What requirements will electric vehicles bring to the internal networks of real estates

Abstract

Electric vehicles (EVs) are providing a reasonable option for conventional vehicles in the near future. The car manufacturers are constantly announcing new models of EVs and plug-in hybrid electric vehicles (PHEVs) and the real estate's internal network needs to be ready for the upcoming trend of chargeable vehicles. The aim of this research is to study the adequacy of the existing car pre-heating networks of internal networks of real estate's to slow EV and PHEV charging (around 3 kW per vehicle) and to consider reasonable improvements to inadequate networks. Also some required enhancements to new vehicle charging/pre-heating networks are considered.

Seven example cases showed that existing pre-heating networks can support vehicle charging fairly well. The amount of EVs the network can sustain depends mostly on the sizing of the pre-heating infrastructure. The construction year also has an effect as some of the older electricity networks have to be completely renovated before vehicle charging can be considered because the cables are too small. Also existing electricity networks of smaller buildings such as row houses can usually sustain relatively more EVs and PHEVs than bigger apartment buildings.

Almost all real estates can provide charging at least for few EVs or several PHEVs without major improvements. But if and when the penetration level of EVs and PHEVs increases, the maximum electric load will grow substantially. This might prove troublesome to some real estates as they have old and tightly fitted electricity networks and so some upgrades need to be made. It is recommendable to make these necessary improvements when there are some other renovations going on to decrease the costs as the charging network upgrade usually isn't acute.

Introduction

EVs and PHEVs are widely recognized as a highly potential replacement for the conventional combustion engine vehicles for their lower energy consumption and greenhouse gas emissivity. Nowadays conventional vehicles pollute about 150 g/km while with current Nordic energy production infrastructure EVs emit only 15 g/km and PHEVs around 53 g/km [1]. At the same time conventional vehicles are using Earths diminishing resources of fossil fuels while EVs can use cleaner energy e.g. wind energy.

This research is concentrating in charging of EVs and PHEVs in low-voltage networks at home and what requirements they bring to the real estate's internal networks. Nordic countries have existing pre-heating infrastructure in most places due to the cold weather. This infrastructure can be used with fairly small changes in the first phase when the penetration level of EVs and PHEVs is low. With larger penetration level most of the existing pre-heating infrastructures need improvements to withstand a full-scale vehicle charging. In this study this is referred as the second phase.

According to a survey average driving distance per car is approximately 57 km per day[2]. From that is estimated that each EV requires 11,5 kWh per day[3]. Comparison to this Toyota Prius PHEVs batteries hold 5,2 kWh [4]. These figures are used in this research to evaluate the required charging infrastructure.

Large scale vehicle charging will increase the energy consumption of the real estate significantly and in some cases the real estate's electricity invoice will grow significantly if the main fuses need to be enlarged. This is due to the structure of the electricity invoice which is based on two things: used energy and the size of the real estate's electricity connection.

Requirements of the charging stations

The requirements of the charging stations vary with the installation location. Aim of this research is to study residential buildings so the requirements are considered for that purpose. In residential buildings it is reasonable and economical to install low power charging systems that are relatively slow. This requires one-phased (230 V) 16 A power input for each charging station. This would give around 3 kW of charging power and with it a regular 30 kWh battery of an EV would be charged in 10 hours or less. In most cases it can be assumed that the battery is not totally empty and due to this the charging time will be less. PHEVs on the other hand have much smaller batteries (Toyota Prius 5,2 kWh [4]) and therefore charging time decreases to few hours. This way PHEV charging could easily be scheduled to later night when the EV charging peak has passed.

Also some (or all if needed) charging stations could be equipped with three-phase 16 A inputs which would be three times faster than the one-phased system. If all charging stations would be installed as 3-phase systems, the load would grow greatly and some kind of load control system would be needed to keep the total load at reasonable level. However, the 3-phase charging system would be faster than 1-phase system. Higher than 3-phase charging system would be uneconomical and unnecessary in residential buildings.

Moreover, charging stations also need at least an appropriate charging post and mandatory electric shielding systems. The shielding systems include a fuse/circuit breaker and a fault current switch [5]. In addition, the charging station must have some kind of a locking mechanism. In residential areas where each parking lot is user-specific, the best solution would be a lock that can be opened with a specific key. However, this wouldn't work in public charging stations where everyone must have access to vehicle charging. There one option could be some kind of an e-mobility system that could be operated via phone [1]. It is also recommendable to install electricity meters to charging stations so that everyone will pay for their own charging. Like in normal pre-heating posts, it is reasonable to put at least two charging stations into one charging post in order to decrease the costs.

In Finland the charging stations cannot fully replace current pre-heating post because in the winter we still need car pre-heaters. One solution in the market is to put two sockets to each charging station, other one for charging and the other for pre-heating. This would make the station relatively big and so a better solution could be an intelligent charging and heating with the same socket. However, charging and heating cannot be on simultaneously due to the size of the load. This system would work so that the charging would stop when the heater turns on. Depending on the weather this change would happen about 0,5 – 2 hours prior to the user set time when the car needs to be ready.

Real estates requirements

Each charging station requires 3 kW of power which can be provided by a 1-phased 16 A input. In Finland parking station electrifications are normally installed as a cascade network. This would also work well with the EV charging e.g. a three-phased 64 A feed with a 4*16+16s mm^2 cable can electrify around 12-15 charging stations (or 6-7 charging posts). So depending on the size of the parking area it can be powered with a few 64 A feeds.

Alternative to cascade network is radial network. This could be useful especially in new real estates when the electricity network has to be built from scratch because the installation is rather different and major part of the expenses comes from digging. This type of installation would require more electrical wiring but it would be simpler and much of the required intelligence could be placed into same location. It has to be determined case-specifically which installation type is the most cost-effective.

Due to increasing loads the real estate needs heavier cables and bigger fuses. Some new real estates may already be designed to withstand the bigger load at some parts of its electrical network but especially the older real estates need major improvements if vehicle charging is made possible.

A large-scale EV charging will greatly increase real estates power consumption and may require bigger electricity connection. It is worth mentioning that increasing the size of the electricity connection effects directly to the electricity invoice. Another solution for the increasing power consumption is to divide the real estates energy consumption more evenly to the whole day by channelling vehicle charging or other suitable loads such as water boilers to a time when the other loads of the real estate are low e.g. at night. This way the maximum power taken by the real estate would remain reasonable and the electricity invoice relatively small [1].

There are several ways to divide the load which many require communication between charging posts and the switchboard. It is still unclear how communication will be done in the future, is it done by data cable or via wireless system. Therefore it is recommendable to install pipes where they data cables be installed later if needed.

Controlled charging

Controlled charging is essential when EVs and PHEVs penetration level rises because uncontrolled charging increases the load significantly both in the real estates internal network and in the whole distribution network. A large scale uncontrolled charging would require major improvements especially from the distribution network which would be costly. In internal networks of real estate's the increasing load may set up problems to cables and fuses. However, in most real estates electricity connections are already big enough to handle vehicle charging.

There are many different ways to control the load. Probably the simplest solution is the time based control where the charging is shifted to night time or some other time of lesser load. The timing of different chargers should be varied so that a simultaneous start-up and a sharp peak in the load can be avoided. Time control does not have to be rigid. The method can be dynamic and flexible in many ways. For example the

EVs could be prioritized by adjusting the timing process in accordance with the state-of-charge of the battery pack. Especially PHEVs can be charged at anytime due to their small batteries [6].

The simple uncontrolled night charging and the more intelligent controlled night charging are presented in the figure 1. Above are the charging patterns of EVs and below are their impacts on a normal electric network load. Here we see that using intelligent charging we get more even load profile which means that the network needs less improvements. [6].

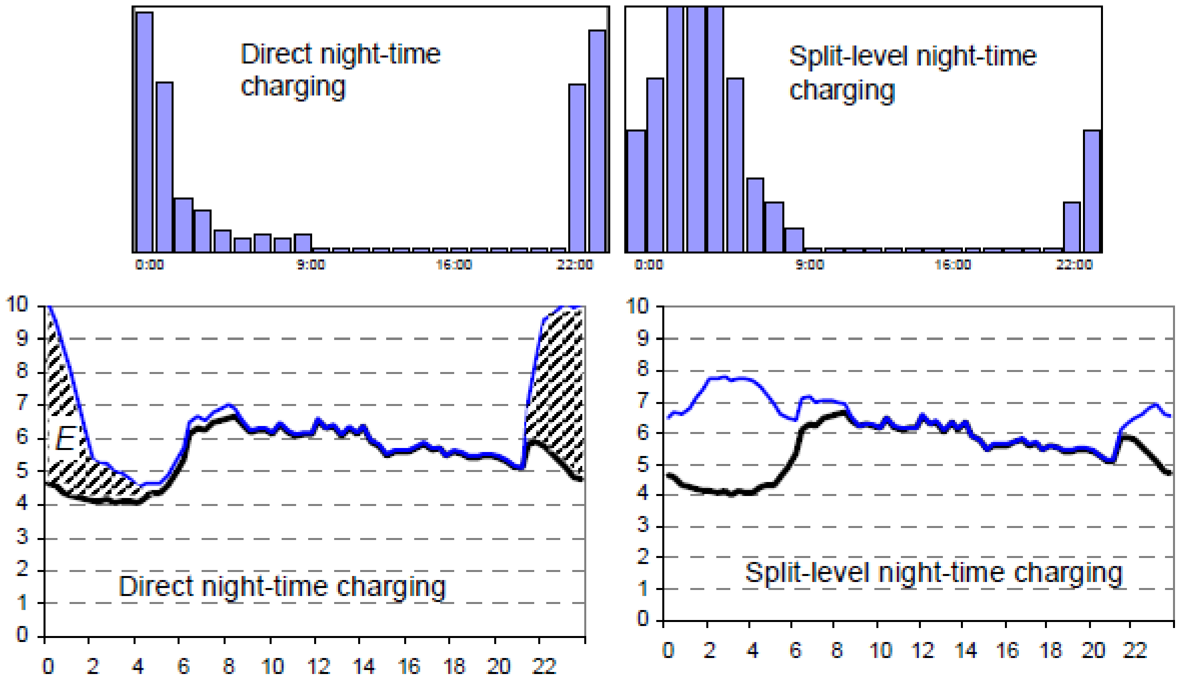

Figure 1. *Time-controlled charging of EVs. [3]*

Another way of keeping the load relatively small is by coordinating the loads of the real estate. In Finland, electric space heaters, electric sauna stoves and boilers are often coordinated with each other to keep the peak power down. The charging of EVs and other loads could also be applied to this alternating system. However in this kind of load control system the load prioritization would have to be carefully thought and balanced so that everything still gets the needed energy.

Automatic meter reading (AMR) and communication systems between real estates and network providers enable a number of new control methods. In communication based control chargers interact actively with information system managed by a service provider. Based on network calculations and measurements, the system can make decisions and give information or operation instructions to the real estate which then share the available power to its loads. [6]

Very intelligent charging control systems may be too expensive compared to their benefits for real estate owners. So choosing the right control system must be made case-by-case as the best solution might vary case-sensitively.

Sufficiency of the current electricity network of real estates

Current electricity networks of residential buildings are not fitted to full scale EV charging because they are designed to the smaller loads of car pre-heating. In this research seven example cases have been studied to get a picture of different kinds of real estates readiness for EV charging. The current capability was estimated by how many vehicles can be charged with 3 kW power when there is no pre-heating load in the network. These seven cases are presented in table 1. This shows that none of the buildings can withstand a full scale EV-charging but they all are able to sustain at least 25-55 % EVs of all vehicles without major improvements. The oldest building (built 1979) however has a TN-C –network system which does not support EV charging because it does not have separate earth conductor so the harmonics build up in the PEN-cable could become hazardous with vehicle charging. [7]

Year of construction	Renovated	House type	Number of parking slots	Max charging stations	%
2004	-	apartment house	55	19	35
2002	-	detached houses	114	63	55
1995	.	apartment house	22	12	55
1967	1995	apartment house	48	12	25
1956	1995	apartment house	29	24	83
1987	-	apartment house	50	36	72
1979	-	row house	40	20	50

Table 1. *Example cases readiness for EVs.*

In figure 2 is presented a simplified electricity network of one of the example cases. This shows the parts where the EV charging effects: The main fuse, real estates internal fuse, connectors between vehicles and main fuses and the vehicle charging/pre-heating infrastructure. The current pre-heating infrastructure doesn't support full-scale EV charging as it can provide enough power only for 19 places of all 55 so for full-scale EV charging the pre-heating infrastructure must be upgraded. However, with a smart charging system the current infrastructure could be used to charge even more vehicles especially PHEVs due to their smaller batteries which require less energy than EV-batteries. Also some kind of power restriction system may need to be used when a tightly fitted pre-heating infrastructure is used for vehicle charging and car pre-heating simultaneously. If pre-heating is allowed at same time as vehicle charging, the number of chargeable vehicles drops significantly.

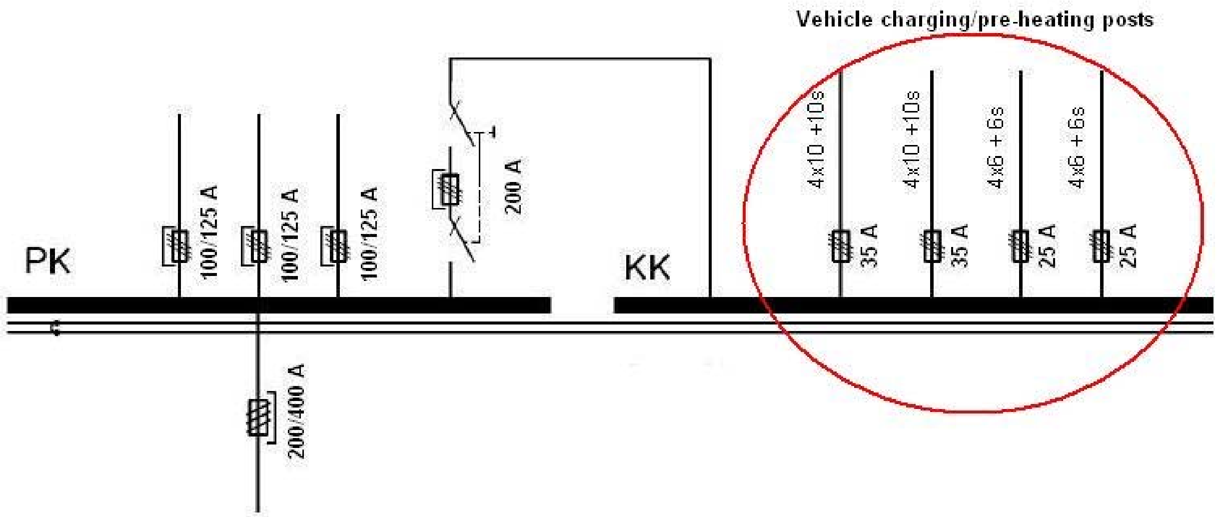

Figure 2. *Simplified distribution circuit of the example real estate. Most critical part is highlighted*

In the study was used EV charging curve where charging is mainly taking place during the night-time and needed energy is 11.5 kWh/per vehicle. Used curve is a simple way of controlling vehicle charging and it is shown in figure 3. In figure 4 is presented the example case's peak load week of the year with and without full-scale EV charging and maximum load endured by the main fuse. This shows that at least in this case the electricity connection is properly fitted and that the EV charging will not be a problem for it. So the most critical part seems to be the pre-heating infrastructure as the fuses endure the peak load easily.

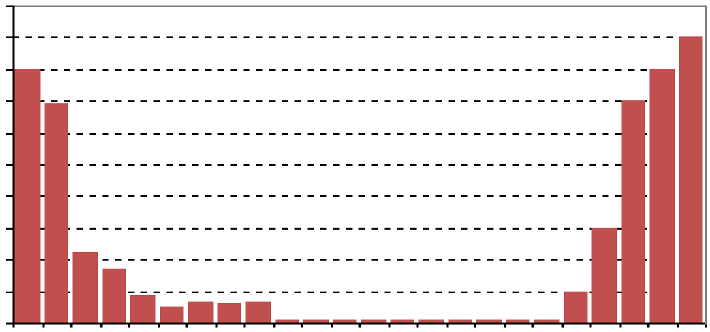

Figure 3*. Household charging curve*

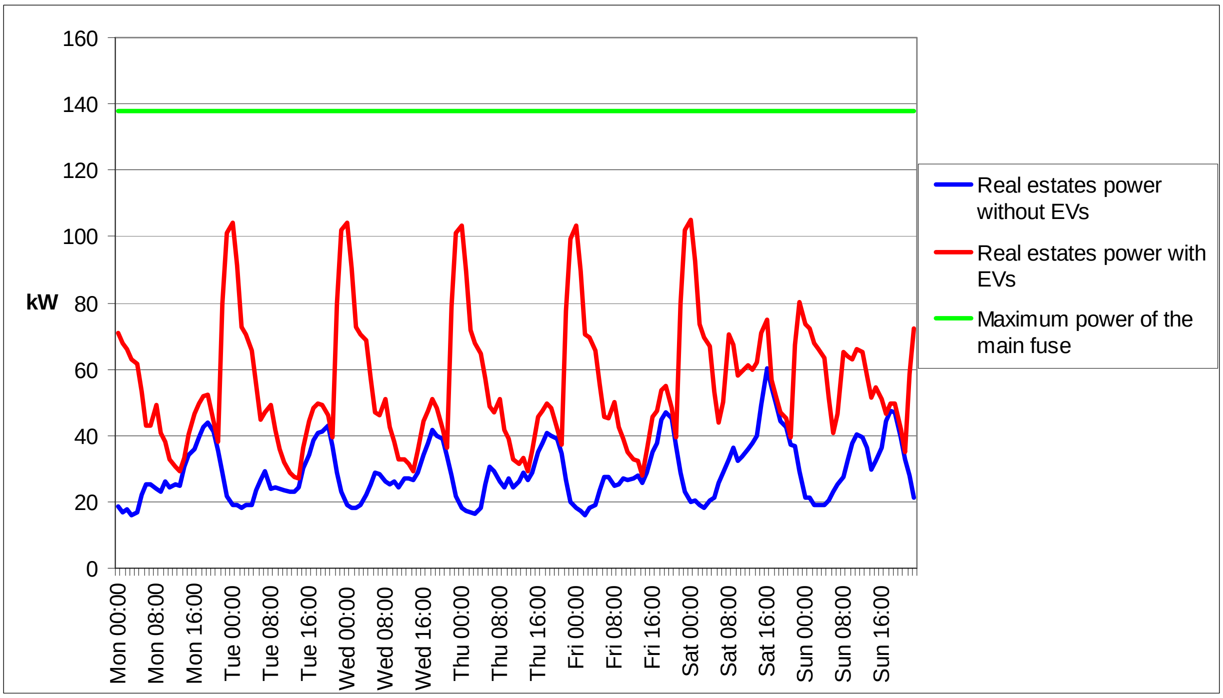

Figure 4. *Example case's peak load week of the year and maximum load endured by the main fuse.*

Without any charging control the peak load of vehicle charging would occur at the same time as the present peak load which could prove to be a problem for the real estate. However, even a simple charging control system prevents problems in real estate's electricity connection and the only real problem is the limitedness of the charging infrastructure which can be dealt with better control systems or preferably by renovating the charging infrastructure. It is also worth noting that PHEVs require much less energy than EVs and this lowers the real estate's energy consumption and provides more options to load control. That way the real estate could support even more chargeable vehicles.

Feasible enhancements to the electricity networks

The example cases show that internal networks can endure EV-charging fairly well without any major reinforcements. At first the existing infrastructure could be partially used for vehicle charging by changing pre-heating posts to charging posts. At this phase it would be reasonable to use some kind of power restriction system so that the limited capacity of the charging/pre-heating infrastructure will not be surpassed. However, in this phase the total load will stay relatively small so complicated load control systems will not be needed.

Due to increasing amount of EVs at some point the charging/pre-heating infrastructure has to be updated to withstand full scale EV-charging. It is best to make the improvements when other renovations are being made to decrease the costs. For the same reason new buildings electricity networks are best to fit for full-scale EV-charging in the construction phase. In full-scale EV charging the real estates required power may grow so much that some kind of intelligent load control system might be needed. Also the electricity distribution companies might be interested to keep the loads down at maximum load times to restrict the peak loads of the distribution network.

Conclusions

Almost all real estates can provide slow charging (3 kW) at least for few EVs or several PHEVs without major improvements. But if and when the penetration level of EVs and PHEVs increases, the maximum electric load will grow substantially. This researches seven example cases show that existing pre-heating networks can support vehicle charging fairly well. The amount of EVs the network can sustain depends mostly on the sizing of the pre-heating infrastructure as the real estate's electricity connection is usually big enough to support vehicle charging. The construction year also has an effect as some of the older electricity networks have to be completely renovated before vehicle charging can be considered because the cables are too small. Also existing electricity networks of smaller buildings such as row houses can usually sustain relatively more EVs and PHEVs than bigger apartment buildings.

In addition to electrical network enhancements EV and PHEV charging require improvements also to the pre-heating posts as they do not adept to vehicle charging as such. The easiest way is simply to change the existing pre-heating post to a charging post. Some manufacturers already have nifty solutions for this.

At the first phase when EV charging is small-scale the electricity connection doesn't need reinforcing. Also complex load control methods are not needed in this phase. It is only necessary to restrict the load so that it won't damage the limited charging/pre-heating infrastructure. In the second phase with large penetration level most of the existing pre-heating infrastructures need improvements. In many cases the whole electricity network especially the parking lot's charging/pre-heating infrastructure has to be rebuilt and in new cases we can design and build the infrastructure to withstand the increasing load of the EVs from the start.

The main fuse size can be kept relatively small by channelling EV charging or other controllable loads to a time when the real estates other electricity consumption is at its minimum. At the simplest this can be done by using a simple timer but more sophisticated methods are also considered. From real estates point of view it is necessary to restrict the load so that it won't damage the vehicle charging infrastructure. Other control methods are not needed because the internal networks are usually well fitted. However, the distribution network needs more controlled charging due to increasing peak loads. So the real estates need to be persuaded to channel their vehicle charging to a time of low load e.g. to night time.

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