Plug-in vehicle ancillary services for a distribution network

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Abstract— **In this paper, we have investigated the possibilities of plug-in vehicles to produce ancillary services for distribution networks. First, special features of plug-in vehicles as controllable resources are discussed and then motivation and methods of four different types of ancillary services are discussed. These services are peak load management, network power flow management, customer back-up power and power quality improvement. Finally some conclusions are made and future work is proposed.**

Keywords— Plug-in vehicles, PHEV, EV, ancillary services, electricity distribution networks

I. 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 [1]. 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 full electric vehicles (EV) offers the potential to partly fulfill 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.

There are some barriers related to the high penetration of plug-in vehicles (PHEV and EV). The most important barrier is the battery technology and its relation to short operating distances. Technologically speaking, batteries are fairly good at the moment, but batteries suitable for transportation appliances are very expensive. However, the prices are expected to go down dozens of percentages over the course of the following years [2]–[3]. PHEVs are penetrating the market more potentially due to their long range and small and thus less expensive battery pack. Secondly, a lack of adequate charging infrastructure is a major barrier. It is often fairly expensive to construct extensive charging infrastructure especially in the existing densely populated areas. However, constructing extensive charging infrastructure for full EVs in scarcely populated areas can also be challenging.

In addition to enabling sustainable passenger transportation, plug-in vehicles can also be used as controllable resources among other resources for the needs of different actors of the power system and energy market. These actors can be distribution network operators (DNO), energy companies and retailers, transmission system operator etc. In [4] these services are handled from the perspective of plug-in vehicle system interface requirements.

In general, the controlling of plug-in vehicle charging and discharging (vehicle-to-grid, V2G and vehicle-to-home, V2H) has been under intensive academic research for a few years and lot of different types of ideas and results have been published in different forums, cf. for example [4]–[13]. This paper concentrates on the services which plug-in vehicles with other resources could produce for electricity distribution networks. In this paper, we have been trying to emphasize the practical point-of-views for plug-in vehicle control. The services for distribution networks are presented in a generic manner, but special characteristics of Finnish distribution networks are highlighted.

The paper is organized as follows. In section II, the special characteristics of plug-in vehicles as a controllable resource are discussed. In section III, different services for distribution networks are presented and motivation and methods for different services are discussed. In section IV, conclusions and future work are presented.

II. PLUG-IN VEHICLES AS CONTROLLABLE RESOURCES

In the context of power systems, plug-in vehicles can be used in at least two ways: as controllable loads or as dischargeable energy storages (bidirectional power flow). Controllable load operation is easier to realize, but energy storage operation offers a wider range of possibilities. Controlling plug-in vehicles alone does not necessarily offer high enough volume for economically attractive operation. Thus, plug-in vehicles should perhaps be controlled with other resources such as loads and small-scale power generation plants. Other loads can be for example electric heaters, heat pumps and storage water heaters. A single term for distributed loads, storages and generation plants is "distributed energy resources" (DER), which is used hereafter in this paper.

Plug-in vehicles can be used as controllable load in at least two ways: by switching charging on/off or by restricting the charging current. On/off switching is simple to realize, but it has to be made in such a way that the control does not interfere the charging system of the car. For example, some models of mode 2 (defined in standard IEC 61851-1) charging related in-cable-control-boxes do not necessarily recover from voltage cut-offs. In mode 3 charging, a maximum charging current level is set for the car by the charging station, and the maximum level can be changed during the charging process. It should be noted that only the maximum current level can be set, and the charger itself decides the charging current.

Efficient and cost effective energy storage capacity would offer many advantages and possibilities which are analyzed for example in [14]. Car electricity storages could store relatively large amounts of electrical energy and the power capacity would be quite large. For example, if there were one million plug-in vehicles (there are about 2.7 million passenger cars in Finland today) in Finland and if 50 % of them would be available for energy storage use and if the vehicles would be simultaneously able to discharge 5 kWh per vehicle on average, the total energy capacity would be 2.5 GWh. If the discharging power was 3.7 kW per vehicle, the total discharge power capacity would be 1850 MW. These numbers are quite remarkable in the Finnish power system.

A question of its own is the use of internal combustion engine of a PHEV to produce power for the needs of the power system. In this case, the liquid fuel stored in the fuel tank would operate as energy storage and thus the energy capacity would be quite high. This concept is, however, mostly suitable for domestic back-up power applications, i.e. producing power for a single household during an outage. For other types of applications this concept is not perhaps very relevant. One must consider user acceptance: people would probably be less exited that their car engines would start and stop by themselves every now and then when parked. In this concept, one must ensure that the car would be parked outside in order to avoid a safety hazard with the exhaust gases.

The use of the car's battery packs as energy storages for the power system inflicts costs for the car owners. Additional charging-discharging cycles pose additional stress to batteries and decrease their cyclic lifetime. When calculating the costs of the energy storage operation, the investment cost of the storage itself can be considered fairly low because the car is bought primarily for transportation purposes and the energy storage operation comes as an ancillary service on top of the driving. The battery degradation cost of discharging a certain amount of energy from a battery pack and recharging the same amount of energy back to the battery depends on the type of the battery pack.

Today, PHEVs and full EVs nearly always have lithium-ion batteries which will be the energy storage solution also in the near future. The cyclic lifetime of a lithium-ion battery cell is dependent on the battery chemistry and especially the type of the negative electrode. In the case of graphite negative electrode the cyclic lifetime of the battery cells is limited to around 3,000 full cycles depending on battery chemistry and design. On the other hand, in the case of titanate negative electrode the cyclic lifetime is considerably higher. However, batteries with titanate negative electrode are more expensive and their specific energy (in Wh/kg) is much lower compared to the many graphite based batteries. Today's investment costs of lithium-ion batteries are from some hundreds of EUR/kWh up to thousands of EUR/kWh depending on the battery chemistry and manufacturer. The cyclic lifetime was expressed above in full cycles. In practice, cycle depth (CD) of a charging-discharging cycle is often less than 100%. The impact of CD on the cyclic lifetime depends on the battery chemistry. For example, batteries with lithium-iron-phosphate (LFP) positive electrode are not so sensitive to CD. Thus, over the course of LFP batteries' cyclic life the total amount of discharged energy from the battery is quite stable and independent from CD. For a battery with a cobalt based positive electrode, CD has non-negligible impact on the cyclic life: the smaller the average CD, the larger the total amount of discharged energy over the course of the cyclic life.

Fig. 1 presents simple calculations concerning battery degradation costs as a function of cyclic lifetime and battery investment cost. The battery degradation cost represents a cost per stored energy (in EUR/kWh) which is caused by cyclic lifetime loss when discharging a battery pack from a certain state by certain amount and then charging back to the initial state. Cyclic lifetime is presented as a number of a certain type of charge-discharge cycles (CD of 100% or something else). Battery investment cost is presented in EUR/kWh. The values of Fig. 1 are obtained by simply dividing the battery investment cost (in EUR/kWh) by the number of cycles which can be obtained from the battery before its lifetime has ended. It can be seen that to obtain a battery degradation cost of a few cents/kWh the cyclic lifetime must be very high and/or the investment cost has to be very low.

Fig. 2 presents a simple calculation about energy storage costs including battery degradation costs of Fig. 1 and electricity price of 0.15 EUR/kWh. The electricity price is in the order of typical present-day costs in Finland. In the figure, the energy cost of gasoline is also represented from two points of view: power and heat. The costs of gasoline mechanical energy and heat are calculated according to

$$C_{gm} = C_g/\rho_g/E_g/\eta_{ICE} \text{ and} \quad (1)$$

$$C_{gh} = C_g/\rho_g/E_g. \quad (2)$$

In (1) C_{gm} presents the cost of mechanical energy (EUR/kWh) produced by a gasoline internal combustion engine (ICE) and in (2) C_{gh} presents the cost of heat produced by gasoline. In (1) and (2) C_g is the price of the gasoline (EUR/l), ρ_g is the density of gasoline (kg/l) and E_g is the lower heating value of

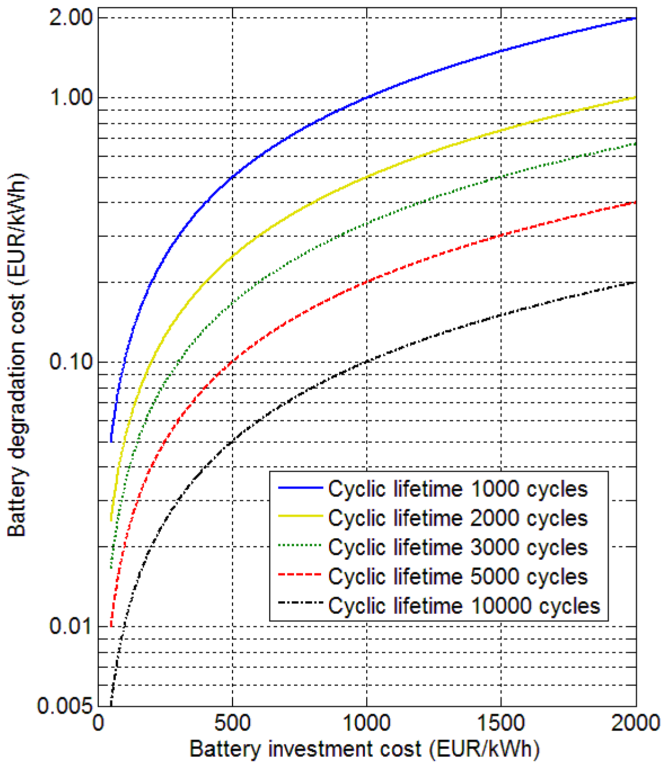

Figure 1. Battery degradation costs as a function of cyclic lifetime and battery investment cost.

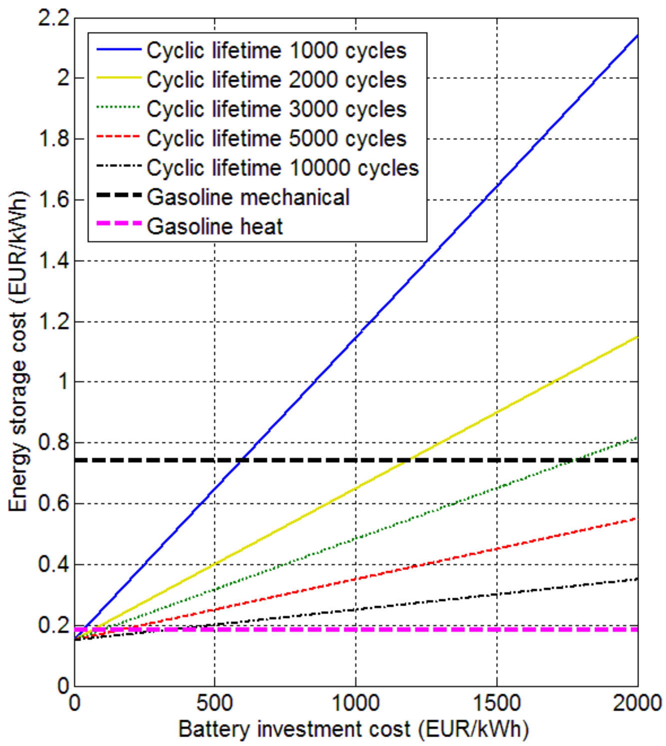

Figure 2. Energy storage costs as a function of batteries' cyclic lifetime and investment cost. Electricity cost is also included. Cost of gasoline mechanical energy and heat also are presented for comparison.

gasoline (kWh/kg), and in (1) η_{ICE} is the thermal efficiency of an ICE. In the calculated values of Fig. 2, the values of the previous parameters are presented in table I. It can be seen that when comparing the costs of gasoline and the degradation cost of the batteries together with the electricity price, some batteries might be competitive when compared to gasoline ICE. It should be noted that during cold weather the waste heat of the ICE is used to heat the car interior depending on the outside temperature and cabinet heating demand. In this case the real cost of the useful gasoline energy is somewhere between the cost levels of mechanical and thermal energies. It should be noted that previous calculations are simple, and the real cost structure is more complicated.

These types of theoretical marginal cost calculation principles have certain drawbacks. Let us consider life cycle costs by means of a simple example. A plug-in vehicle has an effective battery capacity of 20 kWh, which roughly corresponds to 100 km electric driving range. The battery pack has a cyclic lifetime of 3,000 full cycles which corresponds to total electric driving range of 300,000 km. The average daily driving distance of Finnish cars is about 50 km, which is roughly 18,000 km/a. If all of the driving would be made using electricity, which is very hard to realize in practice [15], the total electric driving range could be "consumed" in 17 years on average. The estimated calendar lifetimes of today's lithium-ion batteries and also plug-in vehicles are typically less than 17 years. This means that over the course of a plug-in vehicle's lifetime, part of the battery capacity will not be used. From this point of view, the battery degradation cost of a moderate amount of V2G use can be considered practically zero if there is no significant battery after-car-life market. There have been some ideas about the possible use of batteries in for example power system applications after having been used in cars, but safety and reliability characteristics of reused batteries may have been decreased significantly. Thus, the secondary battery market can be quite small also in the future.

TABLE I. THE PARAMETERS OF THE GASOLINE COSTS OF FIG. 2

Parameter	***Value***
C_g	1.7 EUR/l[a]
ρ_g	0.75 kg/l [16]
E_g	12.2 kWh/kg [16]
η_{ICE}	0.25 [16]

a. Typical gas station price in Finland in 2012

The owners or the users of the cars have certain preferences with relation to the use of the car. The vehicle should be charged to full charge at some stage. If the battery pack was "unexpectedly" discharged during the charging process, the state-of-charge (SOC) of the battery pack would temporarily be decreased and vehicle users would have to accept this. Of course it is be possible to construct some kind of a charging system which optimizes the charging taking into account car use preferences, dynamic energy pricing and ancillary service profits. Users may set the charging system to charge the battery pack to full charge at a certain time at the latest and within that time-frame some optimization could be made.

Using the batteries as power system storages sets some requirements for the car and its electrical interface. In order to use a vehicle as energy storage for the need of the power system, a bidirectional converter to the car or an external module with appropriate protection equipment is needed [4]. Also, energy meters should be able to handle two-way energy flows. Car storages could be discharged to public distribution networks (Vehicle-to-grid – V2G) or to small isolated network islands such as single households (Vehicle-to-home – V2H). These energy storage operation modes differ from each other in some ways. For example, the required protection and other requirements for the network interfaces are different [4].

III. Ancillary services

As presented in [4] plug-in vehicles can be used to produce different services to several parties. A possible concept to realize this kind of flexible and versatile system is that there would be an aggregator or a service provider who would offer an interface between customers and different parties. The aggregator would make contracts with small and medium size energy users and it would lump the DERs into larger entities and offer services produced by these entities to different parties. The aggregator would also carry out the control actions and supervise and monitor the DERs and their use. In this concept the energy users would make the final decision concerning the use of their DERs in a form of contracts with the aggregator. Thus, in addition to asking energy contract bids from energy retailers, which is already done today, customers could also ask for bids from the "ancillary service market" through the aggregator to maximize the utilization rate of their DERs' elasticity capability and thus minimizing their energy costs. The realization of different services would be as automated as possible to minimize the customer effort and maximize customer comfort.

In this paper we deal only with services produced for the needs of the electricity distribution networks. By electricity distribution networks we mean the networks owned by the distribution network operators and the private networks of the owners of the real estates or parking places.

Fig. 3 presents a concept which could provide different services for customers themselves and for the DNOs. Some services are also mentioned in the figure. The aggregator collects the DERs and can offer different services to different DNOs. DNOs monitor their networks using distribution management systems (DMS) and automatic metering infrastructure (AMI) and inform the aggregator about the need for a service. The aggregator makes sure that the service is provided in the energy users' properties or premises. In domestic customers there is some kind of a Home Energy Management System (HEMS) which is comparable to a home automation system. It can control the DERs of the property. There might also be small-scale distributed generation (DG) such as solar panels in the real estate. The control actions required to realize the services can be made locally near the DER or remotely using a communication system [5]. The first mentioned case can also include a possibility for the aggregator to pass setting values and parameters for the local controllers via a communication system [5]. In the following, the different services mentioned in Fig. 3 are discussed.

A. Peak load management

1) Motivation

There might be several drivers for the network customers to restrict the powers in their networks.

The electricity grid connections of properties have limited current capacities which are determined by the rating of the main fuses. A common main fuse size in a Finnish detached house is 3×25 A. The maximum current capacity can be exceeded due to a charging load especially with high charging powers. 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 today's preheating feeders in the parking places of row houses or apartment houses if a large number of slow chargers are connected simultaneously. The capacity of the network connection can be enhanced by enlarging the rating of the main fuses, but this brings additional costs and if applied broadly, it can lead to extra network enforcement investments for the DNO and hence to an increase in transfer tariffs. If the capacity of some parts of the internal network is not sufficient network upgrades are needed.

In addition to restricted current capacity a possible application of demand tariffs in electricity distribution may offer incentives to restrict the peak load of a network connection. If the transfer tariff is based totally or partly on the peak power, for example the highest hourly mean power of the network connection, some financial savings can be achieved by management of peak loads.

Another incentive for peak load restriction could come from the needs of other services. For example, the "network power flow management" service discussed in section III.B can be realized with a load restriction system. If the load level of some part of a network should be temporarily decreased, this could be achieved by using this kind of a load management method. Thus, a DNO could encourage households and other consumers to reduce load for a while.

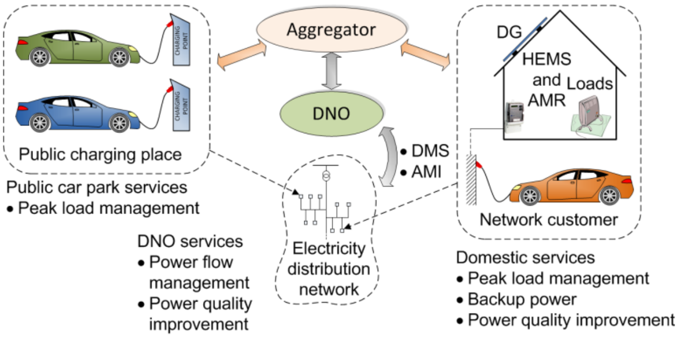

Figure 3. Aggregator driven DER service concept.

Public parking places which have plug-in vehicle charging spots might also be willing to apply some kind of peak load reduction methods. For example, there is a certain amount of charging spots in a parking area. If only a part of the charging spots are in use, it could be possible to allow these spots to use a higher charging power than in a situation where all the spots were in use. The highest allowed charging powers of different charging spots could be adjusted dynamically in accordance with the total power need of the parking area. In this way the customers could be served better and the utilization rate of the charging infrastructure could be increased.

2) Methods

There are several methods which could be used to manage peak loads. Today in Finnish detached houses, 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 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. These kinds of alternating systems could be extended and applied to the charging of a plug-in vehicle [5]. The simplified principle of this kind of a system is presented in Fig. 4 and Fig. 5. Also, it is possible to use a plug-in vehicle as a network's energy storage in order to manage peak load. This means that energy is stored in the vehicle battery pack and later this energy is fed back to the network during time when energy needs of other loads are high.

Peak load management methods can be divided into two types: load alternation and load adjustment. In alternation methods, loads can be switched off and on in accordance with 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 more freely. It is also possible to feed power from the vehicle to the network in order to manage peak load. This feeding current or power could also be freely adjusted. Load adjustment requires communication between a “peak load controller” and the chargers.

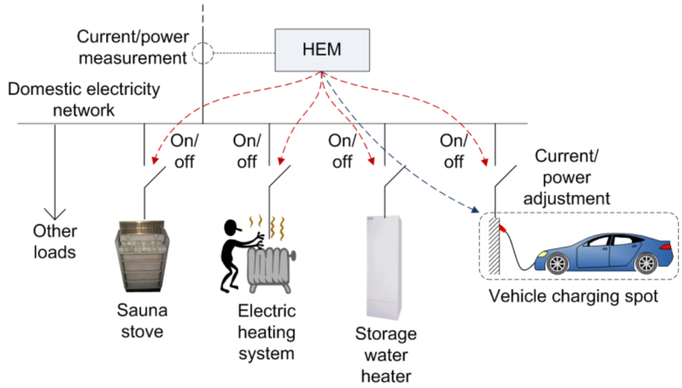

Figure 4. The simplified principle of a peak load management system of detached houses.

Peak load management methods can be divided into two different groups also from another point of view: methods in which the total current or power, for example the current or power of the connection point of a property or a parking place, is measured, and methods without the measurement. This is illustrated in Figures 4 and 5. If the total current/power is measured, loads can be controlled dynamically depending the marginal between on the measured value and the maximum value.

There are many boundary conditions in peak load management 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. Also the battery packs of the plug-in vehicles cannot be strained too much. And of course, the expected financial savings caused by the current restriction system must be higher than the investment costs of the system.

B. Network power flow management

1) Motivation

A possible ancillary service is network power flow management. The aim of this service is to manipulate the power flow of the distribution network in order to reach different goals. One goal could be to clip the power peaks in the networks in order to delay or avoid network investments. Network power flow management could also be used to manage special situations such as disturbances. During a network disturbance, the power flow of a network could be manipulated to ensure the sufficiency of a back-up connection's capacity. In this way power system reliability could be improved. Another temporary special situation might be such that there is lot of renewable DG in the network and it would be necessary to restrict the generation for short times due to voltage rise problems. An option for this could be to increase the network load for a while and thus maximize the power production of DG plants.

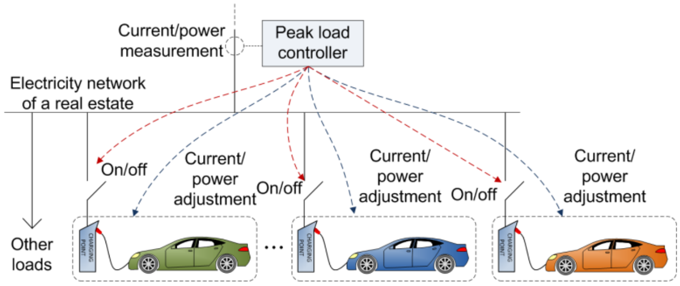

Figure 5. The simplified principle of a peak load management system of different types of parking places.

This type of service can be realized for different degrees of scale. The DNO does not have to manage the whole distribution network but it could be possible to manage only a part of it: for instance a single problematic medium voltage feeder or distribution transformer can also be the target of this service.

2) Methods

These types of services can be realized in different ways. One possibility is to use control based on local information. For example, load could be shifted rigidly in accordance with the time of day and type of day. In addition to pure time shift of the loads, load adjustment can be used. In this case the power drawn by the loads is controlled as a function of time to achieve a desired load profile. The timing of different loads can be different so that big power demand peaks are avoided. Time control, although based on local information, does not have to be static and rigid. The method can be dynamic and flexible in many ways. For example, it would be possible to adjust the timing process of plug-in vehicle charging in accordance with the state-of-charge of the battery packs. This would of course require an agreement between the car owners.

More sophisticated and flexible network power flow methods are based on state estimations of the network and can operate extensively in different network states. In [17] a real-time management of low voltage network using DERs controlled by HEMSs is studied. The algorithm, which gives a good view on the requirement of these kinds of systems, works roughly as follows.

First a state estimation of the distribution network is made. The state estimation of radial networks estimates currents and voltages in all phases and all parts of the target network and is based on static network data and the latest real-time measurements received from DMS and AMI. The DNO has the complete model of the distribution network up to the single final LV customer in the network information system. The calculation results of state estimation are compared to the operational limits of network components. If some thresholds are exceeded, the location of the problem is then found, the location of controllable resources capable to solve the problem are looked for and finally the operational commands (e.g. to reduce power flow) are sent to selected network customers. Load-flow algorithm is used to check the validity of control decisions from the electrical engineering viewpoint. The control commands are sent to the network customers with controllable DERs. The control command includes the following information:

- What kind of control is expected (reduction or increase of demand/production).
- When control may be released or will the system also send the release command.
- How much control is needed (total control need is shared among the available and suitable control resources).
- Where the control should be realized (identification of correct control resources).

The location, availability, resource size, etc. information of DERs in network customers' properties is managed by HEMS. HEMS aggregates the DER information and sends it to the aggregator. The final decision of how the control need of a single HEMS is shared to individual DERs is made by HEMS because the customer may want to prioritize the utilization of resources and the most recent information about DER availability and controllability is in HEMS. The prioritization of DERs might also depend on external factors like outside temperature or predefined conditional situations like plug-in vehicle charging or the presence of high-consumption home appliances such as electrical sauna stove.

In this kind of a system the DNO must be sure that the resources can be used for many years for network management purposes. The system must be reliable enough and its performance must be credible.

C. *Customer back-up power*

1) Motivation

Today's way of living is highly dependent on reliable electricity distribution. In recent years, there have been many serious storms in Finland which have caused long lasting outages for a large amount of electricity users. The reliability of electricity distribution is improved all the time, but outages will always be possible at least to some extent.

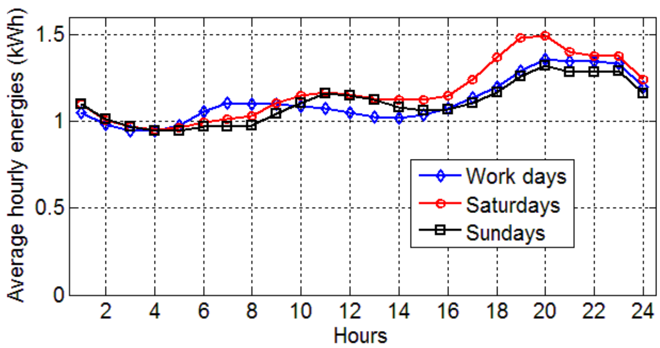

Figure 6. Average hourly energies during different types of days of a 1000 random customers with a 3×25 A main fuses in the distribution network of Koillis-Satakunnan Sähkö Inc.

Plug-in vehicles could be used as a back-up power source during outages. The battery pack would be then used as an energy storage feeding a small network island such as a single household. Also, in the case of a PHEV, the internal combustion engine might also be used to produce electricity from a liquid fuel. The energy capacity of the battery pack is very limited which means that all the energy need of for example a detached house cannot be covered for a long time. However, if the largest loads such as electric heaters and storage water heater were switched off, the sufficiency of the battery capacity would be much higher. If only a very limited amount of loads such as some lighting and maybe cellular phone or laptop charging would be allowed, the battery capacity would offer back-up power capability for a fairly long time. Fig. 6 shows average hourly energies which are measured in 2010 during different types of days of a 1000 random customers with a 3×25 A main fuses in the distribution network of Koillis-Satakunnan Sähkö Inc. The customers of the figure are of different types and also customers with electric heating are included. This simple illustrative example figure shows that with a battery pack from which a few kilo-watt-hours could be used for back-up power purposes, fairly long back-up power capability times could be achieved especially if some of the largest loads were disconnected from the network.

2) Methods

To realize the plug-in vehicle back-up power service, some special equipment and systems would be needed. Fig. 7 illustrates some features of such a system. One requirement is an isolation switch, which is used to disconnect the household or another small network island from the public distribution network. This isolation has to be made because the plug-in vehicle cannot feed other households or customers connected to the public distribution network. Depending on the preferences defined by the user of the back-up power service, it might also be preferable that the electricity connection of the vehicle to the electricity network is three-phased (cf. Fig. 7). Otherwise it would be necessary to connect the loads to be fed to a certain phase. Some load reduction may be necessary to ensure that the power capability of the converter, the line and the energy capability of the battery are sufficient. This requires load disconnection made by HEMS. Assuming that the vehicle works as the only power source (unless there is some sort of small scale power production) during back-up power operation, the feeding equipment has to include all necessary control and protection functions somewhat similar to the ones found in conventional power systems [4].

This comprises voltage control, high enough short circuit current capacity, short circuit protection etc. HEMS and the switching equipment have to include a small battery back-up or other type of back-up power to realize the necessary switching and communication actions during an outage.

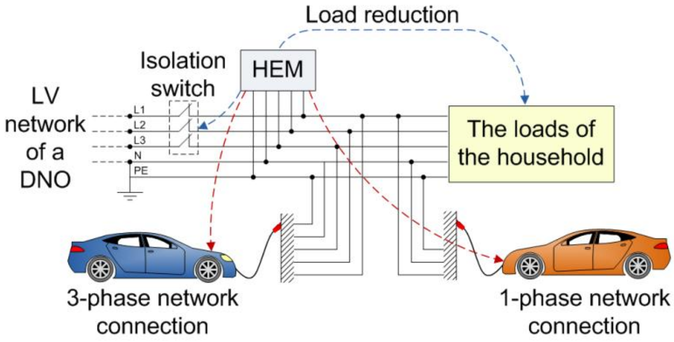

Figure 7. Realization of the customer back-up power service.

The back-up power operation could be automated, but even manually controlled systems can have a significant value during long outages. Automatic operation of the isolation switch and automatic control of the converters of the vehicle are needed. The transfer into back-up power mode could be made with a short interruption or voltage dip, or totally seamlessly. The transfer to back-up power mode after an outage and returning on the basic mode (electricity transfer from distribution network) after the outage could be carried out as follows (cf. also Fig. 7).

1. When an outage is detected in the network by HEMS, the isolation switch has to be opened automatically.
2. After the isolation, necessary load reductions have to be made.
3. “Start back-up power operation” command has to be sent to the converter of the vehicle. Converter starts to feed the loads.
4. When the end of the outage is detected, a “stop back-up power operation” command has to be sent to the vehicle converter.
5. The isolation switch has to be closed.
6. Loads which were disconnected have to be reconnected to the network.

D. Power quality improvement

The importance of power quality issues increases all the time. The significance of good power quality and the amount of the sources of bad power quality increase. Plug-in vehicles could produce a power quality improving service either for an individual network customer or to a DNO. Power quality improvement may mean mitigation of voltage dips, harmonics, flicker and asymmetry in the network.

Using appropriate converter technology in a battery charger, it is possible to adjust the phase specific loading of a three-phase charger to participate in the mitigation of the asymmetry. This could be done based on locally measured voltages of different phases. Chargers would adjust their phase specific loads to mitigate negative sequence component of the voltages. Also, the use of the car converter as an active filter mitigating flicker and harmonics might also be possible. Individual households could use their vehicles to mitigate voltage dips at their network connection. If a voltage dip occurs, the vehicle could feed energy to the network in order to mitigate the dip.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, we have investigated possibilities of plug-in vehicles to produce ancillary services for distribution networks. First, special features of plug-in vehicles as a controllable resource were discussed and then motivation and methods of four different types of ancillary services were discussed. These services are peak load management, network power flow management, customer back-up power and power quality improvement. In the beginning of the plug-in vehicle market penetration many of the ancillary services are not reasonable due to low volume, but when penetration level increases, different ancillary services might become economically attractive.

However, working business models has to be created to realize these kinds of ancillary services. The owners of the vehicles and other controllable resources have to have high enough economic incentives to participate in the ancillary service market. Also, the flexibility and the volume of the resources have to be high enough to be used in ancillary services.

In this paper, the services are only generally overviewed. Deeper investigations with cost analyses, business models and control method developments as well as network simulations and analysis should be made. Also, demonstrations in laboratory environment and pilots in real environment should be carried out.

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