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Impacts of Large-Scale Penetration of Electric Vehicles in Espoo Area

Abstract

Kyoto targets and the increasing trend in oil prices drive countries to search for alternatives for fossil fuels. Transportation is among the major sources of greenhouse gas emissions. In Europe, transport accounts for approximately one quarter of the total greenhouse gas output, and its emissions are growing. In Finland, the proportion of transport is about fifth of all greenhouse gas emissions. Electric vehicles are an upcoming trend, and provide an opportunity to cut the greenhouse gas emissions from transportation sources. Various car manufacturers have launched electric vehicle models that will enter the markets in the next five years. This means that there has to be the infrastructure for charging the vehicle batteries available. Distribution companies have to consider how the charging of EVs will affect the network, and what effort has to be placed on the distribution network to guarantee that the infrastructure is capable of providing energy and power to the customer.

Introduction

The question of the effects of electric vehicles (EVs) on electric power networks is challenging in many ways. Although there are already numerous analyses on EVs on power distribution networks, many technical and economic questions still remain open. The main research question considering electric vehicles and electricity distribution is to define the network effects of the charging process and what kind of technologies should be developed for fulfill the needs of power balancing, charging profile and grid investments. There is a risk of overlapping of the present peak load and the peak resulting from charging of vehicle batteries. This overlapping could lead to a substantial increase in peak loads and thereby reinforcement needs in electricity distribution networks. Finally, it would raise the distribution fee paid by the electricity end-users. Definition of the network effects requires understanding of the wide-scale use of electric vehicles and long-term development of the distribution infrastructure. At the energy market level, rough calculations show that the amount of energy that EVs need for charging increases the Finnish energy consumption by approximately 9 TWh. This is not a significant increase, and it seems that the distribution network can handle this growth; nevertheless, the medium- and low-voltage networks will pose a challenge to the networks.

Even though the increasing trend of electric vehicles is recognised, their market penetration is still unknown. Consequently, this has an effect on the scheduling of the distribution network investments. Secondly, for instance the properties of batteries are developing at a rapid rate. This makes it more difficult to estimate the driving distances, charging rates and charging speeds for EVs. In Scandinavia and in Finland, low-voltage charging infrastructure is already available in most of the places because of the car preheating needed in wintertime. This infrastructure is commonly used as a single-phase system, and for vehicle charging, only low power levels can be used (maximum 3.6 kW). The existing infrastructure can be used up to a certain penetration level, but if

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the demand grows significantly, old parking slots in real estates have to be rebuilt. In these old real estates, preheating is typically implemented by a single-phase system with small cross-section cables and 10 A fuses. Small cable cross-sections and fuses increase the charging time, and the number of vehicles being charged is lower. While the internal electric networks in real estates are renovated, it is easy to update the preheating infrastructure to meet the requirements for EV charging. Also in a case of new real estate it would reasonable to take electric vehicle to concern in the planning and construction phase (for instance in pipe work for electric cables and sizing the cables). Even if the infrastructure is ready for electric vehicles, charging will require some kind of smartness so that the consumption peak will not increase or real estates will not have to increase the main fuse size excessively. In most new real estates built in the 21st century, cables are sufficient for EV charging, and the infrastructure could be used for charging with only minor changes. In many other countries instead, like in the USA, there is no similar network infrastructure available. These countries will face challenges to provide the charging infrastructure for electric vehicles in one-phase low-voltage networks.

Methodology for the definition of electric vehicle loads

In this study, the electric vehicle is considered as a load (grid-to-vehicle). Figure 1 presents the methodology to define the load effects of electric vehicles on the electricity distribution network. When defining the network effects, information has to be gathered from numerous sources. The National Travel Survey gives information for instance on driving distances as well as how, when and how often cars are used. In Finland, the latest survey was carried out in 2004 and 2005; the survey was conducted for the Ministry of Transport and Communications, the Finnish National Road Administration and the Finnish Rail Administration. According to this survey, the average annual driving distance is 18 200 km/a/car that makes approx 50 km/car,day. These figures are applied in this study also.

The energy consumption (kWh/km) of a single electric vehicle depends on various aspects. Factors that affect the consumption include the efficiency of the charging-discharging cycle (including the efficiencies of the charger and the battery), the efficiency of the regenerative braking system, the energy needed for heating and air-conditioning, the coefficient of drag, the rolling resistance, the total mass of the vehicle and the driving cycle. Fortum has recently measured the energy consumption of an electric vehicle in wintertime in Finland, and obtained average values of 0.20–0.25 kWh/km. If the energy required per kilometer is 0.2 KWh/km and the average daily driving distance is 50 km/car, each car requires around 11 kWh/car, day. In the study, the value is assumed to be 11.5 kWh/car,day.

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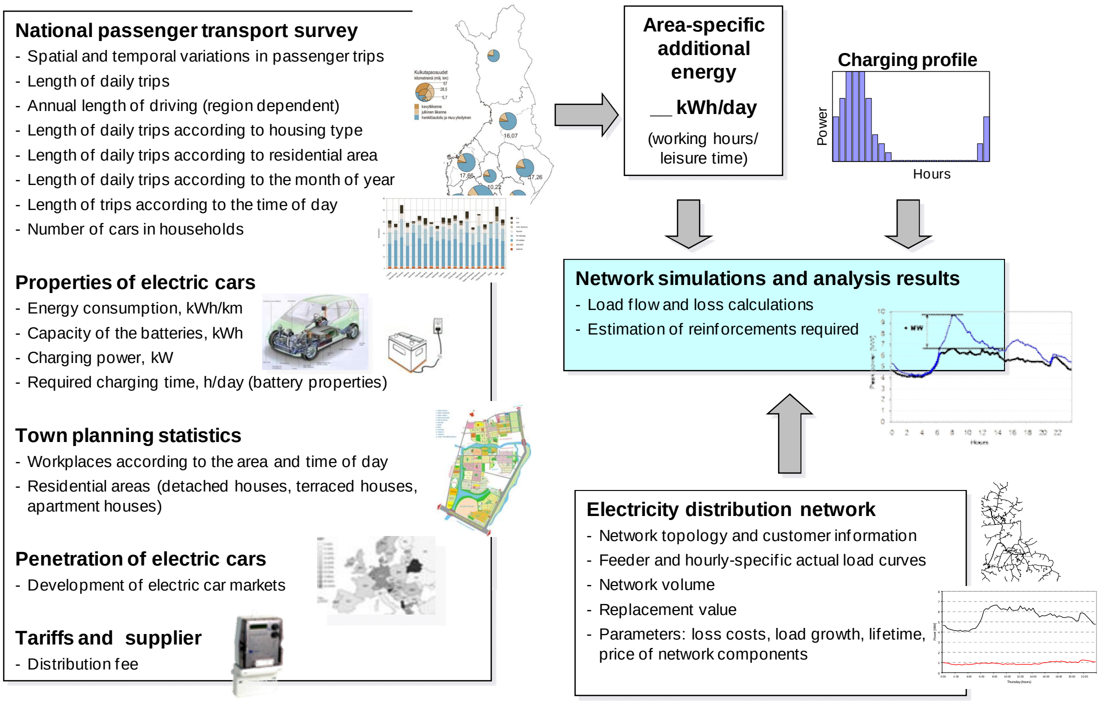

Figure 1. Methodology to define the load effects of the electric vehicles on the distribution network.

Besides driving habits and energy consumption of electric vehicles, charging opportunities (including slow charging, fast charging and battery replacement service) in different locations have also an effect on the energy taken from the distribution grid by a fleet of electric vehicles. However, fast charging and battery replacement are not considered in this work, and the maximum charging power is set to 3.6 kWh/car. The limit comes from the new preheating system in Finland in wintertime. Today, the system operates on one phase voltage (230 V) and 16 A fuses, and this is the application used in all apartment houses in the study. This provides 3.6 kW charging power at maximum for each vehicle. The capacity of the battery is assumed to be 30 kWh/vehicle.

Network analysis

To analyse the distribution network effects caused by electric vehicles, comprehensive information is required about the distribution network components and actual load flows. In the study, one of the main objectives is to investigate transmission capacities in distribution system in a result of penetration of electric vehicles.

In the study, six different 20 kV feeders where chosen for closer investigation. All the feeders are supplied from the same 110/20 kV primary substation. The feeders have different kinds of loads, such as detached houses, terraced houses, apartment houses, offices and service facilities. Several customer types have to be taken into account as the practices in the use of EVs vary. For instance on a city area feeder, where the load is based mainly on office activities, the peak load occurs in the daytime. If the EV charging takes place at the same time (during the office hours), the increase in peak power can be significant. In the residential (household) areas, the time of the day when charging mostly takes place varies more than in the case of an office area feeder.

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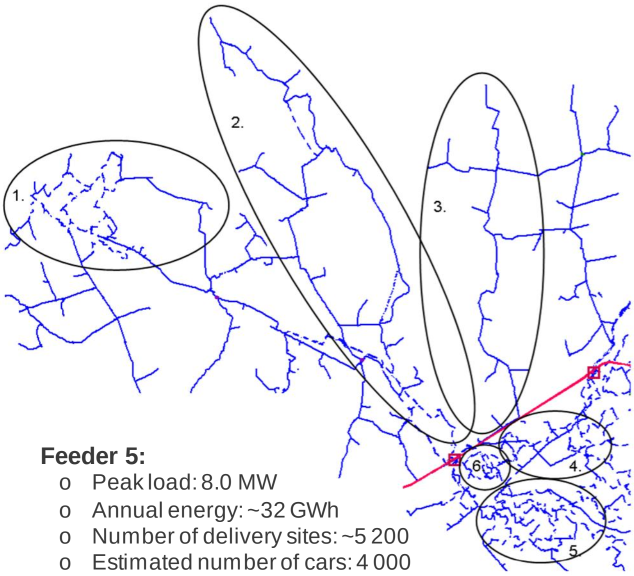
In the area chosen for a closer investigation, there are approximately 9500 delivery sites, 9700 registered cars and 1000 public parking places. Information of the registered cars and the number of public parking places was gathered with the help of the City of Espoo and the company maintaining a register of cars. To calculate the number of vehicles to be charged at the offices, the number of parking places in the area was used in the study. Feeders 1, 2, 3 and 5 are mostly comprised of households (detached houses, terraced houses and apartment houses). On feeders 4 and 6 there are mainly offices and service facilities. In the Nordic countries, the peak load normally occurs in the winter season because of the cold weather and a high rate of electric heating. Figure 2 presents the six feeders chosen for the study.



Feeder 1:
- Peak load: 5.6 MW
- Annual energy: ~18 GWh
- Number of delivery sites: ~1 100
- Estimated number of cars: 1 650
- Houses constitute over 90 % of the delivery sites and total energy consumption of the feeder

Feeder 2:
- Peak load: 5.0 MW
- Annual energy: ~10 MWh
- Number of delivery sites: ~730
- Estimated number of cars: 980
- Over 90 % of the delivery sites are houses and their consumption is over 80 % of the total energy consumption

Feeder 3:
- Peak load: 5.5 MW
- Annual energy:~16 GWh
- Number of delivery sites: ~1 120
- Estimated number of cars: 1 150
- Over 90 % of the delivery sites are houses and their consumption is over 80 % of the total energy consumption

Feeder 4:
- Peak load: 3.7 MW
- Annual energy: ~22.5 GWh
- Number of delivery sites: 960
- Estimated number of cars: ~2 500 (one large shopping and service centre with hundreds of parking places)
- Over 90 % of delivery sites are houses but consumption is only 30 % of the total consumption of the feeder. Consumption of service facilities is almost half of the total and offices take the rest of the total consumption

Feeder 5:
- Peak load: 8.0 MW
- Annual energy: ~32 GWh
- Number of delivery sites: ~5 200
- Estimated number of cars: 4 000
- Houses constitute almost all of the delivery sites (98%), and they account for 75 % of the total consumption

Feeder 6:
- Peak load: 3.6 MW
- Annual energy: ~18 GWh
- Number of delivery sites: ~390
- Estimated number of cars: 1 600
- There are a few apartment houses in the area, where the number of delivery sites is large, but the consumption of houses is only 5 % of the total. The area is mostly comprised of offices and service facilities that are typically open during office hours.

Figure 2. Case feeders and key figures of the network.

The charging time of the electric vehicles depends on where the vehicle is located and how full the batteries are when the charging starts. People commute from home to workplace, after work they may drive on errands, and finally, they drive back home. Moreover, people drive to various free-time activities after work. Hence, we may assume that most of the charging takes place at home and at workplaces, but cars may also be charged for instance at shopping and service centers. It is assumed that the charging starts at home around eight o'clock in the evening. Figure 4 illustrates the charging curves used in the study. There are three categories; households, workplaces and services. Feeders 1, 2, 3 and 5 comprise mostly household feeders. The number of vehicles on these feeders is assumed to be the number of registered vehicles in the area.

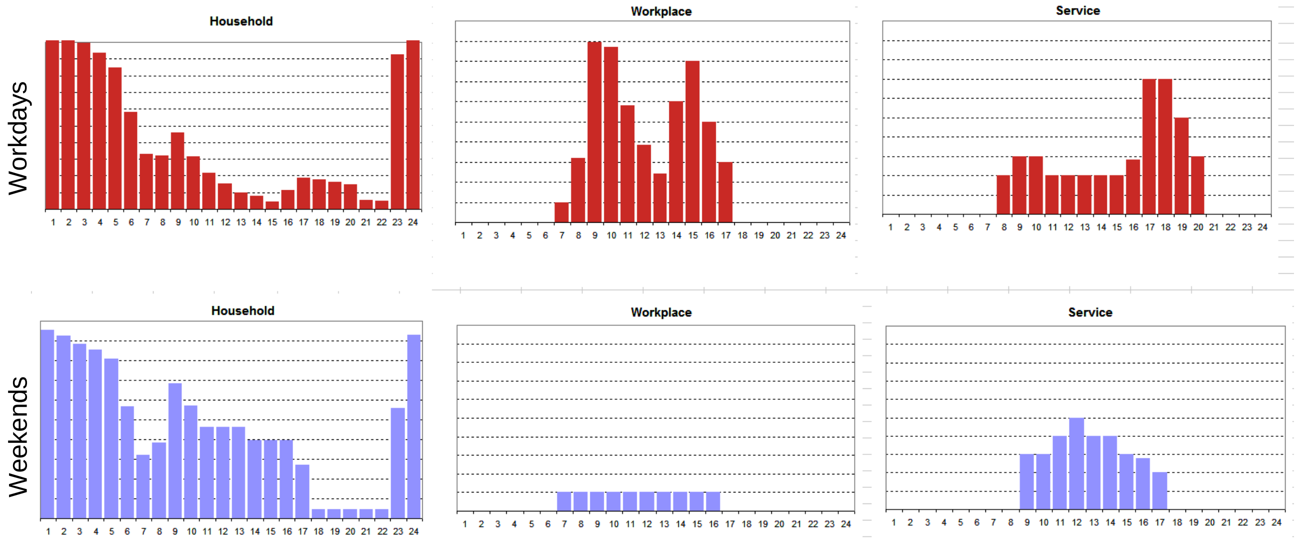


Figure 3. Three charging curves used in the study; households, workplaces and services on workdays and weekends.

The peak load in the case area occurs in wintertime. Table 1 presents the measured load curves of the case feeders. The curves are for a one-week period (the peak week of the year). Load variation during the week is clearly visible. The customer types differ greatly from each other. Feeders 4 and 6 involve mainly service and office consumption.

On each feeder, the number of charged EVs and the combination of charging curves vary. In the third column in Table 1, the charging curves for EVs on each feeder are presented. The red bars indicate the number of charging EVs on workdays, while the blue bars represent charging EVs on weekend. We can see that the number of EVs and the charging profiles vary significantly (cf. feeder 5 and 6).

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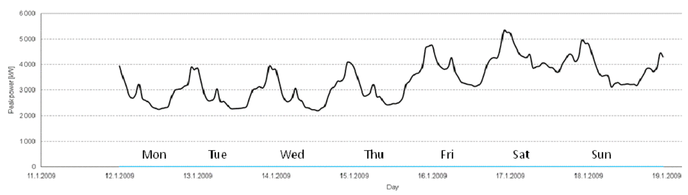
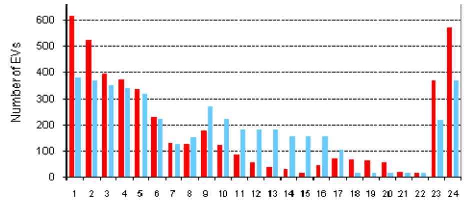
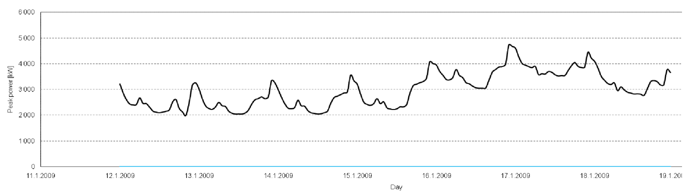
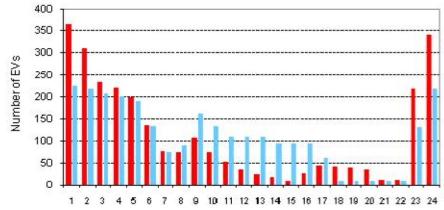
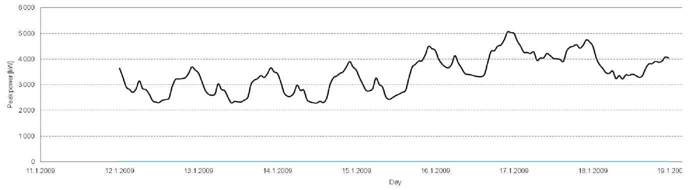
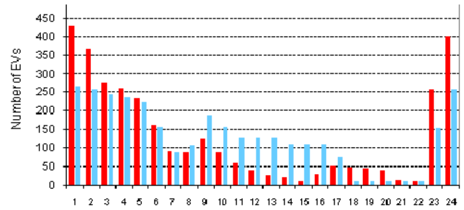
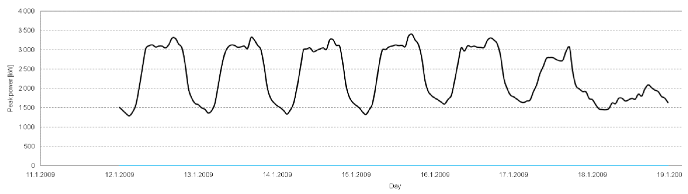
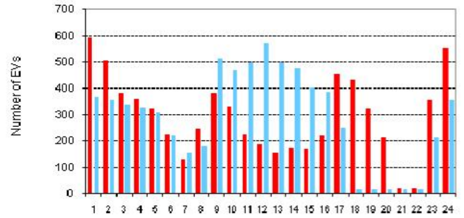
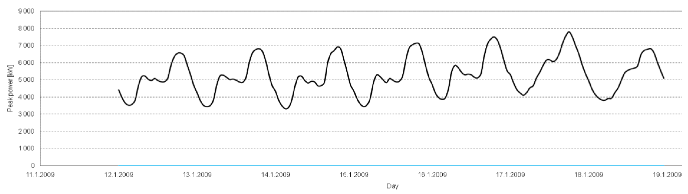
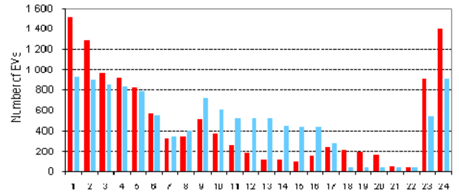
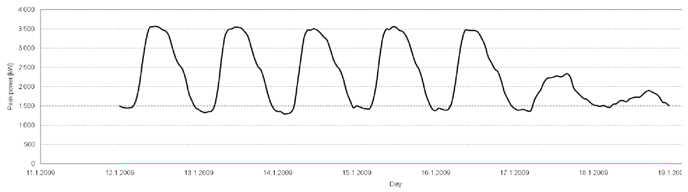
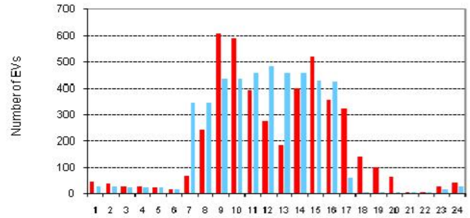
Table 1. Present load curves of the medium-voltage feeders (peak week of the year, without EVs) and daily charging curves for EVs. The number of EVs in workdays; HH = household, WP = workplace and S = service.

Feeder	**Present load curve of the medium-voltage feeder (peak week of the year, without EVs)**	**EV daily charging curve, without basis load (weekday/weekend)**
Feeder 1 HH: 1649		
Feeder 2 HH: 980		
Feeder 3 HH: 1153		
Feeder 4 HH: 1593 WP: 120 S: 800		
Feeder 5 HH: 4061 WP: 110 S: 102		
Feeder 6 HH: 118 WP: 1210 S: 300		

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Results

The results depend strongly on the charging assumptions presented in the previous chapter. The number of EVs and the charging schedule decide how much the peak power can rise from the present situation. The load on the medium-voltage feeder depends significantly on the charging arrangements; whether it is a simple direct charging system or there is some intelligence included in the system to flatten out load peaks. In the household charging curve, it is assumed that charging is carried out in night-time, and charging is only lightly controlled. Figure 4 depicts the one-year load curve with electric vehicles (the topmost curve). The bottom curve illustrates the powers without EVs. The curves include peak powers for each day, while the minimum loads of the days are not presented. Based on the analyses, the change in the peak load in the case feeder would be from 5.6 MW to 7.6 MW, which means a 2 MW increase.

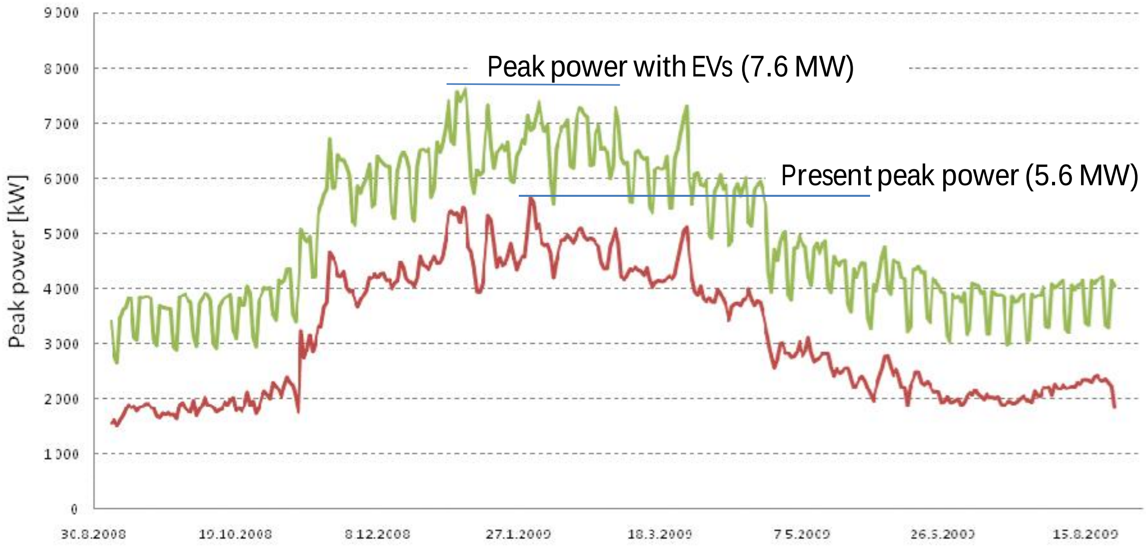
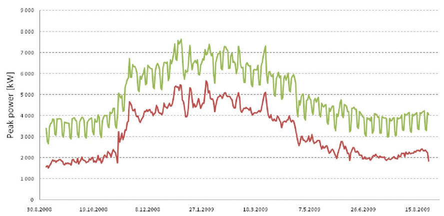
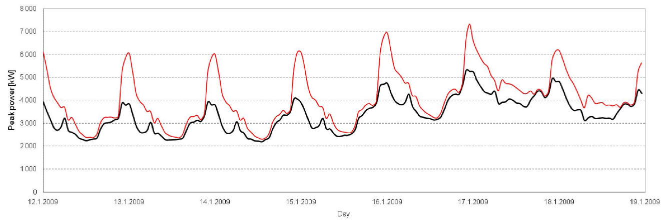
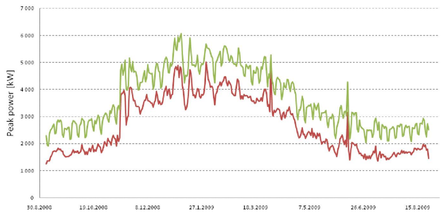
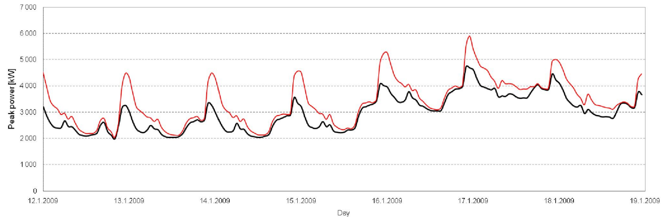
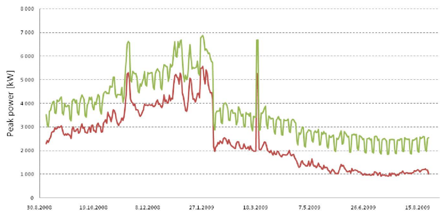
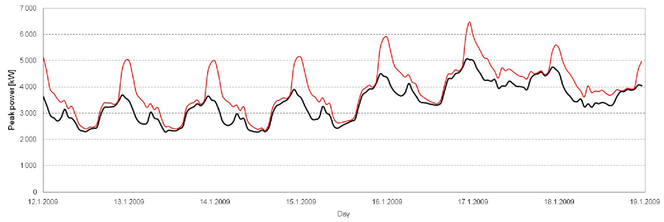
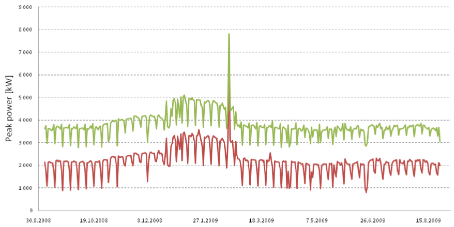
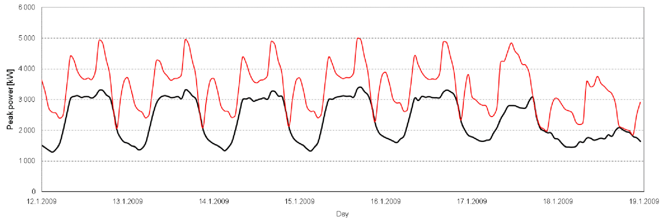
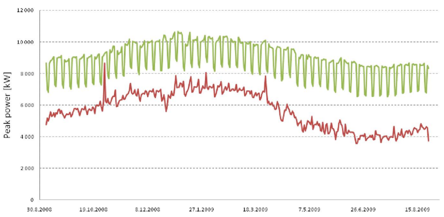
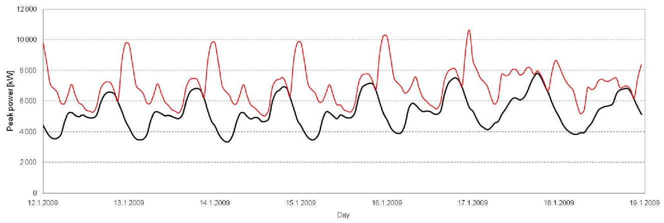
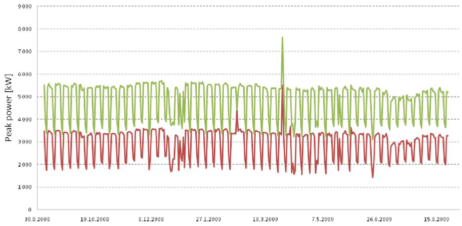
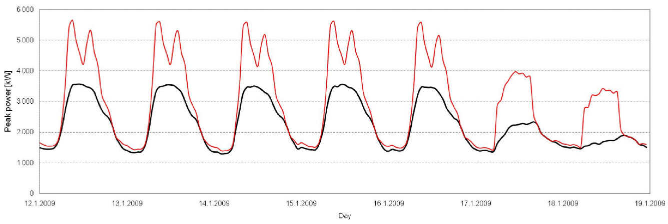


Figure 4. One-year load curve with EVs (the topmost curve) from the feeder 1. The bottom curve illustrates the powers without EVs. The curves include the peak powers of each day; the minimum loads of the days are not presented.

Table 2. Present load curve (bottom) and load curve with EVs (top) for one year. The third column presents the load curve (bottom) and the load curve with EVs (top) for one week (the peak week of the year). The number of EVs in workdays; HH = household, WP = work place and S = service.

Feeder	Present load curve (lower) and load curve with EVs (upper) for one year	Present load curve (lower) and load curve with EVs (upper) for one week (peak week of the year)
Feeder 1 HH: 1649		
Feeder 2 HH: 980		
Feeder 3 HH: 1153		
Feeder 4 HH: 1593 WP: 120 S: 800		
Feeder 5 HH: 4061 WP: 110 S: 102		
Feeder 6 HH: 118 WP: 1210 S: 300		

On feeder 3 the consumptions decreased significantly at the end of January. This is because the new primary substation was taken into use and some of the consumption was transferred to this new substation. Also the peak that can be seen in the figure above in the feeder 6 occurs most probably as a result of a change in the connections resulting for instance from a fault.

Figure 5 depicts feeder 1 with different penetration levels. The black curve shows the power measured from the feeder without electric vehicles. The red line shows the effect when the penetration level is 100 % for electric vehicles, and the gray one plots the 50 % penetration level of electric vehicles.

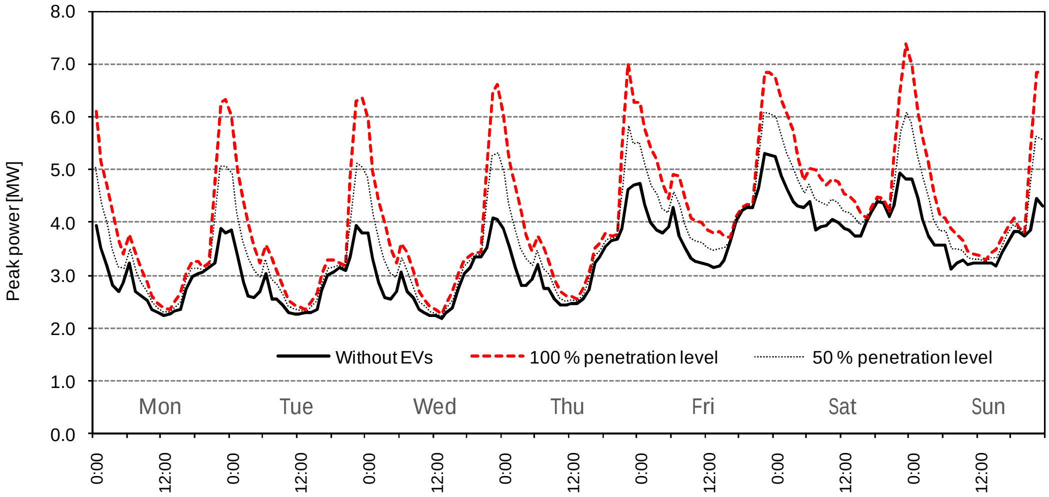


Figure 5. Feeder 1 where over 90 % of the delivery sites are detached houses with electric heating, and the household charging curve is used. The black curves shows the situation without EVs, the purple curve illustrates the situation where all of the vehicles are EVs, and the gray one shows the effect on the network with the penetration level of 50 % of all EVs.

Figure 5 shows that the power on the feeder and the peak load increase. The main reason for this is that the feeder has mainly detached houses with electric heating, and the warm water boilers turn on in the evening. Optimal charging would shift charging to the daytime, but this is the time when people are at work with their vehicles. A slight shift in charging would help in reducing the peak load of the feeder. If the charging started a few hours later, the peak would be smaller but there would still be enough time for charging; this holds especially for a “normal” evening, when it can be assumed that the vehicle battery is not empty when the charging starts. Figure 6 presents feeder 4 and the effect of electric vehicles on the total power at different penetration levels of EVs.

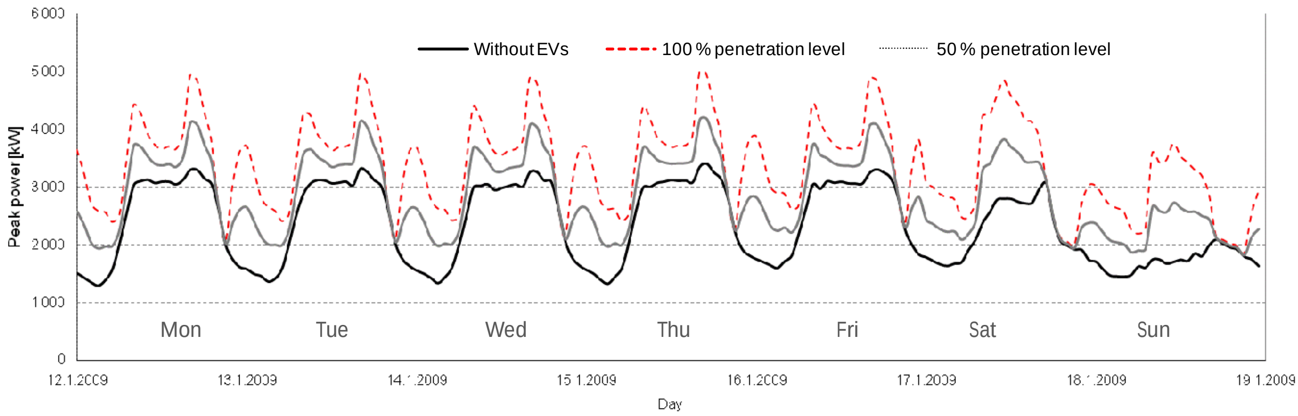


Figure 6. Feeder 4 where households account for 1/3 of the total consumption, the rest coming from the offices and service sector. The number of parking places is estimated to be 800 for the service sector and 100 for the offices.

On feeder 4, all the charging curves are used. Figure 6 shows that some peaks appear also during the weekend. This is due to the apartment houses that are located in the area, but the peaks are smaller than during the weekdays when the normal consumption is high and also the electric vehicles are charged at the same time. Optimal charging on this feeder could help to reduce the peak but the peak would still occur during the office hours.

Even though in the worst case the peak increases from 3.1 MW to 5.1 MW on feeder 4, the calculations show that the load factor increases above 100 % only at a few secondary substations, and in general it seems that the distribution network can handle EVs also with the 100 % penetration level. Half of the secondary substations where the load rate increases above 100 % are small pole-mounted transformers (100, 200 and 315 kVA). In those cases, reinforcement investments will be made when the load increase requires it.

Demands for network development

Depending on the charging method, the peak load may increase considerably on the distribution network. This means additional investments in larger cross-sections of underground cables and overhead lines, and more transformer capacity. The amount of investments required can be estimated by defining the average marginal cost of the network. It is based on the network replacement value and the maximum load of the year, and it describes how much the network capacity has cost for the distribution company per each peak load kilowatt. The analysis is performed for each part of the network (400 V low-voltage networks, 20 kV medium-voltage networks and 110/20 kV primary substations). In this case, the network value compared with the peak load is 360 €/kW in the low-voltage networks, 230 €/kW in the medium-voltage networks and 100 €/kW at the primary substation level (110/20 kV). At the medium-voltage and primary substation level, a statistical approach of additional load can be taken because the load is well balanced. In the low-voltage network, it is more likely that different loads overlap each other. A typical peak operating time in the low-voltage networks is 2000 h/a, in the medium-voltage networks 3500–4500 h/a and at the primary substation level 4500–5000 h/a. In the low-voltage networks, an additional load is difficult to adjust to those time periods when the existing load level is low. On the other hand, there are numerous reasons for the present individual peak loads, such as saunas, electric heating and vehicle electric pre-heating systems, which can be adjusted thereby avoiding the overlapping of peak loads. In the worst case, the additional load in the low-voltage network will be 3.6 kW/car.

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Figure 4 illustrates the principle of defining the average marginal cost of reinforcement in the medium-voltage feeder. The estimated additional power because of vehicle charging is 2 MW (total peak 7.6 MW). If the average marginal cost on the feeder is 230 €/kW, the estimated need for reinforcement is

$$\begin{aligned} &\text{Reincorcement} = \text{Average marginal cost} \cdot \Delta P \\ &= 230\ \text{€/kW} \cdot 2000\ \text{kW} = 460\,000\ \text{€} \end{aligned} \quad (1)$$

The additional network investments are paid by the end-customers. Because the replacement value of the case network is 17 M€ (1 M€/a calculated by p = 5 % and t = 40 a) and the annual delivered energy on the case feeders is 117 GWh, the network value per delivered energy is 0.86 cent/kWh. The estimated additional annual charging energy required by electric vehicles would be 44 GWh (about 12 000 cars, 18 200 km/car,a and 0.2 kWh/km,car). Depending on the charging method and the voltage level analysis of the power increase, a rough estimation of the required investments in a new transformer and transmission capacity in the whole distribution network would be 0–7 M€ (0–415 k€/a), which is 0–650 €/customer. The new distribution fee would be 0.63–0.88 cent/kWh after the network reinforcement. This fee range shows that when the peak power of the network increases more than the delivered energy, the distribution fee will increase. If the additional charging load has only a slight effect on the peak power, it is possible to cut the distribution fees.

Charging optimisation

Charging of EVs may place significant development requirements on the distribution infrastructure. Because of this, the question of charging control and optimisation becomes relevant. In the study, it was investigated whether it is possible to get all the required energy without increasing the peak power in the network. This is of course more or less a theoretical case, but it provides good perspective on the technical limits of the infrastructure.

In Figure 7, the principle of optimised charging is shown. The increase in the load level depends on the basis load as illustrated in the figure. The peak power in a residential area occurs usually in the evenings when the heat storages are switched on automatically at the same time. It can be seen that in this case it is possible to take all the charging energy needed for cars without increasing the peak power on the feeder on the example day. The increase in smart metering and other smart technology in networks provides an opportunity to control the loads more easily than today. This will be the situation also with EVs.

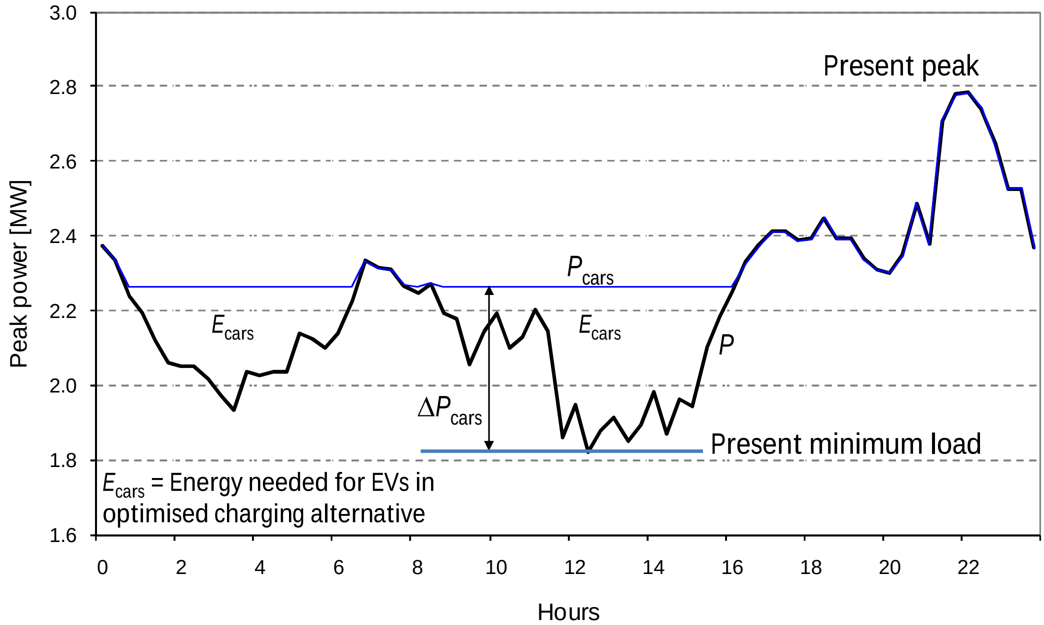

Figure 7. Optimised charging model for a case day. The lower curve represents the existing peak load of the day, while the upper curve represents the load when the charging power is taken into account.

Next, an optimisation method is applied to the case feeders. The target is to find out whether it is possible to avoid an increase in the peak power by charging optimisation. The time window of the charging and discharging is limited to one day (24 hours); all the energy needed for daily driving is charged in the same day. Based on the analyses in the case network in the optimised charging method, the required energy can be adjusted to hours with a low load level so that the peak power of a certain feeder does not increase at all. An example of optimisation on Feeder 1 for one week is presented in Figure 8.

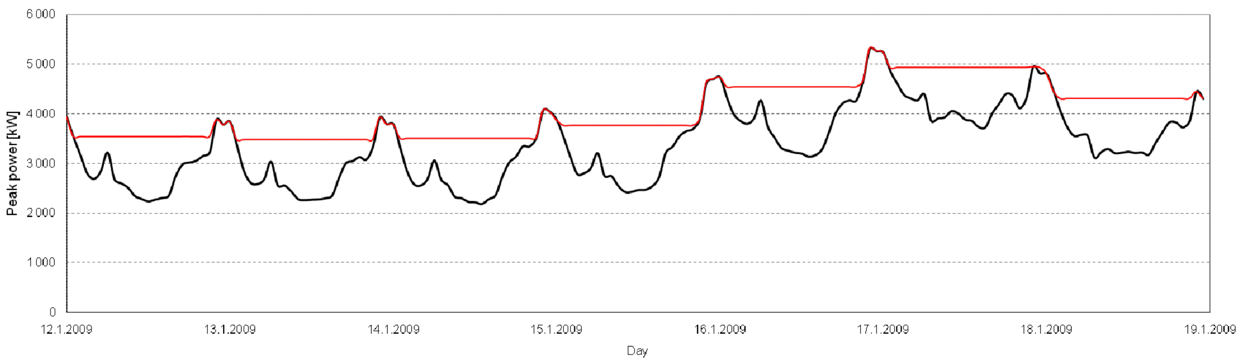

Figure 8. Optimised charging (red curve) for Feeder 1. All the energy for EVs can be taken from the network without increasing the present peak power.

In the case area there are also feeders on which the number of EVs and the present load curve create a situation where an increase in peak power cannot be avoided even if the charging is optimised (Figure 9, feeder 4).

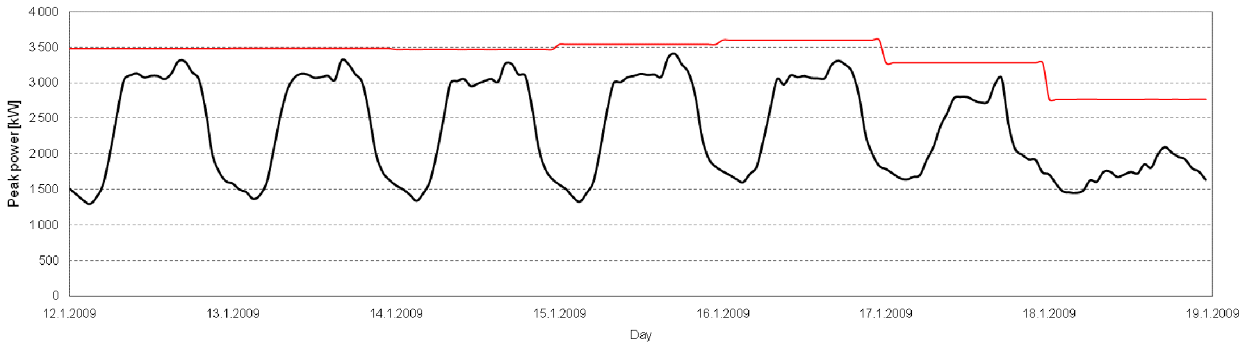

Figure 9. Optimised charging (red curve) for Feeder 4. All the energy for EVs can be taken from the network without increasing the present peak power.

In the feeder 4 there are lot of service parking places (around 800) and this causes uncertainty to the actual charging load. Most of the parking places are located in the same area and they belong to the same enterprise. It can be assumed that these parking places are not ever 100 % reserved and that way charging load is not high as estimated in previous analyses.

In Table 3, the present peak power, the peak power with EVs (100 %), the peak power with charging optimisation and the reinforcement needs are presented.

Table 3. Summary of the feeder-specific results. The present peak power, the peak power with EVs (100 %), the peak power with charging optimisation and the reinforcement needs. MV = medium voltage (20 kV).

	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6
Present peak [MW]	5.6	5.0	5.5	3.7	8.0	3.6
Peak with EVs [MW]	7.6	6.0	6.8	5.0	10.6	5.7
Peak increase in MV network	136 %	120 %	124 %	135 %	133 %	158 %
Peak with optimized charging [MW]	5.6	5.0	5.5	3.6	8.0	3.6
Reinforcement needs in MV level [M€]	0.46	0.23	0.30	0.30	0.60	0.49

In this scenario, the total additional load without load control for the case feeders in the medium-voltage network will be 10.3 MW. An estimation for reinforcement needs is 2.4 M€. When the reinforcements of the low-voltage networks and 110/20 kV primary substations are taken into account, the total reinforcement investments will be 7 M€. This way, the replacement value of the case network would increase by 41 % from the present 17 M€ to 24 M€.

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Electric vehicles as energy storages

There are incentives to consider an electric vehicle as an energy storage to decrease the peak load and to smooth the load curves. As seen for instance in Fig. 7, the hourly load varies greatly in distribution networks. This is illustrated also in Fig. 10 where the annual load measurement of a medium-voltage feeder is presented. The question is, how much the peak power could be decreased by utilising electric vehicles as energy storages on the network, and secondly, how it would affect the future reinforcement needs in the network? Furthermore, what are the requirements for the vehicle charging system to make it possible?

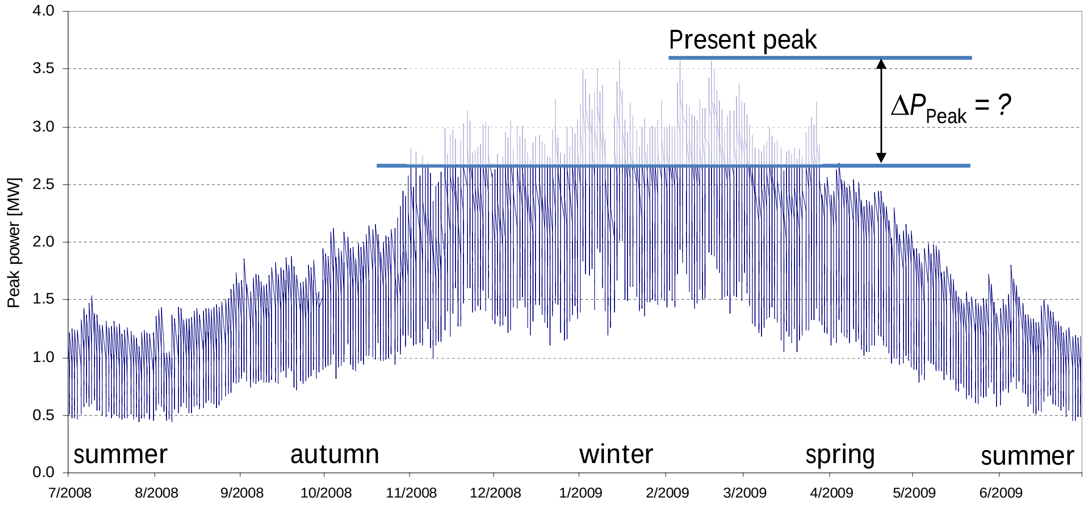

Figure 10. Annual load curve of the medium-voltage feeder and the question of potential to decrease peak power by energy storages.

The analysis method to define the effects of energy storages on the distribution networks is based on optimisation of charging and discharging moments, taking into account the physical limits of storages, the energy needed for driving and the shape of the basis load curve.

From the distribution system operator's point of view, an interesting question is whether it is possible to decrease the present peak load by using electric vehicles as energy storages on the network. This could be done by charging the additional energy to electric vehicles and discharging batteries on peak hours. A balance can be found by taking into account the basis load curve of the feeder, the energy needed for driving and the capacity of batteries to store and discharge additional energy (Fig. 11).

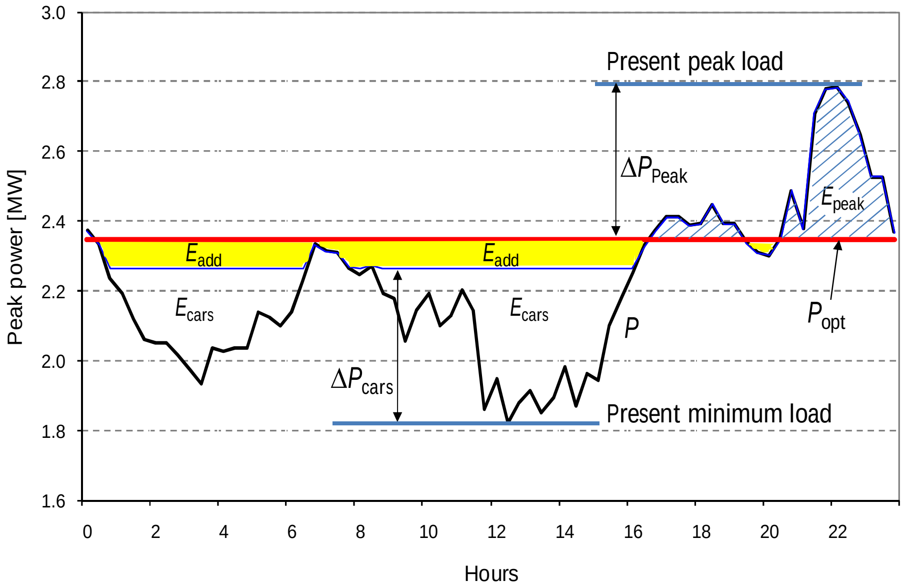

Figure 11. Additional energy (E_{add}) needed to decrease the peak load.

The opportunities of energy storages (V2G, vehicle to grid) from the perspective of the distribution infrastructure will be studied in the coming SGEM program.

Summary

The key target of this study and report has been to demonstrate a methodological approach to evaluate the network effects of electric vehicles in an actual distribution utility. The study has been carried out in cooperation with LUT and Fortum.

At the beginning of the project, network information was gathered and the number of vehicles in the case area was defined. Information of the registered vehicles and the number of public parking places was gathered with the help of the City of Espoo and the company that maintain the registration of registered vehicles. The case area was chosen so that it reflects the whole distribution network at a certain level. That way, the results of this study can be adopted more widely in the company. After information gathering, load modelling for the case network area was carried out. In this phase, feeder-specific information of EVs with appropriate charging profiles was applied both to the research analysis tool and a network information system. In the final phase, the modelling results were estimated from economic perspective; what are the economical consequences of EVs for a distribution utility and for electricity end-users.

The main results are:

- Intelligent control of charging of EVs is strongly recommended in order to avoid a) unnecessary reinforcement investments and b) an increase in distribution fees paid by the end-customers.
- Without intelligent control of charging, the load growth can be significant, varying from 20 to 50 % in the case feeders.

- Even though intelligent charging is possible, it does not cut the peak on every feeder because of variation in customers on each feeder. On some of the feeders, optimal charging would mean that charging should take place in the daytime, yet this is impossible because the vehicles are not there then.

- Utilisation of energy storages is needed on some feeders to avoid the peak increase

- To understand the network effects of EVs, the present electrotechnical condition of the distribution network has to be studied first, and careful estimation of the penetration schedule has to be made.

- More efforts have to put for developing charging profiles which consists both normal household consumption load curve and EV charging curve for different purposes (for instance unoptimised and optimised charging and variations of these)

Additional charging powers defined in the study require expensive reinforcement investments if charging of EVs is not intelligently controlled. First, load control and possible reinforcement investments are needed in low-voltage networks. Overlapping of different loads (electric heating, sauna, EVs of customers in the same secondary substation) is more probable and significant than in the medium-voltage networks. In the medium-voltage networks, distortion of loads (timing and volume) is more common, and load overlapping is therefore not such a problem as in LV networks.

When evaluating the results of this study, certain issues have to be taken into account. There is uncertainty especially in the following areas:

- Definition of the total number of cars (and EVs) in the case area (penetration level)

- Definition of the feeder-specific locations for EVs

- Charging profiles (where, when and how much EVs are charged)

- Charging optimisation presented in the study is only a theoretical approach to define the most optimistic case.

The marginal cost method can be used when evaluating large-scale needs for renovation investments. The method cannot be used to define the exact amount of money needed for feeder or secondary substation renovation. At that level, renovation needs have to be estimated by target-specific renovation planning.

In the coming studies, an approach at a secondary substation level will be taken. This work will be based on customer-specific hourly measured AMR data, where implementation of different EVs charging profiles is carried out. The research will provide answers considering overloading challenges in low-voltage networks. Based on these studies, reinforcement needs in LV networks can be defined more reliably. Moreover, an evaluation of the present network information system considering LV network calculation in the case company can be performed.

Secondly, in the future studies, EVs as energy storages in the network (V2G) will be studied in the case area.

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