TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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THE EVOLVING REQUIREMENTS FOR SMART SECONDARY SUBSTATIONS IN THREE EUROPEAN REGULATORY MARKET ENVIRONMENTS

Master of Science Thesis

Examiners: Professor Pertti Järventausta and Professor Risto Raiko
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ABSTRACT

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This thesis outlines secondary substation concepts for three European countries, them being Finland, Germany, and Italy. The conceptual solutions were formed to tackle the current technical challenges in the distribution grid. At the same time the concepts take into account the current regulatory frameworks and their expected development.

The regulatory frameworks for grid operation are set by national legislation. The return on investment of distribution system operator depends on the regulatory framework, which is why the regulatory framework is a powerful tool for guiding the distribution grid development.

In European level the direction of grid development is on a general level clear. An increasing amount of renewables is to be integrated to the electricity distribution network. Regulatory frameworks by definition should drive the distribution system operators into efficient and reliability maintaining investments.

In detailed level there is much to improve. For instance while regulatory focus lies on operational efficiency, the quality of service easily suffers. Companies focus on maximizing their profits, and therefore quality of supply has to be inbuilt to the regulatory framework and other legislation.

The quality of service is currently ensured by utilizing incentive based regulation. All the focus countries also apply this in their frameworks. The results from interviews conducted for this thesis as well as the literature research indicate the same result: the sufficient reliability incentives together with direct smart grid related investment incentives were discovered to be the most effective drivers for smart solutions. Also long term consistency in regulatory framework development is of utmost importance for investment friendly business environment.

The technical concepts outlined in this thesis affect the grid performance indicators e.g. SAIDI, SAIFI, and MAIFI. Improving these indicators has a direct impact on the rate of return of distribution system operators.

The results, smart secondary substation concepts, of all the countries include features such as remote control, monitoring, and measurements. The country specific concepts include e.g. two concepts for active voltage control in distribution grid with On-Load Tap Changers, and one concept that utilizes inverters for reactive power control. The technology in the presented concepts exists and can be immediately taken into operation to the benefit of the distribution system operators and electricity consumers.

TIIVISTELMÄ

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Tässä diplomityössä on esitelty jakelumuuntamoratkaisu kolmelle eri markkina-alueelle, jotka ovat Suomi, Saksa ja Italia. Nämä konseptitason ratkaisut vastaavat eri markkinoilla vallitseviin teknisiin haasteisiin jakeluverkoissa. Samalla ratkaisut ottavat huomioon nykyisen regulaation eli jakeluverkkoyhtiöiden taloudellisen valvontamallin, sekä regulaation odotetun kehityksen kussakin maassa.

Jakeluverkkoyhtiöiden liiketoimintaa ohjaava valvontamalli on määritelty kansallisessa lainsäädännössä. Yhtiöiden sijoitetun pääoman tuotto on vahvasti sidoksissa valvontamalliin, josta syystä valvontamallin muutoksilla voidaan tehokkaasti ohjata jakeluverkkoliiketoiminnan kehitystä haluttuun suuntaan.

Euroopassa yleisellä tasolla jakeluverkkojen kehitysnäkymät ovat selvät. Kasvava määrä uusiutuvaa energiaa on liitetty ja liitetään sähkönjakeluverkkoihin lähitulevaisuudessa. Regulaation perimmäisenä tarkoituksena on ohjata yhtiöitä investoimaan mahdollisimman tehokkaasti ja samalla ylläpitämään tai parantamaan verkon luotettavuutta.

Tarkemmin tarkastellen verkon kehitysnäkymissä on paljon parannettavaa. Esimerkiksi tilanteissa, joissa regulaatio keskittyy toiminnan tehostamiseen, on vaarana sähkönjakelun laadun heikkeneminen. Jakeluverkkoyhtiöiden tehtävänä on maksimoida voittonsa, joten sähkönjakelun laadun varmistamisen on oltava sisäänrakennettu yhtiöiden kohtuullisen tuoton valvontamalliin ja muuhun lainsäädäntöön.

Sähkönjakelun laatu on tässä diplomityössä esitetyissä tapauksissa varmistettu kannustinpohjaisella valvontamallilla. Esitellyt haastattelutulokset sekä kirjallisuuslähteistä saadut tiedot molemmat osoittavat, että riittävät sähkönjakelun luotettavuuskannustimet yhdessä älyverkkoinvestointeihin kohdistettujen kannustimien kanssa ovat tehokkaimmat älyverkkoratkaisuiden ajurit. Lisäksi pitkäjänteisyys valvontamallien kehittämisessä on erittäin tärkeää investointeihin kannustavan liiketoimintaympäristön ylläpitämiseksi.

Tässä työssä muodostetut konseptit vaikuttavat verkkojen luotettavuuden arviointiin käytettyihin indikaattoreihin, joita ovat esimerkiksi SAIDI, SAIFI ja MAIFI. Näiden arvojen parantamisella on suora yhteys jakeluverkkoyhtiöiden sijoitetun pääoman tuottoon.

Tämän työn tulokset, eli älykkäät jakelumuuntamokonseptit eri markkina-alueilla, sisältävät joitain yhteisiä ominaisuuksia. Näitä ovat kauko-ohjaus, tilatietojen seuranta sekä mittaukset. Maakohtaisissa ratkaisuissa esitellään esimerkiksi kaksi eri konseptia käämikytkimen hyödyntämiseen jännitteensäädössä. Jännitteensäätöön esitellään myös yksi loistehonsäätöä hyödyntävä konsepti. Tuloksissa esitelty teknologia on jo markkinoilla ja se voidaan välittömästi ottaa käyttöön jakeluverkkoyhtiöiden ja sähkön loppukäyttäjien hyödyksi.

PREFACE

This Master's thesis is written as part of the Smart Grids and Energy Markets program (SGEM) of Cluster for Energy and Environment (CLEEN) financed by both Tekes – the Finnish Funding Agency for Technology and Innovation, and the ABB Oy.

In this thesis I'm reaching out to the electricity distribution system stakeholders trying to sew their interests together while keeping the eye on the future of regulative electricity markets.

The especial challenge in this thesis was the vastness of the topic and the many influencing factors involved. The viability of certain technical solution highly depends on the market environment and political atmosphere. The almost overwhelming amount of different use of subsidies, taxation, legislative measures is in itself enough for much wider research. Still I see it essential to understand at least the basics of the complex system with all its national drivers included to fully understand the customer needs.

I want to give credit to the following persons for making this work possible. First of all it should be noted that definitely this thesis would not be reality without my excellent supervisor Dick Kronman from ABB and professional advisors and examiners professors Pertti Järventausta and Risto Raiko from the Tampere University of Technology.

Along the road many people contributed to this thesis by adding their advice and years of expertise. Especially at ABB I'd like to mention Sören Mattbäck for revising the basics and beyond of the physical laws in electricity as well as showing the best lunch places. Jarkko Holmlund I thank for insights to the secondary substation solutions and telling maybe the best jokes. I appreciate the help of Enrico Ragaini for offering his huge contact network of experts to be interviewed. Cheers Steve Atkins for not easily accepting my first fumbling deductions regarding regulatory frameworks. For all the people in our Grid Automation Center of Excellence team I only have one comment: I salute you. Thank you Satu Berg for your always positive attitude, it's worth gold. Ida Rimpiläinen your mental support was also appreciated!

Thank you all the interviewees. The interview summaries are in my opinion definitely the best part of this thesis. At least that part took longest to prepare.

Finally and most importantly I want to thank my family for supporting me all the way to this point. I still have the same twinkle in my eye as when I was younger. Taking and holding responsibility definitely does not include losing the genuine attitude for life. For this I fight until my last breath.

I love you Tytti for being who you are.

CONTENTS

ABBREVIATIONS AND NOTATION

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
ASIDI	Average System Interruption Duration Index
CAPEX	Capital Expenditure
CDU	Christian Democratic Union of Germany
CEER	Council of European Energy Regulators
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CSU	Christian Social Union in Bavaria
DCS	Distribution Control System
DE	Germany
DEA	Data Envelopment Analysis
DER	Distributed Energy Resources
DG	Distributed Generation (Dispersed Generation)
DMS	Distribution Management System
DR	Demand Response
DSO	Distribution System Operator
EA	Energy Authority (past: EMA)
EMA	Energy Market Authority
ETS	Emissions Trading System
EU	European Union
EV	Electric Vehicle
FDIR	Fault Detection, Isolation and Restoration
FI	Finland
FIT	Feed-In-Tariff
FLIR	Fault Location, Isolation and Restoration
GHG	Greenhouse Gas
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HEMS	Home Energy Management System
HMI	Human Machine Interface
HV	High Voltage
ICT	Information and Communications technology
IEA	International Energy Agency
IED	Intelligent Electronic Device

IPCC	Intergovernmental Panel on Climate Change
IT	Italy
LED	Light-emitting Diode
LM	Load Management (equal to Demand response)
LoM	Loss-of-Main
LTE	Long Term Evolution
LV	Low Voltage
MAIFI	Momentary Average Interruption Frequency Index
MV	Medium Voltage
OECD	Organisation for Economic Co-operation and Development
Ofgem	Office of Gas and Electricity Markets
OHL	Over-Head Lines
OLTC	On-load tap-changer
PLC	Power Line Communications
PV	Photovoltaic
QMS	Quality Monitoring System
RAB	Resource Asset Base
RES	Renewable Energy Sources
RES-E	Electricity based on Renewable Energy Sources
RIIO	The network regulation model of Ofgem
RTDS	Real-Time Digital Simulator (in Power system simulations)
RTU	Remote Terminal Unit (e.g. in substation measurements)
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SCM	Supplier Centric Model
SFA	Stochastic Frontier Analysis
SG	Smart Grid
SGEM	Smart Grids and Energy Markets
SPD	Social Democratic Party of Germany
StoNED	Stochastic Non-smooth Envelopment of Data
T-SAIDI	Transformer SAIDI (used in Finland)
T-SAIFI	Transformer SAIFI (used in Finland)
TSO	Transmission System operator
V2G	Vehicle-to-Grid
VVO	Volt and VAr Optimization
CAPEX	Capital Expenditure
TOTEX	Total Expenditure
CB_t	Change balancing
$C_{D,i}$	Reasonable cost of interest-bearing debts in the year i
$C_{E,i}$	Reasonable cost of equity in the year i

$C_{i,0}$	Influenceable costs in the year i
$C_{iB,0}$	Temporary non-influenceable costs in the year i
$C_{ni,t}$	Permanently non-influenceable costs in the year i
CPI	Consumer Price Index
C_t	Allowed revenue [€] on year t
D_i	Amount of interest-bearing debts invested in network operations at the end of the year i
EF_t	Extension factor
E_i	Amount of equity invested in network operations at the end of year i
I	Current
$KOPEX$	Influenceable OPEX of the DSO
LC_{t-0}	Grid losses
n_j	The amount of interruptions experienced by the customer j
N_s	The amount of all customers
OC_{act}	Actual Outage Costs for the year [€]
OC_{ref}	Outage costs reference level [€]
$OPEX$	Operational Expenditure
P	Real power
Q	Reactive power
Q_t	Quality factor
RAB	Regulated Asset Base
$R_{k,post\text{-}tax,i}$	A reasonable return [€] on electricity network operations after corporation tax in the year i
S	Total power
SF_t	Future Smart Grid factor
$STOTEX$	Reasonable demand for efficiency increase [€]
t	Index year in the regulatory framework
t_i	Corporation tax rate in the year i
t_{ij}	The outage time to customer j due to interruption i
U	Voltage
V_t	Allocation factor of the year i
$WACC$	Weighted Average Cost of Capital
XF_t	Productivity factor for general efficiency increase
Θ	Phase angle

1. INTRODUCTION

The first chapter gives a preview to the topic, to the expectations from the thesis supervisors and to the structure of this thesis.

The rapid change in energy systems worldwide is widely acknowledged as the next global shift in energy policies. In the 18th and 19th century it was a shift from human or animal labour to the steam engine driven industrialization, mostly fuelled by coal. In the 21st century it's a transition from fossil fuels to renewable energy sources, from centralized energy production and distribution to a more decentralized one. This change has its advantages, of which the environmental ones cannot be stressed too much.

The human has changed the world in many ways during the recent centuries. The atmospheric global warming together with polar ice melting and warming of the oceans is caused by emitting unnatural amounts of Green House Gases (GHG) such as carbon dioxide to the atmosphere. This is mainly the outcome of coal and other fossil fuels in energy production.

Due to the struggle of the International Panel on Climate Change (IPCC) and numerous individuals as well as organizations it is foreseeable that the nations of the world will start to act together for a cleaner, more sustainable world. It will remain to be seen however if the co-operation will happen fast enough and whether the consensus will spread wide enough to prevent extreme long lasting environmental effects such as the rise of global water levels, increase of droughts, decrease of diversity or an increase of extreme weather events.

Due to the arisen acknowledgement of the global warming, in March 2007 the European Union (EU) set goals to cut its GHG emissions by 20% from the 1990 levels, increase energy efficiency of the EU by 20% and increase the share of energy consumption to 20% to be supplied by Renewable Energy Sources (RES) by 2020. The targets are referred to as the EU 20-20-20 goals. These goals are the main driving force for the energy politics in the EU. Naturally also other factors affect the decision making. Especially national energy sources and the energy independence are of great interest to local governments: In Finland the discussion around peat is never-ending, in Germany the proven reserves for coal and shale gas are under debate and the Italian government has said it will increase the share of local hydrocarbon production while also increasing its share of renewables in energy production. These three countries are in the focal point of this work due to their exemplary differences in legislation, regulation and mix of electricity generation.

The present knowledge mainly gained through the IPCC determines that in order to keep the impact of global warming in tolerable limits, the warming is to be restricted to the maximum of 2 ºC, although the present global development is leading to much more worrisome numbers. In order to keep the only 2 ºC rise within realizable future prospects the European energy strategy goals are set beyond the year 2020. The present roadmap sets ambitious limits for the European energy future: The domestic GHG emissions must decline by 80% from the 1990 numbers, and the low-carbon electricity production must be in the order of 100% by 2050. An improved Emissions Trading System (ETS) will play a critical role in attaining these goals.

In addition to the ETS, the national subsidies play a role in the present market guiding system. In Finland, there are Feed-In-Tariffs (FITs) set for the wind and biomass based energy production, but this is just the tip of the iceberg. Germany has seen the steady development in the use of RES as well as in the energy policies that make the development possible. Germany's over a decade long strong government-led will for renewables is rewarded today by the flagship position in the renewable energy markets, while having a strong say in the energy policies of the whole Europe.

The European electricity markets are expected to merge, but the road is long. The price areas that exist today due to both technical and market barriers have an effect on the viability of renewable energy generation: Governments and companies in the Nordic countries with on average low electricity Spot-prices and little less sunshine do not have the same economic incentives for investing in solar photovoltaic (PV) than those in the Middle or Southern Europe. Then again the abundant hydro power and biomass reservoirs create opportunities of different sort for the short term energy production development. Despite the vivid discussion, Finland and Sweden still relay also on nuclear power as an important and close to carbon emission neutral option.

All the change and strong involvement of political decision making makes it hard for even organizations such as the International Energy Agency (IEA) to predict the future energy mix in the EU. The speed of rising installed capacities of wind and solar based generation has been higher than predicted, although the shares of renewable total electricity production still remain to be relatively low in the EU level.

The economic regression in EU is not helping the situation, where huge investments in the energy production and electricity transmission and distribution are to be made. The times are hard especially for traditional utilities that are used to relatively high profits and little need for external capital. Traditionally the lion's share of the income of a Distribution System Operator (DSO) has been related to the amount of energy distributed. This is cut by especially the PV: The more consumers also produce their own energy and so become prosumers, the more one cornerstone of income of the utilities might narrow. In the rise of Distributed Generation (DG) the DSOs have to prepare themselves with new models of making business, e.g. from energy based to power based tariffs.

On top of the tight economic situation in the credit side, also the debit of the DSO business model is firmly under reassessment. DSO and Transmission System Operator (TSO) businesses are natural monopolies that are under governmental regulation in order to preserve the competitiveness of the system operators and give them incentive to increase their effectiveness. Every country has their distinct model for the regulatory framework that is an outcome of political decision making. All of the regulatory models assessed in this thesis are based on the incentive based regulation model. Its core idea is to regulate the monopoly companies in order to ensure their efficient operation and the consumer benefit by setting target values for e.g. investment efficiency, operational efficiency and the distribution reliability.

The regulatory models assessed in this thesis consider among other factors the historic development of the company economy and operational indicators. Regulatory frameworks are country specific. The regulation compares DSOs of a country with each other in order to reward the efficient and to penalize the inefficient ones. Determining efficiency criteria however is not straightforward. For instance usual and necessary components that include automated capabilities for grid reliability are generally more expensive than corresponding simpler components. Therefore investments in these automated components or solutions appear inefficient or in other words more expensive compared to their traditional equivalents when only comparing the initial investment per customer or other similar indicators, which does not include the assessment of total costs during the lifetime of the investment. Most of the regulatory frameworks do include incentives for reducing outage times and numbers, but these reliability incentives do not always have large impact to guide the investments towards more intelligent systems.

The challenge is that while a rising share of intermittent renewable DG is being implemented, the grid has to cope with increasing amount of tasks that before were not parts of the portfolio. One widely acknowledged challenge for the grid is the possible bi-directionality of the power flow. Traditional power flow from large power plants to High Voltage (HV) transmission, from there to Medium Voltage (MV) distribution and further to the Low Voltage (LV) household and small commercial customers is not all the time the case in the probable near future scenario of the electric grid.

It is not even the case today in parts of e.g. Germany with high PV-penetration. The power flow from a vastly spread domestic PV generation capacity already now at times exceeds consumption and the grid must cope with the LV grid feeding the MV grid through the secondary substations. The most important challenges related to the change represented by the bi-directionality or even of the grid are considered in this thesis.

In addition to incentive based regulation framework, the national regulation consists of technical specifications in the form of grid codes as well as legislation. For example in Finland during the resent years the long outages caused by exceptional storms have been a key driver for a new legislation that took place in September 2013. The legislation sets strict rules for outages and is a key driver for investments to the grid in the short, middle and the long term.

Definitely there is a need for smart solutions. Together these solutions that can handle the RES scattered around the distribution grid and the increased demand for reliability are called the Smart Grid (SG). There are many important nodes in the net of information that covers the whole SG concept. One of them is the secondary distribution grid with the secondary substation as its hub for energy and information.

1.1. The objectives and the scope of the thesis

The main objectives and research questions formed together with the ABB Ltd, CLEEN Ltd and the Tampere University of Technology are:

- *What are the current mechanisms in the regulatory frameworks that push the market for automation in the secondary substations increasing grid reliability?*
- *What are the future mechanisms in the regulatory frameworks that would push for technical solutions enabling integration in large scale of distributed energy resources?*
- *What are the key future automation capabilities in the secondary substations that meet the customer needs and are viable for commercialization within the expected development of the regulatory framework?*

The focus countries in the research are Finland, Germany and Italy. The three countries represent different approaches to the regulatory framework. Even though models of these countries are all based on incentives and the regulation of DSO revenue, there are distinct differences regarding e.g. investment categorization, the DSO efficiency evaluation and grid net present value evaluation. In addition the energy mix and the amount of DG of the country in question have to be taken into consideration.

Since the countries have developed different energy market structures and have variation in the technical solutions for the electricity distribution, the results for all the case countries are expected to be different.

The change from fossil fuel based energy system to renewable based, in German *Energiewende*, is affected by various factors. For instance, on the economical side the rising cost of household electricity is an important factor in two ways. Firstly it is a burden for the people regardless of their level of income, only related to their need for electricity. Secondly the higher price is an incentive for further installing renewable electricity generation capacity.

Aside from the economical evaluation the technical aspects are rarely precisely and accurately considered in the public debate. All of the technical solutions existing will not be represented in this thesis. As an example: A total of 19 technical solutions can be found to the challenge of integrating solar photovoltaic (PV) to the electricity grid (Vandenbergh et al. 2013). In this thesis, based on the literature review and expert interviews, the most viable solutions will be presented for the future needs at the secondary substations in the electricity distribution grid.

This thesis will focus on how the national regulative authorities will combine the EU and national energy policies to route the development of future distribution grids. A specific focus will be put on those secondary substations that function in the interface between the MV and LV networks.

1.2. Structure of this work

The core idea of the thesis structure is to give the reader an extensive overview of the situation of the customer i.e. the DSOs. In order to understand the customer needs, the business environment is presented. Based on the change in electricity mix the need for grid balancing is increasing. The regulatory framework simulates the market and focus on cost efficient way to meet the future challenges. The technical solution must be viable in regard to the energy market, market regulation and technical needs. This is the foundation of the conducted research. This idea is visualised in the Figure 1.

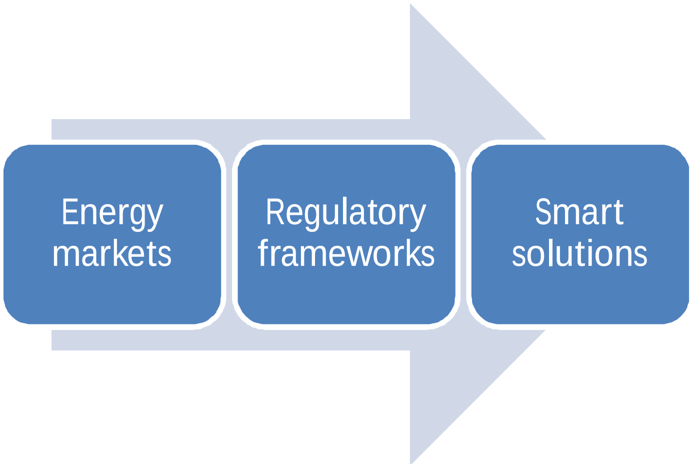

Figure 1 Foundations of the conducted research

The chapter 2 gives the reader an overview of the challenges and opportunities in the distribution grids in regard to the required smart solutions. In addition to introducing the current status in cabling and smart metering, the chapter also introduces the concept of power quality and the present ABB solutions for smart secondary substations.

The chapter 3 introduces the global warming as renewable energy driver and gives insight to the market mechanisms related to the RES implementation. The chapter enlists possibilities for power system balancing in the distribution grid and introduces the most common methods for large scale energy production.

The chapter 4 shows the reader the cornerstones of the DSO regulatory frameworks. General assessments of the framework functionality and specific notes about the smart grid friendliness in specific frameworks are discussed to give an overview of regulation in the focus countries and in some cases in selected reference countries.

The chapter 5 summarizes results from about 40 interviewee opinions related to the energy market development, regulatory framework effects on smart investments and their vision of the secondary substation as part of the future distribution grid.

Lastly chapter 6 draws together the learnings from both literature based analyse and the interview results. Evaluation of viable solutions is conducted. Separate technical feature enlistments for smart secondary substations for Finland, Germany and Italy are among the key outcomes of this research.

2. SECONDARY DISTRIBUTION SYSTEMS

This chapter gives the reader an introduction to the prevailing technical environment regarding secondary substations. The role of secondary substation in secondary distribution grids is identified.

The modern power system is based on the balance of electricity generation, transmission or distribution, and consumption. The transmission is handled by the high voltage AC feeders that can deliver great amounts of power with relatively low transmission losses compared to distribution with lower voltage levels. Transmission systems are operated by separate national Transmission System Operators (TSOs).

The distribution consists of Medium Voltage (MV) and Low Voltage (LV) networks. Their function is to create sufficient distribution coverage for the benefit of the consumer with reasonable investment and maintenance cost level. At the same time reliability levels determined by the regulative authorities have to be maintained. (Lakervi & Partanen 2009) This thesis focuses on secondary substations which act as interface between the MV and LV grids.

The life times of electrical devices in electricity systems are typically in the order of 20 to 30 years (Lakervi & Partanen 2009). This makes it increasingly important to found the investment decisions carefully. Also, investing costs being a dominating part of the cost of many of the Intelligent Electronic Devices (IED) such as protection relays, DSOs are by economic realities led to take full advantage of the investments. For instance this means that the functionalities of Automatic Meter Reading (AMR) systems will be examined carefully before other investments are to be made.

2.1. The characteristics of secondary distribution grids

The countries in the focal point of this thesis are different in terms of distribution networks. As seen from the Table 1 the Over-Head Lines (OHL) are the dominating feeder technology in Finland and Italy. In Germany most of the MV grid consists of underground cable network.

Table 1 Network key figures in selected countries (Casemore & Gohn 2010)

Country	OHL %	Cable %	MV (km)	Primary substation (#)	Secondary substation (#)	Sec. s/s per MV kilometre (#/km)
Finland	78	22	138 000	2 000	50 000	0,362
Germany	30	70	493 000	6 000	557 000	1,13
Italy	71	29	380 000	2 400	424 000	1,12

The amount of MV grid in kilometres and the amount of primary and secondary substations in the Table 1 are shown to give perspective to the focus country's distribution grid structures: The German and Italian grids are denser with more secondary substations divided with the MV grid kilometres as indicated in the last column of the table, Sec. s/s meaning secondary substations.

Other possibilities for feeder structure are overhead lines with bare conductors, overhead lines with covered conductors, aerial cables, underground cables or a combination of such line and cable sections. The feeder lines together with e.g. transformers form the distribution system can be: (1) effectively earthed or (2) non-effectively earthed i.e. compensated. (Casemore & Gohn 2010)

2.1.1. Smart metering

Smart metering includes the DSO to bill the customer based on actual hourly measured data. It also adds power quality measurement points to the grid. Depending on the DSO these measurements can be used for various purposes from close to real time network management and operation to only once a day read billing meters. (Hiscock 2013)

Four out of the 16 European countries that have plans for smart metering implementation have set the goal of metering to be ready by 2013. The first smart meter implementers were Sweden with complete roll-out ready by 2009, Italy where roll-out was complete in 2011 and Finland and Malta with the focus for desired penetration of meters in the end of 2013. Countries such as France and Great Britain have set their roll-out completion goals to be ready by 2019 as shown in the Table 2. (EURELECTRIC 2013)

Table 2 Smart meter roll-out status examples in 2013 (EURELECTRIC 2013)

Country	Status	Beginning year	Completion year
Finland	Completed	2009	2013
Germany	Under discussion	-	-
Italy	Completed	2000	2011
Norway	Mandated	2014	2017
Great Britain	Mandated	2014	2019
France	In planning stage	2013	2019

The Table 3 concludes the development phase of the smart meter implementation by different functionalities. As can be seen the functionalities in Finland and Italy that have the smart meters are fundamentally the same. The abbreviation FI represents Finland, DE Germany and IT Italy.

Table 3 Smart meter functionalities (Hiscock 2013)

	Remote meter collec-tion	Dynamic tariffica-tion	Interval metering	Theft detection	Outage detection	Remote connect/ disconnect	Customer web portal	Meter-to-home
FI	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**P**
DE	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**
IT	**D**	**D**	**D**	**D**	**D**	**D**	**D**	**P**

Nation-wide effort

Jurisdictional effort (province or state)

D = Planned, Partial or Full Deployment

P = Pilot

Italy was the first to implement the smart meters and Finland has them since 2013. Italy is already benefitting from them e.g. through trying out Demand Response (DR) solutions as highlighted in the chapter 3.2.3. Germany just recently decided not to have a national smart meter roll-out but to concentrate on selective roll-out of meters where they are needed. The German meters are implemented for power quality supervision rather than for billing purposes. (Bloomberg 2013)

The different functionalities of smart meters are various. In the Table 3 the remote meter collection enables customer consumption data to be electronically collected and digitally sent to DSO for billing purposes. The dynamic tariffication includes option of changing the customer electricity price according to time of the day or e.g. according to energy market prices. Interval metering means measuring hourly or sub-hourly consumption data. Theft detection compares the metering data with system data in order to find non-technical or otherwise explainable losses. Outage detection communicates with the utility control room in case of power outage. (Hiscock 2013)

A note appropriate here to make is that in case of a prosumer i.e. a combined electricity producer and consumer the protection configuration has to be considered more carefully than in a case of a simple consumer point. Power measurement from the smart meter of the customer is not a safe and sufficient solution for grid operation. While DG is installed a situation can occur when the DG provides power inside the normal operating threshold of the LV grid. From the viewpoint of the smart meter the grid may still operates normally even though an outage occurs elsewhere in the grid. So if relying only on measurements of the smart meter the Distribution Management System (DMS) and the control room of the DSO is unaware of the actual situation. (Olivieri et al. 2012)

The rest of the smart meter functionalities include the remote connect and disconnect option: The DSO can separate the customer from the grid in case of an abnormal situation. The web portal functionality enables customers to view their own data via online application. The meter-to-home means communication of the smart meter with e.g. HEMS is enabled. Meter-to-home is introduced in Finland but according to the source only piloted in Italy. (Hiscock 2013)

2.1.2. Power quality

The definition of power quality is complex and has many variables. The following summary has been created in the Tampere University of Technology together with Lappeenranta University of Technology. The important aspects regarding power quality and distribution reliability are illustrated in the Figure 2.

When defining the power quality the aspects related to reliable power distribution are of great importance. Especially from the customer point of view the reliability means availability: how reliable the DSO is in being able to deliver the customer with electricity.

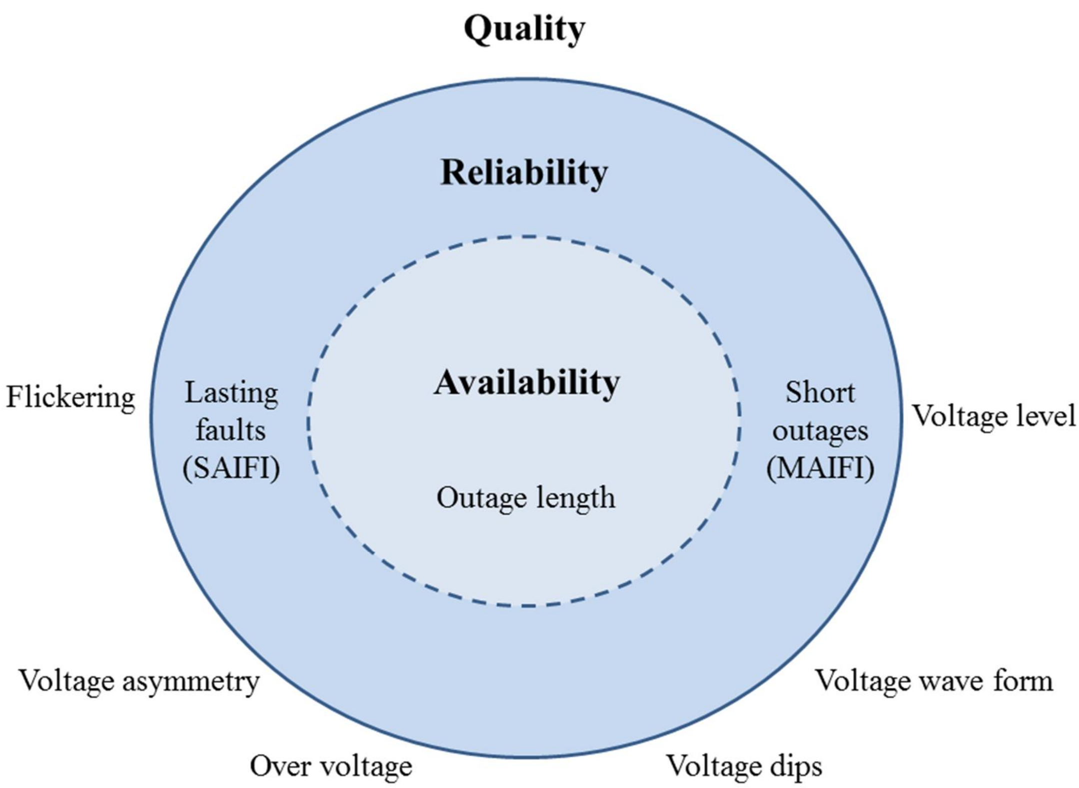

Figure 2 Power quality explained (Partanen et al. 2010)

According to the source (Partanen et al. 2010) the electricity distribution reliability is formed by the grid operational security and network reliability. The distribution reliability represents the average reliability of electricity supply. The grid operational security is the probability by which the grid, to a required extent, fulfills the functionalities set to it in a specific timescale and under the prevailing circumstances. Therefore the grid operational security reflects the system availability i.e. the feasibility of fulfilling the requirements set for the system to carry out.

The network reliability presents the probability of these requirements to be realized. A main functionality of the electricity distribution grid is to supply the customers with power. Thus the grid operational security can be enhanced with all the measures that enable the electricity supply to the customers to continue despite malfunctioning in some parts of the grid. The system reliability on the other hand can be enhanced with solutions that decrease malfunctions of system parts.

On a system scale all the actions that upgrade system operational security do not necessarily heighten system reliability. The operational security actions however always enhance distribution reliability, in the meaning of average reliability of supply. Typically still the same actions are taken for the grid reliability.

A simplified example clarifies the past two paragraphs: The network reliability can be improved by reducing faults while operational security can be improved by restricting the faults to affect as small area as possible. (Partanen et al. 2010)

In the standard IEEE 1366-2001 the most common delivery reliability indexes are defined. They are called as follows (IEEE 2001):

- SAIFI (System Average Interruption Frequency Index)
- CAIFI (Customer Average Interruption Frequency Index)
- SAIDI (System Average Interruption Duration Index)
- CAIDI (Customer Average Interruption Duration Index)
- MAIFI (Momentary Average Interruption Frequency Index)

Out of these the SAIDI and SAIFI are most referred to when explaining the benefits of automated grid solutions. The SAIDI, SAIFI are calculated as follows. Also often used CAIDI is SAIDI divided by SAIFI. (Partanen et al. 2010)

$$SAIDI = \frac{\sum_i \sum_j t_{ij}}{N_s} \qquad (1)$$

Where t_{ij} *the outage time due to interruptions experienced by the customer j*

N_s *the amount of all customers*

$$SAIFI = \frac{\sum_j n_j}{N_s} \qquad (2)$$

Where n_j *the amount of interruptions experienced by the customer j*

N_s *the amount of all customers*

Line reclosers and switch disconnectors divide the feeders into protection zones and so decreases the amount of customers affected by the fault i.e. lowers the SAIFI value. Controlling these components remotely further decreases the SAIDI since the power can be restored faster to the areas of the grid that are not affected by the fault. (ABB Grid Automation)

Supply disturbances

The distribution grid has a few most common fault situations that together form the major part of the grid outage time. The most common fault situation is the single phase-to-earth fault. Other types are phase-to-phase-to-earth fault, cross-country faults and back-fed earth faults.

The standard EN 50160 determines the required quality of electricity. It determines the main characteristics of electricity and its quality boundaries. It’s very challenging for the energy regulator to supervise these values, and therefore the possible remuneration or penalties are up to now laid upon a DSO through complaints received.

The EN 50160 divides downtime situations into two categories: faults and planned outages due to maintenance. An outage is approved as planned situation if the influenced customers have been informed of it in advance. The actual fault situations are divided into voltage dips, short outages and long outages.

Voltage dips are reductions in voltage with the voltage value being between 1 % and 90 % of its nominal value, lasting for 10 milliseconds to 1 minute. The short outages have a downtime less than three minutes. These outages mainly consist of fast reclosing operations and delayed reclosing operations. (EN 50160) These operations aim to clear the fault and restore the power with no occurrence of a lasting fault.

The single phase-to-earth fault is clearly the most common fault situation in the distribution grid. It is generally caused in MV OHL network by a tree falling on the feeder lines. Phase-to-phase fault is quite common and can include two or three phases. Other, more seldom occurring fault types are phase-to-phase-to-earth faults, cross-country faults and back-fed earth faults. The phase-to-phase-to-earth fault can be detected with earth fault protection or the short-circuit protection. (ABB 2011)

Reactive power

The capacity for total power in distribution grid is limited. As the electrical appliances such as electrical motors, lighting, home electronics and so on can only consume active power so the reactive power is mainly a hindrance for effective power distribution. When the full capacity of the distribution grid is needed during the moments of high demand, the reactive power is to be minimized in order to maximize the share of active power. Some appliances require reactive power in order to function, but this need can be satisfied with local generation.

Different power components can perhaps the easiest be presented through the triangle form. The total power also referred to as the nominal power is the vector sum of the active and reactive power as illustrated in the Figure 3.

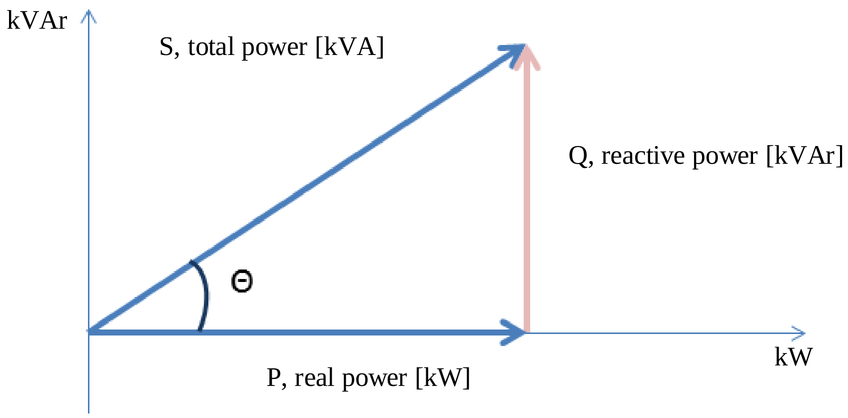

Figure 3 Reactive power in relation to total power (ABB 2000)

The Figure 3 is the graphical presentation of the known physical laws for AC power distribution. These important basics that form the foundation for active voltage regulation presented in chapter 2.2.2 are in another way easily adoptable from equation form as presented below for 1-phase case. (ABB 2000)

$$P = U * I * \cos \Theta \quad (3)$$

$$Q = U * I * \sin \Theta \quad (4)$$

$$S = U * I = \sqrt{(P^2 + Q^2)} \quad (5)$$

Where	*P*	*Real power*
	U	*Voltage*
	I	*Current*
	Q	*Reactive power*
	S	*Total power*
	Θ	*Phase angle*

The reactive power also needs to be kept within a standard window. The DSO is itself responsible for the transmission system operator (TSO) for the amount of reactive power in its grid. DSO buys and sells electricity from and to the TSO. The free of charge reactive power amount in the trade can range from 16 % inductive to 4 % capacitive reactive power amount compared to the true power (P). In regard to the Figure 3 the percentages equal to the equation 6. (TSV 2012)

$$\tan \Theta = [-0.04..0.16] \quad (6)$$

If the DSO does not keep within these limits, it has to pay sanctions to the TSO. Therefore also the DSO implements sanctions for its customers in order to incentive customers in compensating their own reactive power. The sanctions are calculated on monthly basis. As an example for the customers of a Finnish middle size DSO *Tampereen Sähköverkko Oy* the sanctions for exceeding the limits for a customer with billing real power being between 125 kW and 250 kW are from 1st of January 2014 onwards as follows (TSV 2012):

- Free of charge when Q is between -12.5 kvar and 50 kVAr
- 1.25 €/kVAr, when Q = 50 kvar…0,4*P (kVAr)
- 6.25 €/kVAr, when Q > 0,4*P (kVAr)
- 6.25 €/kVAr, when Q < -12,5 kVAr (overcompensation)

The Figure 4 is an exemplary illustration of sanctions that customers of a DSO in Finland have to pay in case of exceeding the limits for producing or subtracting reactive power in the distribution grid. The horizontal axis represents reactive power in kvar while the vertical axis illustrates the amount of sanction in Euros.

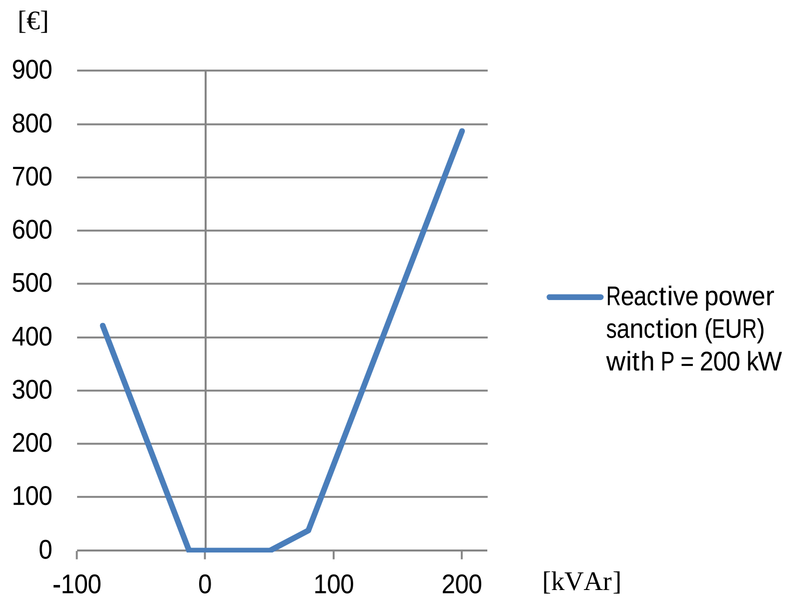

Figure 4 Example of reactive power sanctions in Finland (TSV 2012)

The example above shows a consumer with 200 kW of real power. For a smaller customer with real power 125 kW or less the limits and sanctions only apply to the inductive reactive power. Another example for 100 kW is listed below. The free of charge reactive power window is the same as in the example in Figure 4. The limits are (TSV 2012):

- Free of charge, when Q is between -12.5 kvar and 50 kvar
- 6.25 €/kvar, when Q > 50 kvar
- 6,25 €/kvar, when Q < -12,5 kvar (overcompensated)

The Figure 5 shows another exemplary (different from previous examples) view on the issue. In the figure there are customer values for one month amount of reactive power submitted to or subtracted from the grid. In the figure each dot represents a few individual customers, and the figure is a simplification of the original data. As can be seen, on the capacitive side some customers have had to confront sanctions from the DSO.

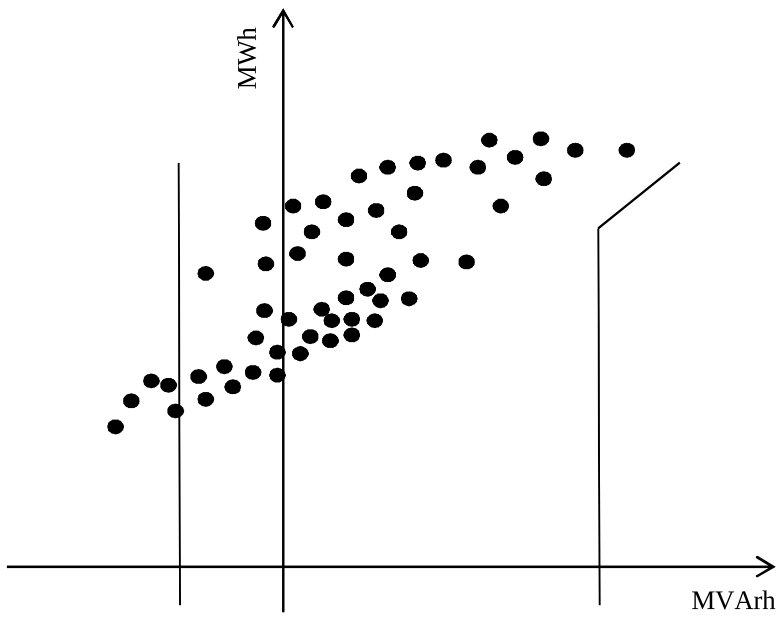

Figure 5 Reactive power window in May 2012 for a Finnish DSO (Virtanen 2013)

Harmonics

Power quality disturbances are not restricted to voltage levels and reactive power. While DG is becoming popular, harmonics increase.

Harmonics are mainly a product of power electronics such as PV inverters or LED lightning. Harmonics are voltages that have a multiple frequency compared to the basic frequency. The effect of harmonics in the distribution grid can be e.g. overheating of the electronic equipment and neutral conductor overload. (Elovaara & Haarla 2011)

Inefficiencies

According to the source the losses in distribution networks in Germany can be evaluated as follows in the Table 4. The exemplary grid under evaluation has 1.4 million residents with about 0.8 million consumer points to the LV grid and 3000 consumer connections to the MV level. More than 80 % of the lines consist of cable. 3.5 GW of DG is installed to this grid with wind power covering a rough 70 %, PV about 20 % and biomass 8 % share of the power mix. (Heckmann et al. 2013)

Table 4 Distribution of the losses on the grid levels (Heckmann et al. 2013)

Grid levels	Northern Germany
HV/MV substations	10 %
MV grid level	34 %
MV/LV substations	14 %
LV grid level	42 %
Total	100 %

The figures in Table 4 cannot be generalized. The French secondary substation losses are estimated to be 36 %. About 79% of the secondary substation losses are not dependent on load. (Heckmann et al. 2013) Even though the distribution of losses does not give information of the amount of losses, the percentages that are presented above give direction to the evaluation of the grid loss reduction possibilities.

Understanding the structure of the losses and improving the efficiency of the distribution system is becoming more important for the DSOs because of the regulatory framework development. (Heckmann et al. 2013) This is discussed in precision in the chapter 4.4.1.

2.2. Solutions to the challenges

One core reason for developing smart grid solutions is to increase the reliability of the grid by reducing outage times (Elovaara & Haarla 2011).

There are multiple solutions to improving and maintaining the reliability of supply in the distribution grids. The source (Lågland 2012) has estimated the effects of different reliability improving investment strategies for the Finnish MV distribution system that mainly consists of OHL. The Figure 6 presents the automation methods that are effective in improving the electricity distribution quality and reliability in Finland. E.g. cabling is presented later on. The T-SAIDI, T-MAIFI and T-SAIFI are the secondary substation measuring based estimated equivalents of respective SAIDI, MAIFI and SAIFI values. The latter are based on actual customer data (Partanen et al. 2010).

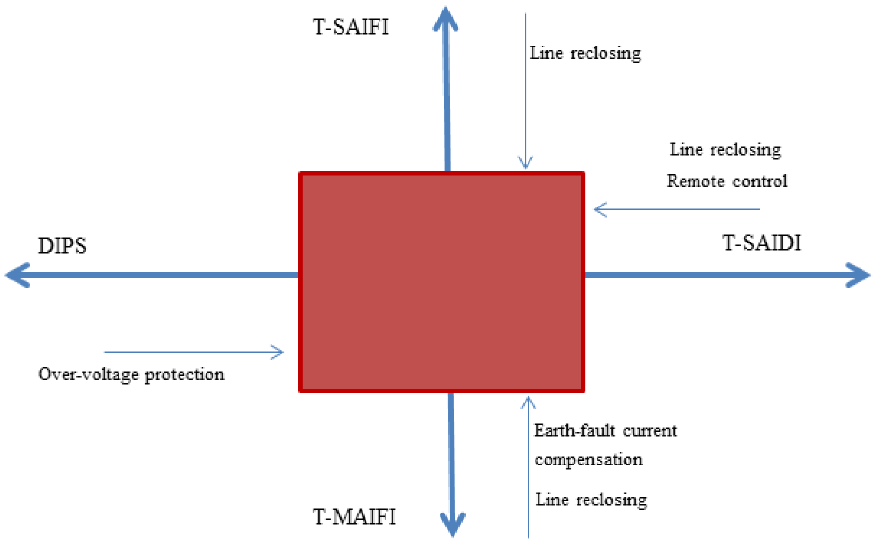

Figure 6 Grid Automation reduces fault effects (Lågland 2012)

The SAIDI value can be best reduced with remotely controlled line reclosers that include protection function. This solution influences three aspects of the presented quality challenges in Finland. Earth fault current compensation is becoming more important due to increased earth fault currents that are the outcome of switching from OHL to cable networks. Over voltage protection has an effect in reducing voltage dips that, as highlighted in the chapter 5.4.2, are going to be subject to close observation in Italy.

Network reliability can be enhanced e.g. by installing cable networks to replace OHL networks, by bringing the grid from forest areas to road sides and by replacing OHL with coated wire. Grid operational security can be further improved with automation solutions, adding ring connections, with protection zones and by enforcing the operational efficiency of maintenance organization. (Lågland 2012)

The reliability of supply, as shown in the Figure 2 on page 9, represents the availability of supply from the customer perspective. The reliability of supply is presented with customer oriented indexes such as SAIDI, SAIFI and MAIFI. (Partanen et al. 2010)

Cabling

Compared to OHL, underground cabling can decrease the SAIFI of a network to 20 to 50 % of the initial value. Also the short outages are greatly reduced. On the other hand it might be hard to locate the fault in a cable network. Cable network investment cost is also higher than that of OHL. (Partanen et al. 2010)

Fault Detection, Isolation and Restoration

The Fault Detection, Isolation and Restoration (FDIR), sometimes referred to as Fault Location, Isolation and Restoration (FLIR) is one of the main focus of Grid Automation concept. Its aim is to reduce the outage time by locating the occurred fault, breaking the fault current with circuit breakers, remotely opening the reclosers closest to the fault location and then restoring the power to all the other areas.

The idea is to divide the grid under consideration into smaller pieces and so to restrict the outage to affect as few customers as possible. Only the small area between the reclosers is still affected by the outage until the field crew removes or repairs the fault. This tremendously cuts down the SAIDI values i.e. the average outage time experienced by an average consumer. (Manner et al. 2011)

The Volt and VAr optimization

With Volt and VAr Optimization (VVO) a utility can increase its efficiency. A rule of thumb outlined in the source (Casemore & Gohn 2010) states that there is a one-to-one correlation between the reduction in voltage and shrinkage of power demand. In other words a 1% reduction in the other reduces also the other with 1%. Efficiency increases up to even 3 % could be attained with VVO according to the source. (Casemore & Gohn 2010)

The idea of VVO is to operate the grid at an optimal voltage level and with an optimal relation between real and reactive power. This helps to get most of the existing infrastructure, delaying the need for investments. Equally interesting is that through VVO solution the DSO can make justified investment decisions based on decreased energy costs or delayed CAPEX. The VVO solutions are mainly viable when invested within regulatory frameworks which emphasize efficiency related to energy and assets. (Casemore & Gohn 2010)

2.2.1. Secondary substation functionalities

In between the MV and LV feeder lines there has to be a substation to transform the electric power to a specific voltage level. The primary substation is located in between the HV and MV networks. The secondary substation that is the focus of this thesis transforms the voltage level in between the MV and LV networks. (Lakervi & Partanen 2009)

The structure of the traditional secondary substation has been very simple and has included very limited functionalities. The capabilities at the primary level have been seen sufficient without any remote operation possibilities. The level of automation has been very low, if not missing. Since most of the faults in distribution systems occur in the MV network, the automation has been concentrated to the MV network including the primary substations. Automation capabilities in this context include features such as selective breakers to break and isolate the fault in MV grid in order to restrict the fault to influence as few customers as possible. (Lakervi & Partanen 2009)

The secondary substation of the future will play a crucial role in the future of the distribution grid. The cost of communication and sensor technologies has come down, which is creating demand for these solutions also in the more price-sensitive secondary substation field. Many energy market trends described in chapter 3 are driving the strong market growth for these solutions. An example of such trends is the PV systems.

Due to these reasons alongside with increasing penetration of data management systems and communication possibilities, the source expects secondary transformer monitoring to take over the transformer monitoring market by 2015. Still the accurate adoption rate for secondary substation monitoring remains a question mark and has a lot to do with the value gained by the customers. (Kellison 2013)

The automation and protection investments made to the primary substations have been seen as minor investments in regard to the benefits. Generally the amount of secondary substations in a system can be e.g. in the order of 100 times more than the amount of primary substations. This can be seen from the Table 1. The distributed power and therefore the income through distributed energy per substation are considerably lower in the secondary level compared to the primary level. Therefore the automation solution cost has been considered too expensive for LV networks that were regarded to be of lower importance. (Interview)

The ABB solution for secondary substation today is divided by the customer need into four categories. As can be seen from the Table 5 the different automation capabilities are divided into four categories or levels of automation. For full solution see the Appendix 4. The functionalities cumulate from level to level, so that the level 4 solution includes all the functionalities from voltage monitoring to Fault Detection, Isolation and power Restoration (FDIR).

Table 5 ABB solution (simplified) for distribution automation (ABB Grid Automation)

	Category	Functionalities
Level 1	**Monitoring**	Current, voltage and energy measurement on the LV side
Level 2	**Control**	Level 1 and additional Control of MV and LV primary apparatus
Level 3	**Accurate MV Measurements**	Level 2 and additional Accurate current, voltage and energy measurement on MV side
Level 4	**Protection (or FDIR)**	Level 3 and additional Protection functions with breakers in In / Out going feeders

Some experts prefer to speak about the FLIR i.e. fault location, isolation and restoration. The latter expression stresses the vital point of the concept: to find out where the fault actually is. The idea behind the level 4 capabilities is to cut down outage durations by isolating the fault to as small grid area as possible and so to reduce the outage experienced by most of the consumers in that area. (ABB Grid Automation)

2.2.2. Active voltage control of LV grids

Active voltage control is a common solution at the primary substation level, but only in progress of becoming a common solution at the secondary substation level. The reason is simple: Not before the rise of DG has there been need for LV grid voltage regulation in a larger scale.

Active voltage control at the LV network can be done in different ways. Of the possible solutions e.g. the distribution transformer with tap changer and the reactive power controlling inverters are presented in this chapter. According to the research conducted in this thesis it is these two solutions that form the most promising base for tackling the voltage regulation challenge in LV grids in the present situation in Germany and Italy. See chapter 6 for further information.

The old situation with LV grid is presented in the upper part of the Figure 7 while the lower graph in Figure 7 shows the current new challenge regarding both over and under voltage situations. The Figure 8 on the other hand shows the effect of voltage regulation in maintaining the voltage within allowed threshold.

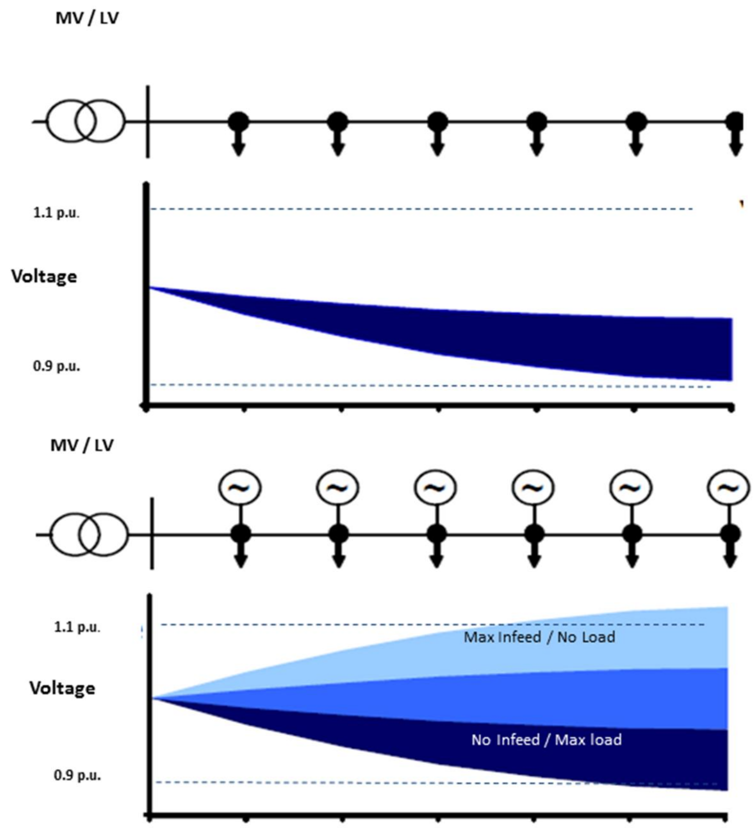

Figure 7 Voltage regulation need. Illustration: (Virtanen 2013)

As seen from the Figure 7 the challenge of voltage regulation is more complex with DG than in the situation without DG. The points in the upper part of the Figure 7 represent consumers. In lower part of the figure these points are equipped with DG. Possible over voltage occur when low consumption and high supply occur at the same time. The allowed voltage deviation according to standard EN 50610 is ± 10 %. This challenge is especially clear in weaker rural distribution networks. (Virtanen 2013)

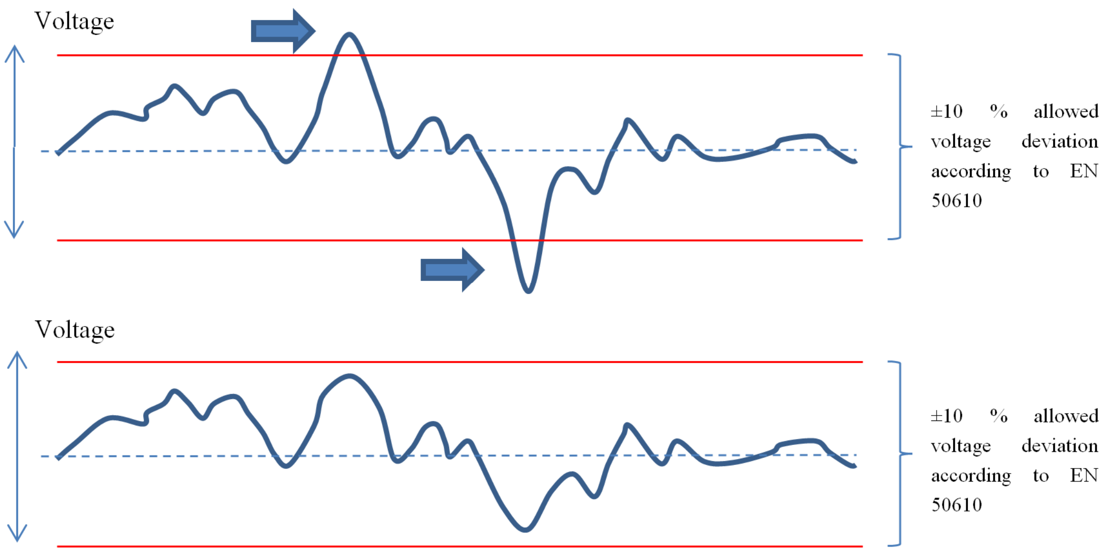

Figure 8 Effect of voltage regulation (Virtanen 2013)

The Figure 8 points out the benefit of voltage regulation concept. On the vertical axis voltage is presented while the horizontal axis represents time. The arrows pinpoint the voltage peak and dip that would in the standard solution break the threshold limits. In the lower graph in the same figure the effect of voltage regulation is illustrated. The voltage control actively shaves the peaks and dips.

Possible solutions for active voltage regulation

The need for voltage regulation is obvious. However there are different solutions for this challenge. From the following technologies the main advantage and disadvantage are presented.

On-Load Tap Changer (OLTC) is a proven solution to the challenge presented above. The concept can be used at the secondary substation level. The main advantage of using an OLTC is that the voltage regulation applies to the entire local network regardless of the grid topology. However the cost of the OLTC transformer is somewhat higher than that of the regular distribution transformer. (Bülo et al. 2012)

Adjustable PV-inverter is an alternative for using the tap changer either on substation or secondary substation level. The LV or MV grid voltage control can be to some extent handled with controllable PV-inverters. The main function of the inverter is to convert the DC produced by the PV-panel to the grid-compatible AC form. If necessary the inverter also can add a specified phase switch to the AC output in order to provide the grid with reactive power for example in case of an occurring outage in order to support the grid. (Bülo et al. 2012)

PV-inverters can function as reactive power tuning devices in order to make most of the PV-inverters also during the time when PV-power is not available. In the source (Maknouninejad et al. 2011) a method is presented of using a single DC bus in drawing some active power from the grid in order to inject a desired level of reactive power to the grid also during the night time.

According to the source (Bülo et al. 2012) the main advantages of the inverter technology in voltage control are that voltage regulation takes place at the source of the voltage increase, the whole local grid is impacted, and all the new installations have the ability available: New PV-inverter installations are legally bound to include the tuning ability of reactive power both in Germany and in Italy. (Bülo et al. 2012; Rödl & Partner 2012)

Combined transformer reactor is a solution specially designed to fit into compact secondary substation. It includes both the distribution transformer and reactor for compensating reactive power. The reactors can compensate e.g. a 10 km cable feeder's reactive power and so also participate in preventing the earth fault current of becoming too high.

Curtailment of distributed generation in Italy is currently handled by the TSO and not allowed at the distribution level. The DSO can request the TSO to curtail certain generation points in order to ensure system security. The capacity that is allowed to be curtailed is that of over 10 MW. Wind farms get compensated at market price for the energy which has been curtailed. In Germany both the DSO and the TSO can use curtailment of CHP plants above 100 kW and PV plants above 30 kW for normal grid operation, and all plants in emergency situations. The compensation is 95 % of lost income in case of congestion in the distribution grid. (Ruester et al. 2013; EURELECTRIC 2013)

Decentralized Electronic Voltage Controllers has a direct effect on voltage. It functions through a common DC-links and includes two converters: one connected to the network and another to a series transformer. The economic viability of electronic voltage controllers could be a challenge compared to PV-inverter technology. (Bülo et al. 2012)

Battery systems, DR and other similar solutions presented in the chapter 3.2.2 currently participate in grid voltage regulation mainly through electricity markets. This is due to utility unbundling explained in chapter 3.3.1.

3. GRID AUTOMATION MARKET DRIVERS

This chapter gives the reader a cross-cutting view of the most important market drivers for the implementation of grid automation in the focus countries. In addition to the intuitive role of renewable energy generation, this chapter also gives insight to the renewable energy effect on the electricity markets. The direction that this development takes could be an important driver for e.g. energy storages and for the viability of balancing power plants.

When reading this chapter it must be bared in mind that the energy markets are guided by various supported structures and differing taxation levels for different energy sources. Even between European countries these mechanisms vary considerably. Therefore the throughout economical evaluation of e.g. a grid automation solution would require a focus to a single case in order to evaluate the viability of the solution. This chapter however gives the reader the ability to put the solution in question to a wider context. Therefore a starting point for further evaluation can be founded. Such a starting point is set for Smart Secondary Substation case by case in the chapter 6 including the effect of regulation. The effect of regulation to grid automaton solutions is covered in detail in the chapter 4.

The ABB conducted a market research in 2010 with Management Engineers about the market prospects for Smart Grid in all its extent. The outcomes of this research were clear: There is huge need for grid automation solutions in Europe during the next years.

The market research gave e.g. the following results that also contribute in adding focus to this thesis (Casemore & Gohn 2010):

- There is consensus among the focus countries energy market stakeholders that the Smart Grid is going to play a role in the future.
- The biggest threats to SG development are the regulatory regimes that are misaligned with SG objectives.
- Decentralized Generation is a very important topic especially in Germany where in addition to PV the Micro CHP was seen as a rising DG form. DG was not an important topic in Finland.
- Tackling DG driven challenges with smart solutions can happen but economic viability is of high interest especially in Germany.
- Storing is handled with hydro reserves in the Nordic. A wide range of storage possibilities exist for Germany and Italy and there was no clear view on which technology to rely on. The timeframe for implementing storage solutions was seen rather long than short. Still the Italian DSOs had already started to develop MV level storage for voltage regulation.

- Smart meters were not seen as a necessity for the SG. The meters should be simple, include a customer interface and not include too many features.
- Demand response was seen an important feature of the future SG. Ensuring customer satisfaction was emphasized.
- Electric vehicles will penetrate the markets but they will not have much of an effect on the grid planning.
- The ICT will play an important role in SG implementation.

Out of the list above, the most determining remarks were taken as the main focus of this further research. Especially interesting and not well understood was the regulation and how does it affect the DSO investment decision making. Chapter 4 focuses on regulatory frameworks. The results of this survey do not remarkably differ from the results of this thesis. (Casemore & Gohn 2010)

Another market research (PWC 2013) highlights in its executive summary a few top solutions to the challenges presented in this chapter. Capacity schemes, measures to introduce demand response or demand side management and the ability for intermittent capacity curtailment are according to the survey the global best practices that would lead towards more balanced grids and an ability to cope with intermittent generation. A total of 53 companies globally were interviewed for the research, including sources in Germany and Italy.

The share of electricity of all final energy consumption will rise. This is due to increasing amount of heat pumps replacing other means of heating, especially district heating in new houses. The electric vehicles are going to contribute a noteworthy amount of the vehicle fleet somewhere in 2020 or 2030 depending if the EU targets or the energy industry expectations are considered. Still the EV's have little to do with grid planning for the time being. (PWC 2013)

The survey states that a strong majority of utility and power sector companies in Europe see that the future generation pallet will be a combination of large-scale centralized and distributed generation. (PWC 2013)

Four most important factors for utility future development and innovation were determined in a recent survey by the European electricity industry association. They are accordingly (EURELECTRIC 2013):

- The increasing share of RES capacity including new requirements for overall system arrangements.
- The increasing importance of end users in the power system due to move towards more decentralized power system.
- The creation of Smart Grid system foundations mainly through smart meters implementation.
- Retail competition as a mechanism and the need to find new businesses in regard to active customers (prosumers).

The development of RES in the generation mix is looked into in the chapter 3.2. The prosumer and consumer participation in the energy markets are touched on among other in the chapter 3.2.3 that highlights the possibilities of Demand Response. Smart meter roll-out in Europe is discussed in the chapter 2.1.1. The new possible market models are not especially focused on in this thesis although the chapters 2 and 3 might be interesting base for such a discussion.

3.1. Global warming

The global warming as an outcome of the rise of human origin GHG emissions is widely acknowledged. The Intergovernmental Panel on Climate Change (IPCC) is bringing together thousands of scientists from all over the world to assess the climate change and how most of its negative effects can be avoided. The latest report of IPCC states that the warming trend is more certain than ever before. The Figure 9 illustrates the trend in atmospheric carbon dioxide concentration.

According to (IPCC 2013) the atmospheric CO_2 reached 391 ppm in 2011 primarily due to fossil fuel emissions. The concentration was 40 % higher compared to preindustrial levels which has with "*extremely likely*" probability contributed at least half of the increase in global temperatures from the mid-20th century onwards. The human caused warmer days and or fewer cold days and nights over land areas from the mid-20th century i.e. the global warming is evaluated to continue in the late 21st century with the confidence of the development being "*virtually certain*". (IPCC 2013)

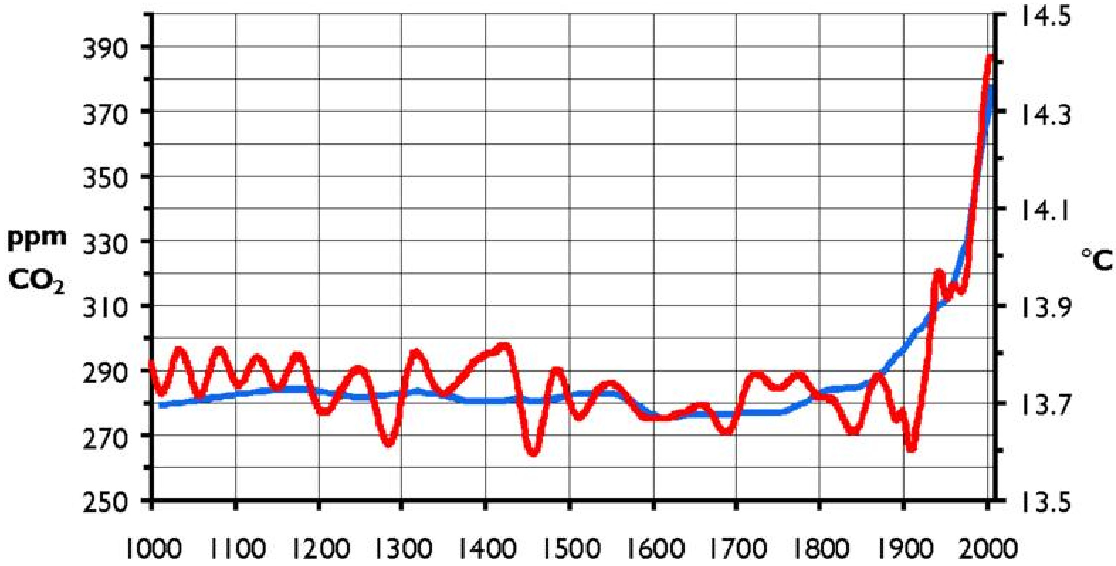

Figure 9 Carbon dioxide concentration in the atmosphere from preindustrial to modern time. (IPCC 2013) Illustration: (Carbon dioxide concentration in atmosphere)

The extent of global warming has so far been acceptable, but serious consequences are evaluated to take place if the global increase in atmospheric temperatures is not restricted to a maximum of 2°. The effects of global warming include e.g. rising sea levels that would put cities in coastal areas to danger and in the long run force large movements when the present coastal areas would turn inhabitable. The IPCC has high confidence that the rise in extreme high sea levels is evaluated to continue in the late 21st. Droughts are expected in other areas whereas floods and vast storms in other are expected to become more common. (IPCC 2013)

In Europe the European council has set legislation called EU climate and energy package in order to limit the global warming. The pack of legislation includes e.g. energy efficiency goals, a switch from fossil fuels towards renewable energy and a general goal of cutting the GHG emissions. In order to restrict the global warming below 2° not only EU level but global scale action has to be taken. (Climate action)

3.2. Renewable energy in the European Union

Renewable Energy Sources (RES) are in the clear focus of the European future energy infrastructure development due to the EU 20-20-20 targets. The trend is also global. As the cost of electricity produced with renewables continuously degrades it is more and more viable option for countries that want independence in terms of energy supply. The imported gas and oil has for long been a vital source of energy in Europe. Reducing the dependence on a few suppliers by replacing the energy supply partly with renewables is therefore easy to understand. (EU 2011)

More competition in energy markets means lower costs in the long run, especially when the wind and solar power are not bound to follow the volatile global oil prices. Naturally for example the prices of commonly used silicon based panels are affected by the price of silicon in the world. Therefore in developing new technologies for PV the expensive or rare materials avoided. An effort is put in bringing the production costs as low as possible.

Global trends in energy investments in 2012 show that the PV is evolving strongly. The prices for panels came down 50% within the year. The onshore wind turbine prices came down with 5% to 10%. Although somewhat magnificent cost reductions were reality, the signals for incentive policy weakening were seen in 2012 and also during the year 2013 as Italy stopped to grant the new PV with FITs. In Germany the prices for PV were low and the Feed-In-Tariffs (FITs) were reduced according to previous plans. The German elections also put a slight shadow over the investment environment for renewables although the outcome of CDU and its sister party CSU joined for the great, and presumably stable, coalition with SPD. (McCrone et al. 2012) For more about the energy politics in Germany see the chapter 5.3.

The 2 ° scenario means the necessary actions to take according to IEA in order to restrict the post-industrial warming within two degrees. The share of power generation from different RES in the OECD Europe according to the IEA 2 ° Celsius scenario gives an idea of the different situations between the EU countries. In 2020 solar PV would provide 3%, biomass 5% to 6% and wind about 11% of the whole electricity need. Hydro power would keep its share with minor growth. Concentrated solar power and geothermal power would stay at insignificant levels in the OECD EU electricity context. The total RES electricity is projected to rise up to a rough 35%. (IEA)

In addition to 20-20-20 goals one important driver for renewable energy is the energy self-sufficiency. It has a clear connection to the current account of any country. In 2011 in Finland the value for self-sufficiency was 49.2%, in Germany 40.6% and in Italy 19.2%. (IRENA 2013)

3.2.1. Intermittent generation

Intermittent generation is unpredictable and uncontrollable electricity generation that is dependent on natural phenomenon. The output of such generation appliances can fluctuate between the nominal and zero output within minutes or seconds. The intermittency is a challenge that can be answered with technical solutions presented in the chapter 3.2.2 and also partly with the smart secondary substation solutions presented in chapter 6.3.

Photovoltaic

It is difficult to have a high certainty over the future development of the energy generation mix. In Germany the long lasting renewable energy support schemes have given the PV a cosy investment environment and lowered PV's Levelized Cost of Electricity (LCOE) to the level equal to or lower than the electricity retail price in residential and commercial segments in Germany (Masson et al. 2013). However for more immature investment areas such the offshore wind energy policies are being challenged. (Fröhlingsdorf 2013)

In Italy the years 2010-2011 were record high for small scale PV investments. This was mostly due to impending expiry of a PV subsidy programme. The Feed-In-Tariffs for PV ended during the summer 2013 in Italy and have gradually declined in Germany from the beginning of the FIT implementation in 2004. The drop in FITs for new PV was in Germany 1.8 % each month from August to October. For the November 2013 the FITs were at the level of 0.141 EUR to 0.097 EUR dropping in the order of 1.4 % every month. For the year 2013 the share of PV of the electricity demand in Italy and Germany was in the order of 5-7 % (Morris 2013; McCrone et al. 2012; Masson et al. 2013)

In terms of grid automation needs, market segmentation of PV should be taken into consideration. The market can be divided into four segments that are ground mounted systems, commercial and industrial rooftop applications and residential panel applications. An overall trend towards the industrial and commercial rooftop appliances can be seen, led by the Italian and German markets. The source (Masson et al. 2013) represents the PV industry view. (Masson et al. 2013)

In Germany the publicly and privately owned rooftop PV i.e. commercial and residential PV generation accounted together for a roughly 65 % of all capacity in 2012. In Italy the similar segment share was less than 40 %. The largest segments were commercial rooftop PV in Germany with roughly 50 % of installed capacity and industrial segment in Italy with a rough 40 % share. In contrast residential segment was the determining segment in Denmark with the share of 100 %. In the United Kingdom a trend of increase in residential sector was seen. (Masson et al. 2013)

Due to rise of the solar PV, the existing capacity in e.g. Germany is over built during the summertime. This forces the energy producers to reconsider their capacity mix, because of the policy that gives the energy from renewable sources a priority. It means that in Germany the RES based production is always running on full power, while the other capacity adjusts to the need.

Photovoltaic price development

The Figure 10 presents an average end customer price of installed rooftop plants in Germany. The price has come down more than 60 % during the past 5 years. The trend still continues although the future price development is uncertain. There are several new technologies seeking for market shares and further funding in order to gain better cost efficiency. What can be estimated though is that the PV will play a major role in the German and Italian markets also in the future. (Wirth 2013) See the chapter 5 for a closer evaluation.

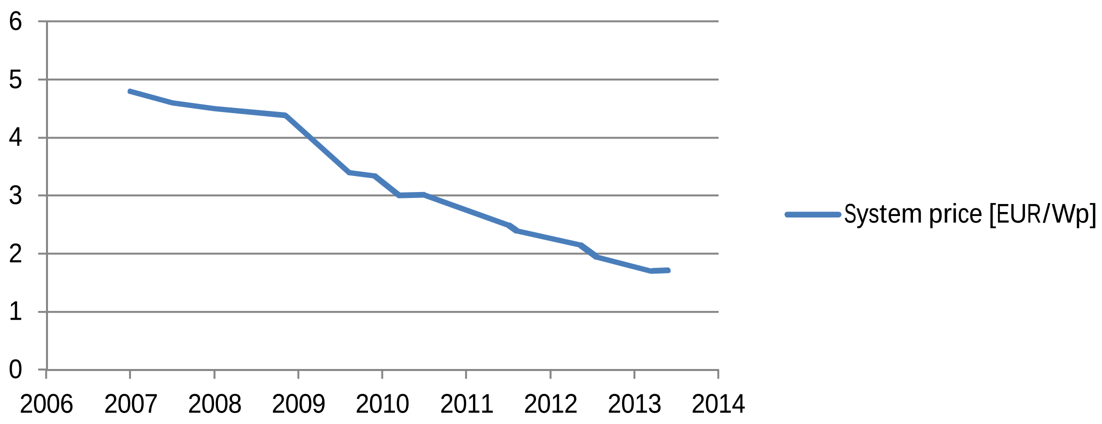

Figure 10 Average net system price for installed rooftop plants with rated power of up to 10 kWp (Wirth 2013)

As the price of PV systems drop, new installations become more and more viable even with continuously lower FITs. At the moment on sunny days a momentary 30 to 40 % of the electricity demand can be covered with PV in Germany. The installed peak capacity of PV – 32.4 GW in 1.3 million plants by the end of 2012 – now exceeds the capacity of any other power generation method in the country.

The price of the PV module in a PV power plant makes more than half of the PV plant's investment cost. The price development follows a rule of learning curve that states that for every doubling of installed capacity a reduction in the technology price of a distinct factor takes place. This requires the efforts in product development to continue. The investment costs represent the largest share of the PV plant lifetime cost structure. The annual cost reductions have in the recent years been in the order of 15 % due to high annual amount of PV installations. The costs can be expected to further fall due to continuity in installations.

The PV grid parity i.e. the point where the cost of electricity from PV generation equals the domestic electricity price is an important factor in determining the PV viability. In Germany the FITs continuously decline and have reached the domestic electricity price in 2011 for ground mounted and in 2013 for small scale PV appliances.

Regardless of the forecasts, the German example has shown that the single most important aspect on energy infrastructure development is the long term national targets and the commitment of the society to the chosen path. Therefore it is somewhat impossible to say which technologies will rule or by which means the energy of tomorrow will be generated with. So much depends on the political decision making and amount of effort put to research and development of future technologies. (Wirth 2013)

Effect of PV on the electricity markets

Power plants are shut down due to rise of PV and wind generation. As an example the German utility RWE decided in August 2013 to take down 3.1 GW of traditional fossil power stations due to low profitability. This trend can be expected to further exist due to the continuity of the German energy policies. A change in energy generation mix can be expected also in other countries that drive a fundamental change in their energy mix. (RWE 2013)

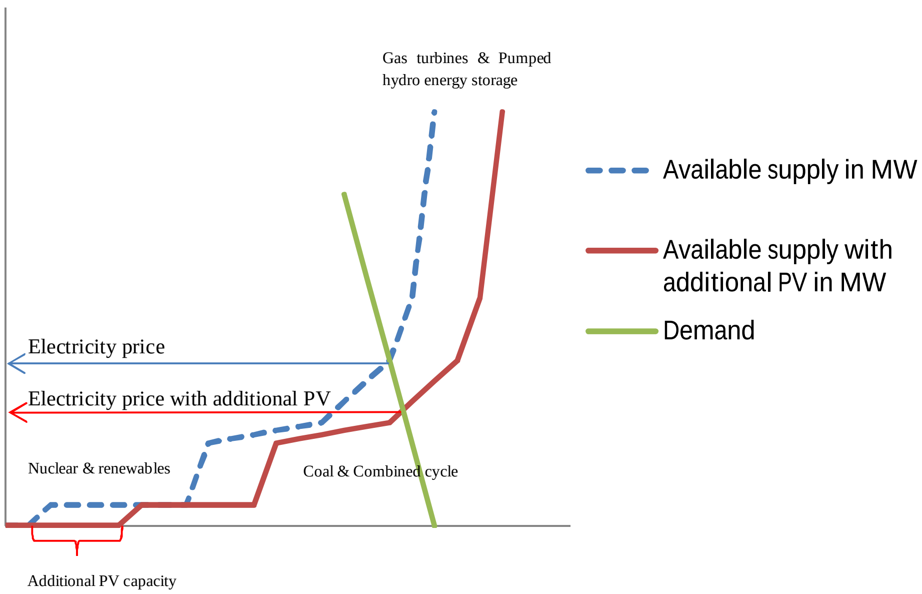

Figure 11 Additional PV effect on the electricity market price (Wirth 2013)

Other forms of intermittent generation

In addition to PV the other methods of solar energy harvesting, wind power are affecting the grid.

For instance, in Finland there is today little solar PV or solar thermal installed. On the other hand the widely existing district heating systems create vast opportunities for intermittent solar or wind energy harvesting since excessive intermittent power can be converted to heat. Economic viability can be met in areas where the summertime district heating relies on oil, and in some cases natural gas. (Pöyry 2013)

Next the most promising intermittent power generation methods are presented. After that follows the possible solutions for system balancing.

Concentrated Solar Power (CSP) makes use of turbine technology when producing electricity from fluid that is vaporized with the solar energy. Although PV is the dominant future generation method in Europe, the CSP seems to be viable in deserts and other areas of low cloudiness. PV performs better in the partly cloudy areas due to ability to also make use of the indirect radiation. There has been practically insignificant discussion about CSP in Europe since the Desertec was understood as too politically tense to push through. The project was initially started for importing low cost solar power from Northern Africa to the Europe. The Desertec project might continue as a local energy supply project but not as a cheap energy solution for Europe. (Morris 2013; Calderbank 2013)

Wind power is, together with photovoltaic, the most determining technology that has an effect on the future energy markets but also the need for grid automation. According to the IEA wind power is expected to account for 12 % of the EU electricity share by 2020. It would so be the single largest RES in the EU. The Figure 12 presents the IEA projection where the wind share of gross electricity generation in the EU should be higher than that of hydro power or any other technology by the year 2020. This includes both onshore and offshore solutions. (IEA)

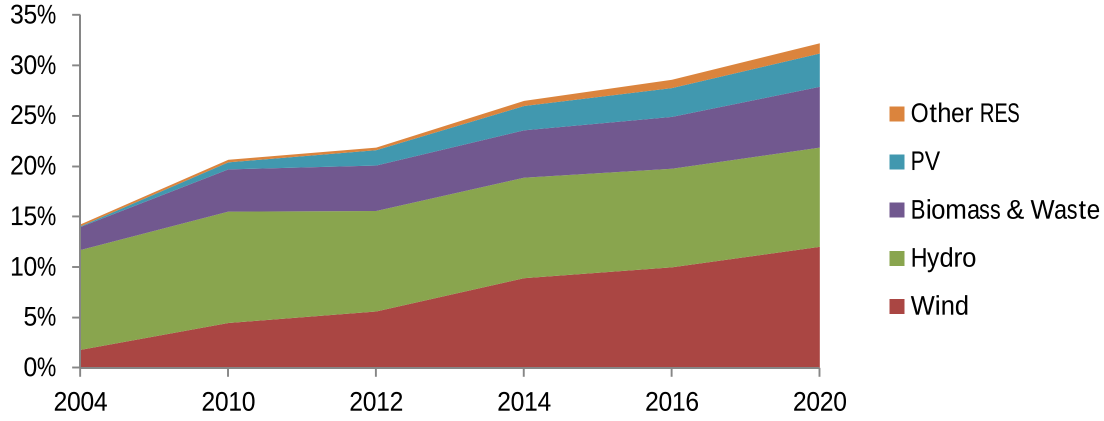

Figure 12 Share of RES power generation in the EU according to the 2° scenario (IEA)

The figure shows the overall output share in the 2° scenario that assumes the efforts to be made to restrict the global warming within two degrees increase from the pre-industrial average

The source (Lucia 2013) shows that in Italy the wind power generation is somewhat evenly distributed in the country and most of the capacity is situated near densely populated areas. In Germany the discussion is ongoing about the challenges of having vast amount of wind power in the north while more the south possesses more industry, denser population and slightly dominating part of the soon to be shut or already shut nuclear capacity. This has spurred ideas, investments and discussion for building three HVDC transmission lines from the north to the south. The Figure 13 illustrates the plans. In the Figure 13 the red circles represent nuclear plants that are shut down while the blue are currently still operating. (Fairley 2013)

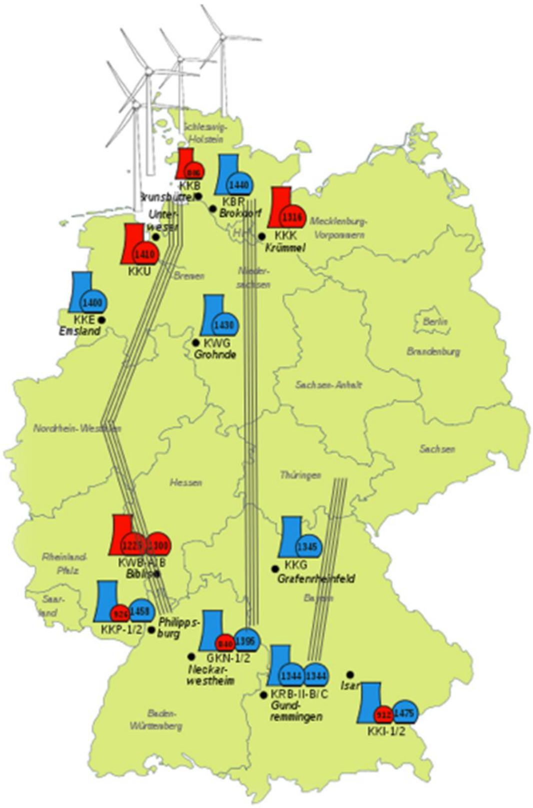

Figure 13 German HVDC plans illustrated together with nuclear power plants. The illustration is based on (Bryan Christie Design 2013; Wikimedia Commons 2011)

It has to be noted that this has only minor impact to the MV/LV smart secondary substations. As seen from the Figure 13 the wind farm output is designed to be fed to the already existing nuclear power output points. This reduces the effect of wind power on MV and LV grid parts. This is the main reason for PV being the most interesting trend in the short term: it has most impact on the general smart secondary substation solutions in Germany.

About predictability

With PV and wind the challenge lies in the intermittency of the generation method. In Germany a partly solution introduced in the RiesLing project combines local solar radiation information with historical load and supply data and the LV side voltage measurements in order to maintain the grid balance through a remote controllable tap changer. For more see the chapter 5.3. In other words historical data is used to aid the real time decision making.

With wind however there are some solutions for predicting the wind output on a daily basis. A solution already at the markets utilizes sensors in the turbine, sky facing cameras, cloud imaging technology and great amount of data analytics to create forecasts from 15 minutes to a month in advance. The method accuracy is though yet not precise enough to reach customer satisfaction. (Tweed 2013)

3.2.2. Power system balancing technologies

Due to lack of accurate predicting methods, the power system balancing requirements have to be met in real time. On the transmission level in Nordic countries the usually abundant hydro reserves together with large scale Combined Heat and Power (CHP) share in the production mix are used to balance the grid. The useful feature in CHP is the ability to control the proportions of heat and electricity outputs and so balance the grid. The excessive energy can be guided to the district heating system or to a separate heat sink. (Aalto et al. 2012)

Hydro power and CHP are not in the same scale present in the Central or Southern Europe. There are also many ways of making the most of the energy infrastructure. Understanding of the whole system is needed in order to create sustainable solutions and minimize overlaps and inefficiencies in energy infrastructure planning.

One of the most interesting near future solutions for grid balancing is storing energy. At present time, none of the storing technologies are truly viable in terms of large scale electricity storing. Still there are single cases where these solutions can prove themselves helpful in grid balancing or local energy storing.

Countries such as Italy and Germany are pushing incentives for storing technologies: Germany mostly in small scale and Italy mainly in grid scale. When these technologies start to increase their penetration via subsidies fast development can be expected. Next the (subjectively seen) most promising technologies for grid balancing are introduced. The listing includes the technologies brought up in the interviews that are described in the chapter 5.

Battery systems are presently developed for both grid scale balancing and for LV prosumer appliances. Italian and German grids are both getting storing solutions implemented in the near future.

In Germany the government is starting to push for the small size batteries for prosumers in order to lower their price and increase their penetration in the German grid, increasing the maximum PV capacity that the grid is able to cope with. An additional benefit to the prosumer is being able to further increase the share of self generated electricity. (Parkinson 2013)

Just recently a Japanese chemical company announced that it is capable of cutting down 60% of the present EV battery cost down to about 212 €/kWh while increasing the battery capacity in order to lift the operating radius of EV to 600 kilometers, more or less the radius of a common combustion engine driven car. Mass production of this solution, based on organic polymer electrolyte materials, could start in 2015. (Electric Vehicle News 2013) Such improvements affect also viability of other grid storage solutions besides EVs by bringing more advanced technology eventually to the markets.

Pumped hydropower storages are an old and reliable way of energy storing. The idea is to pump water from lower to a higher level and let the pumped reserve run through a turbine when electricity is needed. The limiting factors for the usage of this technology are the lack of usable spots for such a technology, the environmental aspects such as effects of building dams and the economic viability of the projects (Gimeno-Gutiérrez & Lacal-Arántegui 2013). Still there is an interesting amount of capacity to be implemented. According to (EU 2013) the realizable potential for pumped hydro could be in the order of 3.5 times the existing capacity with the largest potential lying in Spain and Norway.

Large scale CHP covered a total of 21 % of the electricity generation in Finland in 2012. The Finnish Energy Industries association evaluates that the effect of increased wind power will affect most the operation of the numerous CHP plants in Finland. These plants can change the balance between generated electricity and heat produced. The report of the association especially underlines the importance of such measures at the early stage of the wind power implementation. (Aalto et al. 2012) In Germany and Italy there is potential for CHP balancing as well since their shares in CHP are in the order of 10-15% the fuel mostly used in Germany and Italy is natural gas. (EEA 2012) The output of gas power plants is fast to control.

Small or micro –scale CHP is one of the promising new technologies for distributed electricity and heat production. The fuel can be e.g. locally produced biogas or natural gas. The method of energy production can be e.g. micro turbines or a small combustion engine. Both of these example methods also have a corresponding solution in the industrial scale. The plant could function as balancing power while supplying the heat demand of a hotel or similar customer with a need for a large heat sink.

The viability of a micro-CHP plant in the electricity markets is hard to evaluate and depends mainly of the fuel price. According to the source a system of small scale CHP plants could be viable in the utility perspective in the liberalized electricity markets due to CHP's operation as balancing power and the ability to produce heat in times of low electricity prices. The future electricity market prices however are hard to predict as stated in the chapter 3.3. The negative effect of presently low electricity prices and low heat demand on profitability, which exists during the summertime, could be partly covered by using a combined cooling, heat and power (CCHP) system. (Kallio 2012)

Power to Gas (P2G) -concept's purpose is to gain benefit of the times when electricity prices are low. In the technology perspective the concept relies on the traditional chemical way of storing energy, but with a concept different from batteries. (Morris 2013) P2G uses electrolyser to split water-molecules with electric current. The hydrogen and oxygen are the output of the reaction. The hydrogen that could itself be used as a fuel is then let to react with carbon dioxide to produce methane. While converting the hydrogen into methane, some energy capacity is lost. However the storage of methane is much easier than of hydrogen: Hydrogen has to be kept in about twice the pressure. Methane can be added to the conventional car fuel tank to some extent without problems or need for additional investments. Also the gas network can fully make use of the methane whereas only the order of 2 % share of H_2 is supported by the gas utilizing appliances. (Müller-Syring 2011; NREL 2009)

Power to biofuel refinement could be a viable concept in countries with low population density and large reserves of biomass. In Finland there has been discussion and some projects in replacing coal with wood chips and forest residuals. The potential could be as much as 50 % of the 14 TWh of energy by using the latest technology of torrefied pellets or gasified wood. The energy density of wood chips or forest residuals is about eight times lower than that of coal. It's possible to process the wood into a more energy dense form. Torrefied pellets have an energy density only about 26 % lower than coal. Due to low moisture level the torrefied pellet is as enduring to store as coal. (Happonen 2012) Due to these properties the torrefication is an interesting technology for biomass utilization. The future of the technology however is uncertain and depends on the speculative additional investment support mechanisms as well as the market development.(Laukkanen 2013; Flyktman et al. 2011)

Other methods with lesser estimated significance also exist. These include flywheel storages, compressed air energy storages, capacitors and super capacitors as well as various nonconventional battery technologies. (ESA 2008)

3.2.3. Demand Response

There is a change in consumption in addition to the change in energy production mix. The largely expected increase in the users of Electrical Vehicles (EVs) is adding a new variable to the demand side. On the other hand EVs are an opportunity as an energy storage application on the supply side.

The Smart Grid isn't yet at the state where independent islands of electricity systems are built when needed. Still research has promising results. In Denmark research made in an island of Bornholm has shown that a maximum of 15% share of electricity production can be covered with wind power while maintain the grid frequency stability. (Kumagai 2013)

The future of Smart Grid is to be an integration of small independent and automated grids. Today the so called island mode is under research, and the results so far suggest that it is possible with today's technology to create and maintain a small independent grid part with active demand and market price response. (Kumagai 2013)

Demand Response in system balancing

Albeit being one of the balancing solutions represented in the chapter 3.2.2 the Demand Response (DR) is definitely one of the most interesting topics to the prevailing grid balancing discussion. Due to its potential we own a chapter to this technology.

The most interesting aspect to DR is that it saves energy. The traditional idea of the grid energy balance is that the supply follows the load. According to this basic principle the small changes in demand are blended in to the vast amount of spinning mass in the grid thereby adding a negligible challenge for the grid stability. Larger changes in demand such as the daily peaks of consumption when people wake up, boil their eggs, drive to work and open up their computers all at the same time is taken care of by controlling the output of large scale power plants that take part in the balancing markets.

The today's energy system is flexible enough for the present needs, but in Germany and Italy the clear need in close future revolution in grid balancing is seen. Electricity storing is expected to be viable in the long term. Still DR as well as storage would have wide markets if it would be simple and affordable: these characteristics require development from the present status. At the moment there is no so called one box solution for DR to be implemented to the customer end that would be controllable by the DSO. This is deducted from the interviews, presented in the chapter 5.

The technology and functioning market model for large scale DR exists. The DR is an already viable solution used e.g. in the Nordic countries for transmission by utilizing the industrial processes that due to process characteristics must not be driven continuously. These appliances as well as power plants can make bids at the balancing power market according to the available power in multiples of 10 MW. The duration of balancing availability must be at least 1 hour or its multiple. (Partanen et al. 2012)

DR in this thesis is divided into two categories. The price-based demand response would require an hourly or momentary based electricity price market model also for small scale DR. The incentive-based demand response would require an agreement with the customer. Both are doable but require some effort from the supplier of the service and the regulatory authority in forming the rules and procedures. (Pavan 2013; Klobasa et al. 2013)

DR benefit for the DSO

The source (Navigant Research 2013) states high expectations for DR in Europe. Recently the global market share has been biggest in the United States. Especial growth in the North America is expected in the residential sites. The global DR total capacity is estimated to grow from the present rough 58 GW to about 140 GW.

The clear benefit for a DSO of DR would be the ability to lower the peak demand and so to lower the grid capacity need. The LV grid operation could benefit by being able to cope with more intermittent generation without the need for investments in thicker feeders or larger transformers. (Navigant Research 2013)

According to a Finnish study (Kiviluoma et al. 2012) regarding 20 % wind power penetration in a Nordic energy system, clear benefits of flexibility were introduced. The most important benefit for the system owner is the decrease in system operating cost. The results found different heating related balancing measures to be the most economical solutions in hydro-thermal power system.

DR cost savings were not estimated as the annuity cost information for such a solution was not attainable. According to the summary of the source findings regarding DR the following can be stated: The DR has little effect on the electricity average market price but it might lower the wind power supplier revenues by some 2 EUR per MWh. The DR also is estimated to have quite a little effect in the system operating price compared to e.g. building new transmission connections in the 20 % wind power case.

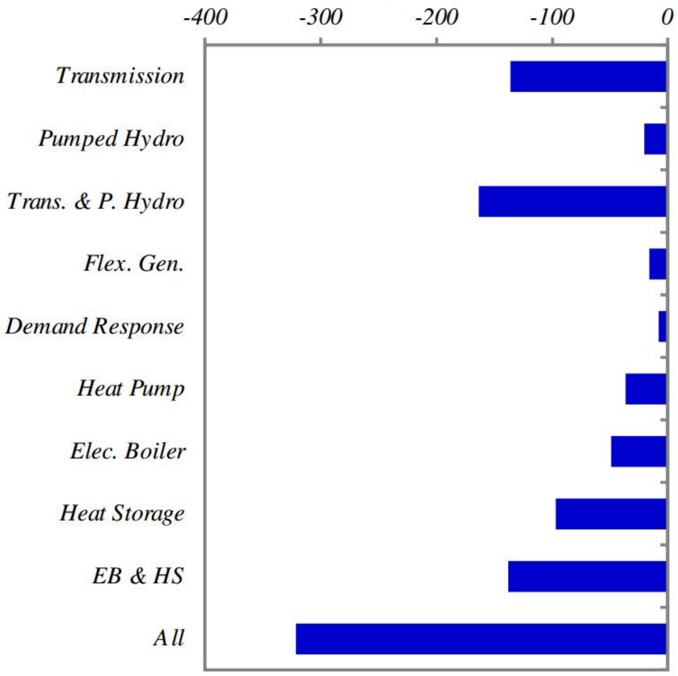

Figure 14 Balancing method effect on system costs (in M€) Graphic: (Kiviluoma et al. 2012)

It also should be noted that no sub-hourly benefits of DR were estimated in the source study. Also only the price-based DR was researched in the day-ahead markets. This leaves away the incentive-based DR as well as the momentary balancing possibilities. (Kiviluoma et al. 2012) As an example the possible market places in Finland include e.g. the frequency controlled normal operation reserve that has a minimum contract size of 100 kW. The price for such service is currently 14.36 €/MWh plus the price of electricity. (Markkinapaikat)

Price-based demand response – an Italian example

According to the source (Pavan 2013) demand elasticity at the Italian day-ahead markets has been and is very low: in 2011 99.8 % of the demand was considered inelastic even though demand is able to participate in the electricity day-ahead market. The balancing market participation framework is also under construction.

In Italy from 2010 onwards it has been mandatory for DSOs to introduce so called time of use tariffs for LV customers. For MV and HV customers these had been implemented already about 20 years ago. Three tariffs for LV customers have been implemented considering about 25 million households with up to date smart meters. The tariffs include the peak, shoulder and off-peak tariffs. The initial difference between the peak and off-peak prices was 10 % of the energy price at peak hours. The peak time was set to be on working days from 8 a.m. until 7 p.m. This was done not for the actual need of DR but to investigate the customer behavior. The customer behavior was researched both before the implementation for half a year in 2010 and after the transition was over for half a year in 2012.

The results were as follows and were gained by researching a group of 28 000 households out of which a restricted customer panel of 8 427 customers showed the following results:

- The share of customers that had at least two thirds of consumption during off peak hours had increased with 5 %.
- Some consumption had been shifted by about 60 % of the consumers.
- An average consumption switch from peak to off peak hours was 1 %.

One clear signal from the source’s survey was that the price difference has to be higher than the one implemented. The actual price difference was less than 10 % due to the market electricity price forming. Still an interesting note is that the Italian power market prices are starting to rise on off peak hours and lower during the daytime peak consumption hours due to high RES based generation in the system. (Pavan 2013)

Other market possibilities

In Germany, there are few financial incentives that would motivate the industry to bring their manageable loads to the markets. There is considerable amount of load suitable for grid scale DR solutions. More than 1 GW of load was found to be potential to be used in a time scale of 30 minutes to 2 hours. The greatest share was found in processes from energy intensive industries and ventilation as well as air conditioning from industrial cross-section technologies. (Klobasa et al. 2013)

According to the study (Klobasa et al. 2013), one of the common hindrances for Southern German firms to participate was the restrictive nature of DR. The firms would want to integrate the load to their production planning, which is challenging because of the hard to predict need for DR.

In Finland Helsingin Energia has developed as part of the SGEM program a method for market based DR. (Koponen & Seppälä 2011)

3.3. The European energy market development

The global economy plays an important role in the power system markets. The most important factor at the medium term for these markets is polarization at the emerging and mature markets. Most technology orientated solutions are sold e.g. in the Europe and the US. The industrialization of emerging markets is in medium term turning the focus of electricity network investments towards more efficient solutions in those countries. The growth of renewable production is an important trend that has its effect both on mature and emerging markets. (Market trends 2013)

The DSOs are more and more starting to act as client organizations who order the construction and maintenance from external parties. This has several aspects, one of which is the also the system operating services to be outsourced. (Järventausta 2013)

Electricity prices

The backbone of energy market policies as well as DSO regulation is to keep the cost of electricity affordable for the customers. As can be seen from the Figure 15 consumer prices have risen during the last five years in all the focus countries. The Figure 15, the Figure 16, and the figures in Appendix 2 all show the prices for customers with annual consumption between 2500 and 5000 kWh.

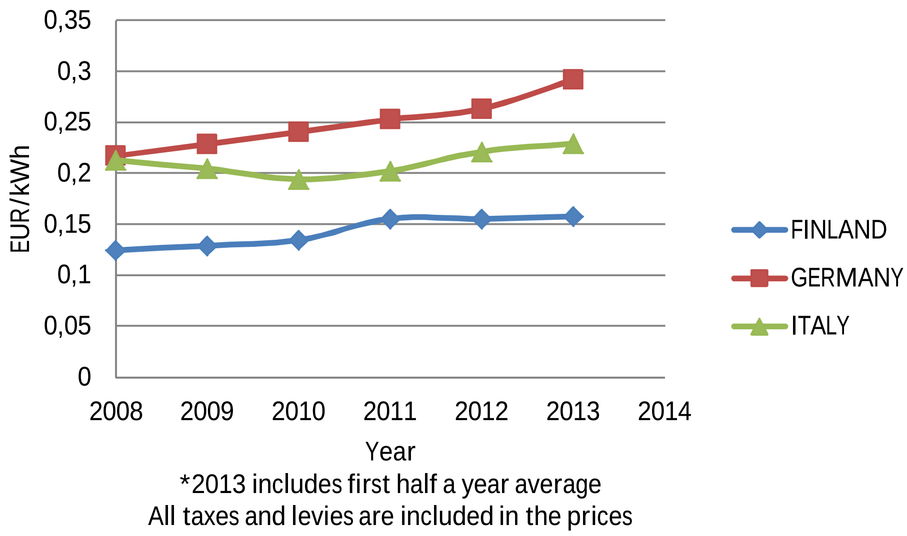

Figure 15 Electricity prices for domestic customers (Eurostat 2013)

The rise in German electricity price is practically only due to rising taxation. Combined energy and grid tariffs have not changed significantly from 2000 to 2011 and therefore the share of network costs in the retail prices for domestic customers have narrowed by roughly 30%. The network costs include transmission and distribution costs. (EU 2012)

In Italy and in Finland the rise in domestic retail electricity price has consisted of slightly increased shares of both taxation and energy price while the share of network costs has come down at least until 2010.

The Figure 16 shows that in Italy despite increase in total electricity price for the customer, the absolute grid costs per energy unit have remained stable during the recent years. (EU 2012) This indicates a functioning regulation, especially when at the same time between 2008 and 2010 Italian DSOs were able to slightly cut their SAIDI value. (CEER 2011)

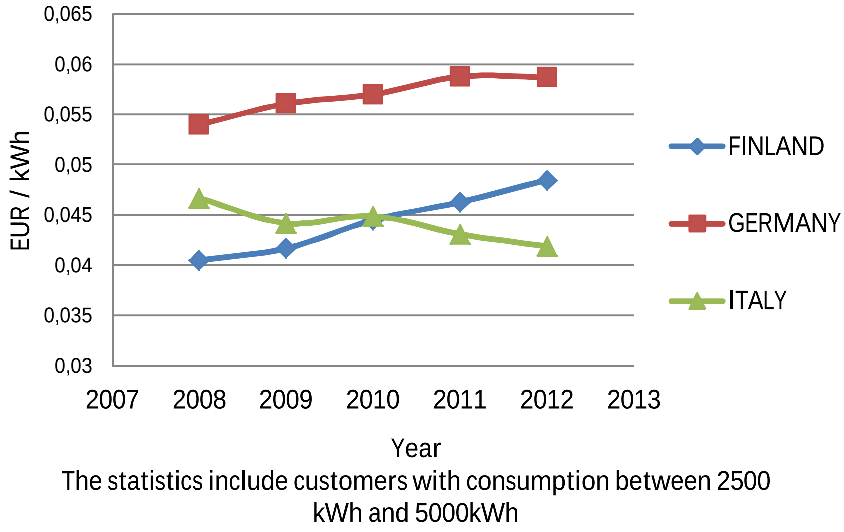

Figure 16 Grid tariffs for domestic consumers (Eurostat 2013)

Electricity price is hard to predict, although its future development is of utmost interest to various stakeholders. The rising share of PV is bringing the prices down on sunny days with low consumption, such as weekends. Same effect can be seen when a larger area of Europe is experiencing windy and sunny days and windy nights. (EU 2013) The effect was shown in the Figure 11 at page 28. The long term effect of RES on the average base load prices however is not as clear as it might seem, since various factors have an effect on the electricity market prices. Such factors include amount of available hydro power, and fuel prices of e.g. coal and gas. The amount of interconnection capacity between market areas is not to be underestimated. The Figure 17 shows the development of regional wholesale price development from 2010 to 2013 in European electricity markets.

The sources (EU 2012; EU 2013) state that Italy has significant amount of renewable power that is expected to lower the country's base load prices. However it is the dependence of Italy on gas and oil as well as insufficient interconnections to neighboring countries that has kept the wholesale prices high. The Central Western Europe (CWE) market has mainly been dependent on the German renewables and nuclear power from France. In the Nordic markets the Nordpool price development mainly follows the fluctuation of hydro power reservoir levels. Recently on yearly average as seen from the Figure 17 the Nordpool prices have been lower than on the other areas. (EU 2012; EU 2013)

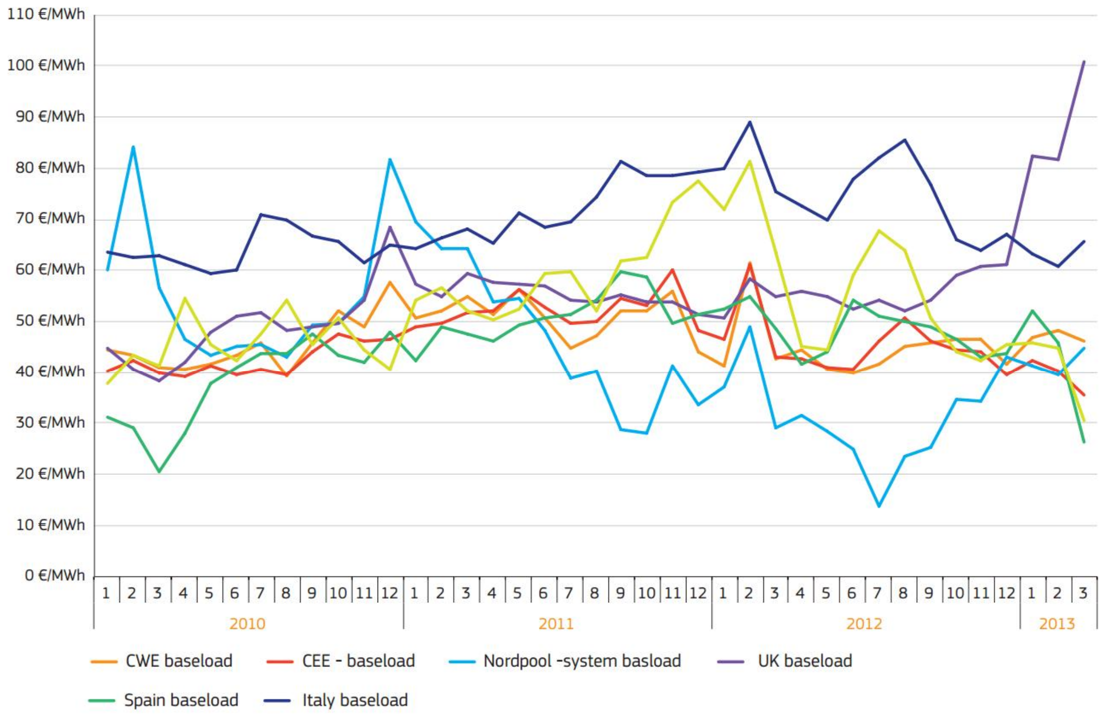

Figure 17 Comparison of monthly electricity base load prices in regional electricity markets (EU 2013)

The effect of low demand and high supply was seen in Germany. The power price of German power market (EPEX) saw for the first time a negative daily average during the year 2012. At two o'clock in the morning on 25th of December 2012 the market made its negative hourly record with a price of -222 €/MWh. The holidays combined with windy weather brought down the wholesale prices.

On 25th of March 2013 the market price was negative for four hours in a row and for the first time this was on afternoon. This was due to high wind and solar power generation. (EU 2012; EU 2013)

3.3.1. Electricity market development overview

Today the utilities are by EU level legislation unbundled i.e. the utilities that before took care of the whole energy supply are now divided into different sectors according to functions that are electricity transmission, distribution, energy production and energy sales. The different functions have to be taken care of by separate companies.

The unbundling has opened the electricity distribution operations to a more transparent observation. The company operations have to be genuinely effective. This is leading to increased focus on the company efficiency that is a strong driver for the moment e.g. in Germany. For more information on the efficiency see chapters 4.4 and 5.3.

A remarkable trend especially in Germany and Italy as well as globally in the United States is the increase in renewable energy based electricity generation. The momentary grid balancing has to be done in the timescale of seconds. Therefore the momentary managing of power balance, questions regarding reserve power requirements, possibilities related to energy storages and demand response solutions are in the focal point in designing Smart Grid operational environment.

The future of the DSO operations will include more precise planning due to bidirectional power flows and intermittent supply. For this reason research has also been done on LVDC systems. They would not only include higher control with more power transfer for LV grid with the existing lines but also include a high penetration of potentially intelligent technology in the form of e.g. power electronic converter technology. This would enable smart applications for both grid control and electricity market management. (Gulich 2013)

European market has to consider its own competing surroundings i.e. the world. There’s little certainty about the future economics, but one thing is for certain: the world energy demand will keep rising in the visible future basically due to BRIC countries i.e. Brazil, Russia, India and China. China is already the biggest carbon dioxide emitter in the world and will maintain its position in the near future despite vast environmental and renewable energy investments. (The Economist 2013)

Displacing fossil fuels with renewable ones has a straight impact on the economy. If a country replaces part of its oil imports with local solar, wind or bio power it saves money. For example in Finland the energy imports yearly cumulate up to 13 billion that accounts for more than one fifth of the country’s trade balance (Auvinen 2013). The cut on imports is not that easily implemented though, since the way the energy market functions.

The demand is met by the energy production in the order of lowest variable costs. Most of the variable cost is formed by the fuel price. This means that wind and solar power with almost no variable costs come first and displaces the most expensive method by variable cost, usually gas turbines. Even if hydro and nuclear power are usually the cheapest methods of energy production, in Germany the electricity from RES has a priority to the grid over all other generation.

The amount of new transmission lines and increased amount of Intelligent Electronic Devices (IEDs) both depend on the placement of electricity generation points in the future network. It is to keep in mind, though, that even though solar and wind power are regarded as distributed production in the general discussion, especially for wind turbines concentrating them is regarded more efficient. (The Future of Energy: Why Power Density Matters 2013)

Vision for the future

A source (Budischak et al. 2012) describes the future energy system consisting of renewable capacity 180% as extensive as the maximum demand to be the most economical concept. It means it would be cheapest to build a system where 90% of whole demand would be supplied by capacity-wise roughly double renewable sources, adding or maintaining only some storage and fossil back up power.

The article though doesn’t make any remarks on the grid enhancements for grid stability needed. In contrary they state that such a system would have a higher reliability than the existing one (in the United States) due to distributed nature of the renewable energy generation. (Budischak et al. 2012) One might argue whether the same amount of SG–associated investments is going to be needed regardless the amount of renewables, as long as it's significant compared to today.

Nevertheless the study shows that from the power generation point of view it is possible to create such a system that is able to economically meet the demand with almost only intermittent renewables. This means a 90% amount of Renewable Energy (RE) in the grid can be treated as an upper limit when designing concepts for SG environment. This would still be rather economical compared to producing virtually all electricity with RES. (Budischak et al. 2012)

3.3.2. Emissions Trading System

The officially acknowledged driving force for the European Union (EU) Emissions Trading System (ETS) is to decrease the dependence on energy imports, to slow down the global warming and to create jobs through energy efficiency. (DIRECTIVE 2012/27/EU) At the same time the EU is trying to adjust the ETS to still maintain the economical prosper possibilities of its export-dependent industry.

The basic concept of ETS is that it provides a market based solution for putting price on carbon dioxide emissions. The ETS lets its participants decide by which means it is most economical for them to reduce the emissions. Early investors on environmentally friendly technologies benefit in regard to others by evading the additional costs. The system works well when the price for emissions is high. However recent price development has shown rather low carbon prices. The price has gone from some 20 €/t_{CO2} in 2011 to the level of 5 €/t_{CO2} i.e. Euros per tons of carbon dioxide. (Kakkonen 2013; European Carbon Futures)

In the European Emission Trading System the next three years will determine a lot of the actions for the next trading period. The hot topic at the moment is the back loading. In backloading some carbon emission permits are to be frozen for some time from auctioning in order to create balance between demand and supply: there is an excess of carbon emission permits caused by the regression in the EU. Recent decision made by the EU parliament states that backloading will be adopted in the EU legislation with the decision on 10th December 2013. More focused decisions could be expected in early 2014 (Climate action 2013; Interview)

The mostly interesting EU statement of the future of the ETS will be the white book that is to be launched as a guideline for EU decision making in the spring 2014. This would act as a guideline for the new European council and the Parliament that are to be elected in the spring 2014 and that begin their work in the beginning of 2015. In order to make fundamental changes to the ETS, the legislation must pass through all the EU levels. An optimist evaluation could expect the new ETS legislation to be in effect at earliest in the beginning of 2016. The EU targets for energy and climate for 2030 that are being crafted, guided by the decided Energy Roadmap 2050, will also have a great impact on the future of the ETS. (Interview)

At the same time that the EU is balancing between the low effects of the ETS and the EU renewable targets, a world-wide climate contract is under negotiation. The goal is to get at least the most important industrial countries, for example the G20, to implement a global plan for carbon emission reduction. This would come as an important statement and a signal for the industry. In the EU the carbon leakage, or industrial relocation of production to third countries, is a known threat.

The outcomes in different scenarios are not clear but estimable. If the ETS will be reformed so that it will have great impact over the energy mix used in the EU, coal will be the biggest loser in the energy mix in favour of gas and the renewables. The core idea of the system is to enable low carbon market where the cheapest methods of emission reduction will prevail. (Interview)

Recently there has been discussion about how the role of ETS should be strenghtened. The various subsidies are partly overlapping and even partly offsetting the effects of each other. Therefore a strong one goal: reducing CO_2 emissions together with ETS or a carbon tax is seen by some as the preferred solution over the rather complex status quo. (Soininvaara 2013)

If the backloading and other mechanisms are not enough to raise the confidence towards the system, vast national subsidy mechanisms will be needed to meet the renewable targets. This is not what for example the Finnish energy industry wants. Still the RES targets are binding. Many energy companies throughout the Europe are flagging for tighter, more predictable ETS: Having one in the whole industrialized world would probably be the best solution (Hassi 2013).

3.3.3. Energy efficiency

The European legislation is following the EU goals of energy efficiency, renewable energy and GHG emission reductions. Of these the energy efficiency might appear as an abstract concept. The concrete example regarding transformers clarifies the efficiency target implementation.

Eco design of transformers

The EU is setting legislation on transformers. From the beginning of the year 2015 all the new transformers installed have to fulfill the new ecodesign requirements. In other words the EU commission regulation (EC 2013) states new ecodesign requirements for transformers that are to be placed on the market or put into service. The aim of the EU is to lower the energy demand in the order of 16.2 TWh per year at 2025 compared to current situation. The regulation includes two steps. The first step is to start installing more efficient transformers from 2015 onwards. The second step implements even more strict efficiency demands from 2021 onwards. For example for 10 MVA the minimum peak efficiency is 99.560% 1.7.2015 onwards and 99.615% from 1.7.2021 onwards. It must be noted that this legislation will be officially put into force during the spring 2014, but these values are likely to remain intact. (EC 2013)

As seen from the peak efficiencies the transformer is already a very efficient machine. Therefore it is not easy to find new technical solutions for further increasing its efficiency. This can however be done by increasing the physical size of the transformer. This means that the important materials in transformer i.e. iron and copper amounts increase per transformer. This increases the price but also the weight of the transformer even to the extent where pole mounted transformers had to be given concession in the legislation in order to keep their size within practical limits. (T&D Europe aisbl 2012; EC 2013) These design factors should be carefully considered when designing new secondary substations.

4. REGULATORY FRAMEWORKS

This chapter focuses on giving the reader a general understanding on the regulatory framework of each of the focus countries. Based on the interview results presented in the chapter 5 the most important regulatory drivers for DSOs are covered. Regulatory mechanisms whose effect on the DSO turnover can be affected by automation investments are presented.

In this thesis two parts are included to the term regulation: the legislation for the distribution operations and the regulatory framework for controlling the rate of return of DSOs in the natural monopoly market. They are both equally important, and closely bound together. The whole regulation is thought as a one large frame where the goal for the legislator is to ensure a cost efficient and reliable electricity distribution for the society.

This chapter presents a general introduction to regulatory frameworks and details the cornerstones of the regulatory frameworks in Finland, Germany and Italy. As pointed out in the source (Joskow 2007) the benchmarking of the regulatory frameworks of different countries can be challenging due to e.g. differences in economic attributes used, such as the calculation of Weighted Average Cost of Capital (WACC).

Also the number of DSOs varies in the focus countries. According to the source (Ruester et al. 2013) Germany had in 2012 a total of 883 DSOs; Italy had 151 and Finland 95 DSOs, of which an overwhelming majority was small DSOs with less than 100 000 customers.

4.1. General development of regulatory frameworks

The development of incentive regulation during the last two decades includes significant changes in the theoretical foundations of regulatory frameworks according to (Joskow 2013). Still the implementation of this theoretical basis has been slow due to the complexity of the regulation in practice. The regulatory authority needs to make decisions regarding weighting of different mechanisms.

The development of regulatory framework according to the source is an evolutionary process. For instance price cap methods are typically followed by mechanisms concentrating on service quality. Also even though advanced incentive based mechanisms are implemented, the capital cost accounting is often left to too little attention. The source even states that insufficient evaluation of e.g. cost of capital measurement protocols, as has occurred in many developing countries following the guidance from World Bank, could lead to problems.

The role of price caps is to function as cost reduction incentive. To avoid speculation with price also the effects of price cap mechanisms should be evaluated from the perspective of quality and other performance indicators, not based on company price structures. The shift from cost reduction to quality related regulation is an overall trend of regulatory framework development. The amount of different incentives in use has grown during the development of regulatory frameworks.

The regulator of UK, OFGEM, has introduced menus to incentive capital investment forecasts. Menus seem efficient in spurring reasonable investments. The use of menus could be the next step also in other incentive regulation models. Menus as well as other models are explained in chapter 4.2. The source notes that without proper access to comprehensive data of the DSOs the incentive based regulation cannot fully function. (Joskow 2013)

Modern challenges

The source (PWC 2013) highlights in its executive summary a few top solutions to the challenges such as integration of renewables presented in the chapter 3.2. According to the survey the global best practices that would lead towards more balanced grids and an ability to cope with intermittent generation are capacity schemes, measures to introduce demand response or demand side management and the ability for intermittent capacity curtailment. A total of 53 companies globally were interviewed, including sources in Germany and Italy.

The same survey states that there is a vast need for utilities to improve their efficiency in Europe. Almost all the respondents in this survey – more than 90% - saw a need for more than 10% efficiency increase whereas clearly more than half of the respondents found a need for more than 20% efficiency increase and cost base reduction. An especially shaking result in the survey was that more than 80% of respondents named asset performance management as the main source of performance improvement. (PWC 2013)

The efficiency improvement trend is especially clear in Germany according to the research made for this thesis. The asset performance management or investment efficiency as referred to later in this thesis is of extreme importance also due to the mechanism structure in the regulatory frameworks. This is because most of the allowed profit of a DSO in all the countries in question in this thesis comes from valuating of the Regulated Asset Base (RAB). In Germany the RAB is not officially referred to in the revenue calculations but the similar idea of valuating the DSO cost structure and its efficiency prevails as the foundation of the regulatory framework. (CEER 2011)

The source divides the general European DSO regulation into four areas that need reviewing in the existing regulatory schemes due to changed market situation. These are: giving regulated remuneration to the DSO as a network owner and operator, the design of the grid tariffs as a basis for DSO income, the unbundling of the DSOs and the DSO relation to the TSO.

The remuneration of the DSO should change when the DSO cost structure is changing. The use of DER seems to be able to contribute to a lower OPEX for the DSO mostly by participating in lowering losses and participating in voltage control. In this context among other DG, EVs and DR are referred to. (Ruester et al. 2013)

The most important aspects for Smart Grid friendly regulatory framework according to the European Electricity Industry representative EURELECTRIC are the following features (Phelps 2011):

- Rewarding and Incentivising Capital Expenditures (CAPEX) in Smart Grids
- Improving the evaluation of Operational Expenditures (OPEX)
- Incentivising innovation and R&D funding
- Clarifying roles and responsibilities
- Safeguarding regulatory stability

In the first bullet the CAPEX needs to be fully taken into consideration. Some regulatory frameworks dismiss some of the expenditure due to inflexible construction of the framework. The fair rate of return is essential for the SG investment enforcement. Secondly the research and development as well as Smart Grid pilot expenses should be excluded from efficiency evaluation. The efficiency of such projects is hard to evaluate through normal operational estimation standards. The third bullet is merely marking the point that in the future e.g. the ICT related innovations will bring new opportunities. These should be further investigated.

The roles and responsibilities for different SG parts are to be clarified. Different nations have different solutions but also within countries some uncertainty exists. As an example the smart metering responsibility is placed on DSOs or electricity suppliers depending on the case. (Phelps 2011)

The last decades of power sector in the EU have included a transformation from public utilities in the mid-90s to privatizations and profitability requirements in early 2000s. In the mid-2000s the full competition in power generation and retail had taken place while the rise of prosumers and RES based DG were on a bonanza. These changes have formed the power sector over time, and the trend continues. (EURELECTRIC 2013)

Country specific evaluation

The focus countries have different means of evaluating their interruptions in the grids. As example Finland is using the so called T-SAIDI for MV grid long outage evaluation as described and collects amount of interruptions data on LV level. In Germany the ASIDI is used to evaluate long outages in the MV grid and SAIDI in the LV grid. In Italy SAIDI and SAIFI are being used for distribution network long interruption indexing, which is also Europe wide the most common practice. (CEER 2011)

The differing methods all aim in evaluating the average outage times and frequencies for the customers, but differing practices complicate the evaluation between the countries. Still the source (Ruester et al. 2013) sees no especial need of EU level combining of regulatory frameworks, although some minimum level requirements are recommended.

4.2. Regulatory concepts

The reason for regulation is to minimize the electricity supply cost for the customers of DSOs while maximizing the quality of supply. The following methods for regulation offer the regulatory authority the tools with which the regulation can been implemented. This chapter 4.2 is mainly based on the source (Joskow 2007).

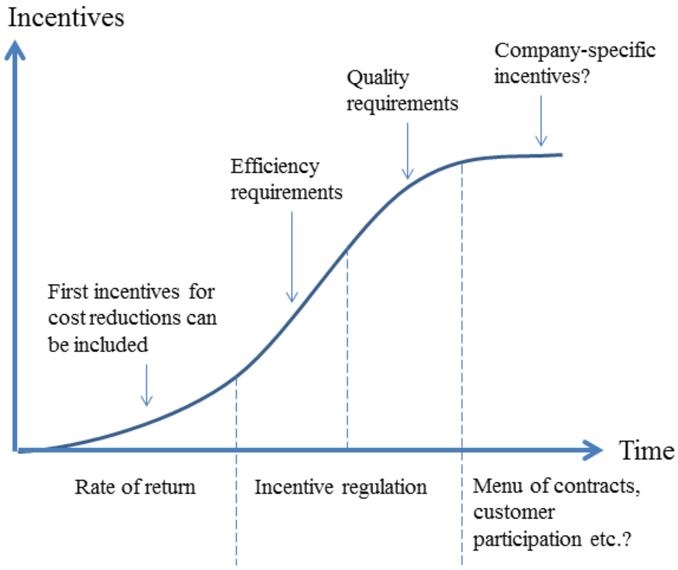

Figure 18 Evolution of regulation in principle (Viljanen 2005)

Rate of return (i.e. cost of service) was the first regulatory method that was implemented to DSO regulation. The main function of this mechanism is to give the monopoly company a fixed rate of return to the whole cost structure that derive from the operation of the distribution network. The yearly multiplication of the cost structure with the allowed rate of return is the most straightforward way of regulation. While being simple it also works well when limited information from DSO to the regulator is available. The more sophisticated methods of incentive based regulation are generally an addition rather than alternative to the rate of return regulation. In the Figure 19 on left side the method of rate of return regulation is illustrated, while the right side of the figure presents the method of incentive based regulation. In the cost based i.e. the rate of return regulation the profit is constant while in the incentive based regulation the profit can be attained by efficient operation. (Joskow 2007; RWE 2008)

In the rate of return method the regulator evaluates the cost structure of the distribution company and determines which costs belong to the reasonable expenditure. The costs that seem unreasonable for normal operation can be deducted from the cost of service i.e. the reasonable cost structure. Therefore the company will not get remuneration for the costs. There are several methods for evaluating the reasonableness of the costs.

The magnitude of rate of return should not be more than what attracts investments, i.e. covers the company investment and a reasonable rate of return for the efficient electricity supply service (Joskow 2007). Still the efficiency of the regulated companies in this form of regulation is questionable, since the companies have practically no incentive on cost reduction (RWE 2008). In the US a form of rate of return regulation is used, under the name cost plus regulation. (Viljanen 2005)

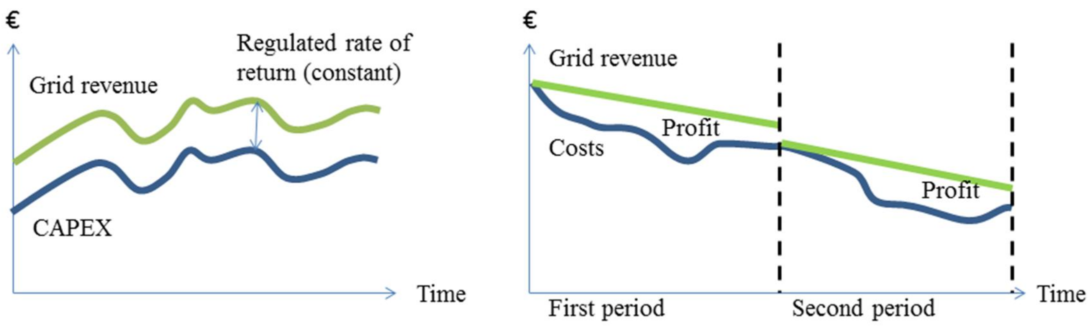

Figure 19 Cost based and Incentive based regulation (RWE 2008)

Price cap regulation sets fixed tariffs i.e. price structures for the whole predetermined period of regulation. This creates the so called regulatory lag. Basically the regulatory lag implies that the DSO charges its customers with a fixed charge although the costs accumulate during the regulatory period. The method will give the DSO incentive for cost reduction and so efficiency increase. In UK the DSOs under the price cap regulation have been noted to tend to make the most to increase their efficiency early during the beginning of the regulatory period and to do less when the period is ending. Scarce investments on quality are a classic challenge with the price cap regulation. (Joskow 2007)

Incentive based regulation i.e. performance based regulation is designed to answer various challenges that remain unanswered with the more simple forms of regulatory methods. If the DSO performs well in accordance to the incentives mechanisms, it receives higher allowed revenue compared to other similar DSOs that didn’t perform as well. As seen in the Figure 19 the allowed revenue is re-evaluated for every regulatory periodbased on the performance of the DSO during the previous period. The costs and revenue are decoupled so that the DSO can temporarily collect higher revenues within a regulatory period. The revenue level decreases yearly in accordance with a general productivity demand. (RWE 2008)

Yardstick regulation is an effective method in evaluating the companies with corresponding companies with each other. This comparison helps the regulator to assess the efficiency of each company in respect to each other. Therefore with the incentive based regulation an effective combination of regulatory models for ensuring efficient operation of the DSOs can be formed. (Joskow 2007)

Menu of contracts gives the DSO the opportunity to choose the performance level that suits its operation the best. A DSO that settles with low profit can choose a contract from the menu with low risk and low efficiency increase demands. On the other hand a

DSO willing to take more risk can pursue for better profits and a more ambitious efficiency target. Menu of prices can include an afterward cost review where a price crossing can be regarded as penalty and price undershoot related to the target can be treated as incentive: the surplus adds to the reasonable rate of return. Such incentive scheme is about to be used for DSOs in the United Kingdom. (Joskow 2013) This progressed regulatory framework is shortly presented next.

The RIIO framework is the UK model of regulatory framework for DSOs. The first period of the framework will be an eight-year period from 1st of April 2015 to 31st March 2023. The features of this method include a special focus on renewable energy and the above presented menus for contracts in addition to already presented features of incentive based regulation.

The RIIO (Revenue = Incentives + Innovation + Outputs) is a framework that aims for long term planning that in the best possible way takes into account the future needs of the RES integration to the electricity network. It also aims to give proper incentive for smart grid related investments in order to retain the investor interest on distribution business.

The RIIO takes a different approach to allowed revenue compared to the revenue cap method. The allowed revenue will be determined in regard to indexation of the cost of debt and on a so called assumption of notional gearing. The appropriate extent of gearing is up to the DSOs to evaluate in their business plans. These plans are subject to evaluation of the regulatory authority in the United Kingdom, Office of Gas and Electricity Markets (Ofgem).

The price control in RIIO utilizes a so called building block system that sums up baseline revenue allowance, performance based part, and an uncertainty mechanism including the debt related indexation in order to determine the allowed revenue.

Ofgem is setting output based incentives on reliability (minimizing the number and duration of interruptions and including adaptation to the climate change), safety, environment, customer satisfaction, connections, and social obligations (e.g. benefits to vulnerable customers). The DSOs are also required to show plans on how they will fit the increasing amounts of low carbon electricity generation into their grids. Plans need to include using smart grid tools. Also a broader view in contributing to environmental objectives receives incentives. There are numerous decisions made that further focus the incentives mentioned. They can be found in the source (ofgem 2013).

Due to difficulties in data acquirement, for instance incentive related to losses will not be implemented before the smart meters will be in place in the UK. This will most likely postpone this incentive implementation until the following regulatory period from 2024 onwards. (Jamasb & Pollitt 2007; ofgem 2010; Joskow 2013; RIIO-ED1 price control; ofgem 2013)

4.3. Finnish regulatory framework

The first 4-year period in the Finnish regulatory framework was started in 2004. Since then improvements to the system have been done for every new period. For the third period 2012 – 2015 the new mechanism introduced was the innovation mechanism. The mechanisms are presented below.

Already during the end of the second regulatory period, more precisely during 2010 and 2011, exceptionally strong storms were experienced in Finland. Thousands of customers were subject to long outages. Therefore legislation for maximum outage duration was implemented. This legislation is presented together with the reliability incentive.

Reasonable rate of return

In the Finnish regulatory framework the formula below defines the most important factor to DSO economics. The calculation method of reasonable rate of return is presented in the following formula (EMV 2013):

$$R_{k,post-tax,i} = \left(C_{E,i} * \frac{70}{100} + C_{D,i} * (1 - t_i) * \frac{30}{100}\right) * (D_i + E_i) \qquad (7)$$

Where	$R_{k,post-tax,i}$	*A reasonable return [€] on electricity network operations after corporation tax in the year i*
	$C_{E,i}$	*Reasonable cost of equity in the year i*
	$C_{D,i}$	*Reasonable cost of interest-bearing debts in the year i*
	t_i	*Corporation tax rate in the year i*
	D_i	*Amount of interest-bearing debts invested in network operations at the end of the year i*
	E_i	*Amount of equity invested in network operations at the end of year i*

In the Equation 7 the first part inside the brackets is the Weighted Average Cost of Capital (WACC), in which the 70 % and 30 % factors represent the average cost structure between equity and interest-bearing debts among the Finnish DSOs. The simplified calculation method therefore goes as in equation 8. Other abbreviations are as in equation 7. (EMV 2013)

$$R_{k,post-tax,i} = WACC * (D_i + E_i) \qquad (8)$$

Where	*WACC*	*Average cost of capital*

The reasonable return is the maximum amount of return a DSO can collect within a year. If the cumulative allowed revenue is exceeded during a regulatory period it will lower the allowed revenue for next period and vice versa: if the realized revenue is lower than the reasonable return, it adds to the reasonable return of the next regulatory period. The calculation of WACC is directly proportional to the 10 year risk-free obligation of the state.

Important is also the DSO cost structure and how it is treated. The OPEX is evaluated through StoNED model together with the outage information to evaluate the DSO efficiency. (EMV 2013) This is treated in the chapter 4.3.1.

4.3.1. Investment incentives

The actual investment incentive is a two-piece system where depreciation aims to give incentive to replacement investments in order to maintain the operational level of the grid. The other part supervises the investment levels of the DSOs. The unit price incentive that enlists grid component unit prices affects both of these mechanisms. The unit prices are based on the evaluation led by the regulatory authority.

The Net Present Value (NPV) of the grid considers the average operational age of the components in the grid in regard to the actual technic-economic operational lifetime of the components. The grid NPV is calculated each year. The NPV is used when calculating the WACC for allowed rate of return. (EMV 2013)

Unit price incentive refers to mechanism where investments get remunerated according to prices that are determined for each component or component group separately. For example the price for secondary substation in cable grid is 33 590 € for the year 2013.

The investment is valued in the regulatory framework as part of the grid NPV according to the list price of the component. The actual realized investment price of the component is not taken into consideration in the regulatory framework. (EMV 2013) Therefore opportunity for profit is evident by pressing the unit investment price and the unit list price e.g. by investing in large quantities. Also possibility for loss of investment appreciation exists by exceeding the price value e.g. due to low unit number in the order or high demand for functionalities.

Depreciation as part of the investment incentive in the Finnish model considers the replacement value of the investment. The yearly depreciation is the value of the grid divided by the designed lifetime of the investment. The planned depreciation is deducted from the realized one, which is then deducted from the actual return of the DSO. The regulator also supervises the target of investments in order to ensure sufficient replacement investments. This is done to ensure the operational capability of the grid in the future. (EMV 2013; Siukola 2013)

4.3.2. Reliability incentive

Quality related incentive in the Finnish model considers the outage costs and gives incentive for DSOs that can keep the outage costs under the reference values.

The effect of the quality incentive on the DSO return ranges from a maximum of 20% bonus to 20% penalty. These limits replace the earlier 10% for the ongoing third regulatory period. A symmetry clause is part of the incentive. It states that if the calculatory maximum effect of the incentive is X % then also the lowest sanction from the incentive is X%. The actual maximum and minimum percentage for quality incentive is calculated as follows (HE 20/2013 vp 296379):

$$Incentive\ effect = -(0.5 * OC_{ref} - 0.5 * OC_{act}) \qquad (9)$$

Where OC_{ref} *Outage costs reference level [€]*
OC_{act} *Actual Outage Costs for the year [€]*

Maximum outage times

The Finnish Parliament decided in 2013 for limits for the governmentally vital distribution grid operations. There are two sides in the reliability. One is the compensation of the long interruptions to the customers whereas the second states legislative sanctions for outage time.

The regulation follows tightly the development of the electricity market law. After 2011 storms in Finland, additions to the legislation were made. The changes that derive from those decisions today include separating the distribution network into two areas: Urban i.e. town plan area and all the other areas, where the allowed outage time is set to be 6 hours, and 36 hours respectively. These frame conditions must be gradually met so that in the end of the year 2028 they are in full effect. If these requirements are not met, the DSO has to pay fines. The requirements are illustrated in the Figure 20. (TEM 2013)

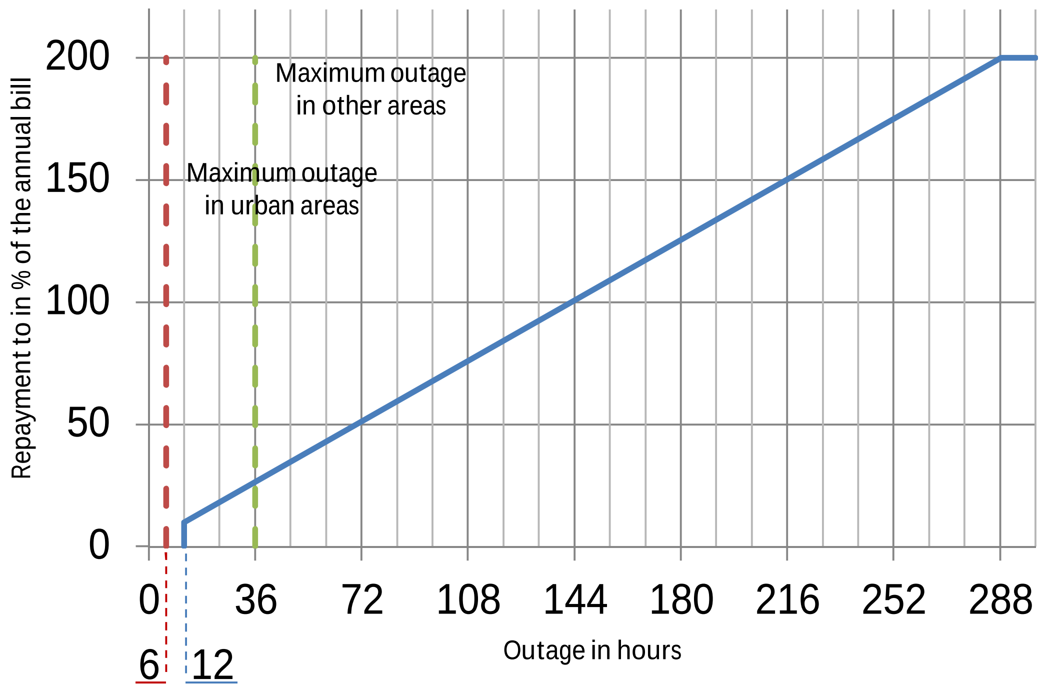

Figure 20 Repayment to the customer of the annual bill due to outage hours (TEM 2013)

The DSO has to form a development plan every 2 years to meet these needs. The EMA considers the plans for their credibility and approves the adequate plans. If it is clear that the cabling investments required by the DSO are vast compared to other DSOs, it is possible to get permission for prolonged transition to the reliability demands. The implementation time can be at maximum prolonged until 2036.

The cumulative cost for prolonged outage time period was heightened from previous 120 hours to 288 hours, so that in abnormal disaster situations the DSO would remain motivated in reducing the outage time also during major outages as illustrated above. The DSO must pay the customer back 10% of the annual distribution bill after 12 hour outage. The payback then linearly increases up to 200% in over 288 hour outages. As illustrated in the Figure 20 the maximum penalty or payback constraint for the DSO is 2000 euros per customer per year. The sanctions presented in the Table 6 are determined case by case in the Market court on the proposal of the Energy Market Authority. (HE 20/2013 vp 296379) The Energy Market Authority is called Energy Authority from 1.1.2014 onwards.

Table 6 Sanctions for exceeding the legislative maximum outage time (HE 20/2013 vp 296379; TEM 2013)

Outage time	Urban area €	Other €
0 to 6 hours	0	0
6 to 36 hours	Sanctions	0
More than 36 hours	Sanctions	Sanctions

In order to make such drastic enforcements to the reliability, the DSOs must invest on for instance cabling and automation solutions. The law described in the paragraphs above has taken force in the September 2013. (TEM 2013)

The current state of cabling in Finland varies from a few percentages to almost 100 % cabled grids and is on average 12 % in the MV and 38 % in the LV grid. In order to reach the 6 and 36 hours restrictions, the cabling percentage on average should be 40 to 75 % in MV and 40 to 90 % in LV grids depending on the circumstances. (HE 20/2013 vp 296379)

4.3.3. Efficiency incentive

The DSOs are given a company specific efficiency target that includes a general efficiency improvement factor. The yearly factor is 2.06 % for all the DSOs. The company specific efficiency target also considers a company specific efficiency factor determined by the StoNED (Stochastic Non-smooth Envelopment of Data) method. StoNED considers among other the company OPEX, number of customers, and share of cabling in the MV level.

From the company specific efficiency targets the reasonable demand for efficiency increase is determined yearly for each company. The effect of efficiency incentive is presented in the equation 10. The STOTEX in equation 10 is determined through e.g. the company specific efficiency target and consumer price index.

$$Incentive\ effect = -\left(STOTEX - (\mathrm{KOPEX} + 0.5 * OC_{act})\right) \quad (10)$$

Where *STOTEX* *Reasonable demand for efficiency increase [€]*
KOPEX *Influenceable OPEX of the DSO*
OC_{act} *Actual Outage Costs for the year [€]*

Therefore if the DSO is able to either lower the KOPEX or the yearly outage costs it can benefit of the efficiency incentive in the regulatory framework. The KOPEX includes among other the storage costs of material, personnel costs, and other internal costs. (EMV 2013)

4.3.4. Innovation incentive

The fundamental idea in the innovation incentive is to give the DSOs the opportunity to invest in pilot projects that they see beneficial for future grid development. Reasonable costs, amounting to a maximum of 0.5 % of the DSO revenue, of research and development costs can be treated as pass through components. It also includes the calculatory costs from smart meter operation to be treated as pass through components when calculating the allowed revenue for the DSOs. (Siukola 2013; EMV 2013)

4.3.5. The future of the regulatory framework

The information in this chapter is based on the interviews with the Finnish Energy Market Authority. For a DSO the premature investments to the grid are not economic. Most components could still have been further used in the old regulatory and legislative frame. Now these have to be changed in order to gain more reliability to the grid. The premature investment cuts the lifetime of the already purchased component and therefore increases the grid costs.

To compensate this negative effect, the Energy Market Authority has decided on additional mechanism for the last two years in this regulatory period i.e. the years 2014 and 2015. Specific investments made on the following are to be considered as special cases:

- To replace aerial lines of 20 kV and 0,4 kV with cabling
- Pole mounted transformer stations to be replaced with secondary substations
- Disconnectors in overhead lines to be replaced with disconnector stations

The lost residual value due to these investments are to be considered as pass through component in the revenue calculation and are therefore allowed to be fully compensated through customer billing.

It's not always wise to choose cabling due to reasons such as rocky ground. Hence an incentive is implemented for certain operative expenses such as the caretaking of the side by forests of the 20kV lines. These expenses could be excluded from the OPEX as pass through components. Also informing the customers and other shareholders from outages is by the law seen as an exception and so the OPEX from these activities could be considered as pass through component.

4.4. German regulatory framework

Overall the German regulatory framework for DSOs is focusing on increasing efficiency. The German energy Agency pointed out in its press release in the end 2012 that a vast survey conducted by them shows that DSOs have an extensive investment need on grid expansion but they won't receive sufficient returns through the existing regulatory framework. (dena 2012)

Since the first introducing tariff regulation in Germany in 2005 the electricity distribution cost for the customer has gone down. This is visualized in the Figure 21. The corresponding trend can be seen also in the business customer and industrial customer tariffs' development.

The German incentive based regulation started in the beginning of the year 2009. The regulation period is five years long. For the second period the Regulatory Authority determines the revenue-cap and incentives for the DSOs. (BNetzA 2013).

The second incentive based regulatory framework period for electricity distribution business runs from 1st January 2014 until the end of 2018. (ARegV)

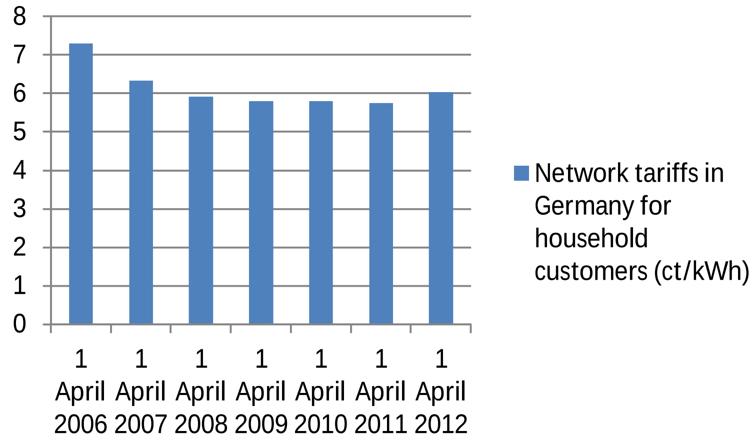

Figure 21 Network tariffs in Germany for household customers (BNetzA 2013)

The reason of the network tariff regulation was cutting down monopoly profits. As seen from the Figure 21 it succeeded well. After the tariffs balanced for a few years significant increase is to be expected in the future. This is due to several reasons of which one important is the increasing challenges from *Energiewende*. The adjustments in the revenue cap calculating method in 2012 had a significant effect on the tariffs whereas efficiency and cost reduction potential had only minor effect. (BNetzA 2013)

The revenue cap calculation is based on the DSO cost structure. The approved costs are divided into controllable and not controllable costs. The controllable costs are then divided into inefficient and efficient part. The share of the inefficient part in percentage is determined by the regulator and needs to be cut within the regulatory period. The already efficient part efficiency needs to be further improved with a general percentage affecting all the DSOs. Due to these mechanisms in the framework all investments made have to be cost efficient. The WACC is part of the costs proved by the regulator. When the costs go down, also the revenue decreases in the following regulation period (ARegV)

4.4.1. Revenue cap

Revenue cap is the level of income that is allowed for the DSO during the regulatory period. In the German framework the revenue cap is evaluated through the following components. The total allowed revenue is the weighted sum of the revenue calculated to the each grid level separately.

The revenue cap is determined through historical costs of a baseline year. For the 1st regulatory period the baseline year was 2006. This means that the regulator evaluates the cost structure of the DSO for the baseline year and considers the adequate costs as the basis for the DSO's allowed revenue for the regulation period. The baseline year for the 2nd period is under discussion. Some signals have been heard about a possible change in the system due to misuses. DSOs have forecasted the baseline year for the 2nd period to be the year 2011 and have made large investments during that year in order to get heightened allowed revenue for the next period of five years. The authority is expected to change the baseline to consider some kind of average cost structure from the previous period. (Workshop zur Anreizregulierung) This is however speculated information.

The allowed revenue in the second regulatory period is calculated according to the equation below (RWE 2008; Workshop zur Anreizregulierung ; ARegV):

$$C_t = C_{ni,t} + \left(C_{iB,0} + (1 - V_t) * C_{i,0}\right) * \left(\frac{CPI_{t-2}}{CPI_0} - XF_t\right) * EF_t + Q_t + (LC_t - LC_0) + CB_t + SF_t \qquad (11)$$

Where

C_t	*Allowed revenue [€] on year t*
$C_{ni,t}$	*Permanently non-influenceable costs in the year i*
$C_{iB,0}$	*Temporary non-influenceable costs in the year i*
$C_{i,0}$	*Influenceable costs in the year i*
V_t	*Allocation factor of the year i*
CPI	*Consumer Price Index*
XF_t	*Productivity factor for general efficiency increase*

EF_t	*Extension factor*
Q_t	*Quality factor*
LC_{t-0}	*Change in grid losses*
CB_t	*Change balancing*
SF_t	*Future Smart Grid factor (awaited to be implemented)*
t	*Index year running from 1 to 5, 0 being the reference year*

Permanently non-influenceable costs are determined in the German legislation § 11 II ARegV (*Anreizregulierungsverordnung*). The listing is expected to change in the beginning of the 2^{nd} regulation period.

Temporary non-influenceable costs comprises of the minimum of 60 % of all costs.

Influenceable costs comprise of the maximum of 40 % of all costs. These costs that were determined in the beginning of the first period have to be cut during two regulation periods. The costs determined from the data of the second period have to be cut during the third period so within 2014 to 2018. The influenceable i.e. the controllable costs are determined through efficiency comparison between the DSOs which incentives investment efficiency.

Allocation factor changes every year and therefore the regulatory model takes every year more of the controllable costs into consideration. The goal is to steadily cut the inefficiency determined by efficiency benchmarking. From the second period onwards the costs have to be cut during one regulation period so within a 5 year timeframe.

Consumer Price Index (CPI) considers the market value change. As seen from the equation 8 the CPI does not affect permanently non-controllable costs, quality factor, grid losses or change balancing mechanisms.

Productivity factor in the second regulation period in Germany is to be 1.50%. The idea is to increase the grid value efficiency, in other words to have a similar feeder length with lower costs. The productivity factor is implemented yearly.

Extension factor considers grid characteristics and heightens the allowed revenue if the grid costs are heightened in the MV or LV networks. Today also the distributed generation is taken into consideration. The incentive effect is smaller than the costs from grid expansion. There is an alternative investment incentive that increases the permanently non-controllable costs if the requirements for the extension factor are not met.

Quality factor sets incentive for improving the quality to the regard of e.g. individual factor calculated through company's own 3-year average on each grid level. The quality factor will be further developed for the second period but the final outcome for the mechanism change is not yet clear. For the first regulatory period this incentive set only small incentive for outage reduction. It should be noted though that there are relatively few outages in the German grid.

Grid losses mechanism values the energy losses in the grid to be 54.00 €/MWh (roughly the electricity price in Germany) for the second period. The DSO benefits for the energy loss it can avoid up to specific limits during the regulation period.

Change balancing takes place if the allowed revenue deviates more than 5% within regulatory period. The factor implements a stabilizing effect on the revenue, forcing the DSO to reconsider the customer tariffs. Source for the whole chapter is (Workshop zur Anreizregulierung ; RWE 2008).

4.4.2. Efficiency incentive

The Authority places demands on efficiency of the DSOs. The OPEX and CAPEX of a DSO are treated as total expenditure TOTEX and divided into three categories based on the DSO ability to affect these costs. The ones that are seen by the Authority as mandatory to the DSO business are called permanently non influenceable costs (in German *dauerhaft nicht beeinflussbar Kostenanteil*). These are named in the German law and include among other the legal payments, operating taxes, retrofitting of inverters for system stability, the costs spurring from nationwide equalization mechanism, certain research and development costs and efficiency-improving cabling construction, operation and modification.

The TOTEX that does not fall into the mentioned category are the ones affected by the efficiency demand. The German regulator uses a combined method including DEA and Stochastic Frontier Analysis (SFA) to determine the efficiency of the DSO. The model considers two input parameter cases: with adjusted grid costs and with standardized capital costs. Whichever of the four possible efficiency outcomes (DEA adjusted or standardized, SFA adjusted or standardised) is the most efficient, the DSO will be evaluated by that value, in comparison to other DSOs with similar results.

The TOTEX is divided based on this evaluation into “efficient” i.e. momentary non influenceable costs and “inefficient” i.e. influenceable costs. The amount of influenceable costs can be up to 40% of the TOTEX after the permanently non influenceable costs. The efficiency increase demand is illustrated in the Figure 22.

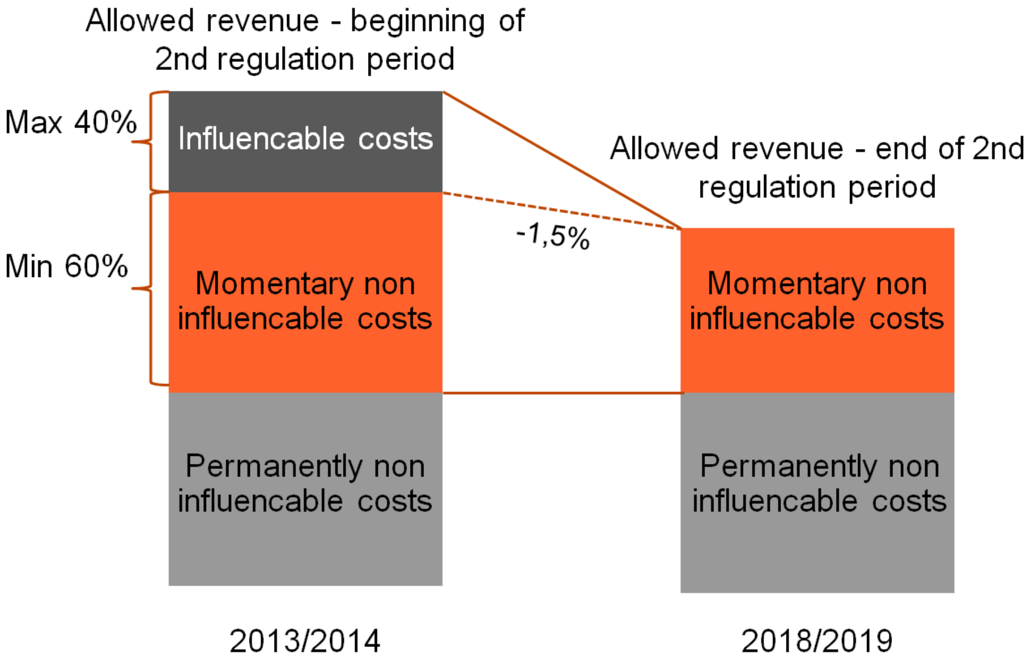

Figure 22 German regulatory framework efficiency demand (Workshop zur Anreizregulierung)

Since the DSO relation between OPEX and CAPEX can be up e.g. to 2/3, there is potential in reducing the OPEX in order to fulfil the efficiency demands. (Workshop zur Anreizregulierung)

4.4.3. The future of the regulatory framework

The German government has laid out a request for the German regulator to form new incentive to boost the SG development. It is yet unclear what kind of regulatory mechanism would be implemented in order to better give incentive to solutions that enable the increased DG from renewable sources. (Workshop zur Anreizregulierung)

However uncertain the future is, it is expectable that the future development of the regulatory framework will follow the general development path described earlier. For more information revise the chapter 4.1.

4.5. Italian regulatory framework

The Italian regulatory framework is based on incentive based regulation. The structure of the calculation of the DSO allowed revenue of the DSOs in the Italian regulatory framework follows the formula seen below.

$$REVENUE = RAB \, x \, WACC + DEPRECIATION + OPEX \tag{12}$$

Where	RAB	Regulated Asset Base
	WACC	Weighted Average Cost of Capital
	OPEX	Operational Expenditure

The Italian regulatory framework has an exemplary incentive for Smart Grid investments. This is conducted in the form of giving an additional 1.5 or 2.0 percentage on specific Smart Grid related investments. These are presented in the chapter 4.5.2.

Otherwise the Italian regulation follows the same incentive based regulation form as the Finnish system. The components are evaluated through respective price listings that in contrast to the Finnish system are company specific and reflect the historical price development.

The regulatory lag that cuts the attainable profit of the DSO in the periodical regulation is for the first time compensated in the Italian framework by giving a 1 % extra WACC on all new investments.

The general efficiency demand for the distribution services is 2.8 % and for metering services 7.1 % during the current 2012 – 2015 regulatory period. (ENEL 2012; Olivieri et al. 2012)

4.5.1. Reliability incentive

There are many reliability related incentives in the regulatory framework in Italy. Inputs for these are SAIDI and MAIFI while leaving out force majeure events. There is also incentive for reliability on the transmission side. The following mechanisms for distribution grids can be indicated. (CEER 2011)

Target for average outage duration

The reliability incentive in Italy guides the DSOs for reducing their SAIDI and SAIFI values. A SAIDI based bonus and penalty system was implemented in 2000. Its idea is to improve the worse grid areas while maintaining the good performance in the better functioning areas.

The Italian DSOs have decreased their SAIDI between 2000 and 2010 roughly by two thirds and are now among the best performers in regard to SAIDI within Europe. The Italian regulation divides the distribution grid into 300 territories. These territories are grouped into three categories based on the amount of customers. Each category has a separate baseline target SAIDI value, as follows (CEER 2011; Hesmondhalgh et al. 2012):

- Urban territories with more than 50 000 consumers: 25 minutes
- Suburban territories with 5 000 to 50 000 consumers: 40 minutes
- Rural territories with less than 5 000 consumers: 60 minutes

These values are evaluated yearly from the two year average. The overall average for Italian SAIDI in 2010 was just above 40 minutes. The same categories apply when baseline targets for SAIFI and MAIFI are evaluated. (Hesmondhalgh et al. 2012)

Customer surveys are being used for determining the penalties and bonuses that are symmetrical, also a mean value of 10 800 €/MWh for LV customer energy loss and

21 600 €/MWh for other customers is in place. The system includes caps for maximum and minimum effects for the DSO. (CEER 2011)

In comparison, in Finland the respective mechanism is symmetrical. The German framework at the moment focuses on the penalty side while the amount of bonus or penalty is related to DSO revenues rather than on the amount of energy.

The baseline targets are not necessary meant to be reached within a regulatory period. The DSOs can apply for less strict targets and include the estimation of unexpected interruptions that cannot be controlled by the DSO. (Hesmondhalgh et al. 2012) However the regulatory authority states that its goal is that the DSOs reach the targets for outage duration by 2015 and targets for the number of outages by 2019. For MV customers also short outages from 1 second to 3 minutes are measured automatically and compensated for according to measured power loss. (AEEG 2012)

Additional mechanisms for grid reliability

A new mechanism in 2012 started a three year project for measuring voltage dips at every MV bus bar in the DSO transformer substations. The measuring must be put to service by the end of 2014.

From the next regulatory period in the beginning of 2016 voltage dips will be surveyed in comparison to the measured data from this regulatory period. For LV customer voltage dips special surveys via smart meters can be requested by the authority. (AEEG 2012)

There are two targets for short outage frequency. Firstly a MAIFI based incentive was introduced in 2008. The Italian grid performs well in interruption duration but there is room for improvement in regard to interruption frequency. The mechanism considered SAIFI during the previous regulatory period, but from 2012 onwards the sum of SAIFI and MAIFI has been used for MV level customers. The mechanism uses penalties as an incentive. (CEER 2011)

Secondly a penalty system takes into account the number of LV customers who suffer from a longer than 8 hour outage. The mechanism was implemented in 2008. The annual penalty is calculated by multiplying the LV customer number that suffered from the outages by 70 EUR. The penalties are paid annually.

4.5.2. Smart Grid incentive mechanisms

In the Italian system the DSO benefits from investing in certain SG solutions compared to investing in the old solutions. The Table 7 clarifies this point by listing the solutions and their respective WACC in the Italian regulatory framework. This has led to investments as pointed out in the chapter 5.4: The largest DSO in Italy, ENEL, is planning on investing in upgrades of roughly a quarter of all its secondary substations, meaning roughly 80 000 units.

Table 7 Smart Grid incentives in Italy (ENEL 2012)

Regulatory period 2012 – 2015, Italy	WACC new	WACC old
Regular (All other) investments	**8.6%**	7%
Replacement of MV/LV transformers with low losses ones	**10.1%**	9%
Reinforcement of MV grids in cities historical centres	**10.1%**	7%
Reinforcement of transformation stations in critical areas*	**10.1%**	7%
Energy storage system pilot projects	**10.6%**	-
Smart Grid pilot projects	**10.6%**	9%
** Critical areas: areas with high concentration of generation connected at MV/LV level (14 provinces and over 600 municipalities in other provinces in Italy)*		

The Italian regulation considers the Smart Grid related investments in the MV grid in three aspects that are: grid technology innovation, new grid services and grid user participation. There are specific minimum requirements for smart pilot projects. In addition to these minimum specifications listed below:

- The demonstration project takes place in an existing MV (1-35 kV) network and includes both passive consumers and generation points.
- There is power flow from MV to HV side that has a minimum of 35 kV voltage level. The power flow must be reversed at least for 1% time yearly.
- Real time control system for data recording to demonstrate that the project exists.
- Open source communication is used for protocols in order to avoid high network interface costs for customers.

The projects for the prevailing regulatory period were selected from the propositions of the DSOs based on several criteria such as size, degree of innovation in the project, usefulness for electricity distribution and the project viability. (Olivieri et al. 2012)

Tripping of DG

ICT is seen as an important SG driver and it plays a significant role in enabling the increased share of DG to be connected to the distribution grid. The two most important functionalities to be enabled by ICT are extremely short latencies that are in the order of some hundred milliseconds as well as reliability also under malfunctioning situations such as outages.

The further developed grid functionality is the so called Loss of Main (LoM) communication between the master and slave relays in order to prevent unnecessary tripping. This way the DG is also able to provide recovery power to the system in emergency situations where the frequency problems occur.

There is a timeframe of 200 ms for the communication between the relays if the LoM occurs. Since the automatic reclosing in fault situations takes place after 400 ms there is enough time to disconnect the DG if necessary. If the communication fails the relays make use of the local configuration. (Rödl & Partner 2012)

Table 8 Grid provisions for renewable energy in Italy (Grid issues in Italy)

Connection to the grid	*Plant operators are contractually entitled against the grid operator to priority connection of a renewable energy plant. The grid operator is obliged to enter into this contract.*
Use of the grid	*Plant operators are contractually entitled to usage of the grid. Electricity from renewable sources shall be granted priority use of the grids, provided that the electricity achieves the same price on the market and the security of the national energy grid can be guaranteed.*
Grid development	*A plant operator applying for connection is contractually entitled against the grid operator to a grid expansion, if the expansion is necessary to satisfy the claim for connection to the grid. As renewable energy plants must be given priority connection, a grid expansion necessary to connect such a plant must also be given priority.*

Example: Effect of the Italian standard

The Italian standard CEI 0-16 determines the needed protection appliances for MV grid connecting DG. The requirements include among other a general device for disconnecting the whole prosumer from the MV grid, an interface device that separates the most critical parts of the customer from the grid and the generator device that separates only the DG from the grid. (ABB 2008)

For LV the most interesting requirements affecting the grid balancing and smart secondary substation concepts are related to remote controlled tripping and reactive power production or consumption. The exact specifications for new PV commissioned after 31.12.2012 are listed below. The DG inverters must have the following operational functionalities (Rödl & Partner 2012):

- “immunity to quick voltage drops;
- disconnection from the power grid by remote control;
- increase of the selectivity of protections in order to prevent untimely disconnection of the PV-plant;
- allow reactive power supply or draw;
- restrain the power put into the net (in order to cut power surges of the net);
- prevent that the inverter itself might power the electric load in the net in the absence of power voltage on delivery cabin.”

The above mentioned functionalities affect the needs and expectations of the secondary substations since functionalities such as remote control of the inverters, measurements for protection selectivity or reactive power need can be supported by functionalities at secondary substations.

4.5.3. The future of the regulatory framework

The next step in Italian regulation according to (Olivieri et al. 2012) will be the large scale incentives to support smart grid development based on the benefits evaluated from the pilot projects. The regulation will move from input-based to output-based scheme. The main idea is to remove the grid constraints to be able to accept a larger amount of DG to the grid. The following points are taken into account when forming the new output based SG scheme (Olivieri et al. 2012):

- Reverse flow time indicator to assess the grids in need of smart solutions
- Separately from Reverse Flow Time the amount of RES in the grid
- An indicator for the amount of additional RES capacity that can be installed to the grid due to SG solutions
- Minimum requirements such as maintaining the already reached reliability levels and the use of open communication protocols for ICT applications in grid user interfaces
- Both reward and penalty should include in the incentive

In addition to these the current SG pilot project incentive will be extended for LV grids. Altogether the benefits expected are e.g. reduction in total capacity needed, lower grid losses, and reduction in centralized power production. (Olivieri et al. 2012)

4.6. Associations with political influence

The final decision maker in the EU is the European Commission (EC) that sets the legal foundation for all operation also on the national level. The enlistment focuses on importance in regard to regulatory framework development so other important associations such as IEEE (The Institute of Electricals and Electronics Engineers, Inc.) and IEC (The international Electrotechnical commission) are left out of this list.

EURELECTRIC (The Union of the Electricity Industry**)** is the European level organization representing the interest of national level Electricity Industry advocates. Currently the union is focusing on three objectives that are listed below. The bullets are a direct quote from the EURELECTRIC website.

- “Delivering carbon-neutral electricity in Europe by 2050
- Ensuring a cost-efficient, reliable supply through an integrated market
- Developing energy efficiency and the electrification of the demand-side to mitigate climate change.”

The objectives mirror the desires of national stakeholders including the electricity industry organizations in all the focus countries of this thesis. (eurelectric.org; EURELECTRIC 2013)

ACER (Agency for the Cooperation of Energy Regulators) is an agency i.e. European Union body established in 2010 to replace the earlier European Regulators Group for Electricity and Gas (ERGEG). The main purpose of ACER is to support the community-based functions of the national regulators and to contribute towards effective functioning internal markets for electricity and gas. (REGULATION (EC) No 713/2009)

CEER (The Council of European Energy Regulators) shares similar goals with ACER but where ACER is an official EU agency and a formal advisory group the CEER is an unofficial association set up by the regulators for themselves. (CEER) Both ACER and CEER also work in contact with the ENTSO-E (European network of transmission system operators for electricity) in grid code design.

National stakeholders

In addition to local ministries, responsible ministers and politicians, there are a few specific associations of specific interest for local energy market and regulation legislation influencing, presented in the Table 9 and in Table 10. There are also other smaller energy associations in the countries in regard to Table 10, but they were not considered as the main stakeholders for the subject of this thesis.

Table 9 National regulatory authorities

	The authority responsible for e.g. regulatory framework development and supervising for electricity and gas market
Finland	*Energiavirasto* (EV)*
Germany	*Bundesnetzagentur (BnetzA)*
Italy	*Autorità per l'energia elettrica e il gas (Aeeg)*
	*Until the end of 2013 this bureau was called *Energiamarkkinavirasto (EMV)*

Table 10 National energy industry associations

Finland	*Energiateollisuus (ET)* *"The Finnish Energy Industries (ET) is a sector organization for the industrial and labour market policy of the energy sector. It represents companies that produce, acquire, transmit and sell electricity, district heat and district cooling and offer related services."(ET)*
Germany	***Bundesverband der Energie- und Wasserwirtschaft e.V. (BDEW)*** *"Natural gas, electricity and district heat, water and wastewater: BDEW represents 1,800 companies."(BDEW)*
Italy	***ASSOELETTRICA*** *"…is the National Association of Electric Companies which brings together around 120 companies operating in the free market providing about 90% of the electricity generated in the country?"* (ASSOELETTRICA)* ***FEDERUTILITY*** *"…Federutility is the federation that brings together the local utility companies operating in the Electricity, Gas and Water … currently providing electricity to approximately 20% of the Italian population."** (Federutility)
	*A free translation from the source.

5. INTERVIEWS

The chapter Interviews gives the reader a more practical view to the topic based on expert interviews. This chapter fulfils the information on energy market development, regulatory framework effect on Smart Grid investments and the viable secondary substation functionalities in regard to the previous chapters. This chapter concentrates on the most interesting observations and remarks regarding the topic of this thesis.

This chapter is summarizing and combining the results from visions of 35 interviewees that represent 14 stakeholders in three countries. 12 of the interviews were systematically guided through the questions that can be found in the Appendix 1. The rest of the interviews were supplementary and focusing on some specific area of interest. The list of interviewees can be found in the references. The interviews were held confidential due to the nature of the topic: Especial subtlety has to be conducted in situations where relations between clients and suppliers are in question.

The interviews revealed that the market situations indeed vary between countries as do legislations and regulatory frameworks. The clear benefits from Smart grid investments are shorter outage times, restricting of outages on smaller areas and decreased costs of operation although efforts are needed to maintain automation systems. The SG investments lead to better surveillance and control of the grid, self-repairing abilities, improved distribution security, ability to increase the share of DER and the enabling of DR. The SG solutions cut down or postpone investment needs, e.g. grid enhancements.

5.1. Questions

The list of questions for the interviews was formed together with ABB experts. The focus was through the questions to get a comprehensive picture of the three aspects that were detected as influencing the secondary substation investment prospects.

Out of the three aspects the first was the interviewees' view on energy technology trends in electricity generation and distribution that would have an effect on the dimensioning of the secondary distribution grid. Second was the regulatory framework of the DSOs in regard to automation investments. The third was the future functionality needs for secondary substation. The questions can be found at the Appendix 1.

5.2. Interview results in Finland

The Finnish energy market development seems clear in the short term. Long term direction towards RES based generation is more uncertain. The regulatory framework is reliability orientated while the secondary substation functionalities also aim to support this development.

5.2.1. Energy market development

The electricity demand is going to rise. This is due to increasing amount of e.g. heat pumps, electrical appliances in households and in the long term also the electrification of the personal vehicle fleet. The development however is highly dependent on the political decision making: whether the EVs or some other technology will be preferred over the combustion engine vehicles. In Estonia the national decision of building the charging network for EVs is an example of the model that is under construction in the EU.

Behind the political decision making are the average consumers. The needs of the customers are the main driving force for any investments. The customer satisfaction is ensured through legislation. On the other hand customers can bring challenges, an example in Finland is the log machine that is disturbing the grid balance by generally being used in the far out end of LV feeders. These kind of cases together with the trends of going towards LED lighting and PV generation spur the increased possibility for disturbances such as voltage dips, harmonics, outages and so on.

The small scale electricity generation and the EU driven climate targets for energy efficiency, emission reduction and renewable energy affect the Finnish business environment. The market is expecting a drive for development in all these aspects and new business models such as the hourly based tariffs for household consumer electricity pricing.

The choice of electricity production method is highly dependent on the economical affordability of the method. Finland has introduced feed-in-tariffs for wind power that have initiated investments. The medium scale (from tens to hundreds of kilowatts) biomass power plants are expected to be important in Finland in the long run. The small or medium scale CHP is already a viable option for example in Switzerland.

The EU wide energy market unification is going to take time. The time scale for a Finnish consumer to be able to choose e.g. a German supplier seems somewhat 10 years from being the reality. The European Union plays a critical role in driving the markets together.

An emphasis should be placed on the electricity distribution tariff structure that would have more weight on the actual operating costs of the grid. Today the focus is on the amount of energy distributed. This would ensure the grid cost covering also in the situation where consumers would more often be prosumers and the amount of electricity distributed to the customer would drop from the prevailing situation.

Technology trends

The interviewees were asked to evaluate the importance of certain technology trends to the distribution grid development and operation. The results for Finland are presented in the Figure 23. At the horizontal axis are the trends that could be regarded as influential to the grid planning and operation. At the vertical axis the value 3 represents high importance, value 2 represents neutral importance and value 1 low importance for DSO planning and operation. The ones rated with the value 0 were brought up by individual interviewees and cannot therefore be treated as comparable.

The vertical trend lines show the variation in results and the triangle points the average response. Most varying results were received for the effect of solar photovoltaic and the nuclear power. For PV there was variation both due to expectations to the importance of PV as a technology but also due to time scale: It seems extremely hard to forecast the future development speed for this technology in Finland.

Wind power was seen as the most influencing trend in the short term together with nuclear power. The latter is expected to reduce need for intermittent renewable energy production in the long run and so hinder the rise of investment needs. Demand response was seen as an opportunity for grid balancing if standardised and thereby commercialized. The findings for all the trends are explained below in more detail.

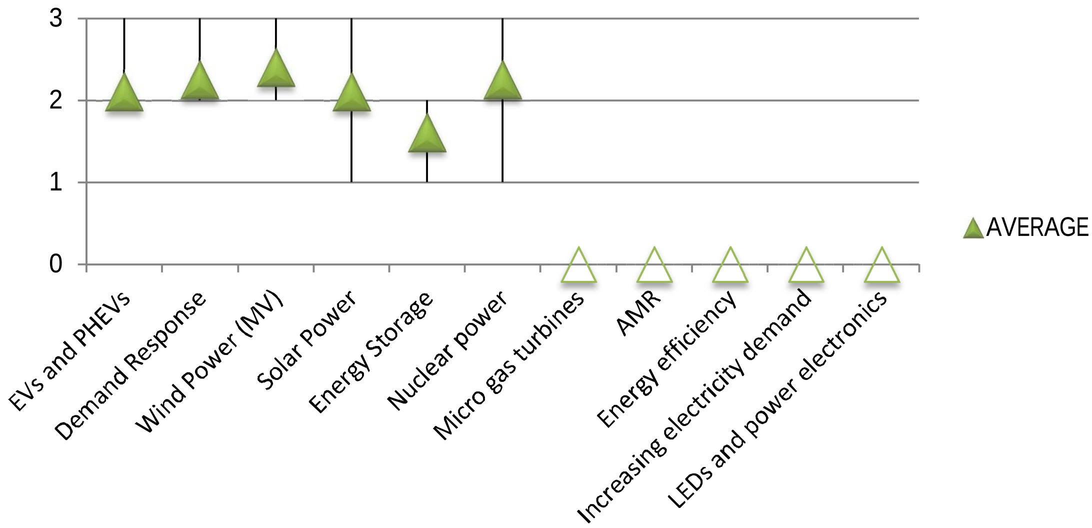

Figure 23 Technology trend effect in the distribution grid in the short term

Nuclear power is expected to keep electricity prices low which is bad for RES promotion. Nuclear will have a significant role in the energy mix for a long time. On the other hand unification of the European electricity market is expected to raise the average electricity wholesale price.

Solar power is not important overall since PV cost efficiency should drastically increase to hit the Finnish markets large scale. Still some interviewees thought PV will be important in specific areas. Due to technical advancements market share was expected to rise in the long term. The interviewees were not unanimous about the importance of PV in the short or medium term,

Wind power is especially important in the MV level. Permission procedures take time and hinder the wind park investment realization.

Demand Response needs simplified solutions. Since DR is evaluated cheaper than balancing power it has vast possibilities in the balancing markets. The consumer electricity price tariff change to hourly prices will open up possibilities for customer DR. The technology exists already.

Electrical Vehicles is not important in short term but in the medium / long term. By 2020 bigger change could be expected. The grid is not restricting EV implementation. However the high market price and low supply capacity of the EVs is seen as a hindrance. EVs can be treated as storage technology.

Energy Storage will be the game changer if it hits grid parity. First applications beside EVs could include increasing reliability in long sparse feeders to eliminate the effect of delayed reclosures and voltage dips. For example the power electronics based technologies are interesting for short duration energy storing. The ownership of energy storage was seen as an open question and comparable to TSO emergency capacity.

Micro gas turbines are expected to become more common in cases such as farms and hotels with own production of waste and other bio based residues. Another driving force is need for electricity and heat.

AMR has collected consumer data from the past 3 years. An hourly based balance settlement is available. The customer can benefit from power supply status information provided by the meter. The easiness of the usage is important especially for the customer. The quality measurements are not enough for detecting voltage dips at the moment. Many outputs in the AMR open up opportunities.

LED lighting and power electronics will increase in market share: LEDs due to their low energy consumption and inverters as part of PV systems. These both however create harmonics that increase grid losses and have to be considered while dimensioning the grid.

5.2.2. Regulatory framework

The reason for regulatory framework to exist is to set incentives to the DSO in the natural monopoly position to improve the efficiency of its business model and to ensure a reasonable level of distribution costs to the customers. At the same time it should ensure a reasonable rate of return to the DSO in order to keep the business attractive to the venture capital. The nature of the DSO as an investment target has been and is described as low risk and long scale sure profits.

The DSOs and the representative organisation Finnish Energy Industry association are in continuous discussion with the Energy Market Authority (EMA) that sets the targets and levels for the DSO economical activities. The EMA for example supervises the reasonable rate of return that is the most important economical factor for the DSO.

The EU 20-20-20 targets have an regulatory aspect through energy efficiency increase. The European legislators take care of this e.g. by implementing new efficiency demands for the transformers. For the time being the local impact on nature and environment is left unattended in calculating the reasonable rate of return. At least in an academic perspective this could be changed in the future.

The main enablers and disablers for smart Grid investments

Today the Finnish DSO regulation has a 4 year long supervisory period. The next periods will remain to continue the 4-year cycle, but the regulatory framework will be frozen for 8 years, as stated by the EMA. This is meant among other things to address continuity to the DSOs and to give time to solve the possible disagreements in the regulation assessments. The next period will start in the beginning of 2016.

The Finnish regulatory framework is divided into two blocks. The first is the valuation of the committed capital in the grid. The reasonable rate of return is then set for this capital. The second is the set of different incentives that affect the actual attainable return of the DSOs.

The most important note to make in DSO perspective is that the relation between profit and risk must be attractive. The investors might find better targets for investments if the attractiveness, i.e. the DSO business profit lowers too much.

An important factor for DSO revenue and therefore regulated profit calculation is the company WACC. It follows the present risk-free interest rate. If the regulatory WACC would be fixed, the low economic situation would not influence DSOs profits. This option was discussed while forming the now operational regulatory framework. The market based WACC was chosen instead. When the interest rates are rising and high, the market based WACC calculation is more profitable to the DSOs. In depression when interest rates are low it directly affects the reasonable rate of return leaving it to a lower level.

At the moment the WACC level is very low, around 2% compared to 5% in the beginning of the first decade of 21st century. This puts DSOs into a tight situation where the reasonable rate for committed capital is valuated low. This cuts their profits compared to years with higher interest rates. It is uncertain when the European and alongside it the Finnish economy will experience undisputable growth. When it does, also the DSO profits will increase.

The most important regulative mechanisms in the present regulatory model are the OPEX and CAPEX related investment incentive as well as the quality mechanism. The valuation of the committed capital might account in the order of 50% of the final profit or deficit of the DSO. If the OPEX or CAPEX calculating functions, in other words the investment incentive is changed, then the limit for investment payback level is changed as well. The level at which the total investments of a DSO accumulates allowed revenue is dependent on those functions. The most important parts of the investment decision are the regulatory framework and the electromechanical state of the distribution network. The latter determines if the investment is mandatory or not. The guidance towards MV cabling is inbuilt to the system, as the cabling reduces outages during nature disasters such as vast storms that bring down trees near the feeder lines.

When a DSO is calculating the basis for an investment decision, in addition to the regulatory framework also the potential impact on e.g. the maintenance costs and other non-regulatory aspects are taken into consideration. The Table 11 presents the evaluated rough relations between the regulatory mechanisms according to interview results.

Table 11 Evaluation of incentive mechanism importance (from 0 to 3 stars of importance, 3 being the highest)

Finland	Mechanism importance on smart investments
Investment incentive	★★★
Reliability incentive	★★★
Operational efficiency	★
Innovation incentive	★

The innovation mechanism in the regulatory framework is insufficient to actually initiate innovative investments. It is meant for pilot projects. The OPEX is based on old data or old lists. DSO receives a 5 € remuneration per installed meter, which on DSO perspective is not sufficient. Some improvement could be done through better classification of the product lists. Now only the remote disconnectors and switches are listed, that also can be seen as Smart Grid products. The product classifications in the markets and in the regulatory framework do not match.

If there would be need for increasing automation that is not covered by the existing regulatory model the increased investment cost should be covered by lifting the distribution tariffs.

The coming functionalities could be fault location of short outages, earth fault calculations and fault detection. One problem is to find the right data from the big data. The ideal Smart secondary substation could collect all the grid functionalities to one place in cable network. In this idea also the regulator would give encouraging incentives to the investments that increase smartness. There are over 80 DSOs in Finland, so the regulatory framework should be as simple as possible.

The islanding concept as part of the official regulation model isn't seen as a believable in short term future. For this kind of innovations to go commercial, there should be enough of positive incentives in addition to the restricting and punishing ones.

5.2.3. Secondary substation solutions

In most grids the remote controlled switches and disconnectors can drastically increase the reliability of the grid. Their SAIDI and SAIFI values can be dramatically cut with the first investments. The benefits decrease as more such investments are being made to a network. In the cities but also in urban areas a lot can be done to improve the reliability of the cable grid by FLIR: by finding the fault location, isolating it and later on restoring the power also to the healthy part of the grid as soon as possible.

In Finland the AMR roll-out is just finished in the end of the year 2013. Disregarding some exceptions, in practical sense all the consumers in Finland now have an AMR capable of among other functions controlling the electric heating of a household. Remote control of such appliances would need permission from the customer, but would be technically doable already now.

The AMR metering in Finland should now be ready for bidirectional hour based metering. The meters are able to follow and report the outages. The net-metering system for DER could be a solution, but the challenging open questions in taxation and in the role of DSO as well as in technical metering seem not to be clear or close to getting an answer. Since Finland got the first round in metering finished by the end of the year 2013, and an average lifetime of AMR is 10 to 15 years, a new installation round with evolution of two meters, i.e. separate meter for DG is not in sight for the next 5 years.

The problem is though that nowadays the information flow back and forth with the customer and the DMS takes minutes. The information should be available in close to real time in order to efficiently participate in the grid frequency balancing. Alongside with Advanced Metering Infrastructure (AMI) the Home Energy Management Systems (HEMS) could be used for the same purposes – although the main purpose of HEMS lies in the comfort and energy management of the household and not in the grid stability.

There could be certain added value in having measurements at both consumer end and at secondary substations. Measurements at secondary substation end can help to keep the transformer from being overloaded. The radiant nature of many LV grids reduces attainable benefits and so more interest has arisen in the MV grid automation. In the LV grid the AMR provides sufficient information of the faults. That is to say measurements on the LV side of the substation are not as important as on the MV side in the Finnish AC distribution grid case. In LV DC case there might be need for automated current direction changes.

Functionalities in high distributed energy resources areas

Challenges and therefore need for automated solutions occur when the intermittent DER share i.e. PV in electricity capacity crosses half of the maximum capacity of the LV grid. Active voltage control at the secondary substation is a known solution to this problem. The solution used in Germany – placing switches to the PV generation end – has not been used in Finland.

To avid safety hazards, it is important for the DSO to know, where for example PV-panels are connected. Otherwise the relay positioning might be out of date and a grid part, that was supposed to be cut off with relays due to maintenance or other reason, still has voltage. This is a real safety risk if not taken care of.

The future smart secondary substation should be adaptive and so capable of controlling the substation automatically. It would use the data sent from AMR to automatically control e.g. the voltage level of the network.

The secondary substation could function as a hub for Demand response information and as a platform for the consumption and electricity generation control. Focusing the functionalities into the substation also increases the investment efficiency: the same structure serves many purposes while sharing the fixed costs and reducing points that need maintenance in the grid.

This would correlate with the trend of moving from centralized electricity generation towards local energy balances. In this vision the local system could be operated by automated ICT based system that takes care of the local energy balance and controls the network respectively. The balance would be kept with one connecting feeder for import and export when needed. Later on energy storages would help the local system to increase its self-sufficiency.

Even though thoughts of local electricity markets have arisen, the trend in the European Union through the decisions of its Commission is towards larger market scale with smaller generation scale.

The most useful lessons from Finnish pilots so far have been the development of cost efficient cabling.

The roadmap for efficient use of tap changers

The following steps could be followed when evaluated the need for a tap changer in voltage control of a distribution network in Finland and elsewhere:

1. There is no need for high accuracy measurements at all the consumer points.
2. Implement the high accuracy measurements to the secondary substations for high situational awareness.
3. Ensure working communication infrastructure between the secondary substations and the primary substation.
4. Use measuring data from secondary substations to control the voltage level with tap changer at the primary substation.
5. There’s a possibility e.g. in Finland for +-1.36% voltage control in 5 seconds. This is faster in voltage control than demand side load management or balancing power plant operating. The maximum voltage regulation through tap changer is +-9*1.36%. That makes a total of +-12.24% scalable voltage.

5.3. Interview results in Germany

The chapter 2.1 shows that the OHL form only a small minority of all distribution grids in Germany. The high share of cabling is a clear advantage to Germany in terms of long outages measured with the SAIDI value. The German SAIDI in 2012 was less than 16 minutes.

The challenges are elsewhere. The German energy transition from nuclear and other fossil fuels, known by the German name *Energiewende*, has already brought such a share of renewable generation to the grid that it is an investment driver for automation and smart solutions.

5.3.1. Energy market development

The financial effect of the *Energiewende* is that the renewable energy law (EEG) makes every household customer pay a contribution to the RES in their electricity bill. The industry is exempted from taking part in EEG payments if they pass the two conditions set by the government: The company business has to be energy intensive and face international competition. The so-called EEG addition that presently makes roughly 18% of the household electricity bill enables subsidies for wind and solar power. Many stakeholders see it as a burden. The subsidies for PV are set to decline due to reaching the governmental installation targets for new PV.

The PV panels are produced locally in Germany. The hard competition between the Asian and European manufacturers has driven the market saturation in PV and wind businesses during the last years. Many of the German PV and wind companies have had to quit operation due to low or negative profitability.

The result of the German council (Bundestag) elections in September 2013 has shown little change to be expected. The Christian Democrats (CDU) was led to clear victory by Angela Merkel. The CDU is known for its conservative movements, with the exception of the nuclear phasedown. They made no comments on the future of EEG before the elections. Out of all sustainable energy technology options the energy efficiency is closest to the CDU policies.

One topic that has got the media attention and that shows the CDU will to fight over local jobs despite the *Energiewende* is the Germany's stand on reducing car emissions. Merkel blocked the law to strongly reduce emissions from all cars. The German car industry would take a blow from such a decision.

There's so far no mention in the German energy politics about the Smart Grids that enable the *Energiewende*. Some improvement is expected at the regulation of the DSOs if not on the higher legislative level. Implementation of new incentive mechanism to the regulatory framework might take place in the near future.

Electricity mix affects grid topology

The German long-term goal is to implement more RES eventually adding up to 80% of the electricity generation. The high share of RES connected to the grid at the MV and LV level has a high effect on the grid balance. The short-term reality however shows lignite and coal booming in order to fill the nuclear gap in the base load production. These large-scale plants can be built where it best serves the grid.

New HV lines are needed when the numerous Northern German on- and offshore wind parks are built. Offshore wind capacity should rise to 10 GW by 2020 and 25 GW by 2030. The windy North needs to feed the energy intensive Southern Germany with its wind energy surplus. Also interconnections between cities are to be enhanced. See the chapter 3.2.1 for updated information about the German plans on wind energy deployment.

Capacity markets

There might be need for capacity markets. The fossil based energy producers are expected to soon need such a new market mechanism due to their relatively high operational costs and therefore low possibility to be able to compete in the day-ahead markets that form the electricity market price based on variable costs. Forming a structure for capacity markets is however at an early stage.

Especially the highly adjustable gas power plants might need the new markets to remain commercial while the RES production is lowering the wholesale prices. Gas power is fast to control and therefore would be beneficial in the high share RES system for balancing purposes. The share of renewable sources of total energy consumption in Germany during 2013 was in the order of 23%.

Other low carbon solutions

Carbon Capture and Storage (CCS) is not discussed at the moment. The CCS could reduce the emissions from coal plants drastically, but it is too expensive. Also some other environmental aspects besides carbon dioxide effect in the atmosphere would have to be carefully considered with CCS since the technology is not fully tested. Similar environmental questions apply to fracking that is turned down for now in Germany. Fracking is a drilling method that utilizes water and a mix of chemicals pumped into the drill hole in order to collect unconventional gas and oil reserves, i.e. shale gas.

There's a governmental target of 100 000 EVs plugging in to the grid in 2020. Although the Plug in Hybrid Electric Vehicles (PHEVs) are contributing their share, most car manufacturers seem to go straight to the fully electric vehicles. Based on the low quantity of EV supply, the set goal of EV implementation will probably not be reached.

The following listing shows the evaluated importance of technology trends for distribution grid development in the short term.

- Solar, DR (DR enabled by EVs in the long term) – High importance
- Storage also together with PV – Medium importance
- Wind (mainly on HV level), Nuclear phasedown – Low importance

5.3.2. Regulatory framework

The driving force for the development of the regulative framework of a natural monopoly in the distribution grid is to ensure efficient investment policies. This is especially important in the German regulatory model. The regulation imitates and aims to investment efficiency. The German regulatory formula for allowed revenue is represented on the page 55.

The incentive based regulation

The main driving force of the incentive based regulation model is the incentive for lowering the costs of a grid. The investments are divided to three categories. 1st and smallest is *the influenceable costs*, 2nd is shown as the biggest – *the temporarily non-influenceable costs*, and the 3rd is *permanently non-influenceable costs*. In which category does a cost fall into has an effect on the approved revenue of the DSO due to the regulatory framework. The share of the 1st investment category is determined by the regulative model and depends on the formation and topology of the grid. The different cost categories are represented in the Figure 22.

The efficiency of a DSO is determined as presented in the chapter 4.4. There is a strong incentive for making efficient investments. Due to the method of efficiency evaluation this is not good for investments in smart solutions. As an example and as pointed out in the chapter 5.3.3 there is a rising need for voltage control since secondary substations are supplying an increasing amount of solar PV. The cost of the secondary substation with a tap changer in the transformer is higher than that of a regular passive transformer. Therefore if an investment on the secondary substation with a tap changer is made, the investment efficiency is lower than with the regular secondary substation. In other words the € per feeder km and € per consumer values are higher and the smart solution worsens the evaluated efficiency of the DSO.

According to the interviews two most determining incentive mechanisms for smart solution investments can be pointed out. The first is the allocation of the costs referred here as investment incentive. The second is the operational efficiency evaluation. These are presented in the Table 12.

Table 12 Evaluation of incentive mechanism importance (from 0 to 3 stars of importance, 3 being the highest)

Germany	Mechanism importance on smart investments
Investment incentive	★★★
Reliability incentive	★
Operational efficiency	★★
Energy efficiency incentive	★
Extension factor	★
Change balancing	–

The *Erweiterungsfaktor* or the extension factor in the formula does incentive all the investments besides the permanently non-influenceable ones in the grids where there is considerable amount of distributed renewable production. This incentive will be available regardless of the “smartness” of the investment. However this incentive effect is too small to remunerate smart solutions.

The most important points in the regulatory model are related to the allocation of investments. For example the company taxes or additional personnel costs (such as education, training) are regarded as permanently non influenceable costs, so they are treated as a pass through components in the formula.

There are a few important aspects related to the two most important mechanisms in the regulatory. Firstly the costs CAPEX and OPEX get remunerated through being accepted by the regulative authority as costs to the regulatory framework. These accepted costs increase the allowed revenue of the DSO. Secondly the efficiency determined for the DSO cost structure has an effect on the DSO revenues. For deeper insights see chapter 4.4.

Also it should be noted, that increasing the efficiency too much might not be at least in theory economical. It will give the DSO low need for efficiency investments for the next regulatory period, but also make the mandatory future efficiency increase harder and probably more expensive than before. Still the DSOs tend to make all the efficiency improvements that are available due to the efficiency comparison between the companies. The most efficient companies are only subject to the over-all efficiency demand.

The future of the regulatory model

According to the discussion, the future of the regulation due to the German election results on the 20th December 2013 is still unclear. As the recent regional elections have shown, the Merkel-run CDU is likely to indicate only slight changes to the prevailing system.

Some improvements to the regulatory framework are still expected. The beginning of the year 2014 determines among other things the way the appropriate investment level is determined: Most likely a method is implemented where the investments of the whole regulation period are levelled. In this method the investment incentive for DSO would be the most stable throughout the regulative period.

The future mechanism is expected to be implemented in order to ensure the goals of the *Energiewende* to be reached. This is to say there is movement among the governmental decision makers to further develop the model to better incentive the future and renewable energy proof investments. There's not much more information about this available yet, but the timescale for this kind of decision to be made could be around the year 2014 or 2015.

Earlier the main turning points in the regulatory framework in Germany have been, among other, the EnWG-Novelle act in 2005 that prepared the way, the implementation of incentive based regulation in year 2009, and the recent change to the "incentive based regulation law" or in German *Anreizregulierungsverordnung* (ARegV) in 22.8.2013. The timescale for regulation in Germany can be seen below.

Table 13 German regulatory framework development

		Base year	Cost estimation	Efficiency comparison Determining the allowed revenue		New concept formed?	Base year?			
1st regulatory period					2nd regulatory period					
2009	2010	2011	2012	2013	2014	2015	2016	1017	2018	?

As pointed out in the Table 13 a new concept for regulation is being developed for the 3rd regulation period that will take place from the beginning of the year 2019. The most decisive moment for the development in the model comes on 31.12.2014 when the

German regulation Authority will publish a report about the future of the regulatory framework and possibly share information about new incentives. The regulatory model is explained in detail in the chapter 4.4.

Lowering OPEX as an automation driver
Based on the situation stated above, there is a way to make the most out of automation investments. The equity based and authority accepted investments are favoured due to the investment mechanism that gives a steady WACC based profit for those investments, as long as they are efficient. The automation investments traditionally are more equity intensive i.e. they cost more than traditional solutions.

However if and when these investments can lower the OPEX of the DSO, the profit comes in the form of both reaching the efficiency goals set by the authority and through changing the cost structure from OPEX based to CAPEX based. The OPEX is not provided incentive to through the regulatory framework whereas the equity based CAPEX can get up to 9.05% return on investment in terms of WACC. Maximum accepted equity-quote is 40 %. The accepted interest on equity capital for the equity capital higher than 40 % is 3.98 %.

5.3.3. Secondary substation solutions

In Southern Germany the Solar PV is an important aspect in grid dimensioning and planning. The German grid is steadily built, but in areas of high PV penetration the point now has been reached where grid enhancement investments need to be done. The increasing number of prosumers is forcing the DSOs to continuously make adjustments to the grid settings in order to minimize the unbalance effect from intermittent power generation.

The most important effect to consider is the variation in voltage levels. The +- 10% voltage bandwidth can still for now be kept. Another – although smaller – challenge is the increasing amount of harmonics in the grid. The harmonics also disturb grid communication.

The future challenges demand lots of active parts and flexibility from the grid. Quick DR might be the only solution to replace the loss of large spinning masses i.e. nuclear power generators. Loads need to be quickly responsive in order to benefit the grid stability maintenance efforts. Despite the clear benefits the DR is not seen as a viable solution in Germany in the near future. This is mostly due to the immaturity of the technology and the lack of technology structures such as metering or HEMS to support the DR.

So due to the lacking measurements elsewhere in the grid the secondary substation is an understandable choice to choose as a hub for measurement, communication and control functionalities. There is also need for e.g. pre-programmed protection schemes where different power flow and grid topology situations are considered.

Today the DSO does not have the momentary information of occurring outages. Getting this information would cut down the outage times since the power restoration could be started immediately. Automated control and protection solutions are vital in operating the grid according to the new power flow scenarios.

Electric Vehicles

The DSOs see the expected increase in the EV fleet implementation as a challenge when the EVs start to reach 20% to 50% of the grid peak power in certain areas. If all the vehicles would charge themselves at once, local voltage dips and overheated transformers might occur. These challenges could be solved through increasing the measurements at the secondary substations and by implementing a charge management system that would deal out so called charging permits for vehicles in order to distribute the charging load over a longer period. This function would have the same benefits as DR with increasing the manageable penetration of EVs in the grid within the present grid limitations thereby cutting grid investment need.

The automation implementation has technical and economic benefits, as stated above. Historically the grid development target was in making the grid work. Now due to change in operational environment there's a definite need for a cheap, smart and reliable system in the new operational framework.

Technical requirements for secondary substation concept

Secondary substation in demanding areas in southern Germany could have the following features:

Features will include accurate measurements from the MV and where necessary LV level with 0.5-1% margin of error with alternatively or additionally smart metering for the same measurements in the customer end.

Additionally data from the MV-side will be sent regularly to the control center while other information like LV-measurement or status information of certain parts can be stored in the substation and only be sent in case of faults or unusual values. For the MV-data a threshold which defines the minimum deviation from the last value in order to send a new one could be used. As an example the threshold of 0.1 kW could be used. The functioning would be as follows:

- Last sent value: 15.25 kW
- Current Value: 15.27 kW (don't send)
- Current Value: 15.84 kW (send)

The voltage level is kept through regulated transformers only in secondary substations in critical nodes of the grid. An alternative solution would include voltage control in all the secondary substations in areas with high DER penetration.

The required communication is currently handled with LTE, GPRS or GSM but usage of other means of communication like fibre; PLC; meshed radio or similar solution depending on the available infrastructure is possible.

A way to see the role of secondary substation is to think it as a hub for information and e.g. remote control functionalities as described earlier. The same idea can be deepened through adding the secondary substation responsibility over local pre-programmed decision-making. Local view reduces need for excessive communication and cuts down reaction times on grid operations.

When collecting data from DR as an example a special care must be appointed to the personal data usage of the consumers. Especially the German people are rightfully careful and interested about their personal data usage and so especial discreetness and security in information transfer and usage must be ensured.

The grid is already divided into smaller areas whether it is a LV grid, an island or a suburb. Microgrids are this kind of ensembles where the area could function as a one single unit that could be capable of island mode functioning. Even more common could be that this kind of single unit has one controlled point of export and import. So for example a suburb or in a smaller scale a farm microgrid could be seen from the DSO view as a single prosumer point. The sense in doing this in Germany is though questionable.

5.4. Interview results in Italy

The Italian energy market is highly dependent on energy imports. The regulatory frame is good for smart grid investments according to the interviews, but long term investment reliability is not the best possible. Technology-wise the standards are bringing new aspects to the smart meter and PV filled grids.

5.4.1. Energy market development

The Italian electricity market is affected by the momentarily high share of solar PV in the grid. It is pushing the prices down during the sunny hours.

One reason for implementing the AMR in Italy was the amount of non-technical losses in distribution systems. Supplementary functionality in addition to power measuring in the AMR system is their ability to easily reconfigure the customer connection size if needed. As an example: A 3 kW connection could be upgraded to 4.5 kW if the customer is continuously exceeding the connection maximum power. Instead of blackouts the customer would get the amount of power he or she needs and respectively pay a bit more of this service.

The hourly based customer billing system has been discussed in Italy. So far this has not become reality. There are different tariffs for the day and night time but due to political reasons the price difference between these two tariffs is not great enough to be guiding the markets for night time consumption.

Actually in the present situation with momentary high amount of PV the tariff system could be turned around: The lowest prices are during high supply of PV during the daytime even though high demand driven by air conditioning.

The momentary low electricity prices are starting to spur utility scale investments to storage. Two MW scale pilots are ongoing in Italian islands. Six more pilots have been chosen with the maximum of 35 MW together. The size scale of the storage capacity per project is in the order of 40 MWh. The technologies researched include Lithium-ion and different batteries of high operating temperature.

The final fundamental decision is still to be made whether it's going to be the DSOs or the TSO to implement the storage. Both would gain technical benefits for grid balancing but also the incentive driven economical possibilities.

5.4.2. Regulatory framework

The Table 14 focuses on giving an illustration of the mechanism importance in the Italian regulatory framework in regard to the interview outcomes. In this chapter the Smart Grid Incentive represents the extra-WACC that certain SG related investments are entitled to.

Table 14 Evaluation of incentive mechanism effect in Italy (from 0 to 3 stars of importance, 3 being the highest)

Italy	Mechanism importance on smart investments
Investment incentive	★★
Reliability incentive	★★★
Operational efficiency	★
Smart Grid incentive	★★★

The greatest driving force in the Italian regulation for the DSO revenue calculation is the continuity of supply i.e. the reliability incentive. Outages are taken into consideration in two ways in the bonus / penalty mechanism: firstly through average time for a customer and secondly through the number of customers to suffer from outages.

The short term development focus is on short outage and surviving voltage dips. Legislatively this will be done through the grid code by adding the following demands in the near future:

- Active power control
- Frequency band increase
- Remote tripping ability
- Control of the reactive power through inverters

These features would give the DSOs more options in maintaining the grid balance. Active power control means a possibility to set the maximum output of generation appliances under their nominal power level. Frequency band increase would widen the frequency limits in which the DG operates normally. The interface for operator remote control on reactive power is going to be further specified in the undetermined future. In addition, there are two concepts that base on the upper mentioned functionalities.

- Fault right through
- Possibility to increase generation for frequency control

In the fault right through concept the generation should stay connected to the grid for longer time in a situation where there is a voltage dip in the grid. To get to the desired effect the lag time for tripping would have to be in the order of 100 milliseconds. Increase in frequency would be done by increasing the generation. This would require the generation to operate at lower than maximum, as referred to in the bullet active power control, in order to have potential for power generation increase.

The technical specifications of power quality are defined by the standard EN 50160 and underneath it the standard IEC 61400 for wind turbines.

Reliability incentive

The reliability incentive in Italy is setting a baseline goal for reliability improvements. The incentive guides the DSO operation towards this set baseline goal, but incentives are set in respect to a previous two year reference value. The DSO gets bonus for improving its operations with a factor given by the authority. Whichever of these two – the baseline or the factor – would lead to lower need of reliability improvements, that is being used. In other words the maximum demand for reliability increase is its baseline value. Generally based on the interviews the reliability in Italy is considered to be quite good.

An example of a medium sized DSO with mixed grid with both urban and rural network areas clarifies the effect of the reliability incentive. The DSO has to pay penalties in urban area for not reaching the set reliability targets and gains bonus for exceeding them in other areas. Penalties are in the order of 4.5% in comparison to CAPEX. The DSO receives a total of 2% bonus in comparison to CAPEX in the less urban areas. For more precise evaluation of the Italian regulation see the chapter 4.5.

New mechanisms in the regulatory framework

Power quality is a new mechanism in the framework, expected to take action from the beginning of the next regulatory framework in 2016. It would take into account voltage dips as the most important part but also other grid stability disorders as harmonics in order to incentive DSOs to improve the power quality.

Historically the Italian regulation has given upper hand to early investors in the regulatory framework. There are well functioning communication channels between the regulatory authority and the DSOs and both are well aware of the changing situations and develop the framework in co-operation.

Distribution business is changing quickly. The need of understanding ICT is of utmost importance just now. The infrastructure for remotely controlling complex system is vital. In a few years the DSO might be allowed to dispatch generation actively, i.e. not only preprogrammed. In such a system the information flows must be ensured.

5.4.3. Secondary substation solution

The Italian grid structure is quite close to its Finnish counterpart in regard to cabling. As seen in chapter 2.1 the share of cable network in Italy is 29 % while the rest is covered with OHL. Then again the Italian LV grid is 1-phase network compared to the 3-phase solution in LV grids in Finland. Also the share of intermittent generation is higher in Italy. Still the reliability of the Italian grid is better, reaching a SAIDI value between the German and Finnish levels.

There are some specific characteristics to the Italian distribution grid:

- The one phase solution in LV feeders makes the grid more sensitive to disruptions.
- In Italy the grounding system is complex. Selective detection of grounding fault is in place.
- The AMR has been deployed nation wide.
- The MV grid consists of circles of connected secondary substations (SS), but the grid is operated in radial form. This enables fast rerouting of the supply in fault situations.

Most likely in comparison to the German development the voltage regulation through tap changers will not be a key solution in the Italian grid due to the grid code that lays a compulsory functionality of reactive power control to the ever increasing PV generation. The voltage regulation could be used in certain cases after power quality investments. Inverter must be capable of tuning the reactive power already now, but the DSOs are not yet using it. Right now the focus is on power quality.

A huge opportunity is seen in implementing fault indication. During the years 2010 and 2011 Italy installed the clear majority of its PV capacity and some challenges still need to be tackled due to this development. The most important part of this system is by ABB seen to be the sensitive fault detecting sensors. Sensors as a part of a secondary substation solution are presented below.

Secondary substation investment review

In Italy there are about 424 000 secondary substations. Out of these a rough fifth, about 80 000 pieces are going to be upgraded to smarter ones within the next few years. The dominating DSO in Italy is ENEL with roughly 400 000 secondary substations. ENEL, due to owning roughly 90% of the Italian distribution grid, has a tremendous weight on decisions regarding the grid development – the vendors such as ABB have to act and develop their solutions on that basis.

Most of the investments are expected to be retrofits. In Rome area itself there are 12000 secondary substations. In Rome there are need for reclosers that can be easily upgraded. The grid in Rome is a mixture of new and old grids. Grid in Rome has in the order of 200 topology changes in a year so easy configuration of the relay is essential for safe grid operation.

The overall need in the Italian grid is in the fault indication, but the relays seem not to be thought as ideal solution by some DSOs. The Italian large DSOs seem to know what they want so specifications have to be done in regard to these needs.

An example of a secondary substation pilot project

The INTEGRIS is a project for building a smart electricity network that is capable of handling a high share of distributed and renewable energy resources.

In this concept the secondary substation makes independent decisions for load shifting and delivers the summarized information upwards to the primary substation and from there to the operator. The method of grid operation could be described as decentralized but hierarchical. The information flow is directed through a combined solution that utilizes PLC and wireless technology. A general secondary substation solution in Italy could include the following functionalities:

- High precision sensors of capacitive or resistive method including 0.5 % precision with 1:10000 voltage divider
- Enable protection decision making
- Concentrating of the AMR data and functioning as an information hub

There are some clear benefits in these functionalities. For instance sensors consume a lot less energy than conventional measuring devices and so save money in the long term. Sensors also save space compared to traditional solution.

Together these specifications form a sophisticated and economically sensible solution for the existing situation. Noteworthy is that there definitely is need for extremely fast communication when also protection is needed.

5.5. Evaluation of result reliability

A total of 35 expert views representing 14 stakeholders from three countries gave a throughout picture of the topic. Also the possibility to review the results was given to the interviewees in order to get a second round of feedback. This added various small details to and fine-tuned the results, but the big picture attained during the first round of interviews remained.

The results were further verified through comparing them to the results of the market study that was conducted during 2010 and 2011 and that initiated the need for this thesis. The short term energy market focus had remained the same although results and new data from pilot projects started in 2011 were already available for this thesis. That is to say the learnings during the years 2011 – 2013 have not changed the main needs for grid automation. There is still a high need for grid automation and high interest in finding viable solutions for secondary substations for increasing their role in secondary distribution grid operation.

The market research included interviews with among other Finnish, German and Italian DSOs and regulator representative. Most of the interview participants share the common view of Smart Grids becoming reality in the future as well as the importance of DG in Germany and Italy. The same results were seen from the interviews conducted for this thesis.

6. RESULTS AND CONCLUSIONS

The expectations for this thesis were presented in chapter 1.1. This chapter begins by directly indicating the main findings in regard to the expectations. Later the results are opened up in a wider sense and finally conclusions are presented as basis for further research and proposals for action.

Comprehensive thinking in energy system development is not often met among energy discussion. The single most important challenge of this thesis research was to understand the complexity of the integration of political short term interests, the long term investment decisions in energy technology and the role of regulatory in regard to the energy system development.

The regulatory authority is balancing in between of pushing the DSOs for efficient operation in order to minimize all avoidable charge to the consumers. On the other hand the DSOs need to be able to collect adequate profits in order to call forth investor capital. The capital is used for investments aiming in maintaining long term operability which is mutually beneficial for all the stakeholders.

The research shows that general understanding exists that in order to maintain grid balance also in the expected future of high RES-E share in the electricity system, smarter grid is to be developed and implemented. These are seen as the next focus for smart investments due to presently low amount of intelligence, automation or remote control in the distribution grids and especially secondary substations.

What are the current mechanisms in the regulatory frameworks that push the market for automation in the secondary substations increasing grid reliability?

The current mechanisms in the regulatory frameworks that affect the smart solution and grid automation market especially in the secondary substations are presented in the chapter 6.2. The grid automation solutions increase the grid reliability so special focus was put on finding out how does increased reliability affect the DSO business because of the regulatory framework mechanisms.

The mechanisms mentioned in chapter 6.2. are to be considered when calculating the viability of single investments.

What are the key future automation capabilities in the secondary substations that meet the customer (DSO) needs and are viable for commercialization within the expected development of the regulatory framework?

At an early stage of the research a focus was put on European Union energy market development. The near future needs for secondary substations such as capability for enabling the integration of high share of RES generation or DR solutions were evaluated. The results presented in chapter 6.3 show that in two out of three cases – In Germany and Italy – the most viable solution focuses on raising the grid capability of PV integration by raising the flexibility of the grid through voltage regulation. The technical solutions formed in this thesis for these two cases however are different.

The German solution in high PV relies on active voltage regulation by either the primary substation or the secondary substations according to LV side measurements. In MV grid the voltage can be calculated from the LV measurements with good precision.

The Italian solution in high PV areas makes use of the inverters' ability for voltage and reactive power tuning. The measurements and intelligence at the secondary substation enable control over the LV grid voltage and power quality.

The Finnish solution has different drivers as high penetration of PV is not an issue in Finland currently or in the near future. Increased amount of monitoring, measurements and remote control are needed in order to meet the high reliability increase demands. The expected increase in earth fault currents and reactive power due to rising cabling share is tackled with reactors at secondary substations, although this functionality is not directly related to automation.

What are the future mechanisms in the regulatory frameworks that would push for technical solutions enabling integration in large scale of distributed energy resources?

This was the hardest question as the energy politics that guide also the regulatory development are mainly unpredictable in the long term. Still continuity and stability of investment environment was seen as the most important factor for smart investments. According to evaluation in the chapter 4 the most stable framework environment can be found in Finland where decisive reliability demand legislatively runs for the next 15 years and regulatory framework is expected to even increase the stability by remaining the same from 2016 to 2024 as brought up in the chapter 5.2.2.

The overall trend in regulatory frameworks goes towards company specific regulation. One example of this more tailored regulation is the use of menus. DSOs can thereby differentiate their regulation to their business targets.

6.1. Grid automation investment drivers

Smart Grid and Grid Automation (GA) as part of it has various drivers globally. These were presented in the chapter 3, focusing on the European view. In regard to the interviews and backed up by literature research the most important GA market drivers for the focus countries are presented in the Table 15.

Table 15 Market drivers for Smart Grid investments

	Energy mix		Legislative	
	Short term	*Medium term*	***Short term***	*Medium term*
Finland	Nuclear power	Wind power (MV) Nuclear power	Reliability demand	Reliability demand
Germany	Solar PV (LV)	Wind power (MV)	High RES share integration	*Energiewende*
Italy	Solar PV (LV & MV)	MW-scale storage?	High RES share integration; Power quality demand	Unclear

In Finland the most determining short term market driver is the reliability demand as presented in the Table 15 in the column for legislative market drivers. Reliability demand's effect is set to continue for the next 15 years. The future of nuclear power in Finland is strong albeit the presently unclear situation with the funding of the planned 6th reactor. The effect of nuclear is negative in regard to GA markets as it cuts the potential need for distributed generation in the electricity mix.

Wind power is going to play a role in creating some need for MV level voltage control but this is not expected to have major impact on GA investments in Finland. Customer Demand Response was seen as something that could be used and that would benefit the grid operation but so far no simple commercial solution was seen to be available.

In Germany integrating the highly increasing share of especially rooftop photovoltaic is the determining market driver for secondary substation based GA solutions. The challenge is both legislative and part of the energy mix development since the renewable energy has a priority in being fed to the grid. The development is part of the longer term goals of *Energiewende* that aims e.g. for 55 to 60 % renewable share in electricity generation by the year 2035. More comprehensive information can be found in the chapter 3.2.

Especially offshore wind power, with a target of 10 GW nominal capacity being installed by 2020 has an effect also on the distribution grid as a whole. This is not a remarkable investment driver for secondary substation solutions.

In Italy similar challenges can be detected as in Germany, but with a special focus on power quality issues that drive the investments towards e.g. controllable inverters.

6.2. Regulatory framework highlights

The Table 16 summarises the results for the effect of regulatory framework on the SG related investment viability. Here only the existing and soon to come mechanisms are taken into consideration. The future mechanisms are fully dependent on political and ministry officials' decision making and are therefore hard to predict.

As a general direction for the future development it can anyhow be said, that the regulation tries to follow and support the energy policies of the country in question. Generally these policy guidelines do not consist of one simple solution and the same way the regulation has to consider many varying situational aspects. The DSOs are different and have different operational challenges. Still their varying needs are all taken through one economical evaluation i.e. the regulatory framework. In all the focus countries this has led to a situation that as a rule of thumb favours larger, more generalized DSOs.

As an example in Finland the cable network share is going to be drastically increased throughout the country. Small rural DSOs with high share of OHL need to invest much more in the coming years than those that already have high shares of cable networks. More investments also mean higher distribution tariffs for customers. Regardless of the situation the investments are to be made, as pointed out in the Table 16.

Table 16 Viability of Smart Grid investments through regulatory frameworks

	SG investment viability	Effect through the regulatory frame
Finland	• Expected to be viable due to new reliability and investment incentives • Investments on reliability are mandatory	• Higher reasonable rate of return due to lower OPEX and higher reliability
Germany	• Not viable, some improvement expected	• Keeping the power quality to avoid penalties • Lower OPEX fulfils the efficiency demand • Lowering losses is remunerated
Italy	• Viable • Good incentives for both pilots and commercial products	• Better return on investment due to reliability and SG incentives

In Finland the regulatory framework influences the potential Smart Grid investments through the reliability incentive and the maximum outage times determined in the legislation. These demands will guide the investments on smart solutions for the next 15 years. Most of the investments are expected to focus on MV and LV cabling and the methods by which the increased fault currents and reactive power can be compensated.

The smart solutions such as replacing the old pole mounted transformers with secondary substations meant for cable networks receive specific incentives that compensate for early investments made due to the reliability demand in legislation. In investment incentive the unit price listing is currently not considering automated secondary substations.

In Germany the most determining feature in regulation is the demand for efficiency increase. It includes cutting the inefficiencies determined in the comparison between the DSOs. The cost structure that is subject to efficiency increase includes both operational and capital expenditure. Their relations as well as the efficiency demand are company specific.

A smart solution could get incentive from the framework through being accepted to the permanently uncontrollable costs i.e. the part of cost that is seen mandatory by the regulatory authority. Other incentive giving mechanism suitable for smart solutions could be the extension factor. However it does not fully remunerate the extra investments. Lowering grid losses has a positive impact on DSO revenue.

In Italy the regulatory framework was established at earliest of the three focus countries. There are two important features besides RAB that have an effect on the smart investment decisions.

The smart investments such as smart secondary substations in areas determined as critical receive about 2 % bonus to their weighted average cost of capital still until 2024. The new energy efficient secondary transformers receive a 1.5 % bonus until 2020. Secondly there is an incentive for improving the company specific distribution reliability from its existing level that now focuses on reducing outage duration. In the future the focus will move towards outage frequency and voltage dips.

6.3. Conceptual secondary substation characteristics

In line with the interview and literature research outcomes a workshop was held within ABB Grid Automation Center of Excellence to form the concrete solutions for smart secondary substations. Further work is needed to specify the products that function together and possess the desired functionalities cost efficiently. Condition monitoring is marked in all the solutions and includes improved awareness at the secondary substation.

In the proposed solution for Finland, as illustrated in Table 17, the measurements are more monitoring orientated aiming for directional fault detection. In German and Italian solutions the measurements needed are in the order of 1 % accuracy. In these solutions the MV level voltage is calculated based on LV side voltage measurement. There is already a tested product for this purpose. This bypasses the need of MV side voltage measurements and therefore simplifies the solution.

Table 17 Secondary substation solutions for Finland

Need for higher reliability and lower OPEX	
Leading challenges	Solution
- Increase in VAr due to cabling - Earth faults in cable grid	- Remote control - Protection and auto reclosing - Fault detection (directional) - Earth fault compensation (reactor) - Transformer condition monitoring (temperature / load)

The overall solution in Finland is highly concentrating on the rapidly rising share of cabling in distribution grids and the challenges that it brings. The main challenges are the rising volumes of reactive power and higher earth fault currents. These are tackled with distributed compensation i.e. reactors in secondary substations. The ABB portfolio includes a combined transformer and reactor product that can be used as the heart of the Finnish solution.

The proposed general solution for Finland includes using the level 4 solution without the accurate measurements from the ABB solution table that can be found in the Appendix 4. Basically this solution includes the use of protection relay REC615 (ABB Grid Automation). The general solution should be enhanced with a combined reactor and transformer. If the target for outage reduction is already reached at the area in question the solution can be simplified by removing the protection functionality.

The proposed solution of Table 18 for Germany differs from others with the voltage control. There is need for active secondary substation based voltage control in some areas of high PV penetration. The solution proposed has two parts (solution 1 and solution 2) that are alternative solutions but yet combinable.

Table 18 Secondary substation solutions for Germany

Need for lower OPEX and energy efficiency increase including avoiding losses	
Leading challenges	Solutions
- High share of PV in LV grid	- Remote control - Voltage control. Separate solutions for high PV penetration areas and medium penetration areas. - Transformer condition monitoring (temperature / load)

The solution one is the dispersed solution where the needed amount of secondary substations in a MV grid is equipped with remote controlled tap changers. These then follow the voltage in the LV grid and do the necessary adjustments when demand and supply fluctuate.

The solution two is the centralized voltage control where the tap changer is situated only at the primary substation, voltage is measured at the secondary substations and if necessary curtailment is used for the PV in case of over heightened voltage levels.

The Italian solution as presented in Table 19 includes accurate measurements in the LV side of the transformer both for voltage regulation but also for detecting outages in case of capacity sized supply and MV outage.

Table 19 Secondary substation solutions for Italy

	Need for higher reliability and smart meter data handling
Leading challenges	Solutions
- High share of PV integration - Power quality management	- Remote control - Protection and auto reclosing - Fault detection (directional) - Transformer condition monitoring (temperature / load)

SAIDI, SAIFI and MAIFI values can be cut by remote controlled line reclosing and the voltage dips can be reduced with over-voltage protection.

The possibility of using the secondary substation as a hub for information and control commands for both smart meters and active reactive power tuning inverters should be discussed.

6.4. Proposals for action

ABB has a strong market position in both Finland and Italy. In these countries the solution outcomes of this thesis can be utilized in the benefit of the DSOs. The better understood regulatory aspects can now be used in making offers to the DSOs and finding deeper rationalization for investments into smart solutions.

Regulatory opportunity to be seized

There is an intriguing situation in the German market during the next years. Due to insecurity in the regulatory framework the investment decision of the DSOs are currently on hold.

A throughout understanding of the changing regulation to the DSO earnings would be needed in the German markets to fully analyse the effect of smart investments. The effects cannot be generalized to all the over 800 DSOs. Therefore certain DSO specific background information is needed in order to make most of the business cases. At least the following should be known of the German DSO in order to fully understand the situation of the DSOs and to be able to serve their needs:

- The relation between OPEX and CAPEX of the influenceable and momentary non influenceable costs

- The efficiency percentage of the DSO in the regulatory evaluation
- The amount of losses in the distribution grid separated into transformer and feeder based losses
- Current SAIDI, SAIFI and their target values.
- The existing role of measuring in the distribution grid
- The capacity share PV in the LV and MV grids and the need for voltage regulation
- Planned penetration of automation in distribution grids

When these are known, it is possible to evaluate the appropriate solution for the DSO and the possible benefits of the solution on the DSO business. Also the need for voltage control the earlier presented solution one and solution two should be estimated with the customer. Of course in the evaluation also other benefits of the smart solution should be noted e.g. even lower SAIDI and SAIFI values as well as preserving power quality in high RES areas. These play a role in the investment decisions.

The relation between OPEX and CAPEX and the TOTEX is relevant for grid automation investments. Smart solutions tend to increase CAPEX but lower OPEX in the short, middle and long term. Therefore if a DSO has a high share of OPEX in the influenceable costs that are subject to efficiency increase within a five year regulatory period, there then is more incentive for the DSO to invest in grid automation. These DSOs should be carefully approached as potential customers. They benefit the most of grid automation solutions in Germany.

Technical concepts need a comprehensive analysis

There are a few possibilities for voltage control in the LV networks. The best practices chosen for the focus countries are general solutions that need to be reviewed case by case.

A comprehensive method of analysis for choosing the right technology for each grid topology, amount of DG in the grid and the main drivers through the regulatory framework have to be assessed. The evaluation would bring the specific solution that would suit the development plan and especially the needs of the DSOs.

6.5. Conclusions

The energy system balancing has many options available. CHP and hydro power capacity in the Nordic are going to take care of most of the grid balancing. The abundant technologies on the electricity and heat sector are currently not taken into full consideration. The electricity markets should be reformed to allow also small scale generation to attend the balancing markets. The implementation of smart metering has made it technically possible to include the small scale i.e. domestic consumers or prosumers to contribute to the system balancing. The markets are slowly moving to this direction, but an opportunity lies for any of the focus countries in this thesis to take the lead in such system thinking approach.

The share of renewable energy in the distribution system is certain to increase. However due to political insecurity the extent of such development is unclear. At the present situation the EU 20-20-20 targets are the best founded guess for the short term development.

The distribution system is in the heart of the change towards the more sustainable future. The smart grid technologies do not only need new market models. The viable future also requires functioning infrastructure i.e. distribution grids in order to allow the change to take place. Every national regulator is aiming for the grids to serve the customer with as high quality of service as possible while keeping the costs of service as low as possible. This spurs need for an advanced regulatory framework that will take into account the new challenges of intermittent DG, change in DSO earning models and the opportunities of new Smart Grid appliances. The new regulatory framework in the United Kingdom, the RIIO, will try to consider the mentioned aspects. The model should be further investigated to evaluate and introduce the best practices for other frameworks, while taking into account the different needs of each country.

The smart secondary substation is without doubt more important part of the distribution system than before. The functionalities of primary substation level are distributed to the secondary level to better control the distribution grid and the new bidirectional flow of electricity. Regardless of the balancing method the secondary substation functionalities of the near future should include better monitoring of the power flow and remote control in order to reduce outage effects on the grid. Accurate voltage measurements at secondary substation on LV side can contribute to gaining also MV level values through calculatory method in areas of high DG penetration. These are capable of resulting in a voltage values in a threshold sufficient to voltage control in LV grid.

The actual voltage control through reactive power tuning or power curtailment with PV-inverters is a sound strategy. A method of night-time reactive power tuning with the PV-inverters also exists although evaluation of the energy losses in this method should be conducted.

Even though the regulatory frameworks have taken steps towards giving incentive to smart concepts, more is to be done. For instance the Finnish model has a perfect opportunity for SG friendly regulatory incentives due to vast investments that are to be made during the next years due to reliability demands.

The Smart Grid enabling functionalities such as e.g. tap changers and accurate measurements increase the investment cost of the substation even though the long term benefits would be undisputed. If the investment incentive is not flexible and values all the investments, smart or not, as equal, the framework does not function as a Smart Grid enabler but as a hindrance.

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APPENDIX 1: QUESTIONS FOR INTERWIEVS

I would ask you to respond specifically according to your perspective. I would like you in your responses particularly to focus on *secondary substations and their regulatory environment*. If a question is not relevant to you, it can be ignored.

The Energy Market

- What are the main trends in the electricity markets (next 5 years)?
  - What about in the long term?
- How do they control or will control the distribution business?
- What are the main policy guidelines and decisions relevant to the distribution business (next 5 years)?
- What are the key factors that drive the distribution network development? (non-regulatory)
- Future technology trends importance for the development of distribution networks (in the medium term). I'd ask you to scale these trends whether they are important, fairly important or neutral.
  - Electric cars (including Plug in Hybrid Vehicle)
  - The demand response (as a tool for the DSO (incentive based) and for the consumer (price based))
  - Increasing share of wind power
  - Increasing share of solar power
  - Energy storage (batteries, hydrogen, electricity and other concepts)
  - Nuclear power
  - Is there another trend worth mentioning?

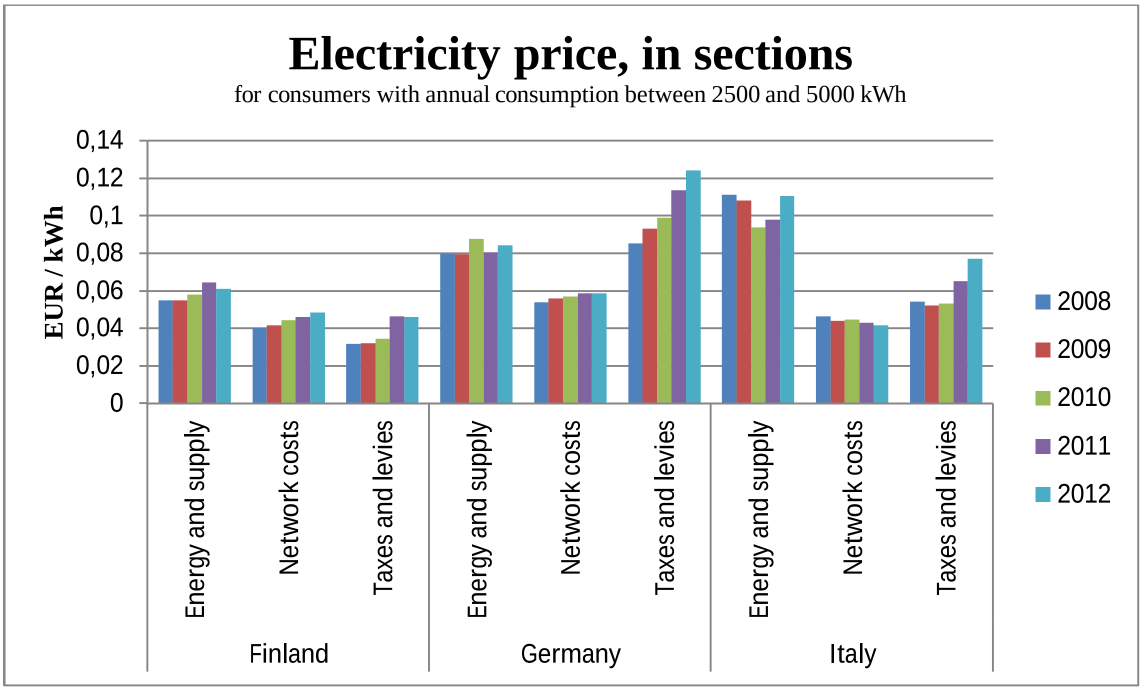
Regulation

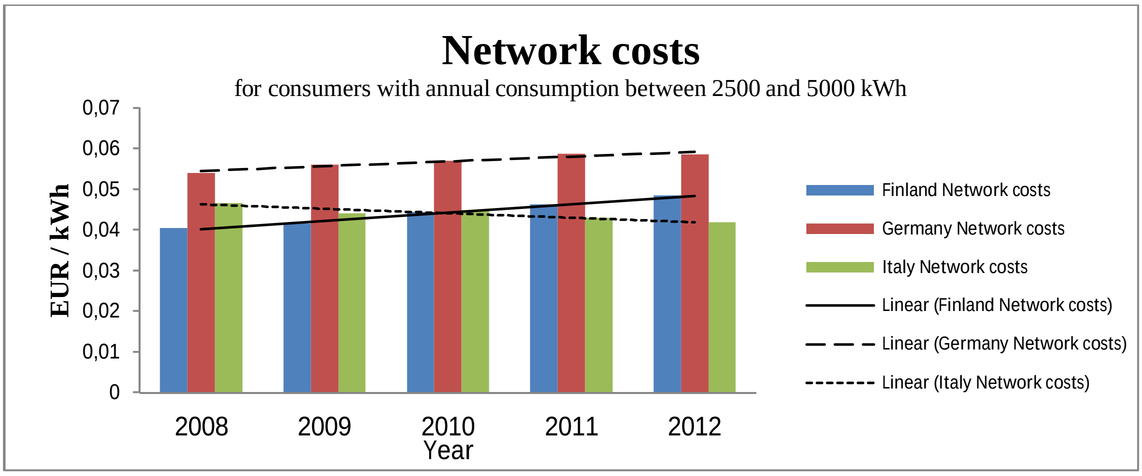
- What are the key factors that drive the distribution network development? (regulatory)
- Which regulatory mechanism has the highest priority for investment decisions?
  - Should the focus of the regulatory framework be switched?
- What regulatory obstacles slow down the investments in automation?
- What kind of changes in regulation (decided, expected or desired) could increase the automation and intelligence in the grid?

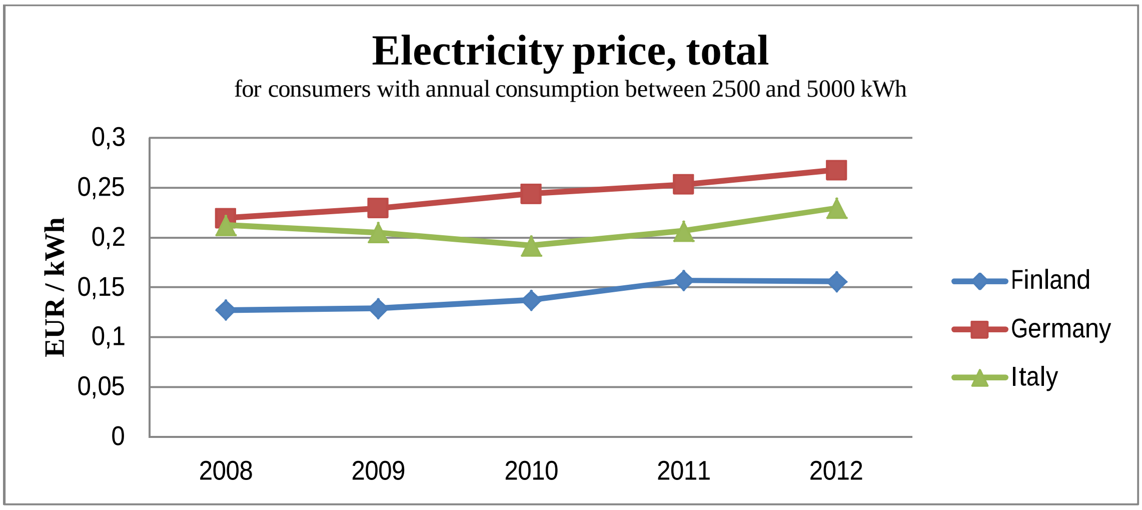
Smart Grids

- Why should automation of medium and low voltage networks be invested in?
- What kind of pilot projects in distribution networks are going on or coming up?
    - What kind of improvements do these aim to achieve?
    - What kinds of challenges could automation solve in these pilots?
    - What kind of automation solutions have come up that could be further developed or used?
- If we consider the situation in which the regulation or current technical specifications are not limiting and do not affect the development of the distribution network, what would be your vision on the role of secondary substations in the distribution grid automation?

APPENDIX 2: ENERGY MARKET DEVELOPMENT







APPENDIX 3: ABB SECONDARY SUBSTATION AUTOMATION LEVELS

	Level 1	Level 2	Level 3	Level 4
				Protection
			Measurement	Measurement
		Control	Control	Control
	Monitoring	Monitoring	Monitoring	Monitoring
	Situation awareness	Fault isolation	Power Flow Measurement	Protection selectivity
Functions	• Indications of switch status • Fault passage indication (FPI) • LV Measurements • Condition monitoring	• Remote control of switches • Remote network configuration	• High accuracy measurements V, I, P, Q, f	• Directional overcurrent and earth fault protection • Reclosing for overhead lines • Protection interlocking by GOOSE
Benefits	• Fault location • Voltage stability even with intermittent distributed generation • Reduced maintenance cost	• Centralized fault isolation & restoration with reduction of the time of outages • Increased network efficiency	• Voltage stability even with intermittent distributed generation • Increased network efficiency	• Reduced number of outages

APPENDIX 4: SECONDARY SUBSTATION FUNCTIONALITIES

Smart Secondary Substation	**Functionalities (existing, proven and viable)**	
	Main drivers	Functionalities that are needed in order to meet the needs and answer to challenges
FINLAND >80% customers have AMR	Need for •Higher reliability •Lower OPEX Challenges •Increase in VAr due to cabling •Earth Faults in cable grid	• Remote control • Protection and autoreclosing • Fault detection (directional) • Earth fault compensation (reactor) • Distribution transformer condition monitoring (temperature / load)
GERMANY No large scale AMR	Need for •Lower OPEX •Energy efficiency increase Challenges •High share of PV in LV grid	• Remote control • Voltage control (2 solutions, 1st centralized, 2nd distributed) • Distribution transformer condition monitoring (temperature / load)
ITALY ~100% customers have AMR	Need for •Higher reliability •Handling smart meter data (analysis etc.) Challenges •High share of PV integration •Power quality maintenance	• Remote control • Protection and autoreclosing • Fault detection (directional) • Distribution transformer condition monitoring (temperature / load)