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Economic evaluation of the grid tariff for households with solar power installed

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Abstract: This study focuses on alternative grid tariffs for household customers with roof top photovoltaic (PV) panels ('prosumers'), and evaluates how alternative grid tariffs might affect the benefit from investing in a roof top PV panel. The study further shows how different orientations of the PV panels can affect the benefits for the prosumers subjected to different grid tariffs (e.g. a power grid tariff), where the idea is that self-consumption will produce the best economic yield. First different alternatives for distribution grid tariffs to household customers and prosumers are presented. Afterwards, the study presents empirical data showing typical consumption and generation for some households with PV panels (located in south-eastern and central Norway).

1 Introduction

Until 2013, the Norwegian market for PV [(i.e. photovoltaic (solar panel)] panels was characterised by isolated installations (island mode), not connected to the power grid [1], but a few grid-connected systems were installed earlier. In Germany, the capacity of installed PV panels was ∼40 GW (2015), and the main share of this was connected to the power grid (In comparison is the installed capacity of large scale hydro power in Norway 25–30 GW.).

In 2014, the total market for PV panels in Norway increased by a factor of 3, and the capacity connected to the power system increased 14 times compared with the year before, representing ∼20% of the total accumulated capacity of installed PV panels in Norway, as illustrated in Fig. 1 [1].

In 2015, totally 2.45 MWp was installed in Norway, which is ∼10% more than the volume installed in 2014 [2].

This paper focuses on prosumers connected to the distribution grid. The content is twofold: first the consequence for a prosumer when changing from an energy grid tariff to a power grid tariff is presented, and then it is shown how the orientation of the PV panels can affect the benefits of different grid tariffs and increase the potential for self-consumption.

The focus on increased self-consumption is a consequence of today's regime in Norway where the prosumers pay a higher price for the electricity delivered via the distribution grid, than what they get pad for the electricity they feed into the grid.

The paper is based on work in the Norwegian research projects 'Flexible resources in the future smart distribution grid' (FlexNett, 2015–2017) and 'SmartTariff' (2014–2018).

2 Background

This section gives an introduction to the Norwegian regulations for prosumers and the status of roll-out of smart meters in Norway.

2.1 Definition of a' prosumer' (Norway)

A prosumer is a customer that both consume electricity and feed electricity into the power grid. In March 2010, the Norwegian Regulator (NVE, i.e. Norwegian Water Resources and Energy Directorate, www.nve.no) approved a general exemption to all the distribution system operators (DSOs) to accept simplified requirements for prosumers [3]. These requirements implied that the local DSO could buy the electricity from the prosumers, and that the grid tariff for the prosumer should not include more than an energy part for the electricity fed into the grid. This was not a mandatory exemption for the DSOs. If the DSO did not want to use this simplification, the customer had to choose a power retailer that wanted to buy the excess power from the prosumer, and deliver power to the prosumers when the local generation could not cover the total load for the customer.

From 1 January 2017, the definition of the prosumers was updated, and is as follows [3]:

A prosumer is a customer with both consumption and generation behind the connection point to the grid, where the electricity fed into the grid should not exceed 100 kW. A prosumer cannot have an installation subject to a concession behind the connection point, or a sale of electricity behind the connection point that require concession.

From 1 January 2017, the arrangements for the prosumers are mandatory, and all prosumers have the right that the grid tariff should not include more than an energy part for the electricity fed into the grid – independent of which DSO they are connected to. The prosumer is responsible to find a power retailer interesting in both buying the excess power from the prosumer and selling power to the prosumer when the self-generation does not cover the consumption.

2.2 Smart meters in Norway

In Norway, smart meters should be installed within 1 January 2019, and then all customers will get (at least) hourly metering of their electricity consumption.

The regulations require that the smart meters should be able to [4]:

- Store the meter data with a registration frequency of a maximum of 60 min. It should be possible to change the registration frequency to a minimum of 15 min.
- Have standardised interfaces that allow for communication with external equipment based on open standards.
- Be able to connect different types of meters (gas, heat, water etc.).
- Secure data storage in case of voltage outages.

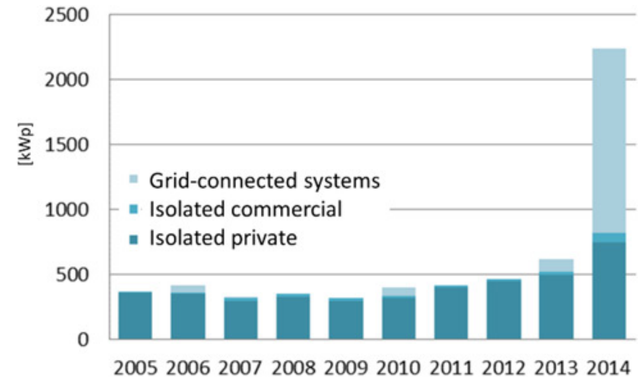

Fig. 1 *Accumulated capacity of installed PV panels in Norway [1] (source: Multiconsult)*

- Disconnect or reduce ('electrical fuse') the total load at the customer, except customers metered with a transformer (large customers).
- Send and receive price information (from energy contracts and network tariffs) and signals for load control and earth fault detection.
- Provide security against misuse of data and unwanted access to load control functionalities.
- Meter both active and reactive power – in both directions (in/out).

The smart meters will be an enabling technology for new grid tariffs for the customers in the distribution grid.

In addition, since all meters should be able to meter both active and reactive power, to and from the customer, the new smart meters are already prepared if a customer wants to invest in a PV panel and become a prosumer.

3 Alternatives for distribution grid tariffs

If a household customer invests in a PV panel and becomes a prosumer, she or he gets the possibility to feed-in excess power to the grid, and buy electricity from the grid. When buying electricity from the grid, the prosumer is treated as a residential customer, with the same grid tariff as a residential customer has with the local DSO, and also an energy contract with a power retailer. For the electricity fed into the grid, the prosumer is paid a price as agreed upon with the power retailer.

In 2015, the SmartTariff project performed a study of the alternative grid tariffs in Norway – for different types of customers [5]. Nearly 80% of the customers in Norway were covered by this study.

The most common grid tariff to residential customers are an energy grid tariff with a fixed part (€/year) and an energy part (Eurocent/kWh), as illustrated in the following equation:

$$\text{Energy tariff} = \text{Fixed part} + \text{Energy part} \tag{1}$$

In 2015, the Norwegian Regulator (NVE) sent out a discussion paper related to the future grid tariffs in the distribution grid, stating that the grid tariffs should contribute to an efficient utilisation of the existing grid, and encourage correct investments in both the grid, consumption, generation and other alternatives to electricity [6]. A summary of the responses on the discussion document was presented in 2016 [7].

Changes in consumption with reduced use of energy, and increased peak load (contributing to reduced utilisation time of the grid) have changed the focus towards capacity-based grid tariff for customers in the distribution grid. Based on the hearing related to the future grid tariff, NVE suggests that the grid tariff should be capacity based and give customers incentives to reduce the peak load, since the peak load is the basis for future grid investments.

In [7], NVE suggested that the energy part in the future grid tariff should only cover the costs related to marginal grid losses.

The new smart meters will be an enabling technology for such grid tariffs. The power grid tariff (capacity based) can for example consist of a fixed part (€/year), energy part covering marginal losses (Eurocent/kWh) and a power part (€/kWh/h), as illustrated in the following equation:

$$\begin{aligned}\text{Power grid tariff} &= \text{Fixed part} + \text{Energy part}\\ &\quad + \text{Power part}\end{aligned} \tag{2}$$

The settlement of the consumption is based on hourly values from the smart meter. The power part can be settled based on the average of the three maximum values during a month, the average of three maximum values in defined peak load periods and so on.

3.1 Case #1: consequences for a prosumer when changing from energy grid tariff to a power grid tariff

The first case study in this paper focuses on a prosumer located in Central Norway. The data used is the hourly values for a typical residential customer (calculated from 100 residential customer) and hourly values for a PV model, based on solar irradiance for the specific area [8]. The calculations are performed for 2015. Fig. 2 shows the load (blue curve) and generation (orange curve) for this prosumer.

With the revenue cap regulation in Norway, the DSO gets the same income from the group of customers, independent of the actual grid tariff. In this study, the calculation with an energy and power grid tariff is therefore based on the assumption that an average household customer should have the same yearly costs with both grid tariffs.

This average household customer has a yearly consumption of 16659 kWh, the modelled PV panel (3.06 kWp) has a yearly generation of 1692 kWh and the prosumer is buying 14967 kWh from the grid per year.

The calculations of grid tariff costs are based on the different alternatives of the grid tariff presented in Table 1, where 1 € = 10 NOK.

With the alternative grid tariffs in Table 1, the household customer get a yearly grid costs of 934.00 € (excl. VAT/taxes and energy costs), both for the energy grid tariff and the power grid tariff.

For the prosumer, the changes in the different tariff elements affect the total yearly costs. With the energy grid tariff the prosumer get a yearly grid costs of 798.68 €. With the power grid tariff the yearly costs decreases when the energy part is increased and the power part is decreased. This means that for alt. 6 the yearly grid costs are 831.76 €, but for alt. 1 this value is 914.10 €. This is illustrated in Fig. 3.

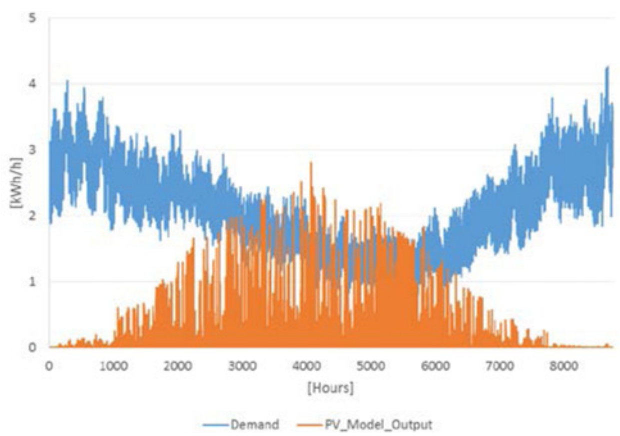

Fig. 2 *Load curve for typical residential customer and modelled PV generation*

Table 1 Alternatives of the grid tariff to household customer and prosumer

Alt.	Energy tariff			Power tariff	
	Fixed part[a]	Energy part[b]	Fixed part	Energy part[b]	Power part[c]
1	200	4	200	0.5	17.98
2	200	4	200	1	15.42
3	200	4	200	1.5	12.85
4	200	4	200	2	10.28
5	200	4	200	2.5	7.71
6	200	4	200	3	5.14
7	200	4	200	3.5	2.57
8	200	4	200	4	0

[a](€/year), [b](Eurocent/kWh), [c](€/kWh/h).

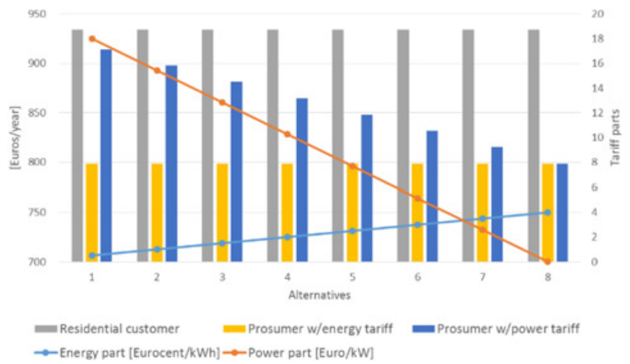

Fig. 3 *Consequences for prosumer when changing different parts in the grid tariff*

Fig. 3 shows that for the energy grid tariff the yearly costs for the household customer and the prosumer are unchanged, but the cost level for the prosumer is lower due to reduced amount of electricity bought from the grid. For the power grid tariff, the yearly grid costs for the household customer are unchanged, but the yearly costs for the prosumer are reduced when the energy part is increased and the power part is decreased. This cost reduction occurs when a larger share of the costs is moved from the power part to the energy part of the grid tariff.

The calculations in this case show that when changing from an energy grid tariff to a power grid tariff, the benefits will be reduced for the prosumer, when keeping the total income to the DSO from households unchanged. This will support the assumption that increased self-consumption for prosumers will be most beneficial, when a power grid tariff is introduced. Self-consumption in peak load periods is most beneficial.

4 Electricity generation from PV panel

The electricity generated from a PV panel can be estimated with the formula presented in the following equation [9]:

$$E = A * r * H * \mathrm{PR} \tag{3}$$

where E is energy (kWh); A is the total solar panel area (m^2); r is the solar panel yield or efficiency (%); H is the annual average solar radiation on tilted panels; PR is the performance ratio, coefficient for losses.

The formula shows that generation from equal solar panels are dependent on the annual solar radiation at a given location, through the H-part of the formula (3). Different locations will have different annual average solar radiation, affected by for example the amount of clouds, shadows, orientation (south/east/west/north) and the angle of the PV panel.

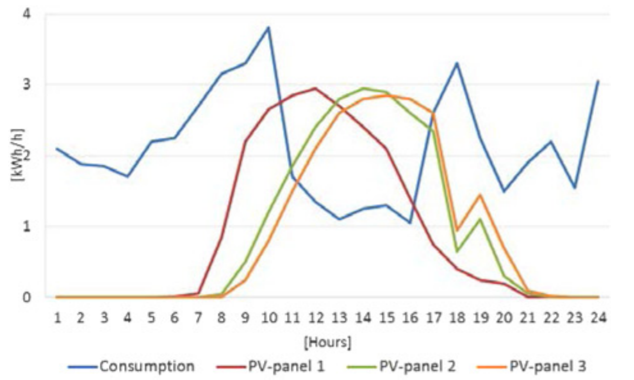

Fig. 4 *Changes in feed-in of electricity, as a consequence of the orientation of the PV panel*

Since the orientation of a PV panel affects both the volume and the time of the generation, the orientation of the PV panel for a prosumer can be optimised to increase the potential for self-consumption.

4.1 Case #2: the prosumers' potential for self-consumption

Hvaler is an area located at 60° north, in south-eastern Norway, where several household customers have installed roof top PV panels. Empirical data shows how generation with equal equipment (installed capacity of 3.1 kWp.) varies with season, geographical location, roof orientation and inclination. The generation profile for 15 August 2016 is compared to a reference consumption profile, and presented in Fig. 4.

Fig. 4 shows how different orientations of PV panel give generation of electricity at different time during a day. The PV panel oriented towards south (panel 1) gets the peak generation earlier than the PV panels oriented towards west (panels 2 and 3).

This suggests that due considerations to a household's particular consumption profile prior to installing a PV panel on the roof should be made. Most people follow a similar daily routine that creates a power peak in the morning and in the early evening as shown in Fig. 4. During the day the energy demand is often much less. A south oriented panel is likely to produce the best annual yield in terms of energy. However, economically it may be less attractive. It will not eliminate or reduce the costliest part of the consumption. Changing consumption behaviour after installation can be hard as routines are often difficult to change. Consequently, an hour-by-hour analysis of the consumption before investments are made is recommended.

Additional generation profiles (south and west orientations) are illustrated in Fig. 5. This figure is for illustration purpose, showing

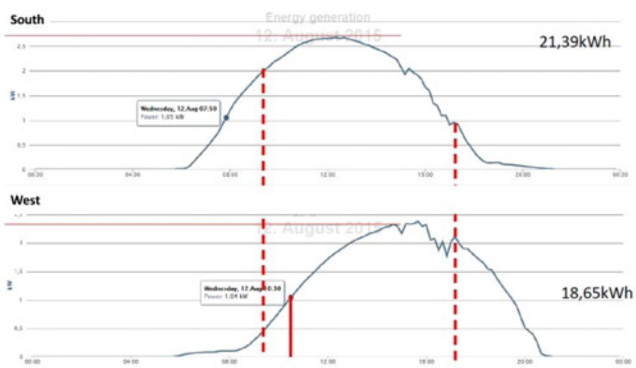

Fig. 5 *Generation by PV panels with different orientations – south and west (12 August 2016)*

how the generation profile differs with different orientations of the PV panels.

The evaluation of the potential for self-consumption, with different orientation of the PV panels, shows that:

- *South*: The production from PV panel covers a large share of the peak load in the morning (Fig. 4). Very little contribution to the peak load in the afternoon.
- *West*: Cover nearly the total peak load in the afternoon during the summer, and ∼50% during the autumn (vegetation and terrain reduced the sun irradiation during the autumn).

5 Summary

This paper focuses on prosumers in the Norwegian distribution grid, and is based on ongoing work within the national research projects ‘FlexNett’ and ‘SmartTariff’.

The paper presents different alternatives for distribution grid tariffs to household customers and prosumers, showing that when changing from an energy grid tariff to a grid power tariff, the benefit will be reduced for the prosumer, when keeping the total income to the DSO from households unchanged. This will support the assumption that increased self-consumption for prosumers will be most beneficial, when a power grid tariff is introduced. Self-consumption in peak load periods are most beneficial.

Further, the paper presented empirical data for typical consumption and production for some households with PV panels. With a south-oriented PV panel the generation will cover the peak load in the morning, while the generation from a west-oriented PV panel mainly will cover the peak load in the afternoon.

Summarised, the prosumers should install their PV panel with an orientation corresponding to their consumption pattern, since the economical benefit will be larger from self-consumption of their generation than from feeding the electricity into the grid.

6 Acknowledgments

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