Customer-Utility Interface for 2030

- Identification of functionalities and applications

Yasir Arafat
Jimmy Ehnberg
Tuan Le

Technical Report 2015:5
Department of Energy and Environment
Division of Electric Power Engineering

CHALMERS UNIVERSITY OF TECHNOLOGY
SE-412 96 Göteborg
Sweden, 15 October, 2015

Customer-Utility Interface for 2030 – Identification of funcitionalities and applications

Technical Report 2015:5
Department of Energy and Environment
Division of Electric Power Engineering

CHALMERS UNIVERSITY OF TECHNOLOGY
SE-412 96 Göteborg
Sweden, 16 October, 2015

Summary

Smart metering is considered to become a central part in distribution grid management in the future and will be able to provide a lot of new functions if they have the right specifications. Many DSOs are in the process of preparing for the next generation of Smart Meters (SMs) – which is referred to as the future customer-utility interface (CUI) and thereby needs to know the required specifications. This report is proposed to assist in this process by providing suggestions of research to establish minimum technical CUI specifications with regards to the different possible functionalities of CUI. To investigate the requirement of new functionalities, the report addresses how both the distribution system operator (DSOs) and customers could benefit from the new functionalities and what challenges the functionalities can meet. The project focused specifications for increasing the efficiency of grid management. Moreover, the report discuss functionalities required to enable customers' participation in Demand Response (DR). The report is based on a literature review on functionalities requirement for the future CUI which satisfy the general requirement by the European Commission (EC) and Swedish Energy Market Inspectorate (EI) and at the same time will enhance the operation and planning practices of the DSOs, and promote more active customers. Based on how the grid may look like in 2030 in terms of electric power generations, loads and equipment of the grid and the expected changes in electricity demand but also other demands from the rest of the society is research issues selected and discussed. In the end the challenges are ranked and the risk of congesting due to higher covariant between loads and due to customer's participation in different types of markets may be the most challenging is considered the most challenges in the nearby future for the distribution grid. There is therefore an urgent need to developing methods for more load forecasting and market modelling to understand where in the grid problem will appear before they actually happen. There are different methods on how to meet the congestions but more load modelling is needed to explore the potential of changes between different operation strategies. Finally there is also a need to develop a method to be able to compare the different method to find the most cost efficient way to solve each problem.

Keywords: Customer-utility interface, demand response, emergency grid management, load modelling, load forecasting, power quality, smart meter functionalities

Acknowledgement

The report is based on a project that has been funded by Göteborg Energi AB (GEAB) and the financial support is gratefully acknowledged. We would like to take this opportunity to thank members of the reference group Katja Almberg, Niklas Almgren, Emil Andersson, Erika Antonsson, Gunilla Le Dous from GEAB for their contributions and useful discussions during the project. In addition, we would like to thank Prof. Ola Carlson for his great support and contribution in the project.

Contents

List of Abbreviations

CVR	Conservation Voltage Reduction
CUI	Customer-Utility Interface
DSM	Demand Side Management
DR	Demand Response
DLC	Direct Load Control
DSO	Distribution System Operator
EC	European Commission
EI	Swedish Energy Market Inspectorate
EU	European Union
GEAB	Göteborg Energi AB
GENAB	Göteborg Energi Nät AB
HVAC	Heating, Ventilation and Air conditioning
LV	Low Voltage
NTC	Net Transfer Capacity
PEV	Plug-in Electric Vehicle
PQ	Power Quality
SCADA	Supervisory Control and Data Acquisition
SM	Smart Meter
STLF	Short-Term Load Forecasting
TSO	Transmission System Operator

1 Aim of the report

This report aims to identify the functionalities of the future customer-utility interface (CUI) which satisfy the general requirement by the European Commission (EC) and Swedish Energy Market Inspectorate (EI) and at the same time will enhance the operation and planning practices of the Distribution System Operators (DSOs), and promote more active customers. Moreover, the report aims to contribute in different project proposals based on the literature studies performed on different future potential applications.

2 Background and motivation

This section will discuss how the electricity grid may look like in 2030 and what factors might impact the future distribution grid. The section attempts to identify functions for future Smart Meter (SM) based on national and international requirements on the functions and applications of future smart meters to offer new services to the customers and also to increase efficiency of grid monitoring, planning and operation. Moreover, new functionalities are required to increase active participation of the customers in grid management and also to provide options to the customers to participate in different market based solutions for Demand Response (DR). In addition, the future CUI may need to support home energy management system since more and more smart home appliances and load control devices are expected to come in future.

2.1 Electric power system in 2030

2030 is in only 15 years and 15 years is not much when it comes to electric power system. Many of the large investments has of economic depreciation of more than twice that time. But a lot is expected to happen anyway both in electricity production and usage in Sweden until 2030. That will create challenges for the infrastructure, the grid, which needs to facilitate this change. But there are of course measures that can be taken to find economical feasible solutions to meet the challenge.

2.1.1 Electricity production in 2030

Electric power system is expected to undergo some changes by 2030 due to technological advancement, new national and international regulations on e.g., energy efficiency, climate change and renewable energy target. Renewable energy has been growing rapidly over recent years in Europe. Following the current renewable energy target of 20% by 2020, Europe is currently debating new targets of renewable energy for 2030. Greenpeace has put a demand of at least 45% renewables by 2030 in order to reach the climate target. At least 65% to 70% renewable electricity will be required to reach the goal of 45% renewable energy by 2030. The majority of the renewable electricity will come from variable solar and wind due to economic reasons [1]. In Sweden, wind power electricity is now being produced around three times compared with that of 2006 and the growth is expected to continue in future [2].Generally larger wind farms are connected to transmission system while smaller wind farms are connected to distribution systems due to lower connection costs. Integration of more and more small wind farms are expected in the distribution grid by 2030 which may pose power quality and reliability concerns such as harmonics, over voltage, thermal overloading and frequency of tap changes due fluctuating nature of wind. On the other hand, the Swedish solar-cell market is still very limited, but has begun to grow slowly with the aid of government funding. However, this scenario may change in future since the European Union, EU directive on energy efficiency in buildings, suggests a future widespread integration of on-site solar technologies. More small scale solar power is expected to come in the future distribution grid which needs to be incorporated in the operation and management of the distribution grid. According to [3], the nuclear power plants could almost be entirely phased out by 2030.

2.1.2 Electricity consumption in 2030

European Union has set a target of 10 per cent of all transport fuel to be derived from renewable sources by 2020. However, Sweden has set a goal to reduce Greenhouse gas emissions by 40% compared with 1990 by the year 2020, and also to have a vehicle fleet of completely fossil – free fuels by 2030 [4]. Moreover, with the advancement of technology, more and more electric transport system is coming and expected to grow faster in future. In addition, Electric Vehicles (EVs) are on rise with fast and slow charging facilities which can pose an additional challenge on the operation and management of the distribution grid.

The products that waste energy are being phased out through the EU Renewables Directive. Energy wasting products are now phasing out from Sweden which started with light bulbs. Conventional light bulbs have been replaced by low-energy bulbs, halogen lights and LEDs following a three-year phase out. The conventional light bulbs may neither be imported into nor manufactured in Sweden [5]. Other products that have been made subject to stricter energy requirements are televisions, white goods digital TV boxes, electric motors and circulation pumps. Moreover, the portion of constant power load in the grid is expected to increase more in future. The market of smart home appliances and home energy management system is also expected to grow rapidly in future. In addition, the electricity consumption has been increasing due to the installation of direct electric heaters and heat pumps [6]. Ground-sourced heat pumps make up a large part of new heat pumps installations in the Swedish market and the country currently has the highest amount of ground-sourced heat pumps installed in Europe. Moreover, the installation of new ground-sourced heat pumps is expected to increase significantly in the next 10 years. These new types of loads in the distribution grid may change the result of optimal load flow analysis which considers the traditional loads in the distribution grid.

Demand Side Management (DSM) and Demand Response (DR) from residential customers are expected to come for congestion management in the distribution network, voltage control and asset management. Active participation of residential customers in different market based solutions is also eminent in the future electric power system to manage network congestions and provide ancillary services. In [3], a 2030 scenario has been investigated and the results indicate that different levels of demand-side management in the system and inclusion of storage devices would not result in significant impact on the type of upgrades required on the grid.

2.1.3 Electricity grid in 2030

In the power circuit in the distribution system there are no large changes expected until 2030 since the investments are long term and there has not happen any major technology advancement in the latest year that is expected will make a major impact. There will of course be some refurbishment and green field installation but current technology is expected to be used. The challenge for the refurbishment and green field is that they should last for 40-50 years and this will be well beyond 2030.

Regarding the communication is larger changes expected, mainly due to considerable short expected life time of communication systems then in the power circuit but also the increased need for communication as will be discussed later. One major challenge is the smart meters that will be needed to be replaced due to age.

The changes in the electricity production and consumption will have an impact on the grid. There is an expectation that there will be a higher correlation between the different customers due to more local generation, customers participating in different kind and new peaks in the consumption patterns due to new types of loads. The anticipated local generation is mainly solar power which has a high correlation and can be an effect of the neighborhood-effect, which means that if your neighbor does something you will do the same. This may create very local congestions in the grid. Today are very few customer participating in some kind of market in the electric power system (so called active customers). However, the more volatile electricity prices will be the higher will the interest be for participation at electricity markets. A reduction is in most cases not a problem but the rebound may be because a high correlation between the return loads are high. EVs can be the next big thing driven by the neighborhood-effect and thereby create new peaks either just after office hours at the same time as the afternoon domestic peak or during night when the electricity price is low. The afternoon peak may be the most challenging but the night time may coincident with maximum heat load due to low outdoor temperature or the rebound effect of the DSR during daytime.

The expectations of society on the grid is also expected to change. The availability is expected to increase because the society is getting more and more dependent on electricity since the consequences of blackouts is expected to increase. The grid will also be required to never be a limitation of development or market participation. It will also have to be able to be reconfigured fast to be more efficient to keep the costs low but still enable customers to use electricity in their way and participate in different electricity markets. The grid will also need to be able to supply the customers with information beyond grid data, like electricity price and/or temperature forecast. The requirement of the quality of the supply, the power quality (PQ), will also increase because the acceptance of the disturbance due to the grid will be lower.

2.1.4 Meeting the grid challenges in 2030

There are a range of different strategies to meet the challenges in a distribution grid. Below are the strategies introduced and their advantages and disadvantages.

Do nothing

The “do nothing”-strategy is based that the grid operated does nothing and if something happens it will treated as a non-planned outage. The strategy requires no measuring system and no supervision system but a fast response maintenance team is needed. If the number of outage are low will it only result in bad will for the grid company but it will have a negative impact on the quality parameters, SAIDI and SAIFI. If the SAIDI and SAIFI will be too high the energymarketinspectorate (EI) be require the operator to increase the quality not to lose the concession for the area and thereby their right to operate the grid. The strategy is bad asset management because the strategy could imply a lot of equipment will be taken out of operation to early.

Disconnect customers

The disconnect customers-strategy is to disconnect costumers to avoid damage to components in system. This is a cheap solution because no upgrades in the system is needed but it is only allowed in extreme situations and the issue is how many situations per year can be considered extreme enough. If it happens to often is the concession at risk.

Limit the customer’s behavior

The limit the customer’s behavior-strategy is based not allowing the customer to do what he/she wants to do even it in agreement with current contract. It can also be considered cheap because not upgrades in the grid is needed but not allowed according to current contracts with customers.

Upgrade the grid
The upgrade the grid-strategy is to increase the capacity in all places where congestion may occur. If the planning is well done is the strategy will create a very reliable grid but the cost will be high and a lot of space will be required. It will also have other environmental impact like EMC and extensive use of material. The losses will be low and the expected of life time of the components is not expected to decrease.

Non-optimal operation
The non-optimal operation-strategy of the grid is to reconfigure a grid to solve temporary problems. This reconfiguration can often be done fast but the losses will increase and there are no guarantee that it will be enough to meet the challenge if it has any impact at all.

Active customers
The active customers-strategy is based on the let the customer react to the situation in the grid. This strategy will not require any expensive upgrade of the grid but the capacity is uncertain.

Power quality measurement by smart meters
The power quality measurement by smart meters-strategy is based on PQ measurement in each smart meter. This will result in a well monitored system but the requirement on measurement in each smart meters will increase and also the need of communication and data processing.

To be able to meet the challenges and enable customer to use the electricity in the most efficient way and participate in the different types of markets is it important that all parts of grid will be able the meet the challenges. It will probably be most challenging for the distributions system to the meet that challenges because current markets and earliest of the expected markets are focusing of meeting the challenges of the energy and power balance and the limitations in the transmission grid.

The grid will also need the follow any existing and new requirement of the EI which also include the utilization the required specification of the grid.

2.2 Functions of smart meters

SMs can provide energy consumption data and voltage data from the lowest level of the distribution grid i.e., customer level but also functionalities such as on-demand reading, remote switching, remote management. The historical data from the SM can be used for operation and planning of the distribution grid. However, new functional requirements are proposed by national and international authorities. The functionalities of the SMs need to be adjusted to provide best possible service to the customers and to increase the efficiency and reliability of the distribution grid operation and management. Table 1 shows the functional requirements for future customer/utility interface recommended by EC [7] and proposed by EI [8]. Most of the functions proposed by EI are similar to the functions recommended by EC. However, there are some functions proposed by EI which are not recommended by EC, e.g., to include new functions like alarm for neutral error and also to record voltage, current, energy, active and reactive power in both directions for each phase. Moreover, there are some functions which were recommended by EC but not proposed by EI, e.g., support for advanced tariff system and limitation of power flow to the customer.

Table 1: Comparison between functional requirements of Customer/Utility interface recommended by EC and EI

	Recommended by EC	Proposed by EI
For the Customer:	• Provides readings from the meter to the customer and to equipment that he may have installed; • Updates these readings frequently enough to allow the information to be used to achieve energy savings;	• The customer gets access to near real-time values of consumption • The measuring system should be able to register the beginning and end of long breaks on one or more phases. • Alarm for neutral error (new)
For the Meter Operator:	• Allows remote reading of meter registers by the Meter Operator; • Provides two-way communication between the meter and external networks for maintenance and control of the meter; • Allows readings to be taken frequently enough to allow the information to be used for network planning.	• The measuring system will allow remote reading. • Capable to deliver 15 minutes value; at least hourly. • The measuring system must be upgraded remotely.
For commercial aspects of energy supply:	• Supports advanced tariff systems • Allows remote ON/OFF control of the supply and/or flow or power limitation.	• The measuring system shall allow remote turn-on and remote turn-off
For security and privacy:	• Provides Secure Data Communications; • Fraud prevention and detection. (Investigated but not proposed by EI)	• Privacy and security must be analyzed: - Possible measures to increase protection - The protection must be analyzed from a system perspective
To allow distributed generation:	• Provides Import / Export & Reactive Metering.	• The measuring system should record voltage, current, energy, active and reactive power in both directions for each phase.

Table 2 shows the functions that are already included and are in use in some of the existing smart metering system and also the functions that exist in the system but not in use. Moreover, the table shows the functions that are by recommended by EC or proposed by EI but not included in the smart metering system in some SM systems.

Table 2: Summary of functional requirements

Existing Functionality (in use at some DSOs)	Existing Functionality (not in use)	Recommended by EC (not in use)	Proposed by EI (not in use)
1. Monthly/hourly metering value 2. Hourly Meter value to customer system 3. On demand readings 4. Power outage alarm +Registration +statistics 5. Remote ON/OFF 6. Usage statistics 7. Monitor power usage /voltage levels 8. Monitoring and alarms	15-min metering value (proposed by EI)	Readings from the meter to the customer and to equipment that customer may have installed Updates meter readings frequently enough to allow the information to be used to achieve energy savings; Supports advanced tariff systems	The customer gets access to near real-time values of consumption Alarm for Neutral error. (new) The measuring system should record voltage, current, energy, active and reactive power in both directions for each phase.

3 Applications of future customer-utility interface

This section will discuss potential applications of the new functions of the future CUI presented in Table 3. The applications are divided into those for distribution system operation and planning, and those for promoting active customers engagement in managing their energy consumption. The section attempts for each application to explain why the applications are important both for utility, society and individual customers. Finally is important research questions identified which need to be addressed in the future project.

Table 3: Required new functions of Customer-Utility interface for the identified topics

Functions No.	Description	Potential Applications
1	Smart ON/OFF switch	Emergency load shedding of large number of customers by smart meters
2	Data with very high sampling rate	i) Power quality monitoring at customer level ii) Load composition identification
3	Data in fine time-resolution (high sampling rate)	i) Load modelling; ii) Information for grid operation; iii) Forecasting (short and long term) and faults for new areas
4	Real-time display of data for customers (e.g., energy consumption, market price, and other tariff options)	Demand flexibility and grid services from the customers
5	Alarms on faults/abnormal behaviors (after the meter)	Abnormal-behavior alarm services
6	Common information gateway	Multi-carrier energy system

3.1 Distribution system operation and planning

3.1.1 Emergency load shedding of large number of customers (using Function 1)

One of the most interesting and challenging strategies is to use the system for a large scale disconnection of non-critical customers during emergency situations. By disconnection at customer level, public institutions may be prevented from being disconnected and there would still be a considerable potential for the load relief of the system. Emergency situations leading to large scale customers shedding are rare but a requirement of large scale shedding has since many year been established by the Transmission System Operator, TSO (Svenska Kraftnät) in Sweden. Due to large scale introduction of renewables in the Nordic system more stability issues can be expected. It is important to be ready to handle these issues with a minimum impact on the society.

EI has proposed that the function to turn on and off can be used for planning of prioritizing vital public electricity users, such as hospitals during load shedding at the extreme power shortage [8]. The purpose of emergency planning is to mitigate the consequences for society at an electric power shortage. In the current situation the technology does not allow that individual socially important users of electricity can be prioritized, but priorities need to be made at management level, i.e., all facilities connected to the same line as an important public function priority. A technology that allows decoupling and coupling of individual electricity consumers in a crisis situation would both improve crisis management, and streamline the planning process that largely implemented by the county administrative boards, municipalities and network concessionaire.

Small scale tests on the operation of switches have been done to gain experience on testing and investigate the impact on the Low Voltage (LV) grid [9]. Tests have been done that shows that expectations of problems are low in the LV grid for small scale disconnections/reconnections. However, some challenges have been identified with respect to implementing disconnections/reconnections in the present system. Moreover, transient events were observed due to inrush current taken by the load which may not be harmful for the appliances due to very short duration of its nature. However, aggregated impacts of transient events need to be investigated. As a spin-off effect the project has identified that the communication system has some unwanted limitations. The impact of large scale SMs switching that are needed for emergency disconnection has not been investigated.

Possible benefits (beneficiary):

- Getting essential services e.g., public services during emergency load shedding (*customers/society*)
- Critical customers e.g., old houses, pharmacy, clinics etc. can be excluded from emergency load shedding (*customers/society)*
- Help maintain system integrity (i.e., avoid blackout) during critical grid condition (DSO)
- Reduce maintenance cost by avoiding major collapse of the grid. (DSO/society)
- Reduce risk of paying penalty fee to the customers for load shedding higher than 8 hours.(DSO)
- Handling future emergency situation more efficiently with better planning. (DSO)

Next step:
To able to make sure that availability of the grid is sustained is there a need to investigate the impact of large scale load shedding on voltage and frequency stability of the grid but also the what is the maximum limit of switching time delay for efficient emergency load shedding.

To be able to make it more cost effective to investigate possible consequences of large load reconnection in all parts of the grid like protection systems and co-ordination between tap changers to avoid unnecessary operations.

To increase the compatibility is there also a need to investigate possible consequences of large load reconnection like tap changing and on voltage controllers to avoid undesired voltage variations for the remaining customers.

3.1.2 Power quality monitoring at customer level (using Function 2)

The PQ in the LV network and consumer premises, especially homes, is largely unmonitored and is not well understood. Specific monitoring typically takes place only after consumer complaints have been laid or abnormalities noticed. Poor PQ has the potential to cause a range of issues affecting both consumer loads and the distribution network. With the development and growing penetration rates of new technologies such as photovoltaic generation and PEVs, voltage profiles on LV feeders are likely to be affected. Distribution networks are tightly regulated to deliver voltages to consumers within an acceptable range to ensure compatibility with consumer loads connected to the network. Non-conformance of the supply voltage has a high societal cost as it impacts the lifetime, efficiency, and performance of consumer loads.

By using the capabilities of modern SMs, grid PQ monitoring can be improved while keeping costs low. Improved monitoring gives electricity providers proof of PQ that can be delivered to residential customers. Moreover, PQ monitoring would allow residential customers to monitor their own PQ which offers greater potential for early problem identification and preventive maintenance. Finally, it could enable electricity providers to better optimize the voltage delivered, which may lead to a reduction of the energy consumed. Based on local voltage deviation detections, SMs can trigger events to alert the local grid operator. The events could either trigger a request to automatically increase the sampling rate in the affected area, or be forwarded to a grid operator for manual decision making.

In [10]-[13], a number of PQ aspects have been identified as being of the greatest interest to understand PQ and its implications in their LV network. They are: Outage reporting, steady-state voltage levels, voltage sag/swells, flicker, harmonics. If these capabilities are to be used and the PQ variables measured, the meters must also have sufficient storage capability. It is not only the capabilities of the SMs themselves which must be considered, but also the capabilities of the communications networks and the central system. There is a lack of clarity over what data and in what format, timeframe, and level of aggregation would be useful. There is also a lack of clarity over exactly how the data could be utilized to improve the electricity grid operation and business. Without the data it is difficult to develop algorithms and without the algorithms it is difficult to demonstrating the possible benefits of measuring and recording PQ data.

However, EI has mentioned in [8] that for 15-minute interval data, additional communication costs will be required to handle the increased amount of data during collection and estimated an additional cost of 23 SEK per meter for 4.3 million meters. Moreover, investment will be required for increased data capacity for communication servers, databases, etc. and are assumed to be 50 SEK per meter. Furthermore, the additional costs of operation and maintenance in connection with the transition to 15 minute interval data estimated as 84 SEK per meter in a year.

The challenges of implementing PQ measurements in distribution applications include the following:

- Increased cost of SMs with PQ measurement capabilities
- Capability of present communication infrastructure to support for transmission of large data packets, particularly for real-time applications.
- Data integration, long-term storage, and sharing.

Possible benefits (beneficiary):

- Customers can monitor their own PQ which offers greater potential for early problem identification and preventive maintenance.(customer)
- With more PQ monitoring capability, the DSO is more informed about the actual PQ in their network and can easily identify any source of problems (e.g., harmonics, flickers, etc.) which can save a lot of work (and cost) to identify otherwise. (DSO)
- Better PQ in the system can reduce the losses in the system as well as potential faults and mal-functions of equipment in the system (power electronic converters, relays) which can be caused by e.g., harmonics.(DSO)

Next step:

To increase the compatibility in the most cost efficient way there is a need to reduce the number of PQ monitoring location to ensure only really necessary monitoring of the grid and the to determine which parameters needs to be monitored and at what sampling rate. New methods may also be needed to quantify the monitoring for the most efficient grid management and the customers because it is not clear the current methods are the most efficient.

3.1.3 Enhanced load modeling using smart meter data (using Function 3)

The availability of SM data in homes has led to significant interest in analyzing this data to understand device behavior, customer behavior, and key contributors to overall energy use. One of the critical needs for distribution system operations and planning applications is modeling of the load, in particular, its dependence on the voltage. Some literatures [14-18] show that most existing models, however, have been based on overly simplistic assumptions of device operation. For example, most prior work assumes a device will turn on, consume a stable level of power (or possibly one of several stable levels), and then turn off.

Many types of devices do not consume energy in this straightforward way, and therefore more complex models are necessary to present truly device-accurate models. The SM data can be used to improve load models of LV customers. However, as raw energy data is often difficult to interpret without prior knowledge of how devices actually operate, most analysis techniques rely on models of device behavior to interpret data from SMs. Accurate modeling is particularly important when the only data available is aggregated, as is typically the case with a single SM providing energy data from the entire house.

The SMs do not show the exact load at a specific moment but the energy usage. By using hourly energy consumption data, it is nearly impossible to detect that a light bulb was switched ON for a few minutes during that hour. Since the reading indicates the average power usage of a larger collection of loads that were active over the entire hour which makes it harder to identify individual loads. However, by subtracting two consecutive measurements e.g., the average load in a 15 minutes interval can be calculated. This load is expected to be the average load during this 15 minutes interval. If the time interval between the energy measurements is small, the average power used in this period can be estimated. Some SMs can provide even lower minute-level sampling e.g., a reading every 5 minutes. However, there are indications that the next generation of SMs will provide sampling resolution of seconds which can help to build accurate load model.

Aggregated real-time power data from already deployed SMs with a low data sampling rate can be used for modeling home appliance loads under a general assumption. Most home appliances work at one or several fixed power demands, which can be characterized by finite discrete states. Moreover, one power reading at present is independent from early readings in the past. Therefore, according to [14] Hidden Markov model (HMM) seems a good choice and is widely used to model home appliances to extract stable information.

In most of power flow calculation, the load is either assumed to be constant power load or modelled as a mix of constant impedance, constant current, and constant power load which is typically referred to as ZIP model [19]. This approach may not work, since all the loads are not always static or time-invariant. Moreover, it is difficult to know the percentage of different components in the ZIP model and therefore the load cannot be accurately represented. There are mainly two types of load models: static and dynamic. Static model are with combination of constant impedance, constant current and constant power loads while dynamic model has time series simulation of end user loads mainly heating, ventilation and air conditioning and water-heater. In [18], SM data was used in both static and dynamic load model to perform voltage optimization in order minimize the energy consumption. The results of their work show that 2-3% reduction in voltage gives an average of 3-4% of reduction in energy at the feeder.

Voltage optimization is becoming an integral part of the distribution control strategy in the smart grid. For many years, voltage reduction has been used as a demand management function in times of heavy demand. Conservation Voltage Reduction (CVR) refers to the management of service voltage for the purpose of reducing power and/or energy consumption. According to [21], by using CVR for energy savings can be one of the most attractive energy savings investments possible in terms of investment per kilowatt-hour saved. The Load Modelling Initiative can help to identify important customer characteristics that impact the voltage response through testing at both the load level and the system level. This can help DSOs to assign higher priority for CVR implementation to feeders that supply the maximum CVR benefit and also for flattening voltage profile. Moreover, the load modelling effort can help to better integrate different customer categories and the associated voltage response characteristics as part of future utility customer information systems and distribution model databases so that they can be used as part of normal distribution planning studies in the future.

Furthermore, accurate load models are important for obtaining correct results of voltage stability study for the grid. One application with this study is to determine the reactive power support requirement in the grids especially those with high amount of induction machines (e.g., heat pumps) to maintain grid voltage stability when fault occurs in the upstream transmission grid. The DSOs can use the load modelling for planning of the grid more efficiently to keep the secure operation of the grid. Another application of the enhanced load models is to improve the results of the calculations of the net transfer capability (NTC) in the transmission system. If the load models are known for different areas in the transmission systems and for different hours of the day, more accurate results can be found and the system can be operated closer to the limits, i.e., more transmission capacity can be put in the market, and thus reduce the total social welfare of the system. In current practice, hourly load models and locational load models are approximated. The system operators just have to put a margin to the NTC values which accounts for the uncertainty in the load models.

The load models in the literatures did not consider dependence of real and reactive power on voltage. The dependence of both active and reactive power on voltage can be investigated by using SM data, which can reflect the reality much better than the previous studies. Because, when the voltage changes the demand also changes. This means that by changing the voltage, the demand of active and reactive power can be affected. There is a need to develop refined load flow solutions based on SM data which can be used as an input to different market based solution of DR. Moreover, the load model can also be used to determine the voltage control actions required to achieve a certain level of changes in demand for both active and reactive power for congestion management purpose. The SM data can be classified according to different layers, e.g., seasons, day types, hours, load conditions, etc. Data mining techniques such as Davies-Bouldin Index and K-subspace method [22] can be used to derive the load models. It should be noted that in the future, certain types of customers will be required to fulfill certain grid connection requirement with respect to voltage control capability set by the connection code of ENTSO-E [23]. Special treatment need to be given towards these new types of customers' while developing the load models. The following research questions have been identified for investigation while considered the possible benefits of load modelling for the customers, power systems and the DSOs.

Possible benefits (beneficiary):

- Accurate load modelling could support efficient network operation and planning to minimize operation and maintenance cost which in turn minimizes per kWh energy cost of customers. (customers)

- Understand device behavior, customer behavior, and key contributors to overall energy use.(DSO)
- Load modelling can help to identify important customer characteristics that impact the voltage response (DSO)
- Help DSO to better manage the peak demand through voltage control. (DSO)
- Obtaining correct results of voltage stability study for the grid. (DSO)
- Determine the reactive power support requirement in distribution grids to maintain grid voltage stability when fault occurs, e.g., in the upstream transmission grid. (DSO)
- Improve the results of the calculations of the NTC in the transmission system which will lead to more efficient use of resources in the electricity markets (i.e., increased social welfare and reduced market prices). (DSO)

Next steps:

By improving existing load modelling can a more efficient operation of grid be achieved. The model can also be used to understand how non-optimal operating points can be used for grid congestion management.

3.1.4 Load forecasting using smart meter data (using Function 3)

Recent developments in active distribution networks, and the availability of SM data has led to much interest in Short-Term Load Forecasting (STLF) of electrical demand at the local level, e.g. estimation of loads at substations, feeders, and individual users. Local demand profiles are volatile and noisy, making STLF difficult as we move towards lower levels of load aggregation. The recent availability of SM data provides much more detailed information on electricity end-use than was available before. Data from SMs can allow understanding the changes in demand patterns in more detail and help produce more useful forecasts. Analyzing large sets of SM data effectively is a particular challenge.

Accurate forecasting will enable a utility provider to plan the resources and also to take control actions to balance the electricity supply and demand. Most of the previous literature in the STLF area to date focuses on large-scale aggregated loads, such as the aggregated electricity demands for entire countries, or regions, for transmission system applications [24]. Load forecasting on the individual household level is challenging task due to the extreme system volatility as the result of a dynamic processes composed of many individual components. The individual load profile is influenced by a number of factors, such as devices' operational characteristics, users' behaviors, economic factors, time of the day, day of the week, holidays, weather conditions, geographic patterns and random effects.

Several modelling techniques are typically used for energy load forecasting [25, 26]. These techniques can be classified into nine categories : (1) multiple regression, (2) exponential smoothing, (3) iterative reweighted least squares, (4) adaptive load forecasting, (5) stochastic time series, (6) ARMAX models based on genetic algorithms, (7) fuzzy logic, (8) artificial neural networks and (9) expert systems.

The correlations between demand and the variables which influence it, at various levels of load disaggregation is examined in [24]. It is shown that, at the local level, standard STLF models may not be effective, and that simple load models created from historical SM data can give similar prediction accuracies. The results of this paper suggested that, at lower levels of aggregation, very simple demand models (e.g. assuming demand is equal to the demand in the same hour of the previous day), can be at least as effective as sophisticated STLF approaches based on linear or non-linear predictive models. The correlation between the demand and the variables affecting the demand was analyzed on a weekly basis which showed a weak correlation between the demand and the analysed variables has been found on end-user level. However, the correlation with the previous day equivalent hour demand, previous week equivalent hour demand and hour of day increases with the aggregation level. Moreover, the analysis on an annual basis shows strong correlations with the temperature (negatively correlated) and the previous 24 hour average demand.

This paper concluded that at the local level of LV feeders and individual users, the correlations between demand and the influencing variables become much weaker. Accordingly, there was a significant decrease in STLF accuracy as moved towards lower levels of demand aggregation. Moreover, the forecasting showed that the prediction capability of commonly-used STLF approaches based on linear or non-linear predictive models is very limited at the local level. It is shown that high levels of prediction accuracy could be achieved at the primary and secondary substation aggregation levels, if appropriate STLF models e.g., non-linear autoregressive model is used. Future load forecasting methods can be probabilistic, e.g. producing ranges of values rather than point forecasts, in order to better model such demand uncertainties.

According to [26], probabilistic forecasting is more challenging than point forecasting since we need to forecast not only the conditional mean but the entire conditional distribution of the future observations. According to [25], time series methods such as regression models, Autoregressive Integrated Moving Average, ARIMA models, GARCH and hybrid models such as combination of ARIMA and Generalized Autoregressive Conditional Heteroscedastic, GARCH using wavelet transform are not suitable for STLF. This paper showed that artificial neural networks, which, through their hidden layers and ability to learn, seem much more capable of solving forecasting problem. This technique is able to identify hidden trends thereby finding the trends in time series and use them to produce the forecast. This paper concluded that neural network has a good performance and reasonable prediction accuracy can be achieved.

The use of SM data and weather information has been investigated in [27] for developing day-ahead residential load forecast models. Artificial neural network method has been used in the paper for day-ahead load prediction with weather data and historical SM data. Artificial neural networks act via interconnected group of artificial neurons for processing information and it solves a system of non-linear mathematical functions for a set of inputs parameters. The performance of the artificial neural network depends on the selection of the input predictor variables or predictors, set of training data and the number of trained neurons. The predictors can be classified as weather factors, time factors and historical data. The training of the neurons using set of training data involves a choice of the learning algorithm e.g., Levenburg-Marquardt Algorithm which is a sum of squares of nonlinear functions. However, in the results of this work noticeable deviation was found during peak periods and also in the mornings due to the model's approach of linear regression. The paper has concluded that an increase in predictor variables can reduce the forecast error significantly where the increase in volume of training data does not produce corresponding reduction in forecast error.

According to our knowledge, today no DSOs perform load forecasting at lower aggregation level or for individual customers in the distribution grid. By using historical SM data, models for load forecast can be developed to estimate residential demand for day-ahead applications e.g., day-ahead energy markets and also to minimize the imbalance cost to the energy suppliers. Moreover, it can provide more insight for the DSOs on the state of the distribution grid. However, none of the literatures discussed about using load forecasting as an input to DR markets. SM data can be used for load forecasting at lower aggregation level to identify congestion in the distribution network with more accuracy. Moreover, the load forecast from lower aggregation level can be used as an input to create market based solution for DR. Hence, the project has identified research questions relevant to load forecasting based on data from SM to identify the data granularity requirement from future CUI. The possible benefits of load forecasting to the customers and the DSOs have been considered while developing the research questions.

Possible benefits (beneficiary):

- Accurate load forecast can help to reduce supplied energy cost and minimise cost of loss in the system which in turn will benefits the customers by keeping low cost for per kWh energy. (customer)
- Understanding the changes in demand patterns in more detail and help produce more useful demand forecasts.(DSO)
- Plan the resources and also take control actions to balance the electricity supply and demand. (DSO)

Next step:

More cost effective operation and to be able to forecast grid problems like congestions and undesired voltage variation is to improve existing load forecasting models. To able to make a cost efficient forecasting there is also a need to determine the minimum requirement of smart meters and its communication system and at what aggregation level is the forecasting needed.

3.1.5 Load composition identification (using Function 2)

By measurements at high samplings rate in a single point it is possible to identify what actual loads are connected at the moment to the system [28]. To be able to identify the loads with a 90% accuracy, at least 600 Hz measurements is needed [28, 29] and the higher the samplings rate, the higher will be the accuracy. The idea is based on load identification of the load signatures, based on studies of active power and/or reactive power and /or voltage noise in steady state or during start (transient behavior) [29].

By having an active monitoring of actual loads that are connected could be very useful in many situations for the customer but also for the DSO. The customer could get direct feedback on which appliances that they use which can teach them how they use their electricity. Normal feedback is made by a power or energy value but it is hard for almost all people to understand for what purpose they actually have consumed the power. This is especially hard for children or elderly people that might need more guidance which these measurements provide. Such a system will not only warn if the power consumption is too high but also which appliances that creates the problem. The information could also be sent to others and thereby create a monitoring system which could be a very useful tools for example monitoring elderly people in their homes if things are happening or perhaps more important not happening. Also children staying home alone could get support by this system since a parent could help not forgetting to turn of the stove etc.

Possible benefits (beneficiary):

- Direct feedback on which appliances that they use and how the device consume electricity.(customer)
- Monitoring elderly people in their homes if things are happening or not happening. (customer)

- The DSO could use the system to get a better understanding of the behavior of customer group and understand how different life styles effect the consumption but also see changes in the behavior earlier and be able to meet new requirements faster.(DSO)
- The information could also be used for more effective energy saving advices. Since only some of the loads are useful for DSM, such a system could be used to identify the possibilities and the current potential and perhaps also forecast the development of the potential, both short and long term. (DSO)

Next steps:

To be able to serve customers in a cost efficient way about how they are using electricity, there is a need to design an algorithm to distinguish between different loads with a minimum requirement of the SM and also to find out which information needs to be communicated to the customer/DSO/aggregator/adviser so that the customer is able to make well considered decisions of the electricity use.

3.2 Demand flexibility and grid services from the customers

3.2.1 Demand side management (DSM)/Demand Response (DR)(using Function 4)

- *Overview of Demand side management (DSM)/Demand response (DR):*

Demand side management (DSM)/Demand response (DR) technique, a tool for load shaping that can redistribute energy demand over a certain period, to get higher utilization in power grids rather than extensive constructions. The ability of the customers to manage their electricity demand in response to market prices (or some other system-related information) is generally referred to as demand flexibility or DR [37]-[38]. According to DSM principles, customers may decide to subscribe an agreement which can give the utility the freedom to proceed with load curtailments in presence of peaks of energy demand. Among techniques for DR, flexible pricing is an effective tool that can enable users to consume more rationally and more efficiently. In flexible pricing, the basic idea relates electricity prices to grid real-time operation rather than setting average prices, i.e., the price rises when there is a high demand for power causing heavy load, and falls at a low demand. This contributes to demand side's reduction of peak load and load shifting from peak hours to off-peak hours, resulting in a lower peak-to-average ratio in load shaping. There are different flexible pricing methods such as flat pricing, peak load pricing, adaptive pricing, and time-of-use pricing.

As an alternative to time-varying prices to consumers which prompt customers to reduce demand at times of high price, remote control commands can be sent through SMs for DSM using Direct Load Control (DLC) to reduce demand automatically. According to [30, 31], in the U.K. and the USA, appliances that are fitted with load control devices, can detect a frequency drop in the power system and disconnect load automatically. A DLC function will be available in the proposed smart metering system in the U.K to control domestic appliances and will be used by any actor operating in the power system to vary the DR available for transmission system operator [32].

From the customers' point of view, DR scheme ability will enable the customers' better understanding of their own consumption patterns and thereby manage their demand in such a way that minimize their total electricity cost [33]. In the future, the customers may install their own generation, such as roof-top PVs, other types of micro-generation, and may have other types of loads such as PEVs and battery and thermal energy storage equipment. These add up to the flexibility of the customers to manage their own energy consumption [34]. This also opens up new market possibilities for the customers, including the energy export to the grid as well as energy exchanges between customers. Another market possibility includes ancillary services provided by customers' flexibility, such as the voltage control and local network congestion relief, and when aggregated in large scale, this would lead to the possibility to provide for system frequency support services [35]. This can be done in small-scale as well as in a larger scale through a new market player, usually referred to as an aggregator [36].

Possible problems by DRs

From the DSO's point of view, demand flexibility can increase the uncertainty in the grid since the customer's behaviors are now changed which could lead to changes in times in peak demand in the systems and more unpredictable power flow. In some cases, DR can lead to more flat aggregated load profile, but in some cases it can lead to increased local peak demand which can create a problem for the network operation and planning as has been shown in [52].

- *Possibilities of DR/DSM for residential customers using future customer/utility interface*

With future customer/utility interface, the customers can be informed various useful information, such as hourly (or even every 15 minutes) consumption, spot market prices, weather forecast, etc., which can be used in the scheduling of their own demands within their houses or buildings. DR implementation in residential sectors is a recent effort to improve efficiency of the electricity market and stability of the power system. The two main aims of these applications are to reduce electricity peak demand and to match the demand with renewable energy [40]. The DR can be made more effective by fully and dynamically integrating consumers, their loads, and information about their usage into the operation of the grid. The smart metering system can help in realizing the interaction of consumers and power systems [42]. The implementation of a smart metering system means that utilities will be able to offer better targeted tariffs and introduce new business models based on real-time pricing or active load control, which can be used to reduce high-cost of electricity consumption [41]. Data collected from local loads and distributed energy resources by SMs can be provided to electric power marketing system, DSO and electricity consumption management system. The electric power marketing system will analyzes the load characteristics, the electricity consumption and abnormal usage, to control the whole situation of the electricity market. Coordinating with the generation information and weather forecasting, the market can forecast the future load demand and electricity price, which will be released to users' electricity consumption management system [42]. With the information provided by smart metering system, power market, Supervisory Control and Data Acquisition (SCADA) and distribution system, for advanced control and the appropriate economic incentives by the utility, including load control and price policy.

- *Load modelling for DR/DSM:*

With the development of the smart grid, there is a need for load models that can facilitate the study of changes in electricity consumption in response to customer behavior and/or signals

from a utility. Such load models are useful to evaluate the impact of DR at a distribution level. For the load models to represent DR activities, the following characteristics are required [39]: the models should cover all major types of controllable loads so that DR can be simulated considering consumer choices instead of simple load curtailment. Moreover, the models should be built according to the physical and operational characteristics of the appliances to reflect the actual situation. Furthermore, the models should allow interfaces for external signals to simulate the DR control actions and the algorithm should provide reasonable load diversification and aggregation to represent the distribution circuit load profile.
In the context of DR application, residential loads are generally classified as critical loads and controllable loads [40]. Critical loads refer to basic electricity consumption such as lighting, refrigeration and freezing which cannot be scheduled in response to DR application. By contrast, controllable loads include consumption of Heating, Ventilation and Air conditioning (HVAC), PEVs, washing, drying and cooking. Controllable loads can further be classified as thermostatically controlled loads and non-thermostatically controlled loads.

- *One example of DR model:*

A DR system with SM that can implement DR locally is proposed in [43]. In their proposed model, the SMs monitor the real time electric parameters such as voltage and current of the power system and at the same time it communicates with the utility to receive utility messages. However, how frequent the data needs to be measured is not mentioned in the paper. User interface of the SM can be used to set up and display the configurations of the load response strategy locally. Three inputs are considered in the DR model: utility message e.g., when power system's peak is happening and when over, measured or predicted power demands of the system and the DR strategy which can be configured by user. The output of the DR drives digital output of the SM directly. The users can set the load groups for shedding, e.g., HVAC is often a prime candidate for load shedding. The most non-important load groups will be shed first while reconnected last and the most critical load groups will be shed last while resumed first. Demand situation matrix and DR mapping matrix can be configured in the model to get different response operation in different situations.

- *Market for DR:*

Markets where customers could participate, either directly or via an aggregator are the day-ahead energy market (the spot market), intra-day market (adjustment market), different kinds of ancillary service markets and other upcoming markets. The day-ahead market is the energy market that buys and sells the electricity one day head. The intra-day market is cleared after the day-ahead market and used mainly by market players for correcting for forecasting errors in both production and consumption. Ancillary service markets are other markets mainly for supporting the operation of the grid, such as the regulating power market in the Nordic countries. The bids in the regulating power markets are also used for the transmission congestion management purpose. In some of these markets, it is today not even possible for the residential customer to participate, some does not even exist, but this will probably change over time.

- *Privacy based DR:*

Some literatures e.g., [44-46] have discussed about privacy based DR. Information about the household such as types of devices inside the house can be exposed from the fine-grained energy consumption readings. Typical ON/OFF pattern of appliances like refrigerators or coffee makers can be identified using steady-state monitoring techniques [44]. Moreover, higher harmonics analysis with a sampling rate of 8 kHz allows the identification and separation of loads like incandescent light bulbs and computers from the aggregated current signal. Furthermore, media content displayed on a TV can be identified with a sample rate of 2 Hz over a period of 5 min [45]. A common approach to secure privacy is to use a local battery for altering the power consumption profile of a house. In [44,] One Level Consumption (OLC) method is proposed to use with DR management which can hide most EV charging signals and also proposed Maximum Difference method which can hide all EV charging signals.

- *Reporting available DR from domestic appliances by sending only measurement changes*

Reporting available DR from domestic appliances is examined in [32]. Aggregated load profile is constructed by using load profiles of fridges, cooking appliances and washers and dryer which later on used to calculate the average number of load changes in a typical house, at LV substation, and at high voltage substation. it was assumed that a domestic load controller installed in each house, calculates the power consumption of three load groups (fridges and freezers, washers and dryers, and hobs and ovens) at every minute which are available for DR by DLC and sends the calculated values through the SM. The consumers can decide to join a load control scheme and there will be incentives for those who are joining to provide DR. Typical load curves of appliances and probability of appliance use are used from reference work to construct load profiles of different load groups. It is shown that by aggregating and sending only measurement changes, the number of bytes sent per minute through the smart metering communication system could be reduced from 162 M to 30 k for UK smart metering system.

- *DR for voltage control and congestion management:*

Different DR schemes are proposed in [47-50] for voltage control and congestion management in a distribution network. In [47], a scheduling model is proposed to adjust the load level of a given customer in response to hourly electricity price. The impact of the distribution congestion price based market mechanism is investigated in [50] to manage congestion in a distribution network. The congestion charge is proposed based on locational marginal price, and is used to charge the customer with demand that causes the problem. Another DR control mechanism is proposed in [48] for primary voltage control of an active distribution network by using controllable thermostatic appliances. In [49], economic incentives are proposed for DR with respect to congestions to mitigate potential overloads in the distribution system. However, the calculation method of incentives is not mentioned in the paper.

- *Idea for congestion management by new market based solution enabled by DSO*

DR itself could cause problem in the distribution network if almost all customers are active in the DR scheme. Instead of peak shaving, the peak could occur at another time and grid congestion could occur due to DR scheme. New market based solution enabled by DSO could be helpful in this case to avoid congestion in the distribution grid and also to control the voltage within the acceptable limit. Accurate load model and load forecast using SM data would then be helpful to identify the congestion in the grid and take necessary action quickly to solve the problem. However, none of the literatures discussed about using load modelling (based on SM data) and load forecasting (based on SM data) as inputs to the market for DR. This project has found that a bidding market, managed by the DSO and based on DR could be an interesting idea to investigate where load modelling and load forecasting could be the input to the market. Hence, the project has identified research questions related to market based solution for DR to ensure customers' participation in the market. The possible benefits of the market based solution for DR has considered both for the customers and the DSOs.

Possible benefits (beneficiary):

- Enable the customers' better understanding of their own consumption patterns. (customer)
- Manage their demand in such a way that minimizes their total electricity cost. (customer)
- Flexibility of customers to open up new market possibilities for e.g., energy exchanges between customers and or to the grid, and ancillary services. (customer)
- Active customers can, in many cases, lead to flattened load profiles which contribute to peak demand reduction for the distribution grid. This in turn leads to reduced needs for grid reinforcement (i.e., installations of new transformers or cables), i.e., a big cost savings for the DSOs. (DSO)

The challenge here is how to promote the DR while maintaining the physical constraints of the distribution systems. This would lead to a number of research questions which are important to address.

Next steps:

To be achieve the most cost efficient operation of a grid and still enable the customers to be active is there a need to find the minimum requirements for the future CUI but also to quantify the benefits of DR for the customers, distribution system and the society. Also the DRs role in grid support needs to be further investigated but also how can be incorporate into the daily operation. Another issue is to find a strategy to manage the demand flexibility for a large number of customers to make sure the DSO point view is taken into consideration.

3.2.2 Abnormal-behavior alarm services (using Function 5)

Another function for the SM is that the meter can identify what is happening at the customer. Based on measurements the meter could provide different types of alarm to the customer so that he/she will be able to act but the DSO could also act on it if the customer approves it. Some of the things that the system could detect are:
Abnormal high load or abnormal constant load which could perhaps be if someone is stealing electricity or something is broken or soon will break. An example of the latter is when the thermostat in a freeze breaks.
Abnormal low load could be problem in a fuse or something has been broken. This is problem if electricity is needed for example to prevent freezing in building or a pipe. If a freezer is turned off there is both a risk of destroying the content of the freezer but also to prevent water damages due to leaking content for the freezer.
Abnormal fast changes in the load could occur when something is about to break.

Possible benefits (beneficiary):

- Alarm to the customer so that the customer will be able to act at an early stage of problem. (customer)
- Alarms can also be received remotely. (customer)
- The DSO could avoid voltage dips in the grid if fewer faults occur at the customer side. The relation to the customers would also improve because they will get more value for their money. This task could also be valuable for example for insurance companies since this might reduce their costs. (DSO)

Next step:

By the use of the smart meters much more support can be given to the customers and thereby creating more good will and a better relation with the customers. A good relation may help if there will be a need for load shedding for grid operation. However, to achieve this is there need to investigate what different types of the abnormalities that can be identified and what are the minimum technical requirement of the smart meter, internal memory size and sampling rate.

3.2.3 Multi-energy carrier systems (interactions between different forms of energy services) (using Function 6).

Different consumers (industrial, commercial, or residential) require different forms of energy services provided by different networks, including e.g., electricity, natural gas, and district heating/cooling. The different energy delivery networks have been traditionally designed and operated independently of each other. In a world where we consider no boundary between different networks, the can interact with each other and can lead to synergy effects in terms of savings to both the systems and their users [51]. The future networks are those with flexibility to store (electricity, heat, gas) and convert (e.g., power to gas and gas to power, electricity to heat and heat to power, transportation by electric vehicles or by gas) from one form to another. From a system perspective, possibility to combine the future networks into a multi-energy carrier offers higher degree of optimization for utilization of energy resources as well as the transmission and distribution infrastructures.

From the demand level, multi-energy carrier networks are particularly relevant in urban areas where manifold networks interact closely within districts and cities, with the potential to develop “Smart Communities” and “Smart Cities”. The future CUI may have the possibility to integrate information on electricity consumption with information on other energy services, such as heating/cooling and natural gas (if available). This would enable the customers to control and optimize their energy consumptions to achieve the lowest energy bills.

In the case of GEAB, the focus will be on interaction between the electricity supply system and district heating supply system. Such interactions could be found in, for example:

- In large houses or buildings with heating by both district heating and electrical heating (either by electric heaters or by heat pumps) available, depending on the level of spot price of electricity and district heating, the users might chose to switch to use district heating or electrical heating or both.
- Hot water from district heating and water heated by the washing machine itself. If the washing machine has the possibilities for both options, there should be a possibility to control how the hot water can be fed to the washing machine.
- In houses with electric hot water boilers, it is possible to coordinate the use of electric hot water boilers and hot water from district heating. In Denmark, there are instances that the users get paid for using the electric hot water boilers when the electricity price went negative.

Possible benefits (beneficiary):

- Lowered total energy bills. (customer)
- Lowered total energy used (DSO)
- Lowered network losses (electricity, heating, gas) (DSO)
- Reduced demand for investment in infrastructure (DSO)
- Better management of network flow (e.g., reduced distribution network congestion)(DSO)

Next step:

One way to create a cost efficient operation of the electricity grid is to work together with the other energy systems and share the costs but also allow the customer to use different types of energy sources depending on price, availability and/or congestion in the infrastructure. However, to achieve this is there a need to develop models of the multi-energy carrier network and design the control infrastructure. Based on the model can optimization of the dispatch of energies considering the constraints in networks, storage capacities, energy conversion efficiencies and the scheduling methods of the local energy consumptions within houses, buildings, or communities be made.

4 Concluding remarks

The distribution grid facing a lot of new challenges within the closest 15 years like high expectations on the quality of the supply. The grid should also support all new trends in demand, like electric vehicles, and at the same time enable customers to participate in different markets, both existing and future with a sustained quality and cost of the grid. To be able to develop methods to meet all the challenges is a number of the research topics presented.

The most challenging is to meet the expected change in demand that is expected to happen due new demand patterns due to fast behavior changes and new types of loads but also to meet the demands of active costumers to participate in different types of markets. Active customers will increased the covariations between loads. The level of covariations is an important factor during design of any distribution grid to limit the cost. Higher covariations risk to increase congestion problems in the grid, therefore there is a need to be able to identify where congestions may arise before they actually happens to be able to take actions to avoid them or limit their consequences. This can be done using the information from smart meters and on how different market work and might work in the future. Load forecasting will also give information on voltage levels and how the voltage will vary so the number of times when the voltage is not within its limitations and reduced. There will also be a need to further develop the different methods for congestion management and voltage variations. It is mainly the behavior of the load, which needs to be studied to utilize the full positional of different operating conditions to be used as grid congestion management method. In load modelling and forecasting is the smart meters considered a key component to therefore there is a need to establish the minimum requirement to allow a future use of this applications. If the requirement of the smart meters can be identified before ordinary replacement of smart meters will the extra costs be low.

5 Reference

[1] S. Teske, T.Brown, E. Tröster, P.-P. Schierhorn, T. Ackermann, ‘Power 2030- A European grid for 3/4 renewable grid for electricity by 2030’, Green peace report, March 2014.

[2] E. Tröster, R. Kuwahata, T. Ackermann ’European-Grid-Study 2030/2050’, Energynautics, Germany, January 2011.

[3] F. Wilkens, C. Johansson, U. Åkesson, ’Energy law i Sweden- Recent developments in the Swedish energy market’, European energy review report, Advokatfirman Vinge, Stockholm, 2011.

[4] Swedish Institute, [Online]: Available: https://sweden.se/society/sweden-tackles-climate-change/ [accessed 12-10-15]

[5] Swedish Institute, [Online] Available: https://sweden.se/society/energy-use-in-sweden/ [accessed 12-10-15]

[6] J. Campillo, I. Krustok, ‘Electricity demand impact from Increased Use of Heat Pumps in Sweden’, [Online] Available: http://www.idt.mdh.se/kurser/ct3340/ht12/MINICONFERENCE/FinalPapers/ircse12_submission_6.pdf

[7] R. Segovia and M. Sanchez, “Set of common functional requirements of the Smart Meter,” A joint contribution of DG ENER and DG INFSO, Oct. 2011. [Online] Available: https://ec.europa.eu/energy/sites/ener/files/documents/2011_10_smart_meter_funtionalities_report.pdf

[8] Report- Ei R2015:09, ”Funktionskrav på framtidens elmätare”, Swedish Energy Markets Inspectorate. Available: http://ei.se/Documents/Publikationer/rapporter_och_pm/Rapporter%202015/Ei_R2015_09.pdf

[9] Y Arafat, “On possibilities of Smart Meters switching at low voltage level for emergency grid management”, Licentiate thesis, August 2015.

[10] T. Solvang, L. Aleixo and H. Seljeseth, ‘’Power Quality Measurement Capabilities of Smart Energy Meters’’, International Conference on Renewable Energies and Power Quality, ICREPQ, March 2010.

[11] J. Höglund and S. Karnouskos, “Using Wireless Smart Meter Networks for Power Quality Monitoring”, ERCIM news, [online] Avialable:http://ercim-news.ercim.eu/en92/special/using-wireless-smart-meter-networks-for-power-quality-monitoring [accessed 18-12-15]

[12] Assessment of Power Quality Data in Smart Meters, Technical result, EPRI, Nov-2011.

[13] M Campbell, N Watson, Allan Miller, ‘Smart Meters to Monitor Power Quality at Consumer Premises’ EEA Conference & Exhibition, June-2015.

[14] Zhenyu Guo; Wang, Z.J.; Kashani, A., "Home Appliance Load Modeling From Aggregated Smart Meter Data," ," in IEEE trans. Power Syst. Jan. 2015

[15] Jayasuriya, D.C.; Rankin, M.; Jones, T.; de Hoog, J.; Thomas, D.; Mareels, I., "Modeling and validation of an unbalanced LV network using Smart Meter and SCADA inputs," in TENCON Spring Conference, 2013 IEEE , vol., no., pp.386-390, 17-19 April 2013

[16] F.Provoost, M. V. Lumig, “The use of smart meters to improve customer load models”, CIRED, June 2011Shah, B.; Bose, A.; Srivastava, A., "Load modeling and voltage optimization using smart meter infrastructure," in Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES , vol., no., pp.1-6, 24-27 Feb. 2013

[17] Weiss, M.; Helfenstein, A.; Mattern, F.; Staake, T., "Leveraging smart meter data to recognize home appliances," in Pervasive Computing and Communications (PerCom), 2012 IEEE International Conference on , vol., no., pp.190-197, 19-23 March 2012

[18] Shah, B.; Bose, A.; Srivastava, A., "Load modeling and voltage optimization using smart meter infrastructure," in Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES , vol., no., pp.1-6, 24-27 Feb. 2013
[19] T.V. Cutsem and C. Vournas, “Voltage Stability of Electric Power Systems”, Springer, 2008.
[20] S. Barker, “Model-driven Analytics of Energy Meter Data in Smart Homes”,PhD thesis University of Massachusetts, US.
[21] R. Uluski, A. Gaikwad, M. Mcgranaghan, “Load Models for Voltage Optimizaion”, in International Conference on Electricity Distribution CIRED 2011, June 2011.
[22] S. Grijalva et al. “Exploiting Emerging Data for Enhanced Load Modeling”, Final project report, Georgia Institute of Technology, Sept. 2014. [Online] Available: http://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCQQFjAAahUKEwjCzZHioaHIAhWK1iwKHexMCEE&url=http%3A%2F%2Fpserc.wisc.edu%2Fdocuments%2Fpublications%2Freports%2F2014_reports%2FGrijalva_PSERC_Report_S-49_Sep._2014_ExSum.pdf&usg=AFQjCNGtTAvl4-QyXwuGOCK7_qKfjf12iQ&sig2=6pDv1-YtmUi4fhSCqwb8xw
[23] ENTSO-E, “Implementation guideline for network code-Demand Connection”, Oct. 2013. [Online] Available: https://www.entsoe.eu/fileadmin/user_upload/_library/resources/DCC/131016_-_DCC_implementation_guideline.pdf [Accessed 18-12-15]
[24] B. Hayes. J. Gruber, M. Prodanovic, “short-term load forecasting at local level using smart meter data”, in PowerTech Eindhoven 2015, June 29 2015-July 2015, pp.1-6.
[25] T. Zabkowski, K. Gajowniczek, “short term electricity forecasting using smart meter data”. ”, Procedia Computer Science, 2014, Pages 589-597
[26] S.B. Taieb, R. Huser, R.J. Hyman, M.G.Genton, “Probabilistic time series forecasting with boosted additive models: an application to smart meter data” Department of Economics and business statistics, Monash University, June 2015.
[27] Asare-Bediako, B.; Kling, W.L.; Ribeiro, P.F., "Day-ahead residential load forecasting with artificial neural networks using smart meter data," in IEEE PowerTech (POWERTECH), Grenoble June 2013
[28] Y.Kim, S.Kong, R.Ko and S.K.Joo, “Electrical Event Identification Technique for Monitoring Home Appliance Load Using Load Signatures” in IEEE International Conference on Consumer Electronics (ICCE), 2014.
[29] Ahmed Zoha, Alexander Gluhak, Muhammad Ali Imran, Sutharshan Rajasegarar, ” Non-Intrusive Load Monitoring Approaches for Disaggregated energy sensing: A survey”. *Sensors* 2012, *12*(12), 16838-16866
[30] D. Hammerstrom, J. Brous, D. Chassin, G. Horst, R. Kajfasz, P. Michie, T. Oliver, T. Carlon, C. Eustis, O. Jarvegren, W. Marek, R. Munson, and R. Pratt, “Pacific Northwest GridWise testbed demonstration projects, Part II. Grid friendly appliance project,” Oct. 2007
[31] RLtec, “Dynamic demand in refrigeration” [Online]. Available: http://www.rltec.com/sites/default/files/090427_product_application.pdf Sep. 03, 2009
[32] Samarakoon, K.; Ekanayake, J.; Jenkins, N., "Reporting Available Demand Response," in Smart Grid, IEEE Transactions on , vol.4, no.4, pp.1842-1851, Dec. 2013
[33] D. Steen, T. Le, O. Carlsonn, L. Bertling Tjernberg, “Evaluating the customers’ benefits of hourly pricing based on day-ahead spot market, CIRED, Stockholm, Sweden June 10-13, 2013.
[34] D. Steen, S. Al-Yami, T. Le, O. Carlson and L. Bertling, “Optimal Load Management of Electric Heating and PEV Loads in a Residential Distribution System in Sweden,” IEEE

PES Conference on Innovative Smart Grid Technologies Europe, Manchester, UK, December 5-7, 2011.
[35] P. Balram, T. Le; L. Tjernberg, "Modeling of regulating power market based on AC optimal power flow considering losses and electric vehicles," in Innovative Smart Grid Technologies - Asia (ISGT Asia), 2013 IEEE , vol., no., pp.1-6, 10-13 Nov. 2013
[36] P. Balram, T. Le, L. Bertling Tjernberg., "Effects of plug-in electric vehicle charge scheduling on the day-ahead electricity market price," in Innovative Smart Grid Technologies (ISGT Europe), 2012 3rd IEEE PES International Conference and Exhibition on , vol., no., pp.1-8, 14-17 Oct. 2012
[37] G. Strbac, “Demand side management: Benefits and challenges,” Energy Policy, vol. 36, no. 12, pp. 4419 – 4426, 2008.
[38] J. Torriti, M. G. Hassan, and M. Leach, “Demand response experience in europe: Policies, programmes and implementation,” Energy, vol. 35, no. 4, pp. 1575 – 1583, 2010.
[39] S. Shengnan, M. Pipattanasomporn, S. Rahman, "Development of physical-based demand response-enabled residential load models," in Power Systems, IEEE Transactions on , vol.28, no.2, pp.607-614, May 2013
[40] Z. Wang; R. Paranjape, A. Sadanand, C. Zhikun, "Residential demand response: An overview of recent simulation and modeling applications," in Electrical and Computer Engineering (CCECE), 2013 26th Annual IEEE Canadian Conference on , vol., no., pp.1-6, 5-8 May 2013
[41] G. Di Leo, M. Landi, V. Paciello, A. Pietrosanto, "Smart metering for demand side management," in Instrumentation and Measurement Technology Conference (I2MTC), 2012 IEEE International , vol., no., pp.1798-1803, 13-16 May 2012
[42] S. Huibin, S. Ying, L. Wei-Jen, "A demand side management model based on advanced metering infrastructure," in Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2011 4th International Conference on , vol., no., pp.1586-1589, 6-9 July 2011
[43] H. Feihuang, C. Weigang, "One type of smart meter with demand control Local demand response with smart meter," in Industrial Electronics and Applications (ICIEA), 2014 IEEE 9th Conference on , vol., no., pp.546-549, 9-11 June 2014
[44] A. Awad, P Bazan, R. German, "Privacy Aware Demand Response and Smart Metering," in Vehicular Technology Conference (VTC Spring), 2015 IEEE 81st , vol., no., pp.1-5, 11-14 May 2015
[45] B. Greveler, D. Lhr. “Multimedia Content Identification through Smart Meter Power Usage Profiles”. In Proceedings of the International Conference on Information and Knowledge Engineering Las Vegas, 2012.
[46] C. Beckel, L. Sadamori, T. Staake, and S. Santini. Revealing household characteristics from smart meter data, 78(0):397 – 410, 2014
[47] A. J. Conejo et. Al. "Real-Time Demand Response Model," IEEE Trans. Smart Grid, Dec. 2010
[48] K. Christakou et al. in "GECN: Primary Voltage Control for Active Distribution Networks via Real-Time Demand-Response," IEEE Trans. Smart Grid, March 2014
[49] M.R. Sarker et al. "Optimal Coordination and Scheduling of Demand Response via Monetary Incentives," in IEEE Trans. Smart Grid, May 2015
[50] L. Weijiaet al. "Day-Ahead Congestion Management in Distribution Systems Through Household Demand Response and Distribution Congestion Prices," in IEEE Trans. Smart Grid, Nov. 2014
[51] Krause et al., ”Multiple-Energy Carriers: Modeling of Production, Delivery, and Consumption”, Proceedings of the IEEE, Vol. 99, No. 1, January 2011

[52] D. Steen, “Modelling of Demand Response in Distribution System”, Ph.D. thesis, Chalmers University of Technology, December 2014.
[53] M. Jinghuan, D. Jun, S. Lingyang, H. Zhu, "Incentive Mechanism for Demand Side Management in Smart Grid Using Auction," IEEE Transactions on Smart Grid
[54] P. Palensky, D. Dietrich,"Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads," IEEE Transactions on Industrial Informatics.
[55] P. Balram, “Energy scheduling of electric vehicles for electricity market participation”, Lic. thesis, Department of Energy and Environment , Chalmers University of Technology, 2014.