CHALMERS

Technical and economical aspects of remote data transmission ways for *smart metering*

Master of Science Thesis

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Abstract

Smart meters are the next generation of electricity meters and the difference compared to the old meters is that they are able to transmit and receive data. Smart metering is one way to better help customers understand their electricity consumption and thereby help them to save energy. Smart meters are essential for the European Union to reach its targets; to reduce the output of greenhouse emissions by 20%, to improve energy efficiency by 20% and to increase the percentage of renewable energy sources by 20% by the year of 2020. Sweden is the first country with a 100 % roll out of smart meters, monthly readings are mandatory from 1st July 2009 and therefore all utilities have installed smart meters.

The purpose of this thesis was to investigate different kinds of remote transmission ways for the consumption data, from the customer to the utility. The scope is also to find out advantages and disadvantages of smart metering in general. Since Sweden is the first country with 100 % roll out of smart meters a survey with Swedish utilities was performed. Mainly two different transmission techniques are used by Swedish utilities; PLC and Radio. PLC is used by many utilities in Sweden since the infrastructure is already present and there is only little need to install extra equipment. Therefore it is also a cheap solution and another advantage is the independence from external suppliers. The main disadvantage is the sensitiveness for disturbances such as frequency controlled engines, energy saving lamps, flat screens and parabolas. Disturbance problems have increased during the later years and due to this reason one utility in Sweden now changes from PLC to Radio. Radio is more expensive than PLC, both to buy and operate but the advantage is that it is insensitive to disturbances. Further advantages are that no galvanic contact is needed which means that concentrators can be place wherever is wanted and less concentrators are needed compared to PLC.

For a successful implementation in Germany as well as in other European countries there are, above the choice of technique, some critical factors; government requirements, costs and security. If there is no requirement of a full roll out of smart meters it makes it easier for utilities to put the problems off. The lack of requirements may also lead to a short-term solution which probably costs more in the long term compared to an immediate full roll out.

A full roll out of smart meters is a large investment but will also lead to a number of possible savings such as decreased demand to customer service and less driving due to remote read outs. It will also be easier to discover illegal power usage and gives the possibility to disconnect customers not paying their bills. As the technique is further developed the new electrical meters will probably be cheaper than the old electromechanical ones. Disadvantages are the dependency of the system, a failure causes large impacts. There are also larger amounts of data to be handled and complex systems that require another competence. This study has showed that the benefits with smart meters are significant compared to the old meters. The experiences from countries having a full roll out have showed that the necessary techniques are present and accessible at a reasonable price. A full roll out of smart meters across Europe might be essential to reach the 20-20-20 target set by EU.

Keywords: AMM, AMR, PLC, Smart Meter, Smart metering system, Smart Grid, 20-20-20 Target

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Contents

Abbreviations

A	
AMM	Automated Meter Management (sometimes Automatic Meter Management or Advanced Meter Management)
AMR	Automated Meter Reading (sometimes Automatic Meter Reading)
B	
BPL	Broadband over Power Lines
BTS	Base Transceiver Station
D	
DSL	Digital Subscriber Line
DSO	Distribution System Operator
E	
EDL	Endenergieeffizienz und Energiedienstleistungen
EMI	Electro Magnetic Interference
EnWG	Energiewirtschaftsgesetzes (German energy law)
ETSI	European Telecommunications Standard Institute
G	
GPRS	General Package Radio Services
GSM	Global Service for Mobile Communication
H	
HV	High Voltage
I	
ICT	Information Communications technologies
L	
LV	Low Voltage
M	
MessZV	Messstellenzugangsverodnung (German law, concerning measurements)
M2M	Machine to machine
MUC	Multi utility communication
MUS	Multi utility server
MV	Medium Voltage
P	
PLC	Power Line Communication (sometimes Power Line Carrier)
PTS	Post och Telestyrelsen (Swedish Post and Telecom Agency)
S	
SML	Smart Meter Language
T	
ToU	Time of Use
U	
UMTS	Universal Mobile Telecommunication System
V	
VPN	Virtual Private Network
X	
XML	Extensible Markup Language

1 Introduction

1.1 Background

During the 1990s the European electricity markets went through a total transformation in the market structure, from a monopoly to an open market structure. From the start the main objective was to get a more efficient working energy sector and a better usage of the resources to keep down the electricity prices in a free and competitive market. The objective has in the latter years been enlarged to reduce and keep down carbon emissions and improve energy efficiency. Smart metering is a necessity to reach this enlarged objective.

Smart meters are the next generation of electricity or gas meters and the difference compared to the old meters is that they are able to transmit and receive data. Smart metering is one way to help customers understand their electricity consumption and help them to save energy. Through a quick feedback and monthly bills, with statistics over the electricity used, the customers will get a better understanding of their electricity consumption [1]. Customers should be able to analyse and optimize the electricity consumption and the only way of making this possible is by a quicker feedback on the consumption. The supplier or distribution system operators will profit from smart metering since they do not need to dispose so much expensive peak power. Through load variable tariff customers can profit as well, since they can optimise their electricity consumption against the given prices [2]. The identified reduction of operating costs for the utilities can be in the range of 30- 50% [3].

In June 2003 the European Parliament started to discuss about regulations in the electricity market and the right to receive "transparent information on applicable prices and tariffs" (2003/54/EC) for the customers. But it was the Security of Electrical Supply Directive in 2005, which addressed smart metering the first time. Directive 2005/89/EC concerns "measures to safeguard security of electricity supply and infrastructure investment" and Article 5 says that Member States shall take appropriate measures to maintain a balance between the demand for electricity and the availability of generation supply. Member States may take additional measures as encouragement of the adoption of real-time demand management technologies such as advanced metering systems and encouragement of energy conservation measures.

Before the Directive on Energy End- use Efficiency and Energy Services (2006/32/EC), the topic was not so well know in the Medias. The new directive placed many conditions on the meter and billing requirements, but the mandate is very weak. Article 13 specified as following "Member States shall ensure that, in so far as it is technically possible, financially reasonable and proportionate in the relation to the potential energy savings, final customers … are provided with competitively priced individual meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use." It also stipulates that "When an existing meter is replaced, such competitively priced individual meters shall always be provided, unless this is technically impossible or not cost- effective in relation to the estimated potential savings in the long term". As one can see it is far from clear, what the companies are obliged to do and when it should be done.

Article 13 also stipulates that "Billing on the basis of actual consumption shall be performed frequently enough to enable customers to regulate their own energy consumption". However it does not explicitly say that monthly readings are compulsory. The Member States are interpreting the EU directives in different ways, there are countries e.g. Sweden, which has already finished the installation of new meters, other countries that have not even started yet.

The targets for the European Union is to reduce the output of greenhouse emissions by 20%, to improve energy efficiency by 20% and to increase the percentage of renewable energy by 20% by the year of 2020. To be able to reach this goal it is essential with a development of fully operational smart metering systems across Europe, but the stipulations in the Directives therefore are insufficient. What is needed is a clear mandate for the Member States to introduce smart metering, with a definitive deadline for the completion of implementation [4]. Overall, to reach the 20-20-20 target, Europe must modernize and liberalize the aging electricity grid, create economies of scale for renewable energy and encourage consumers to energy efficiency. Smart meters give customers more detailed information about their electricity consumption thus they will get more aware of their consumption and be able to take actions to lower it. Utilities can also introduce variable tariffs to better steer the electricity consumption and thereby improve energy efficiency and lower carbon emissions.

Smart meters are able to measure in both directions i.e. energy can also be measured when fed back to the grid from for instance a small wind power, which enable customers to sell energy back to the grid. This enables customers to invest in own small power plants and thereby increase the percentage of renewable energy sources. The current power grid is based on a centralised power production and the electricity is often transported over long distances from the few large nuclear and water- power plants. Smart Grids are the new generation of power grids where electricity can be generated from lots of small energy sources spread out instead of only some large power generators. Compared to the old grids which are centralised producer- controlled networks, smart grids are decentralised user- interactive one, where consumers can feed surplus power back to the grid. Smart metering is a prerequisite for Smart Grids since smart metering provides the ability to facilitate the adoption and feed- in of micro generation. The implementation of smart meters from the start until reaching full operation is on average seven years. Smart Grids can take up to 20 years to rollout and so far only one utility, Tokyo Electric Power, has completed a full rollout of smart grid [1].

The pre requisites for smart metering have been developed during the last decade and different data transmission techniques are available for a reasonable price. Italy was the first country starting with a full implementation of smart meters, the progress in most other countries is very slow. Even if the technology has been available for quite a long time, it seems that government requirements are a necessity to make utilities adopt smart metering. Therefore the adoption of smart metering in Europe is mainly driven by regulation, which originally comes from the EU-directive. Some countries have defined mandatory requirements for the implementation of smart metering, due to national concerns over the future energy situation and the directive of energy efficiency. In the Netherlands energy conservation is driving similar reforms as in Sweden but the present situation and implementation of smart metering differs significantly from country to country. This is a result of different national factors, including consumption pattern, climate and deregulation path. Even if the electricity sectors in the Nordic countries are similar there are different requirements and plans for implementing smart metering. In Germany the installation of smart meters in new buildings and renovated buildings are compulsory from 1st of January 2010. When an old meter is changed, a smart meter should preferably be installed and if requested by the customer the utility needs to offer and install a smart meter. It is however not stated that it should be free of charge for the customer [6].

It is not only in Europe that smart metering is an actual subject, also in the US, China and Korea projects are going on. In January 2009, President Obama Administration introduced a huge economic stimulus plan, including investments in Smart Grids and at end of 2008 the State Power Grid Corp. of China decided to replace all electromechanical meters with smart meters within five years [6]. The Korean utility KEPCO has announced a replacement of 20 million analogue power meters with a PLC digital version over the next six years, i.e. until 2015 [7].

1.2 Objective

The main objective of this study is to analyse the different techniques available for remote transmission of the data from smart meters to the utility. The study will focus on finding the best alternative for Stadtwerke Ratingen GmbH, a small German utility. This will be done considering economical, technical as well as legal terms.

It will be investigated which possibilities that exists for communication between the individual meters, and if there are dependencies on where in the building the meters are to be installed.

Since the Member States are at different development stages it will be investigated how different EU- countries implementation of smart metering is carried out. Sweden is the first country with 100 % comprehensive remote smart meters, therefore interviews with Swedish utilities will be held to gain knowledge from their implementation of smart meters.

In Germany companies are driving trials with smart meters, RWE for instance have a large ongoing pilot project in the city *Mühlheim an der Ruhr*, where the whole city will be equipped with smart meters, which means around 116 000 meters. The development status and ongoing pilot projects at the four largest German utilities; RWE, E.ON, Vattenfall and EnBW, will also be investigated in this report.

A brief introduction to smart grids will be presented since smart meters are a prerequisite for the implementation of smart grids and also since this is a topic of immediate interest when discussing the future of the power industry.

1.3 Outline of report

To make it easier for readers with different backgrounds and interest a short explanation of the contents in the remaining chapters are given beneath:

- **Chapter 2 Smart Metering:** Describes smart meters and smart metering systems and the objective of implementing them. The EU- directive about the 20-20-20 target is gone through and a short introduction to Smart Grids is made.
- **Chapter 3 Remote transmission ways of the consumption data:** Gives an introduction to the most commonly used transmission techniques of the consumption data; PLC, Radio and GSM/GPRS.
- **Chapter 4 Smart Meters in Sweden:** Gives a background and a status of the implementation of smart meters in Sweden. The results from the survey made with 15 Swedish utilities are presented here.
- **Chapter 5 Smart Meters in other European countries:** Describes the situation and implementation status in some other European countries; Italy, Finland, the Netherlands, Austria and UK.
- **Chapter 6 Smart Meters in Germany:** Gives a background and introduction of the implementation status in Germany as well as a short description of the legal requirements so far.

- **Chapter 7 Development status at the largest German utilities:** Describes the implementation status of the four largest utilities in Germany; RWE. E.ON, Vattenfall and EnBW.
- **Chapter 8 Smart Meters at Stadtwerke Ratingen GmbH:** Includes an introduction of the status at Stadtwerke Ratingen regarding smart metering. Some recommendations for the future implementation are given.
- **Chapter 9 Conclusion:** Contains the final discussion and conclusions.

2 Smart Metering

2.1 What is a Smart Meter?

The old meters are individual units without communication possibilities. Smart meters are the next generation of electricity or gas meters, making it possible for the utilities to automatically readout the meters remotely without the need of physical access to the meter [9]. The customers will only pay for the exact energy used, not according to estimation as before.

Smart meters are usually used for measuring electricity and gas consumption, but it can also be used for water and district heating consumption. The intelligence of the meter is integrated in the electricity meter and the three basics functions are to measure the electricity used or generated, remotely switch the customer on and off and remotely control the maximum electricity consumption. In Figure 1 a schematic overview of a smart meter and its functions is showed.

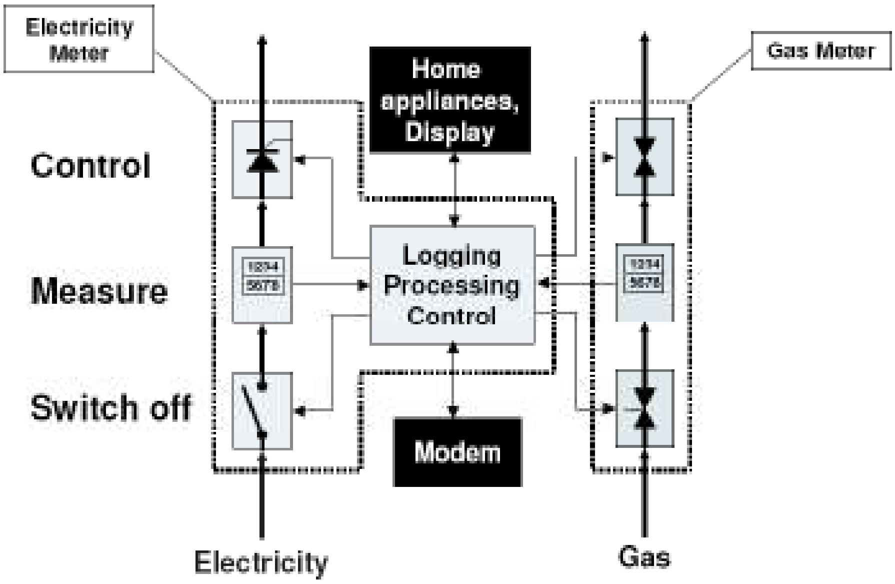

Figure 1 Overview of a smart meter configuration [12].

Figure 2 shows a comparison between an old „dumb“ meter and a new „smart“ meter. As shown in the figure smart meters has a two way communication while an old meter only can be read out manually and communicates in one direction.

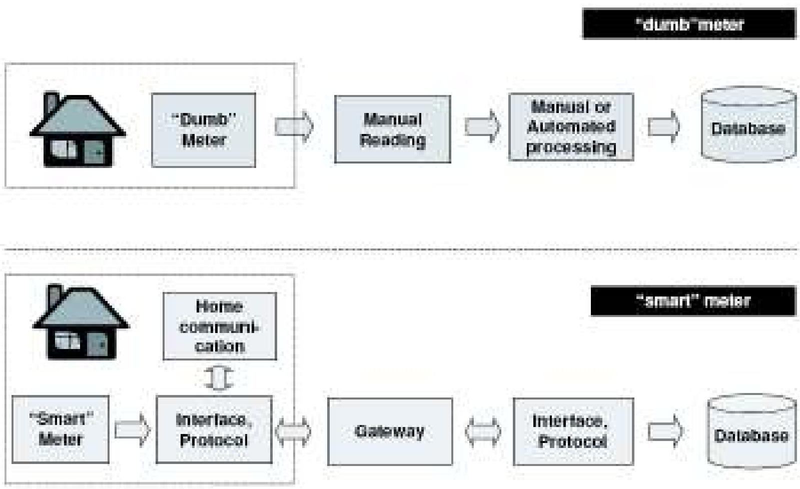

Figure 2 Comparison between an old "dumb" meter and a new "smart" meter [12].

Smart meters have flexible measurements of the energy consumption, gateways for communication with the customers and gateways for a wide range of control functions [10]. A two way communication between the utility, supplier or DSO, and the meter is a minimum, but the majority also include the following functions; accurate measurement of electricity, gas, water or heat usage, a data transmission infrastructure, IT environment suited to the resulting data volumes, consumer- oriented invoice system and a local display of energy usage data [4].

There are plenty of definitions for a smart meter, which sometimes can be confusing and lead to misunderstandings when speaking about how different countries are working with the implementation. When for instance the government decides about a full roll out of smart meters it is important to have a definition of what they mean by smart meters, beneath some definitions are given [12].

Definitions:

A smart meter, according to [13], is a meter which can be remotely readable and controllable. It should also have a communication infrastructure that sends the measured data to the central IT- system. Further on the IT- system should be able to present the data for the parties involved.

"A Smart Grid 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" [14]. To be able to create a Smart Grid, smart meters are necessary.

Smart meter are components with a complex infrastructure which are able to measure the electricity consumption in a flexible way, including a register and/ or possibility of remote meter reading. A gateway for communication with customers and varied control- and regulation also need to be represented [10].

"Smart meters are modern, innovative electronic devices capable of offering consumers suppliers, distribution network operators, generators and regulators a wide range of useful information, enabling the introduction of new energy services…" [4].

2.2 Smart metering system

Different suppliers have different type of metering systems but usually a smart metering system consists of meters, terminals, concentrators and a central system.

- **Meter** The meter is the unit measuring the electricity-, heat- or water-consumption of a household or industry.
- **Terminal** The terminal is the communicating unit which communicates with the meter and sends the data to the concentrator. The terminal also saves the data in the internal memory. Often the terminal is integrated in the meter.
- **Concentrator** The concentrator communicates with and supervises all terminals within a specific area.
- **Central System** The central system is the brain and acts as a command central where it is decided what to do and when. The central system is usually constructed as an operative system and with software it can control and configuration all other units in the system.

Figure 3 shows a schematic overview of how a smart metering system could look like.

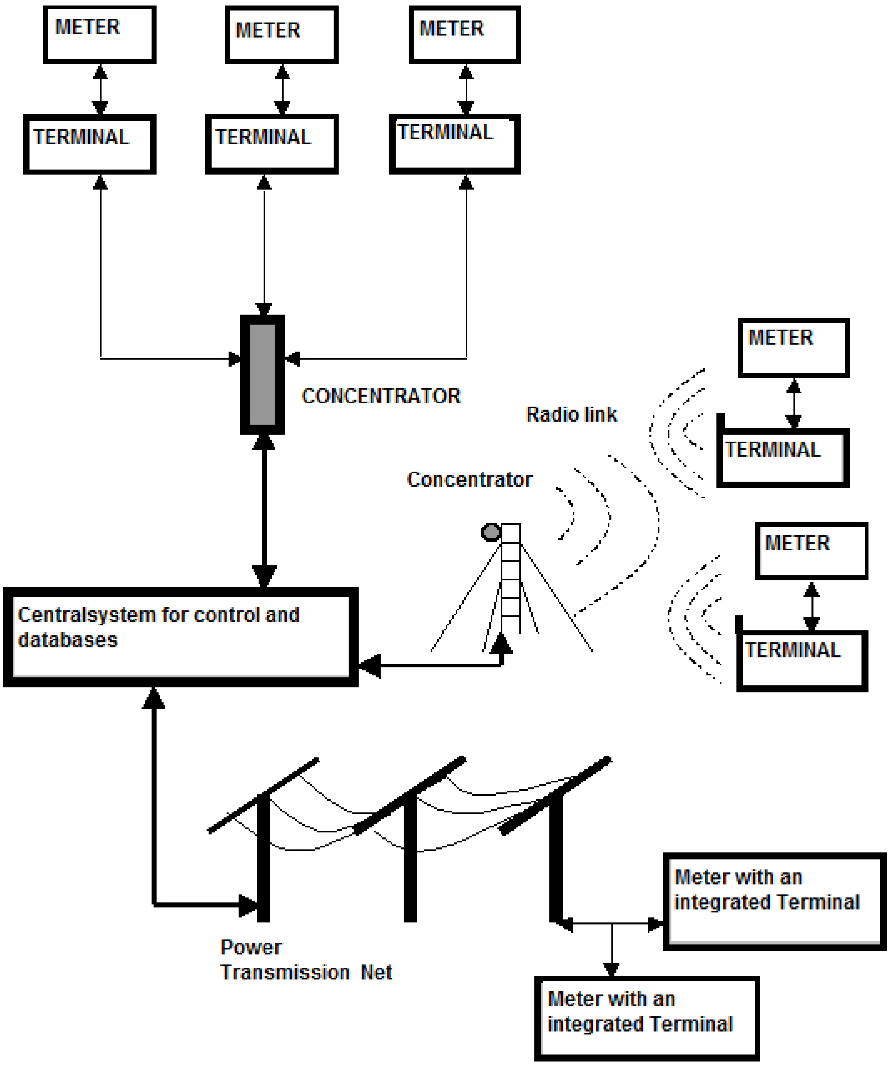

Figure 3 Schematic overview of a smart metering system.

The electrical meter measures the amount of electrical energy supplied to a residence or a business, it is electrically fed and composed of electronic controllers and it has an interface allowing data to be transmitted from the remote terminal to the collector or directly to the central device. The main objective is to measure, display and save actual data connected to the electricity consumption. Most smart meters are also able to measure time for black outs, effect, current and voltage. Additionally remote connection and disconnection is possible as well as alarm functions if someone tries to manipulate the meter.

Typically the terminal is integrated in the meter and makes it possible for the utility communicate with it. The terminal saves the data continually and then transmits all values to the collector or directly to the central system. The data is transmitted regularly, how often depends on what is needed. In Finland hourly readings and monthly bills is a requirement from 2014 and in Sweden the requirement is once every month but some utilities already have the possibility to get the data once every day or every hour. Dependent on for example the conditions in the area where the meter is placed, different methods e.g. PLC and radio are used for transmitting the data [11].

The aim of the collector/concentrator is to collect the data from many meter terminals. Usually the collector is placed in the power station on the low voltage side and then e.g. PLC is used for the communication between the meter and the central communication system. The collector is responsible for the local communication with the meters and if a meter cannot be reached within a certain time it reports to the central communication system. The data from each meter is temporarily stored in the collector and then the central communication collects the data [11].

The central communication system collects the data from the meter terminals which mostly communicates with collectors/concentrators, others communicates directly with the central communication system. To be able to transmit data and to control different signals between the meters and the central communication system a communication system needs to be implemented. There are several communication techniques e.g. mobile technologies, based on radio frequency, transmission over the electrical cables i.e. power line and telephonic platforms e.g. wired or wireless. Functions included in the central communication system are reasonability control of the data and fault management control. The data is the basis for invoice management and statistics is regularly exported [11].

One big advantage with smart meters is that there will be no locally meter readings needed anymore. The readout of the meters is automated and the utility have access to the data immediately. The bills to costumers will be more accurate; previously the utilities estimated the consumption, with smart meter one will pay for the exact energy being used. Further the electricity consumption of the smart meter itself is lower than the old mechanical meters; a smart meter uses around 1.5-2W compared to the old ones using 4-5W. Although, on top of the consumption for the meter, electricity for the data communication and for the IT infrastructure is needed and they are not included in the figures above. System oriented advantages are: motivation of lowering the electricity consumption, flexible and dynamical tariffs which means a shift of the use, adoption of load management and further development of home automation [8], [27].

2.3 Objective

The objectives of smart metering are mainly reduction of the CO_2 emissions, improved energy efficiency and an increase in the use of renewable energy. Further the customers should be able to directly see their electricity consumption and thereby make active choices in their consumption pattern. Utilities are obliged to balance the demand and supply in their grid; they need to have large amounts of expensive peak load capacity since normal consumers don’t adopt their consumption. The peak load capacity can be reduced if customers can be controlled in terms of tariffs and critical peak pricing [4].

According to a study made by the *Bundeswirtschaftsministerium* (Federal Ministry of Economics) in Germany the realistic savings are more than 9.5 Mrd. kWh, i.e. 6.5%, in 2010. Continuous meter readings make it possible to receive information about consumption habits e.g. air conditioning usage and standby losses. It also encourage investments in energy efficiency e.g. a new fridge or lighting and gives direct feedback when the consumption behaviour changes. A possible service in conjunction with smart meter is personal advices regarding the electricity consumption on the basis of the new exact data.

The fact that the readings does not have to be made locally means reduced effort when people are moving, when a meter has to be replaced and at vacancy. The administration of customers not paying is easier with the possibility of remote disconnection; the load can be limited or pre payment can be used. Thereby a control of non technical losses e.g. electricity stealing and improved manipulation security can be achieved. Through an improved database the quality of the data will be better e.g. when changing tariff. Some constraints regarding smart metering are the law of calibration, a lack of investment security and the present lack of incentives for investing in smart metering. The calibration validity time is shorter and there are different calibration validity times for multi- utility solutions. Regarding the lack of interest in investments there are no minimum standards for equipment configuration and data format and there are organisational uncertainty in the liberalisation of the measuring. [15].

2.4 EU- Directive

The European Union has set a goal that by 2020 lower the greenhouse emissions by 20%, increase the energy efficiency by 20% and increase the percentage of renewable energy used by 20%. To achieve this, a full rollout of smart meters is necessary. In Article 5 in the directive from January 2006, concerning measures to safeguard security of electricity supply and infrastructure investment, it is stipulated that "Member States shall take appropriate measures to maintain a balance between the demand for electricity and the availability of generation capacity". "Member States may also take additional measures, …encouragement of the adoption of real- time demand management technologies such as advanced metering systems" as well as "encouragement of energy conservation measures".

Through the directives it is not clear which actions are to be taken and when. It is important that these directives get clearly specified [16].

Below is en extract from the decisions of the ITRE, Committee on Industry, Research and Energy, Committee the European parliament (ITRE/6/53775) the 6th of May 2008 to COM(2007)0528:

- National regulatory authorities shall ensure full interoperability of the information and communication systems to be implemented. For this purpose, they may issue guidelines and may mandate amendments to the proposals referred to in paragraph 3a.
- The Agency or the Commission shall ensure that the information and communication systems to be implemented facilitate the development of the internal electricity market and do not introduce any new technological barriers.
- Member States shall define a format for the data and a procedure for suppliers and consumers to have access to the data.
- National regulatory authorities shall be responsible for monitoring the process of such development and for laying down common standards for that purpose. Member States shall ensure that standards establishing the minimum technical design and operational requirements for meters address interoperability issues to provide maximum benefit at minimum costs to consumers [15].

2.5 Smart Grid

The existing grid in Europe is based on a technology that was invented more than hundred years ago. The traditional power grid uses centralised generation plants that supply end users via long-established and unidirectional transmission and distribution systems. The current grids are inefficient, overcrowded and incapable of meeting the future needs. The demands for more reliable and higher volume power supply from cleaner and more renewable energy sources cannot be achieved by the present infrastructure. The grids need to go through important changes, from a centralised producer controlled network to a decentralised user-interactive one, to be able to meet future challenges. A more intelligent system is needed that can receive power of all qualities and from all kinds of sources [17].

Distributed electricity generation generates electricity from lots of small energy sources instead of only large sources such as nuclear-, water- or gas power plants. Large power plants gives large scale advantages but also means that the electricity needs to be transported over long distances. With a distributed electricity generation the losses decreases since the electricity is produced much closer to where it is consumed. Also the size and the number of power lines are decreased. In Figure 4 a sketch of the vision of how a smart grid will look like in the future can be seen.

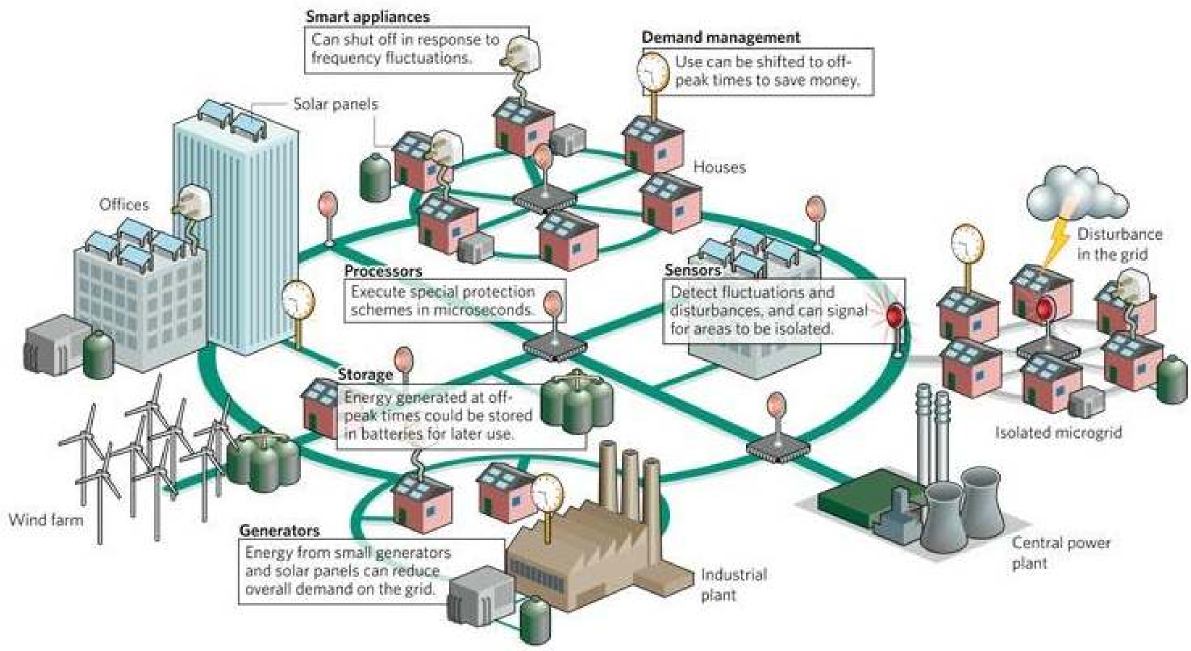

Figure 4 Vision of how a smart grid could look like in the future [18].

The incentives of developing a smart grid are many, e.g. integration of renewable energy sources, integration of electric vehicles, reliability and energy efficiency and demand response. The addition of wind, solar and other renewable energy sources means operational challenges due to their discontinuous character. The benefits of renewable power are in line with the new legislation for climate protection but they will also have a severe impact on the stability of the grid. It will be necessary with a grid that can handle a generation mix with a high degree of renewable energy sources and that enables consumers to feed surplus power back to the grid to realise their full potential. Such a grid will also be necessary to realise the full potential of electric vehicles. With the integration of electric vehicles a storage potential during periods of low demand will occur. When demand rises energy can be feed back to the grid. To balance supply and demand with the integration of renewable energies will be managed by this load and storage function [19] - [21]. Both production and distribution are intelligently steered by a computer [17].

3 Remote transmission ways of the consumption data

There are several techniques for remote transmission of the electricity consumption data from the consumers to the utility. The choice of technique is depending on several factors, such as telecommunication network coverage of an area, the number of consumers within the area and if internet is available. For example in a rural area where no DSL network is available, and because of too few users power line communication cannot be used, the relatively expensive mobile funk communication can be a good alternative for the transmission. In cities on the other hand GPRS or PLC are advantageous [6].

Some of the most common and important transmission techniques are described below. Further transmission techniques are described shortly in Appendix A.

3.1 PLC

Power Line Communication (PLC) is a technique using the already existing and widespread power distribution infrastructure by transmitting data signals through the same power cables that transmit electricity. The idea of using power lines for data communications is not new; the first applications of PLC are dated to over 100 years ago [7], [22]-[23].

PLC can be divided into three different voltage levels; Low Voltage < 1 kV, Medium Voltage 1 kV – 100 kV and High Voltage >100 kV. The communication is also divided into a number of frequency levels which in Europe are decided by the CENELEC Standard EN 50 065-1 and in North America by FCC. More information about the standards for PLC can be found in Appendix B.

There are two variations of PLC; broadband and narrowband and until now narrowband is the one most used for AMR. In Figure 5 an outline of a low voltage PLC communication system can be seen.

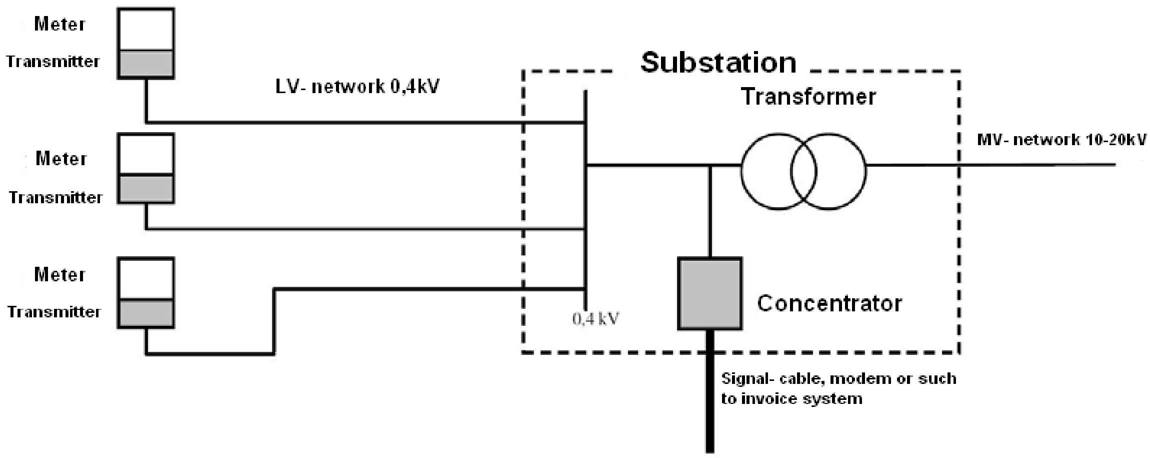

Figure 5 Low voltage PLC communication system.

Some important applications through PLC are [22]:

- Broadband Internet access (Broadband over Power Lines, BPL)
- Indoor wired local area networks (LANs) for residential and business sites
- In vehicle data communications
- Municipal applications such as traffic light and street lighting control

- Smart Grid applications such as advanced metering control, real-time energy pricing, peak shaving, mains monitoring and distributed energy generation
- Remote detection of illegal electricity usage
- Measurement of the quality of power

A barrier to the widespread of PLC is the lack of an international technical standard. However in June 2005 the working group (WG) IEEE P1901 was formed by 20 companies under the sponsorship of the IEEE Communications Society and according to [24], July 2008, a global broadband PLC standard for booth in-home and access applications is within close reach.

Since the power line networks originally were designed for 50-60 Hz the use of this medium for data communication at higher frequencies involves several technical challenges e.g. channel modelling. The power line channel is a harsh and noisy transmission medium that is very difficult to model. It is also time varying, the channel transfer function may vary abruptly when the topology changes, e.g. when devices are plugged in or out or switched on or off. Power line cables are often unshielded which implicate further challenges since they booth are sources of and become victims of electromagnetic interference (EMI). As result PLC technology must include a solution that ensures coexistence with wireless and telecommunication systems, as well as be robust with respect to impulse noise and narrow band interference. The technical problems are related to:

- Both frequency- varying and time- varying response
- Transfer function with dependence of location, topology network and connected loads
- Different types of significant noise.

Power line cables are a shared medium which means that they cannot provide links dedicated exclusively to a particular subscriber, they connect a low-voltage transformer to a set of individual homes or a set of multiple dwelling units without isolating each unit. Since the cables are shared among a set of users, the signals that are generated by one user may interfere with signals generated in a neighbouring house or apartment. It is difficult to locally isolate the signals generated by one user so the more users in geographical vicinity that uses PLC, the more interference is generated. When the interference increases the users will notice a decrease in the data rate because more packet collisions occur [18], [24] - [26].

Turtle

This technique is based on low frequency communication i.e. 5-10 Hz, via the power line and has a reach of 100 km and more. Turtle uses ultra narrow bandwidths and can communicate through the low- and medium- voltage power network. Due to the low frequency the signals can pass through different transformation levels which lower the number of collector stations; they reach large areas and can be placed in distribution stations high up in the network. From the distribution stations existing communication can be used to transmit the data to the utility.

The meter is equipped with a small emitter that continuously transmits the data over the power line to a receiver. The receiver is installed in a substation and can handle up to 2880 receivers. Then the data can be collected from the utility via the telecommunication network, but fibre, radio or signal-cable can be used as well.

The advantage is a secure and robust technique which is insensitive to disturbances. Disadvantages are that it only has one way communication and that it can take up to 27 hours before the data is accessible. Since most customers does not need hourly values this is however usually no problem [27].

Senea CustCom

The communication takes place in the CENELEC's A- band with a frequency between nine and 95 kHz. It communicates through the low voltage network and the concentrators are placed in substations. The concentrator calls the emitters cyclical and there is a two way communication which also is faster than the Turtle- system and can be used to get data hourly.

3.2 Radio

In the meters which use radio communication a radio sender is installed which sends data to the concentrator/collector. In Sweden the transmission normally takes place over a frequency band of 444 MHz decided by *Post & Telestyrelsen* (PTS, the Swedish Post and Telecom Agency). This frequency band has been specially conducted for read outs of meters in Sweden. For utilities the advantage with radio is that they own the infrastructure and are independent of other actors and it is easier to plan the costs.

There are several suppliers offering meters which communicates via radio, one of them is Kamstrup and is used by some Swedish utilities. The meter is equipped with a small radio sender which sends data to the concentrator. The meter never initiates transmission by itself but answers when data is requested from the central system. The rest of the time the meter is inactive and no data is transmitted.

Mesh Technique

A mesh technique is a net structure where the signals themselves find the best way to go through the nodes and the nodes may act as an independent router. The net is also not dependent on electricity to work since the nodes communicate through energy saving and cheap radio senders. Each node acts like a router and since the numbers of neighbours are not fixed, new ones can easily connect and disconnect new nodes. In spontaneous networks this occurs automatically. A mesh network is also self healing i.e. if one node is not working well the signals passes by another node instead. The structure of a mesh network can be seen in Figure 6.

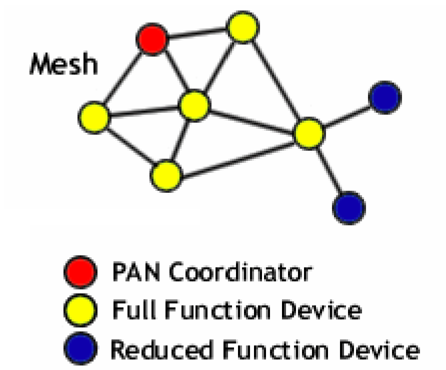

Figure 6 Structure of a mesh network.

ZigBee

Originally the system was constructed for military use but when the radio technique went cheaper single radio was developed to allow more radios per measure node. ZigBee is a license free technique that operates on the 2.4 GHz band and has a reach of up to 100 meter. It is based on the IEEE 802.15.4 which is an open standard and in addition to automatic meter reading it offers many possibilities;

- Home Area Networks (HAN)
- HVAC control
- Heating control
- Home security
- Industrial and building automation

The advantage with ZigBee is that it is a low cost and low power standard. Since ZigBee can wake up (active mode) in 15 ms or less the latency can be very low, thereby the average power consumption is very low and the battery life will be longer.

3.3 GSM

Global System for Mobile communications (GSM) is a technology used for transmitting mobile voice and data services. It is a cellular network which means that mobile phones connect to it by searching for cells in the immediate vicinity. GSM operates in the 900MHz and 1.8GHz bands in Europe; in USA, Australia and other countries other band widths are used.

The disadvantage using this technique is the dependency on another actor and the future for this technique is also uncertain [11].

3.4 GPRS

General Packet Radio Services (GPRS) is a standard from the European Telecommunications Standard Institute (ETSI) on packet data in GSM systems. GPRS offers an air- interface transfer and also allows several users to share the same air-interface resources and enables operators to base charging on the amount of transferred data instead of on connection time. In the initial release GPRS uses the same modulation as GSM [28]. One crucial challenge comes from the requirement for providing a definite quality of service for GPRS traffic without significantly degrading the performance of existing GSM services. In a GSM/GPRS integrated network it becomes necessary to reserve exclusive channels for GPRS in order to provide base-line QoS for GPRS users. On the other hand, this exclusive reservation means reduced capacity of GSM traffic so that has significant impact on the performance of GSM traffic, especially on GSM handover traffic. According to [29] the performance of GSM handover traffic can be significantly degraded by the capacity reduction resulting from the introduction of GPRS but can be amended by using appropriate priority schemes.

GPRS is a carrier service that significantly improves and simplifies wireless access to data packet networks and the basic idea is to utilize rest traffic channels that are not used by GSM traffic. In general GSM traffic has higher priority when allocating channels; this means that ongoing GPRS channels have to be terminated for a pending GSM traffic.

This technology is preferable when the customers are spread out on a large area and PLC is too expensive.

4 Smart Meters in Sweden

From 1st July 2009 smart meters are mandatory in Sweden. In this chapter the background and actual status as well as the result from the survey with Swedish utilities are presented.

4.1 Background and actual status in Sweden

In 2003 the Swedish government decided that it will be compulsory with monthly readings for all electricity customers by 1 July 2009 and hourly for all high consumption sites [30]. However there are no legal requirements for monthly bills. It was assumed that the preliminary debits would vanish on a voluntary basis since the meters are read out every month.

The incentives of the implementation of smart meters in Sweden were primary to make it easier for the customers and to lower the administrative costs. The ability to achieve the climate goals is another reason for installing smart meters. Some advantages seen from the customers and utilities as well as the government are listed beneath [5], [31].

Some of the advantages seen from the customers' point of view are:

- Electricity bills based on actual consumption. Preliminary bills belong to the past.
- Through the bills and or on the internet customers can follow their consumption monthly. Some utilities update the consumption on the website more frequently.
- Change of supplier is considerably facilitated.
- Faster and easier meter read out when moving.
- Through a quick feedback customers get more motivated to control their electricity consumption.
- When changing to a cheaper supplier or a new more energy efficient heating alternative the result can be seen more quickly.
- Utilities do not need to come to the customer for a manual read out, which previously disturbed the customers. All read outs are done automatically now.
- No risk for errors due to a false read out.
- Black outs will get logged by the meter, this might make it easier for customers to get compensation from the utility when having a black out.

For utilities following advantages are to be considered:

- When replacing all old meters with new smart meters a total review of all facilities are made. Technical shortages are discovered and taken care of.
- A total review of the electricity network security as well as the flow through the network is performed.
- More secure investment decisions since better control of the flows in the network.
- A possibility for power interruption register, gives a better control during disturbances or power black outs.
- Quicker billing gives a better control of losses in the power transmission network.
- Enables quicker meter readings for utilities.
- Possibilities selling other services e.g. alarms.
- Easier to discover when electricity is taken from the network but not paid for by any costumer.

The Swedish government sees following positive effects with monthly readings:

- The connection between the customer's actual consumption and the bill is more clear.
- Customers making their usage of electricity more efficient shall se fast results.
- Better information about electricity consumption motivates energy saving activities.
- Easier change of electricity supplier
- Less complicated routines when people are moving.

According to [32], Swedish households can reduce their electricity consumption with up to 10 % if the smart meters would give direct feedback. The numbers for those using smart meters with direct feedback varies between five and 15 %. Customers are able to get information about their consumption on the mobile phone, in the computer or at a display on the wall in the house. With monthly readings the average reduction of the consumption is about five percent [32].

The Swedish government did not set any specific requirements on the meters and the smart metering systems. Most of the installed meters are capable of handling hourly readings and load management. Some network operators have only installed smart meters that can handle monthly readings. There are no requirements of interoperability of the installed systems except for the used data format to transmit the measurement values. The data format called EDIEL is used and it is compatible for the whole Scandinavian market. Some information about EDIEL can be found in Appendix C.

The disadvantage with this approach is that a lot of different systems are not synchronised with each other. As long as the responsibility for the meter readings and the measurement service is a part of the network operator this is however no problem. The possibility of a fast change of supplier needs a consistent language which is ensured through the standardised data format.

4.2 Survey with Swedish utilities

To get a deeper understanding of the work by Swedish utilities with the implementation of smart meters a survey was performed. The aim was to get information on the advantages and disadvantages with the different meter techniques and about smart meters in general. Since Sweden is the only country which have performed a full roll out of smart meters thus the experiences are unique and of great interest.

It was of special interest to see if there are differences in the choice of technique depending on different number of customers and different types of distribution areas i.e. detached houses and countryside. Therefore a large number of utilities with very different size and distribution areas were contacted. Where a contact person was present already they were contacted via phone. When no contact person was given they was contacted via mail through the customer service wherefrom a contact person usually were given. A document with questions was sent by e- mail to the contact person who had some time to read the questions. A day and time was chosen and an interview was performed on phone. Two utilities sent their answers per e- mail and then a short discussion about the answer were held. 18 utilities were contacted and there from 15 utilities answered the questions. The questions can be found in Appendix D.

The result of the survey is presented in the following section. Firstly advantages and disadvantages with smart meters for the customers are shortly presented in Table 1. In Table 2 advantages and disadvantages for the utilities are presented.

Table 1 Advantages and disadvantages with smart meters for the customers.

+ Advantages for the customers	- Disadvantages for the customers
Invoice every month with exactly the consumed energy	Large fluctuations of the electricity bills
Less errors compared to manual read outs	Shorter lifetime compared to the old meters
Can follow their consumption directly on the website	
More detailed information when contacting the customer service	
Easier to get compensation when having a power black out	
Customers are not getting disturbed due to manual readings anymore	
Easier and quicker meter readings when moving	

Table 2 Advantages and disadvantages with smart meters for the utilities.

+ Advantages for the utilities	- Disadvantages for the utilities
Better control of the customers electricity consumption and the flow in the network	Increased total costs of the read outs for at least an interim period
Easier and quicker to discover a broken meter	Costs due to the large investment
The customer service gets better and more detailed information and can easier help the customers	All electronic equipment sensitive to for instance thunder storms, need to change fuses
Less errors compared to with manual read outs	Very dependent on the systems, failure causes large impact
Easier to discover electricity thefts	A larger amount of data to handle
Possibilities of disconnecting costumers that are not paying their bills	Shorter lifetime of the meters compared to the old mechanical meters
Customers pay for the exact consumption, no complicated preliminary invoices	Complex systems requiring another competence compared to before
Better information about power black outs	
No manual readings means less driving and a cleaner environment	
Utilities do not need to disturb customers with manual read outs	
Easier and quicker when people are moving since utilities do not need to come for a manual read out anymore	
Possibilities of effect tariffs in apartments	
Quicker error measures	
Additional services such as alarms	
Alarm function when someone is trying to manipulate the meter	

1. Techniques for data transmission:

The different techniques used by Swedish utilities to transmit the consumption data from the customers to the utility are mostly PLC, Radio and GSM/GPRS. PLC is the most commonly used technique, it is used either alone or in combination with radio or with GSM/GPRS. In Figure 7 the distribution of the transmission techniques being used can be seen.

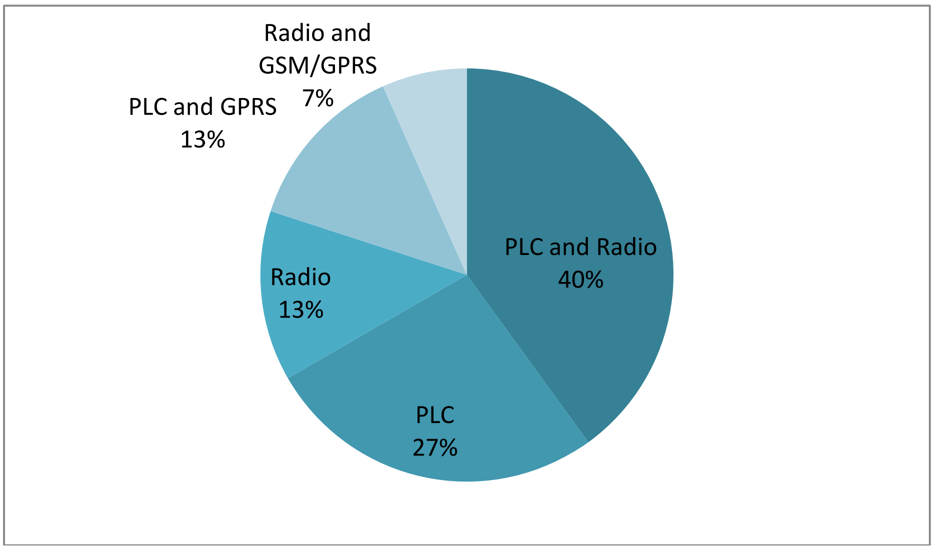

Figure 7 Distribution of the transmission techniques used by the utilities participating in the survey.

The reasons for the choice of technique vary a lot between the different utilities. Some of the main arguments, heard in the survey are:

- The installation cost for the technology
- Costs for maintenance and communication
- Infrastructure ownership dependency (e.g. GPRS vs. transmission network)
- The number of customers and how the distribution area looks like i.e. if it is a compact city or countryside
- The starting point of the implementation of smart meters (Technology and conditions has develop during time)

Many utilities made trials on small areas with different techniques before deciding on which technique to use. Others made study visits before they chose transmission technique. Since Sweden was one of the first countries implementing smart meters, the development has been on-going during the whole implementation period. One of the largest utilities performed three different purchase requests with different outcome. Some of the smaller utilities collaborated during the purchase. Some utilities contracted a supplier to choose the best technique that fulfilled their requirements. The selection- and implementation strategy varies; some utilities did all the work by themselves, some had a company helping them just to install the meters. Others had a contract with a supplier which was responsible for the installation of the smart meters, implementation of the communication system and to get the data into the billing management system.

One advantage mentioned when having a contract with a supplier is that there is no extra unplanned costs, everything is already included in the price and if problems comes up the supplier is responsible of rectification. For one utility, PLC was planned for the whole distribution area but during the project more and more problems came up and it resulted in a replacement of 10 000 meters. Because the installed meters were designed for PLC-communication, they needed to be replaced when switching to radio communication instead. There is no standard type of meters, which works for all transmission techniques therefore the utilities are very dependent on the manufacturer of their choice. There have been discussions about having a standard in the industry but according to one of the persons interviewed the interest is small at the moment. But in theory it should be quite easy to develop a standard for smart meter communication.

2. **Advantages and disadvantages with the different techniques:**

The utilities in the survey have different opinions and experiences of the transmission techniques. Since most utilities uses PLC and radio the majority of experiences are here.

PLC is considered to be a cost effective solution since all infrastructure is already present. Another advantage is that utilities own the transmission net which PLC communicates over therefore they are not dependent on an external supplier of infrastructure. There is only minor extra equipment needed and no communication cost. Disadvantages with PLC are the dependency on the quality of the transmission net as well as the sensitivity for disturbances on the net and external disturbances. One utility started with PLC for about ten years ago and it worked well in the beginning but around five years ago the disturbance problems started and have thereafter increased. Another utility was promised that it should work with PLC in their complete distribution area but it turned out that there were too many disturbances in the city area so the choice of technique was changed. Households have much more electronic equipment now compared to ten years ago. Disturbance sources are for instance 3-G masts, frequency regulated engines, energy- saving lamps, flat screens and parabolas. Other disadvantages are that PLC is a bad solution for people sensitive to electricity and when temporary resection in the network is needed PLC does not work. Utilities having PLC are often offering electricity sensitive customers another alternative technique working for them.

For a utility with mostly detached houses and summer cottages the coverage with GSM/GPRS was to bad and with only a few customers per net station it would have been too expensive with one concentrator in each. Therefore different variants of PLC were chosen.

Radio was chosen by one utility due to the good availability and that study visits showed that PLC did not work very well. GPRS was an alternative but it would have been too expensive. The costs for GPRS are very high since the prices offered by the telecom companies are very high. This might change if they see an increased potential for this kind of services in the future. Radio is often used together with PLC since the radio technique is a good complement where PLC is not working. It is also a commonly used solution for industry costumers or other customers with high electricity consumption. An advantage with radio is that a fewer number of concentrators are needed compared to PLC and they can also be installed at the best location which might not necessary be in the substation. PLC must be installed in the substation since it needs a galvanic connection which radio does not need. However most of the concentrators are placed in the substations since the utility owns the buildings.

One utility already used radio technique for district heating meters and therefore it was convenient to choose this technique for electricity meters as well. Radio is a flexible system which opens up for a lot of new possibilities and it can also handle current trafo-measurements which is interesting for power customers. One utility is working on the possibility to add additional services such as fire alarms and housebreaking alarms. In the future a service to the home- help service of electronic-keys will be developed by one utility.

Radio is more expensive to buy than PLC and to operate but it is less sensitive to disturbances. The radio signal is sometimes vague, since the networks always need to maintain continuous contact with the meters it is necessary to put high requirements on the infrastructure. Most of the utilities that are using radio have the so called mesh technique and the meters acts as routers or repeaters i.e. the signals are reinforced for other meters. In this way the data is transmitted from “meter to meter” until it reaches the concentrator in the substation. One meter alone can sometimes have difficulties but then an additional meter/repeater is installed which the data can be repeated from and then be transmitted to the collector. Problems can occur if the meters are capsulated in cable cupboards or placed in houses with a sheet metal façade because then the signal is very vague or it does not reach the concentrator at all. Usually there is a window which the meter can communicate through otherwise it can easily be solved by adding an additional antenna or placing the antenna outside the cupboard or building. Concrete walls are generally no problem as long as they are not reinforced and usually meters also work well in basements.

The utilities in the survey that are using radio technique have only positive experiences so far. Radio is a stable technique which is insensitive for disturbances and almost all data is collected, one utility mentioned 99, 98% availability. During resection of the transmission net they do not lose communication as with PLC which is another advantage.

GPRS is only used by a few utilities and is often used as a complement to other techniques. This alternative was chosen by one utility since the supplier considered it as the best alternative based on pre requirements such as local conditions and functionality. One utility uses GSM/GPRS only for customers over 80A (Ampere), where no other connection is possible or where there are too few i.e. one to two customers per substation. No specific advantages were mentioned. Some utilities which are not using this technique pointed out high costs as the reason.

3. **How does the distribution area look like and where are the meters placed?**

The next question relates to the distribution areas and how the meters are placed and possibilities of communication between the meters in a building. The distribution area for most utilities consists both of a city area and countryside. The placement of the meters varies a lot and they can be placed in the basement of a house or building, on each floor or in the flat in an apartment building, outside in a cable cupboard or in a separate locker where all meters are placed, sometimes together with other equipment as telephones, internet switches and cable TV.

The new law in Germany obligates utilities to give their customers the possibility to look either on the display of the meter or to get consumption data in another way. Therefore communication between meters or in-house communication is interesting. One alternative when the meter is placed in a locked space is in- house communication. Using radio in- house communication is no problem since the meters are open for each other and transmits the data between each other as repeaters until it reaches the collector in the substation. PLC meters cannot communicate with each other.

4. **How much did the implementation of smart meters cost and who needed to pay?**

The implementation costs of smart meters consists of costs for terminal value of the old meters, purchase and installation of new meters, concentrators and implementation of a new infrastructure for communication system, computer programs and data servers as well as operation of the system. The energy branch calculated with costs around 2 000 SEK (191€) per metering point i.e. cost for smart meters, communication system, installation and implementation. Most utilities are far below this amount. Not all interviewed utilities wanted to mention their cost but one said they are far below 2 000 SEK (191€), four have had a cost of 1 300 SEK (124€) per metering point and one utility 1 545 SEK (147€). Only one utility of those who informed about the exact amount have costs above the expected costs with 2 592 SEK (247€). The workload has also changed from field work to paper work.

The old system was though not free either. According to one utility each manual reading did cost around 400 000-500 000 SEK (38 095- 47 619€) for around 25 000 customers and about the same costs for customer call centre.

Some utilities considering changing to effect tariffs which is a step less system, instead of dividing customers in a number of fuse levels.

5. Advantages and disadvantages for the utilities installing smart meters

An important issue when deciding whether to implement smart meters or not is obvious advantages and disadvantages for the utility. In Sweden utilities had no choice due to legal requirements in Germany on the other hand utilities need to see advantages with choosing to implement smart meters. One utility mentioned that it is a disadvantage to be forced to do the investment at one single time. Normally around 100 meters at a time are changed and if something is wrong it is not so grave but with 100 000 metering points the case looks different.

Generally the implementation in Sweden worked well but some utilities still have problems getting data from all meters every month and must do some manual readings which of course are costly. Utilities have different experiences and opinions about smart metering in general and future possibilities. Most utilities are predominantly positive and see smart meters as a tool for better customer relationship and to more easily help their customers since they have access to detailed information about consumption pattern. With more detailed information utilities can more easily and also faster help their customers regarding invoice questions and customers reacting on a high bill. It is much easier to notice when a consumption pattern changed and why e.g. installation of floor heating. Many costumers are not aware of such factors that may increase their electricity consumption remarkably and for them monthly bills is a great tool to understand their consumption better. Most utilities offer costumers to see their consumption direct on a personal homepage where an update is made each hour, day, week or month.

Nowadays customers in Sweden get monthly bills with the exact consumption information. The invoices are now more precise and they only consist of the exact electricity consumed, thus the old complicated pre debit is over. A lot of customers complained about being debited too high and did not understand the final invoice that they received either in the summer or at the end of the year, these problems does not exist anymore. Many utilities have noticed a decrease in phone calls to the customer service and thereby lower costs while others do not see any difference. Some utilities mentioned an increase of questions during the installation of the smart meters but the questions regarding invoices have decreased after the roll-pot of smart meters. In the future when the system is fully working, utilities hope for a reduction of phone calls but at the moment there are still utilities facing some problems with the phase in of the new billing system.

As a disadvantage many utilities mention the cost of implementing a new system and for the smaller utilities it is their largest investment ever. One utility said that the investment has already paid off since personnel in the call centre could be reduced and they do not need to do manual readings anymore. No more manual readings mean less driving and thereby a cleaner environment which one utility saw as an advantage as well. Most utilities believe that they will get return on their investment in the future. The time it takes probably depends on the size of the utility and how well the system worked from the beginning. The implementation work with smart meters was a new kind of work for the utilities, which has been challenging and time consuming. One utility asked themselves if the implementation of smart meters is worth the money. When everything works it is probably worth it but some utilities also mentioned their dependency of the reliability of the system. But since the Swedish utilities were obligated by law they didn't have any alternative.

Monthly readings means larger amount of data that needs to be taken care of. Some utilities only collect the data once a month while others collect the data every day, usually around 24.00. Utilities receives more detailed statistic over consumption pattern and it is easier to compare different time periods. The easy access of detailed data is positive for customers asking about their invoice. Utilities also get a good view of the flows in the transmission network and can easier find out when investments need to be made. This was not possible before and utilities then sometimes did investment under uncertainty. Utilities have better control of the electricity flow in the transmission network now and errors occurring during manual reading will diminish.

With smart meters utilities can also use effect tariffs in apartment buildings, at the moment the customers are divided in household customers/ less consumers having main fuse ≤ 63A and larger consumers/ industry consumers with a main fuse ≥ 80A. Further advantages are specific information about electrical power outage and if something is wrong with the meter the utility receive an alarm. It is also easier to discover power thefts and if someone tries to manipulate the meter or disturb it through electromagnetism, an alarm is forwarded to the utility.

When people are moving the meter is remotely read out which makes it easier and faster both for the customer and utility. Some utilities also disconnect it so that no electricity can be used when e.g. a flat stands empty. Disconnection is also a possibility when customers have not paid their bill during a longer period, which is a problem that has increased with monthly bills. Before customers were used to get a bill with the same amount to pay each month or each quarter but since they now need to pay exactly for the amount consumed which during the winter months can be essentially higher than during summer time.

On top of the increased costs for read outs, disadvantages mentioned by some utilities are the need for another competence to handle those complex systems. All electronic equipment is sensitive for thunderstorms and in north Sweden one utility already needed to change a couple of fuses. The new meters have a shorter lifetime compared to the older electromechanical meters that could be used for 18 years then after a revision they could be used again. New meters are allowed to have in use for nine years only.

6. **Are any additional services offered since the installation of smart meters?**

Smart meters gives possibilities for additional services, the interviewed utilities were asked if they will offer their customers any additional services compared to before. Most utilities already offer their customer a website where they can login with a username and password and see their consumption. The consumption is presented in graphs and customers can choose which time periods they will see and compare consumption with e.g. the month before or an average consumption.

Many utilities offer their customers an advice service consisting of advices related to energy efficiency and to save energy. This service is mostly for detached house owners, people living in apartments have few possibilities of influencing their consumption.

7. **Can any changes in the electricity consumption pattern already be seen?**

An important question is if customer's electricity consumption has changed after the installation of smart meters and monthly bills. Most utilities answered that it is too early to say but one utility have already seen a decrease. This decrease can although depend on many reasons such as the economic situation, high electricity prices and increased awareness of the environment but the hope that smart meters will be one tool to improve and receive a cleaner environment. Even if the consumption has not decreased many customers are now more aware of their electricity consumption and hopefully smart meters can influence their behaviour in the long run.

Utilities using effect tariffs have already seen a change in behaviour, the effect used has decreased and when people coming home for example they do not start all households' machines on the same time as they used to do before.

8. **What about smart meters having a display installed inside the apartment or house giving direct feedback to customers? Are the possibilities of saving energy then higher?**

There have been critics against Sweden about the choice of smart meters and that the legal requirements from the government only stipulated monthly feedback. According to the British researcher Sarah Darby a reduction of electricity consumption in the order of five to 15 percent is possible when having direct feedback through a display on the wall, on the computer or directly via the mobile phone. According to both Darby and the Finnish researcher Jessica Strömbäck monthly feedback only gives a saving potential on average five percent. Utilities interviewed had different opinions about the saving potential as well as the interest by the customers for direct feedback.

Some utilities in Sweden have installed smart meters having a display but usually the meter is installed in the basement or sometimes in a looked room and then customers cannot access the meter. Even if all customers have the right to be able to see their electricity meter this is not possible for many customers. How smart the new meters are depends on when they were installed and what techniques that was present at that time. It is also a question about costs, the display cost around 1 000 SEK (95€) according to one utility and they also mentioned that the display also consumes electricity.

Many utilities do not believe that direct feedback will lower the energy consumption. Other believes that it could be useful for some customers since they would get a better understanding for their consumption. Most utilities also said that it probably would be interesting in the beginning but after a while only the really interested persons would use this function. It would have been a costly investment which might have only been used by a few customers. Some utilities have meters which can be complemented with a display but then the customer needs to pay for it themselves. There has so far only been a vague interest from the customers and only one utility offers customer the possibility of installing a display.

9. **Data security and data integrity:**

Data security and data integrity has been of great interest in Germany where many customers have reacted. In Sweden all utilities interviewed answered that they have got no or just a few questions regarding this topic. A couple of customers had a negative attitude towards getting a smart meter installed since this would enable the utility to have a view on their consumption pattern. But from most of the customers there have only been positive reactions. For the utilities the main question regarding security is if it is possible to manipulate the meter.

Meters use specific protocols and techniques which makes it difficult to hack the meter, but one utility mentioned that if someone buys the same equipment maybe they can access the information in theory. Common for all utilities is that no personal information is transmitted, only the meter id and the consumption data is transmitted which means that if someone get hold of the data they cannot connect it to a single consumer. Most utilities codes the data and uses passwords as well as fire walls, certificates, clients and qualifications. Some utilities also mentioned that they use VPN- tunnels i.e. a secure tunnel between two units that is used to a secure transmission of data over internet. Some smaller utilities works together with a data security company and for another utility this service and guarantee of security was included in the purchase of the whole system. Overall the interviewed utilities did not consider data security as a problem and very few customers have reacted negatively. There have however been discussions about if the meter measures wrong but the new meters are neither better nor worse than the older ones concerning accuracy. One utility wanted to clarify that it is a difference if the meters measures wrong or if there are errors on the transmitted data.

10. What is the functionality of the present meter and is it possible to upgrade it later on?

The last question relates to the functionality of the present meters and if it is possible to upgrade them later on. Most meters can handle hourly values and one utility also collects the data every hour. Some utilities having meters that can handle hourly values however said that they do not know for sure that it will work since they only collect data every day or month. Normally data is collected once every day at midnight and customers get access to the data on the homepage. Most meters have the following possibilities:

- Measure power and current on every phase as well as reactive effect.
- Measure in both directions which is interesting when customers have solar cells or a small wind power and want to send power back to the net when not needing it themselves.
- Connect to district heating system or heat meters.
- Show instantaneous effect.
- Wireless upgrade of software.
- Integrated switch, when no customer in 15 days it automatically switch off.
- Reset function to register consumption from a new starting point.
- Can change hardware by switching to another module on the meter.

5 Smart Meters in other European countries

The status of implementation of smart meters in other European countries varies a lot from Italy having almost 100 % roll out to other countries where there only are pilot projects. Below the status in some European countries are described.

5.1 Italy

Italy was the first country adopting smart meters and since 2006, digital smart meters are compulsory for all, around 100 electricity providers in Italy. The timetable of the government is that 65% of the customers should have smart meters 2009, 90% 2010 and 95% 2011. That is by 2011 will almost all 36 million Italian electricity consumers be covered [12]. In 2008, 86% of all Italian households were equipped with smart meters and the initiative comes mainly from the utility ENEL. The situation in Italy is unique since it was the private own company ENEL that introduced smart meters in full scale. Between 2001 and 2005 around 30 million smart meters were installed and some of the reasons for the implementation are prevention of electricity theft and a more efficient control of the electricity supplied. The politics also has interest in a full roll out of smart meters; development of the competition in the household customer area, participation of the customers in saving energy through smart meters and decreasing the intervals for measuring to one hour.

For smart meters in the electricity market the roll out should be finished at the end of 2011 and in the gas area plans are going on though a final date is not yet decided. The government agency has determined a couple of requirements for the smart meters respectively the meter systems. In detail as following;

- Time dependent tariffs (up to four time bands per day) and a weekly profile
- Ability for interval measurements
- Data safety while transmitting the data to the control center and by alarm when the meter outage
- Remote controllable actions: periodical meter readings, readings at intervals, connection and disconnection, changes of electricity supply, price changes and load reduction
- Storage of data readings
- Meter display
- Possibility for upgrading the software program
- Information of voltage fluctuations
- A percentage of the yearly remote controllable actions within 24 and 48 hours
- Reporting of the, by the meter readings, registered errors to the communication centre [30]

5.2 Finland

In Finland around 20 % of the three million households have smart meters installed [33]. According to a legal requirement from 1 march 2009 there should be a full implementation of smart meters 1 January 2014. The requirements for the new smart meters are following;

- Hourly measurement (monthly bills based on hourly measurements will be compulsory)
- Two way communication
- Registering of outages longer than three minutes
- One load control output
- Supports simple time-of-use tariffs and controls

- Security of data
- No mandatory connection to house automation. If the customer needs data direct from the meter, the meter will be changed. The customer must pay for the change and at the moment there are change fees of about 300-400 € per meter change.
- No requirements for the meters to support multi- utility metering.

For meters already installed or ordered these requirements are not mandatory.

The reasons for the new legislation of smart metering are energy efficiency by giving energy information to the costumers, developing and harmonization of the electricity retail market, enabling more demand response, regulation of network operations and meeting the Energy Service Directive. The implementation did not solve all problems, Finland is a small area for smart meters which means high cost for them and the services and applications based on them [34]. The smart meters will be used for faster power failure resolution as well as a platform for future services.

Fortum, the largest energy utility in Finland and a leading energy company in the Nordic countries, will perform a large advanced metering infrastructure project with 550 000 customers. The objectives are to offer energy saving and home automation programs for homeowners, the ability to provide hourly measurements of energy use for retail customers and bi- directional net energy measurement for customer own alternative energy generation. The advanced metering infrastructure consists of advanced electronic electricity meters which are accessed via a web service based network operating system over an IP networking infrastructure [35].

5.3 The Netherlands

By 2015 all households in the Netherlands should have smart meters. It is not known how many smart meters that are already installed, but in 2008 there was only one supplier present which indicates that only around three percent of all meters have been changed. The electricity market in the Netherlands was deregulated in 2004 and the electricity supply is very concentrated; the capacity is controlled by a small number of suppliers. The electricity comes mainly from fossil fuels, although ten percent comes from renewable energy sources.

The Netherlands is one of the largest gas producers in Europe and the gas market was deregulated in 2004. The market for the metering and measurement business was opened for electricity in 2000 and for gas in 2001 and the purpose of the opening were competition and lowering of the prices. This was however not reached, the prices were increased and it did not lead to a fast and total implementation of smart meters. To be able to accomplish the implementation the market was restructured. In 2008 the planned roll out was decided by the government and it should occur within six years. Basically the network operators are responsible and they have to deliver a yearly report about the proceedings and potential problems. First of all, the network operator should make a time plan of the roll out and thereafter discussions with electric utilities and households can be held so to not exclude anyone from the process. If requested by the customer a third part can install the meter, as long as it is guaranteed that the network operator can use it. To make it easier for the customer the Netherlands legislator has defined technical requirements for the meter. The Netherlands standardisation office has together with energy supply companies and other involved players, decided some functions for the meters. The following should be performed:

- The meter should be equipped with a measurement function and it must, when possible, be able to via remote transmission decide how much energy that were taken from the net as well as how much that was fed in to the net e.g. from a small solar power plant.

- The meter must have a remote switching function so that the network owner can switch on and off the capacity remotely. This can be necessary to avoid large power black outs and it can also be used when a building is empty for a long time. Furthermore alternative payment functions such as prepaid can therewith be supported.
- A report function must be present so that the network operator is able to control the quality of the electricity supply. Losses as well as theft of electricity can be noticed via a notification and if someone is trying to manipulate the meter there will automatically be an alarm.
- The meter must be able to communicate and this function can for example be used for remote readings. This means that the meter needs to be connected to a modem that is a part of the meter structure. The possibility of remote readings gives the network operator an opportunity to better adjust their offers to the customers.
- Finally the meter needs to have a control function. This function support additional applications that can be added optional to the meter. Examples of additional functions are: local electricity production systems, alarm systems or automatically regulation of household appliances. The use of these functions can be controlled or regulated via the meter for the purpose to e.g. reduction of electricity at certain periods, when using time tariffs.

The above mentioned requirements are only the minimum and they can be expanded if wanted. For example is it possible to update the software remotely, when needed. Through technical specifications a “standard meter” was defined, but it should still be open for innovation [30].

5.4 Austria

In Austria there are around 5.3 million electricity household meters and for the installation and operation the DSOs are responsible. Some DSOs are preparing for smart meters through different projects. Currently the Austrian energy companies Energie AG, Stadtwerke Feldkirch, Linz AG and Salzburg AG are carrying out pilot projects.

Energie AG wants to install smart meters by 85% of their customers by 2015 and in autumn 2008 they started a pilot project, installing 10 000 meters. A full scale roll out is planned at the end of this year and it is the most ambitious project in Austria. Stadtwerke Feldkirch wants to equip all 17 000 customers with smart meters within 11 years and new customers or customers that have a meter that needs to be calibrated will get a smart meter instead of an old one. Around 2 000 meters are already installed and all transformation stations will be equipped with a concentrator. Since Linz AG needs to change around 35 000 old mechanical meters they decided to install smart meters instead, the roll out started in 2008 and 70 000 smart meters are planned to be installed. At the moment almost all Austrian customers only get one bill per year based on their actual consumption of electricity, with smart meters or increased billing/information frequency it can be changed. One expects that the installation of smart meters will lead to an enhanced and more efficient Austrian electricity market model. Currently Austria uses standardized synthetic German load profiles with additional Austrian enhancements. Smart meters will generate an improved data and can make it possible to generate improved Austrian analytical load profiles [36].

Austria has concluded that Smart Metering will increase profitability and are considering introducing smart metering systems throughout the country.

5.5 UK

The spread of smart meters in the United Kingdom is still very low, 2007 only 0.5 % smart meters in electricity area were installed. Until now there are some pilot projects running, mostly by utilities in cooperation with or supported by public or semi public organisations. The largest project, “Energy demand research project” started in 2007 and expire in 2010 [30]. This is a project where four major energy suppliers are leading trials to examine how energy consumers respond to better information about their energy consumption. Around 50 000 households will respond to the trials that are made of different combinations, 18 000 houses will have smart meters and 8 000 homes will get real- time display devices [37].

The market for electricity and gas was deregulated in 1999 and the market for the metering and measurement business was opened relative early. In October 2008 the government decided for a full roll out of smart meters, it should start in 2010 and be finished at end of 2020. The main reasons for implementing smart meters are the change in consumption pattern and the long term development of the energy system towards Smart Grids. For the consumers the advantages are a more accurate bill and no more appointments for meter readings.

The government decided following requirements for the smart meters:

- Preparation of accurate meter readings and information of certain time periods for remote readings.
- Bidirectional communication
- Home networking based on open standards and protocols
- Possibility of using different time varying tariffs
- Ability of load management for the demand side management activities
- Possibility of remote regulation of connection and disconnection of the electricity supply
- Measurements of the in net saved energy (measurement of net export)
- Ability to communicate with a micro power plant meter

Until now the possibility of connection and disconnection of the supply of electricity causes controversial debates. The government have however already decided about a full roll- out until 2020 even thought the exact implementation is not yet clear since the results from the pilot project will be taken into account.

Scottish and southern energy performs trials with 28 000 customers, 11 000 smart meters for 8 000 customers, electricity and electricity plus gas. There will be a Time of use (ToU) tariff for 4 000 customers and real-time display for 5000 customers [38].

6 Smart Meters in Germany

From 1st January 2010 utilities in Germany are obliged to install smart meters in new-built buildings and also for buildings being renovated but there is no legal requirement of a full smart meter roll-out for all customers. There is also an obligation for utilities to install smart meters on request by customers but the cost is then expected to be carried by the customers. The new law is challenging for German utilities, since they need to have smart metering solutions available on relatively short notice. In this chapter some background information about the situation in Germany is given as well as the German legal requirements for meter readings.

6.1 Background

The German government's goal is to become one of the leading countries in CO_2 emission reduction. This will be achieved through an integrated energy- and climate program [39]. According to the Institute for climate, environment and energy in Wuppertal the possible savings with smart meters are five to ten percent of the aggregated energy consumption per household. These numbers are based on experiences from other countries and for Germany it means a reduction of five to ten million tons of CO_2 per year [40].

On the 9th September 2008 the government enforced a competitive measurement business for electricity and gas through a new law, which amongst others gives the opportunity for customers to choose to get a smart meter installed. Furthermore this shall open up for price advantages for the customers as well as development and innovations regarding meter reading and concepts for smart grids. A declared goal is to have a full roll out of smart meters with load variable tariffs within a couple of years. The customers shall also be able to follow and control their electricity consumption.

For the consumers, the arguments' for installing smart meters are; to save electricity, get more transparency on electricity consumption, value added services and a more intelligent net control. For the utilities it is a possibility of preparation for future developments and to learn more about this new technology. The old electricity- and gas-meters are out of date and do not comply with the present technical possibilities.

6.2 Legal framework requirements

The following laws in Germany refer to smart metering: Messstellenzugangsverodnung (MessZV), EDL- Richtlinie (Endenergieeffizienz und Energiedienstleistungen) and an update of the §21b Energiewirtschaftsgesetzes (EnWG) and includes a mandatory liberalisation, an unbundling of the larger distribution companies and calibration. According to the EDL-Richtlinie the installation of smart meters in new-built buildings and renovated buildings is mandatory from 1st January 2010. When an old meter has to be changed a smart meter should preferably be installed and customers shall be offered to get one installed if requested. Although it is not stated that it should be free of charge, the utilities can decide themselves how to arrange it. Metering devices must show the actual usage of electricity and the consumption pattern. Utilities are obliged to offer a shorter billing period e.g. monthly, quarterly or half yearly if desired by the customer. From 30th December 2010 energy saving tariffs e.g. time- or load- variable tariffs shall also be provided [10], [39], [41], [42].

7 Development status at the largest German utilities

Germany is the largest energy market in Europe and there are around 900 utilities that operate on the electricity market in Germany. However, 80% of electricity generation is controlled by the four largest utilities; RWE AG, E.ON AG, Vattenfall Europe AG and Energie Baden-Württemberg AG (EnBW) [6], [43]. Figure 8 shows how the electricity market is divided in different regions between the four largest utilities in Germany.

Figure 8 Shares of the German electricity market from the four largest utilities in Germany [44].

For the utilities the time is narrow, from 1 January 2010 they are obliged to install smart meters in new constructed buildings and in renovated buildings and all electricity- and gas-consumers should have the possibility to get smart meters installed. This should be done preconditioned that it is technically and economically feasible.

Until now about 130 000 new electricity smart meters are installed through different pilot projects around in Germany. The implementation and status at the four largest companies are described beneath.

7.1 RWE

Starting from 2008 RWE performs installations of smart meters for households in Mülheim an der Ruhr. Mülheim an der Ruhr is a city with around 170 000 habitants and 100 000 meter terminals and the supply area includes both a lot of buildings concentrated in the city centre and areas with more outspread houses which means a great possibility to try different transmission techniques. Also schools and administrative buildings shall be equipped with smart meters. Above the installation of 100 000 smart meters around 900 distribution network stations are equipped with necessary electronic equipment for the communication [45].

There are three main goals of the pilot project. First of all it is a push for a new technology; the new meters can deliver much more data about load and consumption than the old mechanical Ferraris meters. The data can be reached at all time which makes it easier to control. The vision in the future is to be able to integrate the electricity-, gas- and water consumption in one meter and be able to read out all remotely. Secondly it will hopefully increase the motivation to reduce energy. When feedback is given directly and changes can be seen ad hoc RWE thinks that both customers as well as generators will be more motivated. The third goal is to give an industrial political impulse to implement smart meters. On the meter market there are a lot of actors but the present smart metering systems are not compatible with each other and manufacturer are waiting for a political decision. With 100 000 smart meters RWE is driving the largest pilot project in Germany.

At the same time as the smart meters are installed a new infrastructure for communication is being built. The communication infrastructure provides remote read outs for the meters, handles the data and adapts the billing process to the new technology. As soon as the technical requirements are fulfilled all utilities in the region who wants to offer customers different services will get the relevant data. One of the goals of the project is also to increase the transparency of the costs for the customers and to strengthen RWE’s confidence by the customers [46]-[48].

7.2 E.ON

In Bavaria 10 000 customers were offered to participate in a pilot project to try the new meters and actively participate in the further development and creation of offers for the customers. The participation is free and the interest was great. 10 000 meters for electricity and around 1 000 for gas and electricity have been installed. Different types of smart meters with different communication techniques for instance power line communication and GPRS are used.

The duration of the project is 18 months and after about one year the technique was running without problems and the customers was satisfied. Especially the Web portal has been a success; there the customers can see their energy consumption from the day before or the previous week or month, their CO_2 balance and the costs. Customers also receive recommendations for lowering their consumption and customers who do not have internet will receive the information per ordinary mail.

The Web portal will also include further features: the customers shall receive forecasts for consumption and costs, the anticipated payments should be comparable with the actual costs and also different periods of time should be comparable i.e. one week with another one. Additionally customers should be able to define a certain level of maximum consumption; an alarm function should then warn the customer before this level is exceeded, according to the previously defined energy consumption budget. Further development will then be to, on the basis of personal consumption, give the customers individual recommendations for saving energy.

According to the experiences from the pilot project at E.ON, the awareness level of smart metering by the population is very low but using selective marketing campaigns the customers can be positively influenced. In the meantime 70 % of the customers accept installations of smart meters and about 40 % are interested in further services such as individual recommendations for energy savings. The experiences of the Web portal so far however shows that the diversity of tariff alternatives makes it hard to present the costs for the costumer. E.ON in Bavaria has for instance a special tariff which is not able to be monthly accounted [49]-[50].

7.3 Vattenfall

Vattenfall is driving a pilot project with 500 customers each in Berlin and Hamburg. The aim is to see how the customers react as well as to find out changes needed in the intern process due to smart metering systems. Since February 2008 the customers have the possibility to see and therewith control their consumption of electricity. The consumption pattern and the amount of energy that has been used can be seen on a display in their home.

Vattenfall uses a technique from Görlitz due to several reasons. Since a lot of meters are placed in cellars with an armoured concrete and the contact via wireless LAN or GSM- radio is not possible the consumption data is transmitted directly via the power line. Due to the physical structure a conventional internet connection was not possible either. Additionally the meters needed to be able to save load profiles in different intervals as well as to connect and disconnect empty buildings remotely.

During this project Vattenfall was working together with building societies which helped them with the contact to interested customers. The replacement of the old meter with a new smart meter is free for customers participating in the pilot project and the interest to participate was great.

Since the dimensions of the new so called *Profizähler* are the same as by the old meter no modification in the structure was needed. The smart meters are not widespread installed but rather concentrated by a large amount of customers on a street or in a terrace house residential area. The reason for this course of action is due to the meter and the data concentrator needs to be installed in a so called low voltage island. The concentrator is for this purpose installed in the substation that supplies the participating customers with electricity. The concentrator communicates with the smart meters via PLC and samples the data continually. As a functional collector the data concentrator organises the local administration of the meters via power line as well as the remote connection to the net station. Vattenfall has a new digital interface for the consumption data, a data management system. All data concentrators which each can receive signals from around 1 000 meters are directly connected to the data management system via mobile radio communication or GPRS.

From the very beginning of the pilot project the security aspects was very important both for Vattenfall and the government. One of the representatives for the data privacy protection asked for information about the actions regarding prevention of the consumption data before the project started. To have a secure transmission of the data between the concentrators and the data management system so called Virtual Private Networks (VPN) are used. In this way the transmission of the data tunnels through the open internet so that no unauthorised person can spy or manipulate the data.

Since last year the customers can login to a personal homepage at Vattenfall Europe and see the actual consumption. The smart meters send values every 15 minutes. Based on real-time information on consumption a lot of new products and individual tariffs can be developed and offered to the customers. Direct feedback offers the customers a great tool to control and actively influence their energy consumption. Smart meters are also an important medium for the utilities to have a good customer relationship and attract new customers [40], [51].

7.4 EnBW

Since August 2007 smart meters are being tested by 1 000 customers in Baden- Württemberg and from October 2008 they are offered to all customers. The customers must although pay 100 Euro for the installation of the new meter, a DSL connection is also required and the installation is only possible in houses with maximal six apartments. The smart meter is connected via the DSL- Router and the PC and therefore the PLC technique is used, the powerline is connected to an adapter close to the DSL- router and through a network cable it is connected to the router.

From the smart meter data is automatically sent to the so called *EnBW Cockpit* where it is graphically presented. The data can be seen on the computer through a secure internet communication and the customer can choose to get data for different time intervals e.g. daily, weekly or monthly. Consumption, costs as well as CO_2- emissions is then shown for the chosen time period and can be compared with another time period so to see if and how the electricity consumption is changing.

Additionally customers can use the software called *Stromradar* which can identify the electricity consumption for individual devices. This shall be a useful instrument for customers to realise where the energy is consumed and thereby be able to change behaviour and save energy and money. On the bill which comes once every month customers can get energy saving tips and if energy is used between 20 pm and 8am during the night and on weekends they receive a bonus. The goal is that this tariff will lead to a targeted use of electricity and a possibility to reduce the energy consumption and thereby save money. If the consumption of energy rises above a pre defined limit the customer will receive an alarm- SMS.

According to Uli Huener, manager at EnBW Distribution, more than one third of the customers participating in the pilot project reduced their electricity consumption more than ten percent. But the installation of a double tariff meter costs ten Euro and if a DSL connection is not already existing the costs for a new meter probably exceeds the potential savings so [52]. [52]- [54].

8 Smart Meters at Stadtwerke Ratingen GmbH

From 1st January 2010 all customers in Germany should be able to get a smart meter installed if requested, they may although need to pay for it themselves. Stadtwerke Ratingen will offer their customers a solution, where an extra data interface is installed. It is up to now not decided when it should be a full roll out of smart meters in Germany; therefore a full implementation of smart meters at Stadtwerke Ratingen is at the moment not planned.

8.1 Conditions /Prerequisite

Normally there are not only electricity meters but also gas-, heat- and water meters that have to be read out. This means that an implementation of smart meters would be most meaningful if all meters can be connected and the data can be remotely transmitted, otherwise people still need to go out to the customers getting the meter values.

Stadtwerke Ratingen has a supply area consisting both of a city area and a country side and supplies around 90 000 customers. The supply area can be seen in Figure 9, where Ratingen Mitte and Ratingen West are a city area and the rest is country side.

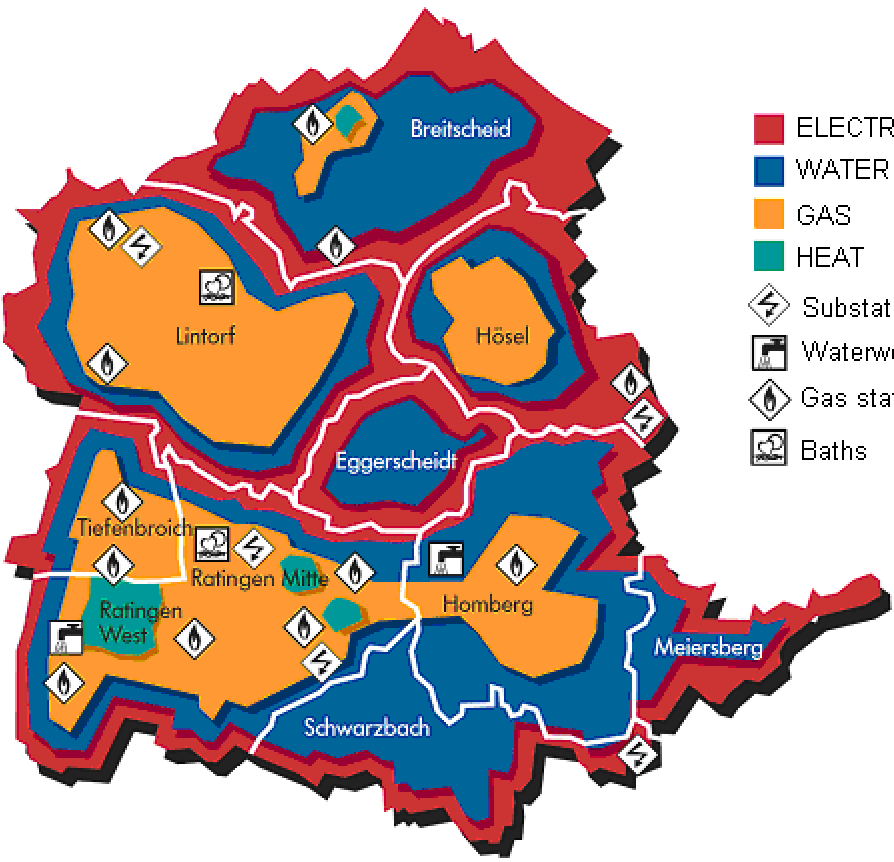

Figure 9 Supply area of Stadtwerke Ratingen GmbH [55].

When deciding to install smart meters it is important to define already at the start which functions that are the most important and need to be present. If further services for the customers are planned e.g. a web portal to see consumption or alarm functions it is a good opportunity to develop these functions at the same time. How fast and how frequently the utilities want to get the data influence the choice of technique. Installing smart meters is a good way of preparing for harder legal requirements in the future as well as possibilities of cost savings.

There are many advantages and motives for Stadtwerke Ratingen and other German utilities to implement smart metering;

- Better customer contacts
- Easier and faster meter readings
- Alarm functions if someone tries to manipulate the meter
- Easier to detect power theft
- Reduction of peak power capacity need
- More transparent invoices for customers and thereby less questions
- Additional services such as advices regarding electricity consumption
- Preparation for future demands
- More environment friendly profile of the utility

8.2 Criteria's for choosing technique

It is important that it from the beginning is clear what kind of functions that are requested from the meters. Adding additional functions later on is rather expensive. Interesting factors to consider when choosing meters and communication technique are following:

- Robust technique with long lifetime
- Hourly or monthly transmission of the data
- Possibilities of upgrading of the meter
- Independency of other operators
- Two-way communication
- Remote connection and disconnection of the meter
- Time and/or load variable tariffs
- Additional services for customers
- Display showing actual consumption
- Personal website for customers
- Alarm functions
- Registration of power black outs

Different kinds of areas may need different transmission techniques and it could be a good idea to start with a pilot project for instance in one of the countryside areas to see how a certain technique works. Thereafter, if this technique is working well it can be used in other areas with similar conditions. One of the disadvantages mentioned by Swedish utilities was the fast implementation period. Since the time was narrow a large number of meters needed to be replaced in a short time and if the meters did not work satisfactory it also meant a large cost to change them. If starting with pilot projects before a legislation of implementation of smart meters comes, Stadtwerke Ratingen will have more time. Taking one area at the time will minimise the risk of changing a large number of meters if the technique is not well working.

In the city area the prerequisites are different since there are more customers on a relatively small area. An advantage is that there are many customers living close to e.g. a substation where a concentrator can be placed but disadvantages are disturbances occurring due to flat screens, frequency controlled engines as well as parabolas.

8.3 Costs

Costs arising when implementing smart meters are for instance:

- Write-down of old meters
- Cost of new meters
- Assembling of the meters
- Implementation of communication system
- Computer software
- Databases

Even if large costs arises with the implementation of smart meters there are also many potential savings coming along. Potential savings mentioned by Swedish utilities which also can be assumed for Stadtwerke Ratingen are following:

- Cheaper meters
- Less personnel in customer centre/call centre
- Decreasing costs for read outs
- Income from additional services
- Less driving and no equipment needed for manual readings

According to Swedish utilities the new electronic meters are cheaper than the old mechanical meters and as the technique is further developed the price will probably decrease. When customers receive monthly bills it will be easier to understand and control the electricity consumption and fewer questions arise. Due to a clear invoice the questions related to consumption will probably decrease which can lead to less personnel needed for customer support. According to the study made by *ESN Consult* for Stadtwerke Ratingen, almost two third of the customers would like to get more detailed information about their consumption and they think that it will help them to lower their consumption. Smart meters are a solution to please this request from the customers and thereby get a better customer satisfaction.

Automatic read outs also mean less driving and additional expenses that did arise when the customer was not present at the time of the read out are eliminated. The customers will not be disturbed by manual readings anymore. The handling of mails to the customers concerning read outs as well as appointment bookings will vanish through smart meters. The data will be transmitted directly from the customer in to a billing system that handles the invoices. Manual errors will not be present anymore which is an advantage for both the customer and utility.

According to Enel, the Italian utility, the investment got paid off within four years and now they can count in annual savings. The same situation should have effect for Stadtwerke Ratingen even if the potential savings can vary in different countries.

8.3 Lessons learned

Experiences from Swedish utilities that have used a supplier that was responsible for everything during the implementation of smart meters are very good. It is important to specify exactly what shall be included in the price from the installation of the meters to the system is in full operation. The main advantage to engage a supplier for the whole implementation is that if there are any problems it is up to the supplier to solve these and no extra costs are added after the purchase. For instance one Swedish utility had problems with PLC in the city area and needed to change 10 000 meters when switching to another technique since the meters were constructed for PLC and were not compatible with another communication technique.

Regarding having a display showing the actual consumption most utilities interviewed did not believe that this would influence the consumption. If utilities offer their customers a website where they can see personal and frequently updated information of the consumption this will probably be sufficient. The costs of a display are quite high and are only motivated if the customer shows a real interest for it. Since the display also consumes electricity a reduction of the consumption in general is needed to motivate the display.

9 Conclusions

The main advantages with smart meters are quicker and more exact information about electricity consumption for the customers, which can lead to more efficient use of energy. Other advantages are easier and quicker read outs when people are moving or changing electricity supplier and it is easier to discover electricity thefts.

Smart meters are essential to be able to reach the climate goal set by the European Union (EU). It is an excellent tool for customers to be able to get exact information about their consumption and then take actions to lower the consumption e.g. by changing heating system. It is positive that the actions taken can be seen almost directly by logging in on a personal website. Many utilities in Sweden also offer their customers a service which includes advices regarding lowering electricity consumption.

Implementation of smart meters can be cost efficient for all parts involved. Since the EU set its goal about smart meter implementation progress has been made but in most of the countries the development is quite slow. Sweden and Italy are the pioneers, when they started with the implementation there were not so many alternatives available but with legislations and pilot projects around the world more alternatives are now available. The choice of technique in Sweden has therefore changed depending on the time of the installations. The development is still going on and smart meters and smart metering systems are a growing business with lot of potential.

For Stadtwerke Ratingen and all other utilities in Germany as well as in the rest of the European countries there are several critical issues for the implementation of smart meters. The most critical areas are government requirements, costs, choice of technique and security. Each of them will be discussed below:

Government requirements: The requirement in Sweden is monthly readings from 1st July 2009 and to be able to fulfil these requirements utilities have installed smart meters. In Finland a full roll out of smart meters shall be finished 2014 and the government in Italy requires a full roll out by 2011. In Germany there has so far been no requirement of a full roll out, this makes the utilities putting the problems of. Without legal requirements there will probably be no full roll out of smart meters in Germany. Utilities need to install smart meters in new constructed buildings and in renovated buildings from 1st January 2010 and customers shall have the possibility of getting a smart meter installed which they although need to pay for themselves. The lack of legal requirements means a short-term solution which probably will cost more in the long term run compared to invest in a full roll out immediately.

Sweden has been criticised for not having really smart meters with a display showing actual consumption installed. This is however also a question about costs and benefits both for the utility and the customer. For some customers it could probably be a good investment with direct feedback in form of a display in the apartment or house but it also requires an interest from the customer otherwise it is wasted money. The display also consumes electricity.

Possible savings when using direct feedback is five to fifteen percent according to studies made. With only monthly readings the possible savings are around five percent. One Swedish utility installed display by a number of customers and at the beginning the interest was high but after a while customers did not care about the display anymore. In some years when smart meters have been installed in more countries around the world and the techniques have been further developed this function is perhaps cheaper and more interesting. When other countries are installing their first meters Sweden probably are about to install the second generation of smart meters with additional functions. Then experiences and research can tell if a display with immediate feedback will make a great difference and a new decision can be made.

Costs: In Sweden it is the network owner company that pays for the installation of smart meters. In Germany it is until now not decided who will pay and when it should be a full roll out. The transmission network structure and ownership in Germany and Sweden are different and therefore the solution used in Sweden may need some changes before using it in Germany.

In Sweden most of the utilities had a company installing the smart meters for them. The time was narrow and they usually did not have enough time performing it themselves. A purchase was done and the one fulfilling the requirements and offering the best price was selected. The transmission solution and the type of meter was also decided step by step and depended on the time of the decision and the development status at that time. There has been a rapid development of solutions for remote transmission during the last years and the demand continuously increases.

A question to ask if it is worth all money invested. New meters are cheaper than the old mechanical meters but one disadvantage is a shorter life time. Customer questions about invoices can be better treated since utilities have more detailed information and customers do not need to get disturbed due to local readings. But one question to think about is if customers shall they receive something they did not ask for.

Most of the utilities in Sweden believe that the cost of implementing smart meters will be covered by among others a decreased demand to the customer service. Mostly they see advantages in being able to help their customers more easy and specific with actual consumption and questions regarding their bill. Further it is easier to discover theft of electricity and when e.g. an apartment is empty they can disconnect the electricity remotely.

Choice of technique: There are advantages and disadvantages with all transmission techniques and when choosing it is important to consider to have a robust and reliable system with a long lifetime. The most used techniques in Sweden are PLC and Radio but also GSM/GPRS is used by some utilities.

PLC is used by many utilities in Sweden since all infrastructures is already present and there is no or only a small need for extra equipment. It is a cheap solution and another advantage is that utilities own the network and they are not depending on another party. PLC is however sensitive to disturbances such as frequency controlled engines, energy saving lamps, flat screens and parabolas. Some disturbances can be removed using filter. Due to the increased disturbance problems during the last years one Swedish utility is now changing to radio instead.

Radio is more expensive to buy and operate than PLC but insensitive to disturbances. Due to this reason it is often used in combination with PLC and installed where PLC cannot be used due to large disturbances. Another advantage with radio is that less concentrators are needed and no galvanic contact with the meter is needed.

An important issue regarding the purchase of a smart metering system is compatibility, meters from different companies must be able to communicate with each other and the energy utilities do not want to get dependent of only one company delivering the meters.

Security: There are several security aspects to consider regarding smart metering. According to data security consultants of the British government survey smart meters can be hacked thus security is an important aspect. The meters can be infected by so called worms, similarly to those transmitted by e-mails, and can lead to serious damages. In Sweden it is just the meter number and the data that are transmitted. This means that if someone hacks the system this is the only information they got, no personal information is transmitted over the net.

Some customers are hesitant to smart meter since that the utility can see what is going on in their house e.g. when electricity is used and when there is a high consumption. Utilities are worried about manipulation of the meters. Another essential aspect is the disconnection function of the meters, it is both in the costumers and the utilities interest that this function cannot be manipulated.

The benefits with smart meters are significant compared to the old meters and the technology is already accessible to a favourable price. The development will however continue as the market develops and growths. The experiences from countries having a full roll out shows that the implementation can be done fast and that the costs are relatively low. The security aspects are of importance and should be consider when implementing the systems, but this is something that is needed for all systems handling data. To get a full roll out of smart meters it is necessary that the government takes greater action as already done in some countries. 2020 is approaching fast and many claims that smart meters are an essentiality to reach the 20-20-20 target set by EU.

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11 Appendix

A Remote transmission techniques

UMTS

Data in the Universal Mobile Telecommunication System (UMTS), also called 3G, is treated on the same way as for GPRS but has higher transmission rates. A higher transmission capacity is however at the moment no advantage due to limited amount of data in the AMR-system [Rohlin, S, *Informationssäkerhet i AMR- system*, XR-EE-ICS 2006:01].

DSL

Digital Subscriber Line (DSL) is a type of transmission technique, using the broad band to communicate and transmit data. DSL enables fast surf in the internet and a comprehensive transmission of data through the telecommunication network. This is done by using a high frequency. The advantage is that one can speak on telephone and at the same time data is transmitted over the cables [http://www.dslweb.de/dsl-schritt1.htm].

M2M

M2M means machine to machine communication. By combining two already wide used techniques as GSM and Internet, devices can be connected in a constantly-present network which gives a two way communication between the device and the business application. The Figure below shows the basic concept of a M2M- application [http://www.maingate.se/about-m2m-1.aspx].

B Standards for PLC

CENELEC

CENELEC is a standardisation committee for different electrical standards in Europe. One interesting standard is EN 50 065-1 which deals with allocation of the frequency band for signalising in the network.

EN 50 065-1 defines different frequency bands for signalising on the power network, they are called the CENELEC- bands are divided as following:

- A- Band. Frequency between 9 and 95 kHz which are reserved for the utilities signalising in the network.
- B- Band. Frequency in the range from 95 to 125 kHz meant for customer installations of PLC without access protocol.
- C- Band. Frequency between 125 to 140 kHz reserved for customer installations of PLC with access protocol. Requirements apply; a signal transmission cannot last continually for more than one second and is only allowed when the frequency band is not already in use.
- D- Band. Frequency band between 140 to 148.5 kHz and is like the B- Band reserved for customer installations without access protocols.

Figure 3 shows the CENELC- classification of the frequency bands.

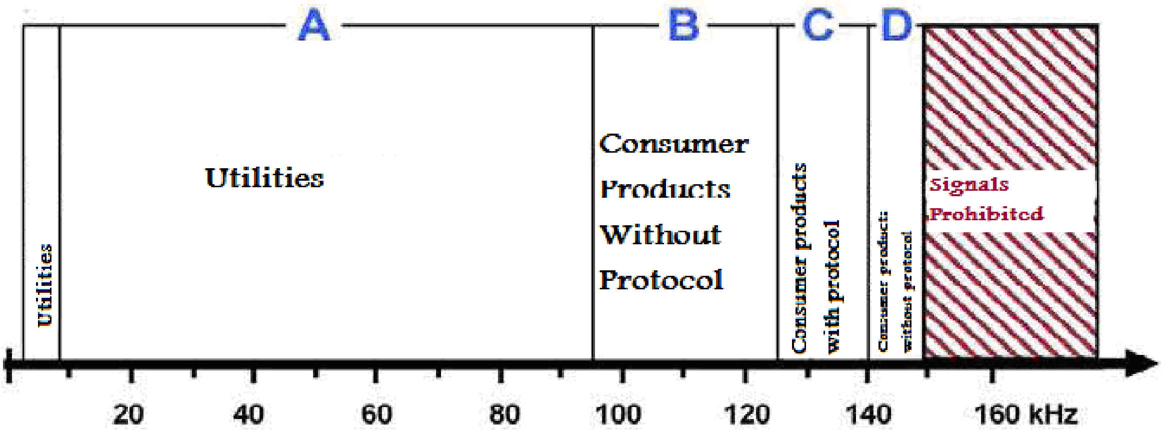

Figure 10 CENELC- Bands and their respective using areas.

IEEE Standards

- IEEE P1675: Standard for Broadband over Powerline Hardware
- IEEE P1775: Powerline Communication Equipment- Electromagnetic Compatibility (EMC) Requirements
- IEEE P1901: Draft Standard for Broadband over Power Line Networks

OPERA: Open PLC European Research Alliance, a R&D project with foundings from the European Commission.

C Ediel

Ediel is the EDI- system (Electronic Data Interchange) of the energy branch and it is used for electronic information exchange between all actors on the Nordic energy market. All actors participating on the energy market, except the consumers are obliged to use Ediel in its communication with other actors. To be able to use Ediel a contract is needed which is signed with Svenska Kraftnät. The standard used for the information exchange is called EDIFACT. The transmission is performed through SMTP over internet and different Ediel- messages are used for different kinds of information e.g. when changing supplier or to report meter values [http://www.svk.se/Energimarknaden/El/Ediel/].

More information about Ediel can be found on http://www.ediel.se/EdielPortal/index.aspx#.

D Questions to Swedish utilities

1. Which technique is used to transmit the consumption data from the customers to the energy supply companies?

2. Why did you choose this technique? What criteria's were used? Which are the advantages and disadvantages with these techniques?

3. How is the possibility of house intern communication between the different meters? How does your supply area look (apartment buildings, one family houses…) and where are the meters placed? (in the basement, on each floor or inside each apartment)

4. How do you work with data security and the directives of data integrity? Have the customers reacted?

5. Which advantages and disadvantages do you, as a utility, see with smart meters?

6. Will you, with the implementation of smart meters, offer new services?

7. Is it already possible to see a change in electricity consumption pattern?

8. Costs? Who will pay for the implementation?

9. Sweden has become critics since they have not installed really smart meters, with a display that shows real time electricity consumption, from the beginning. What is your opinion?

10. How much are these new meters able to do? Is it possible to update them later on?