LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Faculty of Technology
Electrical Engineering

Master's Thesis

TECHNOLOGICAL AND BUSINESS CHALLENGES OF SMART GRIDS

Aggregator's Role in Current Electricity Market

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Abstract

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Growing recognition of the electricity grid modernization to enable new electricity generation and consumption schemes has found articulation in the vision of the Smart Grid platform. The essence of this vision is an autonomous network with two-way electricity power flows and extensive real-time information between the generation nodes, various electricity-dependent appliances and all points in-between. Three major components of the Smart Grids are distributed intelligence, communication technologies, and automated control systems.

The aim of this thesis is to recognize the challenges that Smart Grids are facing, while extinguishing the main driving factors for their introduction. The scope of the thesis also covers possible place of electricity Aggregator Company in the current and future electricity markets. Basic functions of an aggregator and possible revenue sources along with demand response feasibility calculations are reviewed within this thesis.

Contents

List of Acronyms

AMM Advanced metering management

AMR Automatic Meter Reading

BRP Balancing Responsible Party

CENELEC European Committee for Electro-technical Standardization

CHP Combined Heat and Power

DER Distributed Energy Resources

DG Distributed Generation

DR Demand Response

DSM DemandSide Management

DSO Distribution System Operator

EN European Standard (developed by European Committee for Standardization)

GHG GreenHouse Gases

HAN Home Automation Network

HV High Voltage

ICT Information and Communication Technologies

IEC International Electrotechnical Commission

IT Information Technology

LV Low Voltage

PV Photovoltaic (power generation)

RES Renewable Energy Source

ToU Time of Use

TSO Transmission System Operator

UPS Uninterruptible Power Supply

VPP Virtual Power Plant

µCHP Micro Combined Heat and Power

FAN Field Area Network

FACTS Flexible AC Transmission Systems

GIS Geographic Information Systems

HEV Hybrid Electric Vehicle

LAN Local Area Networks

MDM Meter Data Management

OMS Outage Management System

PHEV Plug-in Hybrid Electric Vehicles

PLC Power Line Carrier

SCADA Supervisory Control and Data Acquisition

V2G Vehicle to Grid

WAN Wide Area Networks

WiMax Worldwide Interoperability for Microwave Access

SOA Service Oriented Architecture

1. Introduction

Electric power and electronic communications are one of the main technologies that enabled rapid development of civilization in the twentieth century. Alexander Graham Bell and Thomas Edison stood at the roots of electricity and communication. As we enter the 21st century, Edison would probably still recognize all of the major components used in the electricity grid. That particularly concerns distribution level, where modern technologies are still absent. Bell, in comparison, would recognize very few of the components in the modern telecommunication system. This observation underlines the robustness in thought and economy of design of the existing electrical power system. It also calls for a review of current practice to determine what may be gained through new technologies.

The electric power industry needs to be transformed in order to cope with the needs of modern digital society. Customers demand higher energy quality, reliability, and a wider choice of extra services. And at the same time they want prices to be lower. In principle, the Smart Grid is an upgrade of 20th century power grids, which generally "broadcast" power from a few central generation nodes to a large number of users. Smart Grid will instead be capable of routing power in more optimal ways to respond to a wide range of conditions and to charge a premium to those that use energy during peak hours.

By 2020, more than 30 mega-cities will emerge on the Earth. Increased population together with a growing energy-dependence trend will require new technologies that are able to cope with a larger amount of energy resources. A rough estimation shows that by 2050, the world's electricity supply will need to triple in order to keep up with the growing demand. That will require nearly 10 000 GW of new generation capacity.

Climate change is now more real than ever. The era of fossil fuels will soon come to its end. And our nation is pretty much dependent on finite natural resources for energy generation. We are living in times when significant changes need to be made in the utility industry. [1]

In the next coming years, the industry will not only experience advanced metering infrastructure deployment, but also new improved grid technologies. These new technologies will greatly expand the scale of benefits to both customers and utility.

But despite the changing environment, there are still some challenges that prevent utilities from rapid development of the smart grid concept. Decision makers and investors are still skeptical about the benefits of smart grid technologies. Therefore, it is important to present all these benefits in a clear and understandable way.

Improved grid reliability and power quality rules gain more and more attention as more regulators think about applying penalty-reward system against performance. Customer satisfaction rating should also be considered. Introduction of new telecommunication technologies with encryption and remote inspection of assets will increase the security of a grid and strengthen it.

Along with the push from regulators, the environmental representatives are calling for integrating large amounts of distributed renewable generation. AMI-enabled demand response has also played a huge role in the quest of finding less-expensive alternatives to building new power plants. Introduction of consumer decisions for reducing energy usage will provide significant load reduction which may offset new investments for a few years into the future.

Over the past years the technology functionality has increased. For example, SCADA systems have evolved into advanced applications of distribution management systems (DMS). GPS-based Geospatial Information Systems are now integrated with Outage Management Systems, which makes fault location easier than ever. Introduction of smart sensors will enable real-time evaluation and asset performance.

Moreover, the industry has benefited from a dramatic reduction in specific equipment costs. For example, disconnect relay switch cost have reduced from 86 euro to just 40 over the past three years. [1]

Nowadays, many people ask how real the impact from the introduction of smart grid is. The answer is simple: smart grids will bring the utility a lot of benefits. Although not all these benefits will be in monetary form (i.e. reliability and customer satisfaction), some of them will be in a form of monetary reductions from the current costs, other will reduce future costs. Especially in the form of deferred or even cancelled capital investments.

Smart grid will bring a customer the ability to control energy consumption, using demand response. Such factors as peak shifting and overall conservation will impact a demand response system.

2. Smart Grids

2.1 Defining Smart Grid Concept

2.1.1 What is Smart Grid?

In order to fully understand the challenges and issues, it is important to define what a 'Smart Grid' is.

"Smart Grid is a necessary response to the environmental, social, and political demands, placed on energy supply." [2]

It would be quite difficult to draw a clear distinction between a "smart grid" and a regular grid. Therefore, it is much more practical to consider "smart grid" as a term that enables the opportunities for improving power system operation.

In general, the 'Smart Grid' can be defined as 'a system of systems'. It is a platform that enables functioning of different technologies and systems. It can be viewed as a better electricity delivery infrastructure.

A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies [3]. See Figure 1 for a visual representation of the Smart Grid concept.

Here are some other definitions of the Smart Grid:

- A power system that contains multiple automated transmission and distribution (T&D) systems, all operating in a coordinated, efficient, and reliable manner.
- A power system that serves millions of customers and has an intelligent communications infrastructure, enabling the timely, secure, and adaptable information flow, needed to provide power to the evolving digital economy.
- A power system that handles emergency conditions with 'self-healing' actions and is responsive to energy-market and utility needs.
- The smart grid is a broad collection of technologies that delivers an electricity network that is flexible, accessible, reliable and economic. Smart grid

facilitates the desired actions of its users and these may include distributed generation, the deployment of demand management and energy storage systems or the optimal expansion and management of grid assets [4].

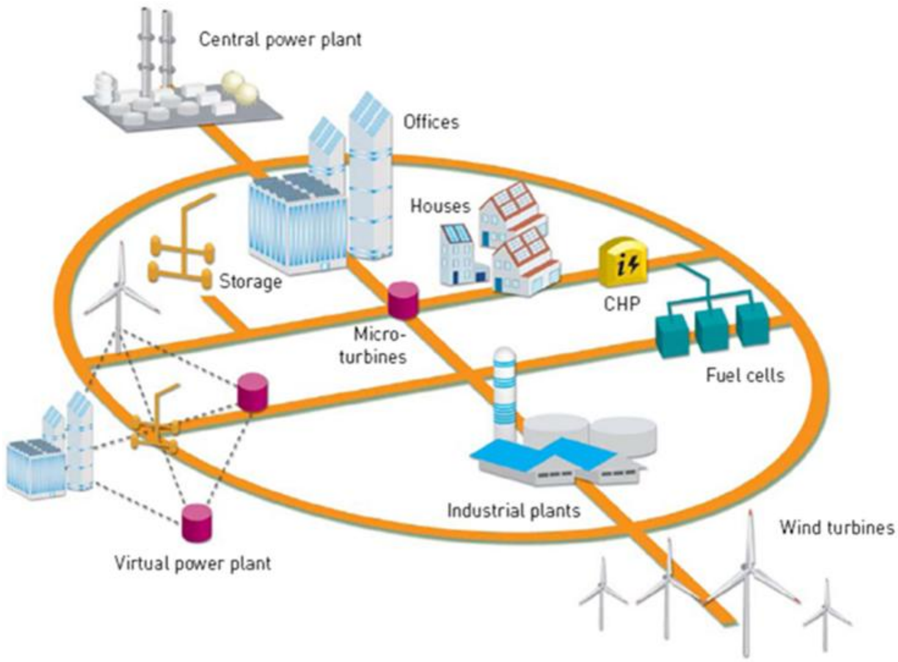

Figure 1 Smart Grid Concept [5]

From the Information Technology point of view, the Smart Grid technology will significantly increase the amount, quality, and use of data received from various sensors and meters. This will solve two of today's main problems in the grids: environmental concerns and power disturbances. Introduction of Smart Grid will increase both security and efficiency of the supply. New software, implemented in various microcontrollers will help to avoid grid congestions and enable distributed generation, making accent on the use of renewable energy resources. Imagine a network, in which a customer can manage his consumption and take advantage of pricing schemes, while being able to choose the type of electricty supply (i.e. 100% renewable energy, conventional energy, mixed mode).

After analyzing the definitions stated above, the following characteristics of the Smart Grids can be distinguished:

- Optimized for best resource and equipment utilization
- Distributed by its structure (assets and information)
- Interactive (customers, retailers, markets)

- Adaptive and scalable (for changing situations)
- Proactive rather than reactive (to prevent emergencies)
- Self-healing (can predict/distinguish/bypass abnormal situations)
- Reliable and secure (from threats and external disturbance)
- Efficient and reliable
- Open for all types and sized of generation
- Environmental friendly (using renewable energy resources)
- Integrated (monitoring, control, protection, maintenance, EMS, DMS, AMI)

The Figure 2 and Table 1 provide a side-by-side comparison of the traditional and smart grids.

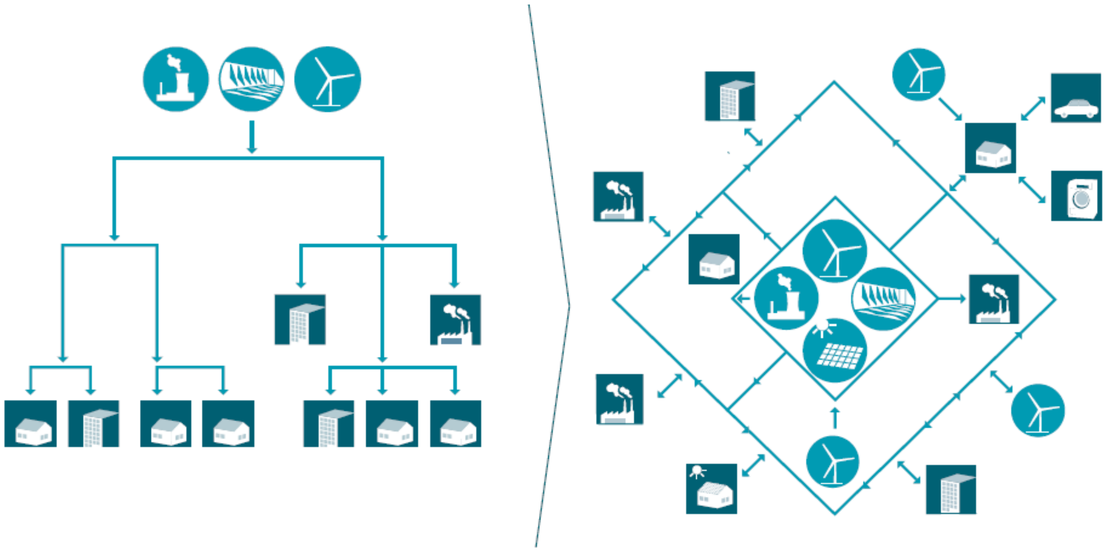

Figure 2 Traditional Grids vs. Smart Grids [6]

Table 1 Comparison of Traditional Grids and Smart Grids

Traditional Grids	Smart Grids
Centralized power generation	Distributed power generation
One-way power flow	Two-way power flow
Empirical-based operation (load indexes)	Renewable power generation
Limited grid accessibility for new producers	Loads follow generation
	Operation based on real-time data
	Extended grid accessibility
	Customers participate in electricity

Traditional Grids	Smart Grids
	market

After analyzing the purpose and possibilities of the smart grids, the following transformation guidelines can be distinguished (see Figure 3):

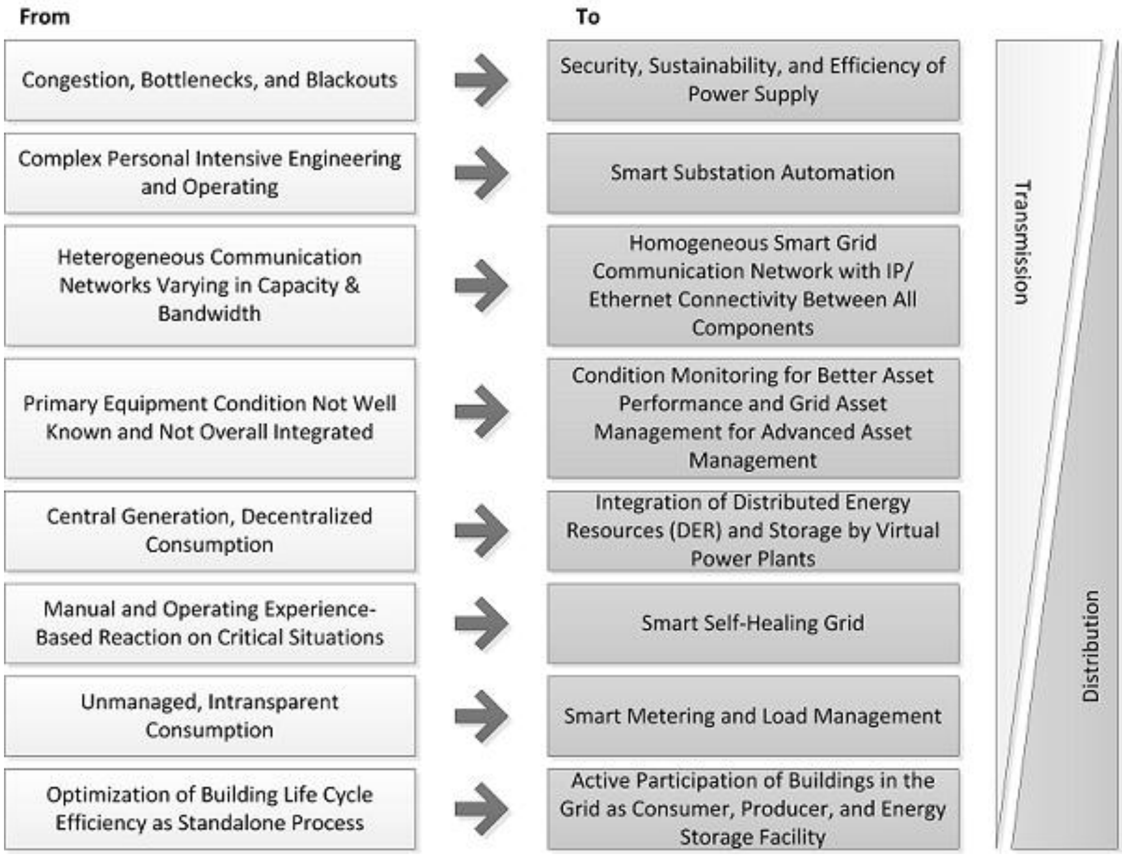

Figure 3 Transforming to Smart Grid [7]

2.1.2 Smart Grid from Energy Industry Point of View

The real-time two-way communications available in a Smart Grid will allow customers to be compensated for their efforts to save energy and to sell energy back into the grid through Advanced Metering technologies. After spreading distributed generation concepts such as residential solar panels and small wind turbines, the Smart Grid will improve the efficiency of energy industry by providing green energy recourses and reducing peak loads. It will allow small domestic customers and businesses to sell power to their neighbors or even back into the distribution grid. The same concept can be applied to larger commercial organizations that have renewable power systems that can give the excess power back into the grid during peak demand hours.

Implementation of Smart Grids promises to reduce grid operational expenses, improve SAIFI and SAIDI, enhance asset management, and improve distribution operations.

The Figure 4 represents Smart Grid taxonomy categorized by industry players:

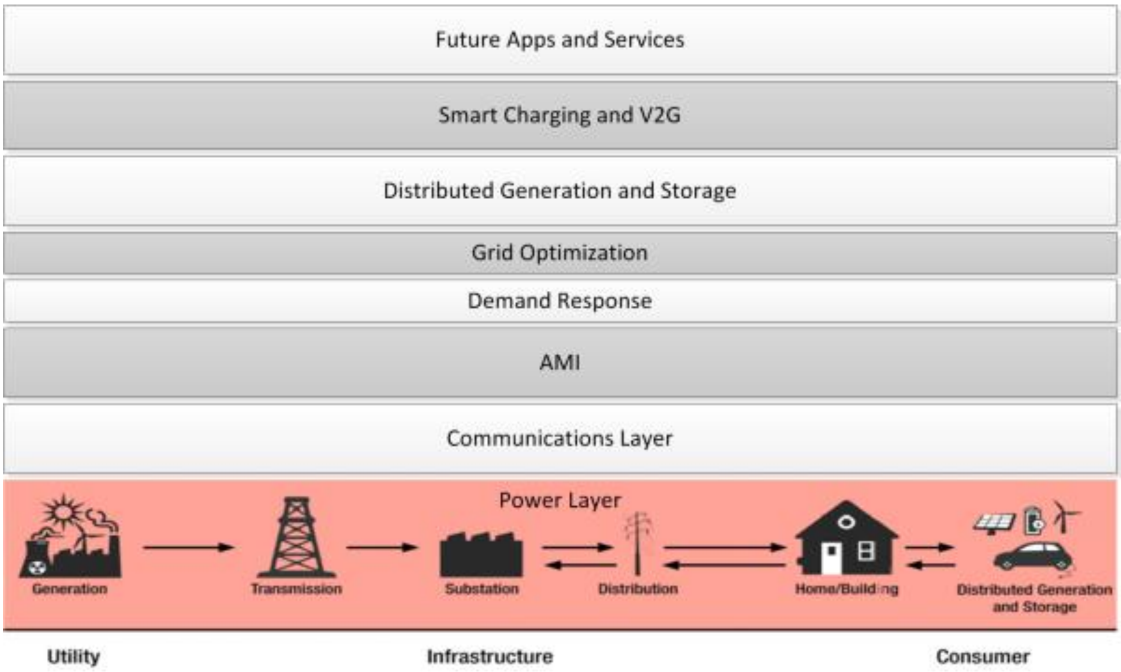

Figure 4 Smart Grid Taxonomy by Industry Player [8]

Smart Grid platform is viewed as a core component of the solution to such modern challenges as growing electricity demand, aging utility infrastructure, and the environmental impact of the greenhouse gases produced by conventional electric generation.

Integrated Smart Grid solutions combine advanced metering technology, two-way high-speed data and power transfer, constant monitoring and analysis software, among with other related services aimed to provide location-specific real-time data as well as home energy management solutions. When combined, these solutions will significantly increase the efficiency and reliability of the electric grids. And at the same time, the environmental impact will be reduced due to the use of renewable energy resources. Smart Grid solutions, including Asset Management, Demand Response, Demand Side

Management, Distributed Energy Management, Advanced Metering Infrastructure, and Distribution Automation will allow utilities to identify and fix a number of specific system challenges through a single platform.

Nowadays, industry officials are moving towards framing standards to help modernize current power grids. IEEE groups are working at identifying existing standards and filling technology holes that need to be fixed in order to deliver smart grid interoperability.
Here is an overview of different industry vendors and their opportunities:

Field Area Network Vendors
The missing link between the customer and the utility is one of the first solutions for the smart grids to be deployed. Therefore, the companies that specialize in the networking technologies such as Field Area Network (FAN) and Advanced Metering Infrastructure (AMI) have received a huge share of venture capital from the investors. AMI companies might consider investment in companies that partner with wireless telecom carriers, as the technologies that are being developed (i.e. WiMax/4G) may replace the current dominant solution (RF mesh networks) in future.

Home Area Networks Vendors
The Home Energy Management System space has also attracted a large venture capital. However, such large software companies like Microsoft and Google have made a statement that they are going to develop Home Energy Management Systems and give them away for free will make it harder for new participants to receive financing. Moreover, this market field is still in making its first steps of development as it is first needed to have a smart meter and the functioning network in place in order to generate and transmit the customer data. This valuable input is still missing. Although some pilot projects are expected to launch as early as 2010 (US) [8]. As for the standards of communication between appliances in Home Area Networks (HAN), the main alternatives are WiFi/WiMax and ZigBee. Each standard has its large companies behind itself. Therefore, this area promises to be rather competitive.

Software Vendors

As the distributed renewable energy generation and advanced energy storage solutions will be developed and will spread widely into the market, their integration into the distribution grid and management will be essential. This is mainly a software challenge. Industry will need applications that will be capable of managing data coming from the smart meters and sensors. It is expected that the applications sphere is going to be the main competition area in the next 3-5 years.

Smart Meter Vendors

This field, unlike the other ones, has attracted little venture capital as almost all of the leading smart metering companies developed directly from the traditional metering industry. These companies (e.g. GE, Elster, Itron, and Siemens) are well-established already and the main challenge for them is to be the first to provide smart meters that support various communication protocols for the needs of industry. In the field of Advanced Control Systems, some new start-up companies that produce sensor hardware and software systems can evolve.

Demand Response Vendors

Demand response providers play the role of an intermediate link between a customer and utility. Such vendors can be split in two categories according to their main specialization field: small-scale residential market and large industrial clients. These companies provide software/hardware communication solutions. This market field can be quite difficult to enter for the new participants as they are going to need to gain a certain level of confidence by utility industry, which is quite conservative. It should be noted, that as the utilities advance their communication networks and management systems, they will be able to fulfill these services themselves.

Meter Data Management Vendors

Meter Data Management (MDM) is one of the market segments, where the start-ups and young companies can compete. Smart metering is a relatively new technology and very few companies have experience in handling the tremendous amount of data, generated by smart meters.

2.2 Driving Factors of Smart Grids

According to the recent research by Powel company in Norway, the majority of European utilities consider technology as a main driver for Smart Grids [9]. Table 2 provides an overview of the main driving factors for Smart Grids [8]:

Table 2 An Overview of main driving factors for Smart Grids

Technology Advancement
• Smart Grid can be seen as the convergence of IT, telecom, and energy markets • New products and solutions through technology advancement • Significant amounts of venture capital investment in Smart Grid technologies and solutions
Higher Efficiency With the Help of Grid Optimization
• Multiple integration points for intelligent grid hardware and software from transmission to consumption • Embedded sensors and monitoring capabilities • Deployment of advanced two-way communications networks • Growing Supply of Renewable and Distributed Power Generation and Storage • Network and systems architecture to support many forms of distributed generation and storage • Intelligent support for multiple forms of intermittent renewable power sources (centralized and/or distributed)
Advanced Customer Services
• Robust, simple consumer energy management platforms • Networked devices within the "smart home" • New, efficient pricing models for electricity usage
Infrastructure Reliability and Security
• Networks/systems tolerant of attack or natural disaster • Ability to anticipate and automatically respond to system disturbances
21st Century Power Quality
• Delivering power that is free of sags, spikes, disturbances and interruptions

Additionally, new energy conservation technologies are needed for Smart Grids. As such technologies may reduce the need for reserve power plants and can cut the costs of power failures. Energy conservation technologies may also help to smooth out the variability of renewable energy generation, such as wind and solar.

Another driving factor of Smart Grid is the new 'smart' way of energy use. It implies energy resource optimization (e.g. own generation or distribution grid), as well as optimization of time of use (e.g. avoiding peak hours usage). The new grid should also be environmentally friendly and economically viable.

Additionally, the regulators in Europe and United States have been one of the leading drivers of Smart Grid. A lot of research and development projects regarding Smart Grid implementation are going on at the moment. Both government and private companies invest into these projects nowadays.

2.2.1 Power Quality

Nowadays people are very dependent on electricity. It is indispensible part of their lives. Not only it is now critical to have reliable power supply, but the power quality needs to be sufficient to support modern demands of the digital life.

Grid operators today are mainly focused on the outages of electricity, rather than power quality issues. But it may soon change as the regulators create more strict rules, regarding power quality. Without the proper power quality, an electrical device can malfunction or not operate at all. With all our data centres, cellular networks and medical equipment, it is easy to realize that having reliable power quality is almost as important as having power itself.

2.2.2 Safety

Safety is an important factor in Smart Grids. As systems rely more and more on sophisticated hardware and software, safety is increasingly dependent on the intercommunication between systems and their responses to inputs. Functional safety depends on equipment or a system, operating correctly in response to its inputs. It is the part of the overall energy system safety. Functional safety includes:

- Software
- Hardware
- Electromagnetic Compatibility
- Safety management

Functional safety aims to minimize the risk of physical injuries or damaging health of people (directly or through the environment). Making our electricity grid safer is, without any doubts, a driving factor for a change to a smarter grid. Refer to Appendix I for a list of functional safety standards [10].

2.2.3 Energy Independence and Security of Supply

Energy independence is high on political agenda [11]. Import supply of gas and other resources for energy generation from foreign countries has proved to be unreliable. That is why it is important that a Smart Grid would support self-sufficiency. That can be done by optimizing energy use (demand response) and increasing energy generation from renewable resources as well as distributed generation.

Case Example:

Electric vehicles are sometimes viewed as a solution for reducing dependence on foreign energy as they do not use oil imported from foreign countries. However, this technology can't realize its purposes without having an underlying Smart Grid. For example, Advanced Control System and communication network, which is a part of intelligent grid will be able to charge electric vehicles without causing 'accidental peaks' that can be created as a result of thousands of household charging their vehicle after work.

2.2.4 Increasing Renewable Energy Generation

Without introducing Smart Grids, renewable power sources will stay niche. Both customers and utility will benefit from a true integration of renewable energy generation into conventional grids. This integration need to be properly done in a way that is not only advantageous, but also not disruptive.

A lot of European countries are now racing towards ‘20/20/20’ goal: a 20% cut in emissions of greenhouse gases by 2020, compared with 1990 levels; a 20% increase in the share of renewable sources in the energy mix; and a 20% cut in energy consumption. Introduction of Smart Grids will not only help to achieve this goal, but also promises to provide additional energy storage possibilities. Energy storage issues are further discussed in section 2.3.2 of the thesis.

2.2.5 Technology Development

Some of technologies that enable Smart Grids are available on the market today. Smart Grids will move the utility industry into the information age as the information about energy consumption, generation, distribution and storage will become available in the real-time.

Until today, the electric utility industry has lagged behind other industries in taking advantage of the modern communication and networking technologies. Therefore, first steps towards introducing Smart Grids will not be ‘creating new technologies’, but introducing the technologies of today. The Figure 5 shows the proposed evolution of Smart Grids:

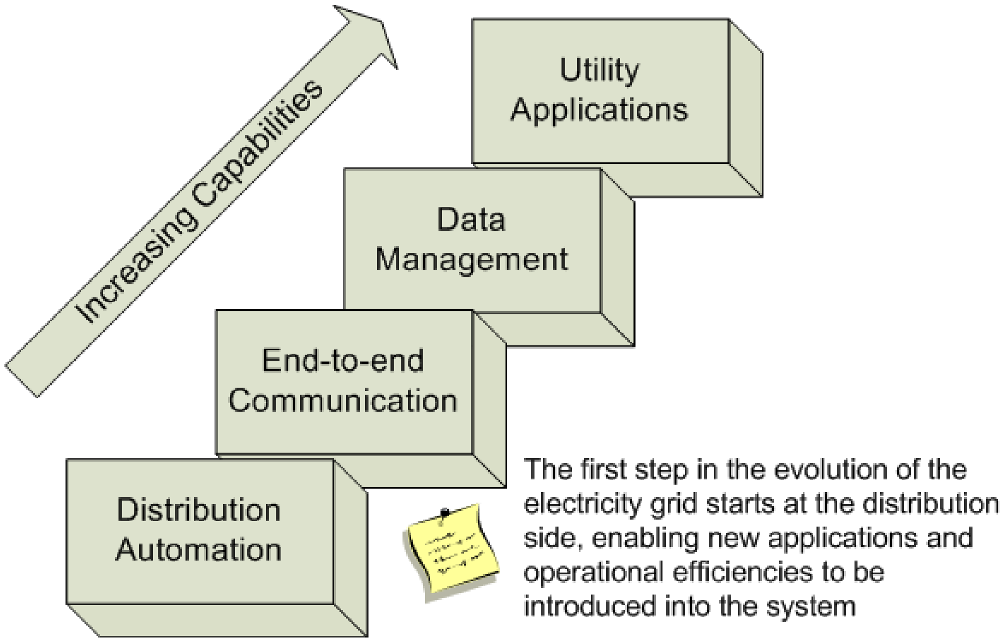

Figure 5 Steps towards Smart Grid

2.2.6 Energy Demand

Global energy demand is expected to soar 44% by 2030 (see Figure 6) with most of the demand coming from developing countries such as China, Russia, India, and Brazil.

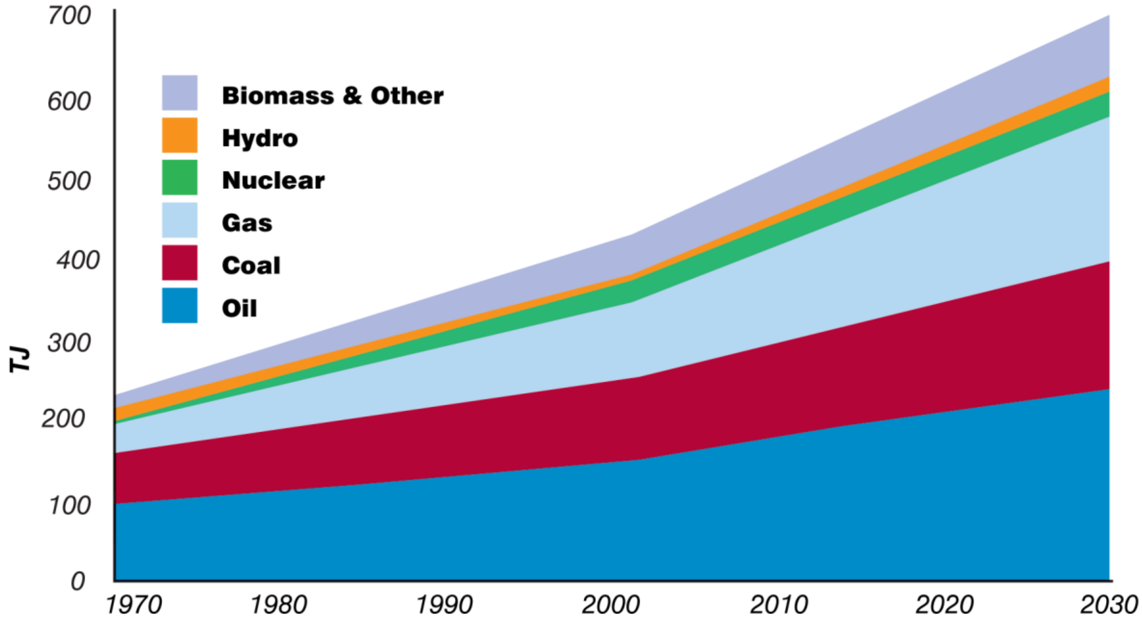

Figure 6 Energy Demand Forecast [12]

However, EU countries will also be affected by a global energy demand increase. The electricity prices are constantly rising. Therefore, alternative energy resources should be considered. And the market should adapt for the new technologies.

Smart Grid platform supports both direct and indirect energy efficiency efforts. Advanced Metering Infrastructure promises to provide control centers with real-time information about consumption. This will significantly improve the operational efficiency of the distribution grid and allow for energy-efficient applications such as Demand Response to be enrolled at full scale.

2.2.7 Peak Levelling and Time-of-use Pricing

In order to reduce demand during the peak usage periods when the price of electricity is very high, communications and metering technologies inform smart devices, installed at homes or in the offices, when energy demand is high. These devices in turn track the amount of used electricity and log the time of its use.

To motivate customers to cut back their energy use and perform so-called peak levelling, prices of electricity are increased during high demand periods, and decreased during low demand periods. It is expected that consumers and business will tend to consume less energy during peak time if it possible for them to be aware of high price premium for using electricity during the peak periods. For example, some families may decide to cook dinner at 9pm instead of 5pm.

It is thought that such policies will reduce the amount of spinning reserve that electric utilities have to keep on stand-by. The load curve will level itself through a combination of prices and central control of a large number of devices by power management services (aggregators) that pay consumers a portion of the peak power saved by turning their devices off.

2.3 Applications of Smart Grid

In this chapter, most common applications of Smart Grids are going to be described. The Figure 7 provides an overview of the applications of the Smart Grids:

Future Apps and Services	Real Time Energy Markets	
Business and Customer Care	Application Data Flow to/from End-User Energy Management Systems	
Smart Charging of PHEVs and V2G	Application Data Flow for PHEVs	
Distributed Generation & Store	Monitoring of Distributed Assets	
Grid Optimization	Self-healing Grid: Fault Protection, Outage Management, Remote Switching, Minimal Congestion, Dynamic Control of Voltage, Weather Data Integration, Centralized Capacitor Bank Control	Distribution and Substation Automation, Asset Protection, Advanced Sensing, Automated Feeder Reconfiguration
Demand Response	Advanced Demand Maintenance and Demand Response; Load Forecasting and Shifting	
AMI	Remote Meter Reading, Remote Disconnect/Connect, Theft Detection, Customer Prepay, Mobile Workforce Management	

Figure 7 Smart Grid Applications

2.3.1 Demand Response

Demand Response (DR) has recently gained a lot of interest of regulators and government. It is a relatively simple concept the benefits of which are mostly experienced by end-customers. It encourages consumers to reduce their electricity consumption during peak price hours. Demand response solutions vary from simple advanced metering systems to fully automatic home systems.

Historically, the customer loads of electricity distribution systems have mainly been uncontrollable. The load of a customer seen by different market players (DSO, TSO, supplier, aggregator) has only depended on the behavior of the customer and the related appliances. The average load profiles of equal types of days and hours (working days, Saturday, Sunday) are quite stable. The load profiles depend mainly on weather conditions and duration of day light. The distributed generation and energy storage resources at the customer load have been negligible.

The technical development (DG, ICT, Smart Metering, Power Electronics, batteries) will convert the static customer grid connection into an active multifunctional gateway for all electricity market players.

The demand response system consists of at least two interconnected devices, installed at customer’s premises: a smart load controlling device and a smart meter. The Figure 8 provides a visual representation of this concept.

Improved demand response system can include a Smart Display that allows continuous interaction between a consumer and a utility grid. It would also be possible for the customer to log onto a webpage that contains information about electricity usage and tariff-schemes available for selection.
DR is a faster, cleaner, cheaper and more reliable solution compared to adding a new power plant during peak hours. Both end-customers and utilities will benefit from the introduction of this solution. The fact that both parties will save money will be a huge driver for adoption of demand response technique.

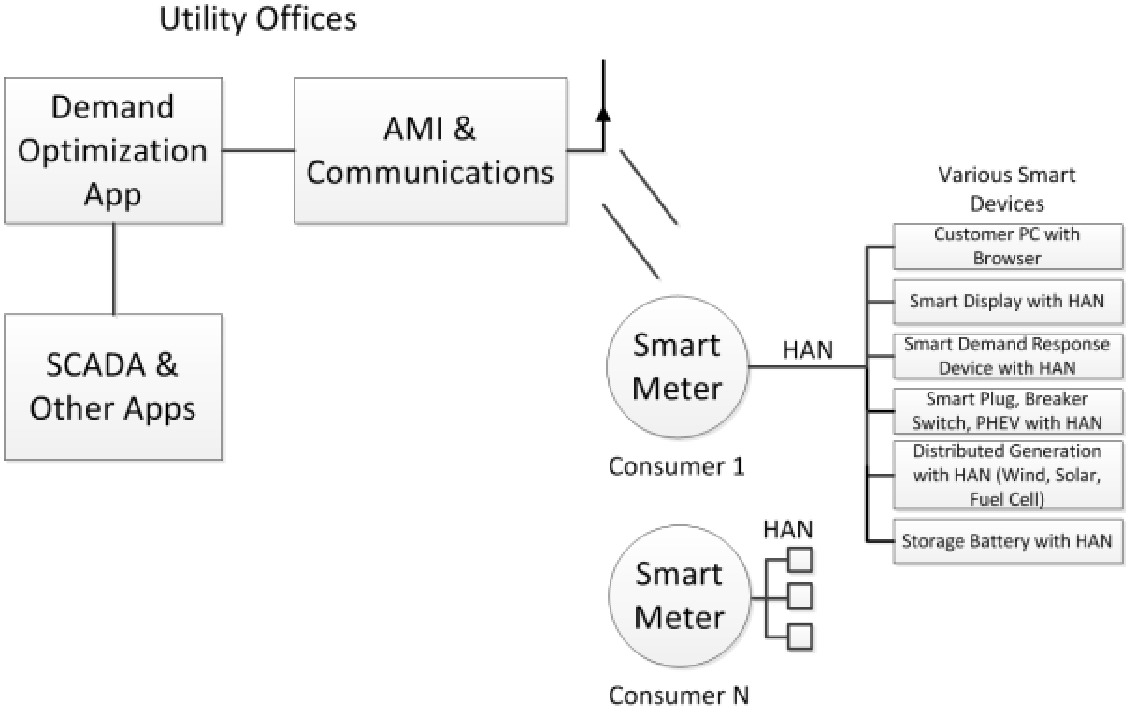

Figure 8 Demand Response Structure

2.3.2 Energy Storage

Energy storage possibilities hold a lot of hope for the future of Smart Grids. A next-generation grid without energy storage possibility resembles a personal computer without a hard drive: extremely limited. Energy storage across the distribution grid can provide dispatchable power that can be used during peak hours. Therefore, this solution will decrease (and consequentially eliminate) the use of expensive plants that are introduced by system operators as a ‘last hour’ resort during peak demand hours. Also, it will make distribution network less volatile as it will smooth the load and may help to avoid consuming electricity high-price tariffs.

Additionally, energy storage solution will be crucial for storing energy from renewable generators (wind and solar power are only produced at certain times, which are not necessarily coincide with the times when the electricity is needed; therefore it is important to utilize energy storage technologies to conserve electricity for times when direct generation is not possible).

2.3.3 Home Area Networks

Home Area Network (HAN) is an essential tool in the Smart Grids palette of components. It allows Smart Grid applications to communicate with various home appliances.

HAN are an extension of Advanced Metering Infrastructure, which makes possible two-way communication between devices, users, and utility. The customer can manage intelligent home appliances using real-time monitoring system according to the time-of-use tariff system. The utility will automatically determine the tariff rates according to generation/consumption data received from Smart Meters.

The Figure 9 shows the Home Area Network structure and home appliances interconnection:

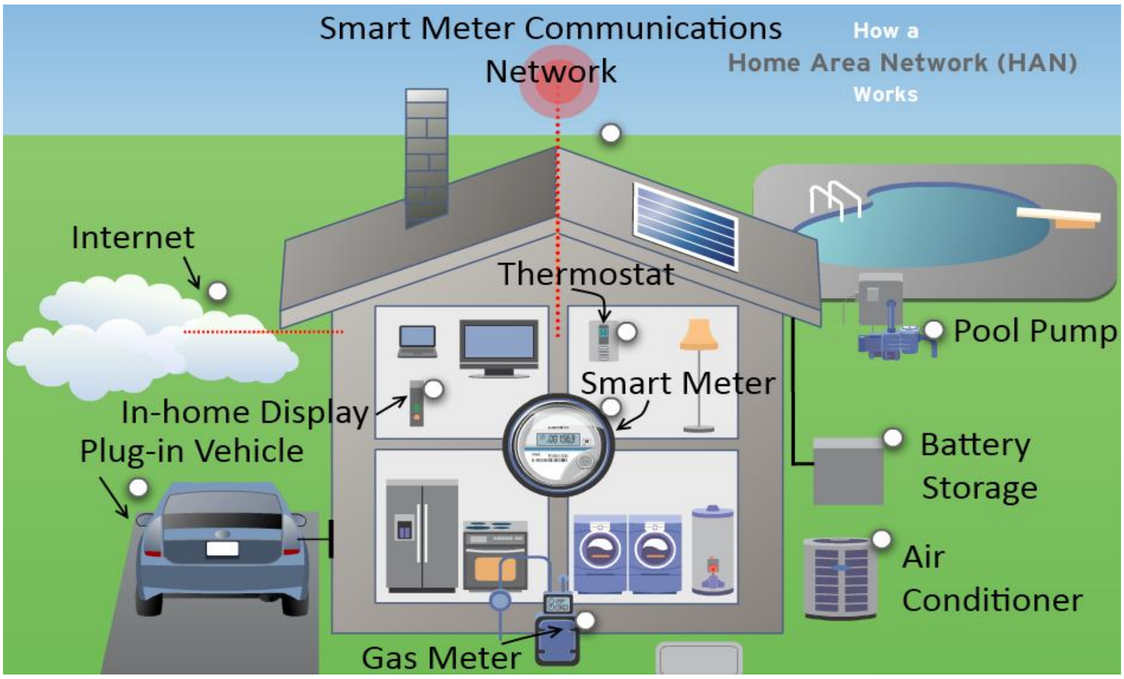

Figure 9 Future Home Area Network

2.3.4 Advanced Metering Infrastructure

Advanced Metering Infrastructure (AMI) is a system that measures, collects, and analyses energy usage data from advanced devices, such as electricity/gas/water meters. The data can be sent back and forth using a two-way communication network. The energy usage statistics can be collected upon request or on a pre-defined schedule.

The AMI includes hardware, software, communications, and customer systems and meter data management software. Therefore, AMI can be explained as a two-layer structure: application layer and transport layer [8]. The application layer is responsible for data collection and analysis, operational control, and real-time monitoring. The transport layer is responsible for a two-way information transfer between utility and customer.

The Figure 10 represents AMI communication network structure:

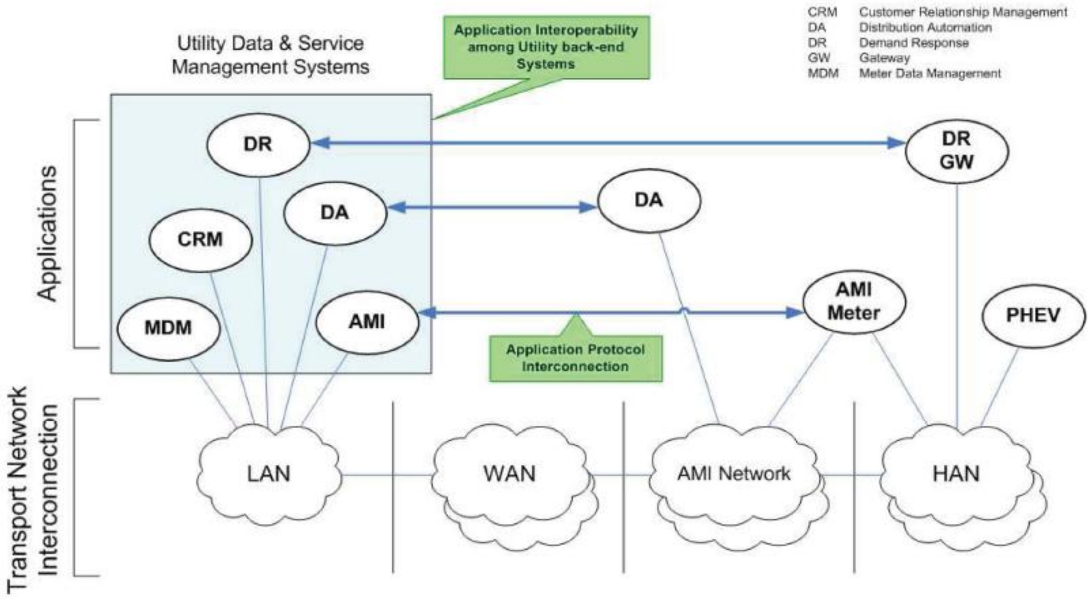

Figure 10 AMI Communication Network Structure

2.3.5 Integration of Distributed Generation

Renewable energy sources, such as Solar or Wind power have been utilized for many years. But what has been missing is an infrastructure that integrates these energy sources into conventional distribution grids (DG). The goal is to achieve ‘plug-and-play’ integration of renewable energy sources into DG.

In order to reach mass penetration of renewable energy sources, they must be able to deliver energy directly to end-users. The ability of distributed generation to create so-called ‘microgrids’ has recently gained attention of the investors. Microgrid is an independent, small and self-reliant grid that generates and stores the power for the consumers within it. The microgrid can be connected to the conventional distribution grid during normal operations, but in case of any faults on the DG side the microgrid can be isolated. While being isolated or 'islanded' it will be able to continue to meet the electric requirements independent of the DG. The same can work in the opposite directions: the owners of renewable energy sources inside the microgrids can sell the energy back into the distribution grid or even directly to a neighbor across the street.

2.3.6 Advanced Utility Controls Systems

Advanced Utility Controls Systems (AUCS) aim to integrate different control systems and technologies in order to support control and optimization of a distribution grid. It consists of the following components:

- Meter Data Management (MDM)
- SCADA Systems
- Distribution Management Systems (DMS)
- Energy Management System (EMS)
- Customer Information Systems (CIS)
- Geographic Information Systems (GIS)

AUCS within the boundaries of Smart Grid platform will help to integrate demand response, distributed generation of renewable energy, as well as it will provide customers with the information on their consumption.

Bringing together such systems will dramatically improve consumption forecasting, reliability, protection and performance of the grid. It will also be possible to achieve such aspects of Smart Grids as power quality, energy storage, and self-healing. The Figure 11 shows possible connections between different information systems:

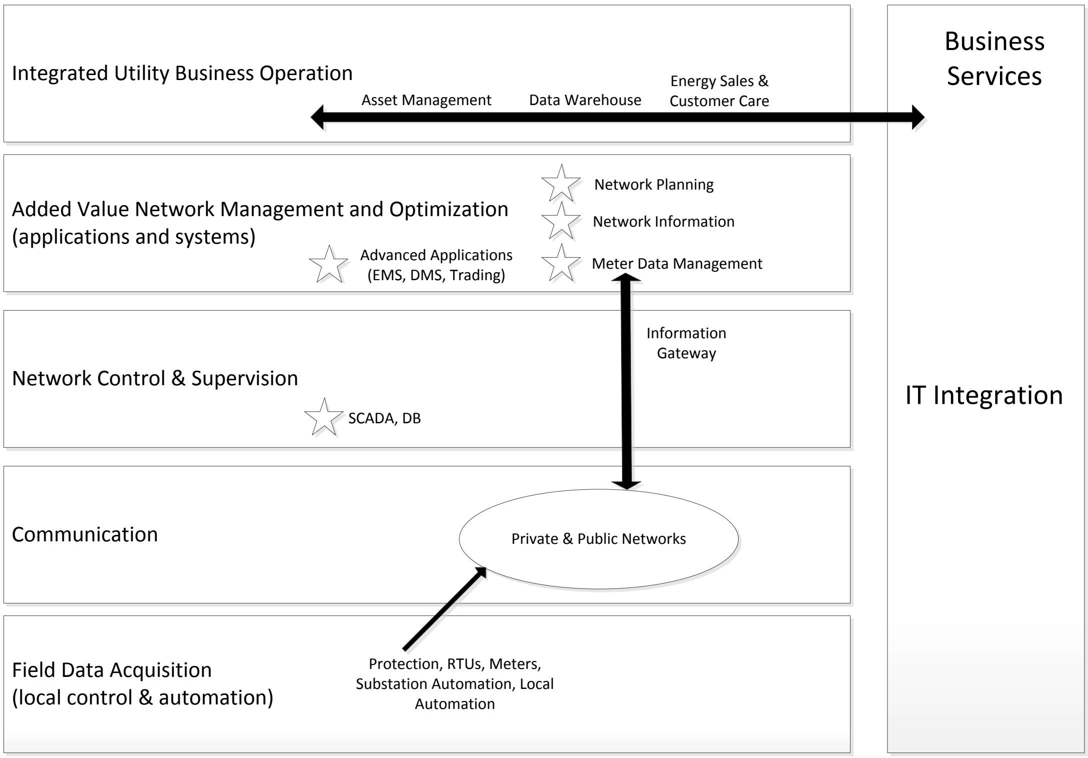

Figure 11 Integrated Utility Control Systems

2.3.7 Smart Charging

Electric Vehicles (EV) become more and more popular nowadays. Therefore, a question of charging of the EVs emerges. The new grid must be able to cope with a growing demand of EV charging and should not crash during peak times when a large amount of customers decide to charge their cars. It is a task of software applications to design EV charging station in such a way that cars would charge during off-peak times (e.g. after 9 p.m.). Both customer and the grid utility will benefit from it. The off-peak charging will smooth the load while reducing the price of electricity (e.g. night tariff will be used).

3. Smart Grid Challenges

Smart Grid is a promising platform for future electricity networks. However, there are a lot of challenges on the way towards its implementation. Therefore, different market players need to combine their efforts and concentrate on making the technologies and infrastructure possible for Smart Grid implementation as well as finding the sources of financing and returns.

Different surveys have been conducted across the world to estimate the readiness of the industry and energy consumers for the Smart Grids. Here are some of them:

- One-half of the utilities surveyed in the recent Pacific Crest Mosaic Smart Grid Survey [13] named *cost* as the strongest barrier to Smart Grid projects within their organization. Technology immaturity is also a key barrier to Smart Grid projects but is rated a "top" barrier for fewer respondents. Here are the most popular answers:

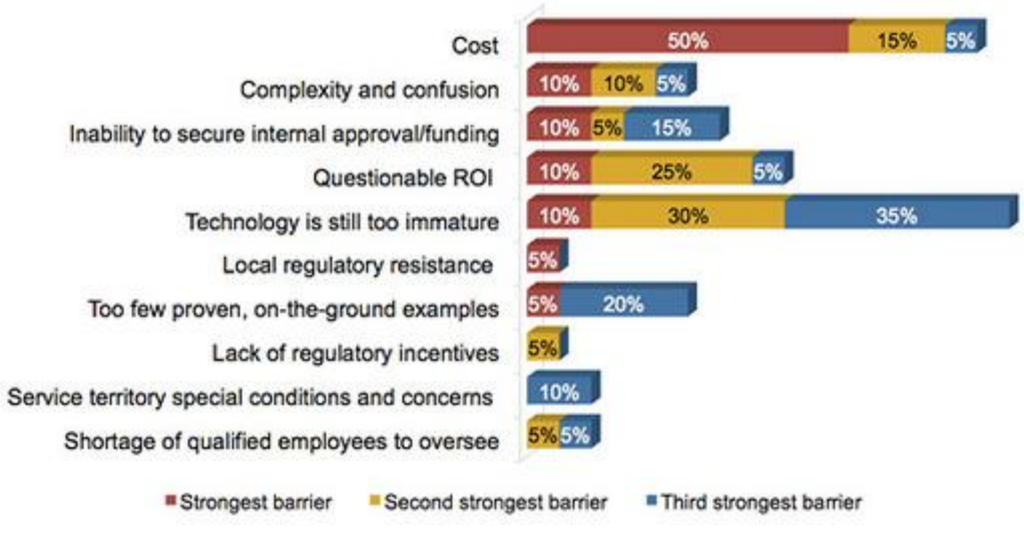

Figure 12 Smart Grid Barriers Survey

- According to a new survey by software giant Oracle Corp. [13], ninety-five percent of electricity customers would like to have detailed data about when and how they use power, but just 20 percent are willing to pay for real-time information.
- New research on the payment processing trends in the utility industry found that 65 percent of respondents say the current economic environment is making

processing customer payments more difficult, and 85 percent of the utilities are using outdated, legacy systems. [14]

Nowadays is the right time for utilities to implement the Smart Grid technologies and educate consumers on the benefits of reducing peak electricity demand. Since the utility is already old and needs renovation (most of the network's 30-40 years lifetime has run out, it is a good opportunity for the utility companies not only to replace the old equipment with the same new one, but to try out the new promising Smart Grid technology platform. Electricity customers will help them. If a consumer has more information about its consumption, he will start changing his behavior. It concerns not only the types of appliances he buys, but also *when* he uses energy. [15]

However, certain challenges stand on the way towards Smart Grids. In this chapter, the following challenges will be reviewed:

Table 3 Smart Grid Challenges

3.1 Technology Challenges
3.1.1 Communication Coverage of Transmission and Distribution Grids
3.1.2 Choice of Communication Technology
3.1.3 Information Security
3.1.4 Distributed Energy Resources Integration Challenge
3.1.5 Distribution Automation
3.1.6 Synergy with Advanced Metering Infrastructure
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3.1.8 Grid Network Design
3.2 Economic Challenges
3.2.1 Market Barriers to the New Business Models
3.2.2 Social and Economic Issues
3.3 Business Challenges
3.3.1 Integration Challenge
3.3.2 Energy Management
3.4 Regulation Challenges
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3.1 Technology Challenges

3.1.1 Communication Coverage of Transmission and Distribution Grids

The management of Smart Grid systems will require the use of a highly capable communications network that can provide guaranteed levels of performance in regards to bandwidth and latency.

The Figure 13 illustrates the extension of communications and control infrastructure that currently covers the comparatively smart transmission system to include the existing distribution system.

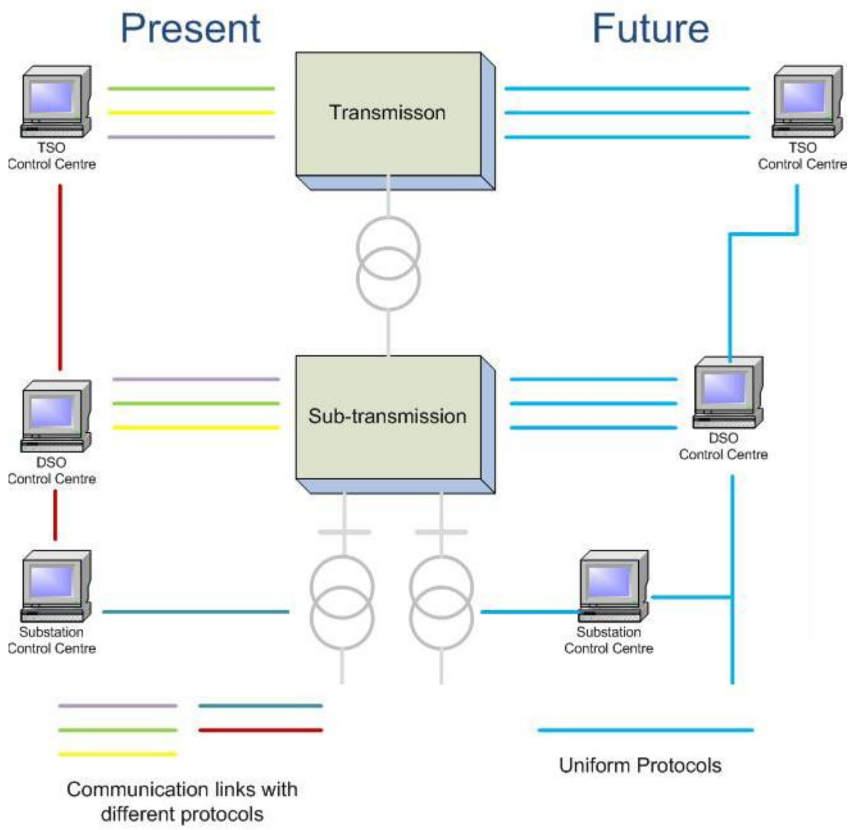

Figure 13 the Smart Grid Roll-out of Communications Coverage to the Distribution Level [4]

An extension of communications coverage to the distribution network can support a variety of distribution automation functions including the control of switch gear to achieve rapid restoration and self healing properties. It now becomes possible to extensively monitor assets such distribution transformers and to actively manage feeder voltage profiles with automated tap changes or VAR support. Nowadays, almost every distributor faces challenge in developing a coherent communications solution that will support their Smart Grid aspirations and allow the easy integration of Smart Grid operations within their business systems. Their response will determine the effectiveness of their organizations for years to come. Key issues include equipment and jurisdictional interoperability, open communications standards and cyber security. Many distributors have current programs in place to increase the level of automation of distribution assets primarily for reliability improvement purposes.

3.1.2 Choice of Communication Technology

The dilemma of choosing the most suitable communication standard at both local and wide area network levels has bothered decision makers, vendors and regulators since the development of automated meter reading (AMR) technology introduction. The initial alternatives included transition from mobile to fixed standard. The current debate includes broadband, Radio Frequency (RF) and PLC standards. While the question is still opened, the RF standard seems to gain popularity.

The next wave of selecting an appropriate communication technology for Smart Grids is centered on three groups of competing technologies.

The first group is the current set of technologies (RF, PLC, and broadband) that are constantly improving in terms of bandwidth, latency and Internet Protocol capabilities.

The second group is the advanced communication technologies (3G, GPRS, and WiMax). The future of these technologies is a highly debated issue. However, the GPRS standard is favored in Nordic countries.

The third group of technologies focuses on customer interaction and service provision through an existing Internet connection. In this model, a meter is essentially replaced with a data server at home that acts as a "virtual meter". This meter will be linked up with a customer’s PC as an interface and will provide the requisite HAN functionality, while sending the metering data back to the utility that needs it. If this model will be adopted it will bring certain problems that need to be solved. These problems include: physical disconnect, broadband access availability, data confidentiality and usage. The listed problems are not critical and most probably will be ruled out during the first years of exploitation. This model is especially attractive for competitive retail markets in which retailers use AMI and HAN services to improve their retailing value proposition in order to win over customers from rivals.

While introducing any of the proposed set of communication technologies, the utilities must keep in mind that the technology game will continue to change. Therefore, they must be ready to a certain level of risks that are connected with the introducing any particular technology [16].

3.1.3 Information Security

We are living in the digital age, where almost everyone has access to the Internet. Modern power infrastructure is quite vulnerable to terrorist attacks. Nowadays, SCADA systems have the ability to be access remotely. As the power flow on the bus is controlled by a SCADA system, an attack on SCADA system can cause a power outage in current electrical infrastructure.

In future, when Micro Smart Grids (MSG) with employed Distributed Control System (DCS) will be introduced this kind of attacks will not be possible. Instead of following centralized SCADA implementation structure, which is the case nowadays, the new Smart Grids will utilize the distributed SCADA topology where each MSG will have its own SCADA system [17].

The Figure 14 represents a new Distributed Control System (DCS) approach for the Smart Grid platform. The proposed Smart Grid topology contains several MSG. Each MSG has a local SCADA controller, which acts as a primary/secondary controller, depending upon the applied conditions. Remote Terminal Units (RTU connect the controllers to Intelligent Field Devices (IFD) such as advanced meters or FACTS devices.

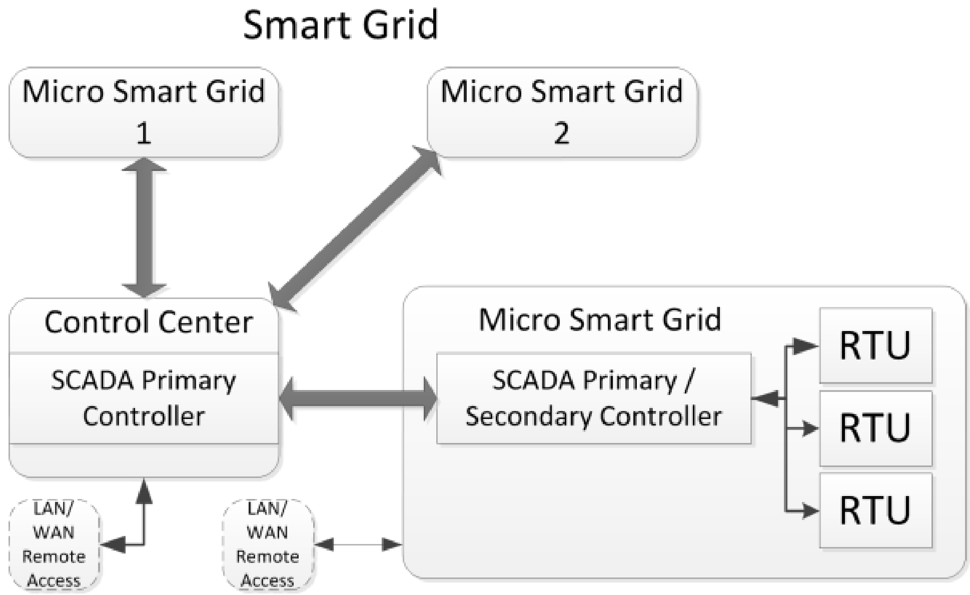

Figure 14 Proposed Smart Grid SCADA Network Layout

Every local MSG controller acts as a secondary controller in the presence of the central primary SCADA controller depicted by Central Controller (CC) block. The SCADA data is relayed to/from IFDs to the central SCADA primary controller via the SCADA secondary controller, installed in each MSG. Every SCADA controller can be connected to LAN or WAN and therefore allows remote access [18].

The first advantage of the SCADA CC is that all the updates can be done via the SCADA CC. It will allow exchanging these updates across all the SCADA controllers in each MSG. Second advantage of the SCADA CC is that in case of any failure in any MSG, Central Controller can provide the fault reporting and upon the diagnostics of a cyber attack, it will isolate the remaining network from the attack. In the scenarios described above, each Local SCADA controller in MSG acts as a secondary controller to the SCADA CC, which behaves as a primary controller. If the SCADA CC has a problem, the connection of the MSG with the CC will be dropped and local SCADA controller at MSG will act as a primary controller. As a consequence, the MSG will operate in island mode. Upon the recovery of the CC, the connection between the MSG and CC can be resumed.

The proposed topology promises to provide dual redundancy and increased reliability to the Smart Grid network, since it will isolate the infected sections of the power grid.

The ANSI C12.22 protocol is specifically laid out for the two way communication between electrical metering devices. The same standards of communication protocol can be employed for the intelligent communication between controllers and sensors [19].

3.1.4 Distributed Energy Resources Integration Challenge

Advanced metering technologies and improved communications will enable more intelligent incorporation of the distributed energy generation by utilizing sensors and two-way metering. This will enable customers to play a role of energy supplier if they have excess energy.

However, distributed energy generation is partly weather-dependent and non-scheduled (in case of wind or solar generation). This fact brings certain challenge in regards of controlling the variable energy flow. As the penetration of distributed generation increases, more advanced control of the power system is required to maintain system reliability. These controls can include more efficient use of transmission, use of demand response, and energy storage [20].

In order for the integration to take place, an appropriate load modeling and forecasting must be developed. For example, wind strength long-term patterns analyzing can take place in order to estimate the time-of-day availability and the amount of electricity that can be generated by a wind plant.

For the actual operation of smart grids forecasts of future requirements are essential to be able to prepare the flexible systems to behave in the appropriate manner. Non-scheduled renewable energy resources add another variable to an already complicated balancing act. The fact that the renewable energy generation cannot be dispatched in the traditional sense can cause problems for conventional system operation. A Smart Grid takes advantage of potential improvements that can be made through applying communications and information technology. The employment of accurate renewable energy forecasting is a key component in implementing a Smart Grid.

Meteorological processes drive renewable energy generation and therefore it is highly variable. This variability occurs across all of the time frames of utility operation from real-time minute-to-minute fluctuations. However, recent wind integration studies have shown that the variations that have the largest effects on the system reliability operations and costs of operation are those in the hourly and daily timeframe [21]. Refer to Figure 15 for an example of day-ahead and hour-ahead graph examples. All this information must be kept in mind for estimating the necessary reserve capacity for the system, following reliability and frequency control requirements. If the Smart Grid will be able to process this kind of information, this will be a large improvement in the operation of renewable energy resources.

Keeping the generated energy output within a certain limits can be challenging. Forecasting does not solve this issue entirely and new ways of controlling the output are needed. The relay protection systems should sense the variation of the output and disconnect the DER when the voltage level is unacceptable.

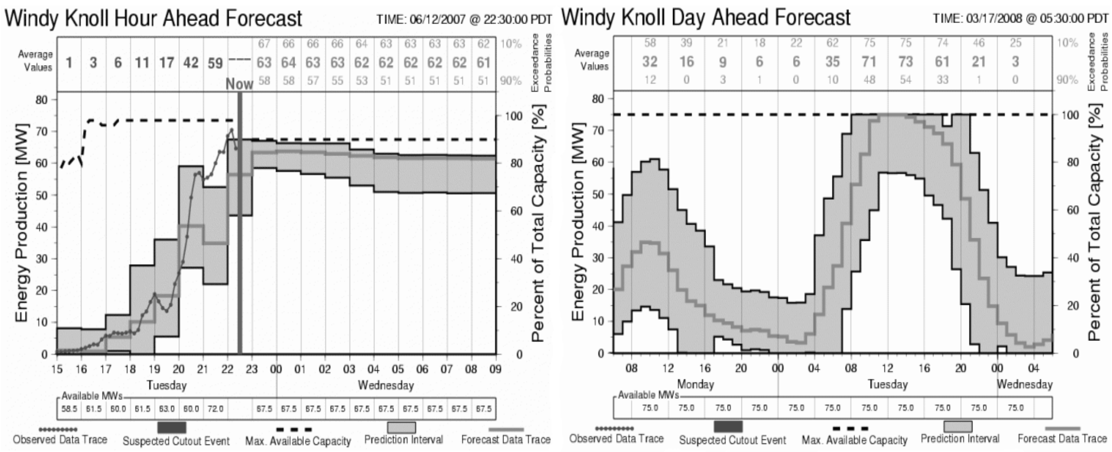

Figure 15 Plot of the day-ahead and hour ahead forecast information [22]

3.1.5 Distribution Automation

The planning of the Smart Grid platform will have a huge impact on distribution network operation modes as they are the crossroads of many electricity market players. Conventional distribution network have been design with one-way power flow concept kept in mind. Thus, the power flows from a large generation node to consumers. The new Smart Grid will employ two-way power flow. Therefore, distribution network need certain changes to allow the new possibilities offered by advanced communication and information technologies.

Some automation functions can already be introduced to current distribution grids without significant changes [23]:

A1.Fault Diagnosis and Alarm Processing Function

This function is automatically triggered immediately after the occurrence of a fault. It produces a diagnosis of events on the basis of a set of pre-defined scenarios (a comparison of the remote information flow is made with the patterns predefined by experienced operators). The diagnosis produces an analysis of the type of fault enabling the operator to quickly understand what happened in the network under its control. The function can also detect missing remote control signals.

A2.Fault Location Function

After fault detection and analysis, it is necessary to locate a fault. The goal of this function is to quickly determine the section of the feeder where the fault occurred. This is performed by analyzing the information sent from fault indicators to the control center. After receiving such information, operators can interfere and isolate the fault area by remotely opening corresponding switches. The degree of accuracy depends on the density of fault indicators on the MV network.

A3.Service Restoration Function

Once a fault has been located, this function tries to find available schemes for power restoration to disconnected customers of the non-faulted section of the feeder, while considering technical constraints. Each scheme consists of a series of actions, (opening/closing of switching devices) leading to power restoration.

Existing SCADA systems provide measurements of the current flows and voltages at the HV/MV substation, but very few information is usually available beyond the substation. This data is insufficient for getting a picture of overall network operating point and cannot be used as an input to the automation functions that are needed to improve hosting capacity for distributed generation. Therefore, the following three automation functions need to be developed:

B1. Distribution State Estimation

Automation functions need a continuous evaluation of the system state in order to improve efficiency with the help of optimization tools. The knowledge of the distribution system state is expected to come from the use of a distribution state estimator. While this type of technology is used throughout transmission systems, it is not yet applied to distribution systems. This function would require additional measurements from remote sensors placed in MV/LV substations and Distributed Generation connection nodes.

B2. Volt Var Control

Voltage Rise Constraints are often described as main technical barrier to the connection of Distributed Generation in present MV and LV networks. Such issues are currently solved through a so-called fit-and-forget approach (network investment is made in order to avoid any voltage constraints). However, such issues can be solved by using a coordinated voltage control function, which has two main goals:

a) Optimize the state of the network (i.e. by minimizing losses through reactive power compensation) during normal operating modes.
b) Remove Distributed Generation voltage (possible solutions include: on-load tap changers at the HV/MV substations, bank capacitors connected to MV busbar, and active/reactive power range of Distributed Generation.

B3. Network Reconfiguration

The topology of conventional distribution networks is only changed after the fault occurrence. This is done, due to the single-direction power flow planning. However, with the introduction of Distributed Generation certain changes to the network topology might need to be considered. For example, network operator can consider changing network configuration according to the period of the year. These steps can help integrate renewable energy resources.

3.1.6 Synergy with Advanced Metering Infrastructure

Smart meters are a central part of future Smart Grids. It is important to integrate advanced metering management into smart grid platform. In order to prepare for the massive Smart Meters instalment roll-out, a pilot projects are being set up across Europe. These pilots aim to confirm the proposed business cases, secure the change management, and consolidate IT reliability, ensuring the success of roll-out project.

The approximate structure of the Advanced Meter Management is shown on the Figure 16. Different communication standards can be used for different kind of customers. PLC protocol can be used for urban areas, while GPRS protocol – for rural areas.

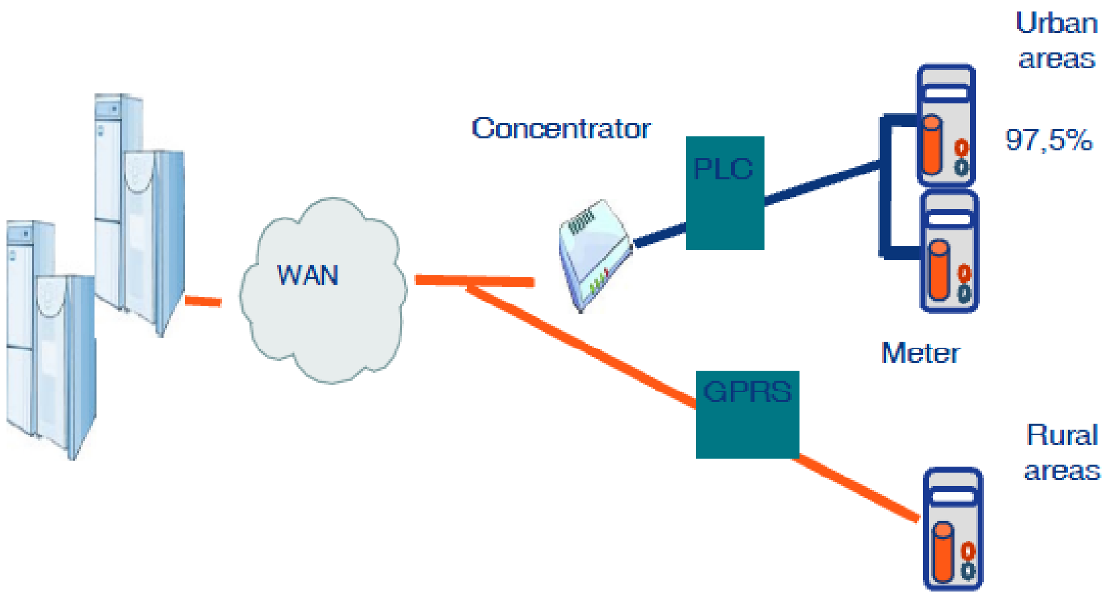

Figure 16 Structure of the AMM [23]

Advanced metering management promises to offer wide possibilities in demand response area. The customers will be able to receive information on their consumption via displays, internet, and mobile phones.

Advanced meters will need to communicate with equipment from different vendors to ensure different functionality. It is also viable that each device would understand another. Therefore, it is necessary to obtain a good level of data interoperability and allow evolution of the technology without any dependence on a single manufacturer. The adoption of standards will help to solve this issue.

It is essential to develop a global strategy which will allow taking advantage of all the possible synergies to maximize the benefits of the implementation of new systems and improve their interoperability and exchangeability.

3.1.7 Cheap Energy Storage Technology

Some of the features of energy storage technology have been described in chapter 2. In order for massive penetration into current grids to take place, energy storage technologies must become cheaper. Until that time, such technologies will remain a barrier for smart grids. This is a great challenge for start-up companies, as new technology, if adopted system-wide, will open almost untapped marked of energy storage solutions.

A lot of energy storage technologies are being tested nowadays. Battery companies that have been developing devices for vehicles are starting to look for the applications for smart grid power. Here is a list of promising energy storage technologies:

- Ultracapacitors
- Heat-storage
- Compressed Air
- Pumped Hydro
- Flywheels
- Sodium Sulphur (NAS) batteries
- Flow batteries
- Lithium-ion batteries
- Fuel-cells

3.1.8 Grid Network Design

Future models of electricity grids have to adapt to changes in technology, environment and business. System operation is going to be divided between central and distributed generation and control. The distributed generation trend will continue to gain its power along with the environmental concerns growth [24].

Integration of renewable energy sources, such as wind, solar, biomass, tidal, and hydro in both a distributed and centralized structure is an important issue. In order to operate non-dispatchable renewable energy sources economically, solutions for energy storage are needed. Although they are not yet commercially viable today, it may change in future with technology advancement.

Bulk transmission and distributed generation will co-exist in future Smart Grids, but the distribution will become increasingly blurred. Negotiations about reinforcing existing networks and upgrading them to a voltage level of 1100 kV alternating current and/or 800 kV direct current is going on in countries like China, India, and Russia.

But the network design is going to change, mainly due to the rise of information and communications technology, which will enable electricity networks to adapt to actions in real time. Distribution networks will become more active, linking power sources with consumer demands.

There are several proposed network designs for future Smart Grid platform. For the long term, there is a possibility of hub networks – the interface between participants and transmission systems [24]. Hub networks will condition, transform, and deliver energy to meet customer needs. These networks will communicate with consumers, producers, storage, and transmission devices either directly or via conversion equipment. The Figure 17 illustrates an example of such network. Hub Networks will incorporate PHEVs into an electricity distribution grid and manage their impact. For more information, please refer to [24], [25].

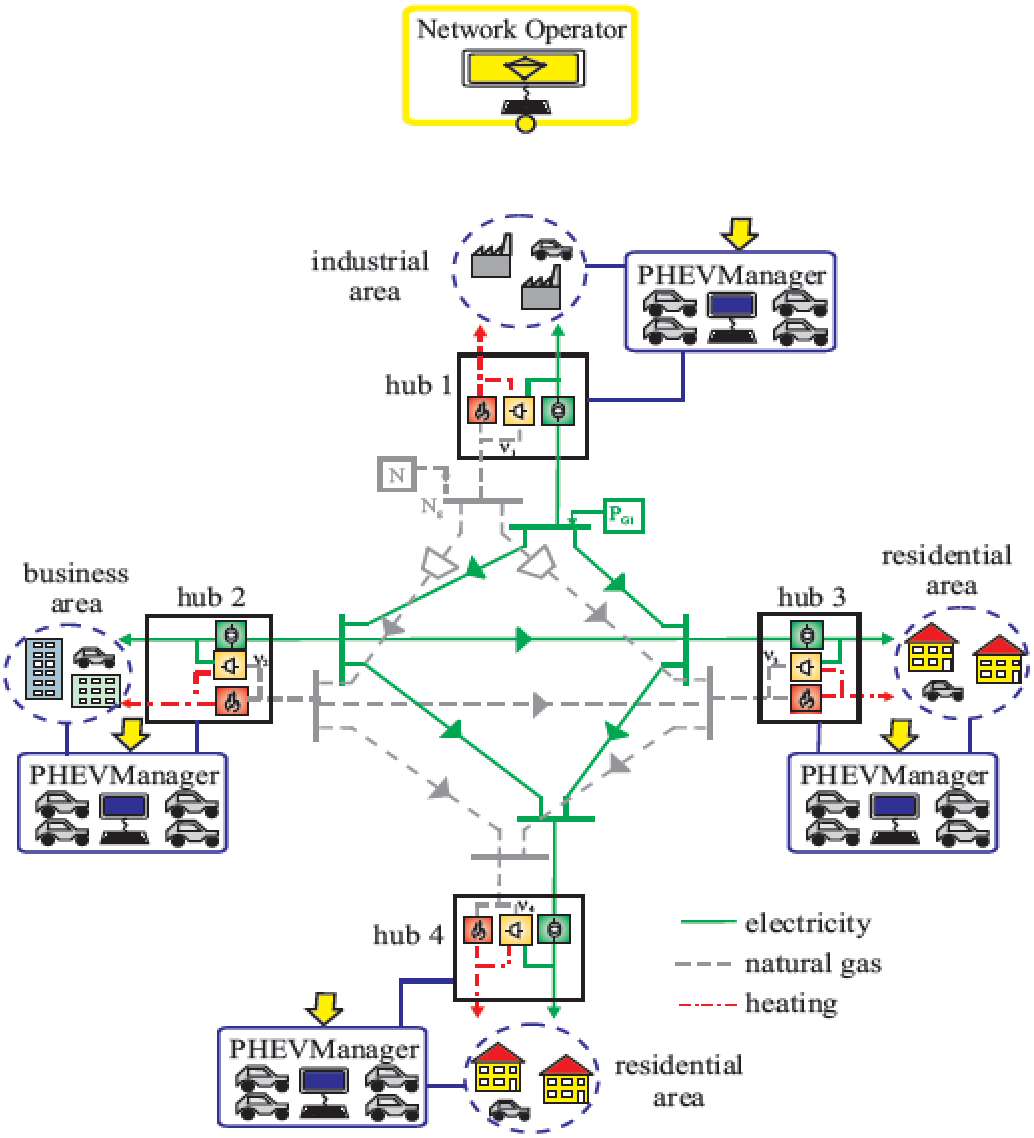

Figure 17 Energy Hub System Example

Other proposed designs include micro-grids (Figure 18) and virtual utility model (Figure 19). Micro-grids are low voltage networks with distributed generation sources, combined with local storage devices and controllable loads with a total installed capacity of a 1-2 megawatt (i.e. water heaters and air conditioning). One of the features of microgrids is that, although they operate connected to distribution network most of the time, they can be automatically transferred to islanded mode, in case a fault occurs in the upstream network. It can then be resynchronized after restoration of the upstream network voltage.

Within the main grid, a microgrid can be regarded as a controlled entity, which can be operated as a single aggregated load or generator. It can also be regarded as a small source of power or as ancillary service that supports distribution network. For more information on microgrids, please refer to [26].

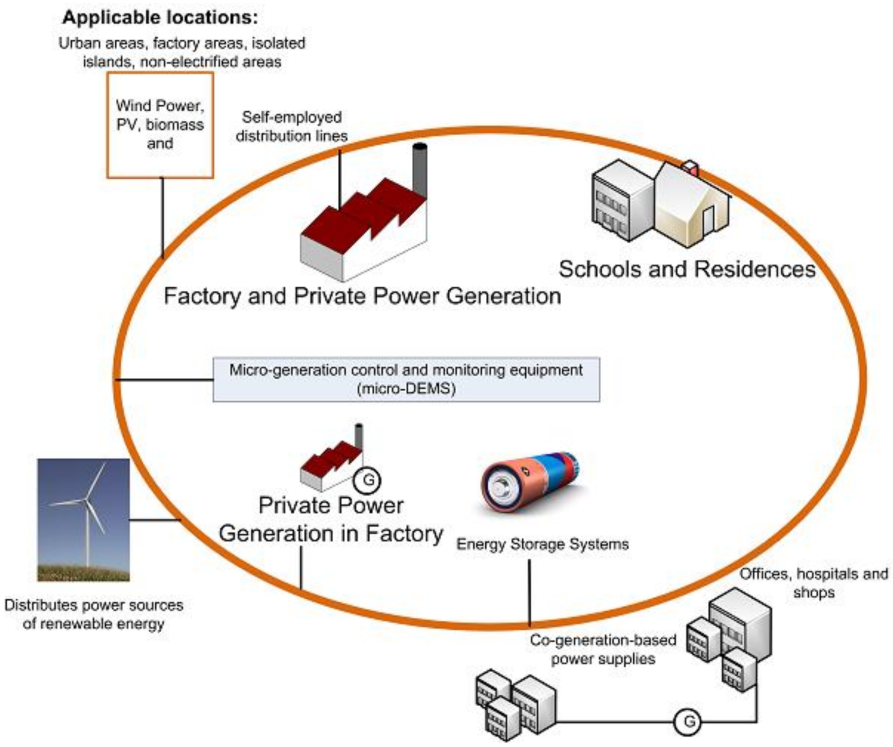

Figure 18 Microgrid network model

The virtual utility network model proposes adoption of an Internet-like model, with its information and trading capability. In this network, the power can be purchased and routed to an agreed point, but its source (conventional generator, renewable energy) is determined by supplier.

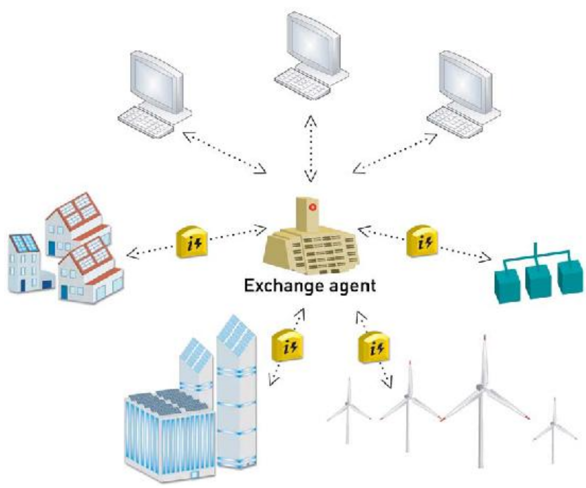

Figure 19 Virtual Utilities Network Model

3.2 Economic Challenges

3.2.1 Market Barriers to the New Business Models

The new technologies introduced by Smart Grid, such as low-cost communication and control technologies can drive new economic models that can challenge the responsiveness of regulators and legislators. Here are some examples:

- *Virtual Power Plants*
  Potentially, the aggregation of a number of distributed generation sources (Wind Turbines, Solar Panels, etc.) to a size that is large enough and profitable to bid into an energy market;
- *Private Enterprise Demand Response*
  Demand Response can be introduced using the equipment that is situated entirely within the consumers' premises and aggregated to a large scale using Information and Communication Technologies (ICT). Privately controlled demand response could be sold to intermittent generators to improve their market power or to distributors to improve their asset utilization;
- *Third Party Electric Vehicle Energy Service Providers*
  Electric vehicle owners may lease battery services from a third party that bids a large aggregated load, energy storage, reactive power, and spinning reserve services into energy market;
- *Appliance and Energy Bundling*
  It may become a common practise for customers to buy a new efficient appliance with a bundled green energy supply contract;
- *Peer-to-Peer Transactions*
  Under full retail contestability a consumer can seek alternate energy supplies. As distributed generation becomes more prolific, smaller generators will make off-market bilateral agreements. For example, the output of a domestic solar panels array may be sold to a neighbour.

Some of the business models proposed above may not be able to operate effectively under existing market models. An entrepreneur that operates his own distributed generation can certainly sell the real power, but would struggle to secure an income stream from benefits such as improved voltage profile, reactive power support, or the relief of a distribution or transmission constraint. Some of these issues can be solved by introducing off-market contracts between the interested parties. However, market restructuring might be more effective [27].

3.2.2 Social and Economic Issues

Introduction of Smart Grid platform will eventually make electricity more reliable, efficient, and cleaner. It may also become cheaper. But what would it cost to actually build it and how much would it save for all market players? That’s a tough question to answer at the moment. It’s difficult to put a price tag on a new grid, and almost impossible to count potential savings.

There are few estimates of what it would cost to modernize the grid. In U.S.A, for example, the estimates vary from $100 billion to $2 trillion [28]. The main problem with estimation of cost is that the grid isn’t one coordinated entity – it consists of hundreds of little parts, which could be built and managed by different players of electricity market. It should also be noted, that the current grid is achieving the end of its lifetime. Therefore, the grid renovation is inevitable. Since a lot of money have to be invested into equipment replacement already, why not take this opportunity and test the new smart grid platform?

Another problem of cost estimation is that people often disagree what the grid must look like. The length of transmission lines for integration renewable energy sources, such as wind and solar power, location of different nodes, types of terrain that the lines need to cross, the amount of energy that must be generated by renewable sources – all these questions are highly debatable. Hopefully, introduction of standards for Smart Grids will help to solve this problem eventually.

However, pretty much everyone agrees on one thing about the grid: it is not going to be cheap. Introduction of smart energy meters alone would cost a lot of money.

Let's make a simple estimation:

- There is approximately 2 382 000 households in Finland [29].

- The average price of a smart meter device for a household (including installation) is 190 € [28].

Result: $2.382 \cdot 10^6 \times 190\text{ €} = 452.58\, millions\text{ €}$

That's a tremendous amount of money at the first sight. The question of "*who's going to pay for it?*" might emerge in a mind of a reader. It will not be a one-time payment by the government. However, government pays a vast role in the introduction and investment of smart grids. The majority of money will come from the private-sector investment. Power companies and private investors are going to invest into smart grids. They are expecting to make a certain percentage of return on their investments.

But the cost of smart gird is eventually passed onto end-customers in the form of bigger electricity bills. The transmission and distribution part of the bill is going to rise. However, the investments in the grid will lower electricity costs over time as the aggregators will become popular and the DER will be integrated into the grid. The new network will have improved reliability, efficiency, and better access to renewable energy sources.

Smart Grid may be expensive, but investing in an improved grid will also generate returns. We are investing in a tremendously valuable long-term infrastructure that is going to enable new business growth. Also, smart grid will help to reduce the impacts of global warming, which are by no means costless.

A more efficient system, along with smart technology, could reduce congestion and fluctuation costs significantly. And access to renewable resources could mitigate the potential costs of climate change by reducing our dependence on coal.

3.3 Business Challenges

3.3.1 Integration Challenge

While most utility and vendor attention has recently focused on implementing AMI and grid applications, the attention is now turning to various systems integration. As AMI and grid services are being integrated, it is important to ensure that the information – the lifeblood of smart grid investments – is delivering what is expected at reasonable costs and within the predictable frames.

Data volume will multiply as meter read intervals will become shorter and grid operations data will be retrieved through a more extensive and intelligent sensors. This raises a big challenge. The role of system integration and information delivery becomes a critical issue in this environment. Integration of engineering and field-force systems, as well as linking them to customer information system, billing system, and business decision system is not an easy job. One manifestation of the change is the discussion on the need for utilities to have a "super" data mart. In addition to the large information technology (IT) consulting companies, back office IT providers are also entering into the field to provide services.

System Integrators (SI) are going to have increasing influence in smart grid investment decisions. Two basic models in which utilities are engaging system integrators can be distinguished:

- Bundling AMI and System Integration contract together and selecting a consortium led by a SI as a prime.
- Separation of SI role. In this model, the AMI will play a key role in helping the utility determine the rest of its smart grid deployment plan.

The following figure illustrates these two models:

Figure 20 System Integrators Engaging by Utilities

By helping to define key areas of functionality in the business cases, assisting with vendor selection, and driving pilot design as well as deployment, SIs are positioned to step beyond the traditional integration role into the downstream aspects of utility smart-grid decisions.

As the integration process requires an increasing reliance on SIs, there is a great opportunity for a big revenue stream for them. This can be explained by a fact that winning a smart grid partnership deal potentially locks in multiple years of support and integration.

But before the SI is engaged, utilities need to scope out the role of systems integration with great care. They also need to ensure that they have established a view of the IT budget for systems integration to support smart grid activities [27].

3.3.2 Energy Management

Demand Side Management (DSM) is a set of algorithms by which power utilities manage the energy and load profile. Currently, power utilities are using algorithm that based on load shedding and/or price modeling [30]. However, it is important that new regulations and policies would be introduced upon the implementation of Smart Grid infrastructure. Unbalanced load distribution from the main feeder and non-linearity of the connected loads are among the conditions where the new DSM strategies can shield the power network from transient effects and dynamic instability.

A new smart DSM strategy can include shedding off loads that have a higher value of Total Harmonic Distortion (THD) from the power system. This will reduce the value of reactance (X). As a consequence, the Micro Smart Grids where the DSM will have Advanced Metering Infrastructure, local controllers, and sensors, would have a possibility to reform the load shaping policies that can result in more net flow of real power. This, in its turn will result in an increased power factor (PF) to a value closer to "1".

The Demand Side Management projects which involve self healing and self optimizing capabilities of Micro Smart Grids can minimize reactance (X) for output by reducing the loads with high THD_i.

Synchronous Vector Processor (SVP) is another active processing device which can be used for the implementation of smart DSM strategies. The processor has the ability to *"measure phase shifts on each phase, for the implementation of stability margins, SVP can measure angle between transmission buses and distribution buses, and therefore adjusting the load scalability"* [31] to suit the smart DSM model.

3.4 Regulation Challenges

3.4.1 Interoperability

Deploying distributed intelligence, two-way digital communications, and decision software will quickly reveal that they are not interoperable. Brand A may not always work with Brand B. In fact, Brand A may not be even compatible with Brand A. How are utilities and customers going to be able to monitor and control successfully in real time if all the systems don't operate seamlessly?

Utilities take different approaches to solve this problem:

- "One Stop, One Shop" policy. Obtain a complete, turn-key solution from a single vendor. Unfortunately, this means that the utility will have to sacrifice some Smart Grid functions and features in order to sustain interoperability. This means accepting less than the best in some parts of the system that are available depending upon the competencies and capabilities of the vendor. Moreover, this may get even worse when three basic categories are mixed. For example, it is very unlikely that the best SCADA vendor is going to have an equally great CIS. Or that an acceptable telecommunications network provider will offer CIS or SCADA.
- Vendor to Vendor Cooperation. There are two ways of achieving this for utility. One way is to buy only from vendors that have already demonstrated integration with other vendors. Another way is to require vendors to agree to integrate their systems in order to be selected. The last way can cause some extra expenses and time delays.
- Industry Standards. This comes from the vendor cooperation. Only those vendors who are willing to cooperate are going to survive in the new market. TCP/IP protocol can be taken as an example of this. If you want to communicate over the Internet, you must use this protocol. However, it is really

difficult to achieve industry standards in an emerging market. This can be explained by the following factors:

- Everyone hopes to take over the market immediately and therefore has no interest in being easy to integrate
- Most of the market participants are start-ups with limited capital. They might not have enough resources to create a new industry standard before launching a product.

- System Integrators. Retain one or more experts to create the necessary interfaces between and among the various vendors. This can be helpful, but it can also be extremely expensive and time consuming.
- Service Oriented Architecture (SOA). This is the ultimate system integration. It involves a universal web-service based data bus architecture that allows dynamic data exchange with each vendor independently. Unfortunately, this is hard to realize in real life as it depends upon the vendors' co-operation in integrating with SOA and continuous development and maintenance of SOA, in order to implement new features and functionality. One possible solution for this is MultiSpeak. It is a standard-based web services oriented architecture, which has been developed by Cooperative Research Network company. It is a voluntary data exchange standard that competes with other commercial standards [16].

3.4.2 Lack of Standards and Regulations

The Internet could not have arisen without HTML, Internet Protocol, and other open standards. Similarly, the Smart Grid needs consistent standards worldwide [32]. That is why certain steps towards standardization need to be made.

Here are some of the reasons why Smart Grid standards should be developed:

- Avoid re-inventing the wheel
- Easy requirements specification
- Ability to learn from industry best practices
- Reduced integration costs
- Prevention of single vendor "lock-in"

The Figure 21 shows the possible relations between utilities and vendors, users, and standards organizations. Concerted actions of those 3 groups will help to create better standard in a fast and efficient way.

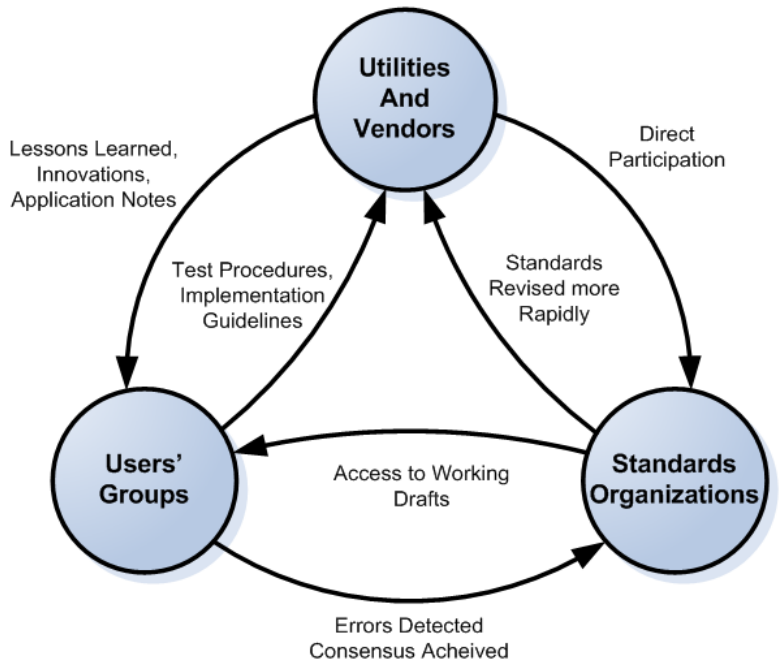

Figure 21 Making Standards Work

The IEEE has recently launched an initiative to develop smart grid standards and write operational guidelines for the power engineering, communications, and information technology areas.

When completed, IEEE P2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System and End-Use Applications and Loads will define key elements of the modernized grid and tap into IEEE's existing grid standards [33].

The above mentioned IEEE P2030 standard will focus on integrating energy technology with information and communications technologies. The standard aims to achieve seamless operation for electricity generation and delivery. In order to do this, the knowledge of grid architecture will be expanded to promote electric power systems that are more reliable and flexible. The IEEE Standards Association, along with other groups, is collaborating with the National Institute for Standards and Technology to create a document called '*Smart Grid Interoperability Standards Roadmap*'. The document will identify the short- and long-term plans for architecture development as well as associated standards and infrastructure development for the smart grid.

The P2030 standard will help the power system to work with end-user applications and devices, such as smart meters. Other efforts will include developing smart grid design strategies and operation guidelines.

New standardization projects are starting to take place in EU nowadays. For example, Open Public Extended Network Metering (OPEN) project. The main objective of the OPEN meter project is to specify a comprehensive set of open and public standards for AMI, supporting electricity, gas, water, and heat metering, based on the agreement of all the relevant stakeholders, and taking into account the real conditions of the utility networks so as to allow for full implementation [34].

IEC TC57 has created a family of international standards that can be used as part of the smart grid. These standards include IEC61850 which is an architecture for substation automation, and IEC 61970/61968 — the Common Information Model (CIM). The CIM provides for common semantics to be used for turning data into information [35]. The IEC61850 standard is used in the following areas of the Smart Grids:

- Substations: inside substation, substation to substations, substation to control center connections.
- Renewable Energy: Wind Power, Hydraulic
- Distributed Energy Sources

The EU has recently defined Mandate M/441 for all activities promoting AMM standardization. The general objective of the mandate is to ensure European standards that will enable interoperability of utility meters (water, gas, electricity, heat), which can then improve the means by which customers' awareness of actual consumption can be raised in order to allow timely adaptation to their demands [36]. The following figure represents M/441 connection with other standards:

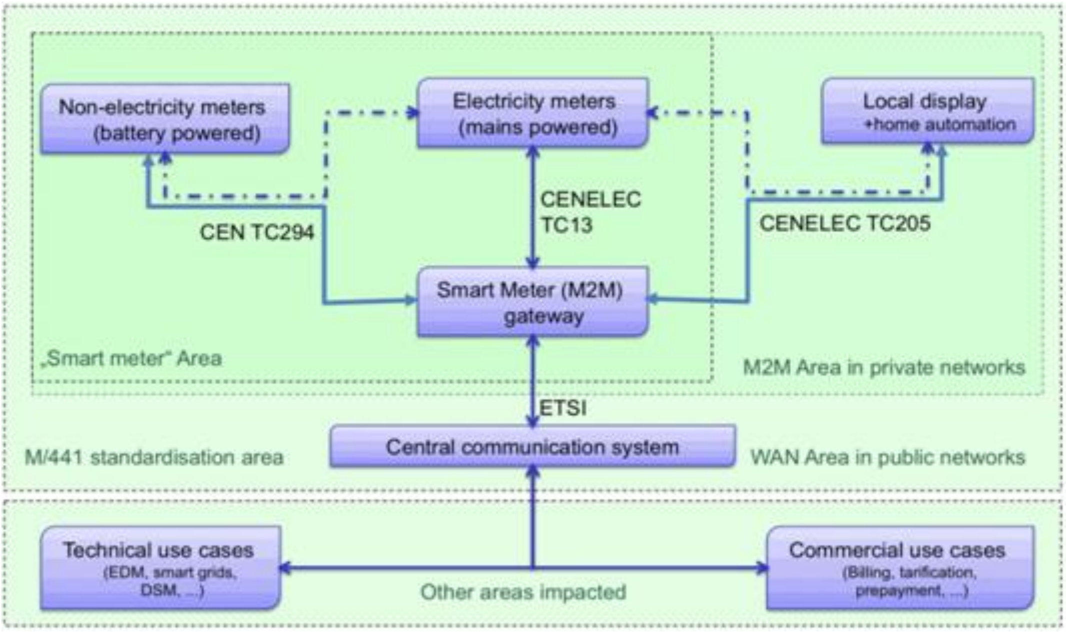

Figure 22 EU – mandate M/441with connection to other standards

Here is an overview of standards available for Smart Grids:

Table 4 Overview of Smart Grid Standards [37]

Essential standards	**Promising Standards**	**Needed Standards**
IP-based networks	WiMAX	Standard Field LANs
IEC 61970 CIM/GID	ZigBee / HomePlug	Modems for Field LANs
IEC 61968 Distribution	OpenADR	More field bandwidth!
IEC 61850 Substations	6LowPAN	CIM Design Framework
IEC 62351 Security	BACNet	CIM Application Security
DNP3	OPC/UA	CIM/61850 Harmonization
ANSI C12.19, C12.22	NERC CIPs	IEC 61850 Outside Sub
AMI-SEC		ANSI C12 Guidelines
OpenHAN		AMI-SEC
		Asset Management, DER, PHEV

4. Aggregator Business Model

Most domestic energy use, most of the time, is invisible to user. Most people have only a vague idea of how much energy they are using for different purposes and what sort of difference they could make by changing day-to-day behavior or investing in efficiency measures. The Aggregator's purpose is to make energy more visible and more amendable to understanding and control.

Demand response is an important part of future Smart Grid platform. It is thought, that it can be activated more easily with the help of an intermediary company. This company is usually called *the aggregator*. The aggregator can be responsible for the following aspects:

- Grouping customers and participating in the wholesale market to get the lowest possible prices
- Planning the use of the Distributed Generators when the associated cost is lower than the market prices
- Shifting and managing the movable loads of the customers to hours with a low electricity price

As the name suggests, the aggregator groups small-scale customer services into larger bundles and then sells them to grid companies. Simply speaking, the aggregator empowers the consumers to manage their energy use and save money without sacrificing their comfort and lifestyle. However, the relationship with end-users and other electricity market participants can take different forms.

4.1 Demand Aggregation

Based on the main purposes of DR, two mains types of aggregators can be defined:

- demand aggregators
- generation aggregators

The first type of aggregators collects demand response from different types of customers and offers the aggregated DR to different market players. Although, it can also include the generation at customer's premises (i.e. utilization of energy storage resources for DR). The second type of aggregators collects and utilizes dispersed generators and offers that to the market. This type of aggregated generation is called

Virtual Power Plant (VPP). However, a combination of these two types of aggregators can exist.

4.2 Background

Energy management and advanced metering systems open new opportunities for demand side initiatives in the electricity business. Smart Grids will require more active participation of the demand side management in power systems. Here are a few reasons for this:

- Difficulties in building new power lines
- Growing popularity of renewable energy resources
- Greenhouse gases emissions concerns
- Demand-side regulation can be more profitable than increasing of generation capacity

To fully understand the areas of business of aggregator, it is important to define what Demand Response (DR) is.

DR is ability to manage customer consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times [38].

The usual reaction time of a customer should not exceed a few days. The term 'load profiling' can also be used when referring to an event in which the load has been controlled, thus creating demand response.

In this chapter, a business model for aggregator will be discussed. The relationship between various electricity market players will be reviewed.

Currently, there are a number of various research projects going on in EU regarding the possibility and profitability of exposing electricity consumers to the needs of the power system. Some of these research projects mention the business opportunities for an aggregator company.

EU-DEEP (Distributed EnErgy Partnership) R&D project took place during 2004-2009. This European project aimed to produce business solutions for improved DER deployment in EU-countries. Other action-points included:

- Rules and recommendations for regulators and policy makers
- 3 proposed business cased for bringing DER to the market
- Specifications and equipment for connection DER units to existing grids
- Business options for supporting DER integration
- Effect on electricity markets and utilities from the DER penetration

The Figure 23 shows the money flow between the aggregator, his customers, and buyers of aggregated services. The idea of this model is to balance intermittent generation with the use of DER. Besides balancing, the resources can also be used on the spot market and offered as reserves to TSO.

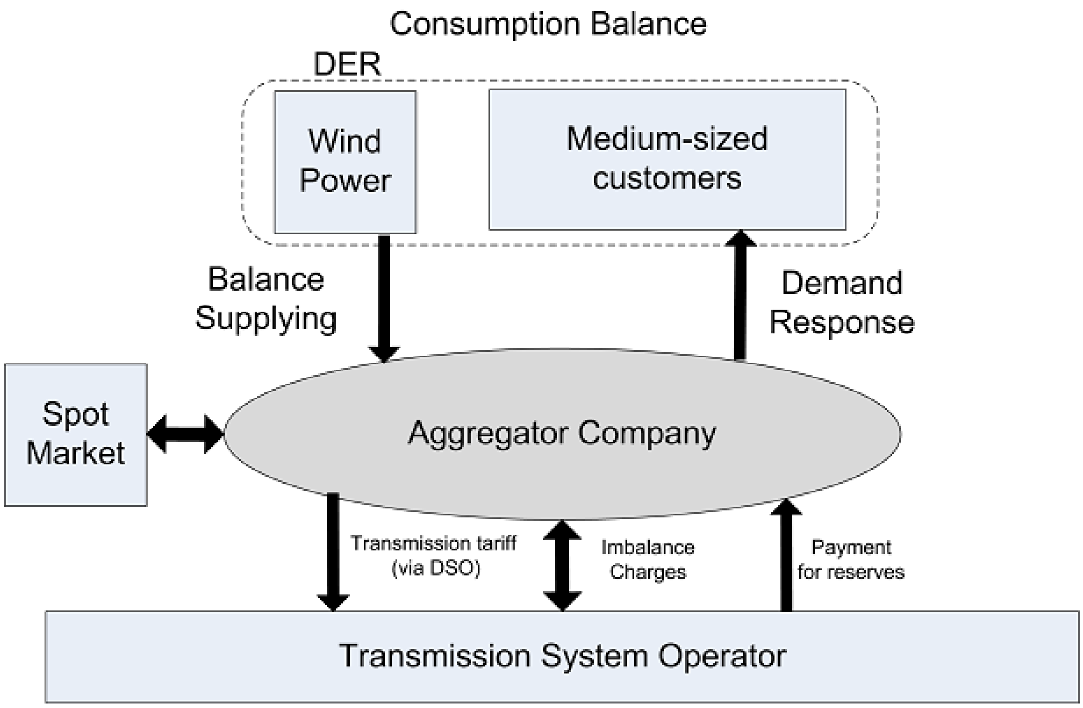

Figure 23 Money Flows according to EU-DEEP business model 1 [39]

ADDRESS ("Active distribution networks with full integration of demand and distributed energy resources") is a research project led by European Commission in the Energy area. It aims to enable the "active demand" in Smart Grid platform. That means increasing initiative for participation of small and commercial consumers for providing demand response to different power system participants. According to ADDRESS project, the aggregator communicates with consumers via "energy boxes", which perform load control and measurement. The following figure represents the approximate communication scheme:

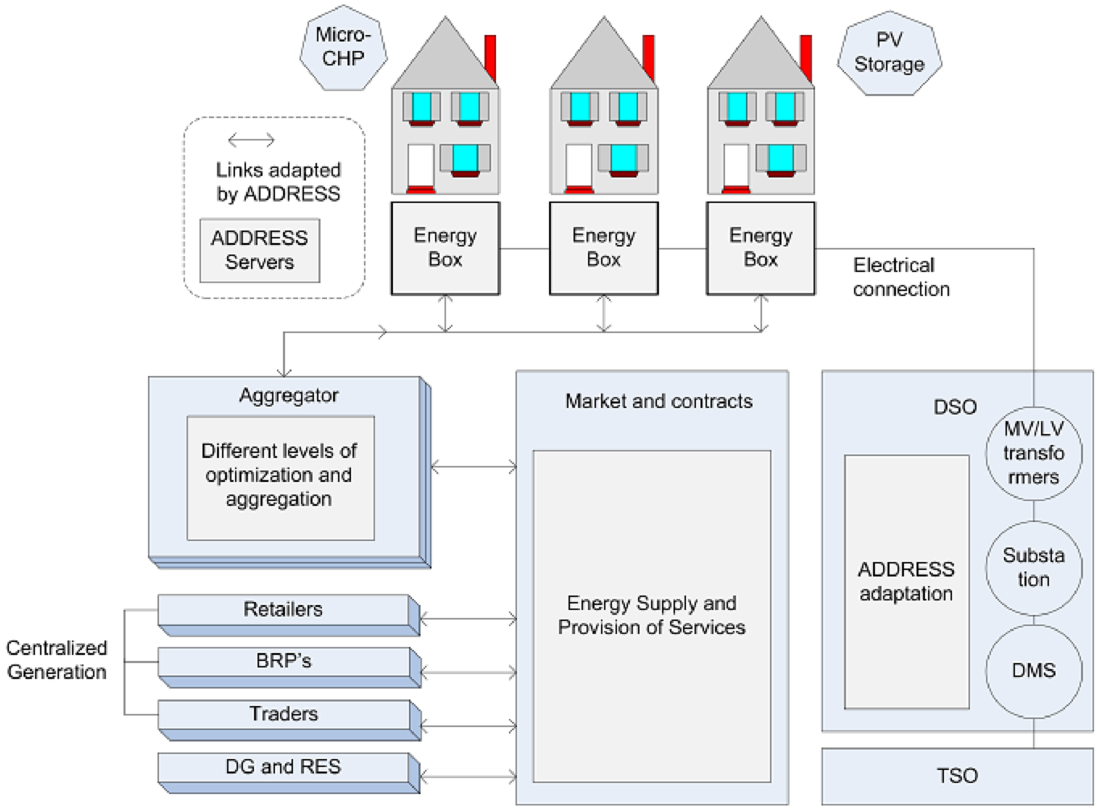

Figure 24 ADDRESS communication scheme

FENIX (Flexible Electricity Networks to Integrate the Expected energy evolution) is another European research project. Its central topic is distributed generation. However, a lot of similar ideas and approaches can be useful in connection with demand response. FENIX has proposed a concept of virtual power plant (VPP). VPP is a portfolio of distributed energy resources that can be operated as a single entity.

4.3 Justification of Aggregator Existence

The task of empowering electricity consumers by giving them financial rewards for changing their consumption requires new business models. The main purpose of the aggregator is to expose customer to electricity markets in an efficient way.

4.3.1. Enabling Customer Exposure to Electricity Market

Recent studies have shown that there exists a significant amount of potential demand response in small and medium-scale customers' area but so far it remains untapped. Most retail price rates slowly change and are not very useful in exhorting the customers to help the system. The aggregator company's task is to enable demand response of its customers and bring it to the wholesale market. This task requires that aggregator does the following procedures:

- Advertisement of demand response services to potential customers
- Initial study of whether customer's demand response provision can be profitable
- Installation of control and communication devices at customer's premises
- Paying premium to the customers for provision of demand response

Before getting into the business, the aggregator company needs to conduct a study in the area about different types of users and their potential for providing DR. Also, it is important to study the magnitude and cost of DR that different equipment can provide. Additionally, the aggregator must study how much would DR response affect the comfort of customers' life and determine the amount of premium that the customers require.

It would be difficult for a customer to evaluate the profitability of providing DR, especially if the customer is a small company or even a household. Therefore, the aggregator must take this responsibility on itself and accept only profitable customers. The methodology for the evaluation can be developed by an aggregator. Alternatively, a customer can hire a 3rd party company to do it. The evaluation process should include the studies on the appliances/equipment that can participate in demand response as well as the possible offset schedule research.

During the first stages of entering the market, the aggregator should advertise his services to public. The information must be given in easy-to-understand way, so that the adoption of such business would become more popular. Later, when the competition among aggregators rolls out, they will try to distinguish themselves from others by providing better offers or focusing on a certain customer group.

4.4 Aggregator Behavior

The aggregator can offer DER to the disposal of other power system participants. This can be achieved via one-on-one basis by bilateral contracts or through organized markets by submitting offers to these markets.

The reaction on the requests must take place via ex-post system (afterwards). Although, a decent forecasting system will help to react on such requests, as well as prepare for them. The aggregator should collect different requests for demand respond and evaluate his resources and contractual position. Next, he needs to calculate an appropriate respond to a request by load control. The aggregator can take advantage of economies of scale in controlling a large group of customers. Moreover, the development of optimization software for load support will increase the profitability of load control decisions for aggregator.

The aggregator can also provide additional services for DSO's, such as sending planned schedules for controlling the load. That would prevent the network from fluctuation caused by load controlling. The DSO can validate the power quality constraints and send the result back to the aggregator for execution. Services like frequency control or voltage control can add up to total revenue earned by an aggregator.

4.5 Aggregator Types

When talking about aggregator types, it is important to distinguish *who* can be an aggregator. There are a few possibilities. One alternative is that an aggregator will be a new company, which concentrates on the aggregation activities only. Another alternative is an existing market participant who already has relations with customers (retailer). Both variants imply different business models. In case a retailer takes up a role of an aggregator, such model can be named aggregator-retailer. This model eliminates balance calculation procedure as customer's demand aggregator is his retailer at the same time. Any changes to customer consumption are automatically included in the retailer's balance account. However, if the aggregator is *not* a retailer, such balance arrangements must be done. Therefore, such model is possible only when the aggregator has relationship with retailers to which it reports its balance.

The figure below provides comparison of different business models for aggregator:

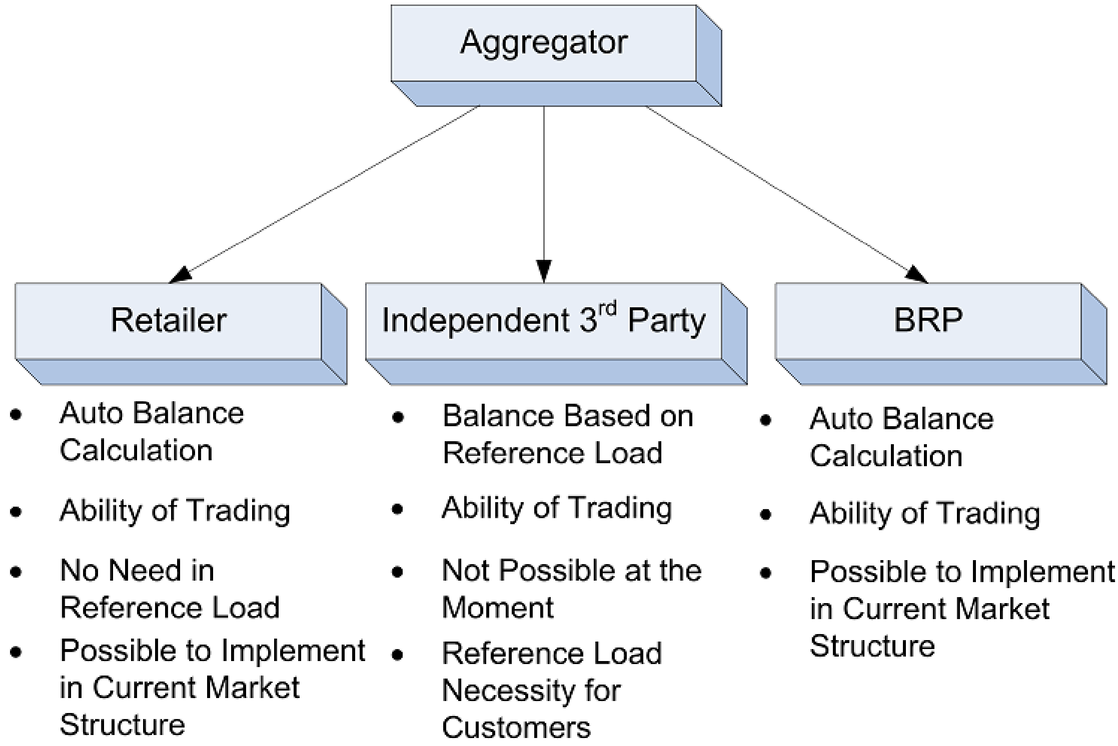

Figure 25 Aggregator Business Models and Characteristics

4.6 Types of Customers for Aggregators

Most certainly, the aggregator company will have to specialize on a certain type of customers, as the technologies for controlling loads differ greatly. The following customer types are usually distinguished: households, commercial customers, and industrial customers (small/large). Commercial customers may include: supermarkets and shopping centers, educational establishments, offices, hotels, hospitals, etc.

Small and medium enterprises can also be a customer for an aggregator company. Although, controlling the loads of various enterprises is a great challenge for an aggregator as they vary widely. Agriculture can also be viewed as a potential customer as greenhouses consume a great amount of electricity by using a lot of lighting lamps.

Additionally, distributed generation resources can be contracted by an aggregator. Nowadays, the only profitable small-scale energy storages are heat storages. They can be combined with CHP for increased flexibility of operation.

4.6.1 Relationship between Aggregator and Electricity Consumers

Electricity consumers play a role of *suppliers* for an aggregator as they provide controllable loads for it. The buyers of demand response, TSO's and DSO's, play a role of *customers* from the aggregator's point of view.

Joining a DR program will bring a consumer a relatively small benefit, when compared to his total electricity bill. Load controlling will sacrifice consumer's comfort standard. As, for example, he may need to cook his dinner later than usual in order to avoid peak-hour tariffs. Therefore, it is important to allow consumer not to respond to aggregator signals.

If an aggregator will act as a retailer as it was previously proposed in the possible business models, one important issue arises: a customer in Finland has a right to choose a retailer. Therefore, if a customer decides to change a retailer, the aggregator-retailer will then lose money for the installation and dismantling of the control devices.

It should be noted that aggregator-customer relationship can take different forms. The aggregator can pay part of the profit that it receives from selling customer's energy resources to the market back to the customer. The amount of money that a customer receives must be big enough to attract customers to participate in the load controlling program and keep him satisfied, so that it does not wish to terminate a contract with an aggregator. The amount of money paid to the customer must be calculated in a clear and easy way. This should be done for cases when a customer thinks that he received too little money. An aggregator must be able to justify that the premium for providing the load is correct. To promote himself, an aggregator can advertise its program and give an approximate amount of premium that a certain type of customer can receive by participating in load regulation. The possible ways of communication between the customer and the aggregator is shown in the Figure 26:

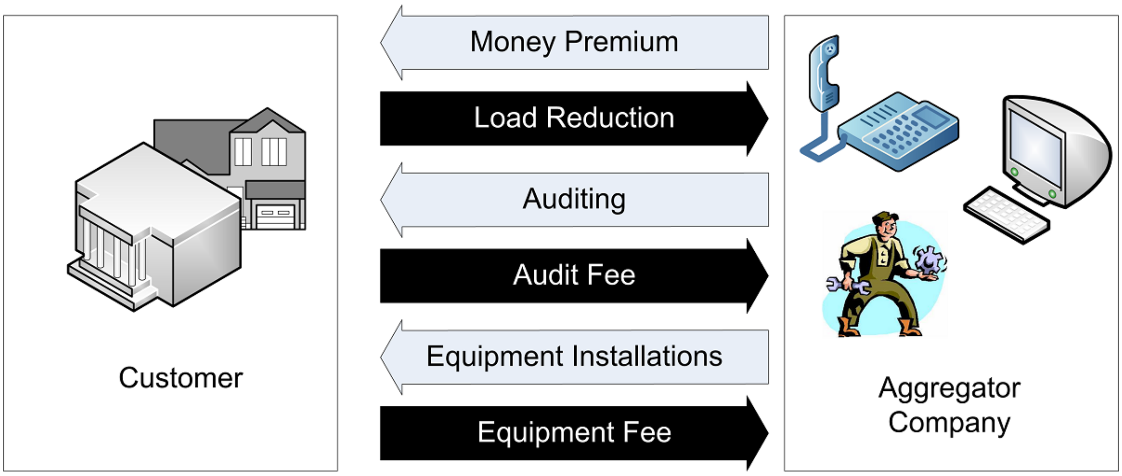

Figure 26 Relationship between aggregator and customer

In this relationship a lot of different fees can be created to gain profit for both aggregator and customer. An availability fee can be paid to customers who make a contract with the aggregator and enable load control. This fee can then be opposed with penalty payments for failing to comply with aggregator's control signals. Equipment fees can also increase profit of the aggregator. If a customer has a DER resource, he can receive from the aggregator an agreed percentage of a profit from selling the electricity on the market. A combination of different payment schemes can be used to achieve a suitable risk incentive level.

As an alternative to monetary relationship between a customer and aggregator, the customer can receive extra services in exchange on load regulation. These services may include real-time measurements and monitoring, which can help to save energy. The services can be provided online, through an aggregator web-site or via specific software.

Here are some factors that influence the relationship between customer and aggregator:

- Legal status of the customer (individual/company)
- Customer's risk aversion
- Customer's level of expertise
- Type of appliances / generators of the customer
- Existing automation at customer's premises

Here are possible ways of sharing benefits between an aggregator and a customer:

Table 5 Ways of Sharing Benefits

	Alternative 1	Alternative 2	Alternative 3
Investment funding	aggregator	aggregator	both
Availability premium	+	+	-
Penalty payment	-	+	+
Call payment	-	+	-
Profit sharing	Aggregator keeps profit	Aggregator keeps profit	Shared profit
Profitability for Aggregator	Low	Medium	Medium
Profitability for customer	Low	Medium	Medium

Investment Funding – is investments in the load controlling equipment and its maintenance/installation.

Availability Premium – is the premium that an aggregator pays to the customer for providing equipment that can be utilized in load controlling procedure.

Penalty Payment – is a fine that a customer pays to an aggregator for not being able to participate in load control requested by an aggregator.

Call Payment – is a premium that an aggregator pays to a customer for an opportunity to make calls (e.g. asking for participating in load profiling) a certain amount of times during an agreed period.

There are different ways to control the customers' resources in order to obtain DR. However, all of them fall into two categories:

- Direct Load Control

  In direct load control the aggregator can remotely control customer's appliances consumption. The control can take place either automatically or via prior notification of the customer.

- Price-based Control

> In price-based control customer adjust their consumption level in response to tariff changes. The tariffs can change either at specific periods of time (i.e. every several hours) or on a real-time basis.

In price-based control DR the so-called *banded real-time pricing* can be used. Different power zones exist in this pricing scheme. These zones adjust to a certain level dynamically. A certain electricity tariff corresponds to each power zone. For example, a customer may have a fixed price for his historically average profile, but any difference will be charged according to real-time rate. This is called incremental real-time pricing and represented on the following figure:

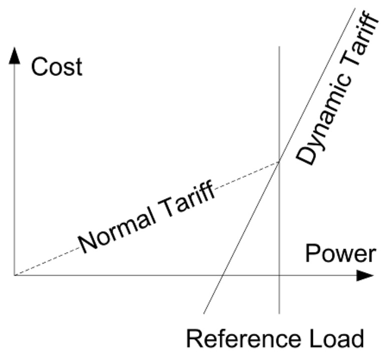

Figure 27 Incremented Real-time Pricing

However, such real-time pricing schemes can increase the customer's electricity bill due to high price volatility. For the small and medium-sized industrial customers this problem can be eliminated through the use of simple forward purchase contracts that hedge price risk for a fixed quantity of power.

Whatever pricing system is used, it is important to ensure that a customer has the possibility to override load control operation. If there is no such possibility, the customers will be doubtful about participating in DR programs by aggregator as it will affect their living comfort.

4.6.2 Possible Value Exchanges between Aggregator and Customer

Value Exchange #1

If an aggregator is a retailer, it sells the electricity to the retail customer. The electricity bill is formed by three items: the electricity retail fee, the electricity tax and the Value Added Tax (VAT).

The Electricity retail fee should include the cost of electricity for the Aggregator and his profit. The cost of electricity for the Aggregator includes purchases in the market and purchases of the distributed generation. Purchases in the market are charged with overprice, while DG electricity and T&D costs are only charged at cost price.

- Electricity retail fee = T&D cost (including taxes) + DG electricity cost + (market electricity cost * (1+Overprice of retail)).

Value Exchange #2

The Aggregator offers the best consumption pattern for the retail customer and receives scheduling fee in return. Scheduling fee is a monthly based fixed fee charged by the VAT. In this value exchange an aggregator only provides information about the prices and forecasts. The final decision is given to the customer:

- Scheduling fee = Scheduling price * 12 * Number of Retail customers
- VAT

Scheduling price can be 1€/month.

Value Exchange #3

The Aggregator offers consumption control to the Retail Customer and demands control fee in return. Control fee is a monthly based fixed fee charged by the VAT. In this case an aggregator can control customers' loads by itself or via phone call requests:

- Control fee = Control price * 12 * Number of Retail customers
- VAT

Control price can be 1€/month.

4.7 Means of Interaction between Customer and Aggregator

Interaction between a customer and aggregator is basically an information exchange. It can be implemented in different ways. The information exchange can take either by telephone or via "energy boxes" as it has been proposed by the ADDRESS project described earlier. The aggregator can communicate with the customer's appliances through a home area network of the building. He can also install own automation system. But in this alternative a link to the smart meters (a property of DSO) should be considered. The aggregator should also be able to assure the DSO that he will not interfere in the metering process.

The following table contains a list of possible interaction signals between the customer and aggregator:

Table 6 Possible Interaction Signals between Aggregator and Customer

Direction	Signal	Description
Aggregator → Customer	*Simple Tariff*	The price for each kW during a certain time period (i.e. 1 hour).
Aggregator → Customer	*Banded Tariff*	The price for each kW within a certain consumption power band during a certain time period.
Aggregator → Customer	*Flexible price*	The price for each kW reduced below a certain reference load during a time period (i.e. 1 hour).
Aggregator → Customer	*Temperature Control*	Controlling of the temperature level of an appliance (i.e. heating system or boiler).
Customer → Aggregator	*Do Not Disturb*	This signal can be sent if the customer do not want to be disturbed and wants some extra kW's of energy.
Customer → Aggregator	*Consumption Forecast*	Forecast of individual consumer's total

		consumption for a certain time period in future.
Aggregator → Customer	*Power Control*	Aggregator directly controls the power of an appliance.

4.7.2 Customer Remuneration Settlement

After a certain time period (e.g. monthly) or in the after the control event takes place, the aggregator verifies delivered services and calculates required payments related to load control. The settlement of delivered services is based on consumption measurements, control signals, received by a customer and a contract between the customer and aggregator as it is shown in the following figure:

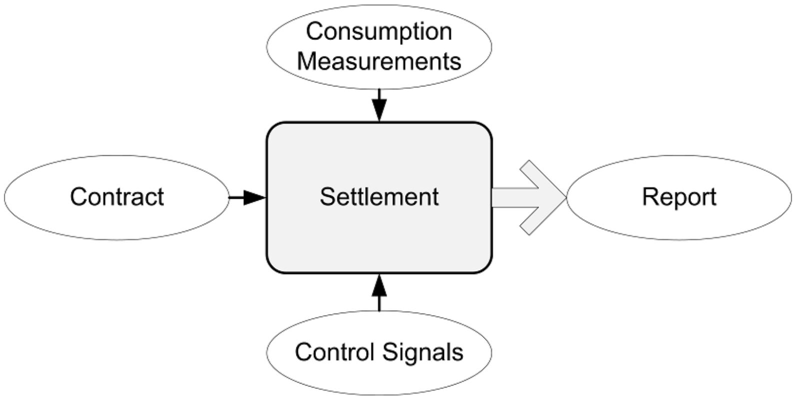

Figure 28 Remuneration Settlement and Reporting

4.8 Aggregator and Other Market Players

The aggregator should have contracts with BRPs, or if he is a balance responsible party himself, with the TSO. The aggregator company can participate in wholesale power markets (Nordpool). It can also have bilateral contracts with generation companies and retailers. If the aggregator company is not DSO itself, then relations with it should also be considered, as the DSO provides electrical connection of the aggregator's customers. The possible information and monetary links between the aggregator and other market players are shown in the following figure:

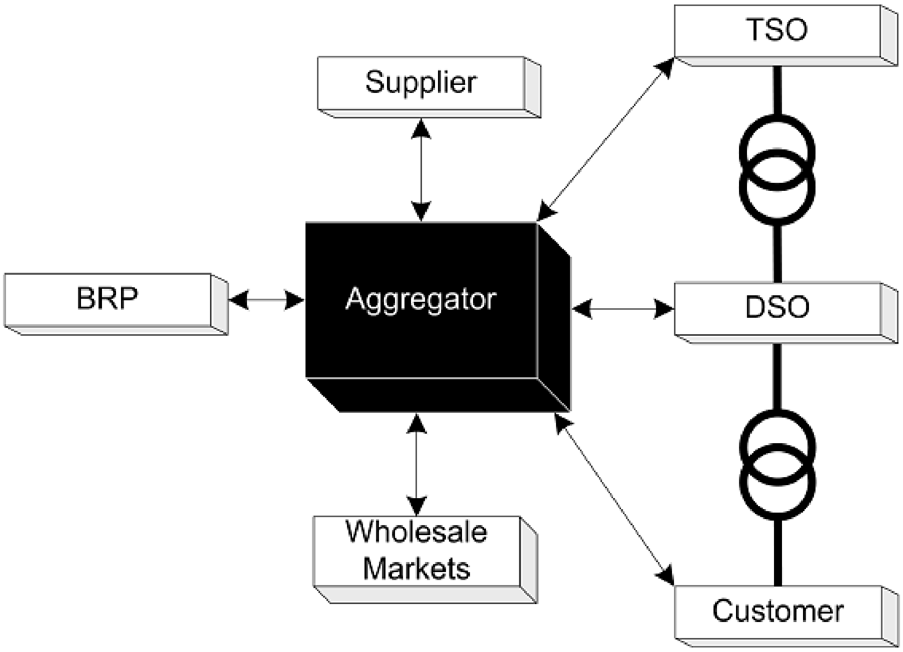

Figure 29 Information Exchange and Monetary Links between Aggregator and Other Market Participants

The following figure represents some activities between various market players and shows the possible place of an aggregator company in the electricity business value exchange model:

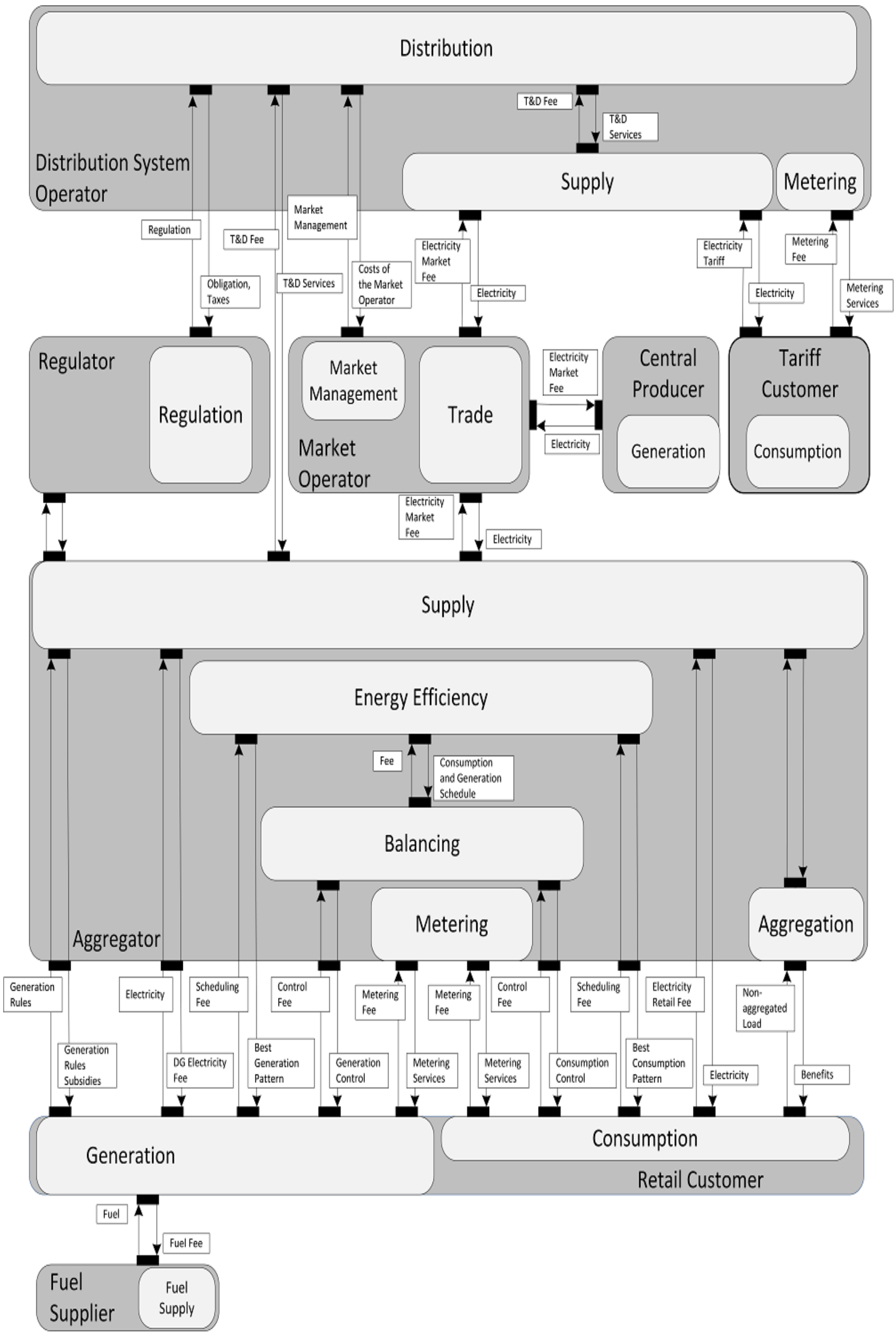

Figure 30 Market Players Activities with Aggregator Company

4.9 Relationship between Aggregator and Other Market Players

4.9.1 Relationship between Aggregator and Retailer

If an aggregator is a BRP that has customers' retailers in its balance portfolio, the load changes are automatically included into its consumption balance. The downside of it is that the load changes are also included into the consumption accounts of retailers (calculated internally by BRP). Therefore certain agreements must be made between retailer and BRP to avoid unearned benefits, caused by high imbalance prices, for the retailer.

Another possible relationship is an aggregator acting as an independent 3rd party company, which has made no agreements about income sharing or service provision with retailers. In this case, the aggregator's account will be directly credited by load reduction, caused by load regulation of its customers. Such business model is impossible in the current market laws. The retailer currently provides all energy, which the end-users consume. The introduction of this model would require changing this principle. This can be very challenging.

The EU-DEEP research project studied the business model in which the aggregator itself is a retailer. Therefore it aggregates the DER, which his customers offer. The advantage of this business model is that the change in customers' consumption is automatically included in the retailer's consumption balance. Hence, it is possible to trade the load reduction on wholesale markets.

In case an aggregator is a separate service company to the retailer, it has no position on the electricity market. Hence, it performs forecasting, optimization, load control, and scheduling functions and later on the effect of load control is given in the consumption balances for the retailer. In this case, the aggregator receives no direct income. However, it then gains profit by making a service contract with the retailer. The retailer in turn pays to the aggregator for the provision of the services mentioned above. This model's advantage over *aggregator-retailer* model is that the aggregator is not tied to a certain customer group by a contract. The downside of this is that it needs to sign a few contracts with retailers for the business to be profitable.

4.9.2 Relationship between Aggregator and DSO

DSO plays a role of a customer for an aggregated demand services. The DSO can solve some of its problems by utilizing DR, offered by an aggregator. Additionally, the DSO can use controllable DER resources to reduce the amount of expensive spinning reserves. Currently, the scale of DER is quite small, but future Smart Grids promise to increase it.

Operation of DR, DG, and energy storages affects the active and reactive power of the distribution network. This can lead to unwanted under-/overvoltage. In order to avoid this, the aggregator may have to validate the impact of introduction of its DR by presenting it to the DSO beforehand. Although, it's totally voluntary and actually the aggregator may want to charge DSO for such grid optimization services.

The aggregator can use its relationship with DSO for utilizing DSO's communication infrastructure for interaction with customers. Currently, each DSO has its own system of communication with smart meters. This imposes a possible compatibility issue. Introduction of standards of smart meter communication may solve this problem in future. Also, the DSO can set the price for using its communication system too high if he is not regulated and there is no competition in this area.

4.9.3 Relationship between Aggregator and TSO

The TSO can buy aggregated demand services from an aggregator company. Similarly to DSO-Aggregator relationship, the TSO may want to validate the load control actions prior to the regulation. This can be done through DSO's, which will collect all the validation requests, calculate the possible effects, and then forward suggested control actions to TSO. The TSO in turn will make his own calculations, taking into account transmission grid needs, and send back the possible changes to DSO's. Then the DSO's will update the requests and forward it to the aggregator.

4.10 Aggregator Business Processes and Optimization

There are quite a few business processes going on inside an aggregator company. One of the main process that should be done on a daily basis is buying load and generation control from its customers. However, other business activities such as buying and selling electricity on the market are closely connected to it. When combined, they make up the core business area of an aggregator.

The aggregator deals with power. It regulates it from one side (customers) and trades it on the electricity markets on the other side. In order for the business to be profitable for both aggregator and its customers, this process requires a lot of optimization. Some of optimization aspects are described in this section.

4.10.1 Trading Optimization and DER Scheduling

The signals that sent and received from the customer are used to control DER. These signals include power control signals and tariffs. The optimization of these signals is a complex task that requires mathematical optimization methods. The resulted model must comply with the rules of a certain electricity market (i.e. balance management). The optimization can be done through specific software that has all the necessary interfaces to the sources of input data, and the corresponding channels for the result output. The software must consider control signals for customers as well as offers for selling the load reduction on electricity markets or through bilateral contracts.

The following requirements can be applied to optimization software:

- *Consideration of different market segments in synergy with bilateral contracts*
  Different electricity market design exists in different countries. Therefore, creating unified software for optimization is a great challenge. Most probably it will be developed for specific aggregator and aimed at specific electricity markets. The same issue concerns balance mechanisms.
- *Consideration of various customer contracts*
  The software should be able to perform probabilistic forecasts for market and imbalance prices. This is also quite challenging, as such algorithms might be difficult to implement.
- Forecast span of at least a few days ahead
  This should be done due to implications of future price and load profiles on decisions made by aggregator according to its contracts. For example, the customer may not want to reduce their load too often. There are a lot of

variables involved in such calculations. Therefore it is a complicated task to do. Variables for customers may include: indoor temperature, time of the year, time of last control call, appliance type, etc.

- *Calculation based on customer groups*

  Considering every customer in the aggregator's portfolio individually may take forever. Therefore similar customers must be grouped together and treated similarly.

- *Time requirement*

  The speed of forecast calculation must be low enough to allow balance settlement. For example in Germany, the resolution of balance settlement is 15 minutes. Therefore, the software must provide a new set of control orders every 15 minutes.

- *Independency*

  The software should be able to provide approximate output results when working in offline mode, based on historical profiles. This secures the aggregator in case of connection link interruption between the software and information from smart meters.

4.10.2 Load Forecasting

Load forecasting is a vital component of aggregator's business. The aggregator should forecast the electricity consumption of its own customers, in case it is a retailer-aggregator. It should also forecast its own power balance.

The consumption can be forecasted within different time ranges. The most important one is short-term load forecasting. Its range is usually seven days. Not only this forecast is important for secure and economic operation of power system, but also it can be used for demand response aggregation, hydro-thermal coordination, and network status analysis.

Various mathematical methods can be used for load forecasting:

- Neural networks
- Time series models
- Linear regression models

Neural networks are machine learning tools. In this approach the user does not have to specify relationship between forecasted load and other variables. However, this method has some issues. It might be difficult to determine the best suited parameters for the neural network. Therefore, empirical determining of such parameters might be needed. This process can take a lot of time. Another issue is that a large amount of historic data (i.e. 1-2 years) is required for this method.

Time series forecasting is the use of a model to forecast future events based on known past events: to predict data points before they are measured. For example, it can be used for predicting the opening price of electricity price based on past information.

Linear regression models express load function as function of exogenous inputs (i.e. weather, holidays, etc.). However, forecasting nonlinear dependencies with linear model can be inaccurate and can create unnecessary errors in the results.

4.10.3 Distributed Generation Forecasting

The aggregator may have to forecast distributed generation (i.e. wind power, solar power, hydro power, and CHP) in order to forecast its own imbalance position or imbalance position of deregulated parties with whom it has made bilateral contracts. This forecast requires extensive information about DER generation portfolio.

Distributed generation forecasting is usually based on weather predictions to which mathematical methods described in *Load Forecasting* section are applied. Forecasting accuracy depends on the local weather variability. A typical forecast error is usually 5-15% of installed power.

4.10.4 Market Electricity Price Forecasting

Time series models and multiple regression methods are used for price forecasting on short-term electric power market. The artificial neural networks can also be used. The benefit of using neural networks is that the user does not have to set relationship between weather and price as the forecasting is mainly based on historic spot prices, power demand, wind speed, sun shine, and temperature.

4.10.5 Issues Connected with Forecasting

The usual business is that the aggregator company predicts customers' load reduction in response to control signals as a function of time. But the realized customers' load can differ from the forecast and therefore it has influence on the imbalance position of the aggregator. The penalties that a customer pays for possible deviations in load are usually not equal to the penalties that the aggregator company faces. Therefore such imbalance probabilities from the customer must be taken into account when making a balance for DSO.

4.11 Existing Aggregators

USA

Some of the largest demand-response aggregators in the USA are:

- EnerNOC Inc.,
- Comverge Inc.
- Energyconnect Inc.

Comverge has signed up hundreds of businesses and governments that have agreed to reduce their electricity demand within hours of notice. Collectively, these organizations can reliably lower their power consumption by 948 megawatts. That's approximately two natural gas-fired plants that don't have to be built [40].

Similarly, EnerNOC has 796 megawatts of load reducing capabilities under contract. And investors are taking notice of this business models. EnerNOC customers include a wide range of classes from large industrials to high-tech facilities to grocery stores to state and local governments (e.g. Adobe, AT&T, Pfizer, the State of California's UC and CSU systems, General Electric, Raleys, Whole Foods, Xerox, the State of Connecticut, and Sheraton, Hilton, and Marriott hotels). The backbone of EnerNOC's success is the network operations center (NOC), which automates demand response via non-proprietary, open communications protocols and technologies. This automation provides benefits to demand response program administrators (ISOs, utilities). It enables fast and reliable response and real-time performance and results. The NOC also provides benefits to end-customers who, on their own, might not be willing or able to participate in demand response programs because they either (a) do not know how to participate or (b) do not have the in-house staff capability to do so effectively.

Both Comverge and EnerNOC had successful initial public offerings in 2007 [41]. Comverge's stocks, which were listed in April at $18, had doubled by early July. According to a recent research by these aggregator companies, establishments such as schools, hospitals, shopping malls, and office buildings are ideal candidates for demand response programs.

Telecommunications companies, such as Bell and Rogers, can also consider getting into the aggregator business – their broadband networks can be used to automate and execute reduction in electricity use.

4.12 Example of Justification of Aggregator's Existence

Let's imagine an electricity system of a small city. Usually the electricity demand for it does not surpass 25000 megawatts. The electricity procurement takes place during 8760 hours (1 year). Among those 8760 hours, the peak electricity demand surpasses 25000 megawatts for a period of 32 hours. It can be as high as 27000 megawatts.

Natural gas plant capital costs are estimated at 700-800 €/kW [42]. The peak electricity demand surpasses the existing capacity by 2000 MW. That results in approximately $(700 \cdot 1000)\ € / \mathrm{MW} \cdot 2000\ \mathrm{MW} = 1.4\ \text{billion}\ €$ of investments.

Taking into account the facts, stated in the previous paragraphs, we have two alternatives:

- Invest 1.4 billion Euros in building and operating natural gas plants that can give an extra 2000 megawatts during 32 hours of the year.
- Spend considerably less to pay companies that have promised to reduce their electricity consumption by 2000 megawatts for those same 32 hours of the year.

The second alternative is cheaper, cleaner, and makes more sense. In this regard, the demand-response aggregators are going to play a pivotal role in the energy management of future Smart Grids.

4.13 Findings on the Business Analysis

According to the EU Project BusMod the estimated savings for the customers who participate in load shifting procedure can be as high as 15% [43]. These savings can be even higher considering that the aggregation market will develop over time and will work out more efficient way of operating its business. Customer savings via load shifting services dynamics are shown in Figure 31:

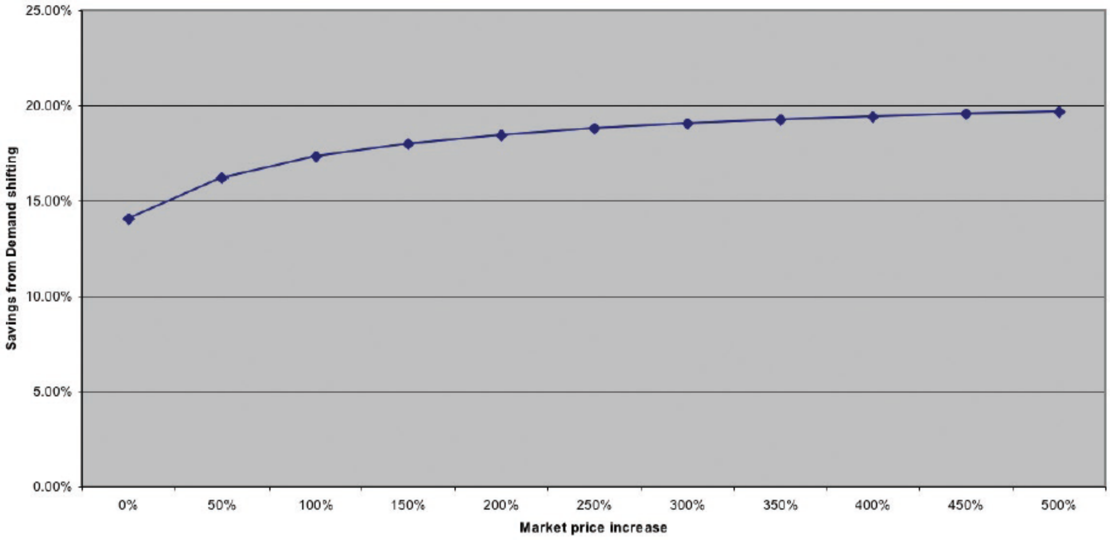

Figure 31 Customer savings via load shifting service

However, such reductions in electricity bill would not be enough for customer to pay for the planning, control, and metering services provided by an aggregator (e.g. the price can be as high as 1€ per month for each service). Therefore, an aggregator can lower or omit some fees to make the participation more attractive for the customer.

Load shifting should not be provided independently, but rather the revenue of an aggregator should be summed up from the combination of services, such as electricity supply, aggregation, scheduling and metering.

The use of distributed generation for covering own consumption during peak hours is not itself profitable for the customer due to the under-utilization of the equipment.

However, it may become profitable to sell the generated energy to the market or to the DSO in future.

4.14 Future Development

An open-architecture communication protocol might be required to standardize signals sent by aggregator to both trigger and terminate events. Creating a standard for what information must be exchanged between parties will allow the parties to determine the optimal hardware for load controlling, does not lock parties into one technology or vendor, and allows for technical innovation to drive down the costs of implementation. A demand response system which encourages both automated demand response technology and involvement by third party aggregators will result in efficient, low-cost load reductions that are going to be profitable for all stakeholders [44].

4.15 Potential of Load Control in Finland

The control of large industrial loads in Finland is either going to be introduced in the coming years or already in place. However, untapped business possibilities can be found in electricity consumption control of the various domestic appliances and household heating, as well as small-/medium-sized industry electricity consumption control.

The control potential of electrically heated detached houses is estimated to be in the range of 1-2 kW per household. The electricity consumption level during winter period is clearly higher than during summer period. Houses with good insulations and exhaust air heat recovery allow offsetting heating without significant inconveniences.

Electrical heating is also very responsive and quick to operate. However, controlling the load of usual houses with numerous household the load of which is often less than 1 kW might not seem profitable at the first sight, especially when compared with large industrial load control. But more thorough analysis shows that if managed, the combined effect of a large group of detached houses and small/medium-sized industry is quite profitable.

5. Demand Response Profitability Calculations

In this chapter, two business models are reviewed for feasibility:

- **Model 1:** Customers enrol to aggregator's DR program, buy and install automatic load controlling devices that receive real-time electricity price signals and shift the electricity consumptions according to the preset algorithm (e.g. 5 highest prices during the day are shifted to the cheapest hours).
- **Model 2**: Customers install automatic load controlling devices and subscribe to an aggregator's DR program with extra benefits, such as additional payments from aggregator for load shifting. This way, in addition to usual electricity bill savings gained from load controlling the customers will receive 30% of the revenue made by an aggregator from selling the peak-hour electricity (shifted from those customers) on the electricity market.

These models have been chosen as an example of consequential aggregator business development. First model can be accepted on the initial stages of aggregator introduction on the market. During this stage, an aggregator should try to educate customers about the importance and possible profitability of DR. It should also accumulate a large customer base. After gathering a certain amount of customers, allowing the aggregator to trade the controlled load on the electricity market, additional services and benefits can be introduced.

The following picture provides a visual representation of possible aggregator business development:

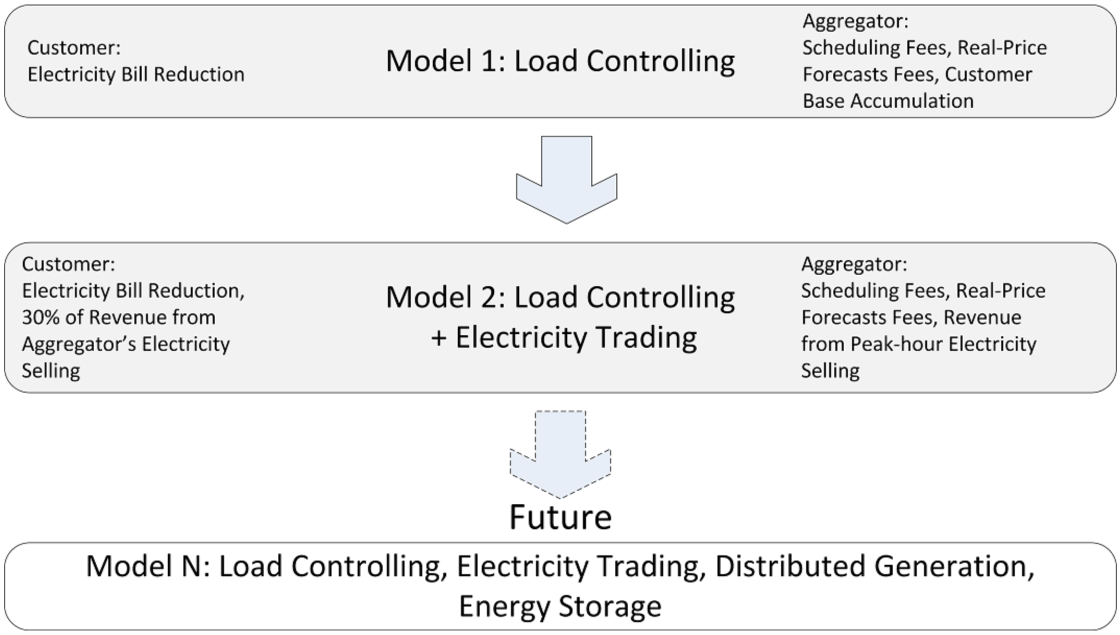

Figure 32 Aggregator Business Development

5.1 Assumptions

Historical data from the ELSPOT market (hourly area prices for the FI area from 2009 for 365 days) has been taken for feasibility calculation [45]. The following figure represents the development of the electricity price (€/MW) during the studied period:

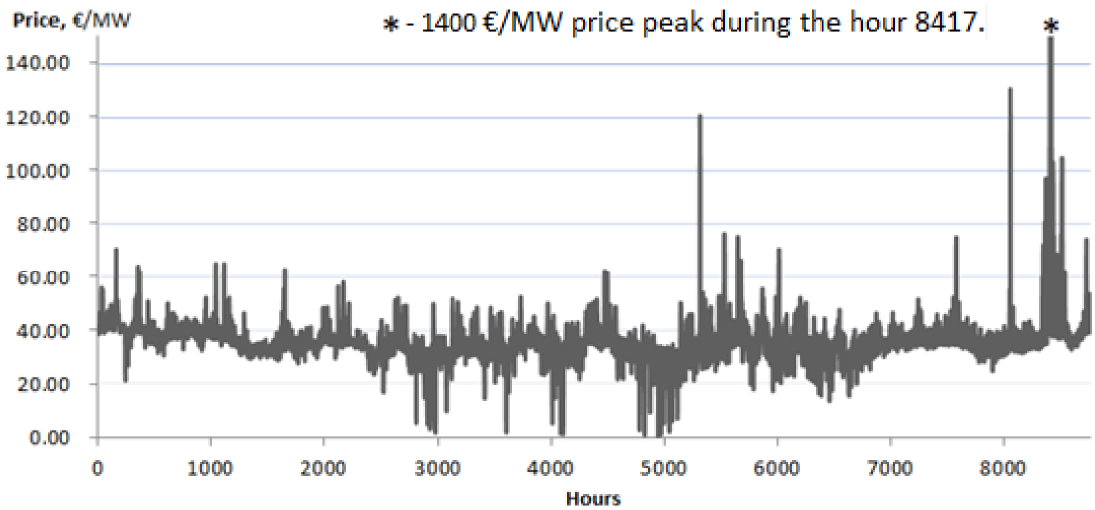

Figure 33 ELSPOT Price Development During Year 2009

Load curves for a typical Finnish detached house with room-specific electric heating and 300 liters boiler have been used in the calculations [46]. These load curves have been measured in 1992. Therefore, the load growth coefficient of 45% (based on load from 1992) has been applied to reflect consumption pattern of 2009 [47]. Formula (1) incorporates this coefficient for calculations:

$$P_{2009} = P_{1992} \cdot 1.45 \ \ (\mathrm{MW}) \qquad (1)$$

where:

P_{2009} – load level of year 2009 (MW)

P_{1992} – load level of year 1992 (MW)

Load curves contain seasonal consumption data for winter, spring, summer, and autumn. The graphical representation of load curves for each season with applied growth coefficient is presented on the figure below:

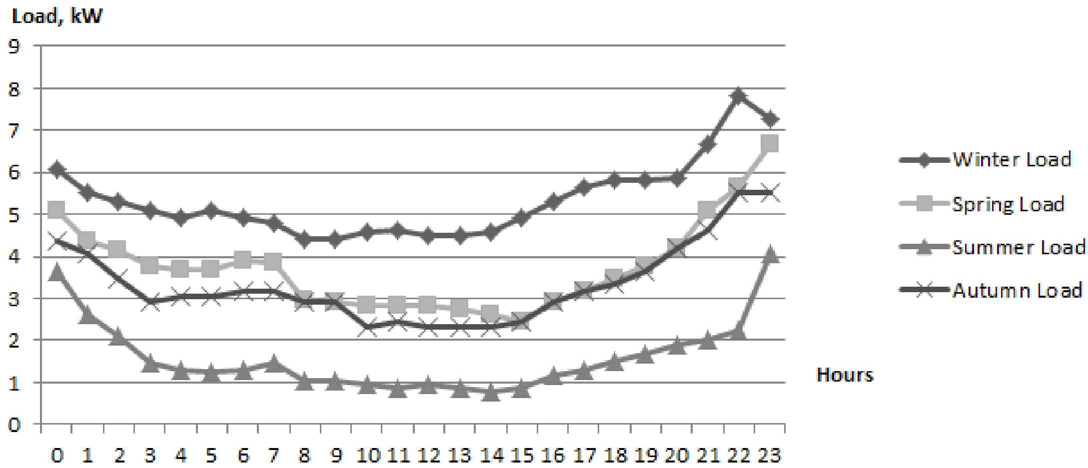

Figure 34 Load Curves for Detached Houses with Applied Growth Coefficient

The weekend (Saturday and Sunday) hourly load curves have been equalized to those for the workdays (Monday to Friday) for calculation simplicity. The load deviation error between a weekend and a workday is assumed to be low enough (5-10%) to not affect the final results significantly. See Appendix II for numerical load for individual hours.

Five most expensive hours (according to ELSPOT prices) have been selected and matched with appropriate demand for each day of the 2009 year. The peak price hours are considered to be shifted to three cheapest hours of the day by using load controlling equipment. It is assumed that the price forecast for the next day will be available for the customer either on the online web-portal or via installed smart meter display.

5.2 Calculation Methodology

For DR feasibility calculation, the load controlling equipment was assumed to have the following algorithm:

1) The devices receives hourly prices forecast for the next day from the aggregator
2) It automatically determines 5 most expensive hours of the day
3) The shiftable load from these five hours is then programmed to be offset to the cheapest 3 hours according to the following pattern:
   a. Let's assume that "**O**" (kW) is the shiftable amount of electricity. Therefore, we have "**5 * O**" (kW) of shiftable peak-price electricity available for a single day.
   b. During the 1st and 2nd cheapest hours "**2 * O**" (kW) of electricity is shifted, and "**O**" – during the 3rd hour.
4) The customer is then notified via in-home display or web-portal about the coming offsetting schedule

The DR feasibility calculation includes the following consideration:

- Savings from DR are calculated as a difference between prices of two behaviour principles: *usual behaviour* and *behaviour with installed load controlling equipment*. The prices in question include 5 most expensive and 3 cheapest hours of the day. This difference is calculated for each of the 365 days of the year 2009 with a corresponding price and load. Formula (2) represents these considerations:

Savings from Demand Response:

$$S_1 = \sum_{n=365} \left[(C_{usual.topN} + C_{usual.lowM}) - (C_{DR.topN} + C_{DR.low1} + C_{DR.low2} + C_{DR.low3}) \right] (€) \qquad (2)$$

Electricity trading feasibility calculation includes the following considerations:

- Aggregator submits electricity, offset during 5 most expensive hours (based on the forecast), as bids for the next day on the electricity market.
- The results from the electricity trading from each day of the year are summed up. Formula (3) represents these considerations.

- Aggregator receives revenue from trading
- Aggregator shares 30% of its revenue with the customer. Such settlement can take place every month.

ELSPOT Load Shifted Electricity Trade:

$$S_2 = \sum_{n=365} E_{topN} \cdot O \cdot A \, (€) \qquad (3)$$

where:

$A = 10\,000 \rightarrow$ Amount of Aggregator's Customers

5.2.1 Introducing Variables

The amount of shiftable load for a typical Finnish detached house is approximately 1-2 kW per customer [48] (see the *4.15 Potential of Load Control in Finland* chapter for more information on shiftable load potential). In order for this amount of electricity to match the electricity consumption pattern, the following assumptions have been made:

Table 7 Estimations of the Shifted Load

Time of the year	Amount of shiftable electricity
Winter	2 kW
Spring	1.5 kW
Summer	0.6 kW
Autumn	1.5 kW

The number of customers for calculations is considered to be **10 000**. The minimal amount of electricity customers for the ability to sell the shifted load on the electricity market is approximately 1700 customers (a minimum of 1 MW is traded on the ELSPOT). Also, the participation fee may need to be considered by an aggregator when entering the electricity market game.

The margin of the retail company (i.e. over-price of electricity) has not been considered in the calculations as it does not affect the difference between the prices (i.e. final results). This is so because the over-price of electricity is usually fixed. Therefore it can be neglected.

5.2.2 Other Formulas Used in Calculations

Prices for usual consumption behaviour:

$C_{usual.topN} = E_{topN} \cdot P_{topN}$ (€) (4)

$C_{usual.lowM} = E_{lowM} \cdot P_{lowM}$ (€) (5)

where:

N=1..5

M=1..3

$E_{topN} -$ 5 most expensive hour prices during the day (ELSPOT) (€ / MW)

$P_{topN} -$ load corresponding to the most expensive hours (MW)

$E_{lowM} -$ 3 cheapest hour prices during the day (ELSPOT) (€ / MW)

$P_{lowM} -$ load corresponding to the chepeast hours (MW)

Price for consumption behaviour with installed load controlling equipment:

$C_{DR.topN} = E_{topN} \cdot (P_{topN} - O)$ (€) (6)

$C_{DR.low1,2} = E_{lowM} \cdot (P_{lowM} + 2 \cdot O)$ (€) (7)

$C_{DR.low3} = E_{lowM} \cdot (P_{lowM} + O)$ (€) (8)

where:

N=1..5

M=1..3

$E_{topN} -$ 5 most expensive hour prices during the day (ELSPOT) (€ / MW)

$E_{lowM} -$ 3 cheapest hour prices during the day (ELSPOT) (€ / MW)

$P_{topN} -$ load corresponding to the most expensive hours (MW)

$P_{lowM} -$ load corresponding to the first two chepeast hours (MW)

$P_{low3} -$ load corresponding to the third chepeast hour (MW)

$O -$ shiftable load for a corresponding season (winter/spring/summer/autumn) (MW)

Profit of an Individual Customer from Electricity Trade:

$S_3 = S_2 \cdot 30\%$ (€) (9)

The electricity trade takes place on the same hour on ELSPOT market.

Combined Customer Savings (DR + Electricity Trade):

$$S_4 = S_2 + S_3 \text{ (€)} \qquad (10)$$

5.3 Calculation Results

5.3.1 Model 1 Results

The following table provides the results of the calculations for business model 1:

Table 8 Model 1 Results

Electricity Bill Reduction per Customer (S_1)**:**	37.17 € per annum

5.3.2 Model 2 Results

The following table provides the results of the calculations for business model 2:

Table 9 Model 2 Results

Electricity Bill Reduction per Customer (S_1)**:**	37.17 € per annum
Aggregator's Revenue from Trading Shifted Customer's Electricity (S_2)**:**	1 148 510 € per annum
Profit of an Individual Customer from Aggregator's Electricity Trading (S_3)**:**	34.46 € per annum
Combined Customer Savings (DR + Electricity Trading Share) (S_4)**:**	71.62 € per annum

See Appendix II for calculation examples.

5.4 Business Models Feasibility Conclusion

The savings from model 1 are approximately 3.2% of the annual customer bill (provided that the customer is charged by a real-time tariff, the annual electricity bill is approximately 1149€). Model 2 savings are 6.2% when compared to the annual electricity bill.

While 37.17 € may seem like a good electricity bill reduction at first sight, it should be noted that the smart meter and its installation will cost on average 240€ for a typical house. This cost does not include the price of individual load controlling devices which are required for each appliance to automatically switching on/off according to received signals.

Advanced meters will be obligatory for all Finnish households in the near future. There will be a regulation model that would allow customers to pay back for the meters over a 5-10 years period (e.g. 24 € per annum). That makes DR participation even more attractive for customers, since it would be possible to compensate part of such monthly payments for the meters with savings from the electricity bill. However, it is not yet clear whether the payments for meters would be included in distribution service bill or charged separately.

The first reviewed model is good for customers who don't want to pay extra fees to an aggregator and are interested in controlling the electricity consumption on their own based on price information. The price information can be taken either from online information service portal or from a smart meter display installed on the customer's premises.

The second business model is an evolution of the first business model, as it is only feasible when an aggregator has a large amount of customers (i.e. controlling load is large enough for trading). In this model, the aggregator shares a part of its revenue gained from the DR trading with the customer. The customer, in turn, pays certain fees (e.g. availability fee, metering fee, scheduling fee) to the aggregator. In the second business model, the participation of the customer in DR program is obligatory upon a receiving of price signal. If a customer does not respond to the signal sent by an aggregator, he then pays the agreed penalty payment to an aggregator.

In future, investing in distributed generation equipment might save even more money for customer. The customer will have the opportunity to earn money from selling the generated electricity back to the grid.

Author's study of the load profiles for different typical Finnish types of customers has shown that currently the aggregation program participation is the most profitable for the customers with average loads above 3-4 kW. Therefore, DR participation of apartment houses with typical loads less than 0.5 kW is not yet profitable for (low individual savings). However, when the aggregator business develops in future, it might find the ways to group these small customers and make participation in DR attractive for them.

Electricity prices have almost the same profile for every day, therefore customers in the apartment houses with loads less than 0.5 kW can purchase load controlling devices that turn appliances on/off at a certain time, like those used to turn central heating on/off at a desired hour. That way, these customers have a small initial investment for control devices and might not be taking the full advantage of demand shifting, but they do not have to pay for scheduling or control, and, in the end, they will probably save more money by controlling appliances themselves.

As to the market dynamics, it might look like customer load reduction during peak price hours may decrease these prices and increase cheap night prices to which the electricity is being offset. However, this is only possible when the aggregation reaches high level of penetration. Currently, or at least during a first few years of the aggregation introduction, load reduction may not decrease market prices as the amount of reduced load is very small when compared to the consumption of tariff customers, or large industry customers.

Moreover, if the aggregator company is an aggregator-retailer, it will have to procure additional electricity amounts during the offset time (usually night time). Therefore, it will probably have to adjust its forecasting algorithms to include customers with DR programs. This is not bad, because both retail company and customer benefit from the load offset (retailer company procures more electricity during the night and therefore receives profit, customers save money by offsetting load and receiving premiums for that). However, if the aggregator is a 3rd party company, it doesn't have to adjust to anything.

5.4.1 Results Validity

Calculations for both models are based certain approximations aimed to simplify the analysis. More complex estimations may result in greater savings for customers and profit for an aggregator. For example, the load profiles are dated 1992 and they are for typical detached houses. A load growth coefficient has been applied in order for these profiles to reveal today's consumption level. However, more recent study might make the load curves more accurate. Also, holidays and weekends consumption pattern were approximated to usual workdays in the performed demand response calculations. The error of this estimation is not big, but may potentially increase customer savings. However, actual consumption pattern of an individual household may be lower and therefore the profit will decrease. Obviously the figures received in the calculation are not guaranteed for every household, but they show an approximate magnitude of savings from participation in demand response program.

It should also be noted that all costs related to operating and management (O&M) the electricity systems in model 1 and model 2 have not been considered for simplicity of calculations.

The ELSPOT market prices have been used for calculations of electricity trading. In reality, an aggregator company is probably going to trade DR on the balancing market (i.e. ELBAS). Although the ELSPOT/ELBAS prices are often different, the magnitude of the revenue is still valid.

5.4.2 Correlation with Other Years

Similar calculations have been run for the year 2008. The results turned out to be higher due to higher prices during this year both on average and by price peaks. The following table shows the results of Model 1 run for year 2008:

Table 10 Model 1 Calculation Results for Year 2008

Electricity Bill Reduction per Customer (S_1):	44.52 € per annum

Model 2 results have shown approximately the same savings increase as Model 1:

Table 11 Model 2 Calculation Results for Year 2008

Electricity Bill Reduction per Customer (S_1):	44.52 € per annum
Aggregator's Revenue from Trading Shifted Customer's Electricity (S_2):	1 438 844 € per annum
Profit of an Individual Customer from Aggregator's Electricity Trading (S_3):	43.17 € per annum
Combined Customer Savings (DR + Electricity Trading Share) (S_4):	87.67 € per annum

Therefore, the difference between savings in years 2008 and 2009 is about 19%. As it has been stated earlier, this can be explained by both higher average prices during the year 2008 and more price peaks during the day.

5.4.3 Calculation Considerations

Various considerations have been discovered during the analysis of calculations. First, the pattern of load controlling equipment was assumed to follow a fixed algorithm. That means that the hours during which the load was controlled were fixed (the load was offset from 17:00-22:00 time frame to the 03:00-06:00 timeframe). That pattern yielded poor customer savings: S_1 = 14 € per annum, S_3 = 8 € per annum.

As a second alternative, the dynamic pattern of load controlling equipment was considered. Five most expensive hours during the day were offset to the three cheapest hours. The results of these calculations have been presented earlier.

After that, the same analysis has been done for the year 2008. The 19% increase in savings has been discovered. Utilizing this algorithm for the prices of the first 2 months of year 2010 have shown that the increase in savings can be even higher (up to 50%) but that led to the following idea: the customer should not be charged according to those price spikes. Instead, the price spikes should be used as a reference for the load controlling equipment (or customer itself). This way, the customer (load-controlling equipment) will be aware of the times when to turn on/off an appliance. However, the customer will not be charged according to those price spikes, but will have another dynamic tariff (see chapter 4 for more information on tariff types and descriptions). This dynamic tariff will have much lower prices when compared to real-time price spikes. The aggregator, in its turn, will be able to trade the offset electricity on the electricity market according to the real-time prices (e.g. trading process during spike prices can be very profitable).

5.4.4 Other Load Reduction Researches

Similar aggregator feasibility studies have been conducted in other European countries. For example, the BusMod project [49] analyzed electricity aggregation services in Spain. Its study has shown similar customer savings results (26.91€ per annum). However, regional differences (e.g. climate, price levels, and price volatility) affect the consumption pattern greatly.

Another study [27] has shown that installation of the energy-consumption information system led to a 9% reduction in power consumption in residential sector. This study focused on the awareness of residents to energy conservation and on the potential of reducing energy demand through energy-saving activities.

6. Conclusions and Summary

It is clear that nowadays the electrical power industry is undergoing some changes. Regardless of how quickly various utilities will accept Smart Grid concept, they all agree on the necessity of the massive transformations. It is not only technologies that need to be adjusted to the new standard of electricity consuming, production, and storage. It is obvious that new business models and behaviors must also be created for a proper Smart Grid functioning.

This thesis tries to define the Smart Grid concept, and where it is going as the infrastructure. It does so by providing an outlook on the electricity market and its players, explaining the main smart grid drivers, applications, challenges, and benefits.

Smart Grid platform promises to transform the way power is delivered, consumed, and accounted for. Introduction of intelligence in the grid will have the following effects:

- Increase in reliability and power quality
- Improvement of responsiveness
- Increase in efficiency
- Coping with growing demand
- Potential reduction of costs for the provider and consumer in future
- Provision of communication platform for new applications

Seven primary Smart Grid market drivers have been reviewed in this thesis:

1. Power Quality
2. Safety
3. Energy Independence and Security of Supply
4. Increasing Renewable Energy Generation
5. Technology Development
6. Energy Demand
7. Peak Levelling and Time-of-Use Pricing

Four groups of challenges (14 in total) that the Smart Grids are facing have been distinguished in the scope of this thesis:

1. Technology challenges
    a. Communication Coverage of Transmission and Distribution Grids
    b. Choice of Communication Technology
    c. Information Security
    d. Distributed Energy Resources Integration Challenge
    e. Distribution Automation
    f. Synergy with Advanced Metering Infrastructure
    g. Cheap Energy Storage Technology
    h. Grid Network Design
2. Economic challenges
    a. Market Barriers to the New Business Models
    b. Social and Economic Issues
3. Business challenges
    a. Integration Challenge
    b. Energy Management
4. Regulation challenges
    a. Interoperability
    b. Lack of Standards and Regulations

The following aspects of applications of Smart Grid have been reviewed:

- Demand Response
- Energy Storage
- Home Area Networks
- Advanced Metering Infrastructure
- Integration of Distributed Generation
- Advanced Metering Infrastructure
- Smart Charging of PHEVs

All applications stated above can be united under the Smart Grid platform.

The Smart Grid concept is an intersection of energy, IT, and telecommunication fields. The electricity utility networks need to have the same revolution as the telecommunication technology has recently undergone.

Introduction of Smart Grids will help to reduce CO_2 emissions by introducing renewable generation sources. Currently, electricity generation is the number one source of greenhouse gases.

It has been shown in this thesis that from an architectural point of view, the Smart Grid consists from three layers:

1. Physical layer (T&D)
2. Data transmission and control layer (communications and control)
3. Applications layer (various services and applications)

Provided the energy storage technology advances in future, the number of PHEVs is going to increase exponentially. This fact raises certain challenges for utilities that will need to create an infrastructure for charging PHEVs and charging schedule algorithms to smooth the load.

The following Smart Grid market segments have been distinguished in this thesis:

- Demand Response
- Advanced Metering Infrastructure
- Distributed Generation
- Advanced Utility Control Systems
- Home Area Networks

Possible roles for an aggregator company on the Nordic electricity markets have been reviewed in the thesis. Unfortunately, 3rd party aggregator company scenario is not yet possible in the current electricity market situation as the regulations and relations between aggregator on one side and retailer, DSO/TSO – on the other are not yet clear. However, scenario in which an aggregator company is a retailer at the same time (so-called 'Aggregator-Retailer') is possible and was proven to be feasible.

Two business models have been reviewed for feasibility in this thesis:

- **Model 1:** Customers enrol to aggregator's DR program, buy and install automatic load controlling devices that receive real-time electricity price signals and shift the electricity consumptions according to the preset algorithm (e.g. 5 highest prices during the day are shifted to the cheapest hours).
- **Model 2**: Customers install automatic load controlling devices and subscribe to an aggregator's DR program with extra benefits, such as additional payments from aggregator for load shifting. This way, in addition to usual electricity bill savings gained from load controlling the customers will receive 30% of the revenue made by an aggregator from selling the peak-hour electricity (shifted from those customers) on the electricity market.

The following picture provides a visual representation of possible aggregator business development:

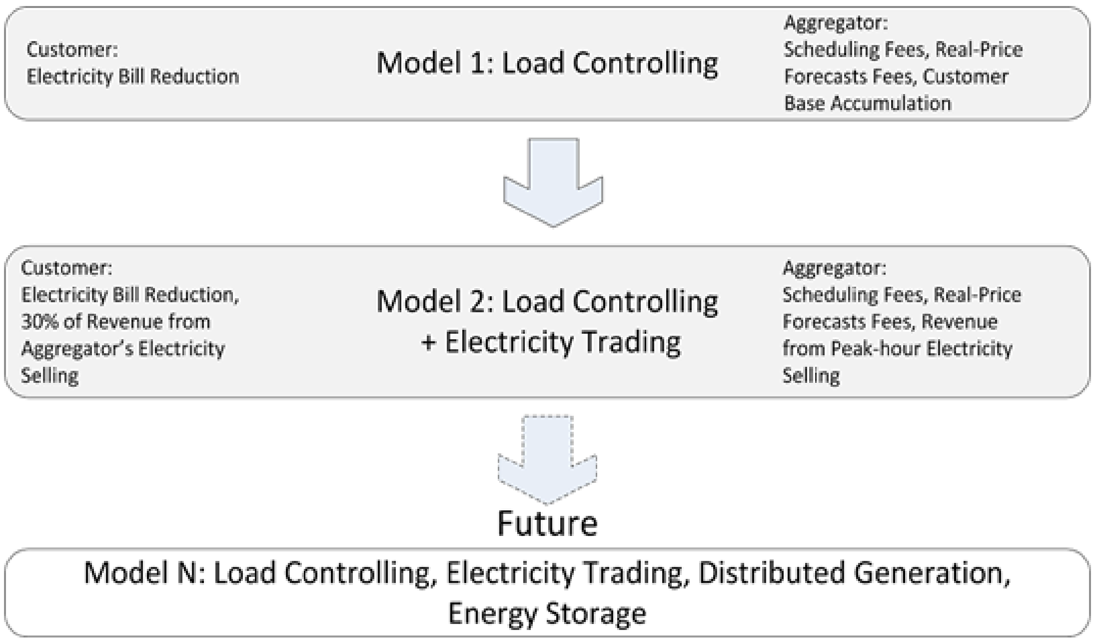

Figure 35 Aggregator Business Development

These models have been chosen as an example of consequential aggregator business development. First model can be accepted on the initial stages of aggregator introduction on the market. During this stage, an aggregator should try to educate customers about the importance and possible profitability of DR. It should also accumulate a large customer base. After gathering a certain amount of customers, allowing the aggregator to trade the controlled load on the electricity market, additional services and benefits can be introduced.

It has been shown that demand response is a promising business. However, further fine-tunings are needed for these models. DR promises not only to provide utilities with virtual peak power, helping utilities to stop investing in expensive spinning reserves maintenance, but also attract more customers by providing them certain monetary benefits.

Currently, distributed energy resources are scattered and still remain a small niche when compared to conventional energy generation. Smart Grid platform promises to integrate renewable energy technologies into distribution grids. This will allow us to take the most out of such resources.

Besides optimizing energy consumption patterns and delivery, the Smart Grid concept is a significant economic growth engine field. It may create new jobs as a result of its projects.

New customer electricity tariffs must be created as a regulatory reform that encourages customers to participate in load reduction during peak hours. Fixed retail rates must be replaced with time-of-use rates. This is a crucial fact as flat-rate tariffs in combination with smart meters and load controlling equipment will have little results. Customers need to have information about the hourly price dynamics, as well as forecasts for the next few days. With this information in mind, they can then decide the optimal way to consume the electricity according to their best interest and comfort.

In the same way the customers need new tariff regulations, the utilities need regulatory reforms for energy efficiency and compensations. These regulations might include incentives for utilities to earn their revenue not only from volumes of electricity sales, but also from other activities. Otherwise, advising utilities to reduce their power sells may not coincide with their best interests.

Development of new energy storage technologies will assist in making small-scale DG a feasible alternative to centralized power stations. However, despite the tremendous amounts of funding in recent years, this field still remains a 'holy grail' for the electricity industry.

6.1 Recommendations for Fortum

This thesis was intended to gather major challenges connected with Smart Grid introduction, as well as justifying an aggregator company existence for Fortum Sahkonsiirto Oy company experts.

The results of the calculations have shown that the reviewed aggregator behaviour model 2 (i.e. selling DR on the electricity market (ELSPOT/ELBAS)) has a clear advantage over the model 1 (see Figure 35 for model descriptions). Customers' savings are almost doubled when an aggregator shares a proposed 30% of its revenue from DR electricity trading with them.

Combining Fortum's experience in operating the Nordic wholesale market can create a winning position over various stand-alone energy saving applications, offered by many technology providers.

The demand response profitability calculations for two possible models have been reviewed in this thesis. However, further researches may be needed to fully understand the nature of an aggregator company positioning among other players on the electricity market.

Author recommends the following researches for conduction in this regard:

1. Estimation of operation and management costs of an aggregator-retailer business.

2. Determination of optimal fees and payments charged by an aggregator-retailer.
3. Possible regulatory changes of electricity market for enabling the profitable existence of a 3rd party aggregator company.
4. Effect of distributed generation on household savings and profit of an aggregator-retailer company.
5. Incorporation of PHEVs charging network into existing distribution grid and ways of making business out of it for an aggregator company.
6. Demand response profitability studies for other customer groups (e.g. apartment houses).
7. Determination of the most profitable country areas for introduction of aggregation business.

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Appendix I

Functional safety standards:

- IEC 61508 - Functional safety of products, components and systems. Evaluation covers electrical/electronic/ programmable electronic (E/E/PE) safety-related systems and assessment of the proper safety integrity levels (SILs) of your product or system
- IEC 62061 - Safety of machinery and functional safety of safety-related electrical, electronic and programmable electronic control systems
- IEC 61496 - Evaluation of safety-related electro sensitive protective equipment
- ISO 13849 - Safety of machinery and safety-related parts of control systems
- UL 1998 - Assessment of software safety and evaluation of computer/ software-controlled products
- UL 991 - Assessment of controls that employ solid-state devices and are intended for specified safety-related protective functions

Appendix II

Example of calculations of load controlling savings of individual customers (detached houses) that are charged according to the real-time tariff:

Table 12 DR Results for 7 Winter Days of 2009*

Day	Five most expensive hours, €/hour					Three cheapest hours, €/hour		
1-Jan-09	0.27	0.25	0.26	0.26	0.23	0.17	0.17	0.19
2-Jan-09	0.27	0.31	0.32	0.29	0.26	0.21	0.22	0.23
3-Jan-09	0.26	0.26	0.26	0.23	0.25	0.19	0.19	0.19
4-Jan-09	0.27	0.27	0.26	0.24	0.26	0.19	0.2	0.2
5-Jan-09	0.24	0.25	0.21	0.22	0.27	0.21	0.22	0.23
6-Jan-09	0.23	0.23	0.25	0.21	0.25	0.2	0.2	0.21
7-Jan-09	0.37	0.38	0.29	0.32	0.23	0.2	0.21	0.2

* Note that the results were rounded to 2 decimal places. Actual calculations have been conducted with 5 decimal places.

Example of ELSPOT trading calculations for the load offset from 10 000 customers (detached houses):

Table 13 ELSPOT Trading Results for 7 Winter Days of 2009*

Day	Five most expensive hours, €/hour				
1-Jan-09	936	899.8	892.6	880.2	871.6
2-Jan-09	1119.2	1100.8	1100.6	1080.6	1057.2
3-Jan-09	918.4	907.4	879.6	871.2	857
4-Jan-09	948.2	927.4	905.6	903.8	876
5-Jan-09	991	954.8	943.6	943	937.8
6-Jan-09	875.4	875.4	873.4	867.6	859
7-Jan-09	1401.6	1348	1161.2	1096.6	1022.8

* Note that the trading is assumed to take same day. Market transactions fees are not considered in the calculations.

Load curves for a typical Finnish detached house [47] with applied load growth coefficient. See formula (1) for more information:

Table 14 Load Curves for a Typical Finnish Detached House

Winter												
Hours	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Load, kW	6.09	5.51	5.29	5.08	4.93	5.08	4.93	4.79	4.42	4.42	4.56	4.64
Hours	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Load, kW	4.50	4.50	4.57	4.93	5.29	5.66	5.80	5.80	5.87	6.67	7.83	7.25

Spring												
Hours	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Load, kW	5.08	4.35	4.13	3.77	3.70	3.70	3.92	3.84	2.97	2.90	2.83	2.83
Hours	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Load, kW	2.83	2.76	2.61	2.47	2.90	3.19	3.48	3.77	4.21	5.08	5.66	6.67

Summer												
Hours	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Load, kW	3.63	2.61	2.10	1.45	1.31	1.23	1.31	1.45	1.02	1.02	0.94	0.87
Hours	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Load, kW	0.94	0.87	0.80	0.87	1.16	1.31	1.52	1.67	1.89	2.03	2.25	4.06

Autumn												
Hours	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Load, kW	4.35	4.06	3.48	2.90	3.05	3.05	3.19	3.19	2.90	2.90	2.32	2.47
Hours	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Load, kW	2.32	2.32	2.32	2.47	2.9	3.19	3.34	3.63	4.21	4.64	5.51	5.51