# Peak load management in internal networks of real estates with plug-in vehicles

Rautiainen, A., Repo, S., Järventausta, P., Valavaara, T.

Tampere University of Technology, P.O. box 692 FIN-33101 Tampere Finland (e-mail: antti.rautiainen@tut.fi)

## Abstract

In this project report, different motivations for peak load management systems were discussed and principles of a few peak load management methods were presented. Three different main drivers for peak load management were recognized: possibly too small main fuses of the customers' electricity connections, too small current capacity in internal networks such as feeders of the pre-heater sockets of parking places and possible application of demand tariffs in the future. Peak loads can be managed by switching loads off and on, and some loads, for example plug-in vehicle chargers could be adjusted if appropriate control system was available. If methods such like the ones presented in this paper would be applied in real life, the systems have to be designed case-by-case.

## 1. Introduction

Transportation has a very important function in today's society. Globally, the energy production of transportation systems is highly dependent on oil, and there are strong expectations that the price as well as the volatility of the price of oil will increase in the future. The transportation sector is also a significant consumer of energy and a significant source of greenhouse gases and other emissions [Dav09]. Today's climate and energy policies imply strongly towards diversification of transportation fuels, improving energy efficiency and reducing emissions. The use of electrical energy in a broader manner by means of plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV) offers a potential to partly fulfil these challenging requirements. Emission reductions and the amount of primary energy conservation due to plug-in vehicles are, however, highly dependent on the energy system. Plug-in vehicles are only a single way to contribute to reduction of oil dependency, reduction of primary energy consumption and reduction of $CO_2$ emissions. It seems obvious that to achieve sustainable transportation system many other ways are also needed. Such ways are for example reduction of fuel consumption of conventional internal combustion engine based cars, development of bio fuels or other alternative fuels and development of public transportation such as electrical rail traffic.

There are some barriers related to high penetration of plug-in vehicles (PHEV and EV). It is, however, widely believed, that PHEVs and EVs will become common at some time frame, but there are differences of opinion about when and at what rate the market penetration will happen. The most important barrier is the battery technology. Technologically batteries are fairly good at the moment, but batteries suitable for transportation appliances are very expensive. However, the prices are expected to decrease remarkably in the near future [Lac10]. Secondly, a lack of adequate charging infrastructure is a major barrier. It is fairly expensive to construct wide charging infrastructure especially in densely populated areas.

Vehicle chargers affect the power system in many ways. Impacts on the energy production capacity, transmission networks, medium voltage networks, low voltage distribution networks and residential low voltage networks are very different in nature. Plug-in vehicles are not very big loads, when compared to electricity consumption in Finland, when considering the amount of energy absorbed. However, plug-in vehicles *can* be big loads when considering instantaneous power. A remarkable penetration level of plug-in vehicle increases the loading level of the power system, which might influence the dispatch of power plants and thus the specific $CO_2$-emissions of energy production. The impact on the dispatch depends on the timing of charging and the level of charging load. In the transmission network level the impacts of plug-in vehicles are probably minor, being mostly a small, usually negligible, reduction in stability margins due to load increase. In medium voltage and low voltage networks the impacts are, without counter actions, probably the rise of peak load levels in some parts of the network [Las09] and possible temporary over loading situations. Plug-in vehicle charging can raise the peak loads in the electricity networks of real estates which can have some consequences. These peak loads could be managed by certain systems.

In this paper, incentives and methods for local peak load management in internal networks of real estates are discussed.

# 2. Motivation for peak load management systems

Real estates' electricity grid connections have limited current capacities which are determined by the rating of the main fuses. The maximum current capacity can be exceeded due to charging load especially if "semi fast" (three-phase, ~15 A) charging is used. For example, in Finland, three-phase sockets are widely available only for inhabitants of detached houses and semi-detached houses. In addition to exceeding the rating of the main fuses, plug-in vehicle charging can also cause exceeding of the maximum current levels of *some parts of the internal network*. Maximum current capacities can be exceeded in the today's preheating feeders of the parking places of the row houses or apartment houses if large number of slow chargers (one-phase, ~15 A) connected simultaneously [For11]. The capacity of the network connection can be enhanced by enlarging the rating of the main fuses, but this brings additional costs and if this is applied broadly, it can lead to extra network enforcement investments for the distribution network operator (DNO) and hence to an increase in transfer tariffs. If the capacity of some parts of the the internal network is not sufficient network upgrades are needed.

In addition to previous drivers, a possible application of *demand tariffs* in electricity distribution may offer incentives to restrict the peak load of a network connection. In this case, the main point is to manage the peak *power* and not the peak currents. The methods which manage *currents of the network* cannot be necessarily perfectly used to manage *powers* *of the network connections*. This is because the voltage levels of the network may vary typically a few percents from the nominal value. However, the uncertainty caused by this is fairly small and often negligible, but should be considered in system planning. If the transfer tariff is based totally or partly on the peak power, for example to *highest hourly mean power*, of the network connection, some financial savings can be achieved by management of peak loads. Demand tariffs offer network companies a tool for better utilization of distribution networks, although these kinds of tariffs are not applied in Finland today for small customers such as residential houses. Network companies are, however, interested in the possibility to apply demand tariffs, as the installation of smart meters could make this possible. Properly designed demand tariffs could bring benefits both to network customers and network companies, as the utilization rate of the network could be increased.

Different types of demand tariffs could be developed. Different tariffs have different features and effects on the total transfer fee and thus to consumer behaviour. Tariffs can be based on hourly measurements, but the length of the *measuring period* could also be something else. The smart meters in Finland are able to measure hourly energy values, but capability to do measurements of some other measuring periods depend on the meter type.

Typically demand tariffs include a basic charge and then a fee based on real transferred energy. One possibility is that the *transfer fee* $H$ for a certain time interval including $N$ *measuring periods* corresponding to transferred energies $\{E_1, E_2, \dots, E_N\}$ during those periods would be

$$H = a + \sum_{i=1}^{N} b(E_i) \cdot E_i, \tag{1}$$

where $a$ is a basic charge, $E_i$ is the amount of energy transferred (in kWh) during the period $i$ and $b(E_i)$ is the transfer tariff (in €/kWh) of the period and is a *function of the amount of the transferred energy*. In this model, the transfer fee of a certain measuring period is dependent on the average active power during the period. Higher average power leads to a higher transfer fee.

Another possibility for transfer tariff could be

$$H = c + \sum_{i=1}^{N} d(E_{max}) \cdot E_i, \tag{2}$$

where $c$ is a basic charge, $E_{max} = \max\{E_1, E_2, \dots, E_N\}$ and $d(E_{max})$ is the transfer tariff (in €/kWh) of the period and is a function of the *maximum of the periodically transferred energies* of the selected time interval. This means that the transfer tariff for all $N$ measuring periods would be determined by *the peak period* during the certain time interval. In practice, this could mean for example that the transfer tariff for all *hours of a month* would be determined according to *the peak hour of the month*.

Third option for a demand tariff could be

$$H = e + f(E_{max}) + g \sum_{i=1}^{N} E_i, \tag{3}$$

where $e$ is a basic charge, $E_{max} = \max\{E_1, E_2, \dots, E_N\}$, $f(E_{max})$ is a fee (in €) which is a function of the *maximum of the periodically transferred energies* of the selected time interval and is not dependent on the amount of energy transferred during the selected time interval (e.g. a month). Coefficient $g$ is a constant transfer tariff (in €/kWh). Tariffs similar with (3) are already applied today for large customers in Finland.

The tariffs similar to (2) or (3) may form, depending on the parameters of the tariffs, a much stronger incentive for the network customers to manage their peak loads than the type (1) tariffs, as the peak energy of the measuring periods may have stronger impact on the total costs. The tariffs (1), (2) and (3) are only some possible options and do not, of course, cover all the possibilities.

There are different ways to determine the peak mean power in (2) and (3) measured within a measuring period with certain length. The measuring periods can be *predefined* $\{T_1, T_2, \dots, T_N\}$, or *a sliding measuring period* could be applied [Muu86]. Fig. 1 presents an example illustrating the differences between the predefined and sliding measurement periods. In the example, a big load is switched on for a certain time. Fig. 1 presents two different situations: in fig. 1a the load is on only during the first predefined measuring period $T_1$, and in fig. 1b the load is on so that the middle point of the "on-time" is in the border of measuring periods $T_1$ and $T_2$. In fig. 1a, if the predefined measuring period is applied, the mean power of the first period would be large, and in the second period the mean power would be small. In fig. 1b, the mean powers would be the same being half of the mean power of $T_1$ in fig. 1a. The case in fig. 1b may be desirable for the network customers in many cases if predefined measuring periods would be used. In both figures 1a and 1b the sliding measuring period is also illustrated. Sliding measuring period means that a measurement system tracks *continuously* the time period of length $T_{sliding}$ which *includes the highest mean power* during a certain time interval (for example a month). If predefined measuring periods is used, it might encourage network customers to time their large loads as in fig. 1b. This might cause power peaks in the networks, which is against the main idea of demand tariffs. The main aim of the demand tariffs is to utilize network more efficiently. Sliding measuring period would encourage customers to decentralize their energy use more efficiently. Predefined measuring periods are, however, easier for customers to understand.

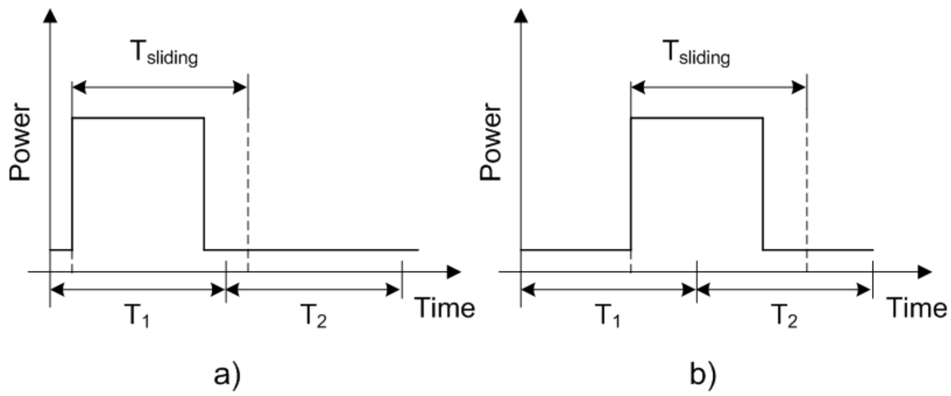


***Fig. 1.*** *The differences between the predefined and sliding measurement periods.*

The functions $b$ in (1), $d$ in (2) and $f$ in (3) can be of different types. They could be affine or non-affine or they could be continuous or discontinuous (stepwise). Fig. 2 presents simple examples of different possibilities for the *form* of the hour based tariff functions $b$, $d$ and $f$ for a network customer having 3×25 A main fuses which corresponds to nominal maximum mean power of 17.25 kW. Stepwise, affine and non-affine functions are presented in the figure. The continuous non-affine function implies that a certain increase in transferred energy brings more costs on high levels of delivered energies than in low levels of delivered energies. In the case of the affine function, a certain increase in transferred energy would bring the same amount of additional costs in all levels of delivered energies. With the stepwise function load should be controlled mostly in order to avoid exceeding the values in which tariff increases. In different tariff structures, it is important that the tariffs are simple enough so that customers can understand them.

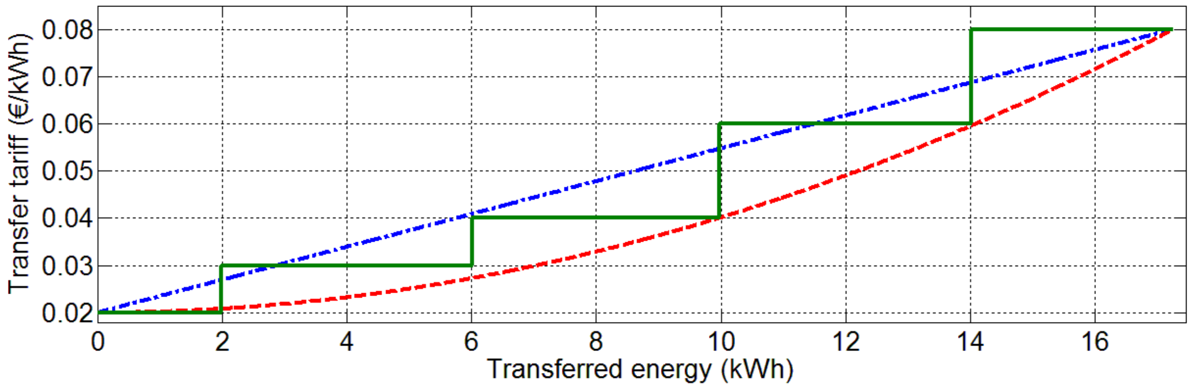


***Fig. 2.*** *Example of the possible forms of the demand transfer tariffs for a certain customer group.*

Another incentive for peak load restriction could come from DNOs. In some networks, load rise caused by simultaneous charging of large amount of plug-in vehicles can cause remarkable problems in the *DNOs'* distribution networks [Las09]. Thus, some DNOs could encourage households and other consumers to apply peak load reduction methods for plug-in vehicles.

# 3. Methods for peak load management

Today in Finland, electric space heaters (total amount is usually some kilowatts depending on the size of the house etc.), electric sauna stoves (typically 4–11 kW), which are very common in Finland [Ada08] and storage water heaters (typically 1.5–6 kW) are often alternating with each other to restrict the peak power of a household. When for example a sauna stove is switched on, some space heaters are automatically switched off. The power of the storage water heaters is designed together with the volume of the reservoir. One option is to choose a big reservoir with small heating power, and then the water is heated during night time. Another typical option is to choose a smaller reservoir with bigger heating power. In this case the water can be heated around the clock and the water heater is alternating with the space heaters. These kinds of alternating systems could be extended and applied to the charging of a plug-in vehicle [Rau10].

Methods for peak load management with plug-in vehicles can be divided in two different cases: the case of a single charger and the case of many chargers in a real estate. The case of the single charger is relevant especially when semi-fast (three-phase) charger is used. With a single charger, coordination of it with other loads of the real estate is an applicable method to restrict the peak load. In the case of many chargers, coordination between different chargers can offer the elasticity wanted.

Current restriction methods can be divided in two parts: load alternation and load adjustment. In alternation methods, loads can be switched off and on in accordance of different control principles. In load adjustment methods the load current of some loads is restricted instead of off-on-switching. It would be possible for example to switch the charging mode from semi-fast (~10 kW) to slow (~3 kW) or to modify charging current freely. Load adjustment requires communication between a "peak load controller" and the charger.

Current restriction methods can be divided in two different groups also from another point-of-view: methods in which the total current, for example real estate's connection point current, is measured and methods without the measurement. If the total current is measured, loads can be controlled dynamically depending on the marginal between on the measured current and the maximum current. Methods without the measurement can be very simple and can be based on simple rules such as today's practice in Finland.

There are many boundary conditions in current restriction methods, which have to be taken into account. When loads are switched off or the energy they receive is restricted by some other way, the harm caused by the load control cannot be too severe. For example, when space heaters are switched off, it is important that the indoor temperatures do not decrease to uncomfortable levels. During a cold weather this might happen even with fairly short time range. Coordination of local loads could be *enhanced* by incorporating local temperature measurements in the control method to ensure proper temperatures, but this increases the complexity and the costs of the system. Also, when switching heaters off, cold load pick-up phenomenon may occur, and this should be taken into account. Another example could be off-switching of storage water heater, as the sufficiency of the hot water should *always* be ensured. And of course, the expected financial savings caused by the current restriction system must be a higher than the investment costs of the system.

Another boundary condition comes from other needs for load control of customers. When the penetration level of "smart metering" increases, different demand side management (DSM) or demand response (DR) programs will be possible which make different flexible energy products available for customers offered by energy companies or flexible network products perhaps by network companies. These load control needs can be in conflict with the needs of the current restriction system. On the other hand, load restriction methods may offer a tool to realize different DSM or DR services as the amount of load to decrease can be managed efficiently using the load restriction system. Thus, the needs of the customer could, in some cases, be taken into account in a better way. The priorities of the peak load management system and DSM/DR system are, however, solved by the customer who makes the decision regarding the choice of the applied products.

## 3.1. One charger in an internal network

A simple way to restrict a single customer's peak current caused by semi-fast vehicle charging is to alternate some non-critical loads with the charger. The basic idea is similar with the existing Finnish practices presented above in the introduction chapter. The idea is that the system is *fully automatic* and so the customers do not have to actively participate in the restriction activity. Fig. 3 presents a simplified principle of the case of one charger in a regular Finnish household with electric space heating. The charger is coordinated with some non-critical loads of the household in order to manage the peak power. Fig. 3 is a simplified one, as *all three phases should be managed separately*. The current or power measurement equipment may be located in the main switchgear or in the group switchgear of the real estate, depending on the situation.

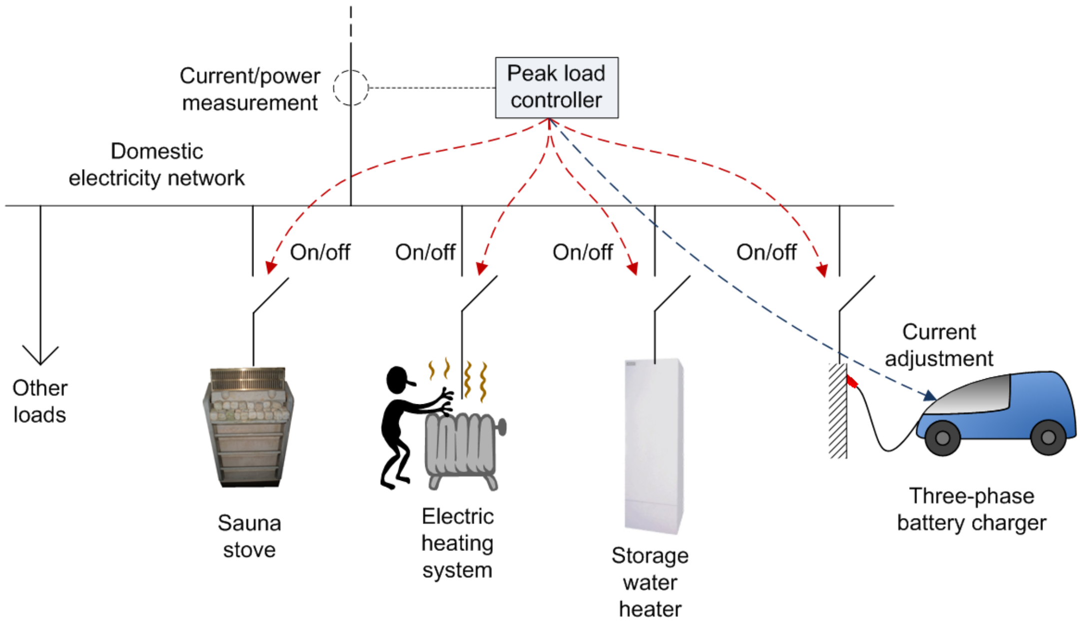


***Fig. 3.*** *The simplified principle of a peak load management system of for example detached houses.*

The core of the peak load restriction system is the peak load controller (see fig. 3) and its operation. Different algorithms can be developed, which make the switching decisions and control the relays or contactors. These algorithms are programmed into peak load controller. The peak load controller could also communicate with the charger in the case of load adjustment.

There are many possibilities to apply peak current restriction methods without the current or power measurement. These methods can be based on simple switching rules. In a case where there are electric space heaters, electric sauna stove and a three-phase charger, a simple way to manage peak load could be as follows. When the semi-fast vehicle charger is switched on, heating is switched off, and if the sauna stove is simultaneously switched on, the charger is also switched off. Another option could be that instead of off-switching the charger the current of it could be decreased to a lower level, e.g. from 15 A to a value of 4.3 A in all phases corresponding to charging power of approximately 3 kW. The method could also be extended by taking the indoor temperature into account.

Fig. 4 presents an example of a simple algorithm, where space heaters, electric sauna stove and a three-phase charger is controlled including possibility for stepwise load adjustment and monitoring of indoor temperature. The main point of the algorithm is that, the sauna is the priority number one, which is definitely thought to be the case for Finns ☺. Second priority is the charging, which is made at full power if sauna is off and the “mean indoor temperature” is above a certain predefined level, and in lowered power if sauna is on.

Another way to restrict peak power is to share energy for certain loads in pulse-like manner. The lengths of the pulses could be for example some minutes or some dozens of minutes. Fig. 5 illustrates this principle, and the figure is a simplified one as all three phases should be managed separately. In this approach, energy is delivered to each alternating load regularly one after the other or in groups and the *energy needs of every load could be met to some extent* during time where many large loads need energy. Lengths of the pulses could be adjusted according to load priorities and the energy needs of the loads. Switching big loads off and on may cause different transients and changes in voltage levels, and if high switching frequency is used this may worsen local power quality. This peak current method differs from the previously presented methods in the way that loads are controlled. In previous methods, loads were switched off and on or adjusted according to certain events such as on-switching of the sauna stove or decrease of indoor temperatures. In this pulse-like control, loads are switched on and off according to time.

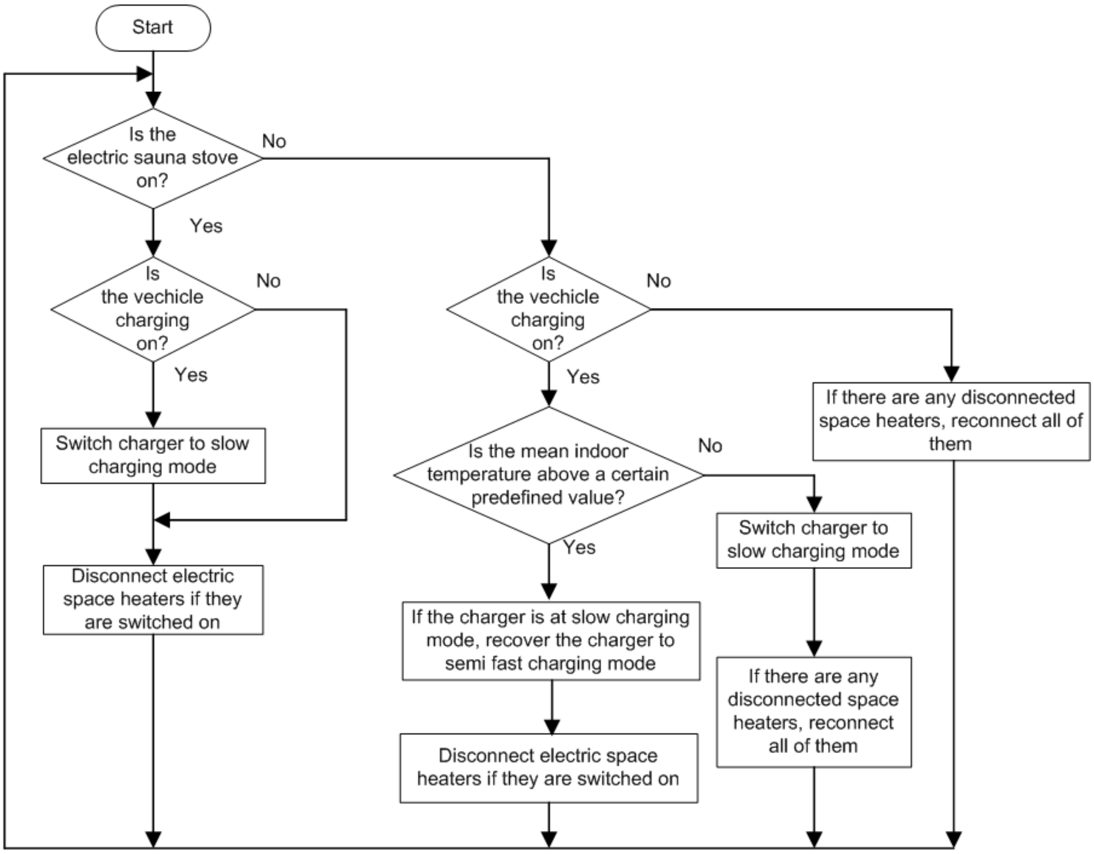


***Fig. 4.*** *A peak load management algorithm.*

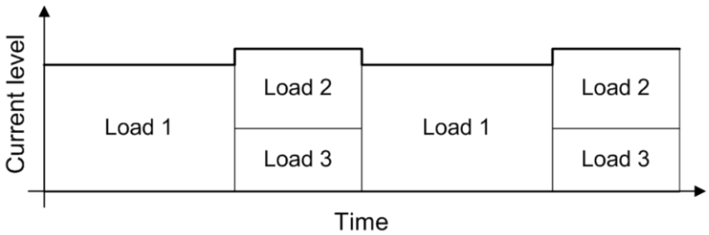


***Fig. 5.*** *Simplified principle of an alternation method based on pulse-like switching*

Previous current restriction methods did not include the use of the connection point current or power measurement, which is presented in fig. 3. The use of the measurement makes more efficient use of the current or power capacity of the electricity network connection possible. In practice, the measurement makes possible to share the *free current or power capacity* of the network connection for different loads. When loads are switched off and on or when current levels of the loads change, free capacity of the network connection also changes.

Fig. 6 presents two simplified examples on *current* restriction methods which use current measurements. The purpose of the system is to avoid the blowout of the main fuses. In both examples, a battery charger with maximum current of 15 A and two loads, 8 A and 10 A, are controlled in order to restrict the peak current. In both examples, the top sub figures present the currents drawn by the loads which are *not* controlled by the current restriction system (corresponds with the "Other loads" in fig. 3) and the lowest sub figures present the total currents. Horizontal axes represent time, but the time scale depends on the chosen pulse lengths.

In fig. 6a, battery charger is alternating with two other loads in the system, and the maximum total current has been set to 24 A. First, all three loads receive one "energy pulse" one after the other. Then the charger receives again one pulse, and after this the basic load current has decreased to such level, that loads 2 and 3 can be *switched on simultaneously* without exceeding the 24 A limit. In such system, energy can be delivered more efficiently to the loads than in systems where connection point current is not measured.

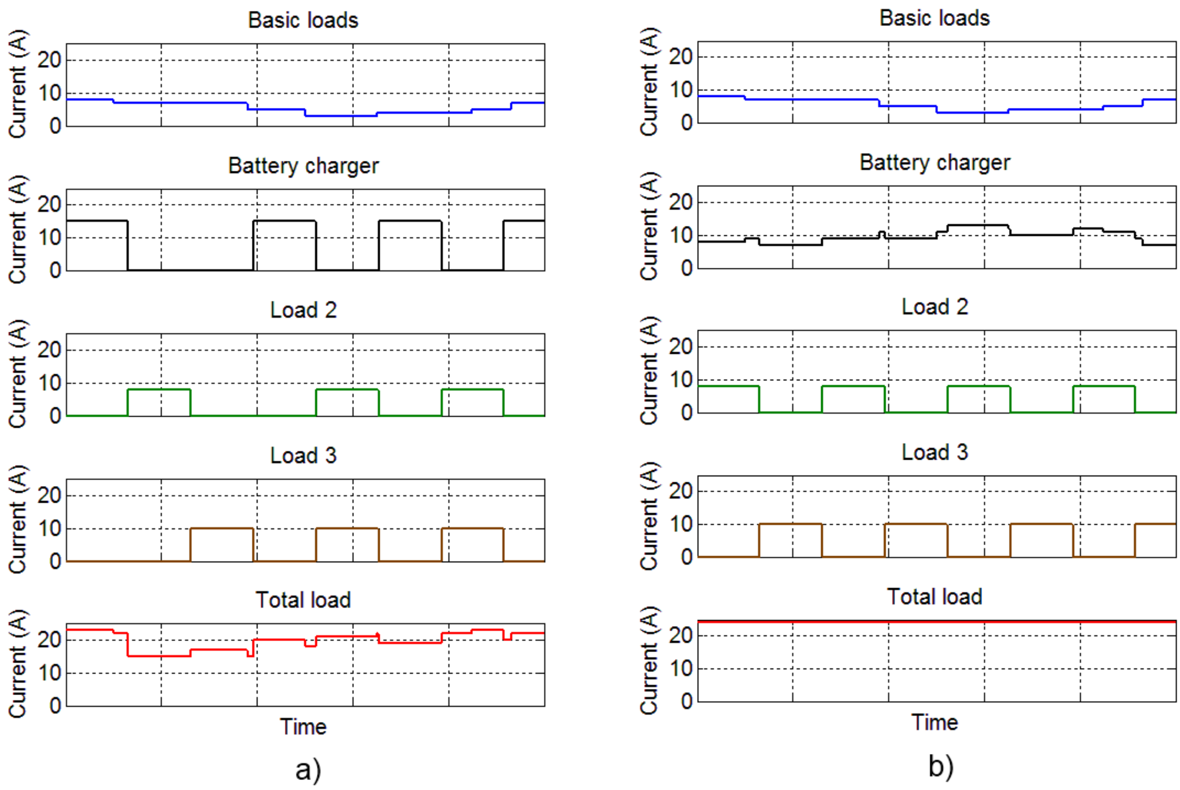


***Fig. 6.*** *Simplified principles of the two different current restriction methods which use connection point current measurement*

In Fig. 6b, it is possible to adjust the current of the battery charger continuously instead of on-off switching only. In this example, loads 2 and 3 are regularly alternated with each other, and the charger current is adjusted in such way, that the total 24 A capacity is used as efficiently as possible. The charging rate of the battery can be modified fairly freely, but this requires a communication system and appropriate features from the battery charger.

In the demand tariff models presented in chapter 2 the mean powers in measuring periods are measured. Fig. 7 presents an example on the behaviour of power during an hour long measuring period. The upper sub figure presents the power during the hour and the lower sub figure presents the energy consumption (mean power) during the hour. In the example, mean power of 7 kW (corresponds to 7 kWh energy) is set for the upper limit for the peak load controller which controls the loads. The dashed line in the upper sub figure presents this power level. The dashed line in the lower sub figure presents the corresponding energy use during the hour. The solid lines in both sub figures present the real behaviour of the load during the hour. It can be seen that during the hour load levels may vary significantly from the mean value and still the mean value can be reached. One way to control loads to keep the mean power of a certain measuring period below a certain value is to measure the power continuously and then compare the energy consumption to a straight line similar to the lower sub figure of fig. 7. If the amount of measured energy exceeds or goes below the reference line different actions could be made. Some methods obeying these types of principles are presented in [Muu86].

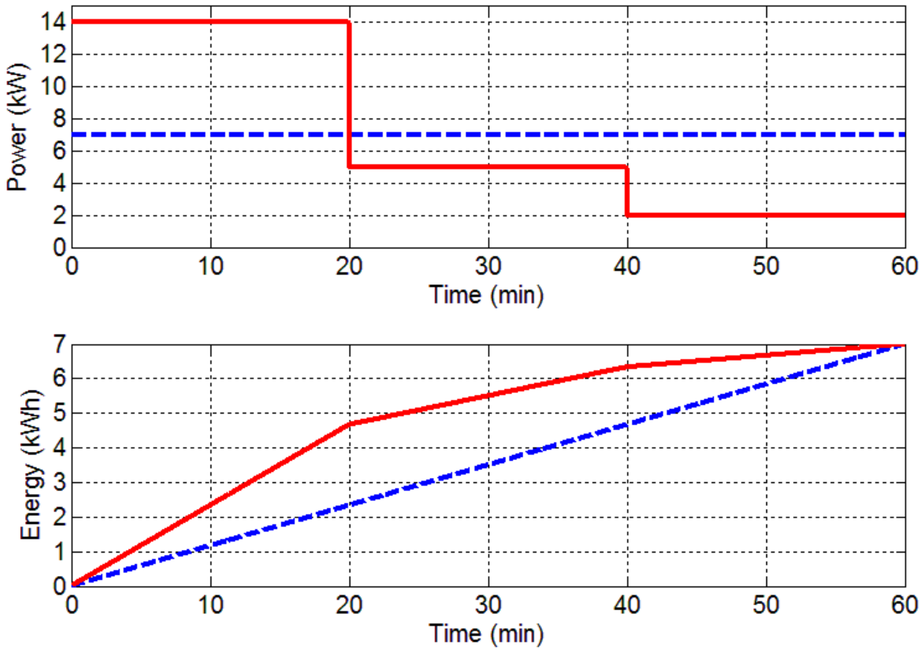


***Fig. 7.*** *Example of the operation principle of the control system during a measuring period in a demand tariff context*

Electricity distribution is made with three phases to almost every customers of the electricity grid in Finland. In such cases the presented peak load restriction methods must be applied for all three phases. If the methods applying connection point current or power measurement are applied, the measurements should be made for all phases. Loads can be one-phase or three-phase loads, and some loads can be connected between two phases. Regular small loads, typically lightning, entertainment, kitchen appliances etc. are one-phase loads. Thus, the loads in different phases are fairly independent from each other. The big loads, which are assumed to be controlled, are often three-phase loads which should be switched off and on in all phases.

Thus, in *current restriction* methods based on measured free capacity should make off-on-switching operation of three-phase loads in accordance of the current of the phase with *smallest free current capacity*. One option is that if a system like in fig. 6b is applied, currents of the charger in all phases could be managed independently to match the selected maximum current level. This would make the current drawn by the charger asymmetric which sets some requirements for the power electronics of the charger.

The operation speed of the load restriction system is an important factor in the current restriction applications, in which free current capacity is used dynamically. If the current level increases suddenly in a situation where the total current is at high level near to the selected maximum value, the total current can momentarily exceed the maximum level. In such case, the current restriction system should react fast enough to avoid the blowout of a main fuse or fuses. These kinds of situations can be partly avoided by leaving some safety margin between the maximum current level of the current restriction system and the rating of the main fuses. The operation speed depends on the dynamics of the current measurement system, data processing unit, switching equipment and possibly the communication system.

In previous methods loads were switched off and on by means of controlling a switch which disconnects the load from or connects the load to the network. When controlling of such loads whose normal operation is based on thermostat control or other similar principles, the operation of the thermostat or similar device should be taken into account. Fig. 8 presents a situation where a thermostat controlled load is controlled also by a peak load controller. When the load should be switched *on* by the peak load controller and switch 1 is closed, then the load may or may not take power from the network depending on the state of the thermostat switch. Although peak load controller offers *possibility* for the load to take energy from the grid, the load may not take any energy because of the thermostat’s operation. In the methods in which total current is measured (see e.g. fig. 6), this is taken into account so that other loads may be switched on instead of the first mentioned load. If the thermostat load is wanted to take energy every time a possibility for that is served, a way to make this is to adjust temporarily the setting value of the thermostat in order to close the switch 2. This option is also presented in fig. 8. This functionality, however, requires a controllable thermostat and a proper communication from peak load controller to the thermostat. Sophisticated home automation systems are expected to penetrate strongly to the market in the future, and this kind of functionality could be realized easily in these systems.

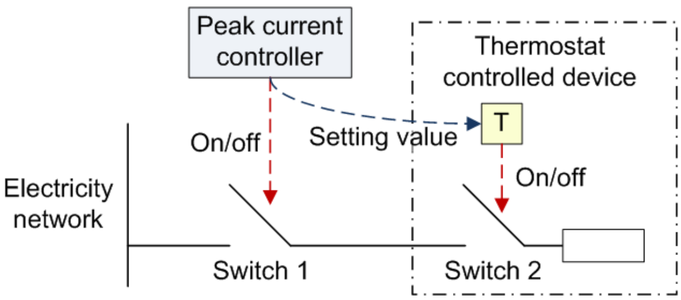


***Fig. 8.*** *Operation of a thermostat controlled device in peak load controller system.*

In such peak load restriction methods, in which energy is delivered to different loads in power pulses (see fig. 5), the lengths of the pulses should be defined somehow. One could assess the typical energy needs of different loads and select a rigid time for each load. The determination of times for “on” states could be perhaps made *automated* and even *adaptive* in different ways. If for example a certain type thermostat load does not absorb energy or stops absorbing energy during the time reserved for it due to the thermostat, peak load controller could switch to next load deviating from the original plan. Also, if the absorbed energies of different loads could be *measured separately*, it could be possible automatically adjust dynamically the proportional times between the loads in proportion to their energy needs. If for example the need for hot water increases suddenly (energy need increases by the thermostat control), time reserved for storage water heater could be extended. Typical moments for energy needs could perhaps also be taken into account. If for example, the need for hot water increases more or less regularly in the Saturday evenings, this could be taken into account when delivering energy for different loads on Saturdays. The peak load controller could adapt its operation to the behaviour the household.

## 3.2. Many chargers in an internal network

In the future, if the penetration level of plug-in vehicles increases remarkably, there will be situations where there are lots of these vehicles charging in parking places. Sockets for pre-heating of the car engines are fairly widely available today in Finland in all types of houses, but also in work places. These sockets could be used to charge plug-in vehicles to some extent. It was noticed in the case studies presented in [For11] that if one-phase charging of 3 kW is applied in parking places of real estates of for example row houses and apartment houses, in approximately 50 % (the range was 25...83%) of the per vehicle parking lots of the parking areas charging could be made without causing overloading of the feeders feeding the pre-heater-sockets. Thus, in high penetration levels of plug-in vehicles, the feeders of the parking areas should be enforced.

Large number of vehicles charging simultaneously can also raise the peak currents of the electricity connection of real estates. Thus, the ratings of the main fuses may be exceeded. Demand tariffs may also offer incentives to restrict peak loads in the future. Very high peak loads could happen especially in working places, where the employees arrive to work places quite the same time every morning start charging immediately. The peak powers caused by other loads in work places are also often in the mornings. People work typically about eight hours a day and often cars are parked during the whole period. Thus, in many cases there is time to apply different alternation methods. At residential real estates peak powers could emerge after the working time meaning a few hours after 16:00.

Fig. 8 presents the basic principle of the system, which is pretty much similar with the system of fig. 3. Loads could be alternated or adjusted obeying for example the same type of principles presented in chapter 3.1. These types of alternating systems exist already today controlling pre-heater sockets. The system could be used to avoid internal network reinforcements, to avoid increasing the rating of the main fuses and to achieve financial savings in the case of power-based transfer tariffs. It is possible, that there are two or more plug-in vehicles also in regular households, and there may be need for peak load reduction systems designed for many cars also in such real estates.

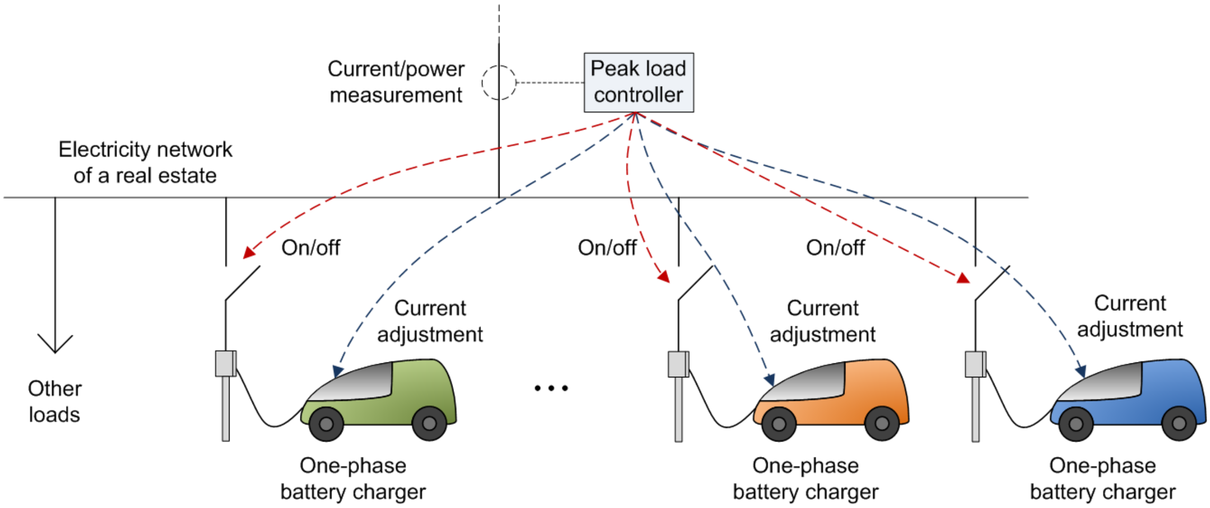


***Fig. 8.*** *The simplified principle of a peak load management system of parking places including many chargers.*

# 5. Conclusions and future work

In this paper, different motivations for peak load management systems were discussed and principles of a few peak load management methods were presented. Three different main drivers for peak load management were recognized: possibly too small main fuses of the customers' electricity connections, too small current capacity in internal networks such as feeders of the pre-heater sockets of parking places and possible application of demand tariffs in the future. The first two drivers need control of the currents of the system, and the third one requires control of powers. Peak loads can be managed by switching loads off and on, and some loads, for example plug-in vehicle chargers could be adjusted if appropriate control system was available. If methods such like the ones presented in this paper would be applied in real life, the systems have to be designed case-by-case.

This paper included only some principles and ideas. These concepts should be simulated in time-domain and demonstrated in a real environment. A demonstration with a real home automation system will be made in the near future. The effect of these methods on the load modelling and network planning should also be investigated. Also, existence of local small power generation or energy storages, for example plug-in vehicles in vehicle-to-grid mode, could be considered. Economic studies concerning the costs of the systems compared to possible financial benefits should be made.

# References

[Ada08] Adato Energia Oy. 2008. Electricity usage of households 2006. Research report, 74 p. Available: http://www.motiva.fi/files/1353/Kotitalouksien_sahkonkaytto_2006_-raportti.pdf [in Finnish]

[Dav09] Davis, S. C., Diegel, S. W., Boundy, R. G. 2009. "Transportation energy data book: Edition 28". Oak Ridge National Laboratory, 379 p. Available: http://cta.ornl.gov/data/index.shtml

[For11] Fortum Oyj. 2011. "Ladattavat autot kiinteistöjen sisäisissä sähköverkoissa -suositus" (Recommendation to plug-in vehicles in internal networks of real estates). Available: http://www.fortum.com/gallery/press/Ladattavat_autot_sahkoverkoissa_suositus.pdf [in Finnish]

[Lac10] Lache R., Galves, D., Nolan, P. 2010. "Vehicle Electrification, More rapid growth; steeper price declines for batteries". Deutsche Bank, Global Markets Research, Available: http://www.scribd.com/doc/28104500/Deutsche-Bank-Electric-Car-Analysis-Batteries

[Las09] Lassila J., Kaipia T., Haakana J., Partanen J., Järventausta P., Rautiainen A., Marttila M. 2009. "Electric cars – challenge or opportunity for the electricity distribution infrastructure?". European Conference SmartGrids and Mobility, Würzburg Germany. 8 p.

[Muu86] Muukkonen, P., Pihala, H. 1986. "Pienen ja keskisuuren teollisuuden sekä palvelusektorin kuluttajien sähkökuormien ohjauslaitteistot" (Control devices of electrical loads for the consumers in the small and medium scale industry and service sector). Imatran Voima Oy, R&D Notes. 56 p. [in Finnish]

[Rau10] Rautiainen, A., Repo, S., Järventausta, P. "Intelligent charging of plug-in vehicles". NORDAC 2010, Ninth Conference on Electricity Distribution System Management and Development, Aalborg, Denmark, 6–7 September 2010, 11 p.