Household customers' assessment to capacity based distribution grid tariff

Hanne Sæle
Dept. of Energy Systems
SINTEF Energy Research
Trondheim, Norway
Hanne.Saele@sintef.no

***Abstract*— This paper presents the status of regulation related to distribution grid tariffs in Norway, and household customers' assessment of having such a tariff scheme. The paper is presenting results from a Norwegian pilot where two alternative tariff models where tested among household customers for 1 year. The tariff models are a capacity-based tariff with a subscribed power level and a time of use energy tariff with a daily peak price period in the afternoon (16:00-18:00). The results from the pilot are based on analysing hourly smart meter data and three customer surveys. The pilot shows that in general household customers have little focus on their electricity consumption, and especially related to peak load. Some minor changes in consumption can be observed, mainly consumption shifted in advance of peak price hours. The customers expect a cost benefit from changing their consumption (50% want to save 100-199.9 Euros/year).**

***Index Terms*— Demand Response, Distribution grid tariff, Meter reading, Power demand, Power systems**

I. INTRODUCTION

The electricity power consumption is increasing due to more energy efficient appliances (for example instantaneous electric water heaters, large heat pumps and induction cookers). Electrification of transport with the possibility for residential customers to charge their electric vehicle at home will contribute to an additional increase in the electricity consumption. Traditionally, the Distribution System Operators (DSOs) invest in the grid to handle such increasing peak load, but giving customers incentives to change their consumption pattern can be a cost efficient solution. The needs for developing new distribution grid tariffs to residential customers have been discussed for several years [1, 2].

For household customers the peak load occurs in a limited number of hours during a year, which is also an argument for developing incentives for demand response instead of grid investments. The example duration curve presented in Fig. 1 shows that the electricity load for an average household customer exceeds 70% of peak load in only 5% of the hours during a whole year.

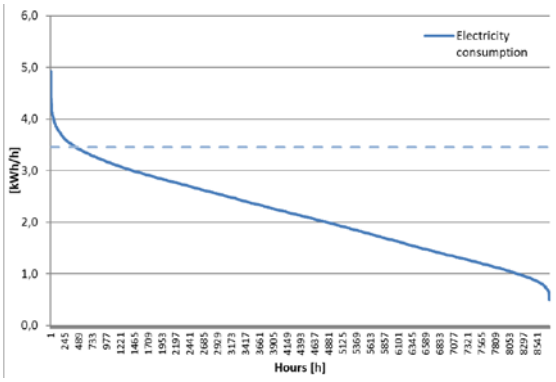

Figure 1. Duration curve representing average electricity consumption of residential customers

The framework related to distribution grid tariffs are under development, and the objective is to introduce capacity-based grid tariffs to all customers, where customers pay according to how their consumption affect the grid, giving customers incentives to reduce their peak load. Several papers are presenting results from calculations of different alternative grid tariffs, but there is also a need for more research related to customers' assessment of this type of grid tariffs [3-9]. The trend towards capacity-based tariffs is also in line with the recommendations from EDSO, proposing that this tariff will give a long-term incentive for efficient utilization of the grid, and give income to the DSOs reflecting each customer's use of the grid [10].

This paper presents framework status in Norway related to distribution grid tariffs, and results from a pilot test with the objective to investigate household customers' assessment of different tariff schemes. The 1-year pilot test was implemented in 2018/2019, demonstrating two different tariff models for household customers located in the western part of Norway. The electricity consumption is analysed based on hourly data. Three surveys were performed, mapping the customers' expectations to the new tariffs, and also their experiences after having these tariff models for one year.

This work was funded by Lyse Elnett (DSO) and the research project "Modelling Flexible Resources in Smart Distribution Grid – ModFlex" (255209/E20).

This is the accepted version of an article published in 2020 17th International Conference on the European Energy Market - EEM
http://dx.doi.org/10.1109/EEM49802.2020.9221937

II. Discussion of tariff framework

In Norway smart meters were fully deployed by 1.1.2019, with hourly metering of the electricity consumption, enabling the possibility for new distribution grid tariffs with hourly settlement of the electricity consumption. Before smart meters were installed, Norwegian household customers had an energy-based grid tariff and periodically self-reading of their electricity meter (typically 4, 6 or 12 times per year).

The discussion about the tariff model has been going on for several years. In 2015 the Regulator (NVE) arranged a hearing process suggesting three different models for a capacity-based grid tariff for household customers [11]. NVE suggested that the grid tariff should have a part reflecting the customers' power consumption. The peak power part should either be based on metered peak load in defined reference hours, based on the customer's size of leading-in fuse or based on a subscribed power level (with a higher price for consumption above this level). Based on this hearing process, NVE recommended among other things that the energy part in the distribution grid tariff should only cover marginal costs for grid losses, the grid tariff should be capacity-based and give the customers incentive to reduce their peak load [12].

In 2017 NVE suggested that customers should get a tariff model based on subscribed power level [13], with the objective to give customers an incentive to reduce their power consumption. The plan was to summarize this hearing process in the summer 2018, but this was postponed due to a lot of comments to the discussion document.

The last hearing document related to tariff model was published in the beginning of 2020 [14], and the time limit for comments was in May 2020. The results of this last hearing process will be available at the end of this year. In the last hearing document, it was specified that the grid tariff should be capacity-based, and the customers should pay according to how their consumption affects the grid. No specific model was required, but three alternative models were presented. This was the same models as suggested in the hearing process in 2015. The main points related to the tariff structure are that the grid tariff should consist of an energy part and a fixed part. Additionally, a power part can be added. The energy part should represent the marginal costs for grid losses and can in addition have a mark-up to give an incentive to reduce consumption in specific peak hours. The fixed part should be differentiated according the customer's need for grid capacity, and the power part can be differentiated according to time. The settlement related to power consumption should be based on the daily peak load.

III. Research framework

The pilot project performed to get more knowledge related to the customers' view on different models for distribution grid tariffs, is described in this section. The focus is on the customers involved (and how they were selected), the tariff models and the structure of the surveys performed.

A. Pilot project

Two alternative distribution grid tariffs were demonstrated among household customers in the period from 17th September 2018 – 1st September 2019.

Two substations were selected, and all customers connected got a new grid tariff. The substations were at two different locations in relation to Stavanger (Western Norway): One substation was in a rural area outside the city (pilot area 1), and the other substation was in the city centre (pilot area 2). The selected substations represent two grid areas with different types of household customers.

The customers could opt-out if the new tariff caused any problems for them. Only one customer opted-out, because this customer had rented out the apartment, and did not live there. Since the customers were selected by the DSO to participate in the pilot, and did not volunteer, it was assumed that during the pilot we would get more variations in the response, and not only those that are especially interested in energy.

The main purpose of the pilot was to test two different distribution grid tariffs that 1) give the customers incentives to reduce their peak load, 2) should be easy to handle for the DSO (especially related to settlement and customer service), and 3) it should be easy to understand for the customers.

42 customers in pilot area 1 (rural) got a capacity-based grid tariff with subscribed power level (described in Section III.B.1) and 143 customers in pilot area 2 (city) got a time of use (ToU) energy tariff (described in Section III.B.2). These tariff schemes were selected because they have been included in the tariff discussion in Norway. The tariff with subscribed power level was deployed to the rural area (area 1), with customers mainly living in single-family houses, because it was assumed that since their electricity consumption was larger than in area 2, the flexibility potential was also larger. The ToU energy tariff was deployed in the city (area 2), where most of the customers lived in apartments.

Smart meter data with hourly resolution of the electricity consumption [kWh/h] of the households were used in the pilot project, and three surveys were performed.

B. Grid tariffs included in the pilot test

The alternative grid tariffs used in the pilot were initially calculated based on smart meter data from 98 reference customers (household customers located in the same area as the pilot customers). Smart meter data for a year was used in these calculations. The data from reference customers were used because at that time there were not enough historical data available for the customers participating in the pilot project.

The calculations of the values of different parts of the tariff models were based on today's energy tariff for household customers. Due to the revenue cap regulations of DSOs, where allowed income is specified by the Regulator, the basis for the calculation was that the total income from the customer group should be the same with the new grid tariff as it was with the initial energy tariff.

The structure and values (excl. VAT) of the initial energy tariff are presented in Eq. (1).

This is the accepted version of an article published in 2020 17th International Conference on the European Energy Market - EEM
http://dx.doi.org/10.1109/EEM49802.2020.9221937

$$T_{Energy,initial} = k_0 + p_{Energy} \cdot \sum_{d=1}^{365} \sum_{t=1}^{24} W_{d,t} = 211.2 + 3.52 \cdot \sum_{d=1}^{365} \sum_{t=1}^{24} W_{d,t} \quad (1)$$

Where:

$T_{Energy, initial}$ = Annual tariff costs for the customer [Euro[1]]
k_0 = Fixed part [Euro/year]
p_{energy} = Energy part [Eurocent/kWh]
$W_{d,t}$ = Hourly electricity consumption [kWh/h]

1) Capacity-based grid tariff with subscribed power level

Customers with this grid tariff subscribed for a specific power level with a given price per kW. The customers pay a higher price if the consumption is larger than the subscribed level. The subscribed level is calculated individually for each customer based on historical data about their consumption. In the pilot the subscription was set at a level where it was estimated that the consumption will be above the subscribed level for 400 hours during a year. This gives the customers incentives to reduce their power consumption. This tariff model can be described as presented in Eq. (2). The values for the different constants in the equation are presented in Table I.

$$T_{Subscribed\ power} = k_0 + k_{subscription\ price} \cdot P_{subscribed} + \sum_{d=1}^{365} \sum_{t=1}^{24} \begin{cases} W_{d,t} > P_{subscribed};\ (W_{d,t} - P_{subscribed}) \cdot p_{peak\ price} \\ W_{d,t} \leq P_{subscribed};\ (W_{d,t}) \cdot p_{price} \end{cases} \quad (2)$$

Where:

$T_{subscribed\ power}$ = Annual tariff costs for the customer [Euro]
k_0 = Fixed part [Euro/year]
$k_{subscription\ price}$ = Subscription price [Eurocent/kWh]
$P_{subscribed}$ = Subscribed power level [kWh/h]
$W_{d,t}$ = Hourly electricity consumption [kWh/h]
$p_{peak\ price}$ = A higher price for the consumption above the subscribed level [Eurocent/kWh]
p_{price} = An hourly price for consumption below the subscribed level [Eurocent/kWh]

TABLE I. SUBSCRIEBED POWER TARIFF – VALUES (EXCL. VAT)

Tariff part	Constant	Value
Fixed part	k_0	211.2 Euro/year.
Subscription price	$k_{subscribed\ level}$	51.5 Euro/kWh/h
Energy price in the summer	p_{price}	2.108 Eurocent/kWh
Energy price in the winter.	p_{price}	2.208 Eurocent/kWh
Energy price for consumption above the subscribed level	$p_{peak\ price}$	0.10 Eurocent/kWh/h

2) Time of use (ToU) energy tariff

In general, the ToU energy tariff has the same structure as the initial energy tariff, except of a time differentiation of the energy part with a higher energy price for predefined periods. The differentiation can according to hours, days, months or seasons. The grid tariff consists of two different energy parts, giving the customers an incentive to reduce their consumption in the predefined high price hours. This tariff model can be described as presented in Eq. (3). The values for the different constants in the equation are presented in Table II.

$$T_{Energy\ ToU} = k_0 + p_{losses} \cdot \sum_{d=1}^{365} \sum_{t=1}^{24} W_{d,t} + \alpha \cdot \sum_{d=1}^{365} \sum_{t=1}^{24} p_{Energy\ peak\ price} \cdot W_{d,t} \quad (3)$$

Where:

$T_{Energy\ ToU}$ = Annual tariff costs for the customer [Euro]
k_0 = Fixed part [Euro/year]
p_{losses} = Energy price for marginal grid losses [Eurocent/kWh]
$W_{d,t}$ = Hourly electricity consumption [kWh/h/h]
α = Factor with value 1 or 0. The value is '1' in predefined peak price hours.
$p_{Energy\ peak\ price}$ = Energy price in predefined peak price hours [Eurocent/kWh]

TABLE II. TOU ENERGY TARIFF - VALUES (EXCL. VAT)

Tariff part	Constant	Value
Fixed part	k_0	211.2 Euro/year.
Energy price the summer	p_{losses}	2.499 Eurocent/kWh
Energy price the winter	p_{losses}	2.599 Eurocent/kWh
Energy price in peak hours[a]	$p_{Energy\ peak\ price}$	0.10 Eurocent/kWh

[a] The peak hours occurred daily from 16-18 (hour 17 and 18)

C. Survey

Three web-based surveys were sent to the customers during the pilot project. In total (from all three surveys) we received 110 answers, with an average number of responses of 37 per survey. The surveys focused on the following topics:

- *Demography*: the customer characteristics in the pilot.
- *Electricity consumption*: ownership of different electrical appliances, if the households are interested in their consumption, and if they have installed control systems.
- *Distribution grid tariff*: the customers' opinion about new tariff models, and their awareness related to this.

IV. RESULTS

The main results from the pilot are presented in this section, focusing on the tariff costs in Section A, and the customers' assessment of the tariff models in Section B.

A. Distribution grid tariff models

1) Capacity-based grid tariff with subscribed power level

Subscribed power level were calculated individually for each household in pilot area 1, based on hourly meter data. This calculation requires at least one year. For customers with data for a limited period, typical consumption (based on meter data from reference customers) were included to extend the data set. When each customer had got meter data for 1 year, a

[1] 1 Euro = 10 Norwegian Kroner (NOK)

This is the accepted version of an article published in 2020 17th International Conference on the European Energy Market - EEM
http://dx.doi.org/10.1109/EEM49802.2020.9221937

correction of subscription level was performed, resulting in reduced level for approx. half of the customers.

The monthly costs (excl. VAT) with the subscribed power tariff, compared with the monthly costs the customers would have had with the initial energy tariff, are presented in Fig. 2. The figure shows both the total monthly costs and the share of the costs related to the different parts in the tariffs.

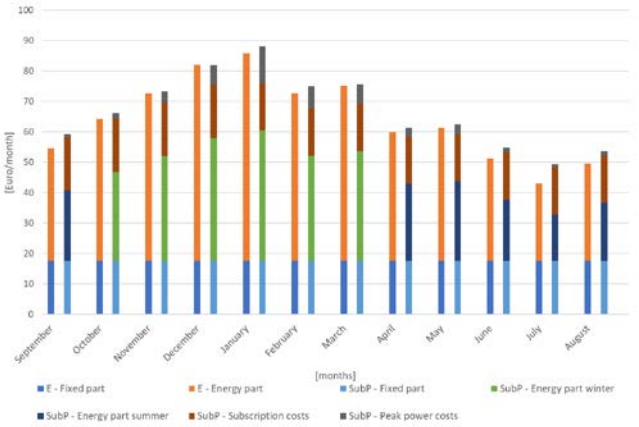

Figure 2 Monthly costs (exl. VAT) for the average customer – initial energy tariff and Subscribed power tariff (September 2018 – September 2019) (E = Energy tariff, SubP = Subscribed power tariff)

With this tariff the yearly costs for the average customer was 801.01 Euros, but yearly costs with the initial energy tariff would have been 772.89 Euros, which means that the costs for the average customer in pilot area 1 increased with 29.12 Euros. The total costs for the customers in pilot area 1 was 104.1% with the subscribed power tariff, compared to the costs with the initial energy tariff.

Due to the revenue cap regulation the income to the DSO is defined by the Regulator, and the total tariff in sum for all customers should therefore be independent of the tariff model. The customers in pilot area 1 should in total pay the same cost with both new and old tariff model, which means that the total costs for the average customer should have been unchanged. The difficulty to calculate the correct subscription level for a future consumption is one reason for this mismatch.

Normalised calculations have been performed related to monthly consumption, peak load and utilization time for an average customer with subscribed power tariff. Further, these calculations are compared with an average customer in the reference group, with the initial energy tariff. The values are quite similar with both tariffs, which indicate no changes in the consumption due to the new tariff model.

When calculating the tariff in advance of the pilot it was estimated that the consumption would be higher than the subscribed power level for 400 hours during a year. Fig. 3 shows the actual number of hours with consumption higher than this level for different subscription levels (2-8 kW). In average the consumption was higher than the subscription level for 388 hours (from 318 to 477 hours, depending on subscription level), but this varies a lot for different customers (represented by the values for maximum and minimum number of hours above the subscription level).

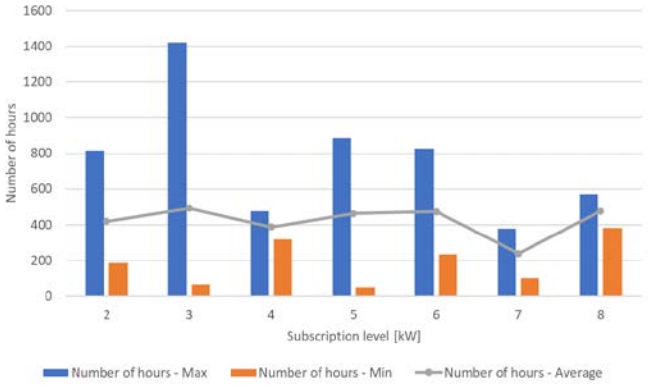

Figure 3 Number of hours with consumption higher than subscribed power during the pilot period

2) Time of use (ToU) energy tariff

The monthly costs (excl. VAT) with ToU energy tariff, compared with the monthly costs the customers would have had with the initial energy tariff, are presented in Fig. 4. The figure shows both the total monthly costs and the share of the costs related to the different parts in the tariffs.

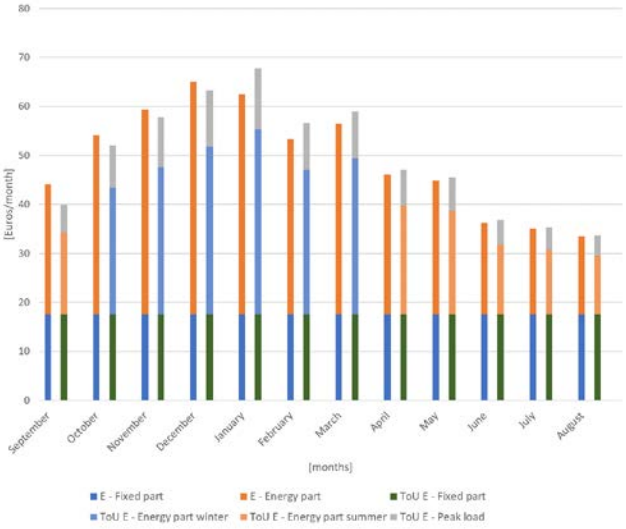

Figure 4 Monthly costs (exl. VAT) for the average customer – initial energy tariff and ToU energy tariff (September 2018 – September 2019) (E = Energy tariff, ToU E = ToU Energy tariff)

With the ToU energy tariff the yearly costs for the average customer was 594.96 Euros, but yearly costs with the initial energy tariff would have been 590.67 Euros. This means that the costs for the average customer in pilot area 2 increased with 4.29 Euros. The total costs for the customers in pilot area 2 was 100.7% with new tariff, compared to the initial energy tariff. Introduction of a new tariff scheme will result in a redistribution of costs between customers. Despite a minor change in costs for the average customer, approximately 3 out of 4 customers got a reduction in their grid costs in this pilot.

Normalised calculations related to monthly consumption, peak load and utilization time are performed for the average customer and compered with a reference customer. These calculations indicate no changes in the consumption due to the tariff model. Calculations focusing on changes in the consumption in the peak price hours (hour 17 and 18), indicate

This is the accepted version of an article published in 2020 17th International Conference on the European Energy Market - EEM
http://dx.doi.org/10.1109/EEM49802.2020.9221937

that consumption has been moved to the hours before peak price hours, and not after.

B. Survey

The results from the three surveys are presented in this section, focusing on the topics: demography, electricity consumption and distribution grid tariff.

1) Demography

In average 7 out of 10 own the building they are living in, with a higher share for pilot area 1 (rural) compared to pilot area 2 (city). The share of single-family houses is larger in the rural area, than in the city. From each survey approx. 50% of the respondents were 30-44 years old, and 25% in the age 45-59 years. 40% of the respondents have education from high school/certificate of apprenticeship, and a similar share has more than 3 years at college/university.

2) Electricity consumption

The customers have access to their smart meter data from a web page, but only 20% confirms that they look into this information. Among those investigating this information, there are approx. 70% with the subscribed power tariff. Approx. 27% of the respondents have an electrical vehicle (EV) and 6% has a plug-in hybrid EV, and most of these customers live in pilot area 1.

According to the survey 21.8% of the respondents have the possibility for automatic control of electrical appliances, and within this group there are 7 out of 10 households with the subscribed power tariff.

3) Distribution grid tariff

In the first survey 57% confirmed that they thought it was possible to affect their grid costs by changing how they used electricity, but in the second and third survey about half of the respondents answered that they had not changed their consumption pattern during the pilot. In the third survey 8% answered that they had made some changes, but only during the first months of the pilot period. This give an indication that it can be difficult to maintain a permanent change only based on changed habits.

Among changes that had been done, most of the respondents answered that they were more aware of not using several appliances at the same time, and that they tried to avoid unnecessary consumption in the morning and afternoon.

Via the surveys the project wanted to map the customers' level for willingness to accept (WTA) a change in how they use electricity. This gives an indication of how customers value their own contribution. The same question was included in all the three surveys, with suggested savings of up to 50 Euros/year, 50.1-99.9 Euros/year, 100-199.9 Euros/year, 200-299.9 Euros/year and more than 300 Euros/year. The results of WTA according to the two alternative tariff models in the pilot are presented in Fig. 5. The figure shows that an increasing share of respondents are positive with increase amount om money saved per year.

The figure shows that a larger share of the respondents with subscribed power tariff are positive at a saving of 50 Euros/year and 200-299.9 Euros/year. For respondents with ToU energy tariff a larger (but limited) share is positive at 50.1-99.9 Euros/year and 100-199.9 Euros/year. If calculating value for WTA independent of type of tariff model, the trend is quite similar as in Fig. 5.

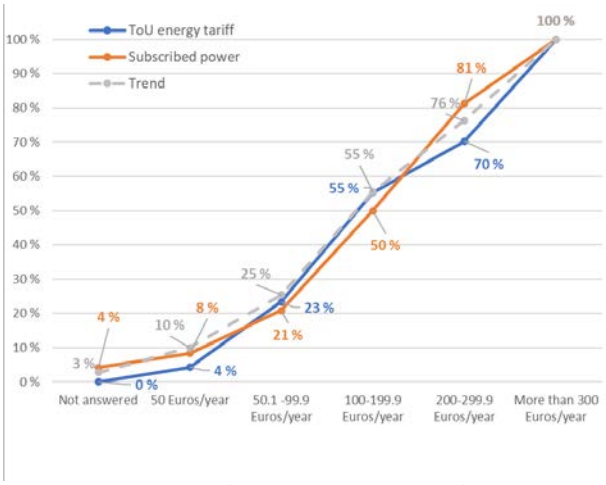

Figure 5 What amount of savings do you expect before you will change how you use electricity? (Sorted according to tariff model)

V. Discussion and Conclusions

This paper presents results from a Norwegian pilot project demonstrating two different distribution grid tariff models among household customers. The customers participating were selected by the DSO and did not volunteer for the pilot. It was possible for the customers to opt-out of the pilot. With this way of recruiting people, we get larger variations about the participants, and not only those most interesting in energy.

The subscribed power level tariff gives incentive to reduce the peak load consumption. The level was calculated for each customer estimating that the consumption should be above this level for 400 hours during the year. The results showed that in average the consumption was above the subscribed level for 388 hours.

The ToU energy tariff had a daily predefined peak price period from 16:00-18:00, giving the customers incentive to reduce the consumption in these hours. A minor change in the consumption was calculated, indicating a shift in consumption to the hours before peak price hours. It was mainly households living in apartments that got this tariff, with limited potential for changing their consumption.

The pilot shows that in general household customers have little focus on their electricity consumption, and especially related to peak load. Some minor changes in consumption can be observed, mainly with ToU energy tariff, where customers shifted consumption in advance of the peak price hours. The engagement related to consumption change was reduced during the pilot period. The customers expect a cost benefit from changing their consumption (approx. 50% want to save 100-199.9 Euros/year).

VI. Acknowledgement

The author would like to thank Lyse Elnett (DSO) for supporting the work and the data acquisition.

This is the accepted version of an article published in 2020 17th International Conference on the European Energy Market - EEM
http://dx.doi.org/10.1109/EEM49802.2020.9221937

VII. REFERENCES

[1] EURELECTRIC, " European Commission's proposal for a Regulation on the internal market for electricity ", April 2017

[2] ENA, "TOWARDS A NATIONAL APPROACH TO ELECTRICITY NETWORK TARIFF REFORM", Position paper, December 2014

[3] K. Lummi, A. Rautiainen, P. Järventausta, et.a., "Power-based distribution network tariff of small customers in different operational environments - case study of two networks", 2017 IEEE Innovative Smart Grid Technologies - Asia (ISGT-Asia), DOI: 10.1109/ISGT-Asia.2017.8378401

[4] H. Sæle, "Consequences for residential customers when changing from energy based to capacity based tariff structure in the distribution grid", 2017 IEEE Manchester PowerTech, Manchester UK, 18-22 June 2017, DOI: 10.1109/PTC.2017.7981177

[5] T. Soares, P. Faria, Z. Vale, H. Morais, "Definition of distribution network tariffs considering distribution generation and demand response", 2014 IEEE PES T&D Conference and Exposition, 14-17 April 2014, Chicago, IL, USA, DOI: 10.1109/TDC.2014.6863380

[6] S. Gansemer; U. Grossmann, "Analysis on variable electricity pricing models and the influence on load curves of household customers", Proceedings of the 6th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems, 15-17 Sept. 2011, Prague, Czech Republic, DOI: 10.1109/IDAACS.2011.6072823

[7] A. M. Ihbal; H. S. Rajamani; R.a. Abd-Alhameed; M. K Jalboub, "The influence of different tariffs schemes on electricity consumption for the UK domestic buildings", Eighth International Multi-Conference on Systems, Signals & Devices, 22-25 March 2011, Sousse, Tunisia, DOI: 10.1109/SSD.2011.5993566

[8] N. H. Mallick, M. H. Maruf, "Analysis of power demand response for smart home in Germany from end-user's perspective based on high resolution power demand model", 2016 3rd International Conference on Electrical Engineering and Information Communication Technology (ICEEICT), 22-24 Sept. 2016, Dhaka, Bangladesh, DOI: 10.1109/CEEICT.2016.7873071

[9] D. Steen, L. A. Tuan, O. Carlson, "Effects of Network Tariffs on Residential Distribution Systems and Price-Responsive Customers Under Hourly Electricity Pricing", IEEE Transactions on Smart Grid (Volume: 7 , Issue: 2 , March 2016), DOI: 10.1109/TSG.2015.2464789

[10] EDSO for smart grids, "Adapting distribution network tariffs to a decentralised energy future", September 2015

[11] T. M. Andresen and V. A. Mook, "Høringer om tariffer for uttak i distribusjonsnettet," NVE, 2015.

[12] V. A. Mook, "Oppsummeringsrapport: Høring om tariffer for uttak i distribusjonsnettet," NVE, 2016.

[13] H. Hansen, T. Jonassen, K. Løchen and V. Mook, "Forslag til endring i forskrift om kontroll av nettvirksomhetne. Utforming av uttakstariffer i distribusjonsnettet," NVE, 2017.

[14] A. B. Eriksen, H. Hansen, J. Hole, T. Jonassen, V. Mook, S. Steinnes and L. Varden, "RME Høringsdokument nr. 01/2020. Endringer i nettleiestrukturen," NVE, 2020.

This is the accepted version of an article published in 2020 17th International Conference on the European Energy Market - EEM
http://dx.doi.org/10.1109/EEM49802.2020.9221937