the operation environment as well as environmental issues. (Honkapuro, 2008) Today, when the role of the DSOs acting under regulated natural monopolies within the electricity distribution sector has changed more towards customer-oriented direction, also the customer service and service quality perspectives should be taken into account in the performance benchmarking. This is almost self-evident in such countries where the development level (maturity level) is high enough to include these aspects in the performance benchmarking.

7.1.2 Possible incentives for DSOs

Traditionally, especially in the Nordic countries quality of supply is a common way to measure DSOs service performance. It is clear that the quality of supply in form of interruption costs is an important factor when evaluating the performance as well as when incentivizing the DSOs. Therefore rewarding/penalizing the DSOs according to quality of supply performance creates important directing signals which should be remained also in future. Nevertheless, the approach could be improved by taking into account environmental conditions, in other words different type of networks like city-, urban- and rural area networks in order to increase the transparency of the method. Also efficiency requirements, including company specific requirements have many positive directing signals towards the companies.

When considering the most important benefits of smart solutions some additional and potential incentives can be identified. In addition to the benefits and development related to the ultimate objectives (EU 20/20/20 targets), there is a need to increase the performance level of the whole network service as the role of DSOs become more and more customer oriented. Therefore one potential incentive in the economic regulation could be taking into account service quality at the performance benchmarking of the DSOs. The benchmarking of this incentive should take into account the changing environment. This means that in addition to the traditional way to measure the quality of service taking into account quality of supply, also other aspects should be taken into account. One way is to consider DSO’s services also from market perspective. DSOs are in a key role when enabling electricity market to function more efficiently and therefore this aspect could be quite logical to take into account as well. The benchmarking should consider traditional customer service performance, but also other DSO’s services enabling increased customer participation like DG connections and introduction of new additional services to market should be considered as well. One possible aspect could also be customer satisfaction index towards the whole network service. Some potential

KPIs related to network services which could be included in the performance benchmarking are presented below:

- *Number of different tariff options available to end-user offered by the DSO (opportunities to choose from).*
- *DSO's procedure concerning distributed resource interconnection policy*
- *Customer promises that the DSO offers.*
- *Measured satisfaction of network users with the network services they receive.*

7.2 Summary

The changing environment within electricity distribution business sector increases pressure towards economic regulation, which should be developed into a more favorable direction towards Smart Grids. DSOs should be correctly incentivized to develop the network infrastructure with smart solutions by enabling better function of electricity market. Regulation should in future concentrate on minimizing total end-user costs instead of network tariffs. Roles of different stakeholders should be cleared and standards for smart solutions should be introduced in order to reach a uniform development and interoperability inside European Union in future.

As DSOs role changes more towards customer service companies, the performance benchmarking should consider DSOs whole service quality including also the traditional quality of supply aspect. By creating new incentives for the DSOs by taking into account service quality the benefits would eventually be reflected towards network customers, including consumers, producers and “prosumers” as well.

8 CONCLUSIONS

This thesis introduces first the theory related to the most common regulation methods used in European Union member states, especially in Finland and in Sweden. There is also an operating environment analysis that discusses the current situation related to energy end-usage and the role of electricity as an energy carrier in Chapter 2. EU accepted a new climate- and energy package on December 2008. It is clear, that the new legislation package is ambitious and in order to accomplish these challenging objectives some new and innovative solutions must be implemented in the energy sector. As many studies have shown, electricity has the potential to answer to these future needs and as a consequence there becomes an increasing need for Smart Grids and smart solutions in the electricity distribution sector. The theory related to Smart Grids and smart solutions was introduced and a definition for the concept of a Smart Grids used in this thesis was made in Chapter 3. The aim was to identify the most important benefits of smart solutions and the ultimate objectives related to the concept of Smart Grids.

Based on the analysis and discussion carried through the work, a tool to measure the level of "smartness" in a network was developed, presented in Chapter 5. The "evaluation tool" has been created focusing on the most important keystones related to Smart Grid development identified during the work. A special approach to evaluate the current level of development related to Smart Grids was developed by using key performance indicators (KPIs) suitable to be used in Nordic countries. The "evaluation tool" has been also connected to practice by performing a case study that evaluates the level of "smartness" within Vattenfall's distribution networks in Finland and in Sweden. Based on the results of the case study presented in Chapter 6, the aim was to identify the most important legislative and regulatory actions to be made in order to enable and accelerate the future development concerning Smart Grids. This has been discussed in Chapter 7. Nevertheless, when considering the scope of this thesis it became clear during the work that compilation of highly detailed definitions for the different levels of development, concerning the KPIs used in the "evaluation tool" was not meaningful. Instead, a more general approach to define the different levels was chosen. This also means that there is a need to accomplish a more accurate definition for the KPIs in future, in order to have more specific results.

On the way towards common European electricity market, the traditional regulation methods will not be able to meet the new requirements arising from the evolution. Instead of focusing on minimizing tariff increases, the regulation should in the future concentrate on securing efficient and holistic functioning of the electricity market. From European wide electricity market perspective, it seems to be essential to harmonize the regulation models in a way that the objectives and directing signals of the models inside European Union would be as similar as possible in order to achieve development into uniform direction. As a consequence of efficient market functioning also the total end-user prices will be stabilized which is beneficial for the whole society. Regulation has a key role among the DSOs in order to make the evolution of the network infrastructure possible and thereby enable to achieve the functional and environmental targets set by European Union.

The roles of different stakeholders must be cleared and defined. It is important and vital issue to recognize what part of the supply chain is responsible for offering additional energy efficiency services for network customers in order to reach the European Union energy efficiency requirements, for example. It is notable, that also external service providers, specialized in offering new services, must be taken into account in order to reach the best possible division between the roles. It is clear, that a large-scale cooperation within the whole industry will be the best solution in order to achieve the best possible and, above all, cost-effective result for the whole society. Nevertheless, the DSOs have the crucial information needed in future services as the DSOs are responsible for metering. Therefore the role of the DSOs should not be ignored.

Standardization of Smart Grid solutions is a precondition for a uniform development at national and European level. There is a need to develop a set of consistent standards within common European framework. The framework should include a variety of standards for communication technologies, electrical architectures and processes and services associated with these. The standardization could facilitate the implementation of different kind of Smart Grid related services and functionalities as well as increase the capability to interoperability which is a precondition in order to achieve European wide electricity market in the future.

A regulation model focusing on minimum requirements is not capable to satisfy the needs of different stakeholders in the future. Instead, standards and adjusted legislation with a regulation model concentrating more on outputs has many beneficial characteristics. This is because more freedom could be offered for the DSOs to make decisions. This increased freedom in addition with the most important and potential incentives especially concerning network investments, services and long term development of the network towards the Smart Grid concept could facilitate the achievement of the future needs by introducing new and innovative smart solutions in the distribution network environment. Too heavy-handed regulation is not desired, either from economical or industry point of view and by implementing incentives to regulation, it is possible to achieve a regulation model that controls less the behavior of the company but instead rewards the company's outcomes which are basically a consequence of the behavior and strategic decisions in the long run.

The case study performed during the work shows that the current development level and progress concerning Smart Grids and smart solutions within Vattenfall's distribution networks in Finland and in Sweden is at relatively advanced level, as shown in the *appendix 14*. The current situation can be seen quite promising; even there has been a lack of Smart Grid incentives before and during regulation period 2008-2011 as shown in Chapter 2. Nevertheless, the current development is not advanced when considering all the DSOs operating in Finland and in Sweden because there are significant differences between the DSOs and the maturity levels of their networks. At the next regulation period, there will be some new incentives in the models, especially in Finland. The new innovation incentive can be seen as development into the right direction and this kind of incentives could be beneficial also in Sweden. Nevertheless, when discussing Smart Grid development, this kind of innovation incentive should be even more attractive at the next regulation periods because the significance of RD&D programs is evident, especially at the maturity level currently achieved in the Nordic countries. On the other hand the new Finnish quality incentive with $\pm 20\%$ effect on the allowed reasonable rate of return can be seen quite oversized because the risks related to this incentive are significant. In Finland, the developed incentive concerning investments should be implemented as soon as possible in order to guarantee continuous network development. It is nevertheless important to adjust the method in future to support and favor especially smart solutions which is needed in Nordic countries. It can be stated, that the current development concerning regulation can be seen preferable in Finland than in Sweden from Smart Grid perspective. On the other hand the new Swedish regulation model is a clear step in regulation development in Sweden and it offers fairly high total revenue frame for the DSOs. Despite of this there should be more incentives for smart solutions as well, because it is not enough for the DSOs just to increase AMR base prices, for example.

In order to develop a performance based incentive regulation scheme promoting Smart Grid evolution, large scale benchmarking of the most important KPIs should be carried out in European and eventually at national level. By including the KPIs in the performance benchmarking and by monitoring them continuously, some new incentives could be introduced in the future. One potential incentive would be to include the service quality of a DSO into the performance benchmarking. By measuring the performance of DSO’s network service processes as well as processes enhancing the function of the whole electricity market, some remarkable benefits could be achieved. The benchmarking of network services could be carried out by considering the following KPIs:

- *Number of different tariff options available to end-user offered by the DSO (opportunities to choose from).*
- *Additional energy efficiency services offered to the customers by the DSO (DSO’s information sharing enabling efficient market functioning and new innovative services).*
- *Hosting capacity for distributed generation produced by renewable energy sources ("RES-DG hosting capacity") in distribution network.*
- *Customer promises that the DSO offers. Measured satisfaction of network users within the network services they receive.*

Benchmarking of some KPIs related to technological issues as well as further development of traditional indicators could be beneficial from Smart Grid perspective, because many of these aspects can be seen as enablers for future development. Also by taking into account local conditions like operation environment in the benchmarking of the DSOs could improve the fairness of regulation. These potential KPIs could be used in benchmarking as well:

- *SAIDI and MAIFI measured by taking into account supply criterion in different residential areas like city-, urban- and rural areas.*
- *Interruption costs. Costs reflecting the inconvenience experienced by network customers as a consequence of distribution disturbances.*
- *Total demand served by advanced meters (AMR-meters) which are capable to monitor and communicate remotely in two directions.*
- *Performance of communication channels towards the different grid elements (availability, bandwidth).*
- *Average HV/MV transformer capacity factor.*
- *Electrical losses in distribution network (technical losses).*
- *Grid elements that can be remotely monitored and controlled in real-time.*
- *Distribution system stability and uniformity of the DSO's distribution stability curve.*
- *Voltage quality performance of distribution network (compared with standards like EN- 50160 etc.).*

The definitions for some potential indicators which could be used in the performance benchmarking purposes in order to develop and couple new incentives to regulation schemes in future has been made. The analyses have been carried out in a way that the significance of Smart Grids and smart solutions has been taken into consideration through the work. However, the study considering the methods needed in order to implement these indicators in use by integrating them with the regulation model in future has been left for further research proposal.

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APPENDICES

Appendix 1 – Regulation models in Europe

	REGULATION SYSTEM	REGULATION PERIOD	EFFICIENCY REQUIREMENTS
GB	Revenue cap with incentives / penalties based on performance.	From 2015 - 8 years	• Cost allowances based on efficiency analysis of past performance using various econometric techniques based on normalised costs. • Analyses based on Opex and total network costs. No single approach is taken. • If a DSO wants to spend additional costs on smart grids it will need to justify them as part of its business plan submission to the NRA during price control review discussions. • Expenditure using money from the LCNF will not be included in any comparative efficiency analysis.
PT	Revenue Cap Regulation with target values for investments.	3 years	• Efficiency analysis of the past performance using various techniques have been performed. • NRA has privileged results from SFA models based on data from business units of EDP Distribuição. • The efficiency requirement is applied to the Opex. Additional costs for smart grids, like pilot projects, were included in allowed revenue for the current regulatory period.
FI	Hybrid Revenue Cap and Rate of Return Regulation.	4	• Both individual and general efficiency requirement only applying to OPEX. • general efficiency requirement: 2,06 % per year. • Method used to calculate the individual requirement is an average of DEA and SFA. All controllable operational costs are included in the efficiency requirement, also all costs for R&D and pilots regarding Smart Grids. capital cost are included as well.
NO	Yardstick regulation.	min 5 years	• Revenue allowances are based on "yardstick-costs" which are calculated by means of a DEA based on total costs. • The Yardstick-factor refers to total costs.
CZ	Hybrid Revenue Cap and return on invested capital.	5 years	• Efficiency is defined through OPEX only. Base is defined at the beginning of regulation period; sector efficiency factor is 9.75% for the whole period. • No DEA or SFA methods used due to small number of distribution companies in the Czech Republic. Sector efficiency factor was set by negotiations of NRA with DSOs.
PL	Hybrid Revenue Cap and return on invested capital.	1 year (3 years for OPEX)	• Efficiency requirements for OPEX only. • Regulatory OPEX (operation & maintenance) was calculated by Regulator as a result of a benchmarking. • Model for OPEX for next regulatory period (2011-2013) is unknown.
SI	Revenue Cap Regulation with target values for investments.	2 years (past: 3 years)	• General efficiency requirement: 1.5 % of OPEX.
SK	Revenue Cap Regulation with target values for investments.	3 years (ending in 2011)	• Efficiency requirement of 5% annually, but RPI-X can not be lower than zero, so in practice it is leading to flat prices across the period. • Efficiency ratios applicable for accepted losses volume for each voltage level separately.

	REGULATION SYSTEM	REGULATION PERIOD	EFFICIENCY REQUIREMENTS
ES	Hybrid Revenue Cap and Rate of Return Regulation.	4 years	• No general efficiency requirement. • In the currently proposed model capital costs are allowed using a reference grid model which looks upon the built-in system efficiency in the grid. Additional costs are not taken into account. • OPEX: Allowances are based on standards cost and negotiations on the efficiency requirement.
AT	Revenue CAP regulation	4 years	• A weighted average of DEA (2 methods) and MOLS gives the efficiency score. • Cost input and of relevance are the total costs (TOTEX). • Additional costs for SG are not considered in the structure-parameters and will so decrease the efficiency-score of the DSO.
NL	Yardstick regulation. In case of a significant and exceptional investment a rate of return is applied.	3 to 5; until now 3 years chosen.	• Revenue allowances are based on "yardstick-costs" which are defined as the average cost of all grid operators. • The yardstick is calculated with a DEA based on total costs, each grid operator is required to move gradually to that common average. • Costs for pilots etc. are treated as ordinary costs.
FR	Revenue Cap Regulation with target values for investments	4 years	• OPEX: Allowances are based on negotiations. General efficiency requirement of 2 %.
DE	Revenue Cap Regulation	5 years	• General efficiency requirement: currently (2009-2013) 1,25 %. • The individual efficiency requirement refers to a DEA and a SFA based on total costs, requirement is relevant for adjustment of total costs.
SE	revenue cap regulation planned for 2012; currently light handed regulation	4	• Only general efficiency requirements. 1%per year in real terms on costs possible to influence. • The RAB via standard costs approved by the Regulator.
IT	Price cap regulation on OPEX - rate of return regulation on CAPEX	1 year	• Efficiency requirements for OPEX. • Additional costs for smart grids do not have in the actual regulatory period specific impact on efficiency requirements.
DK	Hybrid Revenue Cap and Rate of Return Regulation.	1 year	• No general efficiency requirement • Specific benchmarking model (referent network) used to derive the relative efficiency requirement based on the "total cost per component". • Extra ordinary costs and losses are neither included in the benchmarking. • Smart meters are considered extra ordinary costs. It has not been clarified whether other smart grid investments will be given same status.

	RECOGNITION OF CAPITAL EXPENDITURES FOR DETERMINING REVENUES	TREATMENT R&D AND PILOT PROJECTS
DK	• Allowed revenues only increase as a result of necessary investments giving supply to new geographical areas or improving continuity of supply (replacement of overhead by underground wires). • System yields problems in case of increasing needs for replacement investment and in case of increasing DG on distribution level.	• As other cost.
GB	• Revenue path is adjusted every 5 (soon to be 8) years. • Capital expenditure is agreed at the start of any review and is taken into account in the revenue allowance. • There are different incentives depending on the level of CAPEX requested by companies (in comparison with the NRA's estimate) and whether the CAPEX target is exceeded. • In future recovery will be assessed according to whether prescribed outputs are delivered.	• Before 2010: Innovation Funding Incentive which allowed up to 2% of annual revenues to be spent on innovation. • This continues but has been augmented by the LCNF which is a fund of £500m available (payable by all GB consumers) for DSOs to use to trial new technologies and commercial arrangements (DSM etc). • DSOs compete with each other for the finance; the successful DSOs have to share their experiences etc with all other DSOs.
PT	• Capital expenditure is agreed at the start of any regulatory period. • NRA has accepted the proposals from the DSO (EDP Distribuição) for operational investment; the proposed values have been added to the Regulated Asset Base.	• Some public funds supporting R&D in general. • A pilot project on smart grid was accepted by the regulator. The corresponding investments were included in the regulated asset base.
FI	• All investments are included in RAB based on their current (technical) replacement value at standard costs.	• As other cost.
NO	• allowed revenues reflect CAPEX partially (deduction due to yardstick-factor), • Some compensation with calibration-parameter.	• As other cost.
CZ	• New assets increase fully RAB and sector WACC is applied to them. • Old assets (investments before 2010) are in RAB at the level of 60 % of overrated value and algorithm of elimination difference is accepted.	• As other cost.
PL	• For new assets (built since 1.01.2009) book value is a base for calculation of return on capital. • Old assets (≤ 2008) special 5-6 years path to reach book value.	• As other cost.
SL	• Allowed revenues reflect CAPEX fully. • CAPEX is defined at the start of regulatory period. Investments are evaluated on the basis of 10 years network development plans.	• There is no special treatment of pilot projects. They were part of 10 years network development plan and fully recognized in revenue like any other investment.
SK	• CAPEX has no influence on the regulated revenues (neither under nor over-performance), no target CAPEX set	• Not recognised at all.

	RECOGNITION OF CAPITAL EXPENDITURES FOR DETERMINING REVENUES	TREATMENT R&D AND PILOT PROJECTS
AT	• Fully recognition of CAPEX via investment factor in the 2nd regulation-Period (1.1.2010 - 31.12.2013). • Time-delay of two years. • Mechanism: Additiv term in the regulation formula, which simplified is the difference between the CAPEX of the actual year (t-2) and the CAPEX of 2008 plus a "Mark-up" (1,05% of the Increase of the book-value in the actual year).	• No cost recognition for R&D
ES	• Allowed revenues reflect CAPEX partially due to differences between actual investments and those obtained from the reference grid model. • Investments due to environmental restriction or technical requirements imposed by Regional or Municipal Administrations are not modelized. • Capital costs are included in the allowed revenue with one year delay.	• There is no specific public programme to fund smart grid pilot projects. Although some basic R&D projects are partially financed in the national and European R&D programs, the current pilots are fully funded by the companies which are developing them.
NL	• Allowed revenues based on total costs. • Sector wide total cost recovery. • Capital costs are included in the allowed revenues on average 4 years delayed, revenue path adjusted every 3 years.	• As other cost.
FR	• Capital expenditure is agreed at the start of any regulatory period. • Differences between concession and regulation mechanism (municipals receive revenues which are not included in the tariffs) reduces achievable Rate of return significantly.	
GER	• Allowed revenues reflect CAPEX partially (deduction due to efficiency requirement). • revenue adjustment 3 - 7 years delayed: revenue path is adjusted every 5 years (based on a cost review).	• All additional costs for smart grids would not be approved by the NRA.
SE	• All investments are included in the RAB based on their replacement value at standard costs.	• As other cost.
IT	• New investments are included in the RAB and sector WACC is applied to them.	• As other cost.

Appendix 2 – Description of the "evaluation tool"

This application is divided into different sheets, which are each concerning and dealing with different aspects of measuring the "smartness" in a network.

The different aspects are divided into enablers (or inputs) and consequences (or outputs) as presented below:

Inputs: enablers for the "smart" development

Automation & advanced technologies

IT & communication system

Sufficient capacity of the network

Grid access & connections for DG and new customers

Electric vehicle infrastructure development

Funding & investments

Outputs: consequences of the "smart" development

Distribution reliability

Power quality

Consumer awareness & customer participation

Efficiency

Sustainable development of the network operation

All of the different categories are divided into specific **"key performance indicators (KPIs) which describe and evaluate the level of development".**

The KPIs have values for different levels of development between the scale: **Low (1) / Sufficient (2) / Good (3) / Advanced (4) / High (5)**.

There is an exception concerning Funding & investments -category, where there is just three different levels to choose from.

The idea is to choose the corresponding value in column "measured level" by using button.

All the KPIs have also individual **"weight" column to describe the importance of the KPI in question, inside a specific category.**

The **"default weight"** is **100 %**. If a specific KPI is more important, increase the digit in the weight column and decrease it when it is not so important by using button.

Weight can be chosen between 50 % and 150 %.

Individual KPI can also be turned ON and OFF by selecting **1 = ON** or **0 = OFF** at the last column in every sheet.

By filling in all the values for different KPIs in each category, you can review the development level of the different aspects of "smartness in a network".

The results are presented with a green background in each sheet "total development of smartness level in the group".

The application also makes a graph in every sheet based on the values fed into the application, in order to be able to easily compare the results with each other.

The last sheet: Results for the evaluation concerning all the different categories assembled together .

Appendix 3 – Advanced technologies

Level of automation & advanced technologies in the network (inputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Enhanced reliability, network controllability and new services	Supervisory control system (SCADA etc.) connection points (data elements) connected, in relation to the number of primary substations, secondary substations and monitored / controllable grid elements.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI tells the amount of available (SCADA) points of the control system, it describes the DSO's capability to monitor and control the distribution network.	100	1
Enhanced reliability, network controllability and new services	Primary substations that are equipped with advanced relays like microprocessor relays/ feeder managers (terminal relays) and integrated with the supervisory control system. Share of all primary substations.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the level of automation in primary substation level, which describes the DSO's capability to remotely control the primary substations.	100	1
Enhanced reliability, network controllability and new services	Grid elements that can be remotely monitored in real-time, share of all grid elements.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of grid elements, that are remotely monitored in real time by the DSO.	100	1
Enhanced reliability, network controllability and new services	Grid elements that can be remotely controlled in real-time, share of all grid elements.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of grid elements, which can be remotely controlled in real-time by the DSO.	100	1
Enhanced reliability, network controllability and new services	Total demand served by advanced meters (AMR-meters) which are capable to monitor and communicate remotely. Share of all network users.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of end-users, which are equipped with advanced metering devices (automatic meter reading, voltage quality monitoring, fault identification etc.).	100	1
Enhanced reliability, network controllability and new services	Advanced meter device features corresponding the European directives / standards / recommendations. Level of functionalities.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the features that the AMR meters installed are capable to offer, compared with the international standards and recommendations.	100	1
Enhanced reliability, network controllability and new services	Automated meter readings, data transfer frequency supporting different network services. Level of transfer frequency.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the level of automated meter data transfer frequency (For example hourly data transfer versus weekly data transfer).	100	1
Enhanced reliability, network controllability and new services	Network operating systems. Applications exploiting the "real-time" data provided by advanced meters. Level of real-time data exploitation.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the number of network operating system applications, which exploit the real-time information provided by advanced meters.	100	1
Enhanced reliability, network controllability and new services	Automated MV fault identification (locating) / grid reconfiguration during outages. Level of effective fault management capability.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the ability to identify fault location and type, ability to reconfiguration of the grid connections and limit the faulted area to minimum.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 4 – IT and communication system

IT & Communication system (inputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Enable new services, active network management and real-time data exploitation	Performance of communication channels towards the different grid elements (availability, bandwidth, response time). Level of performance.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI describes the capacity of communication infrastructure. How does the communication network between different parts of the network work.	100	1
Enable new services, active network management and real-time data exploitation	Communication standards and protocols, compliance with European and international methods. Level of compliance.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the compliance of the communication standards and protocols with European and international standards.	100	1
Enable new services, active network management and real-time data exploitation	Communication methods supporting different network operations, performance level of real time data exploitation.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring how well the communication infrastructure is supporting different operations of the network management.	100	1
Enable new services, active network management and real-time data exploitation	Real-time data information exploitation to support the DSO's internal processes. Level of performance.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring how well the DSO exploits the real-time information of the network state and operation to support a versatile amount of internal processes of the	100	1
Enable new services, active network management and real-time data exploitation	Integration level between different IT-applications related to network control and management. Level of integration.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the level integration between different network control systems. Supervisory control system and other systems related to network monitoring and	100	1
Enable new services, active network management and real-time data exploitation	Two-way communication. Enabled alerts, remote control and layouts, reading logs, coupling status remote monitoring. Performance level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the ability for two-way communication which enables many of the important functionalities of AMR devices and network control processes.	100	1
Enable new services, active network management and real-time data exploitation	Customer information security / quality of the information. Level of information security and reliability.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the security of individual customer related data, third party access and other risks related to data management and utilization. Data privacy and security issues.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 5 – Sufficient network capacity

Sufficient capacity of the network (inputs)						
Target effect of "smartness"	**KPIs (indicators)**	**Measurement options**	**Measured level**	**Description**	**Weight /100%**	**ON (1)/OFF (0)**
Sufficient capacity of the network, RES-DG factor, efficiency, reliability	Physically installed distribution grid capacity. Maximum injection of power and maximum demand, performance level to avoid congestion risks.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the physical grid capacity. How well does the grid capacity answer to the situations of high demand and high injection of power to the grid.	100	1
Sufficient capacity of the network, RES-DG factor, efficiency, reliability	Hosting capacity for distributed generation produced by renewable energy sources ("RES-DG hosting capacity") in distribution network. Level of DG interconnection capacity.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is vital at the moment. It measures the networks capability to connect DG production to the grid. It can be evaluated by voltage / frequency stability, for example.	100	1
Sufficient capacity of the network, RES-DG factor, efficiency, reliability	Ensuring continuous production by distributed generation, flexible interconnection policy, voltage adjustment, protection methods. Performance of connection methods.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the actions done to ensure continuous production of DG units interconnected to the grid.	100	1
Sufficient capacity of the network, RES-DG factor, efficiency, reliability	Average HV/MV transformer capacity factor and adequacy of the capacity. Performance level of transformer capacity.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the adequacy of transformer capacity in distribution network. HV/MV transformer capacity.	100	1
Sufficient capacity of the network, RES-DG factor, efficiency, reliability	Optimized use of assets. Uniformity of DSO's distribution stability curve. Uniformity level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI monitors the DSO's stability curve flatness in order to accomplish an optimized use of assets.	100	1
Total development of "smartness" level in the group:		**0,0**				

Appendix 6 – Grid access & RES/DG connections

Grid access & DG connections

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Enhanced grid access, end-user participation, energy market integration and accessibility of the market	Time to connect a new user within a reasonable timeframe. Performance level to realize new connections to the network.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the average time, that it takes from DSO to connect a new user to the grid from the day when a new electricity connection is ordered.	100	1
Enhanced grid access, end-user participation, energy market integration and accessibility of the market	Uniformity of grid connections. Non-discriminative grid access for all customers. Performance to realize non-discriminative operation.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring if there is a non-discriminative access to network regardless of geographical location or the type of customer, from DSO's point of view.	100	1
Enhanced grid access, end-user participation, energy market integration and accessibility of the market	DSO's connection charges for generators, consumers and those that do both. Whether the fees are at an acceptable level compared to average charges.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI monitors if the connection charges are justified and at an acceptable level. How many different charges there are for different type users.	100	1
Enhanced grid access, end-user participation, energy market integration and accessibility of the market	Grid tariffs for generators, consumers and those that do both. Tariff calculation methods and whether the tariffs are at an acceptable level compared to average tariffs.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI monitors the tariff calculation methods and measures if the tariffs are at an acceptable level.	100	1
Enhanced grid access, end-user participation, energy market integration and accessibility of the market	DSO's standards and procedure concerning distributed resource interconnection policy. Performance level of the process.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring how well the DSO's interconnection policy is equal to European legislative directives.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 7 – Electric vehicle infrastructure

Electric vehicle infrastructure (inputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
EV infrastructure development	Hosting capacity for / of electric vehicles (EVs). Performance level to interconnect EVs to the distribution network.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the DSO's network capability to connect EVs. Two-way power flow, time shift for the loads, EVs as energy storages etc.	100	1
EV infrastructure development	Evaluation of the DSO's effort to contribute the development of EV charging infrastructure. Performance level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the estimated development of EV charging infrastructure which becomes an important aspect, especially in the future.	100	1
EV infrastructure development	DSO's opportunity to realize load leveling of EV charging, advanced meter data management and utilization to help this effort. Performance of the methods.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the technical requirements of DSOs to connect and manage high amount of EV load in the future.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 8 – Funding and investments

Funding & investments (inputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description
Smart solutions, network development and new funding methods	Selective grid development and innovation funding (tariff structure). Level of selectivity concerning network development and funding.	High Selectivity (3) Partly Selective (2) No Selectivity (1)	0	This KPI measures if the DSO's funding method is selective, so that the grid tariffs relate directly to a real and specific purpose.
Smart solutions, network development and new funding methods	Amount of DSO's total revenue invested for developing network efficiency. Performance level in comparison with regulative / legislative requirements.	High performance (3) In line with legislation (2) Low performance (1)	0	This KPI is measuring how the DSO invests to energy efficiency development. How high is the share of revenue that is invested in energy efficiency improvements.
Smart solutions, network development and new funding methods	Investment incentives coupled with obligations and rewards / penalties in regulation. Is the current level of incentives appropriate from DSO's smart grid development perspective.	High level (3) Appropriate level (2) Low level (1)	0	This KPI measures the investment incentives DSO possibly receives to fund smart grid investments. For example incentive regulation & quality regulation.
Smart solutions, network development and new funding methods	Amount of smart grid investments financed by external funding. Level of external funding options.	High external funding (3) Partly external funding (2) No external funding (1)	0	This KPI is measuring the share of DSO's smart grid investments possibly covered by external funding options.
Smart solutions, network development and new funding methods	R&D programs and funding. Performance level of R&D and demonstration project activity.	High R&D activity level (3) Medium R&D activity level (2) Low R&D activity level (1)	0	This KPI is measuring the level of Research & Development programs. How does the funding for R&D programs be formed. How high is the R&D investment level.
Smart solutions, network development and new funding methods	Total amount of revenue relative to the allowed return (depends also of the regulation model used).	High level (3) Reasonable level (2) Low level (1)	0	This KPI is measuring the ratio between the DSO's total revenue and allowed rate of return.

Appendix 9 – Distribution reliability

Distribution reliability (outputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Increased distribution reliability	SAIDI, overall performance in city, urban and rural areas. Measured by takin into account supply criterion in different residential areas.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	System Average Interruption Duration Index. This KPI is commonly used as a reliability indicator. SAIDI is the average outage duration for each customer served. SAIDI is in unit of time, hours / year. DSO's performance.	100	1
Increased distribution reliability	SAIFI. DSO's performance level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	System Average Interruption Frequency Index. This KPI measures reliability. It is the average number of interruptions that a customer experiences. Unit is a number of interruptions per customer / year. DSO's performance.	100	1
Increased distribution reliability	CAIDI. DSO's performance level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	Customer Average Interruption Duration Index. This KPI is related to SAIDI and SAIFI. It can be calculated as ratio SAIDI/SAIFI. CAIDI gives the average outage duration that customer can experience, hours / year. DSO's performance.	100	1
Increased distribution reliability	MAIFI, overall performance in city, urban and rural areas. Measured by taking into account supply criterion in different residential areas.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	Momentary Average Interruption Frequency Index. This KPI measures the total number of outages less than 3 minutes in duration per total number of customers. Unit is interruptions (< 3min) per customer / year. DSO's performance.	100	1
Increased distribution reliability	Amount of cabling in the DSO's MV distribution network. Cabling level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the development of large scale cabling when creating weatherproof network system which is able to tolerate natural phenomena like storms and thunders.	100	1
Increased distribution reliability	Share of high impedance grounded networks among DSO's MV distribution lines. Level of compensated networks.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the share of high impedance grounded networks in comparison with the whole HV distribution network in the DSO's territory.	100	1
Increased distribution reliability	Energy storages, DSO's connection policy. Performance level for connecting energy storages to distribution network.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of energy storages and the total capacity of the storages in the grid. It has impact on security of supply by feeding electricity during faults. In future,	100	1
Increased distribution reliability	Power system stability. Stability performance of the distribution network.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the stability of the distribution grid operation. DSO's performance in stability control and network planning.	100	1
Increased distribution reliability	Microgrids, DSO's effort to implement controlled island operation. Level of research, development and demonstration activity.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the attitude of the DSO's to implement active microgrid operation in the network. Parts of the grid, which are able to island operation.	100	1
Total development of "smartness" level in the group:		**0,0**				

Appendix 10 – Voltage quality

Voltage quality (outputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Better power quality to answer the customer expectations	Range of different voltage qualities to contract.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring measure the selection of voltages that can be contracted with the DSO. Different customers are able to choose different ranges of voltages according to power quality compulsion.	100	1
Better power quality to answer the customer expectations	Customer complaints related to voltage quality issues (excluding outages). Performance level of power quality improvements based on complaints.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the power quality performance of the DSO. It takes account the customer complaints related to power quality issues.	100	1
Better power quality to answer the customer expectations	Voltage quality performance of electricity distribution network (compared to standards like EN- 50160 etc.).	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI tells the performance of the distribution grid from a technical point of view. How well does the network manage to achieve high quality of voltage in the distribution according to international standards.	100	1
Better power quality to answer the customer expectations	Proactive improvement of power (voltage) quality in the network. DSO's performance to enhance power quality continuously.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring if there are proactive methods to improve the voltage quality performance of the network based on DSO's quality measurements.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 11 – Consumer awareness & participation

Consumer awareness & participation (outputs)						
Target effect of "smartness"	**KPIs (indicators)**	**Measurement options**	**Measured level**	**Description**	**Weight /100%**	**ON (1)/OFF (0)**
Active end-user participation, energy efficiency and new services	Number of different tariff plans available to end-user offered by the DSO (opportunities to choose from). The level of different options.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of options that a customer has, when choosing different tariff plans in order to have savings in electricity invoice.	100	1
Active end-user participation, energy efficiency and new services	Time-of-use tariffs (ToU), fraction of customers served by the DSO. Level of ToU tariffs in use.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the possibilities that a customer has in order to adapt ToU pricing tariffs. It also measures the share of customers that have chosen ToU schemes.	100	1
Active end-user participation, energy efficiency and new services	Fraction of consumers contributing in demand side management (DSM) in DSO's territory.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of consumers / customers that are contributing in DSM. Share of customers which are applying demand response (DR).	100	1
Active end-user participation, energy efficiency and new services	Electricity supplier change process. DSO as enabler for the process. Duration of the process etc. Performance level.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the DSO's performance related to electricity supplier change process, when a customer wishes to change the supplier.	100	1
Active end-user participation, energy efficiency and new services	Ratio between consumers and "prosumers", share of customers acting as consumers and producers.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the share of "prosumers" among the DSO's network users. How well does the DSO allow this action.	100	1
Active end-user participation, energy efficiency and new services	Measured satisfaction of network users with the network services they receive.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the satisfaction of network users with network services that they receive.	100	1
Active end-user participation, energy efficiency and new services	Planned interruptions, DSO's performance on informing the customers inside the interruption area.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the DSO's effort on informing customers, which connection point is inside the planned interruption area on the network.	100	1
Active end-user participation, energy efficiency and new services	Customer promises that the DSO offers. Level of the promises from customer perspective and performance to achieve them.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI represents the development concerning customer promises. It measures the level and amount of different customer promises offered by the DSO.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 12 – Energy efficiency

Energy efficiency (outputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Increased energy efficiency	Electrical losses in distribution network (technical losses), share of total energy distributed. DSO's performance to reach high energy efficiency.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the losses in distribution network. How efficient is the operation of the DSO.	100	1
Increased energy efficiency	Electricity produced by small-scale distributed generation in order to cut down energy bills and consumption, DSO's capability to connect the required hardware.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	KPI tells DSO's performance to adapt with local DG, which cuts down consumers energy bills and enhances network's overall efficiency.	100	1
Increased energy efficiency	Additional energy efficiency services offered to the customers by the DSO. Level of different services.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring the amount of additional / optional energy efficiency services provided by the DSO in order to improve the overall energy efficiency.	100	1
Increased energy efficiency	Share of total energy that a consumer is able to save with ancillary energy services. Level of possible savings.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is measuring how much a customer is able to save by using energy efficiency services provided by DSO. How high is the level that can be saved.	100	1
Increased energy efficiency	Demand side participation in electricity markets and in energy efficiency measures. Level of participation.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is relevant for efficiency, but it can be just partially influenced by the DSO. This KPI measures the DSO's effort as an enabler for DSP as a consequence of implementing the enabling technology.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 13 – Sustainable development

Sustainable development (outputs)

Target effect of "smartness"	KPIs (indicators)	Measurement options	Measured level	Description	Weight /100%	ON (1)/OFF (0)
Increased sustainable development	Quantified reduction of carbon emissions. DSO's performance to achieve reductions in carbon emissions, directly or indirectly.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI measures the smart grid development from sustainability point of view. DSOs are only partially able to influence the emissions, depends mostly on the generation structure and the market situation.	100	1
Increased sustainable development	Environmental impact of electricity distribution infrastructure. Level of DSO's actions to reduce environmental impact.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI measures the impact that the construction, maintenance and deconstruction of electricity network appoints to environment during its lifecycle.	100	1
Increased sustainable development	Quantified reduction of accidents and risks associated in grid operation, maintenance, building and development.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI relates to the DSO's operation, planning and education of employees in order to avoid accidents and risks. It is related to sustainability and safety.	100	1
Increased sustainable development	RES -DG factor, share of electrical energy produced by renewable energy sources.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI is related to reduction of emissions by using and introducing new RES-DG equipments. The factor tells the share of carbon free production methods. It has to be identified, that DSOs can just partially influence this factor.	100	1
Increased sustainable development	Informing of carbon free energy sources and energy efficiency services.	High level (5) Advanced level (4) Good level (3) Sufficient level (2) Low level (1)	0	This KPI measures the level of DSO's information sharing concerning new energy efficiency services and carbon free production methods.	100	1
Total development of "smartness" level in the group:		0,0				

Appendix 14 – Case-study overall results

Finland

Final results of evaluating the "smartness" related to the different categories

	Different categories	Description	RESULT
INPUTS	Level of automation & advanced technologies in the network	This category evaluates the development related to network automation, both in MV and LV levels. Development related to AMRs, network operating systems and technology is evaluated.	4,0
	IT & communication system	This category evaluates the development related to IT-systems and communication. Development of AMI, system level integrations and communication solutions is evaluated.	3,7
	Sufficient capacity of the network	This category evaluates the development related to adequate network capacity. Transformer capacity, line capacity and capacity for DG connections is evaluated.	3,5
	Grid access & RES / DG connections	This category evaluates the development related to grid access of different types of customers. Connection charges, RES / DG connections.	3,4
	Electric vehicle infrastructure	This category evaluates the development related to EV infrastructure development. Capability to connect, develop and control.	3,0
OUTPUTS	Distribution reliability	This category evaluates the development related to distribution reliability. Reliability indicators and development of other advanced solutions is evaluated.	3,3
	Voltage quality	This category evaluates the development related to the quality of voltage. As a reference to standard EN-50160. Continuous improvement of voltage quality is evaluated.	3,3
	Consumer awareness & participation	This category evaluates the development related to tariff structures, information sharing and advanced services is evaluated including continuous performance improvement.	3,5
	Efficiency	This category evaluates the development related to enhanced efficiency of the operation. Level of electrical losses, new services and DG devices accessibility.	3,7
	Sustainable development	This category evaluates the development related to continuous sustainable development by reducing CO_2 emissions, environmental impact and risks related to network operation.	3,8
		Arithmetic Average Of The Result:	3,50

	Valuation
5	High level
4 - 5	Advanced level / High level
4	Advanced level
3 - 4	Good level / Advanced level
3	Good level
2	Sufficient level
1 - 2	Low level / Sufficient level
1	Low level

Sweden

Final results of evaluating the "smartness" related to the different categories

	Different categories	Description	RESULT
INPUTS	Level of automation & advanced technologies in the network	This category evaluates the development related to network automation, both in MV and LV levels. Development related to AMRs, network operating systems and technology is evaluated.	3,1
	IT & communication system	This category evaluates the development related to IT-systems and communication. Development of AMI, system level integrations and communication solutions is evaluated.	3,1
	Sufficient capacity of the network	This category evaluates the development related to adequate network capacity. Transformer capacity, line capacity and capacity for DG connections is evaluated.	3,5
	Grid access & RES / DG connections	This category evaluates the development related to grid access of different types of customers. Connection charges, RES / DG connections.	3,6
	Electric vehicle infrastructure	This category evaluates the development related to EV infrastructure development. Capability to connect, develop and control.	3,7
OUTPUTS	Distribution reliability	This category evaluates the development related to distribution reliability. Reliability indicators and development of other advanced solutions is evaluated.	3,4
	Voltage quality	This category evaluates the development related to the quality of voltage. As a reference to standard EN-50160. Continuous improvement of voltage quality is evaluated.	3,0
	Consumer awareness & participation	This category evaluates the development related to tariff structures, information sharing and advanced services is evaluated including continuous performance improvement.	3,3
	Efficiency	This category evaluates the development related to enhanced efficiency of the operation. Level of electrical losses, new services and DG devices accessibility.	3,3
	Sustainable development	This category evaluates the development related to continuous sustainable development by reducing CO2 emissions, environmental impact and risks related to network operation.	3,8
		Arithmetic Average Of The Result:	3,38

	Valuation
5	High level
4 - 5	Advanced level / High level
4	Advanced level
3 - 4	Good level / Advanced level
3	Good level
2	Sufficient level
1 - 2	Low level / Sufficient level
1	Low level

Appendix 15 – AMR features and functionalities

Appendix 16 – Customer promises, Sweden & Finland

Sweden Launched Customer Promises

1. Compensation for delayed new installations by 180 €
2. Outages more than 6 hours will automatically be compensated with 30 € (3% of annual grid invoice in Finland)
3. More than 5 outages per month the fixed fee will be excluded for that month
4. Compensation if voltage isn't in the right level, the fixed fee will be excluded if it's not rectified in 6 months.
5. Information about outages shall rapidly be presented trough web, IVR, sms, mail.
6. Consumption not billed will after one year not be charged, for business customers three years.
7. If the change of supplier process will be delayed customers will be compensated with 30 €.
8. If appliance have been damaged caused by bad power quality customers will be extra compensated, the regular deduction (350 €) will be excluded.
9. All customer have access to service (My Pages) through the web.
10. To support customers continuously with excellent service we do investment in modern technique and develop the grid in an environmental direction

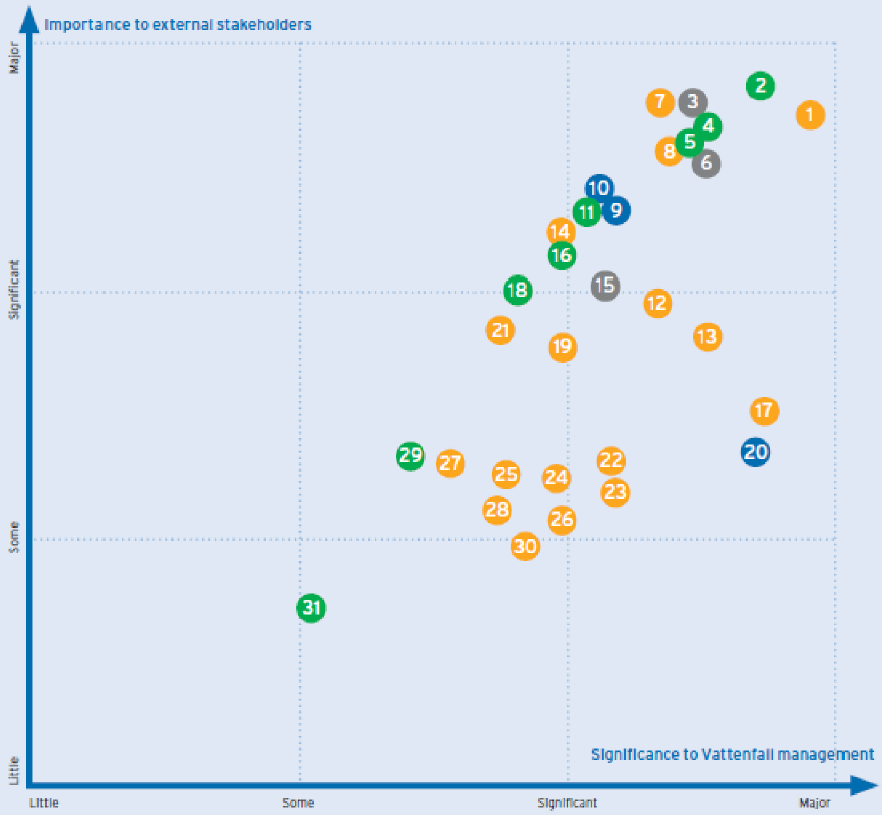
Finland OUR GUARANTEED DISTRIBUTION PROMISES

Compensation for power failure	We will compensate for power failures lasting over 6 hours.
Electricity supply	We will supply electricity within the agreed time. Our delays will be compensated.
We operate rapidly	We will not drag our feet if you want to change the electricity supplier. Our delays will be compensated.
Information on power failures	We deliver information on power failures through all media, also to your mobile phone.
Fewer spark-outs	Less electricity flutter and steadier electricity supply to your home.
Information on electricity consumption	Accurate reports on your electricity consumption through our Online Service.

Appendix 17 – Vattenfall's materiality analysis by external and internal stakeholders

MATERIALITY ANALYSIS

The graph below shows how a range of external and internal stakeholders rated the importance of sustainable and responsible behaviour by Vattenfall regarding 31 different issues. These results are based in part on a survey of 40 external stakeholders (representing different regional and organisational viewpoints) and 112 Vattenfall managers. Responses from external stakeholders were weighed together and thus the chart does not capture the different and often conflicting priorities of different groups. This weighting was one of several factors guiding the choice of topics in this report.



Environment
- 2 Greenhouse Gas Emissions and Climate Change
- 4 Renewable Energy
- 5 Nuclear Waste
- 11 Other Emissions, Pollution and Waste
- 16 Land Use and Ecosystem Impact
- 18 Material (incl. Water) Used in Production
- 29 Transport
- 31 Electro Magnetic Fields

Economic
- 9 Energy Efficiency in Operations
- 10 Market Presence
- 20 Economic Performance

Social
- 1 Nuclear Safety
- 7 Community Relations
- 8 Pricing of Energy and Services
- 12 Corruption, Bribery and Anti-Competitive Behaviour
- 13 Customer Service
- 14 Customer Energy Efficiency
- 17 Security of Supply
- 19 Occupational Health and Safety
- 21 Job Security and Job Creation
- 22 Workforce Training and Benefits
- 23 Public Affairs and Lobbying
- 24 Labour/Management Relations
- 25 Marketing Communication
- 26 Human Rights Issues
- 27 Supply Chain Management
- 28 Gender Equality
- 30 Diversity and Non-Discrimination

Others
- 3 Openness and Transparency
- 6 Stakeholder Engagement and Dialogue
- 15 Corporate Governance

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