Seasonal impacts of EV charging on rural grids

A Case-Study from Hvaler, Norway

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***Abstract*—Rural grids might be subjected to seasonal impacts from plug-in electric vehicles (PEV) that need to recharge batteries after medium-distance or long-distance travelling. A case-study from Hvaler, Norway is presented where this phenomenon has been analyzed. New patterns of use and a rapid growth of PEV sales in Norway may represent a future challenge. Traffic waves build up before weekends and bank holidays during spring and summer on roads leading to recreational areas. If the percentage number of PEVs in this traffic increases a concurrent demand for passive battery recharging may occur. It can be shown that this is likely to cause an aggregated load in the rural grid that must be taken seriously. Critical or close to critical situations might occur before special events early in the year, on Fridays during early summer and around Easter. Each of these situations require customized countermeasures.**

Keywords—plug-in elecrtric vehicles; case-study, seasonal traffic waves, non-stationary process, load accumulation, rural dsitribution grids

I. INTRODUCTION

The work presented here was initiated in the DeVID project [1] where the issue of seasonal impacts of EV charging was first explored. In the Flex-ChEV project [2] these issues have been further investigated as the number of electric vehicles in Norway has been doubling each year since 2010. According to Navigant Research [3] the number of plug-in electric vehicles (PEVs) in the world will reach 352.000 in 2014. At the end of 2013 19.000 PEV's were rolling on Norwegian roads. Halfway through 2014 the Norwegian fleet of PEVs number 32.000 units. By the end of the year this number is likely to surpass 50.000 [4]. This implies that a country with a population of only 5 mill accounts for a significant share of the world's sale. As a consequence the contours of what to expect in the future are beginning to emerge. Despite the fact that the size of the PEV fleet still represents less than 2% of the total number of registered vehicles, the omnipresence of PEVs in the daily traffic has become quite apparent. Grid owners in the major, Norwegian cities have expressed little concern regarding the developments. Distribution grids in central areas can demonstrate a high capacity. Utilities in rural areas have also been indifferent so far as PEV use has been perceived as a city oriented thing, basically related to everyday commuting. Lately, however, as the number of PEVs on the roads grows and the mileage range of newer models is extended we can observe a greater influx of PEVs in rural areas. Local sales are still modest in most non-urban areas. The incentives for buying an electric vehicle are less attractive. Yet, electric vehicles in district areas have become increasingly visible. This influx can be explained by a change in user behavior. The PEVs observed in the districts typically have their home base elsewhere. Medium and long-distance driving is becoming more common place. This is supported by a recent study [5]. Consequently unease is building up with regard to what impact this can have on the rural grids in the future. If the growth of PEVs in the traffic continues like it has, accumulated net loads due to concurrent recharging might become a problem. Electricity infrastructure in rural areas is often less sophisticated than in city areas. Lack of redundancy, less capacity and greater distances of supply are often part of the picture. Add aging of lines and substation equipment and there lies an additional source of uneasiness.

In our research we have addressed the electricity supply in rural areas and small town regions and the effect of anticipated, new loads. Recharging of PEVs can be counted among these. One of our case studies has targeted the municipality of Hvaler at the south-east coast of Norway. The questions that we have asked relate to the impact of PEV charging on specific days during the year. Significant seasonal variations are quite apparent in terms of road traffic in areas such as Hvaler. How will peak periods on the road affect the distribution grid and energy supply in rural areas such as Hvaler if the share of PEVs in the traffic increases? Can peaks caused by a combination of regular electricity needs and extensive, so-called passive charging be predicted and curtailed? If such an increase is imminent improvement of the local infrastructure according to traditional practices may not suffice. What should countermeasures aim for when addressing such a problem?

II. HVALER – A TYPICAL CASE

Hvaler is located next to the Oslo Fjord approximately 120 km south of Oslo. The Hvaler area encompasses an archipelago of smaller and bigger islands and is a popular recreational area during the warmer season. With a permanent population of only 7000 during the winter the traffic in this area is modest in the period, November through February. The number of permanently located PEVs on these islands is currently low (Spring 2014 = approximately 10). In the immediate region the number is 600-800 times higher, while in the capital area this can be multiplied by a factor of 1500-3000 depending on what boundaries are defined. It is part of this fleet of vehicles that represents a potential challenge at Hvaler. During the summer season the population at Hvaler soar and may well reach more than 30.000. The traffic intensity is 4-5 times higher than in January. This can be attributed to tourists and families residing in the 6300 summer houses populating the area. Another phenomenon that can be observed is the traffic wave that builds up prior to holidays, weekends and days between February and mid-summer. On Fridays, after business hours, during the peak season, people drive southwards on the E6 from their offices and homes around Oslo. This tends to build a dense line of traffic on the motorway and the local roads leading to different resorts and cottages typically along the Oslo Fjord. Hvaler is such a destination. Assuming that plug-in PEVs constitute a fair part of this traffic line we could anticipate a collective need for recharging at arrival. This will accumulate an aggregated load during evening hours when vehicles have plugged in. Based on our study of user-behavior we will argue that a scenario like this is likely to manifest itself for at least two causes. One is the presence, but low number of recharging spots along the main roads. Although few, they seem to provide a kind of security for drivers who wish to attempt long distance travelling. However, home charging is still preferred. Even if the number of recharging stations is increased and recharging times cut low home charging still remains a good option for many, if only for economic reasons or convenience.

The second cause is that the distance covered will demand recharging of most PEVs at the final destination. This is likely to be done at the time of arrival (typically a Friday evening), as most people would like to use their cars the next morning. The area of Hvaler is not unique in that sense. In Scandinavia alone several regions have a high concentration of leisure homes and resorts that periodically attract significant number of visitors and non-permanent residents who create comparable traffic situations like the one described here. Large camping areas can cause the same type of situations. Exhibitions, sports and cultural events like festivals, in district areas that want to attract people from central parts or across the local boundaries are just a few examples. With Hvaler as our case-study this is what we have investigated.

III. Method of approach

We recognize that the issue addressed and the scenario drawn out above is currently non-existent. However, with the accelerating sales of PEVs combined with a change of use we may expect rapid changes. Both how and when a problem of this nature can be encountered is important. Our claim is that the issues highlighted here will escalate more rapidly than ordinary processes for infrastructure upgrades are able to cope with. This is supported by our observations. In 2013 we counted one pluggable electric vehicle for every 1000 vehicle at parking lots at Hvaler during popular weekends (average number). The year after that the ratio had changed to 1 per 75. In a recent survey that we conducted during a fair held at the community center at Hvaler app. 4% replied that they had arrived in a PEV.

In order to study the phenomena more closely we have monitored the only inroad to Hvaler on afternoons before weekends and holidays. From this we have gathered empirical data about regular work day traffic, seasonal changes and the occasional traffic waves. These waves typically occur between the end of February until August. Days of interest includes all Fridays. Special attention has also been paid to days before bank holidays such as Friday before Easter, the day before Ascension, and the day before the Norwegians celebrate the country's independence (May 17). The traffic data was manually gathered and plotted against time. The prime target for our study was the period when traffic peaks between 14:00 hours to 20:00 hours on the particular days addressed. We combined the traffic data gathered with information on different electric cars and charging systems. Knowing that an array of options and requirements will be emerging over the next years we chose a conservative approach and adopted a standardized charging scenario with 2,3 kW, 3,3 kW and 6,6 kW recharging facilities suitable for home use. Different scenarios were analyzed, each with a different mix of ordinary cars and PEVs. This was further related to charging technology. Recognizing that not all vehicles entering Hvaler would need recharging we divided the analysis into four groups. The consequences of 10%, 30%, 50% and 100% of the total number of cars plugging-in half an hour after passing the Hvaler boundary were then studied.

Queuing theory has been applied by others to study similar phenomena [6]. However, as our focus was directed towards a very concentrated period when the traffic is building up we could not assume a stationary process. But with the empirical basis gathered we could specify the average arrival time at half-hourly intervals. The charging technology applied specifies service time. The difference between max capacity in the local infrastructure and the base load related to regular use of energy, such as space heating, defines the maximum service stations or service slots in the system. In Norway space heating, together with lights and water heating typically dominates energy use. 50-60% of the total energy used in households is typically used for space heating during winter. Consequently the lower the outdoor temperature, the fewer slots for recharging are available for recharging PEV batteries. The capacity of the recharging system, as described here, will therefore go down. With that overall turnover will be reduced accordingly. Energy use at Hvaler, like most of Norway, is highly, negatively correlated with outdoor temperature. Grid companies are well aware of this and have designed their infrastructure to cope with such days. As the queuing process for the periods of interests are not steady state, arrival frequency is dependent on time. On the other hand we have assumed that the service time is constant. It is only dependent on the choice of charging technology. Before starting we also assumed that arrival frequency would be somewhat dependent on calendar month and temperature. Warmer days close to the summer attracts more people. The average traffic figures gathered supported that. Consequently, we have a situation that should satisfy the mathematical expression (1).

$$L_{max} \leq L_{base}(Temp, month, t) + L_{pev}(Temp, month, t) \quad (1)$$

$L_{base}(Temp,month,t)$ is the regular energy load,
$L_{pev}(Temp, month, t)$ is the load due to accumulated PEV charging

It can be easily established that the calendar month or the week number (January i is in week 1) is also negatively, correlated with the outdoor temperature. L_{pev} can then be allowed to be a function of both temperature and time of day. The temperature element can be broken down into what we have called the Month Mean Temperature (MMT = *Temperature (month)*) and the actual minimum temperature at the day of question. Like for any queuing model $L_{pev}(Temp, month,t)$ defines both an accumulated load, but also the number of service units in the system at any time ***t***. Provided that no countermeasures are introduced a PEV too much that connects to the grid will generate a critical situation. This is because there will be no further service slots available. If neither grid owner nor users are informed a breakdown will occur. Therefore, for this problem the number of PEVs in the waiting line of the queuing system must always be zero. $L_{pev}(Temp, month,t)$ can be expressed as a function of accumulated arrivals and accumulated services at time ***t*** (3).

$$L_{pev}(Temp, month, t) = L_{pev}(Temp, t) \text{ given month} \quad (2)$$

$$L_{pev}(Temp, t) = N(Temp,t) - D(Temp,t) \quad (3)$$

$$N(Temp,t) = \sum_{i=0}^{t} \lambda_i(\text{Temp}) \quad (4)$$

$$D(Temp,t) = \sum_{i=0}^{t} \mu_i * s_i(Temp) \quad (5)$$

$$D(Temp,t) = u * \sum_{i=0}^{t} s(Temp)_i \quad (6)$$

When charging tin

Service time ***u*** is considered constant for each charging scenario. However, the general rule will be that a higher recharging capacity will produce a higher turnover in the system. The number of service slots, *s(Temp,t),* will be dependent on infrastructure capacity and therefore dependent on both time of day and temperature. Based on this we calculated *N(Temp,t)* and *D(Temp,t)* for each charging technology scenario. Finally we addressed the impact of time and temperature on *N(Temp,t)* and *D(Temp,t).*

IV. RESULTS

Peak season at Hvaler typically starts at Easter. If the Easter falls in April, the season might have its debut earlier. Some people will start the season in earnest already in early March. This is noticeable in terms of increased traffic, and as an increased hourly load in the net. In 2013 Easter fell in the month of March. Palm Sunday was on March 24. On Friday 22nd schools closed for the holidays after last afternoon class. Weather, however, was not very attractive and the average temperature that day was as low as -2,9 degrees Celsius. The weather was cloudy. The traffic picture that was observed that day is shown in Fig.1. It displays the number of cars arriving at Hvaler per every 30 minutes.

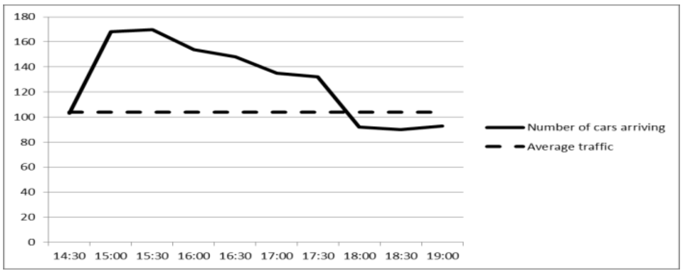

Fig. 1 The traffic intensity for Hvaler plotted against time on March 22nd , 2013. X-axis shows the hour of the day. Y-axis shows the number cars.

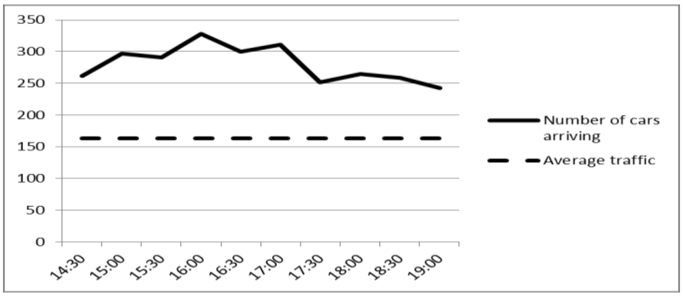

Fig. 2 The traffic intensity for Hvaler plotted against time on June 28th, 2013. X-axis shows the hour of the day. Y-axis shows the number of cars per 30 minutes.

Similar plots were made for other Fridays and holiday prologs throughout the spring of 2013. The situation for Friday, June 28 is shown in Fig. 2. The difference in traffic intensity is quite obvious. Moreover, the traffic wave generated in June is extended over a longer period than for the March instance. It also peaks earlier, suggesting a relative higher blend of local rush traffic. Between 15:30 and 16:30 permanent residents at Hvaler would be returning home from work in the immediate region around Hvaler. In both cases the traffic wave generated lies high above daily average for the given season. Depending on the fraction of PEVs in the traffic on such days and the charging technology applied the accumulated load was calculated according to (2) – (6) above.

In Fig. 3 and Fig. 4 some of the results from these calculations have been shown. To learn the maximum impact of charging on March 22nd 2013, a100% scenario has been displayed. This scenario implies hypothetically that all the inbound vehicles will charge their batteries at arrival with a 3,3 kW charger. In Fig. 4 the same is shown for June 28th. In Fig. 5 and 6 multiple scenarios have been plotted based on the same type of calculations. Each line in the graphs represents a specific scenario specified by the influx of PEVs and a particular charging technology. As can be observed each scenario produces an aggregated load that has been superimposed on the basic net load actually experienced on specific day (15MW and 7,7MW). At Hvaler a critical situation would occur around 22-23MW. However, any lasting load beyond 20MW would be a reason for concern. As can be seen from the graphs the grid will be able to cope most of the time.

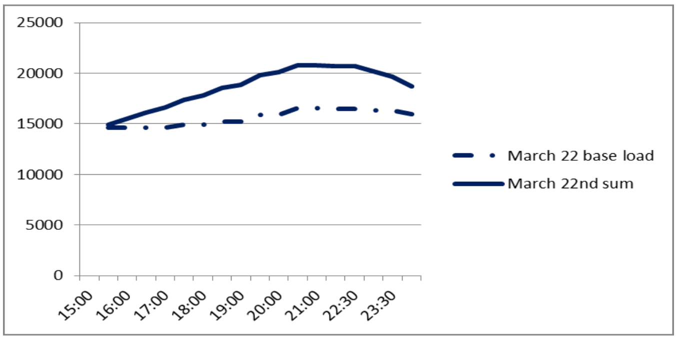

Fig.3 The graph shows a scenario for March 22nd where 100% of the inbound traffic to Hvaler requires recharging. The aggregated effect caused by the 3,3kW chargers have been superimposed on the base load for that day. X-axis shows the hour of the day. Y-axis shows the accumulated effect in kW. A similar scenario is shown for June 28 in Fig. 4. The relative importance of charging is clearly shown.

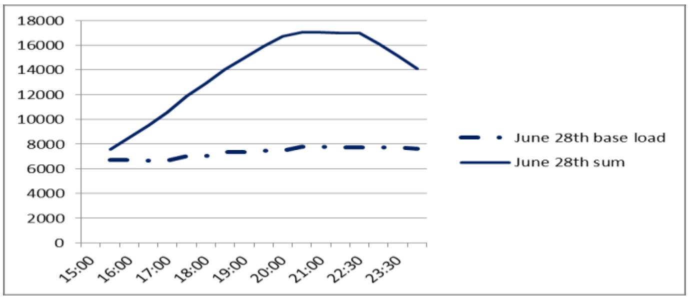

Fig. 4 The graph shows a scenario for June 28th where 100% of the inbound traffic to Hvaler requires recharging. The aggregated effect caused by the 3,3kW chargers have been superimposed on the base load for that day. X-axis shows the hour of the day. Y-axis shows the accumulated effect in kW.

As a general case it can be seen that a high percentage of PEVs heading towards Hvaler will be required to exhaust present capacity. Even though several of the scenarios displayed do not impose an immediate threat to the infrastructure on the days presented here there are certain situations that could produce a more unfortunate result. As expected the 6,6kW alternative peaks higher and slightly earlier than the minimum alternatives. The combination of increased traffic and more heavy-duty battery charging will lead to a situation that could cause very high loads. In the shorter term this is not very likely. But with an increased number of PEV models such as the high-end Nissan Leaf and the Tesla Model S the maximum profile might precipitate as default in a few years. What is more interesting at this point is how the combination of vehicles using recharging systems of less capacity creates, together with the base load, an accumulated effect peak in summer that is comparable to the typical loads experienced at winter time. The 3,3 kW 50% scenario on June 28th scenario is comparable to the base load in March with

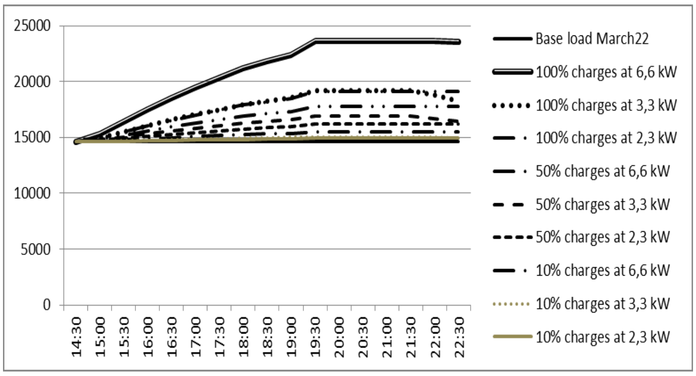

Fig. 5 Different charging scenarios plotted for March 22nd, 2013. X-axis shows the hour of the day. Y-axis shows the accumulated effect in kW. Notice that the base load is varying slightly around 15MW.

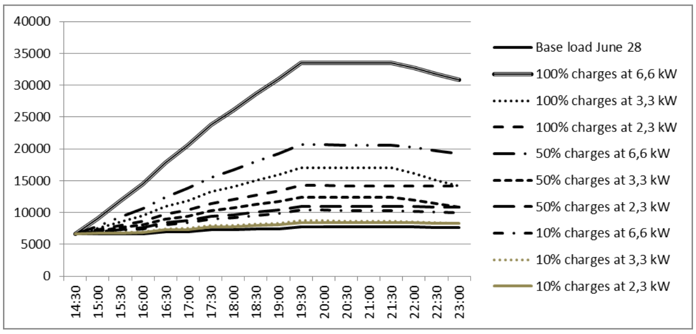

Fig.6 Different charging scenarios plotted for June 28th, 2013. X-axis shows the hour of the day. Y-axis shows the accumulated effect in kW. The base load increases slightly during the evening and reaches approximately 7,7MW

outdoor temperatures of app. -3 Celsius. The temperature dependency is interesting. The base load situation is susceptible to low temperatures that requires heating. The accumulated load from charging vehicles is dependent on the technology applied, the number of PEVs recharging batteries concurrently and the temperature. High temperatures towards summer generally generate more traffic. A sudden drop in temperature from Friday noon to Friday evening can be sufficient to produce a foul combination where the base load increases rapidly while recharging of several PEVs takes place. An early Easter with sunny days and low temperatures close to -10 Celsius after sunset and dark could imply a difficult situation. This was investigated. Fig. 7. It shows a graph where a 3,3kW charging scenario (100%) has been plotted for different dates. The graph shows very clearly that there is some degree of dependency on the month of the year when you combine base load and recharging. Note that the day before Easter and the weekend after mid-summer yields the highest impact. The influence of temperature on the base load is high. For the records obtained for 2013 a negative correlation of 0,92 was found. This is comparable to other years studied. Intuitively it seems logical that it is the season and not the temperature at the day monitored that determines the decision to travel. If higher temperatures and sunshine is anticipated it is likely that more people plan to make a trip. It is natural to assume that experience tells people that the closer to summer the higher

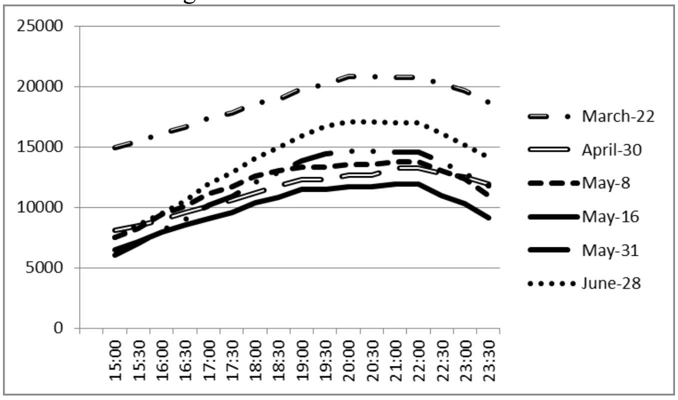

Fig. 7 The graph shows a 3,3kW scenario for different dates during spring 2013. Each line represents a situation where all traffic at the dates shown requires recharging of batteries. The accumulated load has been superimposed on the base load for that day. X-axis shows time of day. Y-axis shows effect in kW.

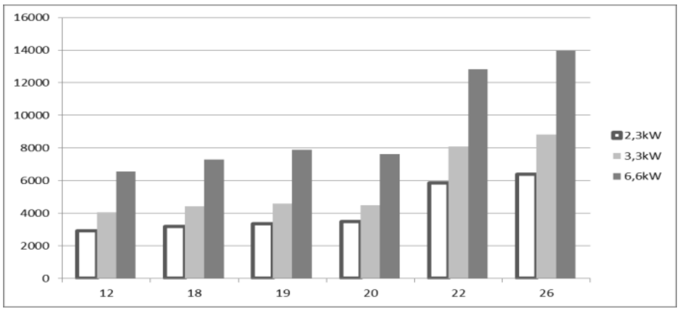

Fig 8 The graph shows the average load L_{pev} *in kWs (y-axis) for peak hours, plotted against calendar time (week number).*

the average temperature will be. However, sudden good or bad weather on the day of the planned departure may trigger some to stay at home. Likewise, a sudden change in weather for the better could encourage more people to travel. It can be shown that traffic is co-variant with week number, calendar month and day temperature. Consequently we related arrival time , *N(Temp,t)* and the accumulated recharging load to the month or middle-temperature (MMT).

In Fig. 8 we have plotted the average max load for the peak periods recorded against the calendar time represented by the week number. This yields a fair correlation, with R^2 equal or a little higher than 0,7. By substituting the calendar time with the MMT of each period studied, and use the minimum temperature on the evenings of observations as a modifying element, a slightly better linear approximation was obtained. The idea is that this models the *expectations* related to weather and average temperature for a given month, and thus the decision to plan a trip or not. The planned behavior might be slightly modified due to the actual temperature on the day observed. Together this can be expressed on the form shown in (7) - (9).

$$L_{pev}(Temp, month, t) \sim L_{pev}(Temp, Temp(month), t_{peak})$$

$$L_{pev}(Temp, Temp(month), t_{peak}) = \hat{L}_{pev}$$

$$\hat{L}_{pev} = a + b\,Temp(month) + u \qquad (7)$$

The regression satisfying the simple expression above has been depicted in Fig.9 for the 100% scenario, 3,3kW charging.

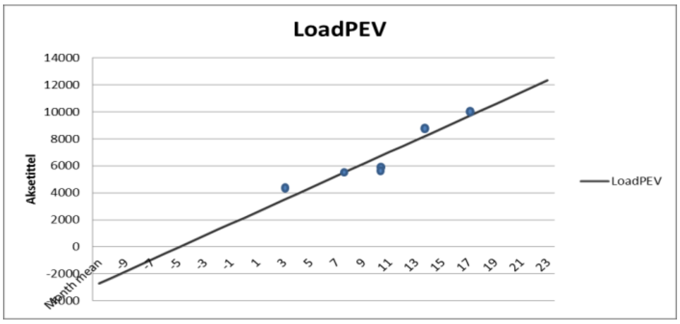

Fig. 9 Linear regression based on the observations shows the relationship between the mean temperature for a given month and the load potentially imposed on the grid based on a scenario where 100% of the vehicles will start to recharge at time of arrival.

The observations made are obviously insufficient to firmly determine such a relationship. It is counterintuitive to think that periods of very low temperature would yield no or negative contribution to the aggregated load. Somehow we would also expect the curve to even out for higher temperatures. Yet the graph in Fig. 9 suggests a tentative relationship based on temperatures sampled over several years. The residual factor ***u*** would, in this context, include the short term aspects related to temperatures for the actual day when traffic is recorded. Consequently we can separate this from the general white noise as shown in (8).

$$\hat{L}_{pev} = a + b\,Temp(month) + c\,Temp_d + \acute{u} \qquad (8)$$

Here $Temp_d$ refers to the actual minimum temperature on the evening when the influx of PEVs is expected. *a, b* and *c* will be dependent on the type of charging technology applied and the number of drivers who wish to recharge batteries at time of arrival. This is exemplified for the 100%, 3,3kW scenario whereby

$$\hat{L}_{pev,\,3,3kW,\,100\%} = 645,47 Temp(month) - 117,79\,Temp_d + 1257,36.$$

With the strong linear relationship between daily temperatures and the base load $L_{base}(Temp,month,t)$ we can combine this with the load imposed by the influx of PEVs which yields the total load $\hat{L}_{total}$.

$$\hat{L}_{total} = \acute{a} + b\,Temp(month) + {}'c\,Temp_d + \acute{u} \qquad (9)$$

When we plotted this against the MMT and the likely, minimum outdoor temperature for a given period it was possible to estimate the total load on the local distribution grid (see Fig. 10 and 11). Having arrived at this we could further estimate the probability for a given load. This is also illustrated in Fig. 11. Reasonable estimates for the load

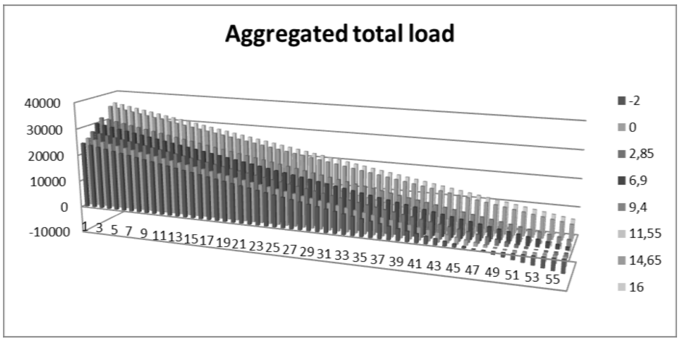

Fig. 10 The combined loads L_{PEV} and L_{base} plotted against the day temperature (x-axis) and Month Mean Temperature (the horizontal axis orthogonal to the X-axis). The likelihood of the temperature combinations will differ according to local weather statistics.

can therefore be based solely on temperature records. We are currently trying to produce a sufficient temperature history for Hvaler that let us calculate the probability of different temperature combinations. Combinations showing a high MMT and very low evening temperatures can be easily spotted. This could yield both high traffic and a high base load. The probabilities marked in red (grey) in Fig.11 constitute part of a density function defining the probability of having one vehicle in the system queue. If no countermeasures are introduced this would imply an infrastructural collapse. Also the number of units being served and the number of service slots at any time can be estimated in this way. In Fig. 12 the aggregated load for the 100% and 3,3 kW scenario is shown as a function of MMT. The fitted curve can be expressed according to (9) as:

$$\hat{L}_{total} = 15199{,}78 + 645{,}47 Temp(month) - 532{,}54\ Temp_d$$

For the actual records obtained a similar graph has been created in Fig. 13, but plotted against calendar period. Compared to the graph shown in Fig. 11 we can see that the estimated curve shows a lower than actual estimate for the warmer period. More important is the shape of the curve which clearly indicates two distinct max areas. One lies in the absolute colder part of the year and the other in the summer period. In the former case the base load (L_{base}) dominates. In the latter situation the influx of cars that could potentially connect to the grid (L_{PEV}) dominates. This is also shown in Fig.13. Also we can see that charging technology makes a greater difference in the summer than in early spring and winter.

V. Discussion

The results presented here show that days before weekends and bank holidays during spring and summer generate a significant traffic wave. This is not unique for Hvaler. Many recreational areas in the mountains or areas close to the sea experience similar things. Most of these areas are inherently rural. Leisure homes, camping sites, marinas and other recreational spots attract people when the weather allows. As the number of PEVs in that traffic wave increases the traffic

Accumulated load

T	2,85	6,9	9,4	11,55	14,65
-11	22897,2504	25511,4039	27125,0789	22058,1394	30513,7964
-10	22364,7157	24978,8692	26592,5442	21525,6047	29981,2617
-9	21832,1811	24446,3346	26060,0096	20993,0701	29448,7271
-8	21299,6464	23913,7999	25527,4749	20460,5354	28916,1924
-7	20767,1118	23381,2653	24994,9403	19928,0008	28383,6578
-6	20234,5771	22848,7306	24462,4056	19395,4661	27851,1231
-5	19702,0425	22316,196	23929,871	18862,9315	27318,5885
-4	19169,5078	21783,6613	23397,3363	18330,3968	26786,0538
-3	18636,9732	21251,1267	22864,8017	17797,8622	26253,5192
-2	18104,4385	20718,592	22332,267	17265,3275	25720,9845
-1	17571,9039	20186,0574	21799,7324	16732,7929	25188,4499
0	17039,3692	19653,5227	21267,1977	16200,2582	24655,9152
1	16506,8346	19120,9881	20734,6631	15667,7236	24123,3806
2	15974,2999	18588,4534	20202,1284	15135,1889	23590,8459
3	15441,7653	18055,9188	19669,5938	14602,6543	23058,3113
4	14909,2306	17523,3841	19137,0591	14070,1196	22525,7766

Probability

T	2,85	6,9	9,4	11,55	14,65
-11	0,0005	0	0	0	0
-10	0,0004	0	0	0	0
-9	0,0008	0	0	0	0
-8	0,01	0,004	0	0	0
-7	0,03846154	0,004	0	0	0
-6	0,02941176	0,0036	0	0	0
-5	0,01923077	0,0086	0	0	0
-4	0,05769231	0,0087	0,0004	0	0
-3	0,07692308	0,0093	0,00047	0	0
-2	0,08461538	0,013	0,0089	0	0
-1	0,08846154	0,032	0,0078	0,0001	0
0	0,05769231	0,0782	0,00923	0	0
1	0,13846154	0,0884567	0,012034	0,00013	0,00256
2	0,06923077	0,112356	0,023563	0,002	0,00312
3	0,07307692	0,13489	0,05769231	0,0567	0,01134
4	0,06923077	0,134569	0,12536	0,093678	0,03846154

Fig. 11 Extract from the numerical basis for the graph in Fig. 10 (left). The critical combinations of Month Mean Temperature and daily temperature are colored in red. On the right the probabilities for those specific temperature combinations (Note: The matrix on the right has been included for illustration purposes. The temperature statistics has not been fully established with sufficient resolution at the time of writing). When the two matrices are multiplied with each other the weighted probability for a given temperature can be found. The expected max temperature associated with a Month Mean and the expected Month Mean for a given temperature can be found by adding up the column and the rows of the resulting matrix respectively.

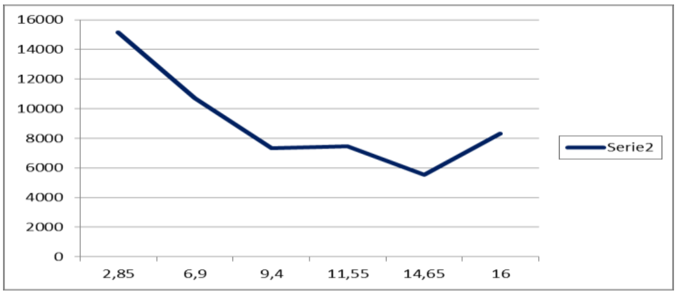

Fig. 12 The combined regression curves for L_{PEV} and L_{base} is plotted against Mean Month Temperature. (The 3,3 kW 100% case).

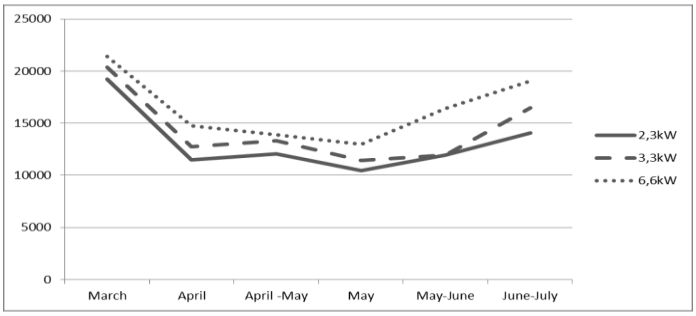

Fig. 13 Aggregated load curves based on actual records for max base load in the net and observed traffic intensity plotted against calendar period. Notice the distinct U-form obtained.

wave may propagate into the grid in the form of a collective load caused by battery recharging. With a critical limit at approximately 23MW the grid at Hvaler has a substantial spare capacity most of the time. In the past years loads higher than 19MW has only been experienced 1,4% of the time. A very high percentage of PEVs among the inbound vehicles is required to fill up the spare capacity that is most often the case. However, a few hours a year may provide a challenge. For the days studied we can observe that low-effect recharging can be well absorbed unless the base load in the net is very high. But charging technologies that applies higher effects may represent a challenge even with a low base load, or even when the number of PEVs requiring recharging at arrival is more modest. Nevertheless, with a dramatic increase in PEV sales in Norway and with an increased tendency to use PEVs for long distance travelling Hvaler may soon see a large concentration of cars that need recharging at arrival. If the current sales trend increases we are likely to see 200.000 PEVs on Norwegian roads in two-three years. As the number 1 or 2 cars is rapidly replaced by a PEV, 35-45% of the inbound cars on a Friday in spring in 2017 needing battery recharging may not be a poor prediction.

We have shown that increased traffic intensity on days before weekends and holidays in spring and summer can be explained by a high MMT At the same time it has been shown that low temperatures on a given day or evening lead to increased space heating and a load build-up in the grid. Having assumed a non-stationary queuing concept for the analysis conducted it has also been shown that arrival time and the number of service slots is dependent on the calendar month expressed in terms of the MMT and the actual temperature at the day the journey takes place. We admit that a single season is insufficient to generate a sound statistical basis. However, the traffic data sampled corresponds well with longer term average figures that go years back. This is also true for the energy statistics gathered. Hence, we believe that the results obtained provide a true, but possibly inaccurate picture.

From our study we also see that there are two periods that demand close attention. From our calculations a third one has also been identified. We will call them Case A, B and C. The two first can be found at each end of a 6 month period. In winter and early spring the base load is high. This is caused by space heating. At Hvaler the average hourly consumption lies around of 3-4 kW per household during cold periods. Consequently this narrows the spare capacity in the distribution grid and reduces the number of service slots for recharging. This is Case A. Due to the low level of traffic the situation can be contained, but the grid will be vulnerable if an increased influx of PEVs is experienced. This can happen suddenly if a special event such as a concert draws an audience at this time. Case B may occur in early summer. At this time the base load is usually low, but the traffic picture changes radically. With a high percentage of PEVs using more heavy duty charging equipment a latent problem should be addressed. In both cases the load challenge is amplified if people also start to apply induction units for cooking and water heating. A third case to watch out for is when a high Month Mean Temperature can be accompanied with a very low evening temperature for the season. This we have called Case C. Case C can happen in early spring with sunny, high pressure days that lead to a significant drop in temperature after sunset. The empirical expressions developed here have been used to estimate the boundary conditions for a scenario whereby 100% of the traffic uses 3,3kW rechargers at arrival. Like the results in Fig. 10 and 11 suggests the likelihood for Case C cannot be neglected. This is supported by our actual observations in 2013 which is shown in Fig.13. Careful attention should be paid to the period in March-April when Month Mean Temperature lies in the interval $Temp(month) \in [2.5,10]$. This is a period where both Easter holidays and sudden drops in temperature from mild to cold are not unlikely.

What is important to note is that the three distinct cases require customized countermeasures to be tackled well. For Case A the base load will be very high and the influx of PEVs will be comparatively low. Today, the traffic during January and February is dominated by local inhabitants and a small influx of business travelers, transportation and service vehicles. The afternoon wave of cars on a Friday will be much lower than experienced in March. The arrival frequency will be sufficiently low to be managed by a limited number of charging spots beyond, but close to Hvaler. More importantly home charging can largely be seen as a part of the general load management issue for permanent households, commerce and industry. It could therefore be combined with more general demand-side management measures. This has already been tested out at Hvaler [7]. Tariffs that penalize charging economically during peak hours have proven viable in such cases.

For Case B and C the situation will be more complicated since the additional loads are mostly caused by non-permanent residents who have distinct demands for a weekend or a short holiday. To renounce comfort and convenience during a brief recreational spell will for most people be unacceptable. To avoid passive charging at home heavy duty charging spots could be placed on the mainland beyond the rural grid at Hvaler. This would allow travelers to recharge before arriving at their cottage, camping site or boat. Two things play against this, traffic intensity and recharging time. More than 10 minutes service times will for most people in a situation like this be unacceptable. With the number of cars needing recharging at the same time queues are likely to build up causing a total waiting time which will be much longer. Close to their destination the spill-over is going to be significant and passive recharging at home will still be an issue. An additional observation that we have made is that once people have settled in for the weekend or holiday at Hvaler the load remains high. In fact the load profile for a weekend is almost symmetrical. A significant ramp-up on Fridays is followed by a similar decrease on Sundays when people leave the area. In between the loads remains at a constant high level or even increases. This is an expression of not only energy demand, but of life style. End-user flexibility for the majority of people causing the added load in Case B and C will be lower than usual. However, a reservation system could be introduced by the local utility like the one that has been proposed in [6]. Designated recharging slots could then be allocated on a first-come-first-serve basis. Latecomers who fail to reserve a slot in time would either have to wait or to use facilities beyond Hvaler. This type of option would require some identification of the units that recharge at home. We also think that partial load reduction strategies tailored to the vehicle characteristics as demonstrated in [8] could work in these cases. Partial loading could be accepted as long as the PEV can be used the day after arrival. With a higher base load for Case C there will be a sufficient energy volume to manage for flexibility purposes, especially among the permanent residents. Controlling slow loads in such homes could compensate for some of the growth imposed by the travelers. But a significant reward mechanism would then be required. This might be worth considering in order to minimize other costs. Close cooperation with the permanent residents may, in addition, boost customer relationships that can enhance business in other ways. For both Case B and Case C prediction systems and careful monitoring of the influx of vehicles is recommended. In addition to the temperature based prediction concept shown here Case B should require a means to count the number of actual PEVs heading for Hvaler and make load estimates on a continuous basis. This can help utilities to deal with the problem in due time. For Case C careful monitoring of both the traffic and the weather forecast would be required.

VI. Conclusions and further work

We have addressed the impact PEV charging on grids in rural areas. A case study addresses a specific problem at Hvaler in Norway. On days before weekends and bank holidays during the spring and summer significant loads in the local grid are likely to build up as the influx of PEVs in road traffic increases. The distance covered and the inherent nature of people's needs and priorities are likely to result in a situation where a high number of PEV owners will connect their vehicle to the rural grid at their destination and expect it to be recharged before the next day or earlier. For very brief periods we may see a rapid load build-up. We have shown that this will be dependent on the percentage PEVs in the traffic, the charging technology, the season and the temperature on a given day. The rural grid that has been specifically addressed displays a robustness that can cater for a significant number of PEVs that needs to be recharged. However, certain load combinations can generate critical situations that need to be monitored carefully. It can be shown that an unfortunate mix between traffic and base loads typically used for space heating can create max-load situations that need to be taken care of. We have identified three such situations that stand out. Each of these must be managed differently. Technical countermeasures and policies must be customized for each case. In this work we have also shown how both traffic and the general base load in the local grid are dependent on outdoor temperature. This temperature can be expressed in terms of Month Mean and the actual average temperature for a given day. We have used a basic non-Markovian approach to model a simple queuing system for the problem at hand. The base load determines the number of service units, while the actual service time is assumed constant for any battery charging technology. The arrival time is governed by seasonal changes and defines a very distinct pattern in the form of a wave that propagates into the grid when vehicles need recharging. The frequency of arrival is not stationary and average arrival times will not be suitable to capture the max loads generated. Based on simple regressions we have further shown that season and temperature determine the required turnover in the system. Because of this it will be possible to calculate the probability of potential grid failure due to overload based on day temperature and season alone. This will be pursued in further work. Similarly we will continue to monitor developments on the road to generate firmer statistics. However, based on the dramatic increase in PEV sales and if the early tendencies related to user behavior that we have observed are reinforced we are likely to see some of the scenarios that we have investigated here materialize in less than four years. This suggests a radical change that traditional infrastructure upgrades will not be able to cope with in time. We will monitor these developments closely in the Flex-ChEV project.

VII. Acknowledgements

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