TAMPERE UNIVERSITY OF TECHNOLOGY

,

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NEW BUSINESS AND PROCESS DEVELOPMENT OPPORTUNITIES UTILIZING METER DATA MANAGEMENT SYSTEM

Master of Science Thesis

Examiner: professor Pertti Järventausta
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ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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Automatic meter reading is becoming more popular amongst the network companies partly because companies own will, partly dictated by the law. Unlike traditional meters, automatically read meters generate consumption information on hourly basis. In addition to hourly-based consumption data the automatically read meters are able to produce information needed to improve the processes of electricity distribution company. This increased amount of information requires a new kind of management tool to process and analyze it and to produce reports for different operating tools of a company. In addition, several other systems can be integrated with the meter data management system, such as customer information system. This reduces the need of storing and retrieving data in many different places.

In this master's thesis, the Vattenfall Verkko's processes' current and future needs of information and reports based on the data received from the automatically read meters are studied. In addition, this thesis examines the current meter data management system, and how reports and features of the current system meet the needs of the information of processes. Furthermore, this thesis analyses the benefits of information to processes as well as to customers. This thesis is done as a part of the Smart Grids and Energy Markets project first phase of work package 3.1.3: Active Resources.

The work is divided into two parts. The first part, which is done as a literature study, concentrates on the backgrounds of MDMS, the automatic metering system. Section describes the meter used by Vattenfall Verkko, Vattenfall previous projects related to automatic metering infrastructure and electricity markets and the development of legislation to the extent that it affects the automatic metering. Furthermore, the partition presents the benefits of an automatic meter reading infrastructure to the network company, customers, other parties and the environment.0

The second part of this thesis presents the needs of data from the meters that have arisen during the interviewing process of the representatives of Vattenfall Distribution Finland. By mirroring the needs with the existing reporting tools provided by the current MDMS system ascertains the need for new reporting tools. In addition, it is found out how the existing reports of support process development and everyday work. Second part of this thesis presents also the possible MDMS-enabled future functions of the Online service which is provided to the customers.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
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Automaattinen mittarinluku on yleistymässä osin yhtiöiden omasta tahdosta, osin lain sanelemana. Toisin kuin perinteiset mittarit, automaattisesti luettavat mittarit tuottavat kulutustietoa tuntitasolla. Tuntipohjaisen kulutustiedon lisäksi automaattisesti luettavat mittarit pystyvät tuottamaan tietoa myös asioista, joiden avulla sähköverkkoyhtiön prosesseja ja toimintoja voidaan parantaa. Tämän lisääntyneen tiedon hallintaan tarvitaan uudenlainen työkalu prosessoimaan ja analysoimaan sitä ja tuottamaan raportteja eri verkkoyhtiön työkaluille. Lisäksi useat muut järjestelmät, kuten asiakastietojärjestelmä, voidaan integroida siihen. Näin vältytään tiedon varastoimiselta ja hakemiselta useasta paikasta.

Tässä diplomityössä on kartoiteittu Vattenfall Verkko Oy:n prosessien nykyisiä ja tulevia tarpeita mittaustiedolle ja mittareilta saatavan tiedon jalostetuille raporteille. Työssä on tarkasteltu nykyistä mittaustiedon hallintajärjestelmää; järjestelmän tuottamien raporttien ja sen ominaisuuksien kattavuutta täyttää prosessien tarpeet tiedolle. Lisäksi työssä on analysoitu lisätiedon hyötyjä prosesseille sekä asiakkaille. Tämä Diplomityö on tehty osana Smart Grids and Energy Markets –projektia, sen ensimmäisessä vaiheessa työpakettiin 3.1.3: Active resources.

Työ jakaantuu kahteen osaan. Kirjallisuusselvityksenä tehdyssä ensimmäisessä osassa (kappaleet 1-4) kuvataan automaattista mittarinlukua sekä verkon prosesseja. Esitellään Vattenfall Verkon käyttämä mittarityyppi, Vattenfallin aiemmat automaattiseen mittarinlukuun liittävät projektit sekä sähkömarkkinoiden ja lainsäädännön kehitys siltä osin kun ne koskettavat automaattista mittarinlukua. Lisäksi osiossa esitellään automaattisen mittarinluvun tuomat hyödyt sähköverkkoyhtiölle, asiakkaalle, muille osapuolille ja ympäristölle. Ensimmäisessä osassa esitellään Vattenfall Verkon järjestelmätyökalut sekä prosessit.

Diplomityön toisessa osassa käydään läpi Vattenfall Verkon prosessien edustajia haastattelemalla esille tulleet mittareilta saatavan tiedon tarpeet. Niitä peilaamalla nykyisen MDMS-järjestelmän olemassaoleviin raportointityökaluihin saadaan selville uusien raportointityökalujen tarve. Selville saadaan myös olemassaolevien raporttien antama tuki prosessien kehittämiselle ja arkipäivän työnteolle. Lisäksi esitellään asiakkaille tarjotun Online-palvelun tulevaisuuden mahdollisia MDMS:n mahdollistamia toimintoja ja palveluja.

PREFACE

This Master of Science thesis was carried out in Vattenfall as a part of Smart Grids and Energy Markets project during autumn 2010 and spring 2011.

I would thank my supervisor in Vattenfall, M.Sc Markku Kauppinen, for proving the topic of the thesis, and for advice, support and encouragement during this work. I would also like to express my appreciation to all of the colleagues in Vattenfall for cheerful time at breaks.

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I would like to thank my parents for both financial and emotional support during all these years. Kiitos äärettömän paljon.

Finally I would like to express my heartfelt gratitude to my long-time girlfriend Sanna for loving me, believing in me when I did not and supporting me to achieve this goal.

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ABBREVIATIONS AND NOTATION

AMR	Automatic Meter Reading
CBM	Condition based maintenance
AMI	Automatic Metering Infrastructure
CIP	Customer Information Pilot, Vattenfall's project to study web-based energy report application
DG	Distributed Generation
DMS	Distribution Management System
DSO	Distribution grid System Operator
EEGI	European Electricity Grid Initiative
EIP	EnergyIP, a MDMS program used in VFV
ESMA	European Smart Metering Alliance
ENEL	Ente Nazionale per l'Energia eLettrica, the largest energy supplier in Italy and third-largest in Europe
ESMIG	European Smart Metering Industry Group
GSM	Global System for Mobile Communications, originally Groupe Spécial Mobile
LON	Locally Operating Network
MDMS	Meter Data Management System
RMS value	Root Mean Square value of voltage in alternating current circuits is equal to the peak value divided by square root of 2, $U_{RMS} = \hat{U}/\sqrt{2}$
RNA/AM	Reliability based network analysis and asset management
SCADA	Supervisory Control and Data Acquisition System
SDP	Service Delivery Point
SGEM	Smart Grids and Energy Markets, Finnish smart grid research program run by Cleen Oy.
SMS	Short message service, text communication service of mobile phone
TBM	Time Based Maintenance
TSF	TeliaSonera Finland, telephone and mobile network company operating in Finland
UI	User interface

VFV	Vattenfall Verkko, Vattenfall distribution Finland
WP	Work Package

Balance deviation	Difference between energy production + transactions to a certain network area and consumption + deliveries from a certain network area
Base load	The minimum amount of electric power delivered or required over a given period of time at a steady rate
Channel	A meter channel defines the type of data collected and its unit of measure (such as kWh).
Corrective invoice	A corrective invoice is sent in cases where a mistake has been discovered in the price after the invoice had been issued.
Elbas	Market place for electricity transactions after Elspot
Elspot	Market place for electricity transactions of the next day
Fingrid	Finnish national grid operator and power balance responsible
Hourly based metering	Metering the actual electricity consumption by the hour
Imbalance power	Energy used to cover the balance deviation
NordPool	Nordic electricity market exchange
NordPool Spot	Nordic electricity exchange for physical power transactions
Online	Web-based service offered by VFV to its customers to observe the electricity consumption and manage account information
Power balance	Difference of production and consumption
Regulated market	Detailed conditions regarding prices and/or actor obligations defined in legislation or regulation
Santra	Santra project was the last step to modernize electricity meters and implement the AMR system in operation in VFV.
Supplier	Sales company supplying energy to the customer
Type load profile	Annual hourly electricity consumption of an average consumer in a group formed b similar consumers

1. INTRODUCTION

Electricity network operation is not any longer merely producing and delivering electricity as it used to be in history. Merely receiving electricity does not satisfy customers as the trend is to demand more: additional services and high-quality delivery – without any extra costs. In addition, marked amount of clients (malls, factories for instance) are more and more depending of continuous and faultless delivery electricity than before.

Unsatisfied customers are more likely to change their energy provider. When interviewed the customers who have changed their supplier of elctricity, seven percent of all named the dissatisfaction to previous supplier as the main reason. Furthermore, as illustrated in figure 1.1 the quality of the customer service is the most important or second most important criteria to 33 percent of customers when choosing the electericity supplier.[1]

Environmental issues are constantly regarded as more and more important. If a company neglects them, stakeholders are not pleased with that and it causes damage to the reputation of a company. In addition, eight percent of all the supplier changers said the other company respected the environment better than previous supplier. Environmental aspect was amongst the two most important criteria to 46 percent of customers in choosing the electricity supplier.[1]

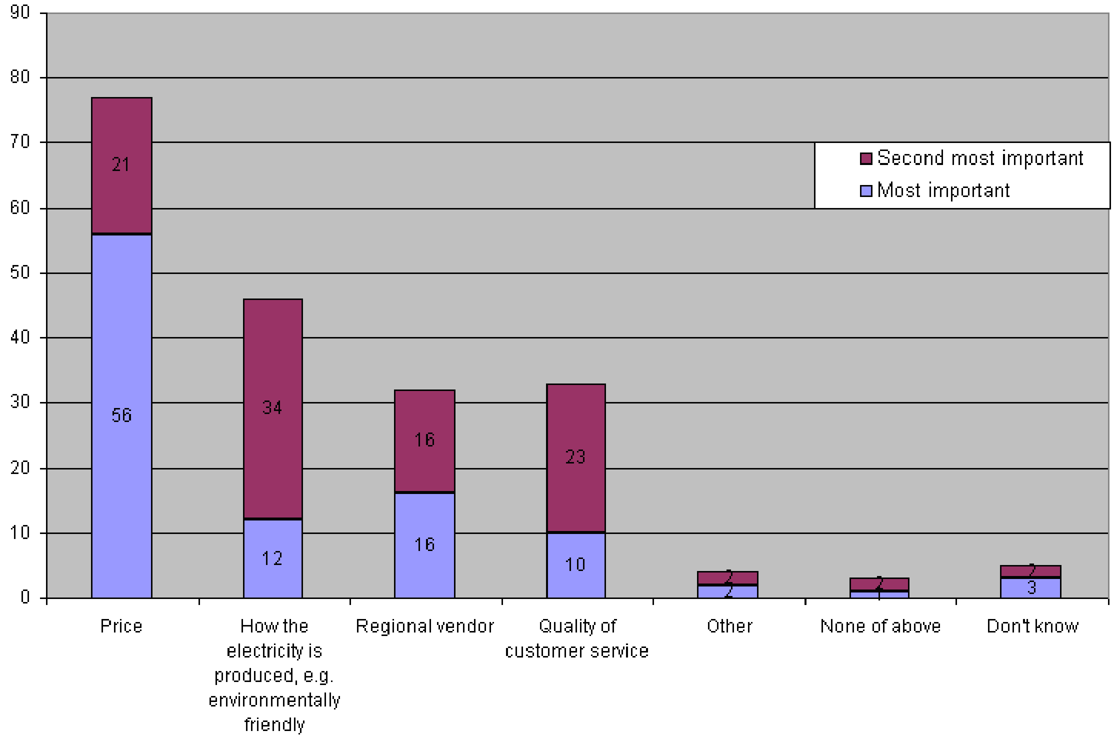


Figure 1.1. *The most important criterias in choosing the supplier of electricity. Adapted from [1].*

One of the biggest reputation losing factor is poor customer service. Constant failures to fulfill the demands or in invoicing result in customer insatisfaction and amongst other reasons affect negatively to public and politicians' opinion. Major failures in any service create a bad reputation to a network utility. To look good in front of the politicians is highly important for the future as the politicians set the acts and laws. Furthermore, they have a major impact on town and country planning as well as to public subsidies. And, a trusted company with good reputation is more likely to be granted a permission to a new power plant than one with a bad reputation.

Thus, bad publicity can affect on the future badly whereas good reputation affects positively to the company. Small interruptions are accepted more likely and investors want to invest on a company with good repute. Good repute affects positively as well to employers' willingness to work for a company. [2]

In addition, Finnish electricity act allows only a limited profit to electricity companies. Profit margin increases if the delivery has been faultless. This is the case when costs of power outages are less than the reference costs of outages. All these factors have led to a situation where electricity utilities have constantly to improve their processes.

In Finland, network companies are responsible of metering the consumption of electricity. Finnish network companies have approximately three million residential customer electricity meters in total, of which Vattenfall Verkko Oy (Vattenfall Distribution Finland, VFV) makes 400 000.

To reach the needed network operation performance and maintain the competitiveness the recent electricity metering trend around the world amongst the network companies is to move to the automatic meter reading (AMR) system. In some countries, as in Finland, the legislation obliges electricity companies to replace their traditional electricity consumption meters to the remotely read meters.

The main target of this thesis is to research how to achieve full utilization of the whole automated metering infrastructure (AMI) of Vattenfall. Furthermore, in this thesis it is researched how measured data in the metering data management system (MDMS) should be used for further process development.

1.1. Vattenfall

Vattenfall is the fifth biggest producer of electrical energy and the biggest heat energy producer in Europe. Vattenfall operates and has different kinds of business activities in Sweden, Finland, Denmark, Germany, Poland, the Netherlands, Belgium and the United Kingdom. These business activities include both selling and producing electrical energy as well as natural gas, heat energy and brown coal. In addition, Vattenfall acts also as a consultant in various energy market areas.

Vattenfall Finland employs over 500 people in Finland, of which 160 work for VFV. VFV operates in the field of delivery of electricity. In total, Vattenfall has approximately 40,000 employees. Parent company Vattenfall AB is wholly owned by the Swedish state.

As a network company, VFV is responsible of delivering the electricity to its customers. That includes also ensuring the reliability, safety and security of the electricity distribution grid. The services of VFV include electricity network maintenance, development and renovation of the old network in addition to building the new network and new points of connections in cooperation with the subcontractors. Furthermore, VFV is responsible for monitoring of the use of the grid and fault repairs 24 hours a day, and customers' electricity consumption measurement.

VFV operates mostly in rural areas in Finland. Hence, the total length of the electrical network of VFV is relatively long, almost 61,000 km. And – as in the case of every network company – it consists mostly of low voltage grid (0.4 kV). This is due the fact that low voltage grids are mainly radial in order to reach residential consumers' homes. Almost 400,000 customers live in the electricity network area of VFV.

VFV uses AMR meters to supervise the grid and its components, such as secondary substations and transformers. Almost every VFV customer's point of connection is equipped with AMR meter. In total, VFV has approximately 350 000 AMR meters in its network area.

1.2. Scope of the Thesis

AMR meters collect a comprehensive amount of information. This information is been used by many operations and teams within VFV. Main target of this thesis is to analyze and demonstrate how the metered information processed MDMS) more precisely in AMI, and the technology in AMI can be best used by the year 2013. In addition to improve the current system, purpose is also to outline the possible functions of the next generation meters and MDMS which can not be implemented to the current system. Moreover, the novel functions of interactive customer interface are researched.

This thesis will be divided into three parts. To help the reader to understand the importance of smart metering system the first part concentrates on explaining what AMR, AMI and electricity markets are in general. In the second part the current AMI and MDMS in VFV and the processes in VFV are defined. The third part illustrates the needs of processes to the MDMS and gives guidelines to the next generation of MDMS in VFV.

1.3. Smart Grids and Energy Markets research program

Vattenfall is participating in the Smart Grids and Energy Markets (SGEM) consortium research program. SGEM research program aims to develop international smart grid solutions that can be demonstrated in a real environment utilizing Finnish research, development and innovation infrastructure. The SGEM consortium is managed by CLEEN Oy (Cluster for Energy and Environment). In addition, funding of SGEM project is channelled through CLEEN. [3]

The research program is a part of the strategic excellence CLEEN Oy's activities aiming to ensuring the business opportunities of energy sector and to improve energy efficiency reducing environmental impact. SGEM project will last for five years, ending in 2014.

First phase of SGEM program is divided into five research themes:

1) Smart Grids architectures
2) Future infrastructure of power distribution
3) Active resources
4) Intelligent management and operation of smart grids
5) Energy market

Architecture, visions and concepts of smart grids are studied in the first theme. The subject of the second theme is the solutions in the primary network. The third theme studies how the traditionally passive networks can be turned into an active one utilizing active resources, as distributed generation, loads, storages and electricity vehicles. The fourth theme discusses the asset management and network operations of secondary systems providing intelligence to active networks. Alternating business environment and active participation to energy market are the topic on the fifth theme.[4]

This thesis relates to the SGEM Work Package (WP) 3.1 which is a part of research theme 3. The idea behind theme 3 is to give a sketch how to convert the traditionally passive grids into active ones.

WP 3.1 is concentrating on the second generation of Smart Metering and interactive customer interface. Overall objective of the WP is to analyze and demonstrate what can be achieved with full utilization of the technology installed in AMI (automated metering infrastructure) systems by the end of year 2013. WP 3.1 is divided into six subtasks.

This thesis is connected to task 3.1.3 named data warehouses for active resources. It is a subtask of WP 3.1. The aim of the Thesis Work is to research further utilization of implemented Meter Data Management System.

The key question in subtask 3.1.3 is how to achieve full utilization of the whole AMI infrastructure. Moreover, this subtask researches how measured data in the MDMS should be used for further process development.

2. AUTOMATIC METER READING INFRA-STRUCTURE AND ELECTRICITY MARKETS

As said earlier, the electricity consumption metering is a responsibility of electricity distribution companies. Before the AMR system electricity invoices were estimates based on annual consumption. Electricity utilities had to perform queries to investigate the parameters determining in which type group each customer was set. These parameters were for example the household appliances and the number of inhabitants. Meter reading took place manually, visiting each customer at a time. Therefore the electricity utility's knowledge of customers' consumption could not be constantly up-to-date. Then, customers were able to perform readings and inform the reading to electricity utility by telephone, mail or the Internet.

Traditional, manual electricity meter reading was laborious and slow especially in rural areas and it could cause unintentional errors easily. Received traditional meter load profile was also limited. This was because traditional meters provided only annual values of the energy consumed. Thus, hourly consumption behaviour was not available.

Automatic meter reading has grown in popularity in recent decades. Its popularity is due increased meter reading speed, cost savings, improved load profile, load management, interface remote accessibility options and geographical information of the network faults. In addition, benefits include real-time pricing and automated billing. Additional benefits can be foreseen with distributed generation (DG). Furthermore, as mentioned later in Chapter 2.4.4, energy efficiency can be achieved with metering the consumption of home appliances. The difference of traditional ("dumb") metering system and AMR ("smart") metering system are illustrated in figure 2.1 [5, 6, 7]

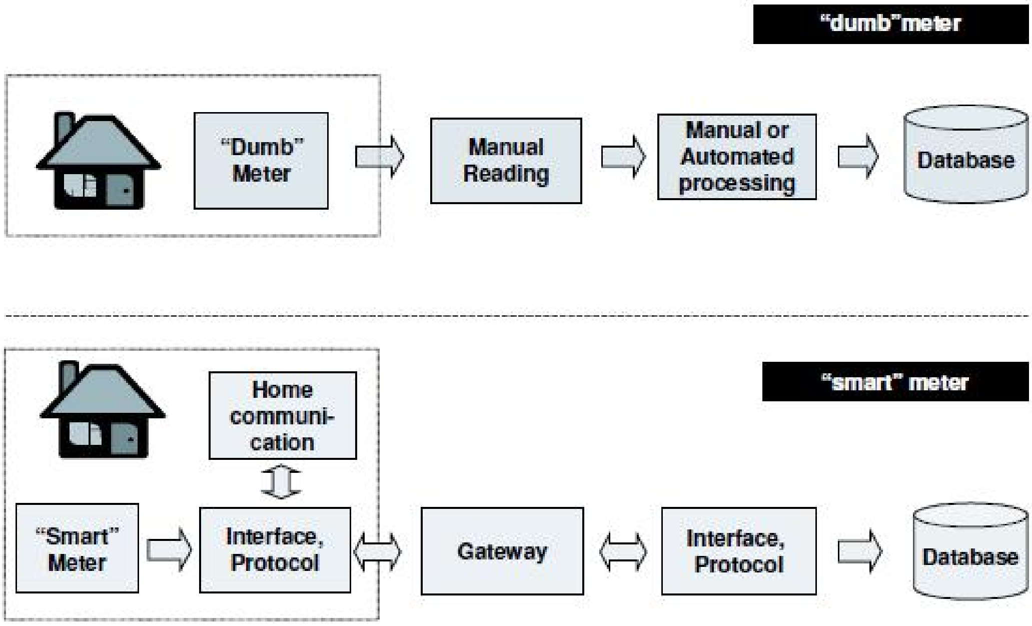


Figure 2.1. *Difference between the traditional and the smart metering processes [7].*

AMR systems have many novel features and functions comparing to the traditional system. The whole information flow chain from the meters to the business systems must be renewed in order to benefit the AMR system. Figure xx illustrates how information systems around AMR, depending on the features of the whole system, can be divided into different levels and functions. One important element in achieving cost effectiveness of AMR investment is to utilize AMR system in many levels. Implementing only remote energy metering does not turn the investment profitable. [8]

2.1. Automatic meter reading system

AMR system is a technology where the customers' electricity meters can be read remotely. That is to say the network company can receive the measured consumption data and fault information without specifically going and checking the meters on the location. AMR enables processes related to distribution and customer service to reach and have information of statuses of both the low voltage network and meters at customers' premises. Until now the personnel in control room have had this kind of information accessibility only to medium voltage (MV) network status information. In other words, MV network has been equipped with automation properties (for example relays, fault detectors and remote switches in substations and along the network) and now the low voltage network will be as well under surveillance.

Principles of AMR system are illustrated in figures 2.2 and 2.3. The system requires a metering infrastructure that makes connections to meters. Connection is made through a gateway and the meters send information to the meter reading system. Then, information from the meters will be stored to a data warehouse. Information is transferred from the meter reading system to various necessary information systems. Data systems using this information access the data warehouse in order of their need of information. Information systems may be for example SCADA (Supervisory Control And Data Acquisition, SCADA software). Figure x. describes the AMR system design [9].

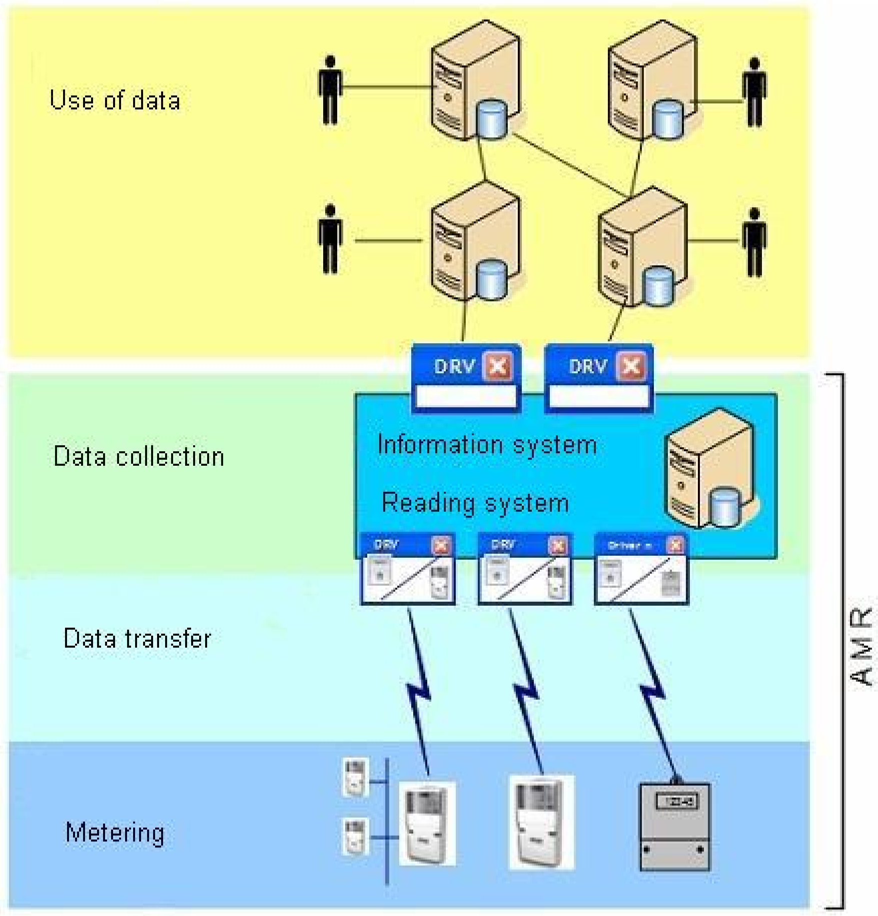


Figure 2.2. *AMR metering chai. Modified from [8].*

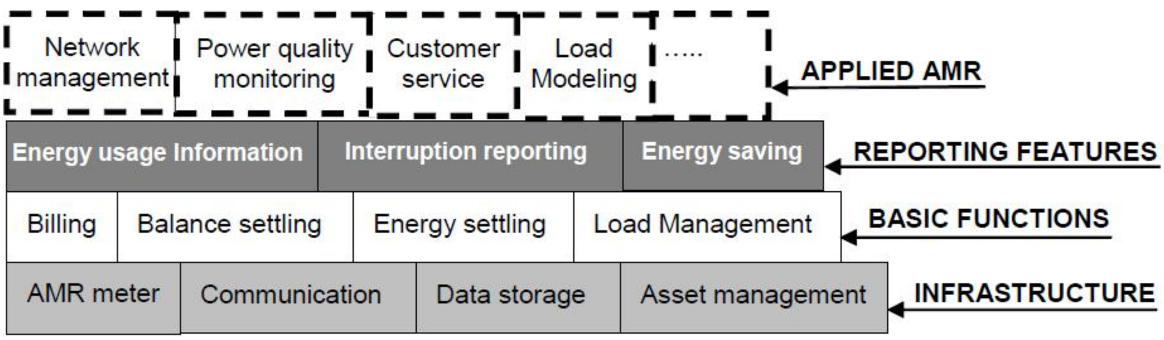


Figure 2.3*. AMR system levels [8].*

The main task of the energy meter is to measure the electric energy consumption. With new, smart electricity meter the electricity consumption, and possibly also its production can be measured in real time or almost in real time. Remotely read electricity meters have to be able to read locally – as the traditional electricity meters – or remotely. Remote reading has also be able to started if needed.[10] Besides metering the electrical energy consumption the new AMR meter functions may include for example the following: [5]

- power outage registration
- active and reactive power hour measurement
- power quality monitoring and measurement, over and under voltages and voltage dips
- remote switching of consumers
- direct load control and tariff-based load control
- remote and timing control of tariffs
- alarm of neutral conductor faults (to improve electrical safety)

Thus, AMR meter is not only an electricity consumption meter in the old sense of the word, but it has many novel features.

2.2. Electricity markets and regulation

The electricity market consists of generating, trading, transmission and distribution of electricity. In Finland the Electricity Market Act says that these must be separated from each others. Power production units generate electrical energy which is transmitted to customers through transmission and distribution networks. Electricity trading is tendered business, and customers can choose freely their suppliers of electricity inside Finland. Supplier of electricity does not necessarily generate the electricity sold, but the supplier can either buy the electricity on the open market or make bilateral agreements with electricity producers. Transmission of electricity at the national level is a responsibility of Fingrid Oyj with a monopoly to high-voltage grid. At regional level, the distribution of electricity to the customers is a responsibility of local-bearing grid companies, which also have a monopoly to regional networks and distribution networks in their respective territories.

2.2.1. Evolution of Electricity markets in Finland

Until 1995, a customer could not choose the supplier of electricity consumed since the local network companies had exclusive rights in those fields of businesses. In other words, customers were not allowed to choose their electricity suppliers. This is still the situation in some parts of Europe.

Deregulation of Finnish electricity markets started in 1995 when the customers of $\geq 500\,\text{kW}$ were the first ones to choose their suppliers of electricity. In 1997 all the customers received theoretically the same rights as the power limit was taken away from the regulation. It was still the next year, 1998, when the electricity markets became completely deregulated. On that year the type curves for estimating the consumption of different customer types were taken in use. Using type curves the constant measuring of power in the grid was no longer obligatory. Finland also joined the Nordic electricity market area, NordPool, in 1998.

Distribution of electricity remained a monopoly of regional network companies even after the deregulation of electricity markets. A pricing system of distribution tariffs to ensure the equality between customers was developed. Every customer in a similar customer group in the same distribution network area pays the same price per kWh consumed, being no matter how far or close to the connection point. So to say, every regional network company must create the conditions where its every customer in a similar customer group in the same region can use the Finnish electricity network with a similar tariff. Only on these conditions the electricity markets are not distorted and consumers can freely tender the suppliers. Distribution companies are allowed to have only a moderate profit. To ensure this the Finnish Government has created different surveillance systems. Surveillance systems have evolved during the years.

On the 1st of March 2009 the Finnish government set an addition to the electricity market regulation obligating network companies in Finland to install AMR meters to every household and low voltage connection point by the end of the year 2013. The aim is to have AMR meter ratio out of all electricity meters to at least 80 percent in every network company. Measured data must be stored to the network operator system for six years. [11]

The market settlement rules were tightened on the new regulation relating to the exchange of information which entered into force on 2011. Whereas previously the network utilities were to deliver the market settlement report in 30 days after the transaction, now the report has to be done in 14 days. [11]

Furthermore, Finland is a member of EU, which has strict regulations and goals on energy efficiency. Finnish legislation obligates every company operating in the field of energy services to support their customers in energy efficient acts. Energy companies must give customers s new products and services which can be utilized to reduce energy consumption. Finnish energy companies must read meters at least three times a year by 2014.[12]

2.2.2. Electricity markets in Scandinavia

Finnish electricity markets are a part of NordPool, a common Nordic electricity market area. NordPool offers three different markets: Elspot, which is a market place for the next day’s electricity on hourly basis, Elbas for the adjustments for the next day’s trade and financial derivatives. NordPool is divided into 10 different market areas. In addition, NordPool is a market place the market derivatives meant to protect the market participants from the future turbulences.[14,15]

The price of the electricity is determined through anonymous offers from both the purchasers and the vendors of electricity. When determining the price of Spot electricity in Elspot markets, demand and supply offers for each specific hour are sent on previous day at 12:00 at latest. NordPool calculates balanced price for each hour from those offers. Thus, the actual price is not necessarily according any single offer, being an equilibrium price formed of all the offers.

Elbas markets act as a secondary market to Elspot. Elbas is open round the clock every day of a year and it is a market place for continuous trade. Hourly contract can be traded until 60 minutes before the delivery hour. Unlike in Elspot markets, one party can make purchase and sales offers for the same hour’s electricity and the price of a certain hour can alter during a day.

Suppliers of electricity buy very seldom the exact amount of electricity consumed beforehand. The difference is covered with balance trading with a legally responsible party (Fingrid in Finland) or with an open partner. Open party is a pre-defined member of electricity markets which is committed to supply the electricity currently needed. This matter is discussed with more details in Chapter 2.2.3.

Currently the Finnish residential customers cannot purchase the electricity from other Scandinavian country. Hence, the electricity markets within the Nordic countries are not fully liberalized. NordReg project aims to make the full liberalization possible in NordPool market area and enable for example a Finnish customer to purchase energy from a Norwegian supplier.[16, 17]

Integration process of networks and energy markets does not limit only to Scandinavia. The European Electricity Grid Initiative (EEGI) has proposed a 9-year research and development project concerning smart grids. One goal of EEGI is to create a pan-European electricity grid.[18] The European Council set the new deadlines for the implementation of pan-European smart grid to the year 2014. By then the European energy market should be fully functioning, interconnected and integrated. In addition, the technical standard of smart grids and smart meters should be adopted by 2012 throughout the Europe.[19]

2.2.3. Power balance and balancing power markets

Best possible forecasts of supply and demand are the interests of every party in the electricity markets. Because the forecasts rarely meet the actual consumption and generation, the surplus or deficit are handled as power balance. National power balance controlling aims to control and continuously maintain the balance between supply and consumption of electricity with ensuring the security and quality of electricity supply. The Finnish national grid operator, Fingrid, is responsible of maintaining the power balance in Finland. The main objective on power balancing is to maintain the frequency within acceptable limits.[14, 20]

The other reason to determine the power balance between the areas of network companies is to know the consumption of each party operating in the electricity markets and the deliveries between parties at each period of time. That is called as imbalance settlement and it must base on consumption measured hourly.[11] Imbalance settlement is based on a hierarchic model, as illustrated in figure 2.4.

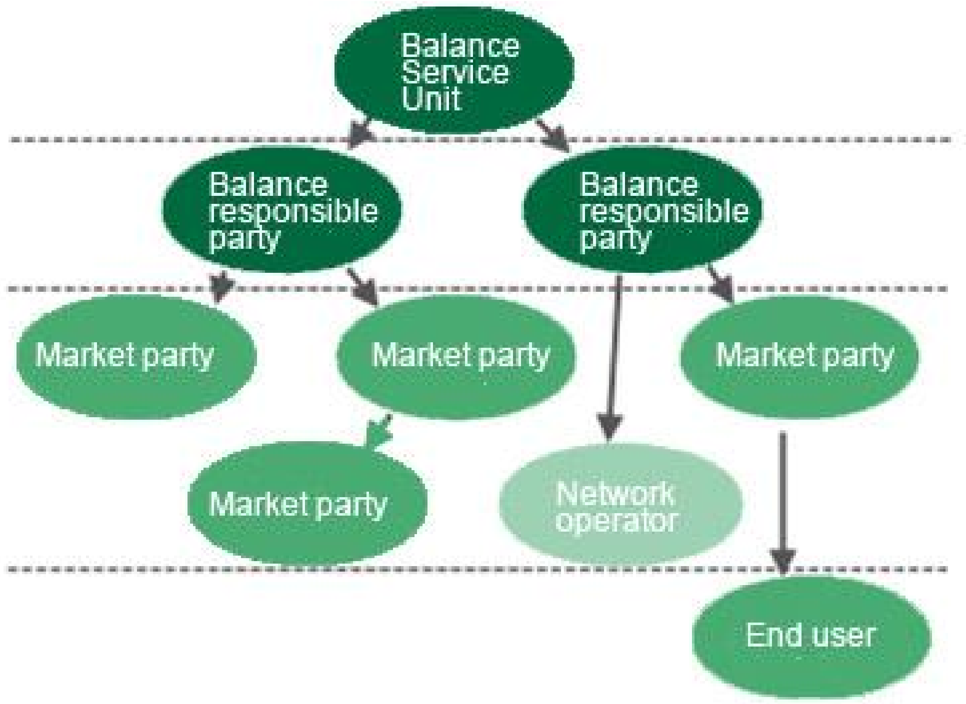


Figure 2.4. *Imbalance settlement hierarchy [20].*

The power balance of each party in the electricity market can be seen in the result of imbalance settlement. National power balance responsible (Fingrid Oyj) forms a report of the national balance as a result if imbalance settlement reports from power balance responsible parties.[20]

Electricity market parties provide the statistics and volumes of their fixed deliveries to the power balance responsible parties. Measuring and ascertaining of the other deliveries is the responsibility of network companies which provide the information of the electricity delivered in their network area. Reports are based on hourly energies.

Power balance responsible provides a summation of these reports to the (Fingrid Oyj) on the next business day at latest. Currently the network companies form their imbalance reports of residential customers in practice according the residential customer type curve estimates and the information from secondary substations.[11, 14, 20]

As a result of national settlement is the information of the electricity transferred between Finland and other countries. This is formed by adding up the variances of different market settlement responsible and corresponding utilities from neighbouring countries, and export and import from the power lines crossing country borders. The result of this summation must be zero, as generation and consumption of electricity must be balancing. Tentative national power balance report must be ready in three business days from the delivery of electricity and the final report in three months after the delivery.[14, 20]

In addition, the difference between the production and consumption is treated in balancing power market. To offer the production to balancing power market the possessors of production and loads are able to submit their capacities of production or load that can be regulated. Balancing power bids can be given of every resource that is able to make a 10 MW power change within 10 minutes. Bids can be either up-regulating or down-regulating bids.[20]

Figure 2.5. *Balancing bids [20].*

As seen in the Figure 2.5, the up-regulating means either increase in production or decrease in consumption. This is used in cases when more electricity is needed to the electricity markets. The balance responsible (Fingrid) buys more electricity according to the highest up-regulating price, which is at least the NordPool area price for Finland. Respectively, Fingrid sells the surplus electricity according to the lowest down-regulating bid, which is no higher than the NordPool area price for Finland. Market participants in need of electricity buy the balancing electricity from Fingrid and vice versa.[20]

2.3. AMI system

AMI (Advanced Metering Infrastructure) is a comprehensive system between smart meters which can measure and collect data of energy usage on a pre-defined schedule or on a request and business systems in a utility. In addition, metered data is analyzed in AMI systems. Currently collected data consists of consumption data and power quality data. Metered data is continuously being collected, processed, and integrated with several applications in the utility's information systems. Thus, AMI is the essential part in energy data collection and management process.[21, 22, 23]

According to Hamrén, Gartner Inc. has divided the functionalities of AMI infrastructure to the following six steps. Different technologies support each step. [24]:

- **Data Acquisition –** Metering devices
- **Data Transfer –** PLC (Power line carrier), GPRS (General Packet Radio Service), Radio links etc.
- **Data Cleansing –** VEE (Validation, Editing and Estimation) tools, MDM (Meter Data Management)
- **Data Processing –** MDM (Meter Data Management)
- Information Storage/Persistency – MDM (Meter Data Management)
- **Information Delivery/Presentation –** Information Portals, Web services, EDI (Electronic Data Interchange), MDM (Meter Data Management)

The Smart Grid Task Force (SGTF) is an expert group advising the European Committee on policy and regulation directions concerning smart grids. Furthermore, SGTF is to outline the technical needs for the future smart metering needs of smart grids. It has identified six high level needs for the future smart metering system, which all need more improved and comprehensive usage of AMI systems to be achieved. [25, 26]:

- To enable the network to integrate users with new requirements. That is to say the integration of distributed energy resources to the distribution network should be guaranteed.
- To improve the functioning of electricity markets. Improved data and data flows between the electricity market participants improves market performance and reliability. This will increase the customer experience in the market.
- To enhance efficiency in day-to-day grid operation. Continuity of supply will increase on faster fault identification. Enhanced automation, monitoring, protection and real-time operation is needed to optimize the operation of distribution assets. In addition, through more detailed operational information the understanding of losses can be increased.

- To ensure network security and quality of supply. Outcome: Foster system security through an intelligent and more effective control of distributed energy resources, ancillary back-up reserves and other ancillary services. Maximize the capability of the network to manage intermittent generation, without adversely affecting quality of supply parameters.
- To help in better planning of future network investment. Collecting data especially in the LV level also taking the new grid users into account the network utilities could optimize their network investment planning better in the future. Introduction of new methodologies for more 'active' distribution, exploiting active and reactive control capabilities of distributed energy resources.
- To enable stronger involvement of customers. That means the network utilities have to provide sufficient information for energy saving and offer a method for electricity consumption surveillance to customers. In addition, customers should be instructed to change their consumption behaviour according to alternating electricity price. The idea behind this point is to reduce peak loads and network investments.

2.4. Benefits of AMI system

Only implementing the smart meters to the network operation does not bring much additional value. If done so, only labour costs from metering services are reduced. Instead, the functionalities of smart meters should be utilized and the information refined in order to benefit fully from the system. New types of reports, alarms, and self-piloting function are needed to take the most out of the AMI system.

One example of AMI system benefits to the customers is the support to reduce the energy consumption. As the smart meters do not itself reduce the energy consumption they do not directly contribute to the energy saving. However, the metered data can be retrieved and refined quicker and more efficiently. Smart meters and AMI system reduce energy by providing the reports of consumption patterns and customer behaviour with energy saving reports.[27]

The same principles can be extrapolated to benefiting the processes in network company. With the new reports and functions of AMI the processes can enhance their efficiency and reduce the amount of wasteful work. Cost savings can be achieved for example in loss management and with reduced compensations paid to the customers from outages or power quality.

In addition, despite the fact the electricity companies' sales will decrease due the energy efficiency, they can still find new business opportunities on that. The electricity companies can enter and even create new market areas in field of energy efficiency.

Thus, energy efficiency tools and support services can be major parts of the electricity companies' business in the future.[28]

2.4.1. Network company

The systems connected with automatically read electricity meters enhance and refine the daily work of the network companies. Monitoring the events in the network and network calculation will be easier and more accurate utilizing smart meters and AMI system through collecting the consumption values of consumers. In addition, with accurate and extended reporting and statistics the network losses and failures can be tracked more effectively leading to better quality of distribution. More and improved data of the network status is obtained, which can be use in network planning. Electricity companies may therefore dynamically distribute the power transmission, optimize the networks and invest to them more accurately. Furthermore, market models can be shaped. Benefits of AMI system are illustrated in figure 2.6. [29, 30, 31,]

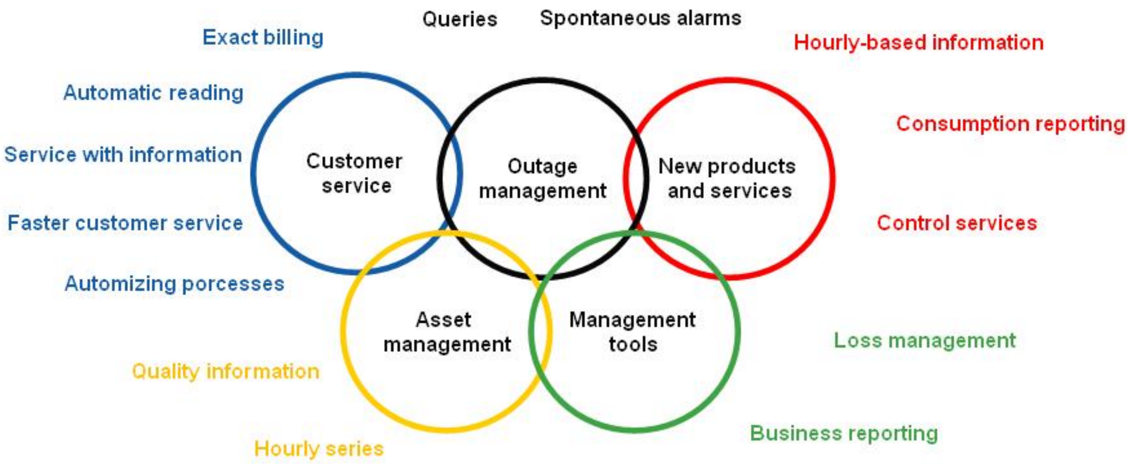


Figure 2.6. *Benefits of AMI system [32].*

Remotely read meters provide outage information and the reasons of outages to the AMI system of network utility. In Vattenfall, for example, outage information and reduced time in troubleshooting have lead to faster fault repairing and shorter interruptions as well as the reduced number of customer trouble calls. Moreover, the number of unnecessary customer visits has declined. Customer security has enhanced with real-time information of zero conductor faults and voltage level. [32]

Thus, with AMI infrastructure and AMR meters network companies are able to improve their operations, including active network management. Low voltage network status and fault data are better known than in the past on the basis of the data from AMR meters. Unauthorized users of electricity can be detected more quickly. Load peak can be lowered using the dynamic load control opportunity. Network companies can therefore perhaps even avoid additional investments in the network. However, load control is possible currently as well, but it will be improved when remote control through AMR meters becomes possible. [28]

In addition, the ability to connect and disconnect premises remotely benefits the network company. This is beneficial especially in rural areas and in the rented apartments. For example, the process of demanding the payment improves as the electricity can be disconnected without any extra costs. Previously merely the disconnection may have cost more than the amount of the bill because it had to be performed on site.[9]

After the information from the AMR meters has been stored to the database it is easily and rapidly accessible. This makes, for example, the calculation of electrical settlement faster and more accurate as the customers can be put to the right load curves. Furthermore, having customers in right load curves helps in hedging the electricity procurement. That means minimizing the market risks with buying the right amount of electricity power in advance and lowering the need of last-minute trade.

To obtain the improvements mentioned above the AMI system must [27]:

- Offer functionalities enabling the consumer involvement
- Be able to handle the cooperation of different data handling systems, such as smart metering systems, network and customer information systems
- Guarantee the secure communication between the consumer premise and data handling systems in network company and within those systems

2.4.2. Customer

“Network operators, by request, should offer their customers hourly measurement equipment with a standardized interface real-time monitoring of electricity consumption." This and the following are mentioned in the Regulation concerning measurement of the electricity adopted in 2009. "The network operator customers are entitled without any compensation to obtain access to their electricity consumption data the network operator has collected in the client's place with electricity metering equipment.[11]

Customer service can be improved since customer data is readily available when customer calls. Similarly, AMI enables a capability to automate the billing and make it more accurate. Traditional method of sending an estimation bill may be dispensed. Vice versa, compensation given to customers for longer power outages, such as discounts on the invoice, can be automated. [31]

In addition to earlier mentioned improvements to customer service and billing, customers receive also other benefits ascribe to the remotely read metering. These include, for example, online reporting on customer’s own electricity consumption. Real-time reporting eases to monitor the use of electricity and hence assists to reduce excess electricity consumption. Electric utility can reach the fault information and power quality abnormality events remotely faster. This enables the electric utility to react more quickly to the problem and customer may not even notice a defect. This increases customer satisfaction. [29, 31]

The customers can also have an access to information on electrical outages, downtime duration and times. This can be done for example by telephone service or text messaging services. [28] For example Vattenfall offers this kind of text messaging service to the customers in its network area.[33].

In the future customers may benefit from greater competition in electricity markets. This is made possible by automation-equipped meters; changing either automatically the electricity supplier company in the market according to lowest market price or controlling the customer's own consumption using the control service offered by the electricity company. [9, 31]

2.4.3. Other parties

Electricity markets can be also improved by enabling residential customers to choose a vendor of electrical energy on hourly basis or to have more specified products. In addition, the functioning of electricity market increases with the simplicity of changing the vendor.

Wholly new products, markets and businesses around electricity markets can be created when faster data transmission is achieved and the current price of electricity is possible to submit to the AMR meters. AMR meters can create new markets to the other parties than normally included in electricity business. For example, meter vendors have new businesses including meters, services and automation solutions.

In overall, smart meters can be seen as benefiting a number of different electricity market participants. In addition to network companies metering information can be utilized as well by the national grid companies as well as the electricity producers, end users and trading companies. If the network companies will develop them only for their own needs smart meters benefits may be relatively small. [10]

With the help of AMR meters and better information collected with AMR meters energy efficiency goals can be achieved. Customers can choose the amount of invoices and invoices have to be according to the true consumption. Starting from the year 2010, vendors of electricity must send a report to their customers once a year including the following subjects: energy consumption from billing period and three preceding years, comparison data to the other similar customers and information how to improve energy efficiency. [13, 34]

Moreover, the requirements for smart meters and metering systems can vary largely between different countries. This is mainly due to the fact that there are no common standards for smart meters and metering systems. Uniform definition of the basic requirements should be made for all parties. The projects aiming to create basic requirements of consolidation and the generalization of smart meters are running in Europe, for example by ESMA (European Smart Metering Alliance).[35]

2.4.4. Environmental aspects

European Union climate regulations have constantly got stricter in order to reduce greenhouse gases. In 2006, the common emission reduction target to EU member states was directive-set to 6 per cent and later it was later increased to 9 per cent. Target was set to 2015. [36] However, in December 2008 the EU leaders and the European Parliament agreed a commitment to reduce emissions by 20 per cent compared to the 1990 emissions by 2020. Should the other developed countries to have comparable targets, the target can be raised to 30 per cent in EU.[37] According to the European Smart Metering Industry Group (ESMIG), the climate goals can only be achieved through utilizing the smart metering.[38]

Overall use of energy in Finland dropped 13 percent from 2008 to 2009. However, when the ongoing global recession eases, the production will rise again. Permanent emission reductions, however, should be achieved to fulfil these regulations. One way is to locate the energy saving targets using AMR meters as well as to compare profitability of the existing energy saving spots. [5]

The new regulation of the measurement also states that the network utility must promote their clients an efficient and economical way to use the electricity and use of power control to exploit the potential. [11] In addition, EU obligates energy companies to provide customers their consumption information. Furthermore, energy efficiency measures, comparative final consumer profiles or objective technical specifications for energy-using equipment should be served to customers.[13]

Automatic meter consumption data is obtained once per hour. At present, such measurement data may already be collected from big consumers, but with the AMR meters it will also become more common from residential consumers. This is a huge improvement on its predecessor, when the meters were reading interval was several months, sometimes even years. Consumers and electricity companies will therefore be able to use a lot more information than previously. This increased amount of data can be used for both the customer and the electricity company, to plan the use of energy and finally to the pursuit energy savings. Manual meter reading is a environmental burden if the meter reader is needed to send in the site. Using automatic meter reading this environmental factor disappears. [5, 9]

Enormous measurement data processing requires both large memory capacity, and effective programs to process them. Programs are not yet so effective that they would be able to calculate a large amount of data on the basis of energy efficiency measures on a large scale. However, in the future, as the information management and information technology services develop, the hourly-based measurements can be used better on this matter. [5].

Energy efficiency methods, which can reduce electricity use can be increased with other solutions as well. These include air and ground heat pumps as well as better insulation of houses. Electric energy efficiency target for companies may sound a bit contradictory, because they make their profits precisely by selling electricity. However, for example the network companies can take advantage of energy efficiency with the ability to postpone their investments. Electricity companies can also improve the public image by providing customers with accurate information about their electricity consumption [5].

Consumers will be encouraged to energy efficiency through more accurate billing. Billing is based on actual consumption instead of former way to send estimated invoices, and consumers will notice the difference in their energy use and savings as soon as they receive their next invoice. Estimated invoices, in contrary did not support to energy savings in this way as they were pre-calculated and not directly according to the households' use of energy.

The meters in use of VFV have casing which is made of self-extinguishable ad recyclable polycarbonate. Thus, they are recyclable. In addition, VFV has run an energy saving competition between three Finnish families in 2010. During this competition every family received customized support and feedback from VFV's energy saving experts. In addition, families were equipped with meters enabling real-time surveillance of energy consumption. In addition to common energy measurement in every family, more specified measurements were targeted to measure energy consumption in different home equipment, such as washing machine, refrigerator, ventilation, entertainment device and sauna. Energy of home appliances was measured in minute intervals with meters developed by BaseN Oy.[39]

In the competition, the energy saving target was set to five percent to each family. However, every family achieved approximately 20 per cent savings compared to the previous year. Because every year is different, annual consumptions were corrected with temperature factors. [39] Since the families represent typical Finnish families, those savings go to show that major energy savings can be achieved with informative consumption reports from smart meters and detailed advices.

Each family held a blog in which they wrote their experiences during the competition. In addition, an up-to-date online report of every family's consumption was provided to competition's website. Thus, competition was easy to follow to everyone. Furthermore, a collection of energy saving hints was available in the website of the competition with the opportunity to ask the VFV's energy expert for energy saving issues. Answers to the questions were left to the website for everyone to see them. It is calculated that if all Finnish households reached the five per cent energy efficiency target set to the competitors it would cumulatively accrue as 500 GWh energy savings nationwide per year.[39]

2.4.5. Economical aspects

Customer connection can be remotely switched on or off without physical activity on the location. Should there be frequent in and out moving (change of residence), the remote connection opening and closing will become even more beneficial to the network utility. As the customer service can remotely perform the readings related to moving out, it is clear that this will be result as savings to electricity company. Cost savings will also be achieved from moving events in rural areas where distances are long and the installer should do long-term switch trips, which appear as financial loss to electricity utility. [28]

In addition, the customers will benefit from the invoicing based on actual consumption and the electricity utility confines of this kind billing as an asset. As the billing is real time, the billing credits will appear on the company's account faster. The money in the company's bank account gives the both liquidity and interest income to the company [9]

The electricity grid utility has to compensate customers for electricity distribution suspension of more than 12 hours. Since the faults in LV network are detected more rapidly and location of faults can be done better and with greater precision, the average duration of outages in the network are lower than today. The annual compensations paid by electricity distribution utilities will be very likely to be at a lower level than present.[9]

Cost estimates suggest that the best economic benefits of AMR meters may be when enabled with the additional services - such as hourly measurement, power quality monitoring, power outage registration, electricity remote switching, enabling market-priced electricity option to the customer and remote control - into proper use. These services will also create the enterprise image benefits that are difficult to value in monetary terms, but at least these are not to the detriment of the customer relationships. [29]

However, changing to the AMI system may not be cost-efficient if AMR-enabled additional services mentioned above are not imposed. It is calculated that during a 15-year period the traditional meter reading should be 19 percent cheaper than the AMR meters of which potential is exploited only with remote read feature. The difference grows larger if the AMR meters are used for a limited number of connection points in the area of electricity distribution utility and not in its entire region. Taking advantage of the above-mentioned characteristics, one Danish electricity company has dropped repayment period to eight years for the AMR meters. [29].

As almost in any business case, bigger companies will benefit from their size in the logistical occasions more than smaller ones. This is the case also in electricity distribution business. Smaller electricity companies can thrive for example by forming alliances in purchasing the meters or in outsourcing the procurement of their business activities [29].

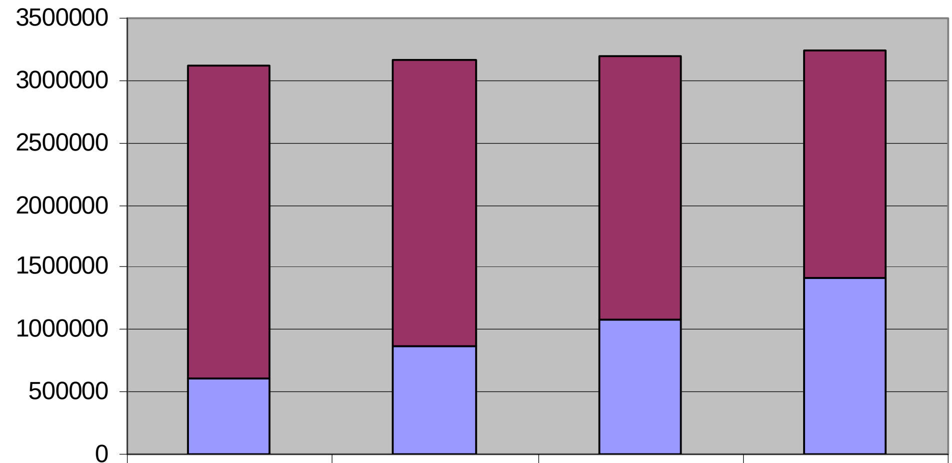
2.5. Widespread development of AMI

As illustrated in Chapter 2.4, the benefits from the existing AMI systems are clearly visible. Hence, it can be foreseen that the smart metering will become more and more popular throughout the world in the future. In fact, energy meter reading is increasing rapidly around the world. The most common causes for this progress are legislation, liberalisation of electricity markets and improving technology. In fact, implementing AMR system is a requirement for common electricity market area.

As electricity utilities want to provide better customer service, they are more likely to change their old meters to AMR. Increasing widespread of AMR system can also be caused by purely technological progress, which inspires to introduction of AMR metering. Network companies may be also forced to renew their metering equipment through legislation. [40]

2.5.1. Finland

By the year 2005, only approximately 7 percent of all energy consumption meters were AMR meters. At the end of year 2006 this number was raised to 18 percent (the same ratio on the customers with the fuse size of over 63 A was already at 41 percent). Again, at the end of year 2007, the share was raised to 29 percent. By that time the majority of electricity companies had not planned intentions to implement AMR in the near future, as seen in figure x.[41] The actual ratio of AMR meters out of all meters in 2010 is approximately the same as in the forecast. However, the rate of growth will most likely to increase.



	2007	2008	2009	2010
Traditional metering	2511000	2299000	2112000	1816000
AMR metering	616000	864000	1088000	1422000

***Figure 2.7**. Number of residential customers within the AMR reading in Finland according to the interview made in 2007. Adapted from [42].*

Figure 2.7 presents the results of a study made in 2005 based on interviews of Finnish power companies. It shows that during that time they did not have plans to implement remotely read meters completely until the year 2025. However, the average goal was to achieve the 90 percent coverage of AMR meters out of all electricity meters by 2012. Some of the smaller power companies had a vision to change all of their meters to AMR meters by 2012. [42]

On the first of March 2009 the Finnish government approved to set an addition to the electricity market regulation, which obliges electricity companies to install the AMR meters to all households in their network area, by the end of 2013. In addition, the minimum target is to achieve at least 80 percent coverage in each network utility.[11]

Finnish legislation has minimum requirements for remote readable measuring devices and measurement data handling information systems [11]:

- Meters have to be remotely readable
- Ability to register outages lasting longer than 3 minutes
- Ability to store metered consumption data and zero potential time information on (measurement data of 6 years, zero potential time 2 years)
- Ability to receive load controlling commands execute them or transmit them forward
- Appropriate data protection

2.5.2. Other countries

Italy's largest electricity supplier ENEL Distribuzione SpA was the first utility to introduce AMR system in 2001 with Telegstore project. ENEL made the decision to upgrade their system to AMR system independently, in other words ENEL faced no market or legislative pressures when making the decision. During the project, over 30 million AMR meters were installed, covering every premise of the ENEL. The project was completed in 2006 and cost about 2.1 billion euros to ENEL. Yet ENEL calculated the decision profitable. ENEL has justified the massive investment with substantial savings arising from customer service, field operations, and income protection. Furthermore, acquisition and logistics operations are more efficient with AMR system bringing cost savings. [7, 43]

However, Sweden was the first country in the world where every premise was equipped with AMR meters. Development of this kind was forced by legislation: market act set in 2003 obligated every energy company to send invoices based on actual consumption (not according to load forecasts) by the end of July 2009. No extrapolation has been allowed after that date. Purpose of this act was to enlighten the customers to understand their consumption and save energy more efficiently. Energy companies have to implement AMR systems since monthly manual meter reading would have become too costly.[7, 38, 44]

In Europe the European Union (EU) supports and advices the member countries to deregulate and liberalize the electricity markets. This has inevitably leaded to unbundling of distribution and supply. In other words, the same company can not own both transmission and energy production or supply activities. In addition, the EU encourages implying competition, economic efficiency, profit maximization and offering customers market-priced electricity products. Moreover, the vision of the EU is to have properly handled cross border trade. Furthermore, since the customers become able to change their energy supplier freely, it will create the need of smart metering.[13, 40, 45]

The energy policy of the EU has spurred setting the national laws for implementing the smart energy meters in laws in several European countries. EU member countries base their national laws to the European Parliament and Council Directive 2006/32/EC on energy end-use efficiency and energy services. Directive encourages the introduction of smart meters in all EU member countries and sets out various obligations to the distribution utilities in respect of energy measurement. The Directive says that with the energy meters energy utilities have to be able for example to demonstrate the end-user energy consumption accurately and at the same time to provide information on electricity use of the time, as far as it is technically feasible and economically sensible. According to CapGemini's estimations, from 25 to 40 per cent of European households are equipped with smart meters by the year 2012. That is a significant increase to the situation in 2009, when only six per cent of premises had AMR meters installed.[15, 38]

In addition, changing the metering systems to AMR meters and AMI systems has not only been European phenomenon. In November 2008 China decided to upgrade the traditional electricity consumption meters to AMR meters within five years. Two months later, in January 2009 the USA decided to invest large amounts of money to smart grids.[a38

2.6. Previous AMI related projects in Vattenfall Finland

Vattenfall Verkko is relatively young network utility. VFV began operations as network service company in 2002 when six distribution companies were merged to one. Every network company had its own network information systems. After having gathered all the information under one system, to Tekla Xpower, VFV has run several renewing processes on its measuring procedures and techniques in the near history.

Renewing processes have had affects to the operational processes and future plans on a revolutionary way. Today AMR is part of practically every team and process inside the whole company, and it has an effect even to parties outside the company. Following subtitles enlighten these renewing processes leading to the current AMR system.

2.6.1. PROMAL

PROMAL was the first project in order to automate residential customers' meter reading processes. This project was carried out in 2000. PROMAL concentrated mostly on evaluating the benefits of automatic meter reading and how processes could be simplified and improved utilizing AMR system. In addition, the opportunities in selling electricity and improving customer service using smart metering system were studied.

2.6.2. Kauko

Kauko project was carried out in 2003 – 2005. Over 35 000 traditional meters were replaced during Kauko with smart meters. Meters installed had the functionality to collect only the consumption information and transfer it online. Hence, no other smart metering features were tested in this project.

In addition, LON-communication protocol was tested and piloted during Kauko project. Additionally, PLC (power line communication) and GSM (global system for mobile communications) were used to communicate with the meters. Using two communication protocols (LON and GSM) caused some problems in use. Moreover, as testing the LV (low voltage) grid in data transmission it was noticed that it is applicable for data transmission only in urban areas. Mobile on-the-job guidance was tested in installation process.

2.6.3. Santra

Santra project was the last step to modernize electricity meters and implement the AMR system in operation in VFV. The key idea behind Santra project was to turn the traditional electric energy consumption meters into modern smart terminal devices meeting the future needs of an electricity utility as VFV is. Now the hourly values of consumption were collected not only from big customers but also from residential customers. Furthermore, meters installed were smart meters with multiple new abilities as illustrated in Chapter 3.1.

In order to take advantage of AMR system and its benefits, all the meters had to be replaced. Thus, VFV renewed its all meters, over 330 000 in total (installations after the project raised the number later to 350 000), in its premises and created a new type of a system infrastructure around them. That infrastructure was fully integrated to the previous information systems. Infrastructure was also renewed according to the needs of the processes in VFV and to enable two-way data transfer from and to the meters (M2M, machine-to-machine communication). Furthermore, mobile on-the-job guidance piloted in Kauko was fully applied to the VFV systems during Santra project.

As illustrated in Figure 2.8, Vattenfall had many turn-key partners in Santra project. Logistics was carried out by SLO and installation of meters was done by Eltel. The meters later discussed in Chapter 3.1. were supplied by Iskraemeco and the reading process was given to TeliaSonera Finland (TSF). This matter will be discussed in Chapter 3.2.

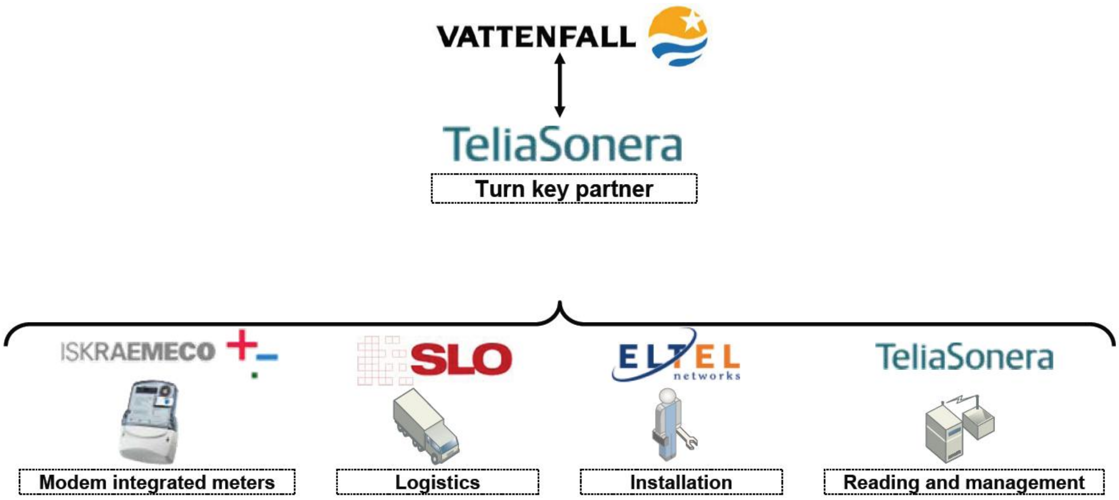


Figure 2.8. *TeliaSonera's AMI concept in Santra [32].*

2.6.4. Customer Information Pilot and Online service

Vattenfall ran a Customer Information Pilot (CIP) from February 23rd 2009 to August 28th 2009 in Sweden. The purpose of CIP was to test the web-based consumption application as well as evaluate the smart metering possibilities and customers' interest to use this kind of application. Over 2700 customers and enterprises used a web interface for eight months to follow their electrical energy consumption online. Customers were given different graphs to illustrate their consumption on hourly, daily, weekly or monthly basis. Other graphs contained temperature data so that customers were able to see how the outside temperature influenced their consumption.[46]

Customer questionnaires during and after the test period along with the gathered statistics showed the high and continuous interest towards this kind of an application. Yet the willingness to pay from this type of service was very low. Now VFV offers a web-based consuming surveillance application to their customers free of charge.[46]

Online service offered to customers in Finland is based on results achieved by CIP. That is to say the reports and layout of Online service are according to CIP project conclusions. The functions of Online service is discussed further on Chapter 3.6.

2.6.5. AMR-DMS integration

AMR-DMS integration was carried out in 2009 with implementing Tekla Xpower 7.3 to use. AMR meters installed in customers' premises are automatically read through Tekla Xpower AMR system. The AMR-DMS system integration is illustrated in Figure 2.9.

Even before the integration Tekla Xpower DMS has allowed observing the LV network switching statuses, but through AMR-DMS integration the data can now be easily imported directly from the distribution management system. Thus, VFV is now able to control the low voltage network automatically and in real time. In addition, AMR-DMS integration has tripled the length of the network under surveillance.[47]

Furthermore, now even the subcontractors at work can be better optimized along the network with the new appliance. That information is very important especially on restoring the grid after big storms when up to hundreds of repair men are working on the field.[47]

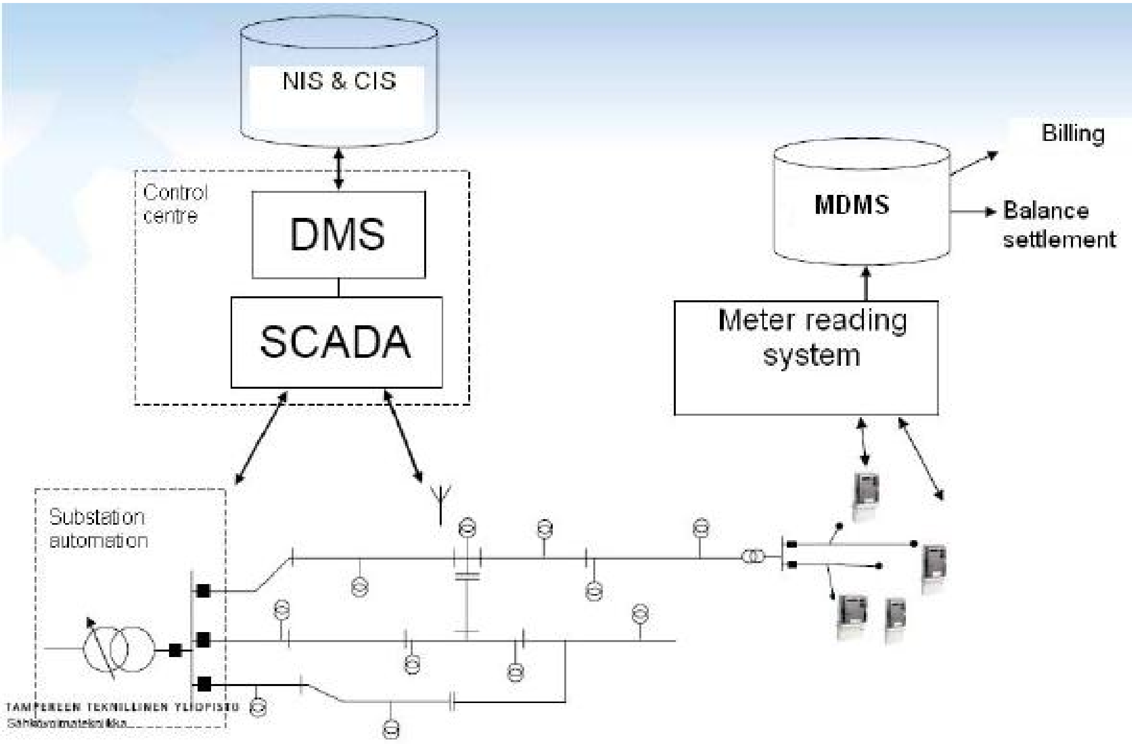


Figure 2.9. *Network management and AMR [48].*

Since the AMR meters make a fault alarm to the DMS system and again to the outage service, faults in LV network are detected faster than before. This means that customer does not necessarily have to make a fault indication to have electricity problems fixed. That is to say customer does not necessarily notice a fault when it can be fixed during a working day. In addition, VFV has applied the online service for their customers to observe their consumption as mentioned in the Chapter 3.6

2.6.6. MDMS

MDMS is an ongoing program due to 2014 affecting both to Vattenfall Finland and Sweden with a scope of creating a new common Meter Data Management System in the entire Vattenfall Nordic.

MDMS is a storage depot not only for metered consumption data but as well for other network operational data, like to power outages, power quality, meter configuration and tampering issues. The purpose of this program is to enable and clarify business benefits from the existing AMR information both in Finland and Sweden and make processes more efficient.

MDMS collects data from meters, verifies the quality of data and does different calculations. In addition, MDMS handles the new demands and volumes of data in a secure way. Moreover, it fulfils requirements on lead times and service hours.

One aspect in MDMS project is to improve customer satisfaction. This is achieved by better customer service; should a customer make a call to complain, client service can access customers' meter data and solve the problem more efficiently. Perhaps the best way for customers to experience the benefits of MDMS project is the Online service. Online service is discussed more in Chapter 3.6.

On a study before implementation process the business processes of VFV have listed the following to be the prioritized functionalities of MDMS [49]:

- Meter data handling, including validation and estimation
- Monthly calculation of total network loss including missing values
- Estimation of missing values
- Move-out/Move-in of residential customers
- Show power outages and power quality to internal and external users
- Request for meter value from AMI systems
- Change AMR meter for one service point/point of delivery
- Master data synchronization from CIS
- Event management

3. AMI RELATED SYSTEM TOOLS IN VATTENFALL DISTRIBUTION FINLAND

Figure 3.1 illustrates system integrations between Vattenfall systems and EIP. EIP requests and receives information from SAP, Xpower, Empower and metering data from Kauko and Santra meters through AMI collection service. Kauko and Santra meter reading is outsourced to Empower and TeliaSonera Finland (TSF) respectively. MDMS receives information from SAP system in incremental and full synchronisations. EIP supplies voltage information, hourly measurement and quality data files to Xpower through FTP gateway. In addition, EIP adds the collected reports such as network loss reports, exception reports, standard reports and AMI SLA reports to shared file server. Furthermore, EIP provides metering information on request to Online services.

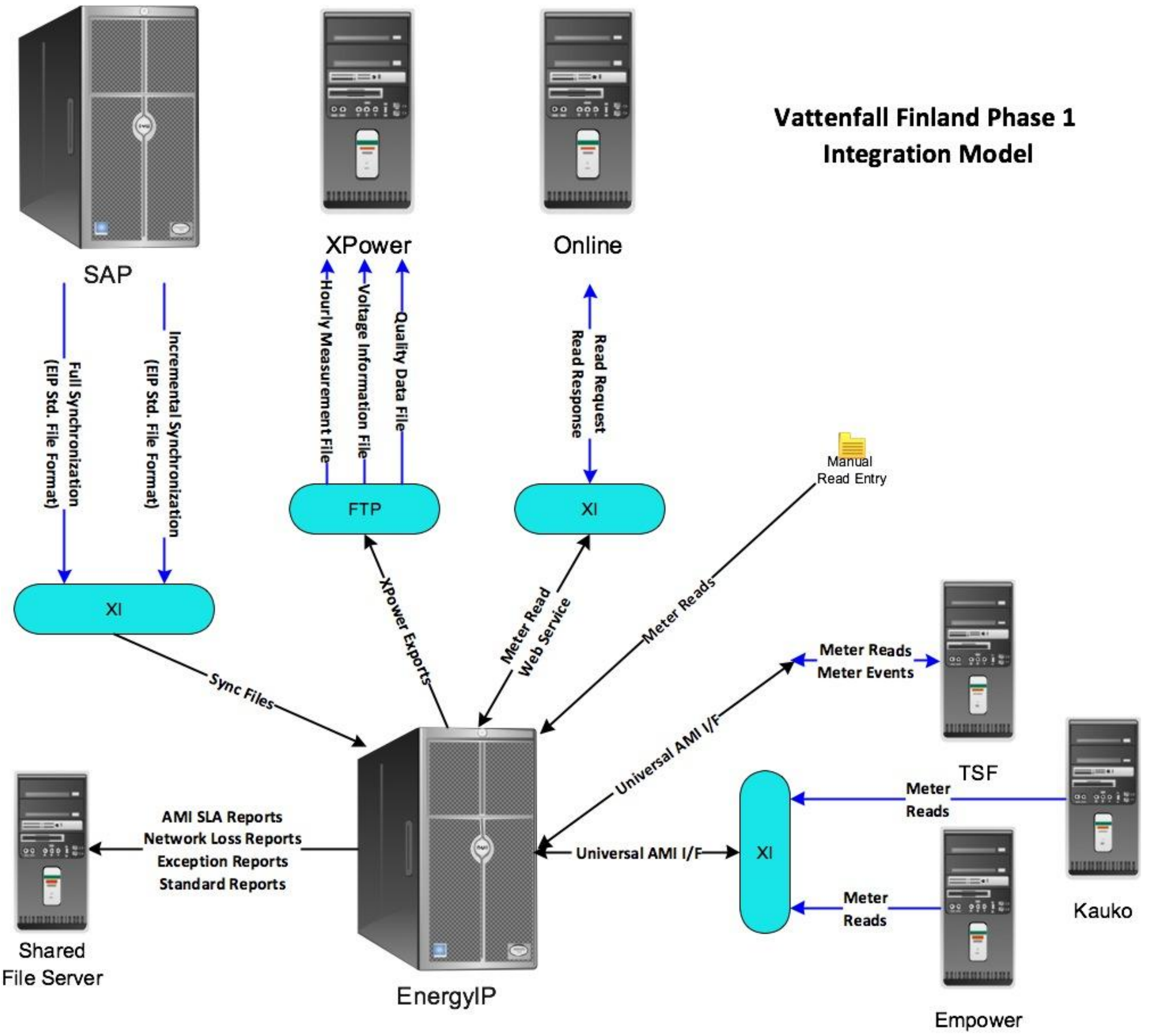


Figure 3.1. *System integration model [50].*

3.1. Iskraemeco MX372.xx meter family

Vattenfall uses currently Iskraemeco MX372.xx meters in its AMR main system. Iskraemeco MX372 is a multifunctional meter that can be used for metering electricity in addition to water, heat and gas consumption through the M-Bus connection. Meter can also measure the outside temperature. Furthermore, M-Bus connection can also be used with an external switching device. Connected this way, it allows the network company to connect and disconnect electricity in a premise. Thus, Iskraemeco MT372 can be used in network load control purposes. [51]

Iskraemeco MX372 meter has a built-in GSM / GPRS modem for communication. An external antenna can be connected to the meter in weak GSM signal areas. For the local use, the meter also has optical communication ability. Optionally to GSM modem, up to 31 meters at a distance of 1200 meters can be connected to one communication loop using a RS485 interface. This feature is mostly used in block buildings. The software of the meter can be upgraded remotely.[51]

Iskraemeco has provided the meters to VFV as pre-configured. In addition, SIM cards with the sufficient information such as meter names were pre-installed in the factory. SIM card can also be changed without having to turn off power.

Iskraemeco MT372 meter activity log can save up to 128 events with time stamps. The meter can measure the following [51]:

- Energy consumption (in watt-hours)
- Hourly consumption profiles
- Daily peak and minimum voltages of each phase with time stamps
- Voltage unbalance
- Amount of short (less than 3 minutes) power downs and total time of power outage
- Over and under voltages (with an alarm)
- Phase faults (with an alarm)
- Power quality parameters

The RMS value of each phase voltage is measured every 200 ms. The meter collects RMS values over a certain time interval (default being 10 minutes). An average is calculated from these values. Calculated average values are then compared to the defined thresholds at the end of each time period. Should the averaged RMS value be within the limits to a threshold, the value in the corresponding counter will increment. Thresholds are set according to the standard SFS-EN 50160. Counters are cumulative. Thus, a network company can see from the number in registers if the voltage level has been according to standard. This feature is used especially in situations where customer has reported about the poor voltage quality. In total, thresholds are seven to each phase and they are presented in Table 3.1.

***Table 3.1**. Defined voltage thresholds.*

Threshold levels	Voltage thresholds
Level 1	U > +10 %
Level 2	+5 % < U < +10 %
Level 3	0 % < U < +5 %
Level 4	-5 % < U < 0 %
Level 5	- 10 % < U < -5 %
Level 6	-15 % < U < -10 %
Level 7	U < -15 %

Iskraemeco MT 372 meters can measure active power measurements in both energy flow directions and capacitive and inductive reactive power Furthermore, Iskraemeco MT372 meters alarm in the following cases:

- power failure
- meter cover opened
- phase voltage (L1, L2 or L3) missing
- phase voltage going under the preset limit
- phase voltage exceeds the preset limit
- asymmetrical voltage
- power down
- neutral line fault
- meter is not registered to central system
- fatal fault

3.2. Collection services

VFV has outsourced its meter reading processes and IT infrastructure related to meter reading processes to TSF. Thus, TSF is responsible of meter reading, data communication with the meters, and maintenance of meters. Meters are read mainly through GSM network using GPRS connection. TSF has a wide GSM network coverage, as seen in Figure 3.2, providing a full coverage in the electricity network area of VFV.

TeliaSonera was merged in 2002 from two previously state-owned enterprises: Swedish Telia and Finnish Sonera. TeliaSonera Finland (TSF) was a turn-key partner during Kauko project.

Figure 3.2. *GSM network coverage of TeliaSonera Finland [69].*

The transfer speed achieved by using the GPRS technology is affected by several factors. Theoretically GPRS has a theoretical data transfer rate of 56 kbit / s, but the data transfer speed in practise range typically from about 20 to 40 kbit / s. The network coverage in general, network load, network failures, and the weather conditions have influences in the achieved data transfer speed.

The total service agreement between VFV and TSF covers the supply, installation and maintenance of the new smart electricity meters and the GSM-modem-based automatic reading in addition with the new functionalities of the entity. Management Services contain different remote management solutions, which can be automated with communication between devices and systems.

Furthermore, Empower Oy and Vattenfall Oy have a comprehensive agreement concerning the areas in energy information management. The agreement covers among other things the balance services to Vattenfall Sähköntuotanto Oy (VF Power generation) and balance settlement services to VFV.[52]

3.3. SAP IS-U

SAP (Systeme, Anwendungen und Produkte in der Datenverarbeitung in German or Systems, or System Analysis and Program Development in English) is a German software company. SAP is the world’s biggest business software company and the world's third-largest independent software provider overall.[53, 54]

SAP IS-U is an industry-specific solution from SAP designed specifically for utilities. The abbreviation IS stands for "industrial solution" and U for "utilities". That is to say the tool is designed to upkeep the basic infrastructure, such as electricity grids.

The SAP IS-U solution supports all major processes of a utility company with regard to the consumption accounting. This solution is widely used in metering electricity and gas consumption.[55]

SAP IS-U is used as a common energy information and customer information system in Vattenfall. SAP IS-U allows utility to perform on-demand customer meter reads, remote connects and disconnects of customer meters, and manage dunning and outage processes and time-of-use rates. In addition, it is used to generate and manage work orders. SAP applications can be custom modified and integrated to other systems.[24, 56]

SAP-IS U is a multi-use tool to manage multiple energy information and tasks related to energy industry. However, SAP IS-U is not a full AMI solution by itself since it offers only minimum capabilities of AMI system. Therefore it is partnered with other vendors of AMI systems, such as eMeter. Figure 3.3 illustrates the different features and actions of SAP and other AMI systems.[24]

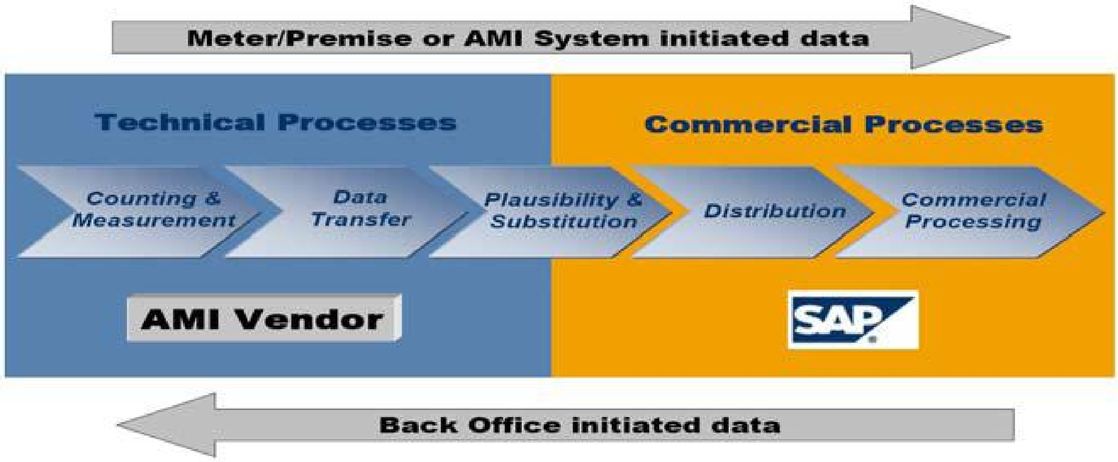


Figure 3.3. *The functional division of SAP and other AMI systems [24].*

The basic functions of EIP provide the technical framework to the energy supply as the data for distributors and settlement coordinators can be exchanged. In addition, basic functions allow managing addresses and regional structures can be managed. Furthermore, basic functions allow generating dates and schedules for meter readings, billings and budget billings and load forecasts can be created. Basic functions provide tools as well to calculate the prices and quotation.

Interval reading, schedule management, and the billing of interval energy consumption is done by Energy Data Management (EDM) module, which has the central database of energy data. Also the real-time pricing billing (RTP billing) and billing of profiles can be done with EDM.

SAP IS-U offers different functions supporting the AMI infrastructure through various modules. These modules include for instance details of premises, service requests, activities and outcomes

Customer information is stored in SAP. That data is migrated and synchronized with EIP at regular intervals. This is called as full synchronization. The EIP system and full synchronization are discussed more thoroughly in Chapter 3.3.

3.4. EIP

MDMS is an important part of AMI system. Metered data from the AMR meters is collected by MDMS, which is also responsible for transmitting that data to the information hubs. [21] MDMS is a data handling tool providing the data collected to the different information systems in a company.

Energy Information Platform by eMeter (EnergyIP, later regarded as EIP) is an MDMS utility and information hub currently in use in VFV. EIP offers an interface and tools to control and manage multiple data gathered from AMR meters, as well as AMI systems, system asset and administrative data and the whole AMI solution. The architecture and information flow in EIP system is illustrated in Figure 3.4.

As a result of integration processes run in VFV, MDMS is currently the central hub of information, as seen in Figure 3.4. The information in SAP is updated to EIP database with full synchronisation. In addition, the parameters and their relationships in EIP are validated in full synchronisation in order to ensure they are according their current status in SAP. Full synchronization should represent the present state of data elements and relationships in SAP at the time of the extract. [57]

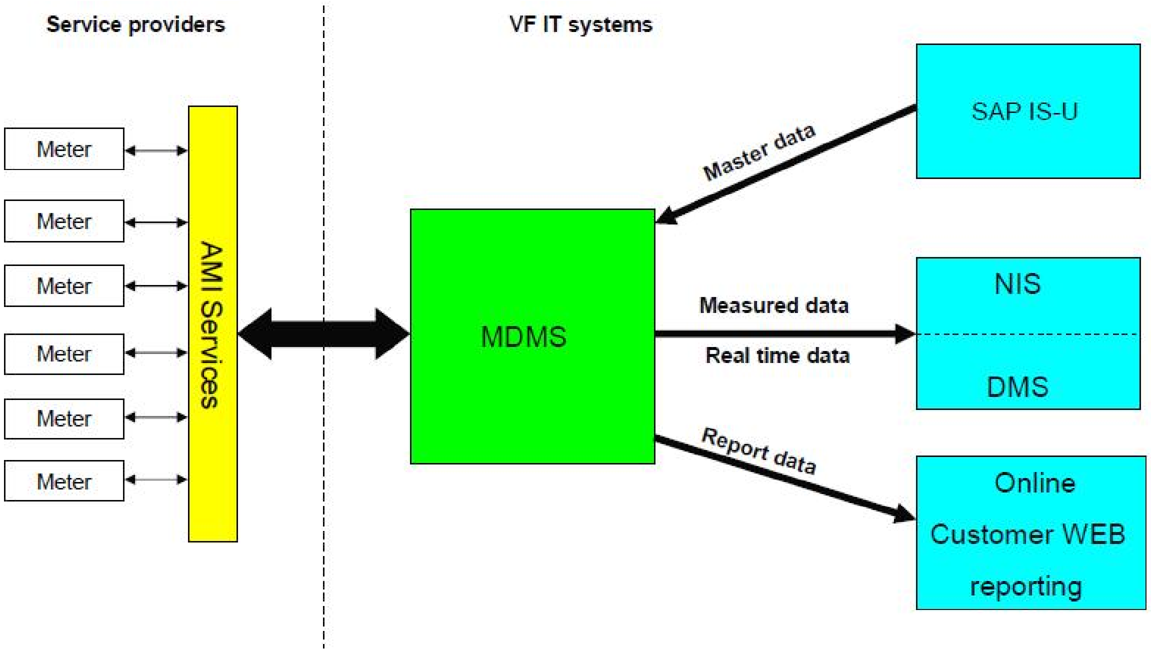


Figure 3.4. *Integration of different information systems with MDMS in phase 1 [49].*

EIP functions in nut shell include the meter data handling, including validation and estimation of missing values. In addition, EIP provides the monthly calculations of total network loss including missing values. [49]

The program architecture of EIP is open, scalable, and extensible. In other words, the analysis, reports and system parameters are configurable, and new or additional systems can be added to EIP. That gives a possibility to include for instance custom features and custom reports. VFV has implemented several customer reports to use. They are presented in a appendix 1.[58]

Figure 3.5 shows how different data models and tasks in EIP are linked together. These data models are displayed to users through the EnergyIP User Interface (UI). An example of UI is illustrated in the Figure 3.5. Trough the UI, users can understand the relationships of data elements in addition to search and view data from the database. The data elements are for example Service Delivery Points (SDP), meters, channels and reads. Also, historical data can be viewed through UI. Historical data contains for example meter swaps, failed reads and change of service agreement.

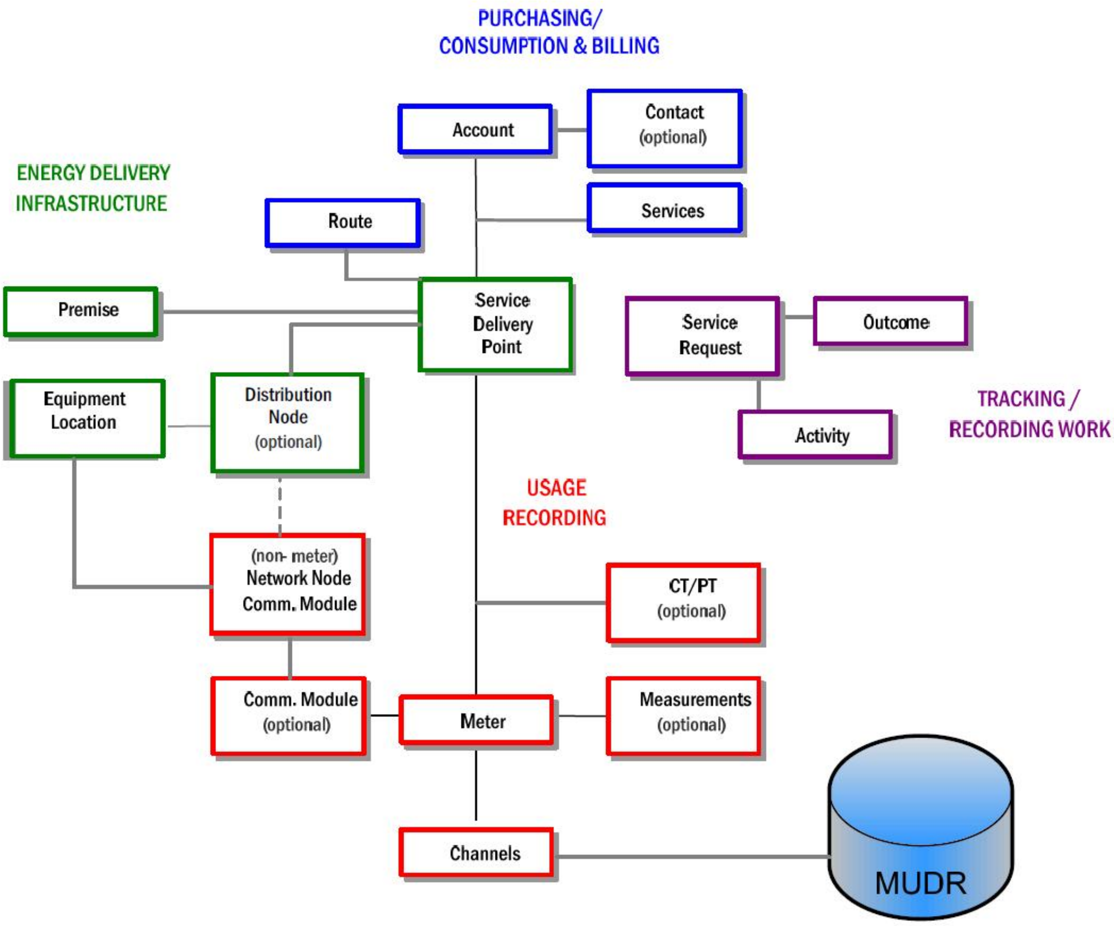


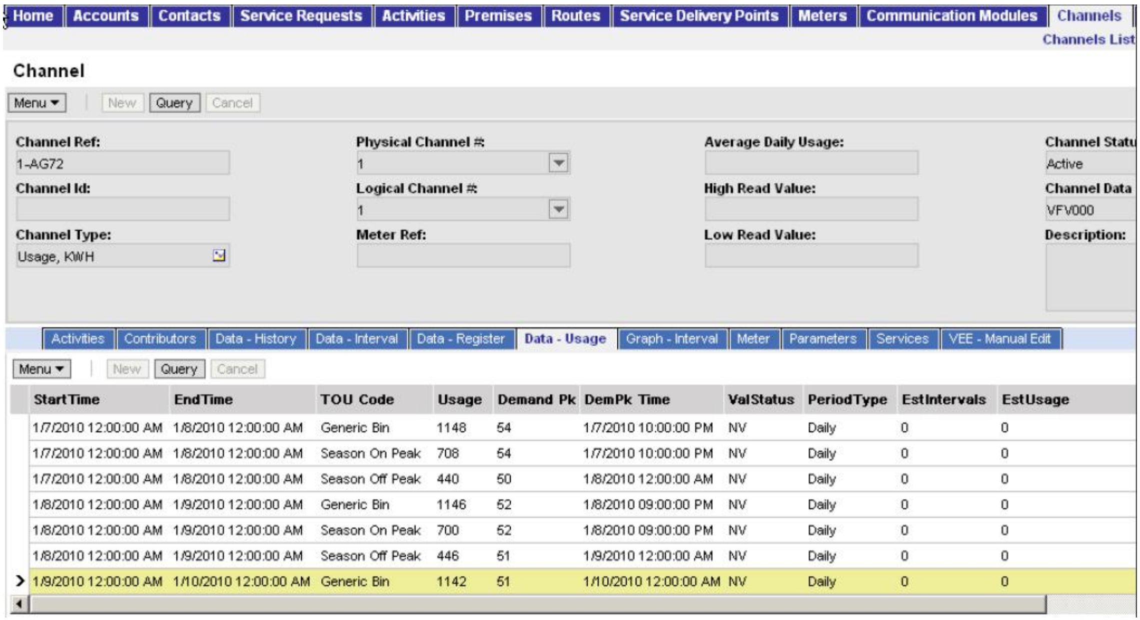
Figure 3.5. *Simplified EIP data model [59].*

The data elements illustrated in the Figure 3.5 are explained in the Table 3.2.

Table 3.2. *Data elements in EIP[59].*

Data element	Explanation
Service Delivery Point	SDPs are the locations of meters. In other words, SDPs are associated with the street addresses of the premises where the meters are located.
Route	Route is normally a geographic grouping of SDPs, arranged to shape the meter reading cycles
Service	For example tariffs, data collection, data delivery or web presentation each SDP
Premise	Premise identifies the physical locations of SDPs
Channel	Channel refers to the data type collected from the meters and its unit of measure.
Meter	Only one meter can be assiciated with each SDP. A meter have channels associated with it.
CT/PT	Current transformer/potential transformer value
Communication module	Communication module records and transmits information from the meter
MUDR	Meter Usage Data Repository, contains the measurements and readings

As explained earlier, the EnergyIP User Interface displays data from the AMI Management Database, as well as the Meter Usage Data Repository (MUDR). Users have the ability to view data and perform functions in the EnergyIP UI according to their business processes. Users can perform hee most common user tasks from the UI. Users can perform queries view and update meter read data, perform meter change outs, move customers in and out of premises, change the status of a customer relationship, perform billing requests, manage service requests and viewing reports from the UI. Figure 3.6 shows the UI view to the user.



StartTime	EndTime	TOU Code	Usage	Demand Pk	DemPk Time	ValStatus	PeriodType	EstIntervals	EstUsage
1/7/2010 12:00:00 AM	1/8/2010 12:00:00 AM	Generic Bin	1148	54	1/7/2010 10:00:00 PM	NV	Daily	0	0
1/7/2010 12:00:00 AM	1/8/2010 12:00:00 AM	Season On Peak	708	54	1/7/2010 10:00:00 PM	NV	Daily	0	0
1/7/2010 12:00:00 AM	1/8/2010 12:00:00 AM	Season Off Peak	440	50	1/8/2010 12:00:00 AM	NV	Daily	0	0
1/8/2010 12:00:00 AM	1/9/2010 12:00:00 AM	Generic Bin	1146	52	1/8/2010 09:00:00 PM	NV	Daily	0	0
1/8/2010 12:00:00 AM	1/9/2010 12:00:00 AM	Season On Peak	700	52	1/8/2010 09:00:00 PM	NV	Daily	0	0
1/8/2010 12:00:00 AM	1/9/2010 12:00:00 AM	Season Off Peak	446	51	1/9/2010 12:00:00 AM	NV	Daily	0	0
1/9/2010 12:00:00 AM	1/10/2010 12:00:00 AM	Generic Bin	1142	51	1/10/2010 12:00:00 AM	NV	Daily	0	0

Figure 3.6. *An example of EIP user interface [59].*

Users of EIP can search data elements and other information from the database. All searches begin with a query with one or more criteria. Queries can be either pre-defined or user-defined queries. The results of queries can be viewed on screen, exported to a file or used as an input to a report. Query results include primary contact or account information such as contact reference number or account number, name, and account status. (EIP user guide)

Pre-defined queries contain set criteria, defined by EnergyIP. Since the criteria are set, users can not edit the pre-defined queries. Instead, user-defined queries are created and modified by the users with specific criteria to locate specific records.

Because the usability of the data is highly important, one of the most important tools of EIP is Validation, Estimation and Editing (VEE) module. VEE module validates the data received from the meters. If missing intervals are received, VEE estimates them.

The metered data is validated according to the rules associated on the channels For example the meter read values are compared to the preset highest and lowest expected read values. If the interval data is valid, it is sent to Meter Usage Data Repository (MUDR).

Should the data be not according to the rules it is sent to manual verification and editing. Start date and end date of the period of data failed the validation is shown. Data can be edited individually, in groups, or in a certain range. User editing the values can compare them with a reference graph. The purpose of this graph is to view values in another channel in order to compare and contrast it with the focus channel. If there are missing intervals in the data, the missing values are estimated.

3.5. Xpower

Tekla Xpower is Finnish network management and planning software used in VFV. Tekla Xpower collects energy network data in a single database and provides it forward to various applicationls, as shown in Figure 3.7. The energy network data contains the characteristics of components in addition to location information. Thus, the software includes also a geographical information system (GIS). Tekla Xpower application allows the user to control the energy network lifecycle from network planning, construction and operation to tasks of maintenance and customer service.

Tekla Xpower is a multi-user system. That means the same network data can be used in simultaneous different work processes. Xpower can be integrated to various other energy management information systems. Thus, its data available for different functionality can be added. These energy management information systems can be for example Supervisory Control And Data Acquisition Systems (SCADA) systems and customer information systems (CIS system). [60]

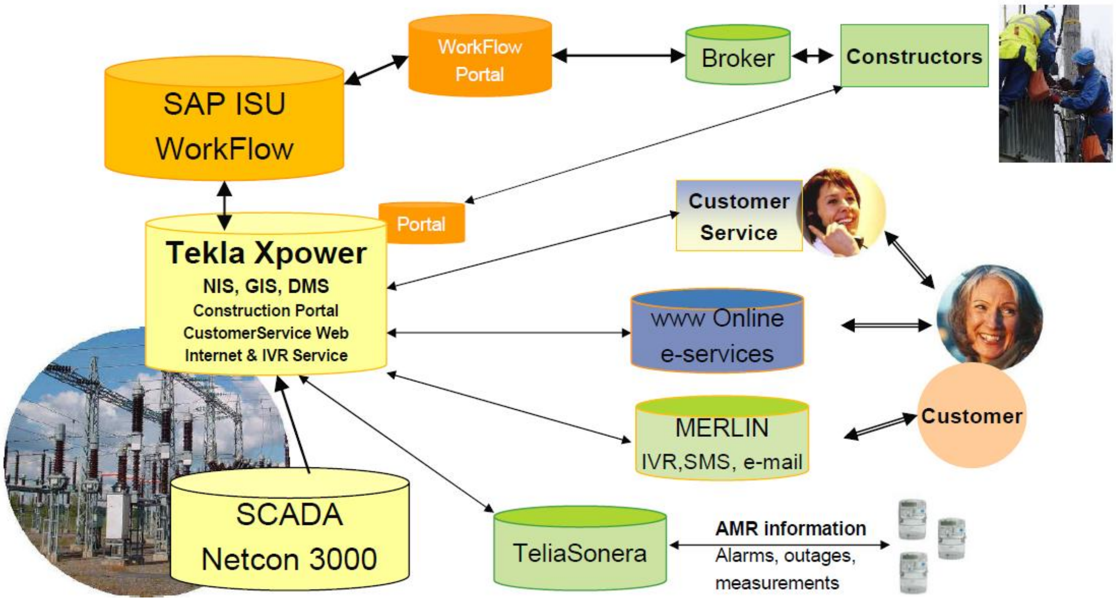


***Figure 3.7**. Tekla Xpower as the strategic information system [61.]*

The XPower Export Interface provides the file-based interface by which EnergyIP can export meter reading data (hourly intervals) or power quality data in a format that can then be imported into XPower External systems. [qq] EIP provides the following reports and alarms to Tekla Xpower system [62]:

- Neutral conductor fault
- One or two phases missing
- Voltage unbalance (not spontaneous)
- Voltage level is not within accepted thresholds (under 184 V or over 253 V)
- Meter is not responding

Utilizing the hourly consumption values has improved the quality of delivery and the reliability of supply in addition with making the network calculations more accurate in Xpower. In the future the network calculations will improve even more when real-time monitoring of low voltage grid status and events is possible. In addition, supply reliability has improved with using Xpower as the network asset management planner. [61]

3.6. Online

VFV has offered its customers a web-based application to observe their hourly energy consumption online since April 2010. When a customer makes a service request, the web application makes a request to access the meters and the collected information on the wanted premise. An example of a consumption surveillance view is illustrated in Figure 3.8. Online service together with AMR has reduced the customer service as the customers could have verified the amount of electricity consumed by themselves. Furthermore, Online service has reduced the amount of suspicions of electricity theft.

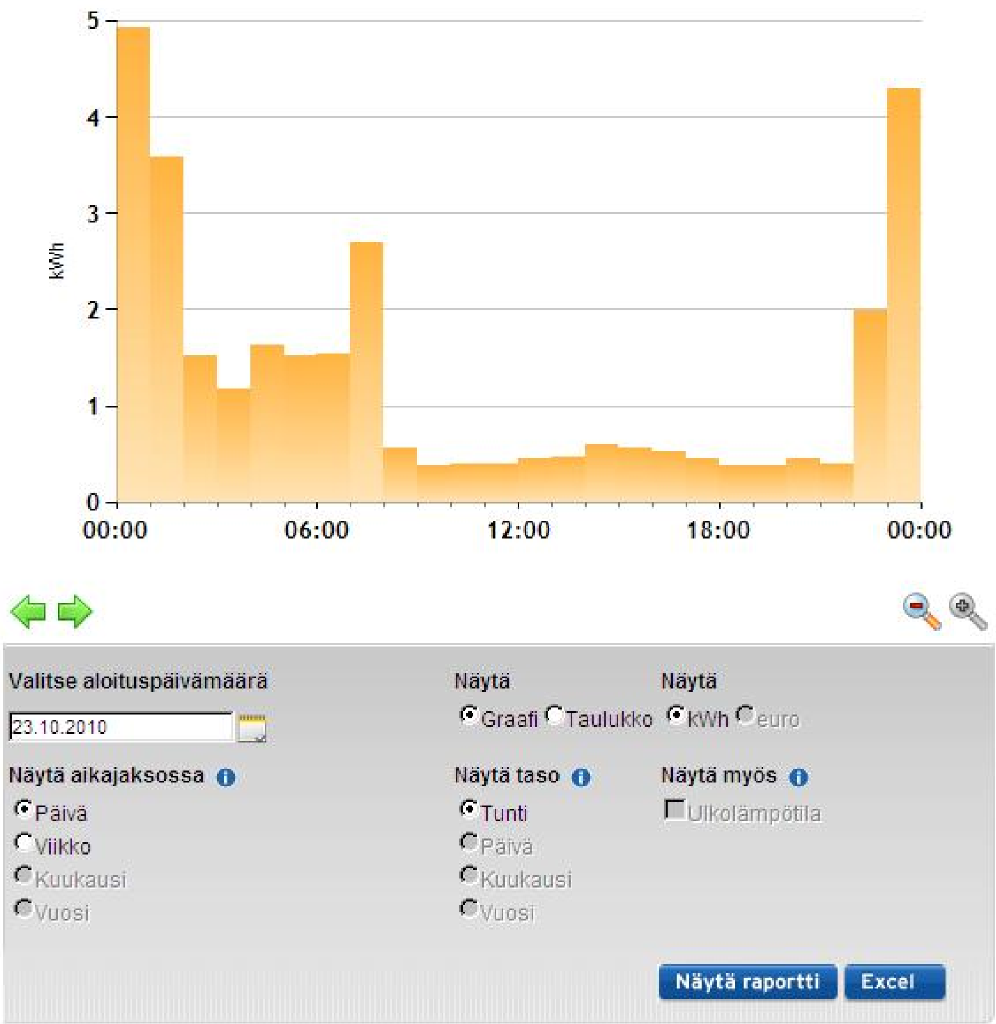


Figure 3.8. *Customer consumption view in Online service.*

In addition to consumption surveillance, customers can manage and renew their contracts, observe and modify contact information, make a notification of change in residence, pay bills and order a SMS fault notification service through online services. The number of users have risen from couple of thousands in summer 2010 to over 30 000 users in January 2011.

4. BUSINESS PROCESSES IN VATTENFALL VERKKO OY

4.1. Delivery of electricity

The goal of the delivery of electricity process is to serve electricity market parties with accurate and timely measurement data aiming at precise customer invoicing and enhanced forecasting of energy consumption. This can only be accomplished with accurate and real-time metering information. Then faultless delivery, accurate invoicing and better estimations of consumption can be achieved.[63]

The flow chart of delivery of electricity process is illustrated in Figure 4.1. The process starts when an agreement of network service is made between a customer and a network utility. In case of new premises this process starts after the connection process. The process ends when the customer moves and pays the invoice. In between those stages the tasks of the process include changing the network product or type of contract, measuring and invoicing the consumption, changing the vendor of electricity and make market settlements. [63]

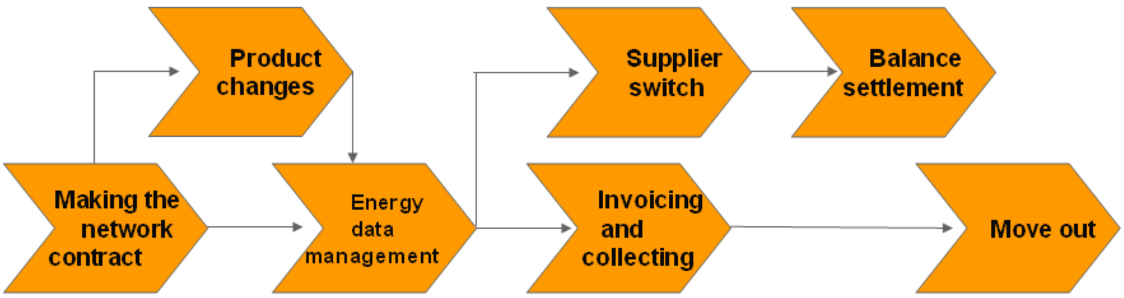


Figure 4.1. *Description of power distribution process [63].*

Handling the measured data of electricity consumed is an important subtask of distribution process. The importance of hourly consumption data has increased and will increase dramatically in the following years. Forthcoming law obligates network companies to store metered hourly consumption value data for at least six years. Current systems do not have this kind of a historical database since VFV has stored automatically metered data starting from late 2009.

4.2. Connection services

Connection process provides new connections to customers or modifications to old connections. This includes providing services related to connections, such as electrical designing of connections. The goal of the connection service is to deliver new point of connection or make changes to the existing connection to the customer with keeping our customer promise.[63]

Process begins when customer has a need for electricity or need for power demand increase. Process ends when customer can start to use electricity from new connection or when the needed changes are done. The flow chart of connection service process is illustrated in Figure 4.2.[63]

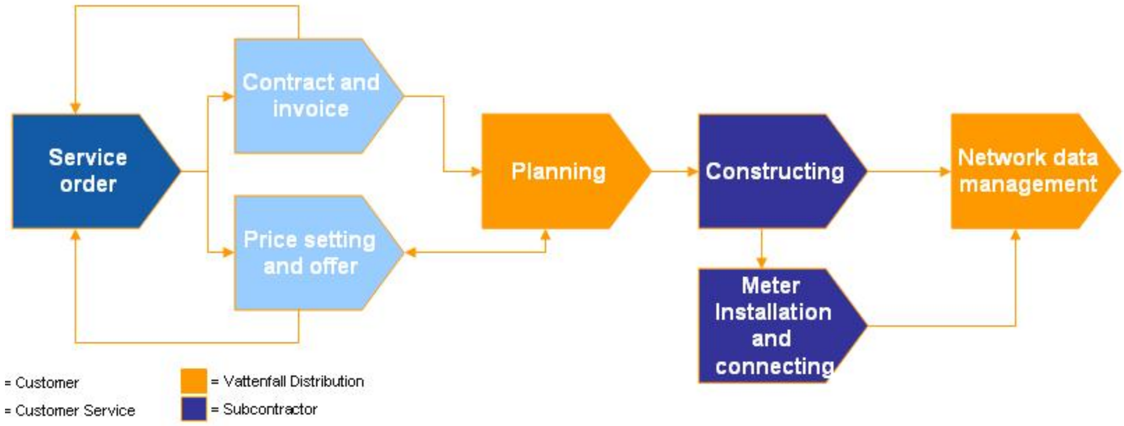


Figure 4.2. *Connection service flow chart [63].*

Services of connection process are listed as following [63]:

- Making new connections
- Changes to the existing connections
- Demolition of connections
- Updating contracts
- Making temporary connection

4.3. Quality of delivery

Quality of delivery process is responsible for the distribution of electricity and ensuring the voltage quality, maintenance and development of the network so that the performance of network is according to regulations and the promises to the customers. In addition, another goal to the process is to guarantee an adequate level of security in network. Furthermore, process ensures that the network fits to the surrounding environment and makes sure that the network is ecologically sustainable and compatible with the surrounding nature and landscape.[63]

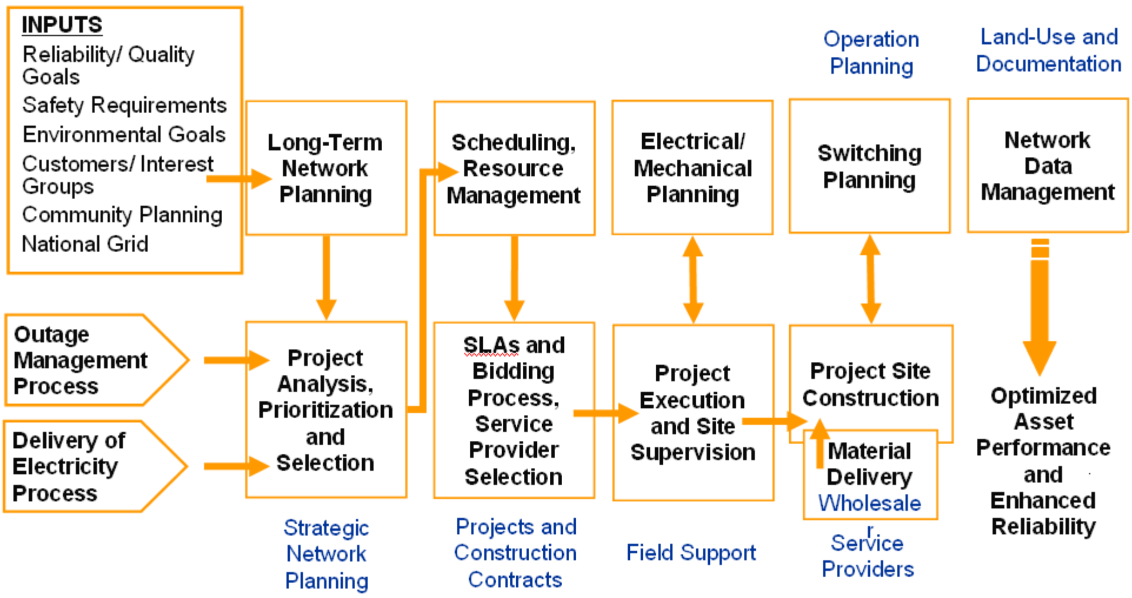


Figure 4.3. *Quality of delivery process flow chart [63].*

As seen in the Figure 4.3, the quality of delivery process starts with taking into account the needs of customers and interest groups. In other words, the process begins with defining the network asset performance goals and objectives and by receiving the project proposals from our customers and stakeholders According to them and the future plans of different processes the target network is designed. The process ends by delivering the enhanced reliability of supply to our customers and by providing the optimized network asset performance. The aim is to have the performance level equivalent to customer expectation and optimized asset management. [63]

Quality of delivery process takes also care of the network maintenance. The main purpose of the maintenance is to maintain the workability of different components in the network. In other words, the operating life of components is prolonged along with ensuring the safety and reliability in addition to preventing operating failures. Moreover, the total costs of the network use are minimized. Corrective maintenance is a sudden and unplanned need of maintenance. Repair takes place after a fault has occurred, without prior planning. Preventive maintenance aims to prevent the faults and correct possible future fault locations. Furthermore, preventive maintenance can be divided into time based maintenance (TBM) and condition based maintenance (CBM).[64, 65]

4.4. Outage management

Customers expect uninterrupted delivery of electricity. However, if power outage has occurred, the problem is expected to be corrected without further delay. In addition, customers should be informed about the fault and given real-time information of the repair process.[63]

Outage management is responsible of returning the network to its normal status after outages, as promised in the network contract. That is to say the purpose of the process is to repair the network during the outages and restore the delivery of electricity back to normal in addition to correct the acute risks to the health in the network and offer the customer service during disturbances. In addition, the outage service process is to prepare to the failures and exceptionable situations with plans, and execute them in case needed. Furthermore, the repair time should be as short as possible and repair work should be as safe as possible both to customers and to repairmen and as cost-efficient as possible. Information concerning the failure should reach the customers, cooperation partners and VFV's own employees during the failure.[63]

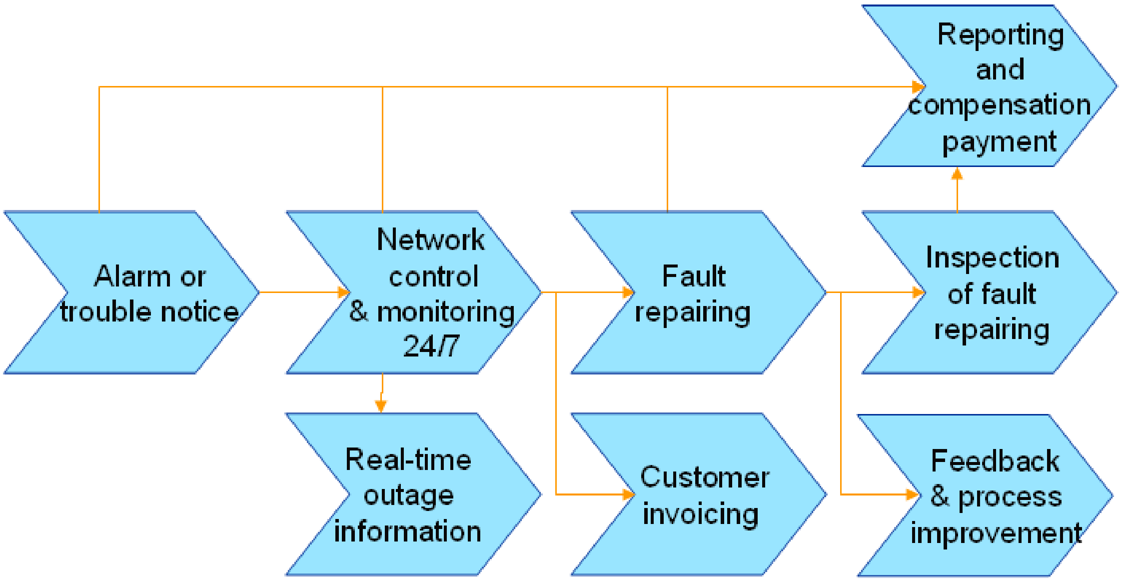


Figure 4.4. *Outage service process [63].*

As illustrated in the Figure 4.4, the process starts when a notice of a fault, threat of fault or security risk in the network is received. The network is under continuous controlling and monitoring. DSOs handle the fault alarms and are responsible of clearing of the fault. Even though many contractors may be involved in the actual repairing, the process is always supervised and guided in the control room. Process is considered as ended when the network has been returned to its normal status, possible compensations have been paid to the customers according to the length of the outage and feedback concerning the functionality of the process has been collected. If the fault has been caused by the customer or an external person, the invoices are sent to the liable parties. [63]

4.5. Take care of my customer response

Take care of my customer response (TCCR) is the customer relationship management process maintaining and strengthening the customer relationships by ensuring that customer information and contacts are correct, and collected and exploited systematically. This process makes sure that the additional services and counselling services meet the customer expectations and needs in according to company's objectives. Customer relationship management process aims to develop customer awareness, improve customer satisfaction and boost customer confidence in Vattenfall. TCCR aims to maintain and strengthen customer relationship by enhancing customer data and contacts for service development.[63]

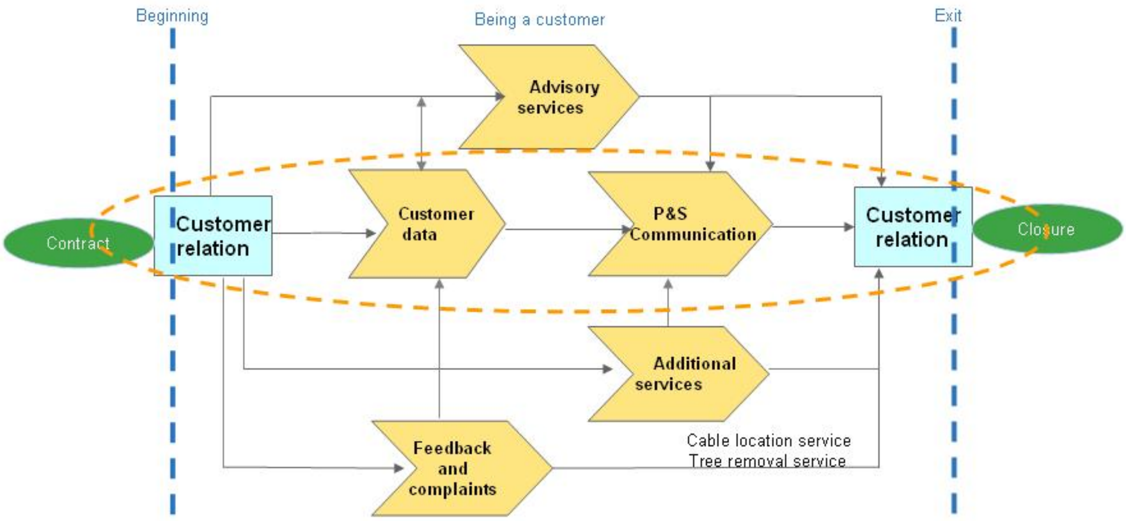


Figure 4.5. *Take care of my customer response flow chart [63].*

As illustrated in Figure 4.5, TCCR process begins when the customer signs the network contract. Process ends when the customer moves and pays the final invoice, excluding feedback and complaints. In between these stages the TCCR process upkeeps the customer relationship with various services.[63]

5. FEATURES AND REPORTS ACCORDING TO NEEDS

Meter data management system stores and processes the data collected from the meters. One of the most important tasks of MDMS is to control and verify the quality of metered data. Errors can occur during the metering process if a meter is broken or if a software bug has interfered the metering. Data can corrupt also while sending and receiving the data from the meters to collection services.[66]

Data must be undamaged, complete (not have any shortages) and correct. Meters provide abundance of data. Any mistakes or flaws in the data do not support the original purpose of MDMS as if the data becomes untrustworthy the same mistakes cumulate to other systems using this data warehouse. The same needs concern as well the information in SAP. Information in central data banks must be correct.[66]

5.1. Improved usability of MDMS

5.1.1. Quality of data

Quality of data is a very important issue concerning MDMS and it can not be overemphasized. Data consisting misinformative or poor-quality values do not serve the purpose of metering. Thus, it is highly important to have an access to defective meters. They are not the only source of inferior data, but one of them amongst for example data transfer gateways. In addition, network companies have to send estimated invoices to their customers because of corrupted data or lack of metered values. In case of corrupted data or no data have been received from the meters, a network company has to estimate the consumption using customer consumption patterns, which are almost accurate for a large group of consumers, but inaccurate for a single consumer. If the consumption in an estimate invoice does not match the actual consumption, a corrective invoice has to be sent. Having only real consumption data would remove this need.[66]

Defective meters create previously mentioned corrupted data. At the moment the personnel have to search information from different sources to identify them. Finding a defective meter is very hard doing so. Thus, a report of defective meters would lower the amount of futile work. If a report tool is created, it has to be sensitive in a way that it would not send up to hundreds of thousands fault alarms because of couple of lacking hours but with what truly defected meters can be found easily.[66]

Power balance report window is 14 days starting from the year 2011. To report the values within such a short period of time is challenging with the tools in use currently. A tool to validate and fix the metered values would be essential. Now the tool operates in a way that if a corrupted data is detected, it is replaced with a calculated value. When the values before and after the shortage are known, missing data should be the difference between those two values. This works perfectly if corrupted values are only from one or two hours. [67] Flaws in the quality of the data affect inferiorly to every single process using AMR data.

However, the reports implemented in EIP can help in locating the defective meters. For example using and combining data from the following Core reports listed in Table 5.1 could be used on that purpose.

Table 5.1. *Reports indicating failure meter [68].*

Report name	Type of validation
Core report 3: Billing No Reads Report	Success of reading
Core report 7: Estimation Failure Detail Report	Success of validation
Core report 8: Excessive Missing Reads Report	Success of reading
Core report 12: Missing Reads Report	Success of reading
Core report 13: Missing Reads Summary Report	Success of reading
Core report 18: Validation Failure Detail Report	Success of validation
Core report 19: VEE Summary Report	Success of validation

5.1.2. Capacity of data storage

The legislation obligates the network utilities to store the metered data for at least six years, as presented in the Chapter 2.2.1. The processes would, however, benefit from longer storage time. For example the TCCR process described the optimal data storage time to be approximately ten years.[70]

5.1.3. Retrieving reports from EIP

Usability of EIP is currently not the best possible. The usability would be improved with more easy-access user interface where more ready-made reports could be retrieved from. Currently multiple steps and many clicks are needed in order to the wanted report can be fetched. In addition, customization can be seen difficult since the Finnish and American practices are different.[71]

A tool is needed with what multiple premises can be loaded into analyzing process in EIP. At the moment when a place is put a list of the questionnaire in the EIP system, it brings out all the places of use in the selection list. But if, for instance a consumption report is wanted, the user has to go deeper in each premise at a time until the wanted report can be retrieved. The desired result could be immediately visible with more reporting tools.[71]

An example of a better report tool is that if a user would like to investigate losses for example in substation case basis, the EIP should pick up a list of places of use (the list from Xpower) behind substation. That list should be load for this group the sum of the consumption series of one hour for the month. Yet, the result could also be on premise case basis, but group size can become very big in some substations. Data deficiencies could be seen in the place of use classification.[71]

5.1.4. Co-operation with SAP

Cooperation with SAP and EIP should function better. Cooperation gives the framework conditions for other services, for example to the functioning of online service. Among others speed of service depends on this. Customer contract data is to apply correctly.[66]

Customer requested and received information should be in comprehensible form. Lack of information and data quality problems cause trouble during the investigation processes done after customer reclamations. Problem is aggravated when the number of users increases, causing needless extra work for the customer service.[66, 72]

5.1.5. Outage history

One of the most wanted information source needed by the outage management is a better outage history. Outage history is already implemented to the MDMS but it lacks some crucial information mentioned in next paragraph and the data source is inconvenient to use.[72, 73]

New functions needed are the length and the reason of the outage, and the correct outage history. False alarms are one of the main reasons to the previously mentioned inconvenience and it is discussed more precisely in the Chapter 5.1.7.[73]

5.1.6. AMR-DMS integration

The data AMR-DMS integration and its benefits do not currently go through MDMS. That causes delay to the information flow to other systems. In the future that would be avoided if the data flowed directly through MDMS. If done so, the power information in network areas could be more visible and coherent, making the measurement of aggregates easier and more accurate.[74]

5.1.7. Detection of false alarms

Meters are currently physically installed after the main fuse in the premises. Thus, when a main fuse is opened, the meter loses the electricity and connection with the meter is lost, similarly as in fault situations. Thereby opening a main fuse at a point of connection causes a fault report to the system. In addition, that causes a situation where actual faults are hard to spot from the flood of false reports. [66]

Since the installation costs are considerable, a tool is needed to identify the actual fault reports from the alarms caused by opening the main fuse. When the amount of false alarms is marked, it is almost impossible for the staff control room to identify the actual faults in points of connection.[66, 73]

5.1.8. Shorter metering intervals

Most of the representatives of different teams said that their teams would benefit from more detailed consumption and power data from shorter metering intervals. Metering intervals could be for example 10-15 minutes. Especially in the case of new types of energy production plants, as in the wind turbines, this would be essential. In addition, more specific trends in consumption could be seen if the intervals would be 15 minutes instead of an hour. Furthermore, if the consumption reports from shorter metering intervals were submitted to Online service, customers could see better how their actions affect to their energy consumption.[67, 70, 72, 74, 75]

Moreover, as the electricity markets integrate steadily towards a common European market, shorter metering intervals might be needed. For example, in the Netherlands the meters are required to meter values in 15 minute interval, in the UK the interval is 30 minutes in the premises using enough energy.[76, 77] One question in the future is that if the electricity market unite across the Europe, which metering interval type is selected. Hourly measuring interval is used mainly only in the Scandinavian electricity markets and has shown benefits there. In the European scale, however, Scandinavian countries represent only a minority and it is yet uncertain if the bigger countries and markets are willing to change their systems to the Scandinavian system.[67]

In literature the following purposes were mentioned to benefit from more precise time resolution of measurements of consumption than one hour.[78]:

- energy management automation
- optimizing the use of loads according to the prices of electricity
- immediate feedback of energy saving measures
- identifying the parameters of power balance model
- identifying the partial loads
- monitoring the distribution load
- power quality control and registration of interruptions in electricity supply

However, the trend curves based on the metered data can become less useful if the frequency of metering is increased. This is because consumption can fluctuate dramatically between consecutive periods of measurements. It can be assumed that hourly measurement produces ”smoother” and more readable. Thus, the consumption data should be able to view on a longer interval as well if wanted.[72, 75]

5.2. Reports and alarms

The most important demand from the Corporate Customers team to MDMS is to have better reports and alarm tools. Sole database itself does not create additional value for this team and its functions. Instead, the processes benefit from the reports and the alarms made possible by the better information. EIP has already reporting tools, and they are listed in appendices 1 and 2.

Information should be easily and rapidly accessible. At the same time, it should be understandable and unambiguous. In addition, the same demands conform to the needs of the customers' (both private and corporate) online services.

5.2.1. Reports of remarkable changes in consumption

Reports of remarkable changes in consumption would give the corporate customer team a better surveillance tool to serve the important clients better and to see if some major changes have occurred. These reports could be of significant changes in [70]:

- volume of consumption
- peak load of the connection point
- grand total of invoice
- reactive power

These changes are not hard to detect, but are really hard to constantly check manually for all of the customers. Now when the billing is done automatically, not even a secretary handling billing information can find these changes by accident. EIP has already a tool to detect and report these kinds of changes: *Core report 2: Billing Data Change Report*. However, it does not take the reactive power into account.

If noticed early enough, issues concerning major changes can be sorted out before it is too late. Regardless the fact that it is not financially a network utility's issue to cover the expenses of a factory's unintended production of reactive power, it is still according to good manners and loyalty to customer to participate in them and negotiate the how to lower the fee. However, should the period of not compensating the reactive power be long, the willingness to give reductions to fees declines. In case the billing cycle has not ended, the issue can be handled without further problems.

If for example a capacitor bank meant to balance a factory's need of reactive power breaks the factory takes reactive power from the network. The report alerting the changes in reactive power production would serve the process by helping it to prevent needless and time-consuming look-up done after customer's contact.

5.2.2. Control of connection capacity

Surveillance of connection capacity is needed in cases where customers either surpass their connection capacity or where the consumption of electricity is higher than what the main fuse would allow to. On the latter case, transfer product sold to the customer is priced too low.[70]

VFV has made two custom reports for controlling the connection capacity:
CUSFEA 177: Consumption greater than X% of Fuse Size
CUSFEA 178: Consumption less than X% of Fuse Size

With these reports the demands from customer service related processes can be fulfilled. In addition, these processes can improve their customer service and imbursement processes.

5.2.3. Neutral conductor fault information

At the moment neutral wire fault reclamations do not reach the customer service in time as the system does not hold the maximum and minimum values in its database no longer than for one day; customer service can only reach only the data from current and previous day whereas reclamations concerning the fault can be sent days after it. Thus, for the reclamation reasons the information from a longer period of time would be essential. If the neutral conductor alarms were stored in the database, they would be both detected easier by other programs and the information could be retrieved easier if needed. [72]

If faults in neutral conductors would set an alarm instantly, these faults could be detected more efficiently. In addition, if the meter could shut the power down after detecting a neutral wire fault, a network company would not have to pay compensations due to these faults and they could be fixed faster. Moreover, the safety of the customer would increase as the neutral conductor faults causes high voltages to some electrical equipment leading to mortal dangers.[72]

5.2.4. Unauthorized usage

Use of electricity either unauthorized or with no agreements in force should be discovered. For this task EIP already has a core report, *Core Report 17: Unauthorized Usage Report.* That is to say the EIP knows where more than 2 kW / day are used in places where there is no valid contract, but this tool is not yet in use of VFV.

The idea is that the in the second phase of MDMS project the commands of opening and closing the relays go through EIP, and this tool will be used. This information of electricity use could be used in for example in investigating the changes of residences when there are mistakes in customer information in SAP, and in renewing the imbursement process.[66]

5.3. More accurate load profiles

Customers use electricity depending on different seasons, day of the week and outside temperature. Thus, load profiles have been developed to give electricity utilities better estimations of the loads. Different types of load profiles have been created to different types of customers to represent their average consumption in a certain period of time, normally in one hour. In other words, load profiles represent the time dependency of power in average customer in a certain group. Load profiles have been formed according the pre-known criteria, season and day of week. Influences of temperature should also be taken as one criterion if load profiles are wanted to improve. In addition, if the metering interval is shortened, load profiles can also be formed for shorter periods. However, these are not considered as needed currently since the electricity markets offer only hourly products.

Better load profiles improve the estimates of consumption. If a gap between the estimated and actual consumption could be narrowed, it will reduce the need for balance electricity. That is to say the energy supply would need to buy less energy from the markets and narrow the gap between the purchased energy and the energy actually supplied. Improving the type loads with the outside temperature is presented in the Chapter 5.3.2. More accurate load profiles will reduce the amount of needed balance electricity and offer new types of business services to the network companies, as purchasing the balance electricity. Moreover, the amount of protection derivatives could be minimized with better load curves.[75]

One way to make the energy purchase more accurate is to implement the temperature correlation tool. Also, a predictive tool which would take the current amount of customers and market trends in concern would be needed to help the decisions when purchasing the energy from the markets. [75]

5.3.1. Placing customers to right load profiles

Customers could be put to the load curves representing their behaviour either automatically or by the customer through the advices in online service, as discussed later on Chapter 5.6.6. MDMS could be used in placing the customers in more accurate load profiles.

5.3.2. Integrated temperature information

Weather conditions and outside temperature have a major influence on energy consumption. [79] In northern countries electricity is used more on winter compared to warmer periods, as seen in Figure 5.1. That can be explained on a need to warm houses up more when it outside temperature lowers. Now that need of electricity is not noticed practically at all when estimating the loads and buying electricity beforehand. Moreover, nor is noticed the consumption of cooling devices during summertime.

That is because there are not very much of data from the past of the correlation between temperature and load. Hence integrated load and temperature data could be used to create better models of customer load behaviour if this kind of data would be accessible. So to say, it would be crucial to investigate how customers’ load varies on different temperatures.

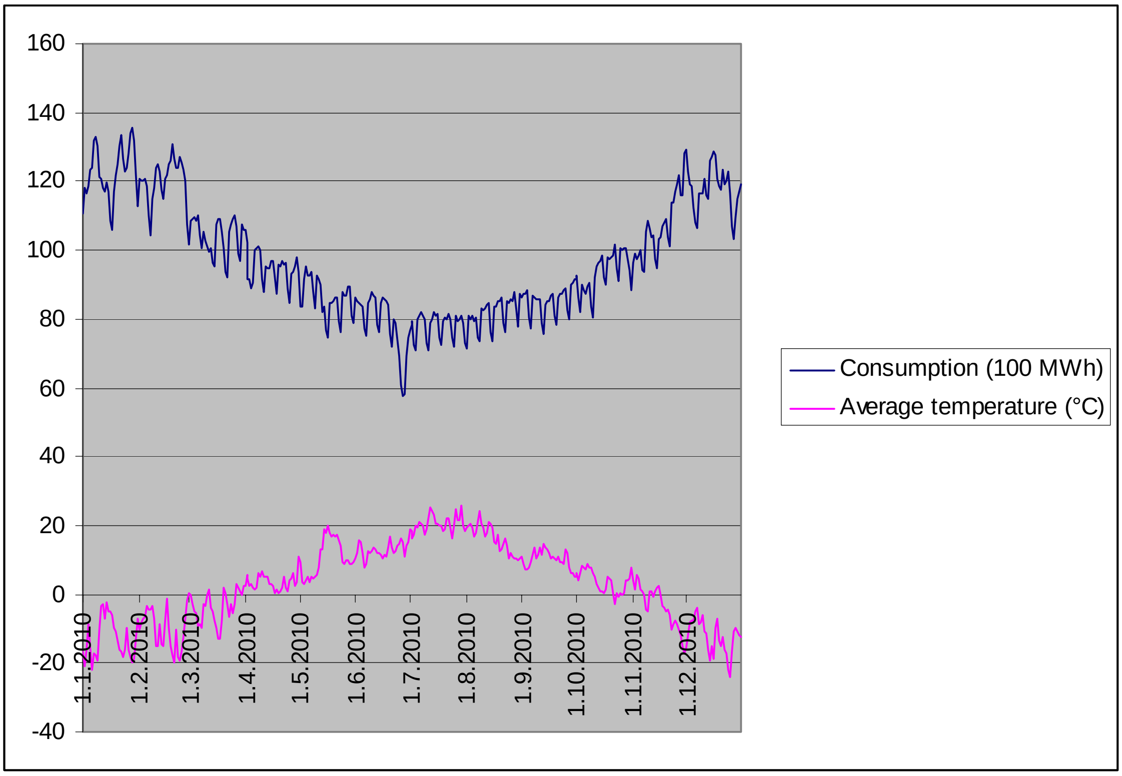


Figure 5.1. *Temperature and consumption of electricity in Finland in 2010. Adapted from [20, 80].*

Thus, integrated temperature data to metered data should be implemented to the metered data of consumption. Temperature information can be collected by VFV itself from selected transformers or bought from external source, for instance from weather forecast service. However, the temperature data from tens of kilometres outside the actual point of consumption may not be accurate since the temperature can vary dramatically within couple of kilometres. That is why the local temperature data is always the most accurate.

With the data collected from the meter a temperature correlation model could be created. In addition, the best model would be the one that could correct itself according to more data. So to say, the temperature correlation model would show the amount of electricity consumed in certain outside temperatures. That model would be a very important tool for the supply of electricity. One possible solution could be to create temperature correlation model to each customer type and finally sum them up to form a temperature correlation model to represent the whole customer group.

5.4. Power information

In addition to active power measurement, which is in use at the moment, network management process would benefit from being able to receive measured data of reactive

and apparent power as well. With these pieces of power information the process could analyze the network status better and see if network needs to be compensated better.
A tool should be created registering the number of power swells and number of power sags.

5.4.1. Reactive power information

In alternative current (AC) networks, apparent power has active and reactive power components. Active power is the power used normally in equipment, for instance in resistive loads. Normally the network companies want to keep the ratio of active power to apparent power, also known as power factor, as close to one as possible.

Reactive power is not working power (as opposed to active power). In addition, transferring reactive power uses as much bandwidth in transmission lines as reactive power. That is why network companies would like to transfer purely reactive power in their transmission lines. The power factor expresses the ratio of real power and apparent power and the desired value is one. The bigger the ratio of the reactive power out of the apparent power, the lower the value of power factor is. Reactive power can be divided into inductive and capacitive reactive power. In the case of inductive power, current is lagging the voltage and in the case of capacitive reactive power the current is leading the voltage.

Simply said, capacitive load produce capacitive reactive power and inductive load produce inductive reactive power. However, they are in opposite phases and in the same circuit they cancel each others out. In addition, induction (inductive) motors need capacitive reactive power to function. The capacitive reactive power needed by induction motors is produced with capacitor banks producing capacitive reactive power. Capacitor banks are used normally to compensate the inductive production of transmission lines.

Fingrid has divided VFV into 10 areas for compensating the reactive power. In each of those areas the average reactive power of the grid must be within the pre-defined limits. Reactive power measurements and compensations are done in substations. If the average ratio of reactive power is too high or low, the system sets an alarm to the control room. After receiving an alarm, control room personnel can turn more capacitor banks on or off in the alarming substation in the area. Thus, previously mentioned average levels are easy to maintain to VFV. However, as those areas are relatively large, variance of the reactive power inside an area can be considerable. Therefore power factor in some parts can be remarkably low, resulting as a bad customer voltage.[74]

Corporate customers using (inductive) induction motors appear as inductive load to the grid. As the power is transferred to the customer as active as possible, machines need capacitive reactive power, or produce inductive reactive power. If that is not compensated, the customers with power tariff must pay for consuming the reactive power (or producing inductive power). Therefore the corporate customers compensate their consumption of reactive power with capacitor banks. However, normally the customers do not constantly examine their production and they keep their amount of compensation stable.

Should the capacitor banks in the factories be kept running even during the small load peaks, it causes problems to the network company since they produce capacitive reactive power. Because overcompensating is the least wanted option causing various harms in the grid, especially corporate customers should be equipped with meters able to reactive power measurement.

However, wires, especially underground cables have a capacitive component, causing natural capacitance and furthermore they produce capacitive reactive power to the network. That cannot be compensated with capacitor banks, but it can be done with the electromagnetic coils. In theory, however, factories using induction motors could use capacitive power produced naturally in network cables. Smart load – or compensation in this case – controlling options of meters in such cases would be beneficial in order to make sure the power ratio remains constantly in acceptable level. In addition, this possibility would also reduce the need of compensating the reactive power.[74]

When the components (energy saving lamps, computers etc.) consuming capacitive reactive power become more common at households, they will also be significant source of reactive power. That will lead to the situation where the ratio of reactive power will increase. Even though one reactive load is not remarkable by itself, the little streams make a big river. As in the case of corporate customers, residential customers may have possibly to compensate their consumption of capacitive reactive power in the future or pay the compensation fee. That is why residential customers' meters should be able to meter the reactive power as well.

Excessive amount of reactive power causes voltage problems to the grid. Thus, to make sure the voltage profile maintains at least on acceptable level, reactive power also in low voltage grids should be measured and compensated. Because reactive power replaces the bandwidth of active power in apparent power the capacity of the grids may be exceeded more easily, hence creating problems in quality of delivery. If AMR meters provided the reactive power information, the reactive power status of the low voltage grid could be calculated more accurately. Calculations, as the total sum of reactive powers from all the feeders in transformer and again the sum of reactive powers in wanted transformers. It would be useful for the network company to locate parts suffering from reactive power.[74]

The system reporting the reactive power problems currently is Xpower, which is only a graphical display of different status reports and has a limited ability to perform calculations. Therefore the calculations should be done in MDMS.[74]

Current Iskraemeco meters measure only the reactive power on basic frequencies. Should the reactive power be measured better a new type of meter measuring the overall reactive power is needed.[66]

5.4.2. Two-way power monitoring

Two-way power monitoring means registering energy flows both to the premise (consumption of energy) and from the premise (production of energy). As the distributed production becomes more general, two-way power flow monitoring will be needed to implement to the metering software and MDMS. A tool to register that is ready to use but not yet fully implemented. Currently registration needs to be set manually on, if a notification of production is given. However, in many cases any information of small production is not received from customers.[74]

The current meters have an ability to measure the two-way power flow, but measuring the production from all the premises would be too expensive. As well, implementing the ability to measure two-way power flow would take too much time and efforts. Thus, meter and/or the MDMS system should be able observe and detect the two-way power flow. Should there be production, a notification of that or automatically started measuring is needed.[74]

Unless all the production and consumption is known, the market settlement cannot be done properly. In addition, electric safety issues should be taken into concern. If the distributed power generator can keep up the voltage it can be a safety risk (if not taken into account as voltages can rise too high). Moreover, forthcoming building regulations demand that every building must have an alternative source of energy.[74]

Currently the number of small power production plants is little and it can be foreseen that the increase of them will not be substantial. Moreover, very few current small power production plants cannot upkeep the voltage and the costs of measurements exceed the financial benefits. Thus, the measurement of two-way power is not an important issue at the moment. However, if the number of small production plants increase significantly in the future, for example due the changes in legislation, this issue should be taken into concern.[74]

Two-way reactive power measurement, however, would be important for electrical design, especially when calculating the power flows and power transmission factors. Reactive component of the total power can be surprisingly important. In this case the residential customers are not the main group to be taken into surveillance, but the customers with the main fuse size of over 63 A are to be taken into concern when measuring two-way power flow.[74]

5.4.3. Voltage level information

Better knowledge of voltage levels could help the network management process and strategic design in their work. This team makes the long-term plannings of network design and maintenance in VFV. New types of load modelling tools could be made if real voltage levels from a longer period of time would be in a database.[74]

Estimating the future power consumption could be more accurate if this kind of modelling tool is used. Furthermore, this tool could be utilized in finding parts of the grid in either a need of reconstruction or higher capacity because of future growth in consumption. These decisions have been based on a enlightened speculation more than to factual support. If voltage level information from customers could be available, need of investments would be more clearly visible. This kind of upgrade cannot be done with merely upgrading the software, hence the hardware of the meter does not support this kind of functionality.[66]

Customer service receives and handles the reclamations from the customers concerning the quality of electricity. Weekly-based information concerning the power quality would help the customer service better than long-term information, which is currently available and in use. This is why now the information they receive is not as useful as it could be.[72] Thus, customer service would find a different display of data more useful. Weekly-based information would be more informative and easy to decode. Currently EIP offers a custom report *CUSFEA 174: Finland Daily Maximum Voltage Deviation Report*

If a customer makes a complaint of the poor voltage levels, VFV uses so called voltage level target table to detect errors in voltage levels. That is to say the one customer's average voltage level for a ten minute period is measured instantly after the reclamation and put to a table. Surveillance is completed after one week when the meter is read again and the average values are put to another table. Those two tables are then compared and it is easy to see if the voltage level averages are according to standard levels. At the moment, VFV uses kind of a surveillance method only on a request from a customer. Thus, a customer making reclamation does not receive an answer until a week has passed by.[72]

Hence the work in surveillance has to be done manually the customer service would benefit if this surveillance was automatic and continuous. A lot of working time would be saved and human errors would be avoided. In addition, customer could receive an answer to a complaint immediately instead of having to wait a week for it. On the other hand, supposing that voltage levels are truly under surveillance, customers may be in favour of the current system.[72] The previously mentioned custom report could be useful in this occasion and the *CUSFEA 175: Finland Weekly Excessive Voltage Alarm Report* meets the needs perfectly.

In the case the same premises do not constantly meet the quality standards there are supposedly some errors in the network. Thus, these places are needed to be known in order to improve the customer service. For that purpose, VFV has already a report: *CUSFEA 175: Finland Weekly Excessive Voltage Alarm Report*

Although customer service can receive already some information concerning flicker from DMS, it would be better for the process if this information could be accessible directly. Customer service cannot be sure about the credibility of the information now since the information has gone through different validation processes and perhaps altered during them. In other words, customer service would rather like to know what has truly occurred at the location.[72] Flicker is discussed more in Chapter 5.4.4.

5.4.4. Detection of flicker

Dimming and flickering of electricity lights are caused by sudden voltage drops and rises in electricity grid. Usually these effects are due switching operations of industrial processes. Electrical equipment have usually complex program cycles where different amount of current is needed in each part of the cycles. That causes the fluctuation of current drawn from the supply. Usually the need of current is biggest at the beginning of the cycle.[81]

Changing current flows through the network impedance, as shown in Figure 5.2. Current peaks cause voltage drops which at particular repeat rates appear as flicker to customers. Harms of flicker to human beings are mainly only irritance but it can be a health risk for those who are prone to epilepsy.[81]

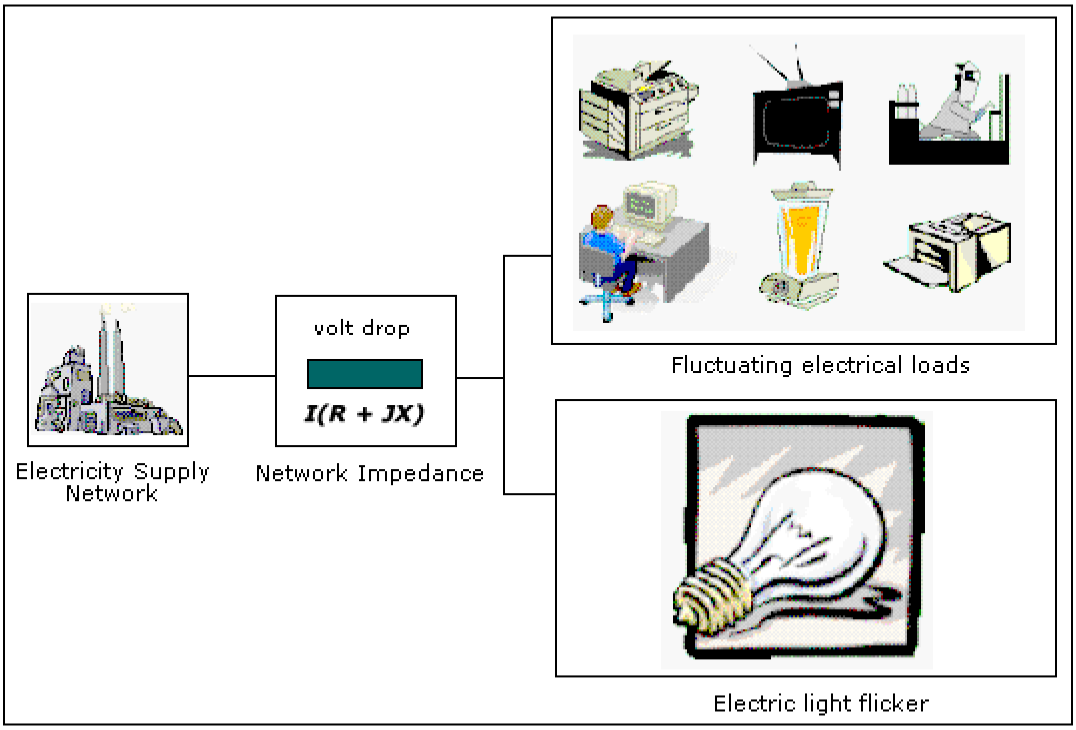


Figure 5.2. *Flicker caused by fluctuating electrical loads [81].*

Network utility is responsible of reducing the flicker in its operating area. Nowadays flicker is noticed from customer feedback. Not nearly all of the customers experiencing flicker make complains of it nor it is easy to prove afterwards. Thus, it is relatively hard for the network utility to say if there is lot of flicker in their grid or not.

One solution is to meter rapid changes in voltage, for instance measuring the biggest change of voltage in the interval of 200 milliseconds. Meters in use at the moment cannot be merely software upgraded to measure this. In addition, flicker detection would not be cost-efficient as VFV receives approximately 300 customer complains per year for flicker.[74]

However, most customers do not give reclamations for flicker. Hence, issue is supposedly much bigger than currently known in the network utilities. In addition, given the fact that power quality issues should be the concern of a network utility, the next generation meters could be able to register flicker. This would not only give better response time to customer complains but also allows to see better if particular areas suffer from flicker. Networks in those areas are most likely to be weak.[74]

5.5. Improving customer service

Customer service benefits from the better information. Services can be improved and boosted. Customer service personnel can concentrate better on more challenging tasks rather than simple, but time-taking tasks. Thereby the efficiency will increase.

Also, the customers benefit from the availability of more detailed information. Then the customer service could give more information to the customer and reply to their questions faster.

5.5.1. Real-time status check

Ability to check the customers' electrical status (power quality information, phase and main voltage levels, etc.) would be useful to customer service. Furthermore, the positions of main switch would be needed to know in some situations. At the moment only status information received from the meter tells whether the meter replies or not, in other words telling if the meter is working and is there electricity in the premise. If customer service personnel could enter the status of clients' meters, it would enhance the helpfulness of customer service. Real-time status check would make the work of the customer service personnel more efficient as they could focus on more challenging tasks instead of spending time on simple but time-consuming operations.

5.5.2. Selling points of connection

At the moment the points of connection are sold mostly according to the estimates of details (main fuse size, need of power etc.) given by the electrical designer of a customer. These estimates are not always accurate being often exaggerated. The network companies are also frequently consulted about these issues and there are marked amount of variance in main estimates given by the constructors. However, without any better knowledge, determining these kinds of details is not easy when it comes to bigger construction sites as for instance shopping malls, logistic centres and service buildings, where the need of electricity vary.[70]

Estimates of the needs of new constructions would benefit from a database of venues already built. This can be achieved by knowing the types of business and with having a database of their levels of consumption in buildings. This could allow forming type user groups. From every type user group a size of a building, specific type of commerce and its type consumption and type load curves would be known. Then connection service process personnel could give better estimates of a main fuse and the power needs to the constructor than now. One example of utilizing this kind of database is the buildings using geothermal energy as a part of heating.[70]

5.6. Online

The online service currently provides consumers their consumption reports. In addition to that there could be more information. The following paragraphs illustrate which kind of functionalities could be added to the online service in order to minimize the unnecessary harm caused by misunderstandings and improve the customer satisfaction. In order to achieve that, the online server has to, besides identifying the customers, know which substation or transformer feeds which customer. Necessary customer information can be retrieved from SAP.

5.6.1. Informative online front page

The customer service experience would increase if customers had an individualized front page with individually allocated announcements and information. In addition, if customers were offered more information in the online service the number of customer calls would become smaller. Currently customer service receives a marked amount of minor customer complaints and requests.[72]

In case of power outages a simple piece of information, as “Outages in the area, the matter is investigated” could be shown to the customers on the area suffering power outages. Changing the message on each phase during the process of identifying and clearing the fault would keep the customers up to date. Furthermore, the known problems with the flicker, for example, could be reported on the online service.[72]

Whether the power quality in the customer’s point of connection is acceptable or not, informative reporting on it would be beneficial. Reporting the quality could be done simply with different colours or words. Understanding network status in the customer’s area would become easy with self-explanatory flags. This kind of service could lower the amount of needless customer reclamations.[72]

As said in the Chapter 5.2.1, one feature of MDMS system could be to detect the sudden changes in consumption behaviour. That information could also be represented to the online service. For instance the unauthorized consumption suspects could be shown in the front page.

5.6.2. More detailed reports

More detailed consumption reports in online service could include for example the peak power and peak energy consumption. Furthermore, online service could offer comparisons of energy consumption with the consumptions of other similar consumers. Reports given to the customers could include the outage history in the premise and the power quality history. [72]

In addition, daily consumption reports should be imported to Online. Currently only the hourly values are viewed, which can distract the consumer in cases where metered values have not been received from the meters for every hour. In those cases the consumption profile can be invalid. Daily usage profiles would show the difference in consumption between different days more accurately.[72]

5.6.3. Modification requests online

When a customer is willing to modify the electric lines and poles in the property, a request is made to the customer service. Occasions where customizing the supply network on the customer request include for example renovations of property or building an annex of a house. As the requests are verbal the human errors and misunderstandings can take place.[72]

Therefore it is argued to offer customers a tool to personally select a location of desired on a map. Customer could select a pole or LV line wanted to remove and put the wanted new place on the map in addition to give a written explanation of the situation. MDMS retrieves the modification request from online tool and returns it to the customer service interface. [72]

5.6.4. Feedback of individual energy saving procedures

According to studies, indirect feedback of consumption, such as the examples mentioned above, has reduced the consumption by up to 10 percent. However, direct feedbacks of consumption are more effect on this matter as they have resulted as 5-15 percent reduction of consumption. Direct feedback would mean as well implementing a display to the meter in order to get the best results. [82]

Report of this tool could be done with comparing the current consumption reports on a wanted timeline with the consumption reports in history. For example, the reports could compare the consumption of current week with the consumption in last week, or the last month with the same month in last year.

5.6.5. SMS services

Online service offers currently the customers various SMS services concerning for example the power outages. Customers can order the SMS services directly from the Online. One type of service is the outage service, where an SMS is sent to the customers which premises are affected from the outage.

A wider range of SMS services could be placed in the Online. Customers could set alarms to notify changes in consumption. This could be useful to the customer in surveillance of their own consumption or unused premises, as summer cottages. In addition, if new services including variable prices, as presented in the Chapter 5.7.1 are used in the future, an option to receive SMSs giving alarms of higher prices.

A list of ordered SMS services would be sent to the MDMS in regular intervals, as once a day. SMS service is currently free of charge, but in the future it is worthwhile to consider of changing that to prevent the exaggerated data traffic. One option can also be that only limited amount of SMSs are sent before re-ordering the service.

5.6.6. Placing customers to correct load profiles and proposing a new contract based on actual consumption

Online service could advice the customers to place themselves to a more precise load profile according to the metered data and consumption habits. In addition, one possible service to the customer in the Online service could be to offer more suitable type of contract according to the collected consumption data.[67]

5.7. New electricity products

5.7.1. Wider range of products

A larger quantity of various hourly values will be collected in the future. Customer relationship management process can offer the clients wider range of services.[y] Those services could be for example new electricity products, consultant service in construction sites and tailored support to improve energy efficiency.

Furthermore, new pricing models can be created. Dynamic prices according to market signals could be implemented. [47] In addition, customized pricing models can be made. Meters in use support this kind of functionality. In addition, the *CUSFEA 190: Monthly Tariff Summary Report* gives a report of tariff case based use of voltage.

As an example of tariff products the French electricity utility EDF (Électricité de France) offers different types of time-based electricity products to its customers. In this model, the price of electricity is given beforehand for each time of the year and customers can plan their consumption according to them. In other words, the price of electricity can be chosen to depend on the days and hours of use, as illustrated in table 5.2. Information on the colour code of the following day is given on the previous day at 5 P.M.

Table 5.2. *Hourly prices in EDF [86].*

Contract power-rating (kVA)	Annual subscription (€)	Blue Off-peak	Blue Peak hours	White Off-peak	White Peak hours	Red Off-peak	Red Peak hours
		Price per 1 kWh (€, incl. tax)					
9	117,04	0,0572	0,0722	0,0901	0,1109	0,1848	0,5175
12	218,02	0,0572	0,0722	0,0901	0,1109	0,1848	0,5175
15	223,68	0,0572	0,0722	0,0901	0,1109	0,1848	0,5175
18	229,34	0,0572	0,0722	0,0901	0,1109	0,1848	0,5175
30	487,45	0,0572	0,0722	0,0901	0,1109	0,1848	0,5175
36	605,07	0,0572	0,0722	0,0901	0,1109	0,1848	0,5175

The colour codes and peak/off-peak hours in the Table 5.2. mean the following:
Off-peak: cheaper electricity 8 hours a day, hours depending to region, for example from 22.30 to 6.30 [86].

- Peak hours: all the rest hours
- Red: 22 days from November 1 to March 31 from Monday to Friday, but never 5 consecutive days
- White: 43 days in a year (never on Sundays)
- Blue: all the 300 remaining days of the year (all the Sundays are blue)

Current meters support changing the tariff, but the reports already implemented to MDMS can help go further with that idea. Unlike in the case of EDF which offers this option to the customers with consumption of over 9 kVA [86], VFV could offer the similar type of products to all of its customers. In addition, even customized products can be offered to the customers.

5.7.2. Pre-paid connection

Pre-paid connection means a type of a connection where customers pay their use of electricity in advance. When their pre-bought credits come to an end, the service ends. Pre-paid services are widely used in mobile phone subscriptions.

Customers having trouble paying large invoices could change to pre-paid connection. This way the expenses are better under control and outlined. As well, electricity utilities would benefit from pre-paid connections. When selling electricity,

electricity utilities subject themselves to credit risks. That is to say bad payers form credit losses in case they do not pay their bills. If customers were using pre-paid electricity, risks would diminish. In addition, lower amount of dunning processes would reduce the yearly administrational costs. Moreover, potential new customer group could be attracted with pre-paid option. [83]

Implementation could be done either with updating the meter software or using daily values for bill run next day. Despite the meters installed during Kauko project can measure hourly values of consumption they do not have functionality to disconnect meters remotely. Thus, pre-paid electricity functionality could not be fully implemented to premises having Kauko meters. However, meters installed during Santra project have all the deeded functionality, as they can both measure hourly consumption values and remotely connect or disconnect customer premises. Yet the metering software update and process developments are needed.

5.8. Condition monitoring

5.8.1. Meter condition monitoring tools

A tool is needed for estimating the condition of meters. The validation parameters at the moment can not capture the faulty meters. Instead, the data needed to condition monitoring need to be collected manually from various databases and analyze them.

5.8.2. Detecting the parts of the network in a need of maintenance

Maintenance of electricity network aims to keep all the components in the network workable with optimizing the economical aspects. Maintenance can be divided into preventing and reconstructing maintenance. Preventing maintenance has traditionally been time-based (TBM, time based maintenance) or according to condition of components (CBM, condition based maintenance). Currently maintenance is performed mostly according to condition of components. [64]

Targets of reconstruction in the network are the parts with the highest risk of having faults. Those are the parts at end of their operating life cycle and the parts under the load surpassing their specified limits. Detecting the problems otherwise unnoticed improves the reliability of the network. Sufficient information is needed in optimizing the life cycle costs and evaluating the levels of risk. Information is traditionally in many systems, as illustrated in Figure 5.3. [22, 84]

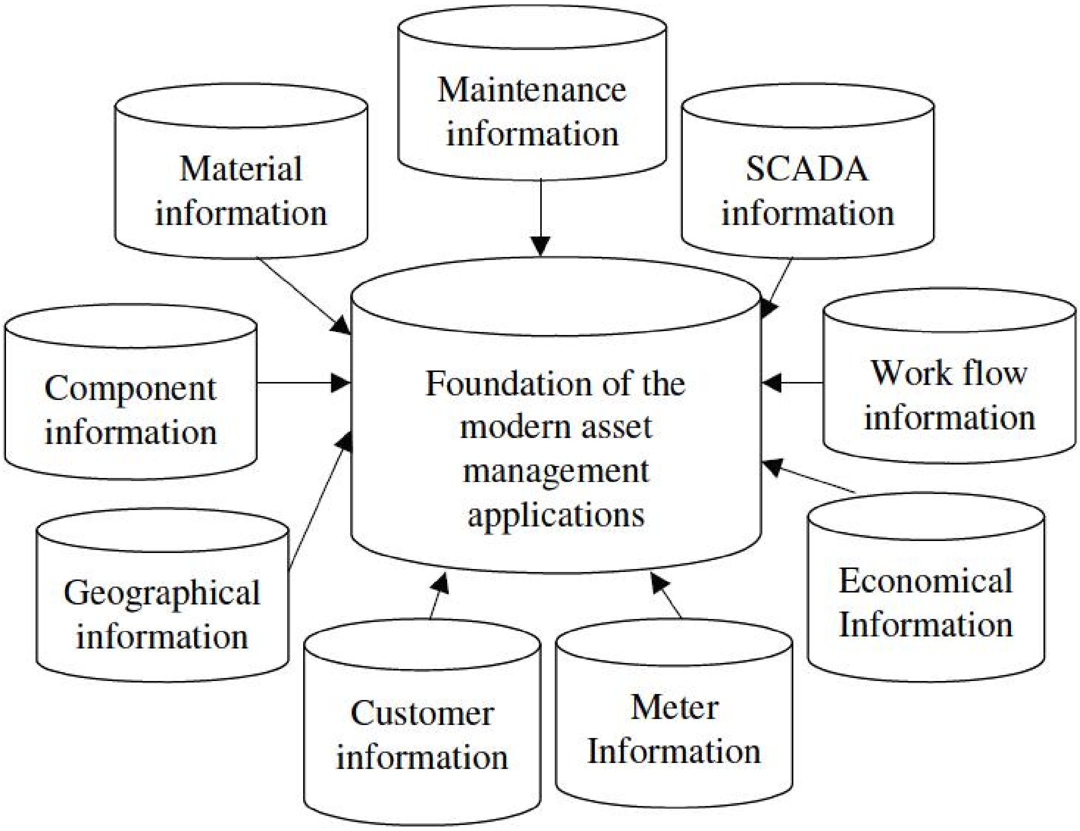


Figure 5.3. *Asset management in modern utility [84].*

The reliability based network analysis and asset management (RNA/AM) tool is based on the results of reliability based network analysis (RBNA) project carried out in TUT between 2002 and 2005. RNA/AM is currently in use of VFV in network condition and asset management and strategic network planning. The RNA/AM tool is used in selecting investment and reinvestment sites in the network on the reliability point of view, updating the planning principles of the network and giving guidance to strategic decisions. As seen in Figure 5.4 illustrating the database relations in RNA/AM, one source of data is MDMS.[84]

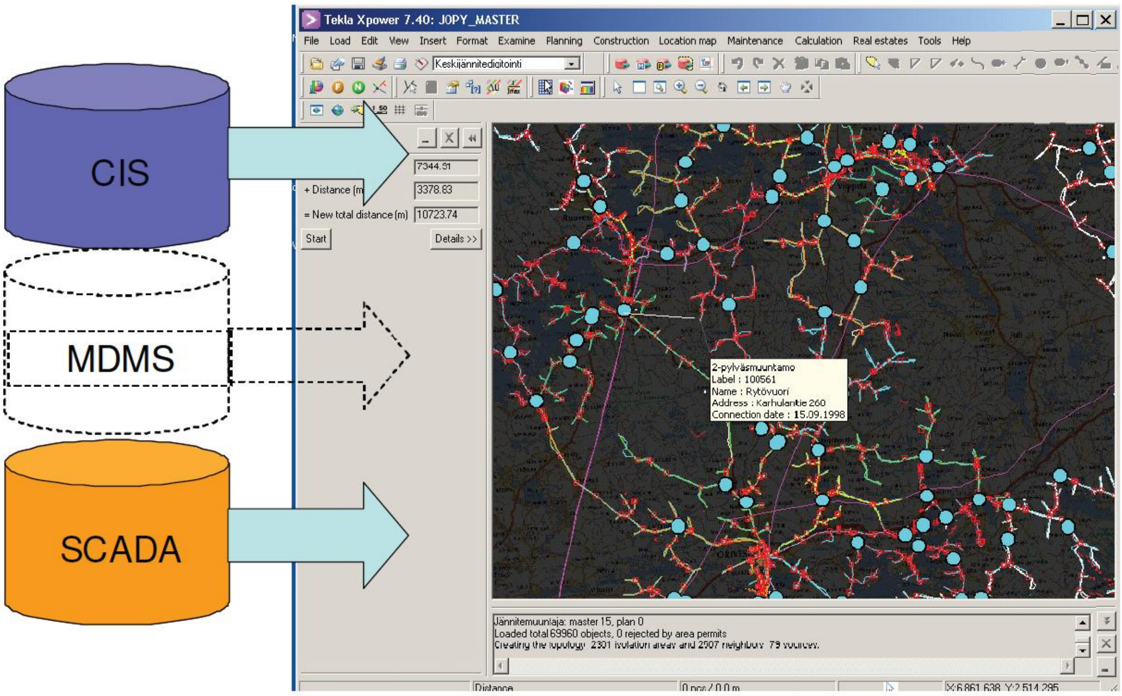


Figure 5.4. *External database relations and Xpower user interface [84] .*

In the VFV network there is approximately 21 000 substations, and of those 135 are primary substations. With the RNA/AM the conditions of transformers can be supervised. Replacing a transformer in primary substation can be difficult as it can take up to one year. This is because the transformer, for instance, is often designed specifically for each primary substation. Transformers can be ranked based on their ages and the loads of transformers, as well as to the hot spot oil temperature. The transformer oil hot spot temperature is currently calculated using customer load curve summarisation. [84, 85]

However, one way to utilize the data from AMR meters is the primary substation condition monitoring. In this case, the same meters as used in customers' premises could be placed directly to the transformer in the secondary substation. The study and calculation methods presented in [&] show that the calculated oil temperature is equal to he measured hot spot oil temperature when the ambient temperature and the transformer load are taken into account in the calculations. [85]

Thus, the network reliability and the continuity of supply increase if the AMR meters are placed in the important secondary substations, especially in the critical loading points.Overloading of transformers could be detected earlier, and possible damages caused by overloading situations could be prevented if the AMR data is used in the real-time calculations of MDMS. Generally, the measured data should be available real-time for the calculations done in MDMS. It would make the asset and data management easier and serve the processes better.[85]

In addition, if the meters are not placed in the substations the summarised metered data from the premises fed by each transformer could be used. In this case, 10 minute measurement interval is desirable as on that case the transformer overloading can be detected before breakdown of transformer. In addition, ambient temperature should be taken into account.[84]

5.9. Placing meters to substations

The phase currents are nearly impossible to sum up even if would be known from each premise. This is because different phases may be in different order in different premises and it is impossible to know which is which phase at the customers' premises. To have an up to date information of phase currents, they would be needed to measure in for example 10 minute interval. Even then, the amount of data collected would be much less than if collected on each customer's premise individually.

Thus, some measurements could be more practically done in substations. Substations feed customers' LV grids and the phase currents could be summarized there, from the feeding end. Without a meter in the output phase currents of the customers can not summing of to reliably That is why better meters could be placed in selected locations, for example in substations.

Moreover, placing the better meters in substations would provide the data that could be used in calculating the network state information. To do that, however, it is needed to know the voltage levels and power information as well. Furthermore, if the power begins to flow in different direction than normally or planned, then it would be discoverable better when these parameters are known. [74]

This matter is not directly attached to the MDMS, but if the currents were known, MDMS could be utilized in providing the values for instance to Xpower. Furthermore, if the meters at the customers' premises were equipped in the future with ability to measure the data mentioned above, it would not be able to used accurately in for example summing up the phase currents. Hence, this situation should be taken in concerns in the process of designing the new meters and the next phase of MDMS. [74]

6. CONCLUSION

In this thesis the needs of the business processes in a network company concerning the AMI infrastructure and MDMS are presented. These needs are mirrored with the existing features of the meters and MDMS system and the reports offered by the current MDMS system.

During the interviews with the team representatives it is found out that the most important task of MDMS is to provide new types of reports and alerting tools. These tools and reports make the everyday operations in Vattenfall easier and make decisions more accurate. In fact the database itself does not add much value to the network operations, but it just makes new information tools possible. That information should be as read and interpreted in comprehensible manner quickly and easily.

The same applies to online services of customers (residential and corporate customers), and their user interface. Functionality definition is not, in principle, the functionality of a database definition, but rather the definition of functionality of an application interface.

Since the defected meters produce incorrect data it is concerned the priority to identify them is considered as high. For this purpose the information systems used by VFV do not directly offer a tool, but it could be created with some reports. The reports that could be used on that purpose are listed in Table 5.1.

As said in the Chapter 5.1.4, the cooperation between SAP and EIP may currently limit the usability of these systems. Another usability issues in the current system found in this thesis are the needs in outage history and that the information from AMR-DMS integration does not run through MDMS. The latter slows the information flow and if done otherwise would improve the measurement of aggregates.

Since the meters are installed after the main fuse, opening of it makes false alarms. It is noticed that the only way to physically alter the situation is to change the cabling in premises. Since the installation costs are relatively high, it is recommended to hold that until the next generation meters are installed in the future. However, if a tool for noticing a main fuse opening the false alarms caused by this reason could be avoided. Making that kind of tool cannot be created with using the pre-made reports or functions.

Different electricity markets in Europe have different standard for metering intervals. Integration process of electricity markets raise a question of what would be the common standard. If, for instance the British model is selected, the metering interval might be 15 minutes instead on an hour used in Nordic countries at the moment. Iskraemeco meters support that interval, but the other systems and reports would need upgrading. However, there would be benefits in metering the values 4 times in an hour. They are listed at the Chapter 5.1.8.

Reports crested from the metered values are one of the main tasks of MDMS. It is found out that the current system can create most of the reports needed from the processes, as remarkable changes in consumption, control of connection capacity, unauthorized usage, and neutral conductor fault information. However, the information from the report mentioned last does not stay in the database for longer than a day. That is not long enough for reclamation investigation purposes.

Integrating temperature data to consumption reports could make load profiles more accurate. In addition, customers could be offered an option to place themselves to more accurate load profile or do the re/placing automatically using the MDMS. Benefits of improvements in load profiles include more accurate purchases of electricity and reduced amount of needing balancing power. Furthermore, a tool for predicting the energy needed is considered as needed.

For instance the network planning would benefit of knowing the apparent, reactive and two/way power information. It is noticed that the two-way and reactive power measurements could be done with the meters in use. However, the two-way power measurement option is not activated and the implementation purposes are very few at the moment. In addition, reactive power can be metered currently only on basic frequencies. Next generation meters are needed if wanted to measure the overall reactive power.

Two custom reports are made to the EIP and they both meet the needs of processes of VFV perfectly. *CUSFEA 174: Finland Daily Maximum Voltage Deviation Report* reports the daily under and over voltages and *CUSFEA 175: Finland Weekly Excessive Voltage Alarm Report* lists the premises that do not meet the voltage quality standards in one week's surveillance period. In addition, a tool to detect flicker would be considered as useful. Very few customers report of flicker, but it can be seen customer reports are only from excessive amounts of flicker and it is more frequent than the numbers show.

Customer service benefits in many ways from the current system tools. Yet, more ways to improve the work of that process was found. Real-time status check was one of them. At the moment the only thing that can be queried from the meter is that if the meter is responding. In addition to that the power quality and voltage information at the moment are wanted from the meter. In addition, a database of main fuse sizes installed to the different premises is needed. Although this matter is not directly related to MDMS, it was looked as helping the customer service to provide better service to customers.

One of the tasks of this thesis was to determine how the Online service could be used better. After all, Online service is the best way to customer to see the benefits of MDMS. After logging in to the service, customer should be able to see directly the p-to date issues concerning the network area and the premise of customer. On that way the Online service can be seen as fulfil its task the best and reduce the amount of futile contacts. In addition, the customer service improves that way since the important information would be directly available. Issues could vary from power outage reporting to electricity theft suspicion reporting if power has started to flow in the premise after a long pause in consumptions. Other future services in Online could be more detailed reports and modification requests illustrated in Chapters 5.6.2 and 5.6.3. Moreover, as the electricity companies are obliged to advice the customers in energy savings, reports on that matter can also be given in Online service. Furthermore, customers could have a possibility to order more personalized SMS services online. These report requests would be forwarded to MDMS.

New electricity products can be offered using current system tools. Iskraemeco meters support the variable pricing model and the MDMS could be used in calculating the prices of each hour. In addition, the *CUSFEA 190: Monthly Tariff Summary Report* gives a report of tariff case based use of voltage. Furthermore, pre-paid connection model could be offered.

Meters in the customers' premises can be used in substation condition monitoring. This could be done with summarizing the power information from the premises fed by a certain substation. However, placing meters to substations could be used both in substation and network condition monitoring. It is found out that the same meters as used in the residential customers' premises can be used in substation condition monitoring. In addition, the phase currencies could be found out. Unfortunately the same meters could not be used for this purpose since the meters do not support this functionality.

As a conclusion, the meters and the information systems can currently handle most of the needs of the business processes within VFV. Some tools needed could already be used, but they are not yet implemented in the system. In addition, the reports may need adjustments or new reports are needed using the data from the existing reports. Furthermore, meters and EIP have functions that could be useful but not yet taken in use. Moreover, the information from the meters should be available immediately. To this and other tasks, automating the actions would improve processes.

The legislation and development of the electricity markets set boundaries and challenges to the network operation. At the same time, they bring new options as well. The future and the future needs of the metered data are yet unknown and the direction and timetable of integration of electricity markets is also unknown. However, the EU has clear plans to have common electricity market area, as illustrated in Chapter 2.5.2. this will most probably bring new needs to the future smart metering systems.

However, it must be remembered that only few processes, teams and people in VFV have had chance to utilize the MDMS solution and experience its possibilities. As the knowledge of the capabilities of MDMS becomes known more commonly within VFV and the personnel have more user experiences they find most probably more things to be improved on MDMS and have needs to more applications of the information. Thus, it is argued to run another survey to illustrate the new needs before the second phase of

MDMS when there is more user experience is the results of this thesis are implemented to the MDMS system.

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APPENDICES

APPENDIX 1: CUSTOM REPORTS

Custom reports of Vattenfall [data from qq]:

Report name	Description	Frequency	Data from
CUSFEA 174: Finland Daily Maximum Voltage Deviation Report	List of SDPs where the difference of daily maximum and minimum voltage exceeds the pre-defined limit.	Daily	Previous day
CUSFEA 175: Finland Weekly Excessive Voltage Alarm Report	Report of SDPs where the voltage does not meet the quality standards on a pre-defined accuracy.	Weekly	Previous week
CUSFEA 177: Consumption greater than X% of Fuse Size	List of SDPs where power consumption is greater than fuse size.	Daily	Previous day
CUSFEA 178: Consumption less than X% of Fuse Size	List of SDPs where the consumption is lower than fuse size over a pre-determined period of time.	Monthly	Previous month
CUSFEA 180: Meter Reading Summary Report	Report lists the percentage of incomplete data of all data received from the meters on previous day	Daily	Previous day
CUSFEA 181: Hourly Product (>63A) Read Detail Report	List of SDPs with hourly energy purchase service, fuse size over 63 A, and incomplete data	Daily	Previous day
CUSFEA 182: Hourly Product (=<63A) Read Detail Report	List of SDPs with hourly energy purchase service, fuse size equal or less than 63 A, and incomplete data	Daily	Previous day
CUSFEA 185: Hourly Product Billing Not Ready Detail Report	List of SDPs with hourly energy purchase service and incomplete data	Monthly	Previous month

CUSFEA 186: Demand Greater than Contract Demand	List of SDPs where use of power is greater than specified in contract	Daily	Previous day
CUSFEA 187: Consumption less than X% of Demand Threshold	List of SDPs where maximum usage is X% less than allowed in the contract over a pre-determined period of time	Monthly	Previous month
CUSFEA 188: Hourly Product Billing Look Ahead Report	List of SDPs where interval data has not been received from	On request	From 1st day of current month
CUSFEA 189: Network Loss Report	List of total loss of electricity (difference between the sum of production and the sum of consumption) in the Vattenfall network.	Monthly	Previous month
CUSFEA 190: Monthly Tariff Summary Report	List of power (voltage) use in tariff case basis.	Monthly	Previous month
CUSFEA 190: Monthly Special Summary Report	List of power (voltage) use in SDP location case basis.	Monthly	Previous month
CUSFEA 191: First Read validation Failure	List of SDPs where the meter has failed to deliver the first read after installation or configuration.	Weekly	Previous week
CUSFEA 270: Production Premise Sync Report	List of production premise SDPs having failed in synchronisation validation step.	Daily	Previous day

APPENDIX 2: CORE REPORTS

The core reports of EIP system are as following [}]:

1. AMR Installation Status
Calculates how many meters are in each stage of rollout

2. Billing Data Change Report (formerly Re-Billing Report)
Compares old and new billing determinants and gives a report of billing data change events

3. Billing No Reads Report
Lists the SDPs where billing data could not be delivered

4. Billing Service Summary Report
Summary of expected reads, delivered reads and undelivered reads by meter reading or billing cycle

5. Daily Read Status Report
Report delivers the number of meters reporting at least one register read on previous day

6. DBSync Exception Report PPE
Lists exceptions that encountered during the database sync process

7. Estimation Failure Detail Report
Lists the messages that failed during estimation process in VEE

8. Excessive Missing Reads Report*****
Report lists the percentage of days missing reads and provides the meter information

9. Framer Exception Report
Report lists exceptions published by three framer applications:
Real time framer
Post process framer
Exception framer

10. Meter Reset Report

Report reports the SDPs where the cumulative read for yesterday is lower than the cumulative read for the day before

11. Missing Interval Aging Report
Report lists the SDPs that have not been communicated with EIP for more than user-defined amount of time.

12. Missing Reads Report*****
Report lists the SDPs where no valid read have been received for a user-defined number of consecutive days

13. Missing Reads Summary Report
Summary of missing reads, grouped by number of missing reads

14. PCT Events Details Report
Report lists the occurrences of an event based on a configurable list of events for a defined time period.

15. Service Request Summary Report
Report summarizes all service reports for the previous month.

16. Theft Flags Report
Report lists meters that have reported with theft flag (reverse rotation or magnetic flag)

17. Unauthorized Usage Report*****
Report lists SDPs, where is reported usage but have been either disconnected or are not paying account

18. Validation Failure Detail Report
Daily detailed report of interval data from SDPs that have been failed in validation tests

19. VEE Summary Report
Detailed information of validation, estimation and verify summaries

The following reports need to be tailored according to the needs of network company, but they are standard reports [}]:

Billing Request Detailed Exception Report
Detailed report listing all exceptions encountered in processing the billing request file

Daily Data Collection Report
Total count of meters that reported at least one register read during the most recent daily period

Zero Consumption Report
Report lists the meters responding but reporting zero consumption over a user-defined period of time