Electric vehicles in Norway and the potential for demand response

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***Abstract*—Norway is currently the largest market in the world for electric vehicles compared to the total number of vehicles sold, and there is also a political goal in Norway to stop the sale of new conventional cars[1] by 2025. Changing to non-emission transport can result in approx. 1.5 mill. private electric vehicles in 2030, resulting in an energy need of 4 TWh, which represents an increase of 3% of the Norwegian electricity consumption. The increased number of electric vehicles will not be an energy problem, but it can be a capacity related problem in the distribution grid if all households are charging at the same time – in addition to their usual consumption of electricity. This paper presents results from a research project evaluating the consequences of the increasing share of electric vehicles and the potential for demand response and flexibility in charging. Results are based on a survey performed among households with electric vehicles and meter data of the energy consumption from charging of a selection of the most common electrical vehicles in Norway.**

Keywords— Electric vehicles, smart grid, demand response, rebound effect

I. INTRODUCTION

The main objective of this paper is to present the status and political targets for electric vehicles (EVs) in Norway and evaluate the potential for demand response among EVs. The first part of the paper gives an overview of the status of EVs in Norway. Followed by a description of how people are charging their EV based on both results from a survey describing how and when people charge their EV and measurements of the charging of different types of EVs. Evaluation of the potential for demand response is also discussed in the paper.

This section introduces today's status of EVs and political targets in Norway, definition of demand response and the ModFlex-research project.

A. Electrical vehicles in Norway

Norway is currently the largest market in the world for EVs compared to the total number of vehicles sold, and this high sale is due to good incentives. The number of electrical vehicles in Norway is increasing, and by the end of 2017 it was more than 142.000 EVs in total in Norway [1], including both private cars and vans. According to [2] electric vehicles represents approximately 5,6% of a total of 2.5 mill. private cars.

The development of private EVs in Norway, and their market share is presented in Fig. 1.

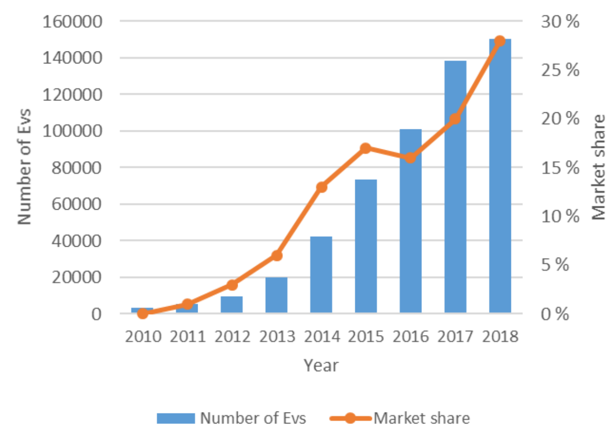

Fig. 1. Status of Electric Vehicles in Norway (per 31 March 2018) (Source: elbil.no [2])

A political goal in Norway is to stop the sale of new fuelling cars by 2025. This means that the number of EVs will continue to increase, but there is a question related to if and how this will this affect the distribution grid.

Changing from fossil to non-emission transport can result in approx. 1.5 mill. private EVs in 2030, resulting in an energy consumption of 4 TWh [3]. This results in a 3% increase in the Norwegian electricity consumption.

An overview of the 10 most popular types of electric vehicles in Norway, per 31 March 2018, is presented in Fig. 2 [2]. Nissan Leaf is the type with the largest market share, with approx. 38.000 cars, with Volkswagen e-Golf as number two with approx. 25.000 cars. In total there is approx. 23.400 Teslas in Norway, split on both Model S and X. The other types of EVs among the top 10 in Norway are BMW i3, Kia Soul Electric, Volkswagen e-Up, Renault ZOE, Mercedes-Benz B250E and Hyundai IONIQ.

[1] Conventional cars use gasoline or diesel to power the engine,

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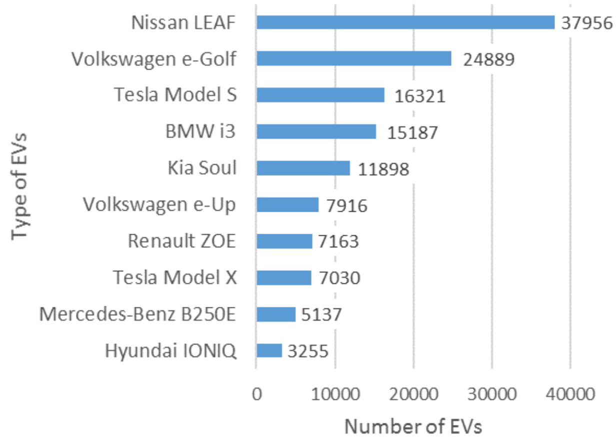

Fig. 2. Top 10 EVs in Norway per 31 March 2018 (Source: elbil.no [2])

Mitsubishi i-Miev was one of the EVs that really speeded up the EV market in Norway. This car was introduced in 2010, and in 2011 this EV represented 52% of the total number (1.040) of EVs sold that year [4]. Peugeot and Citröen released equal models, in cooperation with Mitsubishi – the so-called "triplets". The "triplets" are Mitsubishi i-Miev, Citroën C-Zero and Peugeot Ion, and summed up these cars would be on the top 10 list in Fig. 2.

B. *Demand Response*

With Demand Response (DR) it is possible for consumers to play a role in the operation of the electric grid, by reducing peak load or shifting their use of electricity based on incentives reflecting the situation of the power system.

According to FERC [5], demand response can be defined as: *Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.*

Different alternatives of DR relevant for EVs can be:

- Load shifting (shifting the time of use of an appliance)
- Peak clipping (reduced peak load)
- Valley filling (introducing new load in off peak periods, for example during the night).

C. *Research project "ModFlex"*

This paper presents results from the research project "Modelling flexible resources in smart distribution grid - ModFlex" (2016-2020). The objective of the project is to develop dynamic models representing the consumption and production profiles for different flexible resources in the smart distribution grid, and address how such resources can be utilized to increase the flexibility in the grid – without introducing new peak load hours due to the rebound effect.

The project is focusing on the potential for flexibility at a Norwegian household level, focusing on flexible resources such as EVs, electric water heaters and shiftable loads (washing machines, clothes dryers, dishwashers etc.). This paper presents results from the work focusing on EVs at Norwegian households.

II. Method of Approach

The results presented in this paper are based on data selected from a survey performed in cooperation with Elbilforeningen (Section II.A) and measurements of the charging of different types of EVs with 1-minute resolutions (Section II.B).

A. *Survey*

In both spring 2017 and 2018 a survey was performed among the association for owner of EVs (Elbilforeningen), asking about when and why they purchased an EV, when they normally charge the EV at home, and the potential for flexibility in the time of charging etc.

The surveys were web-based, and in total 12665 persons answered the survey in 2017 and 9520 in 2018. The results from the surveys have been analysed with use of SPSS and Excel tool.

B. *Metering data*

In relation to the ModFlex project the charging of the most common types of EVs in Norway (Fig. 2) have been performed with 1-minute resolution of the data. The measurement method has focused on the electricity used during one charging cycle of the EV, and not on the time of the day/day of the week when charging has been performed. The time of charging is from the survey results.

The measurements have been performed for the following types of EVs: Think, Peugeot 106 Electrique, Tesla X, Mitsubishi iMiev, BMW i3, Nissan Leaf, Volkswagen eGolf and Kia Soul Electric.

III. Results

This part presents selected results from the survey and the charging profiles for different EVs. The objective is to first present when and how households normally charge their EV and the potential for demand response due to changing the time of charging, and then present the volume available for shifting based on meter data from actual charging of several types of EVs.

A. *Survey – Flexibility in time of charging*

The results from the surveys are presented in this section. Elbilforeningen perform yearly such a survey among their members, and the ModFlex project was able to cooperate and add some additional questions in the surveys. The objective of the questions added by the ModFlex project was to map the status of charging (time and connection) and evaluate the potential for flexibility in the time of charging. This give an indicative result related to the potential for demand response related to charging of EVs and will be discussed in the paper.

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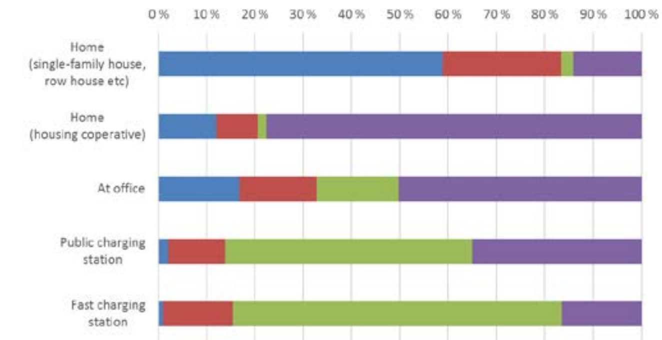
The customers were asked how often they charge their EV at different locations, and the results are presented in Fig. 3. The figure shows that normally the households charge their EV at home daily in 59% in single-family houses and 12% of housing cooperatives. Public charging stations and fast charging stations are used monthly or less, 51% and 68% respectively. A fraction of the respondents use charging stations on a daily basis.



	Fast charging station	Public charging station	At office	Home (housing coperative)	Home (single-family house, row house etc)
Daily	1 %	2 %	17 %	12 %	59 %
Weekly	14 %	12 %	16 %	9 %	25 %
Monthly or less often	68 %	51 %	17 %	2 %	3 %
Never	16 %	35 %	50 %	78 %	14 %

Fig. 3. How often do you charge at different locations? (2018)

Since ModFlex project is focusing on flexible resources in the distribution grid, the main focus is on how the households normally charge their EVs at home. The results from this question are presented in Fig. 4. The figure shows that 49,5% of the users charge their EV at home from a normal socket (typically 10 A). Approx. 43% of the users have a charging station at home, either 16 A (24,1%) or 32 A (18,9%).

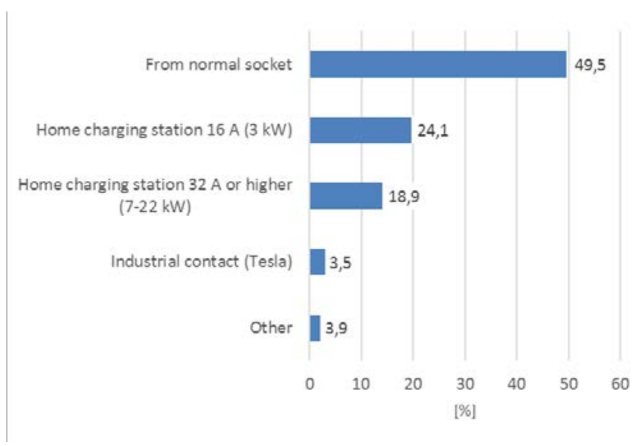


Fig. 4. How do you charge your EV at home? (2018)

In the survey performed in 2017 the customers were asked about which hours during the day they normally charge their EV at home. The results are presented in Fig. 5. The figure shows that most of the charging occurs in the afternoon and during the night. Very few respondents answered that they charge their EV at home during daytime (hour 11-16).

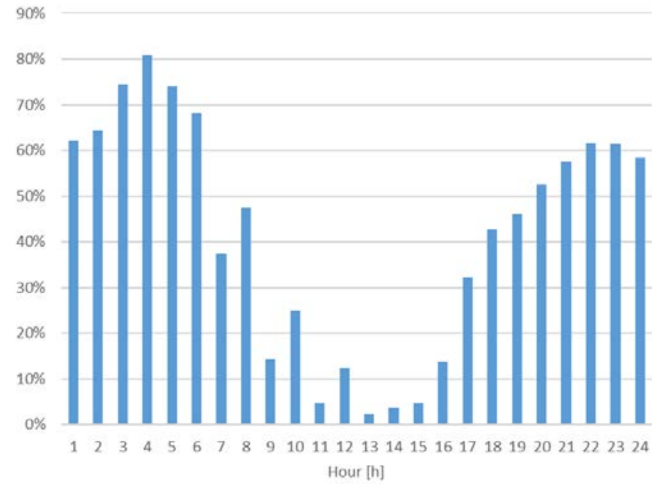


Fig. 5. Time of day when the EV is charged at home, in % of respondents in the survey (2017)

To map the potential for flexibility in time of charging, the respondents were asked about their willingness to postpone the time of charging from day/afternoon to night (hour 21-05). The respondents further supported the idea that if this shift in charging time has no negative consequences for the user, 90% are willing to postpone the time of charging, but if this reduces the driving distance the next day to 80%, the share of positive respondents is reduced to 56,5%. Related to Fig. 5, this would imply a reduction of EV owners charging in the afternoon, and an increased share charging during night time.

According to the survey (2018), 38,2% of the respondents are positive to this change in time of charging if they save 200 €/year. A lesser amount (26,4%) of the respondents are positive if the savings are reduced to 50 €/year.

B. *Charging profile for different types of EVs*

The electricity used for charging has been metered with a 1-minute resolution, for different types of EVs. The meter data show that the charging profile for new EVs are smoother than the charging profiles for the first EVs in the market (rapid on/off). Based on the metering of different charging profiles, they have been divided into three groups: Maintenance charge mode, Step-down and Instant on/off.

1) *Maintenance charge mode*

This group consists of the EVs: Think and Peugeot 106 Electrique.

Think was produced from 1999-2011 [6], and had initially a Nickel-Cadmium battery up until 2007 where it was made available either with a Lithium-ion or a molten salt battery [7]. The charging profile is presented in Fig. 6.

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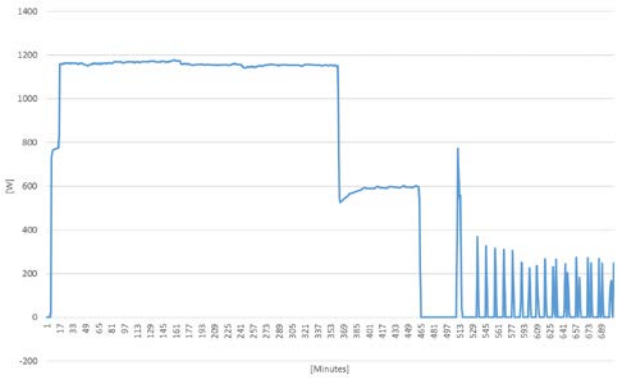

Fig. 6. Charging profile for Think

Peugeot 106 Electrique (1995-2003) were early out in the market with a Nickel-Cadmium battery technology [8], with a battery capacity of 14 kWh [9]. The charging profile is similar with the charging profile of Think, with charging spikes that appear when the battery is going through either a cooling period or a maintenance charging period, due the power electronics found in the older chargers.

2) Step down

This group consists of the EVs: Tesla X, Mitsubishi iMiev, BMW i3 and Nissan Leaf.

Tesla X was introduced in Norway in 2016. This model is an upgraded version of Model S [10]. The standard charging capacity is 16,5 kW for a 100 kWh battery.

Mitsubishi iMiev was introduced in Norway at the end of 2010, and is part of the so called 'triplets' (Citroen, Peugeot, Mitsubishi). The capacity of the battery is 16 kWh, while Citroen and Peugeot have a battery capacity of 14,4 kWh [11]. The standard charging capacity is approximately 3 kW.

A metered charging profile (SOC[2] 10%-100%) for iMiev is presented in Fig. 7. The figure shows constant charging until the start of the stepping down – after 75% of the charging time. There is a break of a duration of 6 minutes occurring after 189 minutes, approximately half way into the charging time, probably due to cooling of the battery pack.

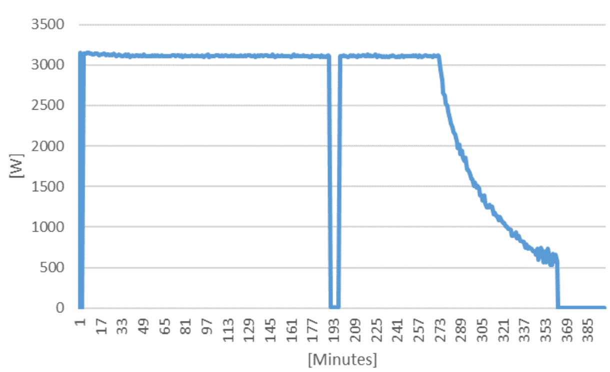

Fig. 7. Charging profile for iMiev

[2] SOC = State of Charge

Nissan Leaf was introduced in Norway in 2011 and is the most sold EV in Norway (Fig. 2). Available battery capacity is 21,6 and 27,2 kWh [12], and standard charging capacity is 3,3 kW. The charging profile of Nissan Leaf is presented in Fig. 8. The figure shows a gradual reduction in electricity used for charging. There is a peak occurring in the later stage of the step-down curve, due to the start of the block/interior heater (when the EV is still connected to the socket).

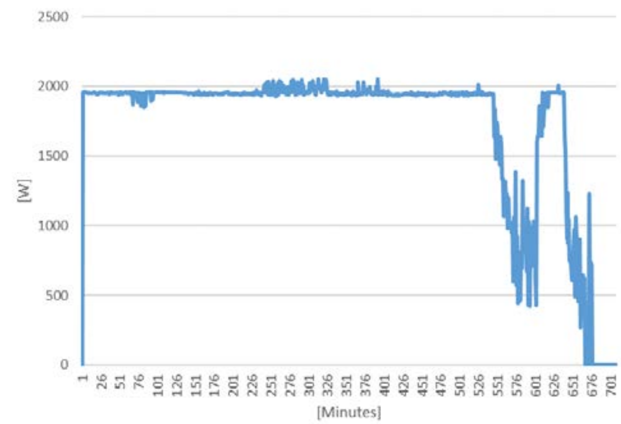

Fig. 8. Charging profile for Nissan Leaf - Including block/interior heating

BMW i3 was introduced in Norway in late 2013 with a battery capacity of 22 kWh. A version with upgraded battery (33 kWh) was introduced in 2016 [13]. The standard charging capacity is 3,7 kW.

Typical charging profiles for selected EVs are shown in Fig. 9. Since the duration of charging depends mostly on the state of charge of the battery, the focus is for step down at the end of charging. Fig. 9 shows how the charging is stepped down towards the end of charging time. To ensure not harming the battery, a typical end of charging period is reached at 80% (can also be set lower by most newer EVs). For some EVs when reaching 80% or beyond 80% SOC, a reduction of charging power is used to avoid overload and thereby causing a reduction of the battery capacity.

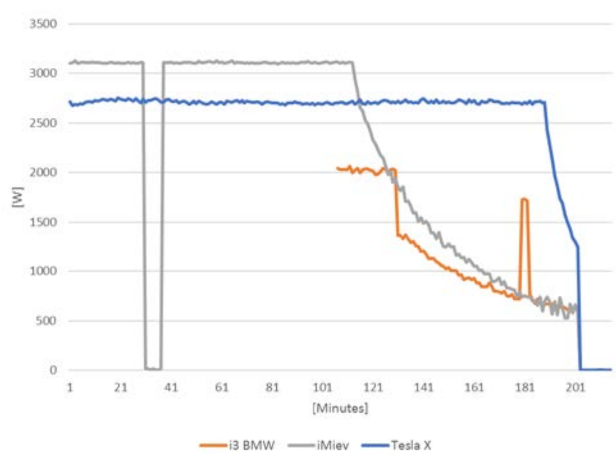

Fig. 9. End of charging profiles for EV types with "stepping down"

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3) Instant on/off

This group consists of the EVs: Volkswagen eGolf and Kia Soul Electric.

Volkswagen eGolf was introduced in Norway in 2014 and is currently the second most sold EV (Fig. 2). The first version was delivered with a battery of 21,8 kWh, and the upgraded version has a battery of 31,5 kWh [14]. Standard charging capacity is 7,2 kW (32A). Charging at 10A and 16A has a capacity of 2,3 kW and 3,6 kW, respectively.

Kia Soul Electric was introduced in Norway in 2014, with an upgraded version in 2017 [15]. The battery capacity was then upgraded from 27 to 30 kWh. The standard charging capacity is 6,6 kW.

The end of the charging profiles for eGolf and Kia Soul Electric are presented in Fig. 10. The figure shows the stable charging, at a level defined by the charging capacity. There is a small ripple in the charging, but this is minimal. The figure shows how the charging ends instantly when the battery has reached its full charged level.

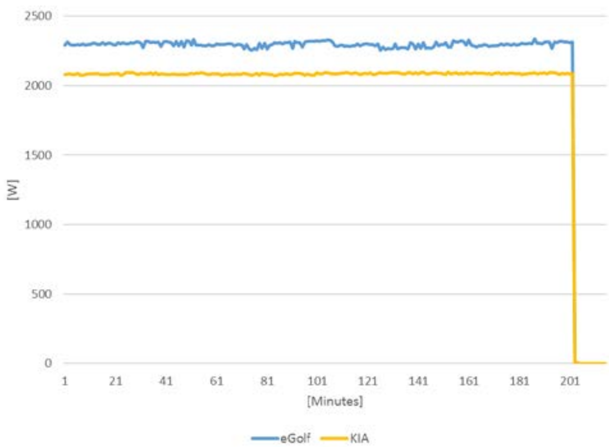

Fig. 10. End of charging profiles for EV types with "Instant on/off"

C. *Demand response from EVs*

EVs are new loads for most households, which has not settled into a regular habit with respect to charging/time of use. With the potential to store energy in a battery, EVs have a flexibility potential and are candidates for DR. Different alternatives of DR are described in section I.B.

Several of the EVs (especially the newer EVs) have the potential for controlling the start of the charging and/or specifying the time when the EV should be fully charged. This can be controlled via a mobile phone application or through the EVs onboard display. With the mobile phone functionality, it is easy for the user to control the time of charging – e.g. for load shifting (move the charging away from peak load periods) and valley filling (charging the EV at night). When controlling the charging from the mobile phone application, the manufactures onboard charging method for start and stop of charging is used, which ensures a smooth start and stop. There is also a potential for DR from EVs by peak clipping, done by interrupting the charging (on/off). If this interruption is performed when the EV is charging at maximum capacity, the charging will restart again with the same load and has its charging duration until the car is charged correspondingly postponed.

In the ModFlex project, the consequences of interruptions during the step-down part (see Fig. 9), has been studied (see Fig. 11). This study has been performed on a Mitsubishi iMiev.

Fig. 11 shows the step-down part of the charging, with two interruption periods followed by a rebound effect when the charging restarts. The stepping down charging starts from approximately 3,1 kW. The first interruption occurs when the charging is at 1634 W. After a break of 46 minutes, the charging starts at 3132 W, and it takes 10 minutes before the charging level again is again back down at the charging level before the interruption. The second interruption occurs when the charging level is at 734 W. After a break of 55 minutes, the charging level restarts at 940 W for the first minute, and then further increases to 1189 W. It takes 14 minutes before the charging again is at the same level as before the interruption.

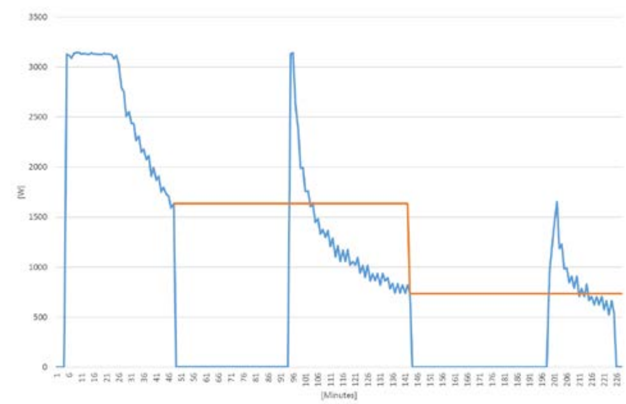

Fig. 11. Interruption periods of EV charging - during the step-down period

To study the consequences of the interruptions during the step-down period, a merged charging profile, where the disconnection periods have been removed, is shown in Fig. 12, in combination with the continuous charging profile from Fig. 7. Additionally, the two curves have been aligned by the end of time of charging.

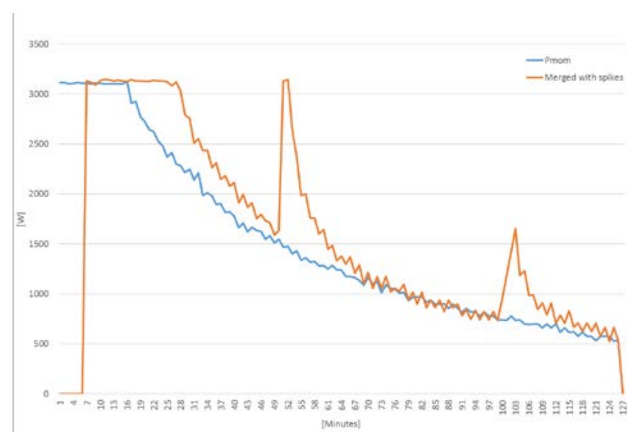

Fig. 12. Step down period of charging, with rebound effect after disconnection periods (disconnection periods are removed from the curve)

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The figure shows that after a disconnection during the step-down period, the charging power increases and a rebound effect occur.

IV. Discussion of the Results

This paper has presented status of the EV fleet in Norway, and expected trends due to political targets for non-emission transport. Estimation indicate that introducing an increased amount of EVs in Norway will not be an energy related problem, but it can become a capacity related problem in the distribution grid if all households charge their EV at the same time – in addition to their usual consumption of electricity.

Since EVs are new loads for most households, which has not settled into a regular habit with respect to charging/time of use and the flexibility potential due to the battery, EVs are candidates for DR. Different alternatives for DR are possible with EVs, such as load shifting, valley filling and peak clipping. According to the survey, 59% of single-family households, normally charge their EV at home, and for housing cooperatives, 12% charge their car daily (Fig. 3). Fast charging stations are normally used monthly or less by the households.

For the households charging at home, 49,5% charge from a normal socket (Fig. 4) and they normally charge their EV during the afternoon and during the night (Fig. 5). Charging during the night will contribute to valley filling and therefore use the available grid capacity in the off-peak periods. Charging during the afternoon in residential areas should be minimized, since this consumption will add up the peak load at the time of day when households make dinner, washing clothes etc. For the benefit of the grid, a large share of the EV charging should be performed in off peak periods during the night.

Based on the measurements performed, the different EV charging profiles have been divided into the following three groups: Maintenance, Step-down and Instant on/off charging modes. These measurements show the maximum load and the profile when charging. The duration of the charging will depend on the energy needed to be stored in the battery.

Measurements have also been performed when interrupting the charging of a Mitsubishi iMiev car, showing that a rebound effect occurs when reconnecting the charging after the disconnection period. If EVs are used for demand response, and controlled by an external part, it should be evaluated how this rebound effect could be reduced to avoid introducing new peaks in the distribution grid.

The status and quality of the distribution grid at the point where measurements of the charging have been performed, is not known. It is therefore an uncertainty related to whether the ripples in charging (for example in Fig. 10) are due to the grid strength or the actual charging.

V. Concluding Remarks

This paper presents status and political targets for EVs in Norway, results from a survey performed among households with EV and measurements of the charging cycle of different EVs. Non-emission transport in 2030 will not be an energy related problem, but rather a capacity related problem in distribution grids if all households are charging at the same time. Households should be incentivized to charge in off-peak periods (during the night), to utilize existing capacity of the distribution grid.

The ModFlex project has performed measurements of the charging power for several EVs and will continue this work studying the potential for DR from EVs, without introducing a rebound effect.

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References

[1] Statistics of Electrical Vehicles in Norway, SSB, https://www.ssb.no/transport-og-reiseliv/artikler-og-publikasjoner/over-140-000-elbiler-i-norge

[2] Statistics of Electrical Vehicles in Norway, Elbilforeningen, https://elbil.no/elbilstatistikk/

[3] C. H. Skotland, E. Eggum and D. Spilde, "What do the electrical vehicles mean for the power system?" (In Norwegian), NVE-rapport nr. 74-2016, https://www.nve.no/Media/4720/elbil_str%C3%B8mnett_rapport.pdf

[4] https://elbil.no/elbil/mitsubishi-i-miev/

[5] Reports on Demand Response & Advanced Metering, FERC – Federal Energu Regulatory Commision, https://www.ferc.gov/industries/electric/indus-act/demand-response/dem-res-adv-metering.asp

[6] https://snl.no/Think

[7] https://no.wikipedia.org/wiki/Think_(bil)

[8] https://en.wikipedia.org/wiki/Peugeot_106#Electric_version

[9] R. Domeniconi, N. Mona, C.-H. Dustmann, R. Manzoni, M. Pulfer, Mendrisio Operating Results using NiCd and ZEBRA Batteries http://www.gunnarmusan.de/Material/Mendrisio%20Operating%20Results%20using%20NiCd%20and%20ZEBRA%20Batteries.pdf

[10] https://elbil.no/elbil/tesla-model-x-90d-og-p100d/

[11] https://elbil.no/elbil/mitsubishi-i-miev/

[12] https://elbil.no/elbil/nissan-leaf/

[13] https://elbil.no/elbil/bmw-i3/

[14] https://elbil.no/elbil/vw-e-golf/

[15] https://elbil.no/elbil/kia-soul-electric/

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