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Report

The impact and flexibility of PV based customers 58° North and beyond

Results from the FlexNett project

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ABSTRACT

This report is developed within FlexNett project (2015-2018) and summarises the results from the demonstration sites focusing on flexible prosumers, located both at NTE Nett and the municipality of Hvaler.

FlexNett project aimed to contribute to increased flexibility in the future smart distribution grid by demonstration and verification of technical and market-based solutions for flexibility on different grid levels and for different stakeholders.

For this report the main focus has been to investigate the increased flexibility of active customers in the interplay between consumption, generation and energy storage, contributing to a more efficient use of energy, reduced costs and new services. In the distribution grid by locating energy storages in substations to reduce peak loads, improve the utilization of existing grid capacity, reduce coincident peak load and postpone the grid investments.

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1 Introduction

This report has been developed within the Norwegian research project "Flexibility in the future smart distribution grid – FlexNett" (2015-2018) and summarises the results from the demonstration sites that have focused on the flexibile prosumers – located both at NTE Nett (Steinkjer) and the municipality of Hvaler.

FlexNett project aimed to contribute to increased flexibility in the future smart distribution grid by demonstration and verification of technical and market-based solutions for flexibility on different grid levels and for different stakeholders.

For this report the main focus has been to investigate the increased flexibility of active customers in the interplay between consumption, generation and energy storage, contributing to a more efficient use of energy, reduced costs and new services. In the distribution grid, by locating energy storages in substations to reduce peak loads, improve the utilization of existing grid capacity, reduce coincident peak load and postpone the grid investments.

The project results presented in this report are focusing on household customers as a resource in the distribution grid with new technologies installed, such as PV[1] panels and electric batteries.

The following topics have been further elaborated:

- Reduced utilization time of the distribution grid due to peak load increasing more than the overall electricity consumption (in kWh) of electricity (Chapter 3).
- The seasonal negative correlation between the time for local generation from PV panels (peak generation during the summer) and local consumption (peak load during the winter) in Norway (Chapter 4).
- Flexibility in orientation of the PV panel and thermal storage can contribute to increased benefits for the prosumer (Chapter 5).
- The orientation of the PV panel can reduce the peak loads for a household and improve the benefits for a prosumer with a capacity grid tariff (Chapter 6).
- Batteries can be installed at the prosumer, in a community and on the substation level, and become an alternative to grid investments, but the economic viability of the alternatives needs to be assessed on case-by-case basis (Chapter 7).

The report is based on contributions from:

- Bernt A. Bremdal (Smart Innovation Norway) (Chapter 6) [1], [2], [3]
- Geir Mathisen (SINTEF Digital/NTNU) (Chapter 5) [4], [2]
- Merkebu Zenebe Degefa (SINTEF Energi) (Chapter 3 and 7) [5], [2], [6]
- Eirik Thorshaug (NTE Nett) [7]

[1] PV = Photovoltaic

2 The FlexNett project

The Norwegian research project "Flexibility in the future smart distribution grid – FlexNett" (2015-2018)[2] aims to contribute to **increased flexibility in the future smart distribution grid** by **demonstration and verification** of technical and market-based solutions for flexibility on different grid levels and for different stakeholders.

The project will promote increased flexibility…

- at *active customers*, in the interplay between consumption, generation and energy storage, contributing to a more efficient use of energy, reduced costs and new services.
- in the *distribution grid* by locating energy storages in substations to reduce peak loads, improve the utilization of existing grid capacity, reduce coincident peak load and postponing the grid investments.
- in *smarter operation of the distribution grid*, for example through energy storage, remote control in the grid and voltage control, contributing to reduced grid losses, improved security of supply and voltage quality.

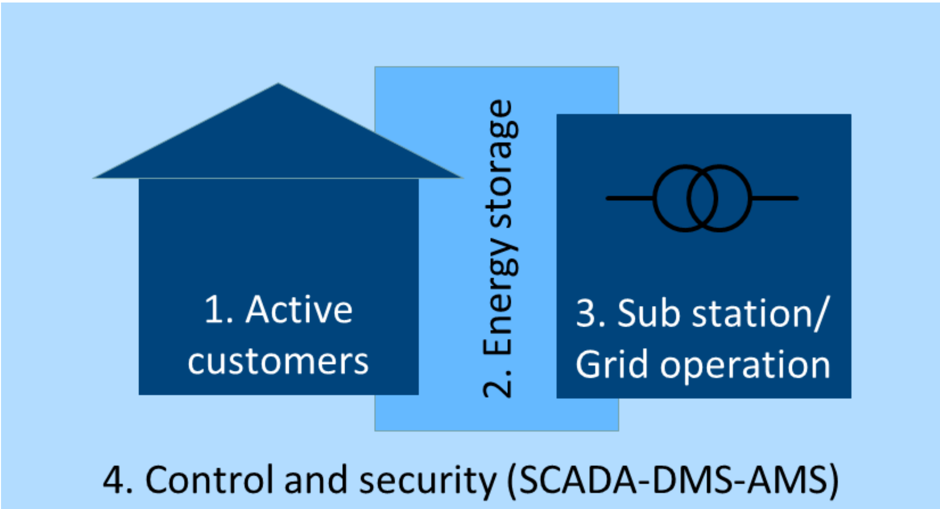

Figure 2.1 Realization of flexibility

The project owner is BKK Nett, and the research partners are SINTEF Energi, Smart Innovation Norway and SNTEF Digital. The research project received funding from the Research Council of Norway, in addition to funding from the 20 partners in the project.

The total budget was approximately 21 million NOK (Approx. 2,1 million Euros), including both funding of research activities and in-kind from the participating partners.

Project structure

The project structure is presented in Figure 2.2. In total the project consisted of five work packages (WPs).

[2] https://www.forskningsradet.no/prosjektbanken/#/project/NFR/245412

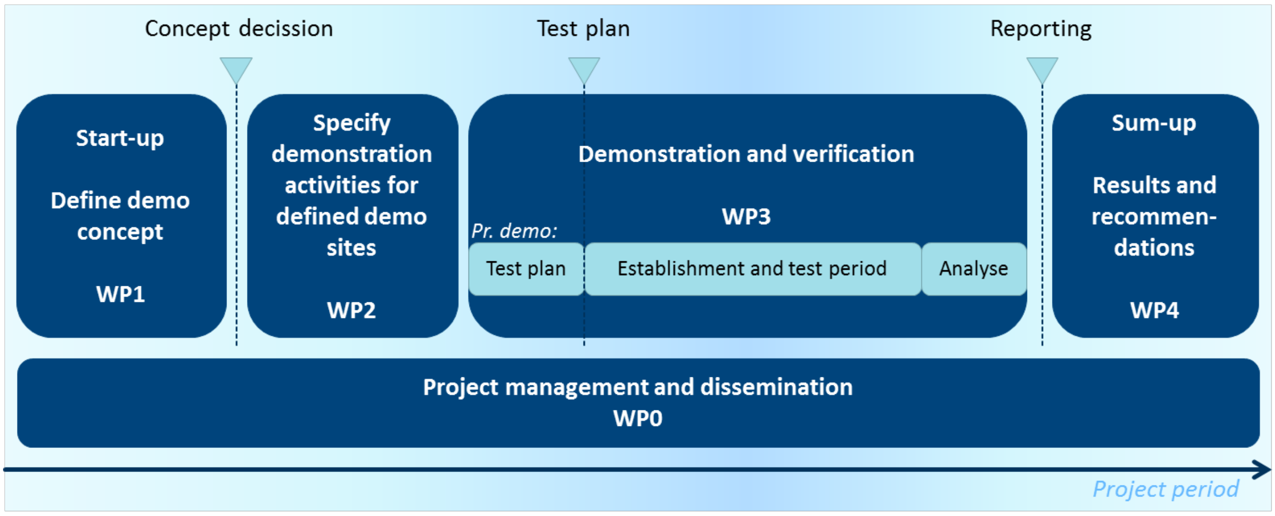

Figure 2.2 Structure of the FlexNett project

The project started with WP1 and arranged workshops with the objective to define the demo concept for the project, focusing on the future distribution grid and demand response. WP2 continued this work and specified the demonstration activities for the three defined demonstration sites. The largest work package was WP3 containing the actual demonstration and verification. The final work package (WP4) summarised the results from the different demo activities in WP3 and developed recommendations based on these. WP0 was project management and dissemination during the whole project period.

Research activities

Three demonstration sites were included into FlexNett project. The work had a broad focus, spanning from the customer-specific to customer and grid topics and sole distribution grid focus. These topics at the different demonstration sites are illustrated in Figure 2.3.

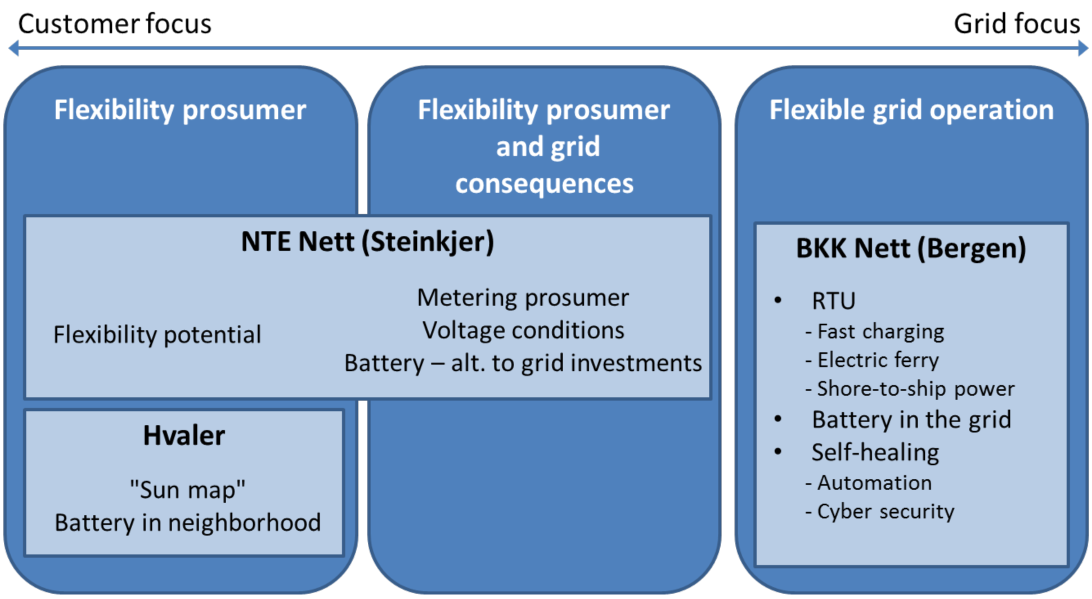

Figure 2.3 Demonstration sites within the FlexNett project

The geographical locations of the demonstration sites are presented in Figure 2.4.

Figure 2.4 Geographical locations of demonstration sites within the FlexNett project (Source: www.zeemaps.com)

The structuring of stakeholders (Distribution System Operators – DSOs, Aggregator, industry, household), systems (SCADA, DMS, Smart meters, RTU, …), technologies (consumption, production and energy storage) and functionalities (control, measurement, security, …) involved into the different demonstration activities, are presented in Figure 2.5.

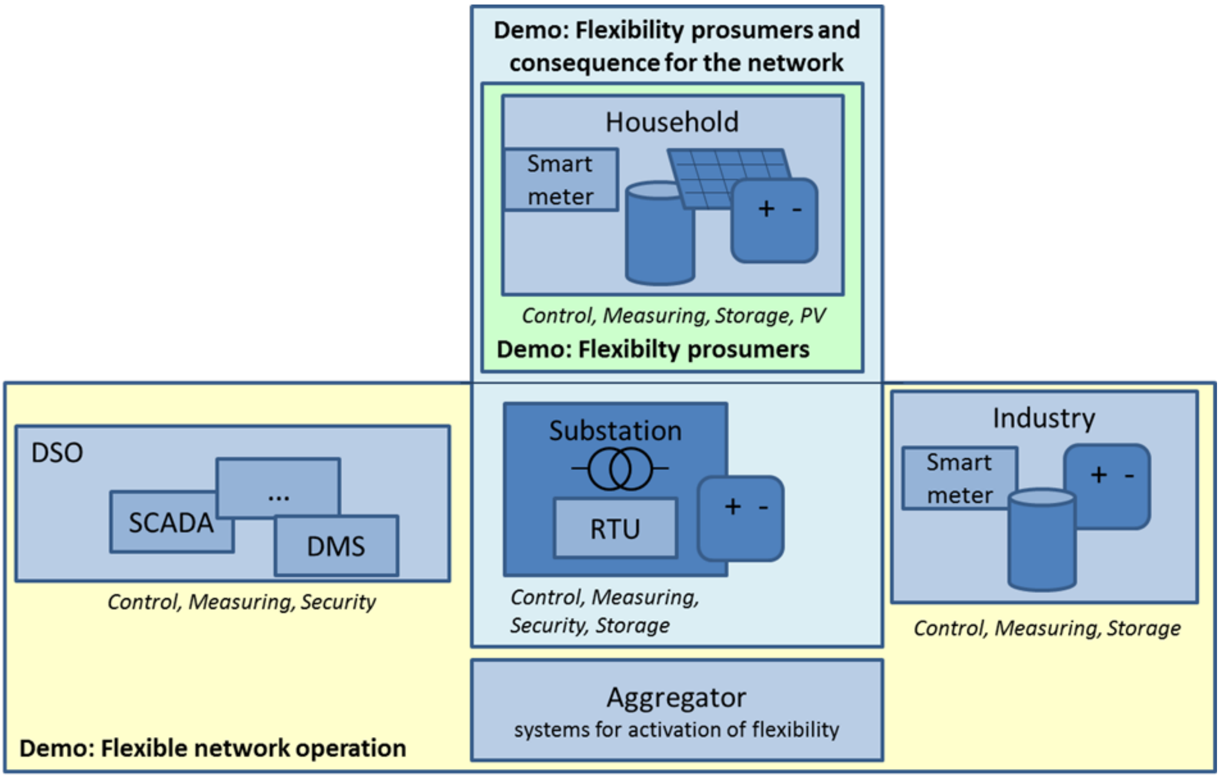

Figure 2.5 Structure of stakeholders, systems, technologies and functionalities [8]

This report summarises results from the demonstration sites focusing on flexibility prosumer – located both at NTE Nett (Steinkjer) and the municipality of Hvaler.

3 The trends in peak load and electricity consumption growth for the Norwegian household customers

Based on data from more than 100 households with their hourly metered electricity consumption for nine years (2007-2015) analyses have been performed to quantify and observe historical changes in the electricity consumption of residential customers [5].

The variations in peak hour of the month, accumulated monthly and yearly energy consumption were calculated for the analysed period. In the results, the peak hour refers to the peak hour of the month for the hour-by-hour average electricity load of all the households in the analysis. The hours are counted from 1 to 24 for each day.

Explanations of some expressions in the figures are listed below:

- *Average monthly peak hour of the year:* Average of the 12 months' peak of the year.
- *Yearly peak hour:* Maximum of the 12 monthly peak hours of the year.
- *Rate of increase:* Means the slope of the linear fit line of the scatter plot of the data.

In Figure 3.1 and Figure 3.2 the comparison between energy consumption and peak hour load are presented for periods of one month and one year. The figures show the values after normalizing data to a common starting point, in this case 2007, and observing how variables change over time relatively to each other.

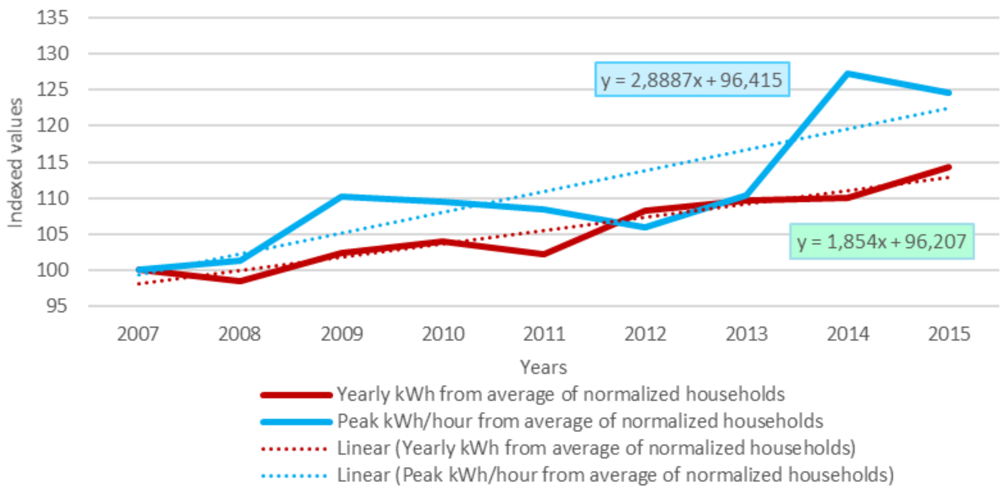

Figure 3.1 Comparison of the change in total normalized kWh yearly consumption with the change in the maximum hourly peak of the year for the normalized load between 2007 and 2015 [5]

From the base year of 2007 the percentage increase of the yearly consumption and the peak hour consumption is growing at different rate. Each year the consumption from 2007 value is increasing by 1,85% and increasing by 2,89% for peak-hour. Finally, in 2015 compared to 2007, the yearly consumption has increased by 14,38% and by 24,57% for peak hour of the year.

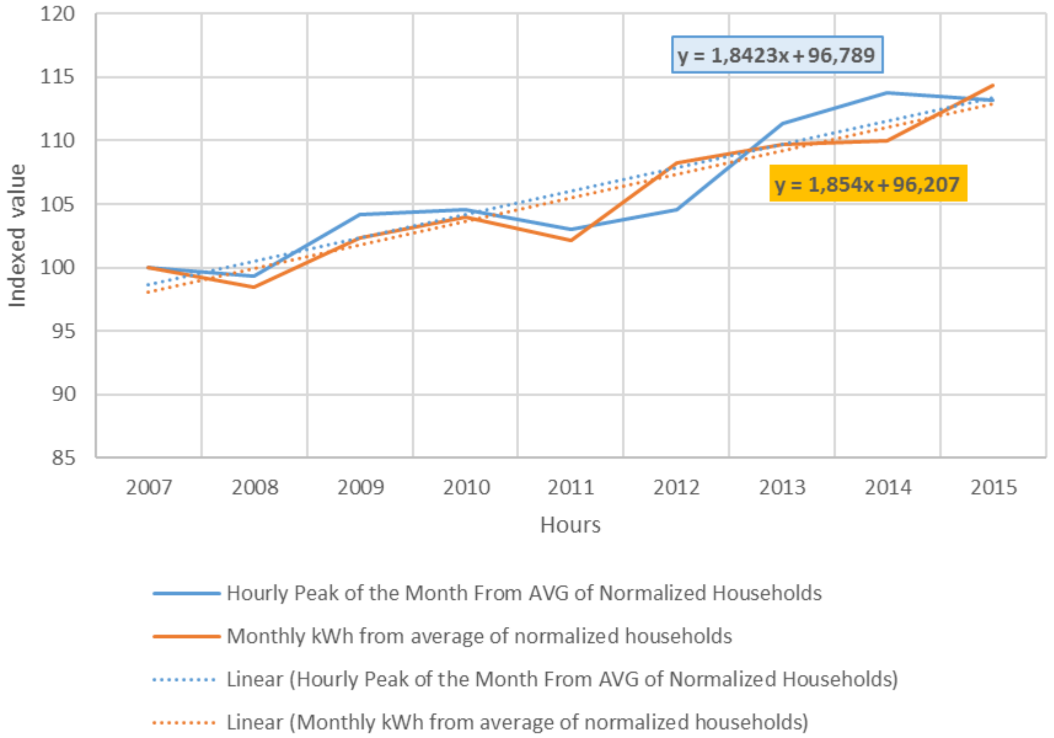

Figure 3.2 For the normalized average load, the rate of change of average monthly peak hours and average monthly kWh consumption in the period 2007 to 2015 [5]

Comparing the increase in peak load presented in Figure 3.1 for hourly values and in Figure 3.2 for monthly values shows that the yearly peak hour consumption of the average normalized household consumption has been increasing at a higher rate (2,88 in Figure 3.1) than the monthly peak hour consumption (1,84 in Figure 3.2).

Figure 3.3:

Most of the peak hours occur in weekdays and not in weekends.

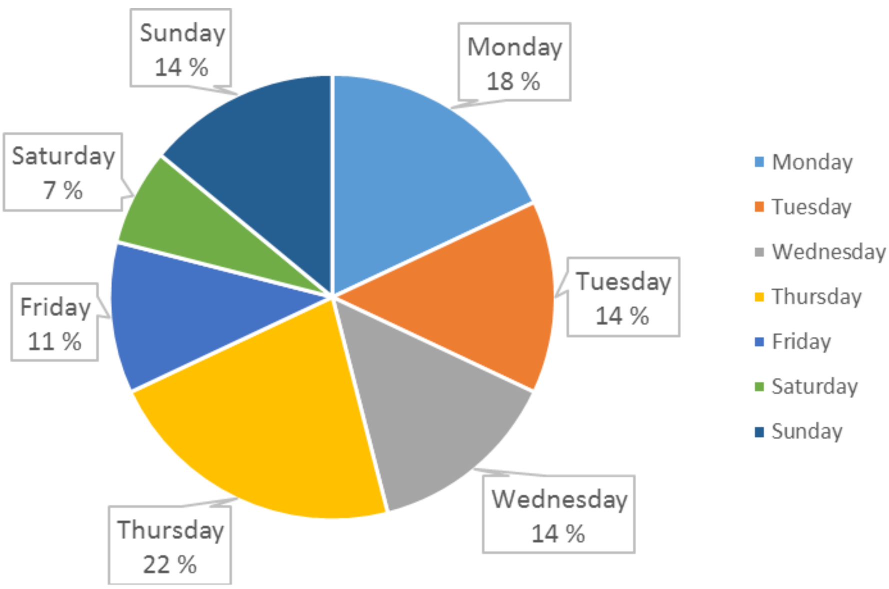

Figure 3.3 Day with monthly peak hourly consumption for the 12 months of the 9 years [5]

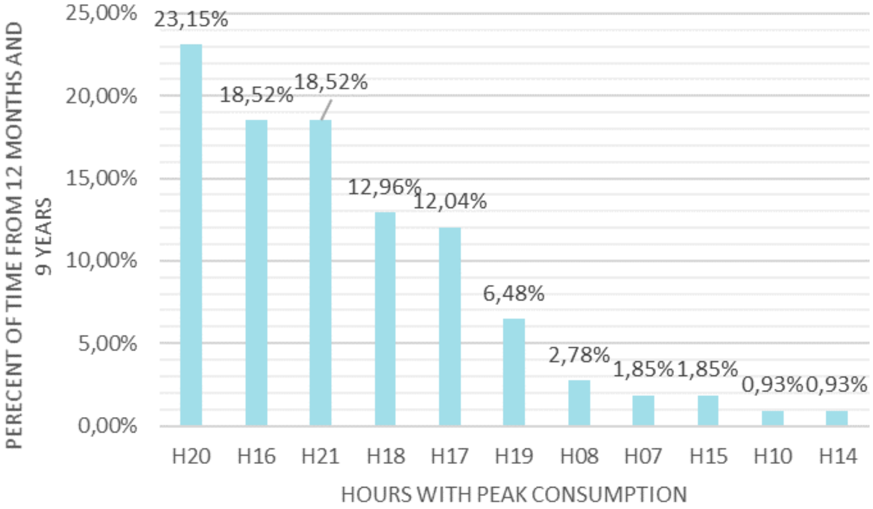

Figure 3.4:

Hour 20:00 is where 23% of the time the peak hours occur, while hour 16:00 and hour 21:00 have equal chances to become the peak hour (i.e. 18,5% of the time).

Figure 3.4 Frequencies of certain hours of the day being the peak hour of the month between 2007 and 2015 [5]

One of the demos has targeted the issue in Figure 3.4 specifically by assuming that self-consumption during specific hours is more valuable than in others. This implies certain measures to be considered when investing in PV panels as well as batteries (See chapter 6).

4 Prosumers in Norway

Until 2013 the Norwegian market for PV panels was mainly characterised by isolated installations (off-grid), but the total installed capacity has increased during the last years, and by the end of 2016 it was installed 26,7 MWp in total. 11,4 MWp was installed in 2016, an increase of 366% compared to the volume installed in 2015. The installed capacity of PV panels in Norway for the last years is presented in Figure 4.1.

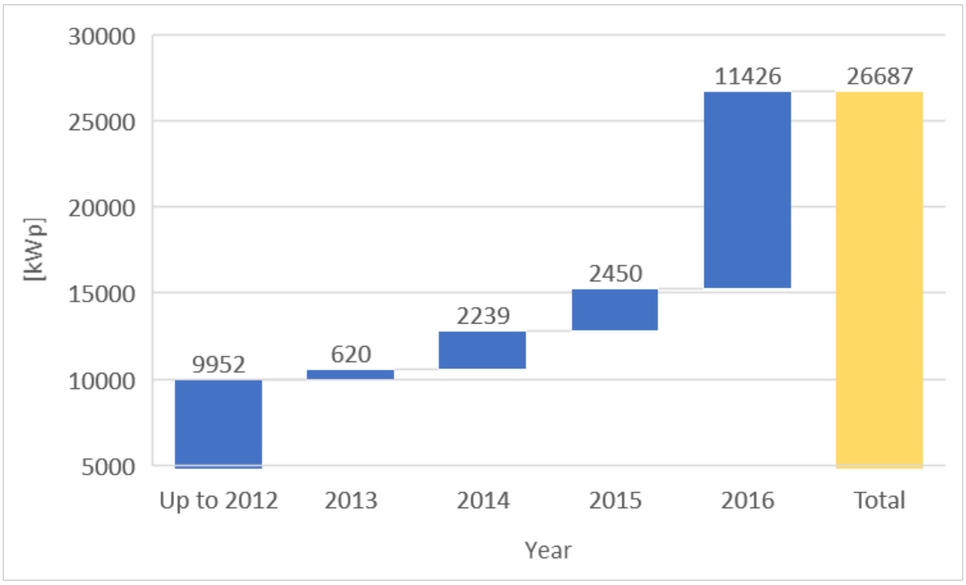

Figure 4.1 Installed capacity [kWp] of PV panels in Norway [9]

The first regulatory framework for prosumers in Norway was introduced in March 2010, when the Norwegian Regulator (NVE) approved a simplified system for all the Distribution System Operators (DSOs) to accept prosumers. This made it possible for local DSOs to buy electricity from prosumers with grid tariffs paid to the prosumer, which covered only the energy part for the electricity fed into the grid. It was not mandatory for the DSO to buy the excess power from the prosumers.

A new regulation for prosumers was introduced on the 1st of January 2017, with the following definition of a prosumer [10]: *A prosumer is a customer with both consumption and generation behind the connection point to the grid, where the electric power fed into the grid should not exceed 100 kW. A prosumer cannot have an installation being subject to a concession behind the connection point or a sale of electricity behind the connection point that requires concession.*

The new regulations are mandatory with a grid tariff including only the energy part for the electricity fed into the grid. In the new regulations it is also stated that the prosumer is responsible for finding a power retailer interesting in both buying the excess power from the prosumer and selling power to the prosumer when needed.

Norway has been adopting solar PV at a much lower rate than other Scandinavian countries. As an example, the cumulative PV capacity for Denmark and Sweden reached 858 MW and 205 MW in 2017, while it was registered 26,7 MW in Norway [9].

Solar irradiance is one of the most important factors when evaluating the potential for PV generation. The locations with the largest potential have a solar irradiation up to 2.500 kWh/m^2 measured towards a horizontal square. In Norway the solar irradiations vary from approx. 1.000 kWh/m^2 in the South and to approx. 700 kWh/m^2 in the North [11]. The solar irradiations in the Southern Norway are on the same level as the irradiations in Sweden, Denmark and Central parts of Germany. This means that the potential for utilization of the solar energy, based on the irradiation is on level equal to our neighbouring countries.

Despite the potential for electricity generated by solar panels, there is a seasonal negative correlation between the time for local generation from PV panels (peak generation during the summer) and local consumption (peak load during the winter). Electricity is the main source for space heating in Norway[3], while the solar panel generates most electricity during the summer time. This is illustrated by the duration curve for consumption and respective PV output during the same hours, in Figure 4.2.

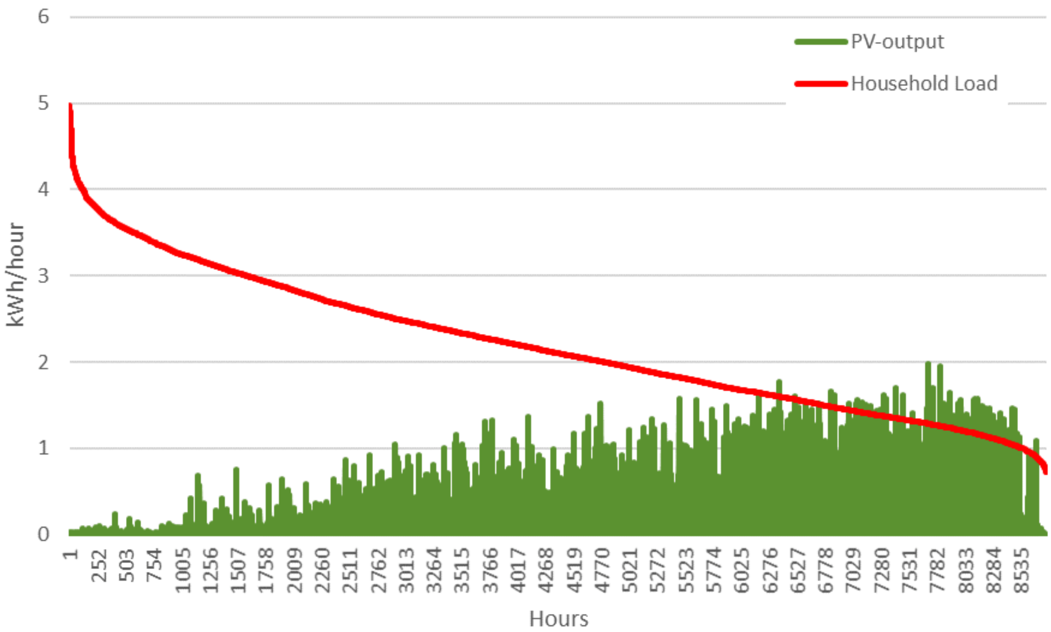

Figure 4.2 Duration curve representing the descending order of household load and the respective PV output [5]

With the technology development and decreasing battery costs the installation of electric battery storage system at household level is increasing. Such batteries can contribute to increased flexibility at customer level and also increase the benefits that can be harvested from the PV panel. It is not realistic with an electric battery for seasonal storage, but such batteries can be relevant for storage of energy on a daily basis. The batteries can be used for load levelling during the winter and for increased self-consumption during the summer.

[3] Approx. 65% of the total yearly electricity consumption is used for space heating for a typical household [5]

5 The flexible prosumer

The potential for flexibility in both demand and generation has been evaluated and simulated for a prosumer located in a weak distribution grid in the middle of Norway [4]. The hypothesis is that flexibility in the form of a battery in this particular case, on the demand side can reduce the amount of electricity fed into the grid and increase the self-consumption. It is favourable for the prosumer to minimize the energy purchased from the grid by maximizing the production and minimizing the energy delivered to the grid.

The starting point is the following relation for electric energy for a prosumer:

Consumption = Energy from grid + Produced – Energy to grid

This question has been studied within FlexNett for the prosumer located in Steinkjer. This prosumer has a water-borne system for space heating and heating of tap water with energy delivered from an electric boiler. The electric boiler has four heating elements (1,5 kW, 2,3 kW, 2,9 kW and 4,5 kW, in total: 11,2 kW), each with an individual thermostat set to 60 °C. The prosumer also has an electric vehicle, using 2,2 kW when charging. The PV panel is 3,06 kWp, 12 panels each of 255 W. The solar panel is located on the roof with an incline of approx. 15 °C, oriented towards South. The case-related installation at the prosumer is presented in Figure 5.1.

The following metering equipment has been installed:

- A – Meters for voltage and current on all the three phases at the connection point to the grid (ElitePro) (1-minute resolution).
- B – Meters for voltage and current on three phases at the electric boiler (ElitePro) (1-minute resolution).
- C – Meters for the outdoor temperature (1-minute resolution).
- D – Computer, collecting the metered data.
- E – 2G modem transferring the metered data.
- F – Smart meter. Hourly metering of the electricity bought from the grid and fed into the grid.
- G – Meter for the electricity produced by the PV panel (Elspec) (1minute resolution).

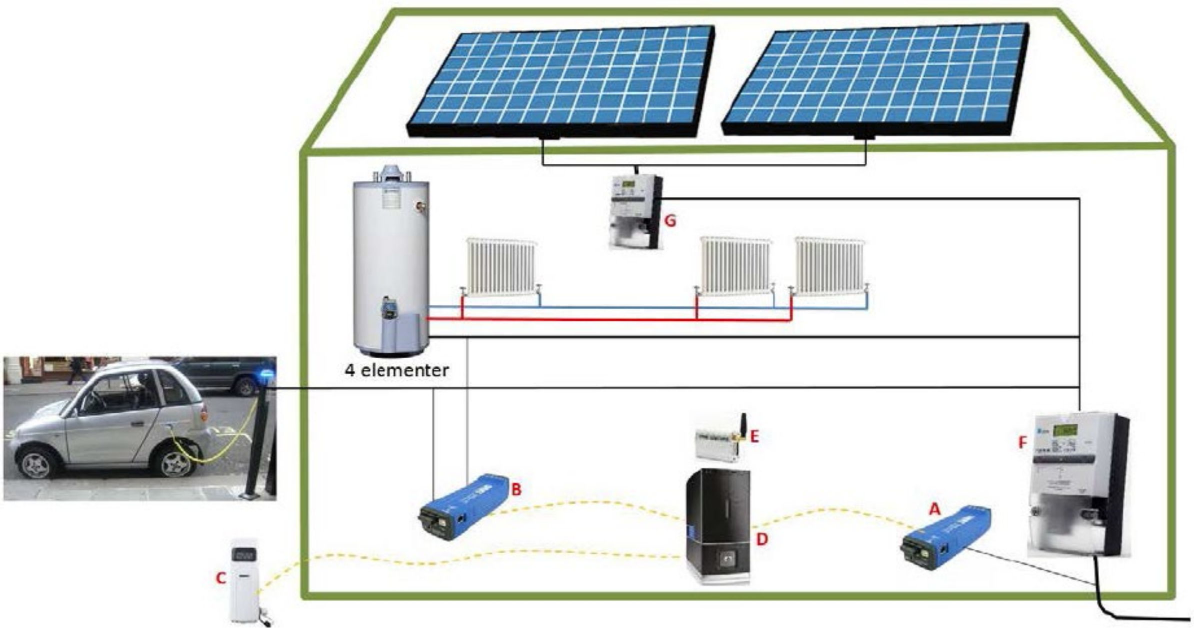

Figure 5.1 Case related installation at the prosumer [4]

The daily PV generation in the period from the 5th of July 2016 until the 31st of August 2017 is presented in Figure 5.2. The production tends to become zero in middle of November for then to increase from the beginning of February. The explanation for this long period without PV production is the low elevation of the PV panel (15^0) combined with low solar altitude/vertical angle (2,9° midwinter).

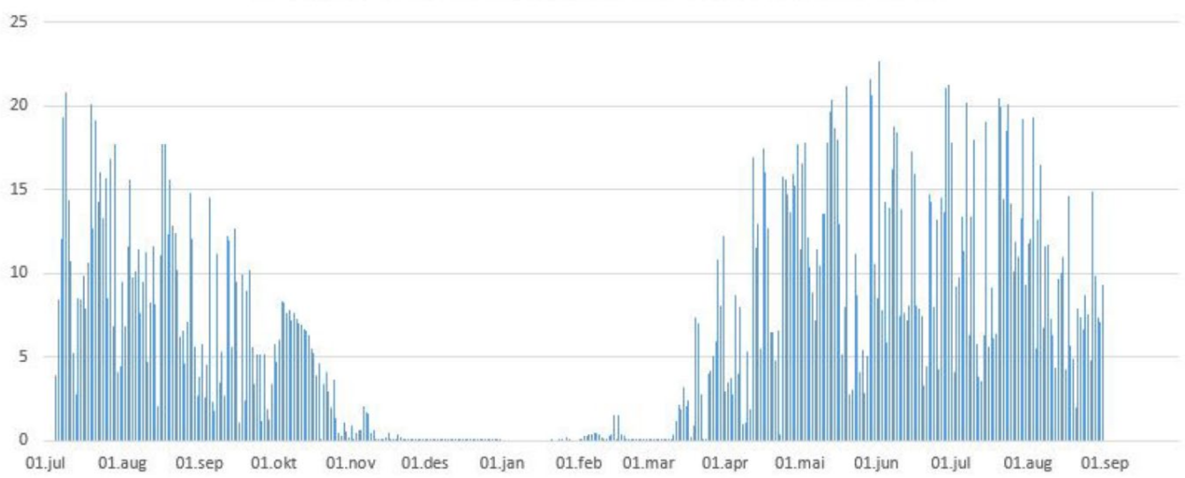

Figure 5.2 PV generation (Period: 5th of July 2016 - 31st of August 2017) [4]

Optimization of PV generation

The orientation of PV panels has huge impact on the potential for electricity generation. This can be calculated based on different irradiance at different orientations of the panel. In Figure 5.3 the leftmost part shows the sun's horizontal (azimuth) angle (V_{Sa}) related to the PV panel, oriented towards South (180°). (With an angle <90 ° or >270° the sun is behind the panel.) In the rightmost part of the figure the sun's vertical angle (V_{Sh}) is presented in relation to the PV panel and the angle (V_{PVh}). If $V_{Sh} > V_{PVh}$ the sun will shine on the panel even if $V_{Sa} < 90°$ or $V_{Sa} > 270°$.

Figure 5.3 shows the relative efficiency factor for a PV panel during three different days with three different elevations. The impact of the elevation is largest in autumn and winter. An increase in elevation can hence increase the production during high load periods in the winter.

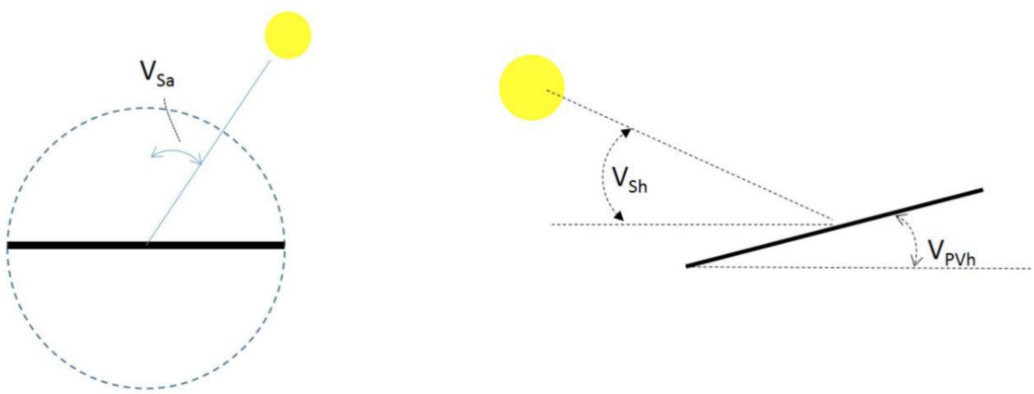

Figure 5.3 The sun's horizontal (azimuth) position related to the solar panel (left) and the hight of the sun related to the solar panel (right) [4]

Figure 5.4 shows the relative efficiency factor from the 1st of June until the 31st of December 2016 with the three different elevations. The value "1" corresponds to optimal irradiance (coincident to the normal vector) and will at most happen once a day. The integral of a curve corresponds to the potential for production that day.

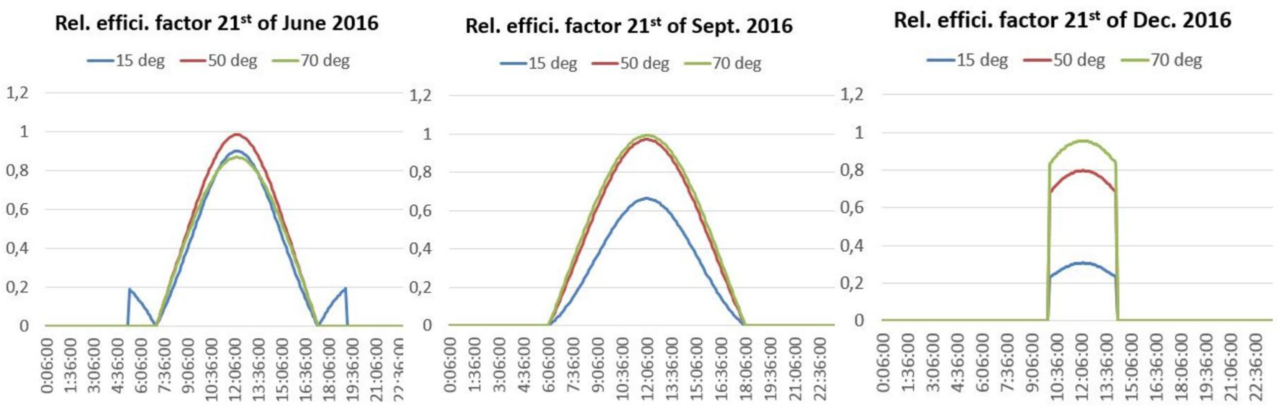

Figure 5.4 Relative efficiency factor for a PV panel on different days, using 15 °, 50° and 70° elevation. Panel oriented towards South [2]

The total relative efficiency factors are presented in Figure 5.5. The figure shows how the production of the PV panel depends upon the elevation, but also how the elevation of the panel can shift the quantity of production to late autumn, when the energy is more needed.

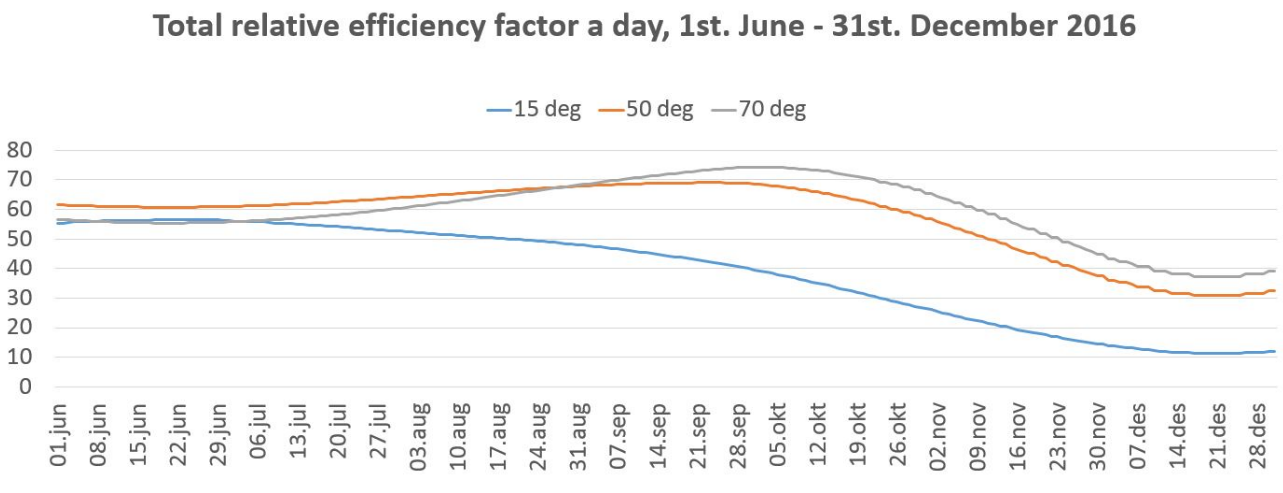

Figure 5.5 Total relative efficiency factor for a PV panel directed towards South [2]

Optimization of thermal storage of energy (demand response)

Based on metered data from the 18th of August 2016, the potential for reducing the electricity fed into the grid has been studied. Energy storage (such as the electric water boiler) can accumulate energy and reduce the amount of electricity fed into the grid. The results from the simulations are presented in Figure 5.6.

The blue curve in the upper part of Figure 5.6 represents the electricity delivered from the grid. This is reduced to zero during daytime when the PV panel (yellow curve) is generating most electricity. The hot water unit is using electricity for heating (i.e. storing energy) during daytime, when the PV generation is at largest, and when the electric vehicle (grey curve) is not charging.

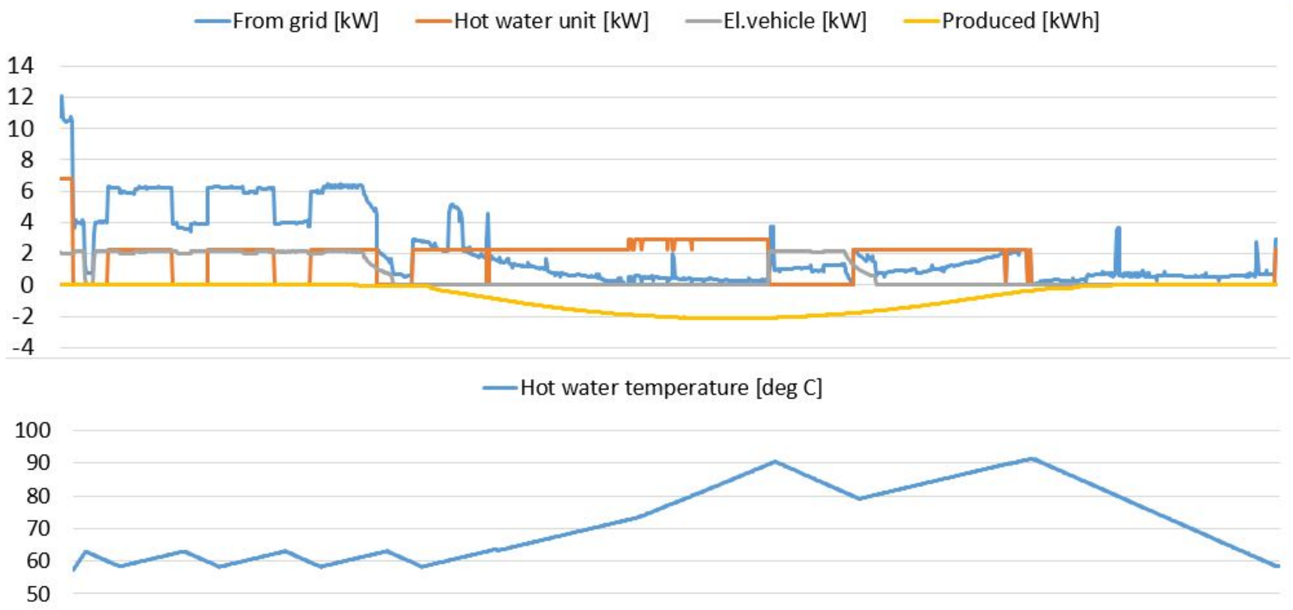

Figure 5.6 Simulated demand data and hot water temperature, based on meter data from 18th August 2016 [2]

This case shows how a prosumer can increase the benefits from a PV system. by reducing the electricity fed into the grid using of the electric boiler as a thermal storage.

6 Aggregated demand and flexibility potential for prosumers

A neighbourhood at Hvaler, with a limited number of PV panels was studied in order to map the aggregated potential for flexibility and the consequences when introducing a capacity-based grid tariff [1]. The residents in this area live in single-family houses built in wood during the 1970-ies Consumption varies between 20.000-40.000 kWh per year. All the households are equipped with smart meters with hourly metering of the electricity consumption, and a small number of them have PV panels installed already.

The houses in this neighbourhood are located close to each other, but their roof have different orientations towards South and West. This will affect the generation potential for the installed roof-mounted PV panels. Meter data of the electricity generation from two different PV panels are presented in Figure 6.1 and Figure 6.2 for two different days (12th of August and 14th of October 2015).

Figure 6.1 shows that for the 12th of August 2015, the generation from the panel oriented towards South is at 1 kW production already at 7:50 in the morning, but the PV panel oriented towards West reaches this generation at 10:30 – at least 2.5 hours later. This is illustrated by the blue point in the upper figure and the solid-drawn vertical line in the bottom figure. In the evening both PV panels generate at least 1 kW at 17:00, but the panel oriented towards West generates 1 kW or more until approx. 19:30. This is illustrated in the figure by rightmost vertical line in the figure. The horizontal red lines show the peak production for each panel. The energy generation during the day is higher for the panel oriented towards South (21,4 kWh), compared to the panel oriented towards West (18,7 kWh) [1].

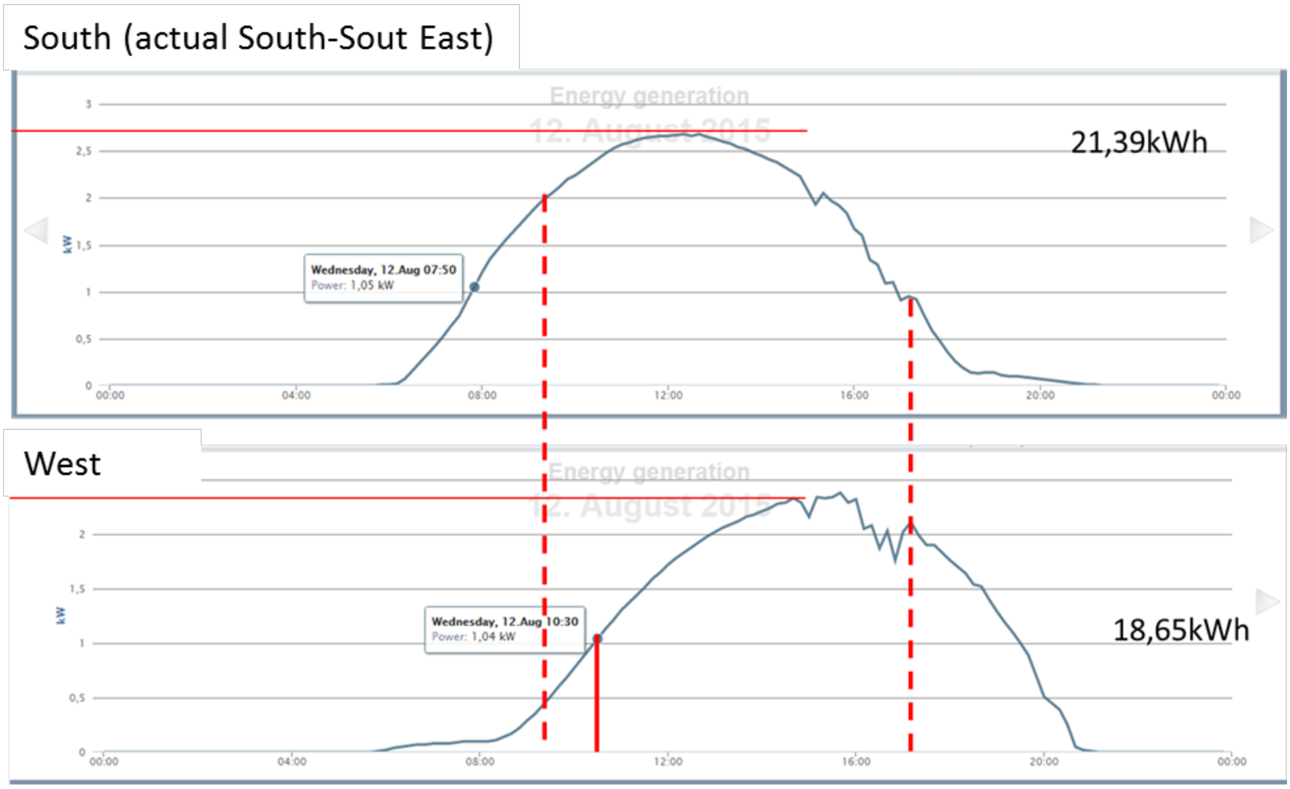

Figure 6.1 Comparison of generation profile of 2 PV panels (each of 3,06 kWp) with different orientation (South and West), registered on 12th of August 2015. The upper panel is oriented towards South (approx. 163 degrees) and the lowest panel is oriented towards West (approx. 200 degrees) [1]

When comparing the generation of electricity at a later day in the autumn (14th October, Figure 6.2) the electricity generated by the panel oriented towards South is approx. twice as high as the panel oriented towards West (13,6 kWh versus 7,6 kWh). Hence the orientation of the panel is crucial for increasing the production in the high-load periods in autumn and winter.

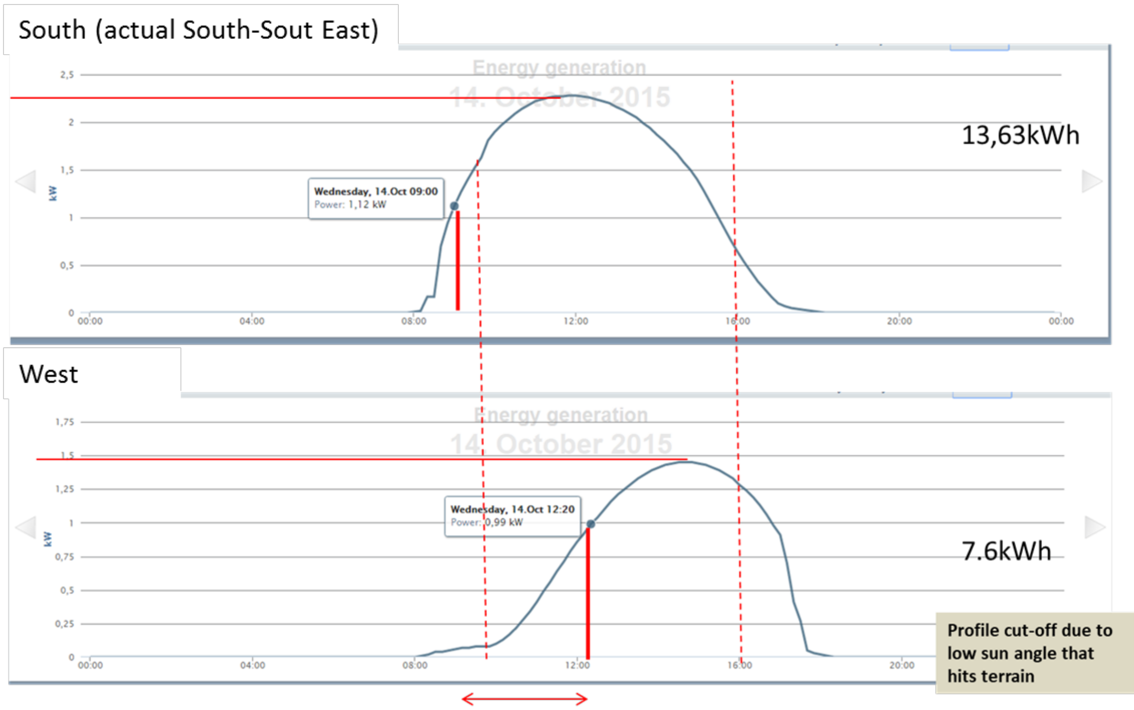

Figure 6.2 Comparison of generation profile of the same PV panels as in Figure 6.1, registered on 14th of October 2015 [1]

Today these households are subject to a capacity-based grid tariff consisting of a fixed fee, an energy specific part and a capacity-based part. The energy part has a unit cost of 0,3 eurocents/kWh. The capacity-based part demands 7,3 € per kW per month for the average of the three highest peaks during the month. For instance, if that average is 4 kW all year the end-user is charged around €350 in total for the use of that capacity. Consequently, self-consumption becomes attractive during peak hours and consequently also cost reduction.

Regular households typically have a morning and afternoon consumption peak. This implies that PV panels, which are, by default, facing South tend to generate most during daytime when consumption is low. This excess electricity is not used by the customer and is fed into the grid.

With the existing capacity-based grid tariff it seemed reasonable to assume that PV installations should, if possible, have more easterly or westerly orientation to absorb the typical consumption peaks. This should level out loads and reduce capacity issues for the DSO and contribute to improved economic benefits for the household. Moreover, it could possibly help to align the interests of the prosumer and the DSO.

An example of the relations between electricity consumption by a household customer (without a PV panel) and the electricity generated by different PV panels with alternative orientations are presented in Figure 6.3. The figure shows the typical "camel back" of the consumption. The figure shows that the PV panel oriented towards East (106 degrees) has a peak generation closer to the peak load in the morning, and the PV panel oriented towards West (200 degrees) has a peak generation closer to the peak load in the evening.

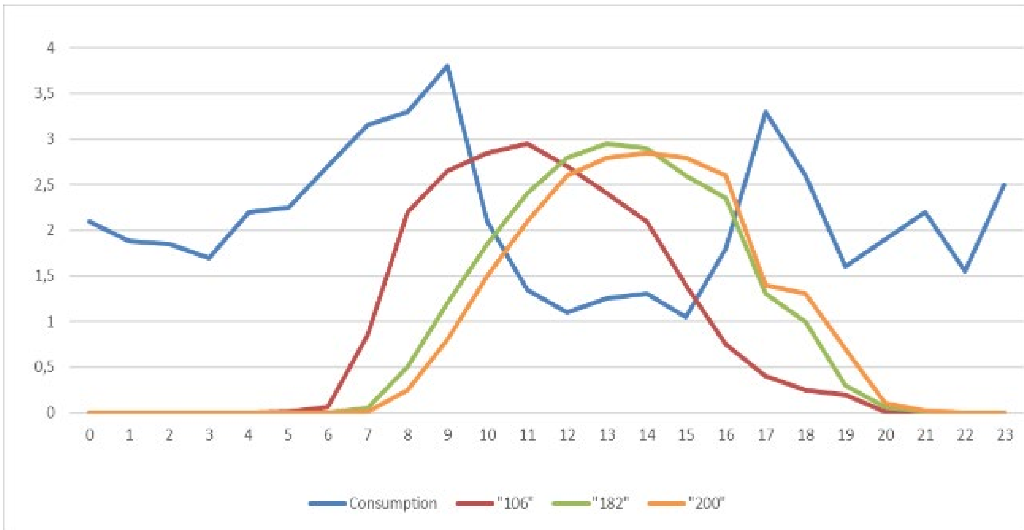

Figure 6.3 Generation profiles for PV panels on 15th of August 2016. Y-axis shows kWh/h. One panel is mounted in an easterly direction (106 degrees). Another is facing south (182 degrees) and a third is facing more West (200 degrees) [2]

A capacity-based grid tariff as specified encourages self-consumption during peak hours, and this self-consumption is profitable for both the prosumer and the DSO. Not all house owners can choose the optimal orientation, but a choice between a larger installation on the main roof and a smaller one on the garage top may be a relevant decision. The garage mounted PV panel facing more East (or West) may provide a better investment case than the south oriented panel on the house itself. To achieve the benefits from this, under a power grid tariff regime, pro-activeness on the behalf of the DSO is important. For example, the DSO can provide advice to house owners and new house-builders on beneficial solutions for both the customer and the DSO. PV panels should be oriented and mounted according to the consumption profile of the household. Pro-activeness implies also that the DSO or someone on its behalf engages contractors and municipal authorities before the design of new neighbourhoods has been concluded [2].

In relation to the demonstration case focusing on the neighbourhood at Hvaler, with several households with PV panels on the roof, a simulation tool was developed to study the potential for PV generation based on local conditions such as weather and geographical locations of different houses, and also data about generation from existing PV panels and hourly data about the electricity consumption for the households in the Hvaler area. With this tool ("sun map") the PV generation, electricity consumption and excess electricity per hour could be estimated for each house in the demonstration case and for the whole Hvaler area [1].

7 Benefits of batteries

The calculations presented in chapter 3 showed that from the base year of 2007 the percentage increase of the yearly consumption and the peak hour consumption have been growing at different rate. Each year the percentage change of yearly consumption from 2007 value is increasing by 1,85% and increasing by 2,89% for peak-hour. (Figure 3.1). These values for increase in consumption have been used for forecasting the future load for a MV/LV substation with 60 households, to study when there will be a need for reinvesting in the MV/LV substation [5].

All households have been modelled as prosumers with a PV panel with an installed capacity of 3,06 kWp. This equals 12 panels of each 255 W power rating. The production from the PV model is presented with the blue curve in Figure 7.1, and the net energy fed into the grid from a prosumer modelled from the average household in chapter 3 is presented with the red curve in the figure.

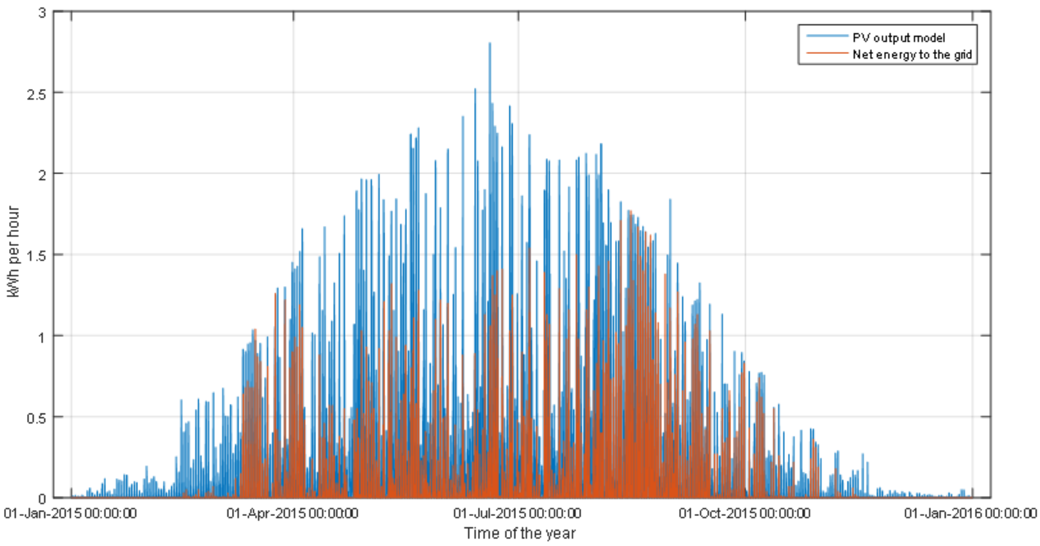

Figure 7.1 Solar PV (3,06 kWp) production for year 2015 [5]

The aggregated load profile at the secondary substation, with 100% prosumers, is presented in Figure 7.2 for year 2025 assuming only the load increases following the trend while the PV system stays the same. In year 2025 the secondary substation will be overloaded up to 120% loading at the peak hour of the year. The customers feed electricity into the grid in 305 hours in a year.

Figure 7.2 shows that for these prosumers, modelled from typical households and a PV panel (3,06 kWp) the winter peak consumption is limited to the rating of the substation transformer and not the electricity fed into the grid during the summer. Nevertheless, reducing the daily peaks by employing storage systems would postpone investment in new infrastructure.

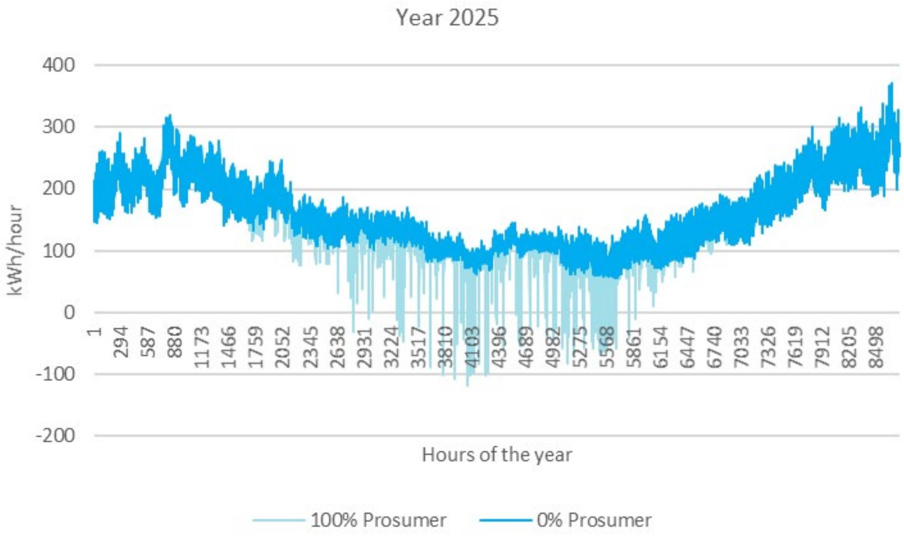

Figure 7.2 Overload 2025 [5]

Further in the analysis it was studied to which degree a battery system could be used to postpone the planned investment in the MV/LV substation (22/0,23 kV 315 kVA). The battery system is planned to be used for storage purposes and increased self-consumption in the summer and for peak shaving in the winter, which eventually leads to levelled loading and reduced peak.

Different electric energy storage systems have a potential for load levelling, which ultimately defer the need for investment in distribution grid [5]. Within the distribution grid, battery storage systems can be placed at different locations and can also be owned by various stakeholders (see Figure 7.3), which will affect their potential for postponement of grid investments.

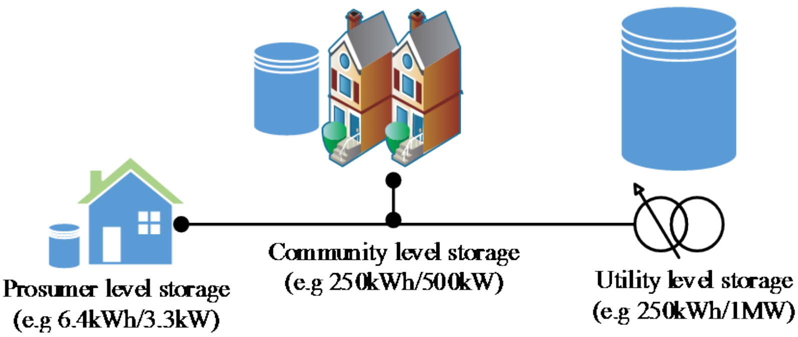

Figure 7.3 Different locations for storage systems [5]

Different locations of storage battery types in Figure 7.3 are:

1. Prosumers owned battery (Size: small scale distributed)
2. Community owned (Size: medium scale)
3. Substation level (Size: large scale)

It has been studied how the alternative locations and sizes of storage elements can be an alternative to grid investment and defer the need for investment in distribution grid.

For this study the battery charging and discharging are optimized for a moving time window of 24 hours, the objective to improve load levelling during winter time and increase self-consumption during summer time. The flow of electricity is presented in Figure 7.4.

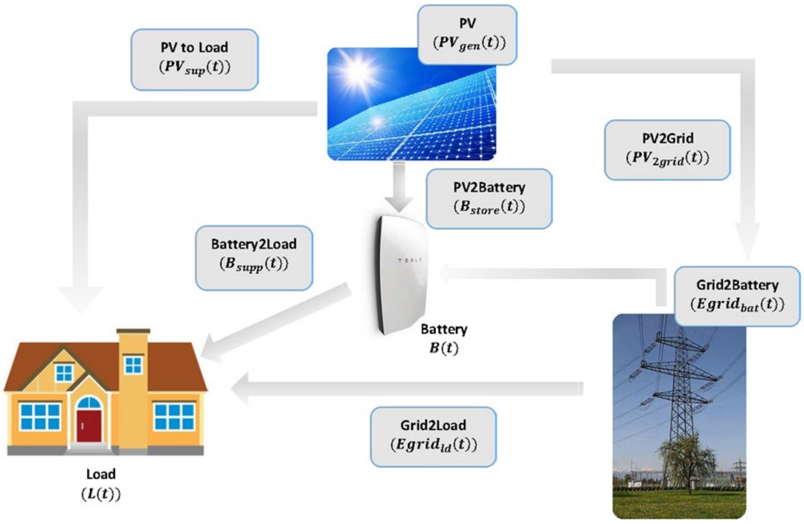

Figure 7.4 Multipurpose utilization of storage batteries inside PV integrated households [5]

The energy flows in the PV-battery system shown in Figure 7.4 are:

- *PV to Battery (PVtoB(t))*
- *PV to Grid (PVsupG(t))*
- *PV to Load (PVtoL(t))*
- *Grid to Battery (GRIDtoB(t))*
- *Grid to Load (GRIDtoL(t))*
- *Battery to Load (BsupL(t))*
- *Total supply from the grid (Egrid(t))*

The results from the optimization of the different solutions for energy storage are presented in Figure 7.5 - Figure 7.7, showing the resulting load on the substation level.

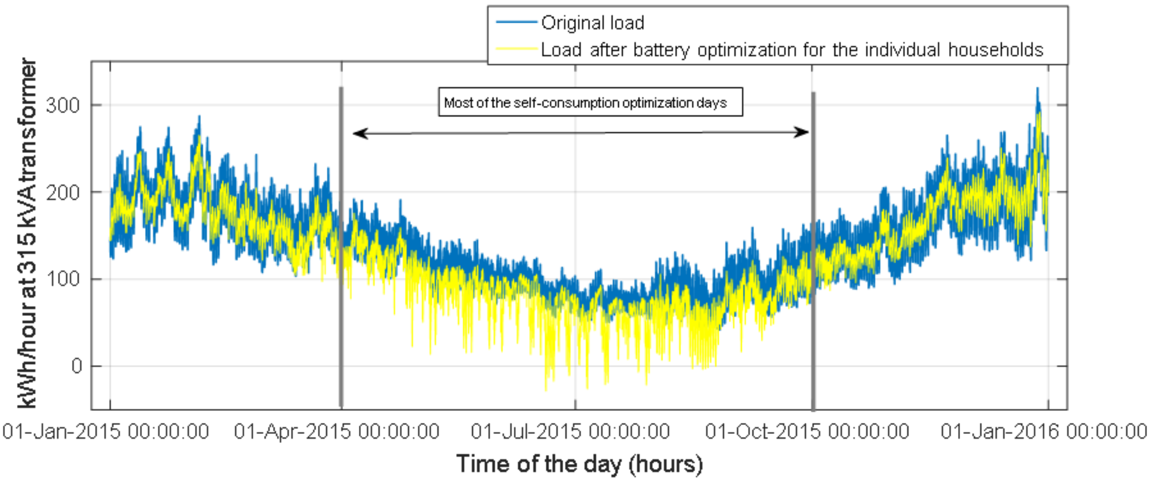

Figure 7.5 Aggregated load profile of 60 households owning 3.06 kW PV system and 6,4 kWh battery system [5]

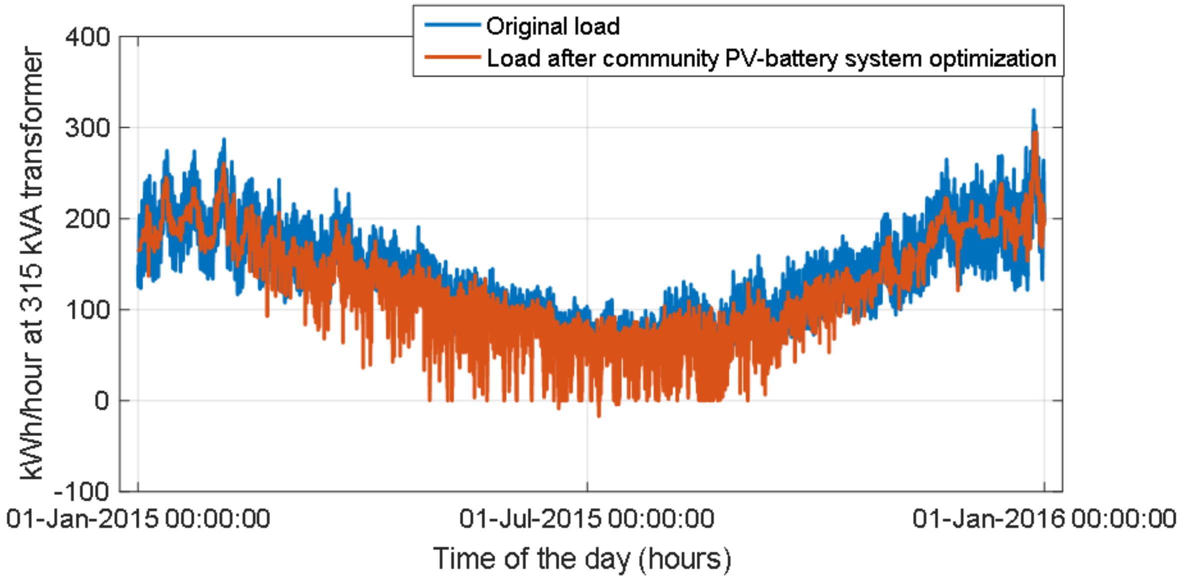

Figure 7.6 Comparison between secondary substation load of 100% consumers and with four community owned 96 kWh/49.5kW battery system with 45,9 kWp PV-system [5]

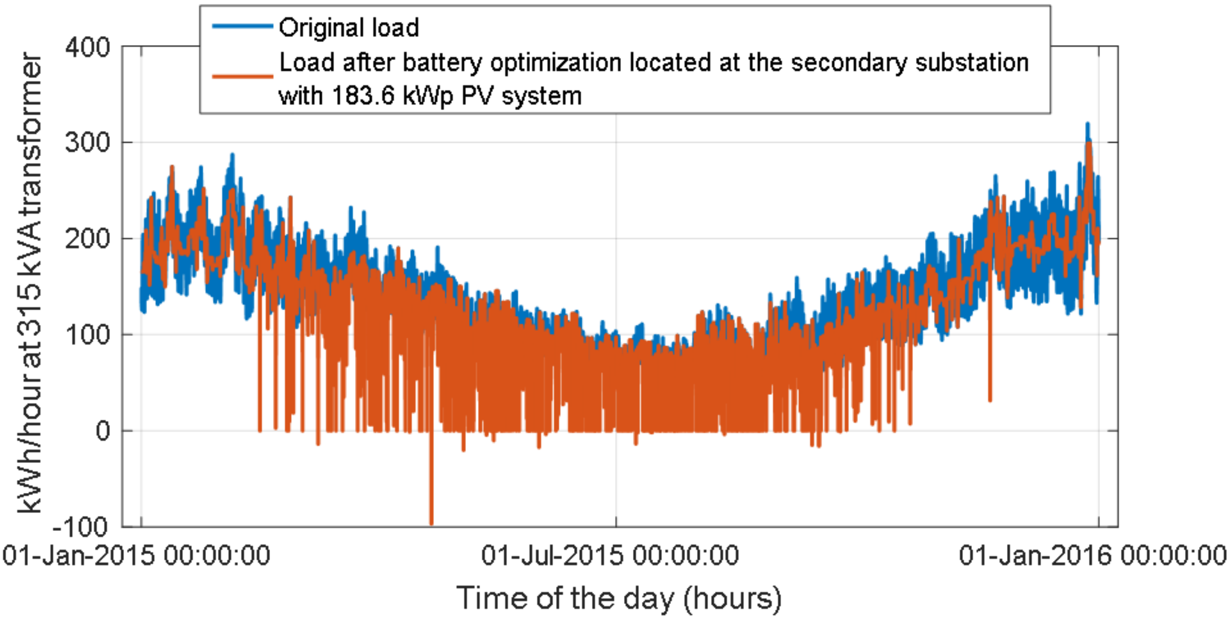

Figure 7.7 Comparison between secondary substation load of 100% consumers and with 384kWh/ 198 kW battery system with 183,6 kWp PV-system [5]

The determination of the size and placement of battery storage system in the distribution grid are dependent upon the purpose the storage system is going to fulfil. As the results in the three cases above demonstrated, distributed energy storage systems at household level might be feasible solutions to reduce the size of the peak demand as seen by the distribution and transmission grid. However, for other services such as increasing reliability against outages of large generating units, centralized storage systems might be more effective.

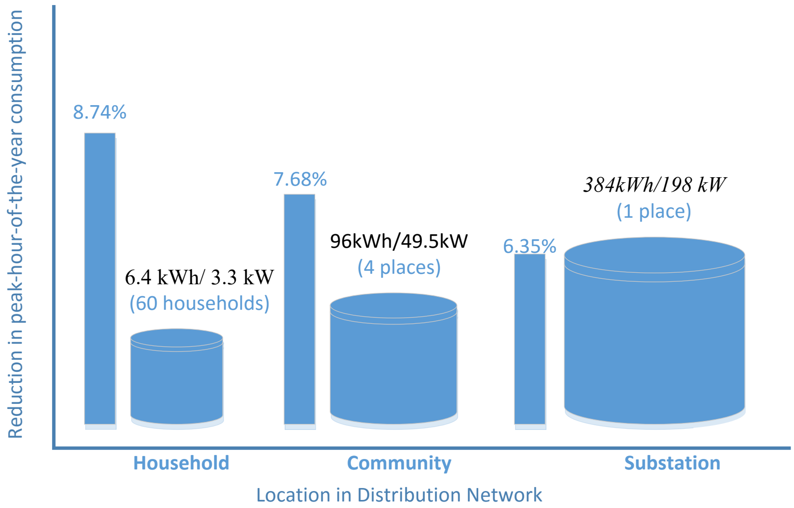

Figure 7.8 Comparison among three placement of battery storage system in distribution network [5]

In this study, focusing on self-consumption and peak-shaving benefits places the profitability of the different alternatives in descending order as: utility scale storage located at locations of MV/LV substation, community level storage systems and finally household level batteries, see Figure 7.8. The profitability of battery storage systems greatly improves when it is used for different services, but in this case the focus has been on storage purposes and increased self-consumption in the summer and for peak shaving in the winter. From utilities perspective the economic viability of the alternatives needs to be assessed on case-by-case basis.

8 Summary

This report has been developed within the research project "Flexibility in the future smart distribution grid – FlexNett" (2015-2018) and summarises the results from the demonstration sites focusing on flexibility prosumer – located both at NTE Nett (Steinkjer) and the municipality of Hvaler.

FlexNett project aimed to contribute to increased flexibility in the future smart distribution grid by demonstration and verification of technical and market-based solutions for flexibility on different grid levels and for different stakeholders.

The trends in peak power and kWh energy growth for Norwegian household customers
Based on data from more than 100 households with their hourly metered electricity (kWh) consumption for nine years (2007-2015) the historical changes in the electricity consumption at residential customers have been analysed and quantified. From base year of 2007 the percentage increase of the yearly consumption and the peak hour consumption is growing at different rate. **Each year the percentage change of yearly consumption from 2007 value is increasing by 1,85% and increasing by 2,89% for peak-hour.** The analysis also shows that most of the peak hours occur in weekdays and not in weekends, and hour 20 is when most of the peak hours occur (23 %). **With a peak load increased more than the energy consumption, it will result in a reduced utilization time of the distribution grid.**

Prosumers in Norway
Until 2013 the Norwegian market for PV panels was mainly characterized by isolated installations (off grid), but the total installed capacity has increased during the last years, and from at the end of 2016 it was installed 26,7 MWp in total. The first regulations for prosumers in Norway was introduced in March 2010, when the Regulator (NVE) approved a simplified system for all the DSOs to accommodate prosumers. An updated and mandatory regulation for prosumers was introduced 1st January 2017. The new regulations states that **the prosumer is responsible for finding a power retailer interesting in buying the electricity fed into the grid.**

Solar irradiance is one of the most important factors when evaluating the potential for PV generation. **The solar irradiations in the South of Norway is on the same level as the irradiation in Sweden, Denmark and Central parts of Germany.** This means that the potential for utilization of the solar energy based on the irradiation in on an equal level as our neighbouring countries.

In Norway there is a seasonal negative correlation between the time for local generation from PV panels (peak generation during the summer) and local consumption (peak load during the winter) during a year. Due to technology development and falling battery costs, batteries at household levels can contribute to increased flexibility on the customer level, and increase the benefit from the PV panel. Such **batteries can be relevant for storage of energy on a daily basis**, and the batteries can be used for **load levelling during the winter, and increased self-consumption during the summer.**

The flexible prosumer
The potential for flexibility in both demand and generation has been evaluated and simulated for a prosumer located in a weak distribution grid in the middle of Norway. The hypothesis is that flexibility on the demand side can reduce the amount of electricity fed into the grid and increase the self-consumption.

Optimization of PV generation
The orientation of PV panels has a huge influence on the potential for electricity generation. This can be calculated based on different irradiance at different orientations of the panel. The simulations for a South

oriented PV panel show that the total relative efficiency factor is increasing with increased elevation, meaning that **the generation from a PV panel increases with a more vertical elevated panel, compared to a horizontal panel.**

Optimization of thermal storage of energy (demand response)

Energy storage (such as the electric boiler) can accumulate energy and reduce the amount of electricity fed into the grid. Simulations (Figure 5.6) show how the hot water unit can use electricity for heating (i.e. storing energy) during daytime, when the PV generation is at largest, and when the electric vehicle is not charging.

Aggregated demand and flexibility potential for prosumers

The houses in the neighbourhood at Hvaler are located close to each other, but their roofs have different orientations towards South and West. This affects the generation potential for the installed roof-mounted PV panels. In August the generation from the panel oriented towards South is at 1 kW already at 7:50 in the morning, but the PV panel oriented towards West reach this generation at 10:30 – at least 2,5 hour later. In the evening both PV panels generate at least 1 kW at 17:00, but the panel oriented towards West generates 1 kW or more until approx. 19:30. The energy generation during the day is higher for the panel oriented towards South (21,4 kWh), compared to the panel oriented towards West (18,7 kWh).

The consumption of electricity for a regular household typically demonstrates a morning and afternoon consumption peak. This implies that PV panels, which often are facing South, tend to generate most during daytime when consumption is low. The excess electricity not used by the customer is fed into the grid. **A PV panel oriented towards East has a peak generation closer to the peak load in the morning, and the PV panel oriented towards West has a peak generation closer to the peak load in the evening.**

The households have a capacity-based grid tariff consisting of a fixed fee, an energy specific part and a capacity-based part, which gives the prosumers an incentive for self-consumption during peak hours.

With the existing capacity-based grid tariff, it seemed reasonable to assume that PV installations should, if possible, have a more easterly or westerly orientation to absorb the usual consumption peaks. This should level out loads and reduce capacity issues for the DSO and contribute to improved economic benefits for the household.

Benefits of batteries

In a case study forecasting the future load for a MV/LV substation with 60 prosumers with a PV panel with an installation capacity of 3,06 kWp, it was estimated that by year 2025 the secondary substation will be overloaded up to 120% loading at the peak hour of the year considering the current load growth rate, and that the customers feed electricity into the grid 305 hours per year. **The simulations show that it is the winter peak consumption that is limited to the rating of the substation transformer, and not the electricity fed into the grid during the summer.**

Further in the case it was studied to which degree battery system could be used to postpone the planned investment in the MV/LV substation with a battery system used for storage purposes and increased self-consumption in the summer and for peak shaving in the winter, which eventually leads to levelled loading and reduced peak.

Different locations of storage battery types are:

1. Prosumers owned battery (Size: small scale distributed)
2. Community owned (Size: medium scale)
3. Substation level (Size: large scale)

It has been studied how the alternative locations and sizes of storage elements can be an alternative to grid investment and defer the need for investment in distribution grid, but the determination of the size and placement of battery storage system in the distribution grid is dependent on the very purpose the storage system is going to be utilized for. **From utilities perspective the economic viability of the alternatives needs to be assessed on case-by-case basis.**

9 References

[1] B. A. Bremdal and K. Tangrand, “Undersøkelse av aggregert last- og fleksibilitetsbidrag fra plusskunder på Hvaler,” Smart Innovation Norway / FlexNet project, 2018.

[2] B. Bremdal, H. Sæle, G. Mathisen and M. Z. Degefa, “"Flexibility offered to the distribution grid from households with photovoltaic panel on their roof" (To be published),” in *Energycon 2018, June 3-7 2018*.

[3] H. Sæle and B. A. Bremdal, “Economic evaluation of the grid tariff for households with solar power installed (paper 0556),” in *CIRED*, Glasgow, 12-15 June 2017, 2017.

[4] G. Mathisen, “FlexNett - Case #3: Last- og fleksibilitetspotensialet for en plusskunde,” SINTEF Digital / FlexNet project, 2017.

[5] H. Sæle and M. Z. Degefa, “AN.17.12.51. The consequence of a battery in the distribution grid. Located at the customer site, in community or close to the MV/LV substation,” SINTEF Energi AS / FlexNet project, 2017.

[6] M. Z. Degefa, H. Sæle, J. A. Foosnæs and E. Thorshaug, “Seasonally variant deployment of electric battery storage systems in active distribution networks,” in *CIRED 2017*, Glasgow, 12-15 June 2017, 2017.

[7] E. Thorshaug, *Oppsummering Flexnett, NTE Nett,* NTE Nett / FlexNett-prosjektet, 2018.

[8] H. Sæle, B. A. Bremdal, I. A. Tøndel, M. Istad, J. A. Foosnæs, P. E. Nordbø, H. Kirkeby, B. A. Høverstad and G. Mathisen, “TR A7536 - Fremtidens fleksible distribusjonsnett. Fleksibel nettdrift, forbrukerfleksibilitet, plusskunder og forretningsmodeller,” SINTEF Energi AS / FlexNett-prosjektet, Trondheim, 2016.

[9] Ø. Holm, “IEA PVPS National Survey Report of PV Power Applications in Norway 2016,” 2017. [Online]. Available: www.iea-pvps.org.

[10] NVE, “Plusskunder,” NVE, 07 12 2017. [Online]. Available: https://www.nve.no/reguleringsmyndigheten-for-energi-rme-marked-og-monopol/nettjenester/nettleie/tariffer-for-produksjon/plusskunder/. [Accessed 16 03 2018].

[11] NVE, “Solenergi,” NVE, 08 05 2017. [Online]. Available: https://www.nve.no/energiforsyning-og-konsesjon/solenergi/. [Accessed 11 06 2015].

[12] N. Feilberg and B. Grinden, “Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe,” REMODECE, 2006.

10 List of abbreviations

NVE	-	Norges Vassdrags- og Energidirektorat (Norwegian Regulator)
DSO	-	Distribution System Operator
PV	-	Photovoltaic
RTU	-	Remote Terminal Unit
SCADA	-	Supervisory Control and Data Acquisition
DMS	-	Distribution Management System
MV	-	Medium voltage
LV	-	Low voltage

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