Impacts of battery capacities and specific electricity consumptions on charging needs of PHEVs

A. Rautiainen[1], K. Vuorilehto[2], S. Repo[1], A. Mutanen[1], P. Järventausta[1]

***Abstract*— In this paper, investigations concerning the effect of PHEVs' battery capacities and specific electricity consumption on daily electricity need, proportional electrical mileage and proportional workplace charging are made. It is assumed that charging is carried out only at home and at the workplace. The investigations are made using a deterministic modeling of the charging based on information about the car use habits of people. An interesting result was achieved during the studies: the first kilowatt-hours of the battery capacity bring most of the benefits of PHEVs. Thus, even with small battery packs many of the goals set for PHEVs can be achieved. The specific electricity consumption has some impact on the quantities mentioned above, but the impacts are not, at least within the selected interval, very large.**

***Index Terms*—PHEV, plug-in hybrid electric vehicle, electric vehicle, charging infrastructure, battery capacity, specific electricity consumption, electricity**

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 strongly imply towards the 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). It is widely believed that PHEVs and EVs will become common within 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 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 in the future [2]. Secondly, a lack of adequate charging infrastructure is a major barrier. It is fairly expensive to construct extensive charging infrastructure especially in densely populated areas.

The paper deals only with PHEVs. A PHEV includes a regular internal combustion engine (ICE) and a midsize battery pack. A part of the cars' mileages can be driven using electrical energy and the rest utilizing the ICE. It is assumed that PHEVs will penetrate to the market widely sooner than full EVs.

Using PHEVs, a fairly high portion of driving could be carried out using electrical energy. Fig. 1 illustrates the cumulative shares of the driving of Finnish people as a function of length of a trip. The data of fig. 1 is drawn up using data from the Finnish National Travel Survey 2004–2005. It can be seen that about half of the driven kilometers are driven as trips shorter than 50 km. PHEVs with "electrical ranges" of a few dozens of kilometers can reach a very high proportion of kilometers driven using electrical energy.

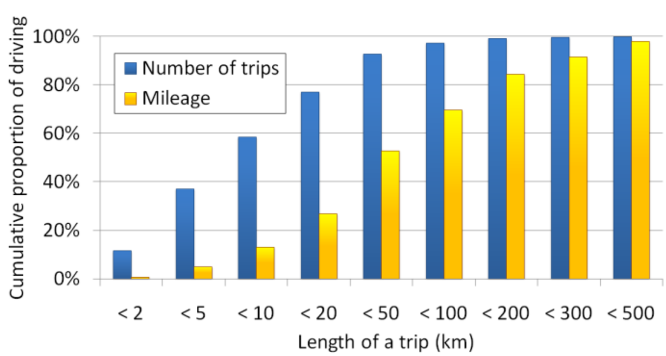


Fig. 1. Cumulative share of number of trips and driven kilometers as a function of a length of a trip.

In general, the bigger the *electrical mileages* of PHEVs, the bigger the potential benefits of them as the use of gasoline or diesel is replaced with the use of electricity. In addition to the electrical range of a vehicle, the electrical mileage also depends on the charging opportunities. The better the charging opportunities are the larger the electrical range is. Today

Manuscript received June 23, 2011.

[1]Authors are with the Department of Electrical Energy Engineering, Tampere University of Technology, P.O. Box 692, FI-33101 Tampere, Finland (antti.rautiainen@tut.fi).

[2]K. Vuorilehto is with Aalto University, School of Chemical Technology, Laboratory of Corrosion and Materials Chemistry (kai.vuorilehto@iki.fi).

Finland offers plenty of electricity infrastructure which could be used, at least with some modifications, for the charging of plug-in vehicles. These sockets located at homes and parking places of workplaces are designed for the pre-heating of car engines in the winter. A few interesting questions arise. How big proportional electrical mileages could be achieved by home and workplace charging with different *electrical ranges*? How much electricity would these cars then draw from the electricity network? How big would the proportions of the electricity charged at homes and at workplaces be? In this paper we have been seeking the answers to these questions.

The electrical range of a PHEV is dependent mainly on two issues: *battery capacity* and *specific electricity consumption*. These are the main factors, but the design of the power train and internal energy management system of PHEVs also has some impact [3]. As the prices of the batteries are the most crucial issues when it comes to the competitiveness of PHEVs in the car markets, it would be interesting to assess the size of the battery needed to obtain a sufficient "energy performance" of PHEVs. In this paper, some investigations concerning the effect of battery capacities and specific electricity consumption on some quantities related to the electricity need and charging behavior are made. Most of the *results* concern Finnish conditions and transportation system, but the presented *methodology* could be used more generally.

The paper is organized as follows. In chapter II, the concepts of effective battery capacity (EBC), specific electricity consumption (SEC) and electrical range are presented. Also, the state-of-the-art and future trends of these properties of PHEVs are very briefly discussed. In chapter III, some sensitivity studies of different quantities regarding EBC and SEC are presented. In chapter IV some conclusions are made and future work is proposed.

II. Batteries, Electricity Consumption and Electrical Range of PHEVs

The battery pack is the most important part of plug-in vehicles, and today it is also often the most expensive part. Thus, the sizing of the battery pack is of major importance in PHEV design. The battery pack should be big enough to produce the benefits of PHEVs, but it also should be small enough to keep the costs at a reasonable level. The capacity of battery packs is often presented in kilowatt-hours (kWh). Nearly always the *nominal capacity* is presented. For example, PHEV Chevrolet Volt's nominal battery capacity is 16 kWh [4] and Toyota Plug-in Prius will have a nominal capacity of 5 kWh [5]. Often in the real appliances the whole capacities of the battery packs are not in use in order to increase the lifetime of the battery packs. *Effective capacities* of PHEV batteries are around 50–65% of the nominal capacity [3], [4], but the proportion depends on the battery chemistry. This effective capacity is the capacity which is really in use for the electricity needs of the car. It should also be remembered that the real effective capacity of a battery decreases in very low temperatures.

The dominant battery type expected to be the choice for plug-in vehicles is the lithium-ion (Li-ion) battery. There are many types of lithium-ion batteries with various chemistries. It is still an open issue, which of the lithium-ion chemistries will be successful in the PHEV market. Toyota Prius PHEV is using a lithium nickel-cobalt-aluminum oxide (NCA) based positive electrode, as it gives the highest energy density. Chevrolet Volt is using a mixture of lithium manganese oxide (LMO) and lithium nickel-cobalt-manganese oxide (NCM). This combination is cheaper and safer than NCA. The choice for Fisker Karma is lithium iron phosphate (LFP), as the LFP chemistry offers the best safety properties and a good cyclic lifetime [6]. The energy density of LFP is modest. However, LFP allows a higher ratio of effective to nominal capacity than NCA, LMO or NCM, and this can partly compensate the difference between the energy densities. The energy density is important for the electrical range, but a high maximum charging rate offers possibilities for fast recharge. If charging spots, especially "fast" charging spots, were available in many places, they would partly work as a substitute for larger battery packs and vice versa. A battery with certain chemistry can be optimized for a large energy density or for large charging rates.

PHEVs have two different driving modes: the charge depleting (CD) mode and the charge sustaining (CS) mode [3]. When the state of charge of the battery pack is above a certain value, the vehicle operates in CD mode using primarily electrical energy from the battery pack for propulsion. In the CS mode PHEV works as a regular hybrid electric vehicle thus using the battery pack only as an energy buffer. In the CS mode all energy is produced by the ICE. CD modes can be divided into two different types: the all-electric and the blended mode [10]. In the all-electric mode a vehicle uses only electrical energy from the battery pack during the CD operation. In the blended mode a vehicle also uses the ICE during situations where high power is needed, such as fast accelerations and high driving speeds [3]. If a PHEV has a very small battery pack, all-electric CD mode is not necessarily possible due to limited power capability of the battery pack.

The specific electricity consumption (kWh/km) of an individual PHEV in the CD mode is dependent on many things. Factors that affect the consumption, considered from the charging point-of-view, are the efficiency of the charging-discharging cycle, the efficiency and the design of the regenerative braking system, the *electricity* needs of heating and air-conditioning, the coefficient of drag, the rolling resistance, the total mass of the vehicle and the driving cycle. Many of these quantities could be improved by means of technology. A typical value of average specific energy consumption for regular passenger car is of the order of 0.15–0.30 kWh/km. Also, the choice between the two different CD modes all-electric or blended, impacts on the specific electricity need.

The definition of the "electrical range" is fairly clear if the PHEV is designed to work in the all-electric mode during CD operation. In this case the electrical range could be defined as *the maximum distance which can be driven using only* *electrical energy in standardized conditions*. If the blended mode is applied during the CD operation, the concept of "electrical range" is a fuzzier one.

III. Impacts of Battery Capacities and Specific Electricity Consumption

The studies of this paper are based on the modeling methodology of the charging load profiling proposed in [7]. The methodology is strongly based on the use of National Travel Survey data. NTS is used to model car use habits of people. The key points and the main assumptions of the methodology are as follows [7].

1. It is assumed that the PHEVs would be driven in the same way as present-day internal combustion engine based cars. Conventional ICE based vehicles are very user-friendly because their range can be over 1000 kilometers, it takes only a few minutes to refuel them and the refueling can be carried out in very many places. This is why people today can generally use their cars to meet all of their their *travelling needs*. Thus, *NTS data can be interpreted to represent the car use needs of Finns*. However, it should be noted that changes in the way of living, prices of electricity and liquid fuels and use of public transport etc. have an effect on the driving needs in the future.
2. Charging can be carried out in two places, at homes and at workplaces. Nowadays, sockets for the pre-heating of the car engines are very widely available in Finland in all types of houses and also in workplaces. These sockets could be used to some extent to charge plug-in vehicles. It was noticed in the case studies presented in [8] that on average approximately 50 % of the pre-heater sockets of different parking places could be used for charging with 3 kW charging powers without overloading the feeders feeding the sockets. Thus, in high penetration levels of plug-in vehicles, the feeders of the parking areas should be enforced.
3. Charging is started immediately when a car arrives at a charging spot and charging continues until the battery is full or the next car trip begins. Different "smart charging" schemes, see for example [9]–[15], in which charging would be coordinated in different ways are excluded. Vehicle-to-grid (V2G) [16] and Vehicle-to-home (V2H) [9] functionalities are also excluded.
4. The maximum charging power is 3 kW in all charging spots. This power could be delivered well with a one-phase feeder with a 16 A fuse in 230 V system.
5. The EBCs and the mean SECs of different cars were formed randomly obeying normal distribution with certain parameters.

In this paper, we investigated the impact of mean EBCs and mean SECs on the following quantities:

1. *The mean daily electrical energy need of the vehicles*
2. *The mean proportion of total mileage driven using electrical energy*
3. *The mean proportion of electricity charged at workplace*

The first quantity, the mean daily electrical energy need, is an interesting quantity as by using it the need of electrical energy of cars can be assessed by different parties such as distribution network companies, electricity retailers and car users. The second quantity is interesting, especially the effects battery capacities have on it. When computing the second quantity, it is assumed that vehicles operate in all-electric mode during CD operation. The third quantity is needed in order to assess the amount of the charged energy in different charging places and the information could also be used in charging infrastructure planning. In addition to these quantities, the impacts of EBC and SEC on many other things could also be investigated such as the decrease in the need for crude oil, the reduction of CO_2 or other emissions etc. These quantities are however excluded from this paper.

The three quantities were investigated as sensitivity analyses by varying the two variables: mean battery capacity and mean specific energy consumption within certain intervals, and then computing the values of the three quantities accordingly. The effective battery capacities were varied having mean values of 1, 2,…, 30 kWh, being normally distributed and having 10 % (of the mean value) standard deviation. It should be noticed that when very small capacities are used, the charging powers lead to fairly high battery charging rates, and the assumption of constant power during the charging process made in [7] may not be valid. Also, in these sensitivity studies the biggest battery capacities are very much overestimated for PHEV use when compared to the today's state-of-the-art battery technology. The specific electricity consumptions were varied having mean values of 0.15, 0.16,…, 0.30 kWh/km, being normally distributed and having 10 % standard deviation.

A. The mean daily electrical energy need of the vehicles

Figures 2–4 illustrate the results of the sensitivity analysis of the *average daily electrical energy need* of the vehicles. Fig. 2 presents the mean daily electricity need as function of the mean effective battery capacity, where 0.2 kWh/km mean specific electricity consumption is assumed. Fig. 3 presents the same quantity but as a function of the mean specific electricity consumption, and in this case the mean effective battery capacity of 10 kWh is assumed. Fig. 3 presents the results of the sensitivity analysis with both varying variables as a three-dimensional graph.

It should be mentioned that in many graphs in this paper the axis labels are shortened for practical reasons. For example, "daily electricity need" in figures 2 and 3 stand for "the mean daily electrical energy need of the vehicles", and " battery capacity" and "specific electricity consumption" in fig. 3 stand for "the mean effective battery capacity" and "the mean specific electricity consumption", respectively.

A few interesting observations can be made from the results. It can be seen that the electricity need rises rapidly when battery capacity is increased from the lowest values. It can be interpreted that the first kilowatt-hours in battery capacity bring most of the electricity consumption. Adding capacity very much over for example 10 kWh seems to increase the need for electricity only a little. It can also be seen that at least within the selected specific electricity consumption interval, a certain proportional increase in average specific consumption often leads to a smaller proportional increase in the *daily electricity consumption*. Thus, as the daily mileage (km/d) is constant, charging infrastructure or battery capacity restrict the electricity use of the vehicles.

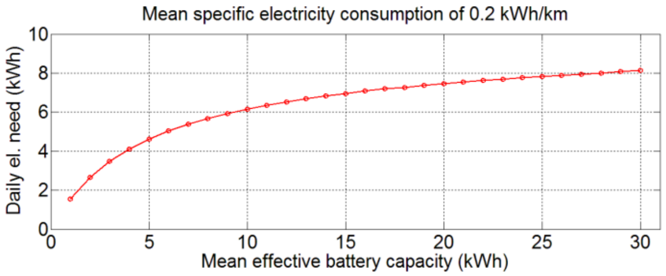


Fig. 2. The mean daily electrical energy need as a function of mean effective battery capacity. The mean specific electricity consumption is assumed to be 0.2 kWh/km.

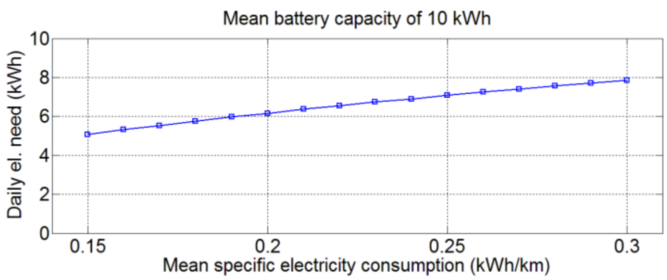


Fig. 3. The mean daily electrical energy need as a function of mean specific electricity consumption. The mean effective battery capacity is assumed to be 10 kWh/km.

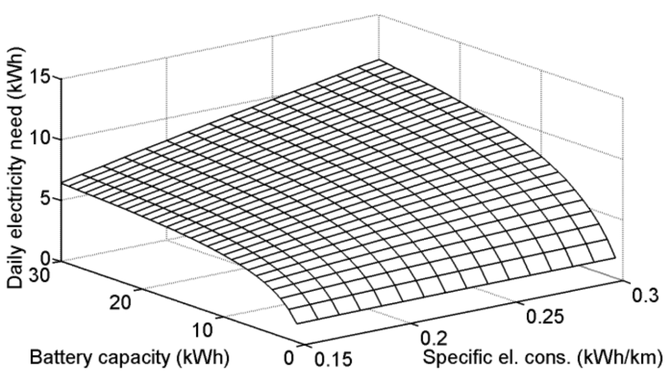


Fig. 4. The mean daily electrical energy need as a function of mean specific electricity consumption and mean effective battery capacity.

B. *The mean proportion of total mileage driven using electrical energy*

Figures 5–8 illustrate the results of the sensitivity analysis of the *mean proportion of total mileage driven using electrical energy*. Fig. 5 presents the mean proportional electrical mileage as function of the mean effective battery capacity, where 0.2 kWh/km mean specific electricity consumption is assumed. Fig. 6 presents the same quantity but as a function of the mean electricity consumption, and in this case the mean effective battery capacity of 10 kWh is assumed. In both figures 5 and 6 two different curves are presented. The curves differ from each other in the *way of calculation*. The first one is computed by first calculating the proportions of the "electrical mileages" of all the mileages of the individual vehicles. After this the mean value of the proportions is calculated. The second curve is formed by first summing the electrical mileages of all cars and dividing it by the sum of all mileages of all cars. Figures 7 and 8 present the results of the sensitivity analysis with both varying variables as three-dimensional graphs corresponding to two different calculation methods presented above.

Some interesting observations can be made from the results. One is that even with fairly small battery capacities, a fairly large proportion of mileage can be driven using electricity. Thus, it can be interpreted that *the first few kilowatt-hours in battery capacity bring most of the benefits of PHEVs*. Very large batteries are not necessarily needed in order to obtain the goals of the electrification of passenger transportation. Another observation is that the effect of the mean specific electricity consumption, at least within the selected interval, on the proportional electrical mileage is not very large. Of course it has some impact, but the effects of small variations are fairly small.

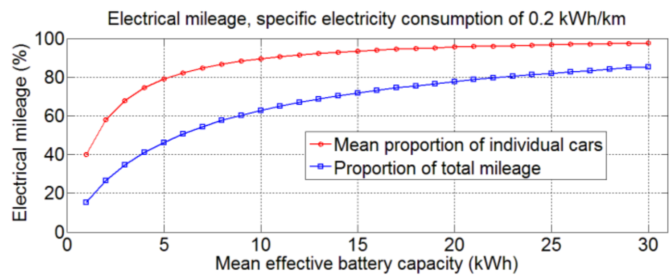


Fig. 5. The proportion of the driven mileage using electrical energy as a function of mean effective battery capacity. The mean specific electricity consumption is assumed to be 0.2 kWh/km.

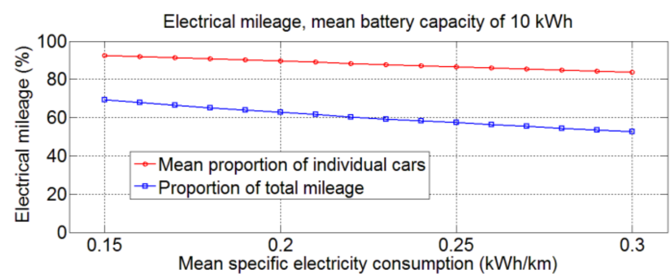


Fig. 6. The proportion of the driven mileage using electrical energy as a function of mean specific electricity consumption. The mean effective battery capacity is assumed to be 10 kWh/km.

In the proportional electrical mileage, there are remarkable differences between the results of the two different calculation methods. The main cause for the differences is that when calculating the *mean proportion of individual cars*, the absolute mileages (in kilometers) are "hidden" behind the numbers. When calculating the *proportion of total mileage*, the absolute differences of the mileages are taken into account. Table I illustrates this by means of a simple example. In the example, total mileages of 5 imaginary PHEVs during a day are presented with the electrical mileages of the cars. Then the car specific proportional electrical mileages and their average are calculated. Then the proportion of the sum electrical mileage of the sum total mileage is calculated. One can see that the difference is remarkable. The quantities based on the proportion of total mileage should be used in a sort of "system level" studies, for example in emission calculations. The mean proportion of the individual cars is more of a "car user point-of-view" perspective.

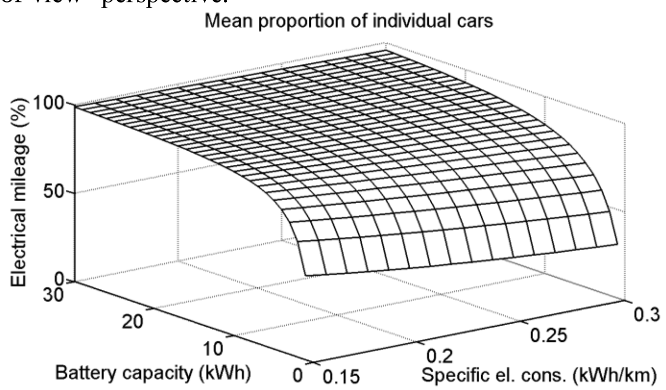


Fig. 7. The proportion of the driven mileage using electrical energy as a function of the mean specific electricity consumption and the mean effective battery capacity. Calculated as a mean proportion of individual cars.

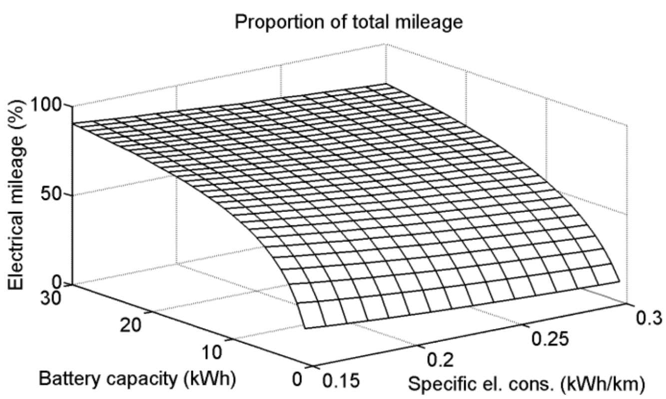


Fig. 8. The proportion of the driven mileage using electrical energy as a function of the mean specific electricity consumption and the mean effective battery capacity. Calculated as a proportion of the total mileage.

TABLE I
ILLUSTRATIVE EXAMPLE OF THE DIFFERENCES BETWEEN THE TWO DIFFERENT CALCULATION METHODS

Total mileages of a single day of the cars (km)	Electrical mileages of a single day of the cars (km)	Proportional electrical mileages of the cars
77	20	26%
12	12	100%
9	9	100%
80	44	55%
75	49	65%
Sum: 253	Sum: 134	Average: **69%**
	Proportion of total sum mileage: **53%**	

C. The mean proportion of electricity charged at workplaces

Figures 9 and 10 illustrate the results of the sensitivity analysis of the *proportion of the electrical energy charged at workplace of the total electrical energy*. These figures also present the two different ways of calculation. The first one is computed by first calculating the proportions of workplace charging of all individual vehicles. After this the mean value of the proportion is calculated. The second curve is formed by first summing the energies charged at work places of all cars and dividing it by the sum of all energies of all cars. The idea of the calculation methods is similar to the previous quantity.

It can be seen that the proportion of workplace charging is very stable with respect to mean effective battery capacities and mean specific electricity consumption. Some non-negligible changes can be seen in the *proportion of total energy*. However, the change is fairly small. The three-dimensional graphs are not presented for this quantity, as they presented very flat profiles and bring no noticeable additional information when compared to figures 9 and 10.

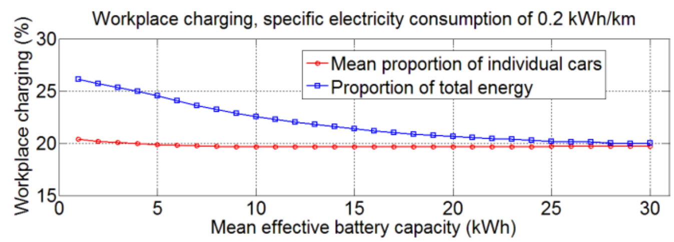


Fig. 9. Proportion of the energy charged at the workplace as a function of mean effective battery capacity. Mean specific electricity consumption is assumed to be 0.2 kWh/km.

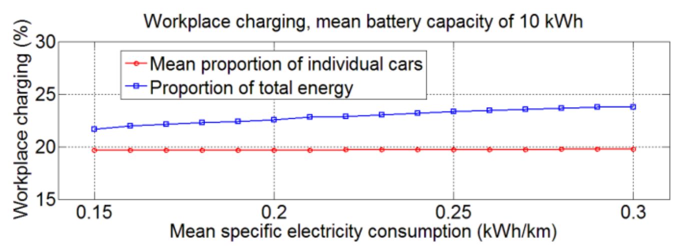


Fig. 10. Proportion of the energy charged at the workplace as a function of mean specific electricity consumption. Mean effective battery capacity is assumed to be 10 kWh/km.

IV. CONCLUSIONS AND FUTURE WORK

In this paper, the effects of the effective battery capacities and the specific electricity consumptions of PHEVs on their electricity needs, electrical mileages and workplace charging needs are presented. It is assumed that the charging would mostly be carried out at homes and at workplaces as "dumb" charging. Nowadays in Finland, these places offer plenty of electricity infrastructure for preheating the engines of the cars and this infrastructure could be used to some extent for charging purposes.

The most important results of this paper are as follows. *The first few kilowatt-hours of the battery packs bring most of the benefits of PHEVs.* There is necessarily no need for very large and expensive battery packs in order to achieve the goals set for PHEVs. The first kilowatt-hours in the battery capacities also bring most of the electricity needs of the cars. With the assumptions made in this paper, the proportion of the charged energy which is charged at workplace is very stable, around 20 %. The mean specific electricity consumption of the vehicles did not affect the quantities under investigation as much as the changes in battery capacities.

Many topics and issues for future work arose in this study. In this paper only three simple quantities were investigated. Other quantities mentioned in the paper could also be studied. Future work could also include investigations of different intelligent charging scenarios. These studies could be further extended by including other charging places besides homes and workplaces. Also, different types of statistical distributions of the battery capacities and the specific electricity consumptions could be applied.

REFERENCES

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

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

[3] J. Axsen, A. Burke, K. Kurani. "Batteries for Plug-in Hybrid Electric Vehicles (PHEVs): Goals and the State of Technology circa 2008". Institute of Transportation Studies, University of California, 2008, 26 p.

[4] Chevrolet. "Chevrolet Volt Uses More than 8 kWh of Stored Battery Energy to Achieve EV Range", [Online] Available http://gm-volt.com/2010/10/08/chevrolet-volt-uses-more-than-8-kwh-of-stored-battery-energy-to-achieve-ev-range/, accessed 20.4.2011

[5] Telegraph. "Toyota Plug-In Prius review" [Online]. Available: http://www.telegraph.co.uk/motoring/car-manufacturers/toyota/6833552/Toyota-Plug-In-Prius-review.html, Accessed: 19.4.2011

[6] M. Yoshio, R. J. Brodd, A. Kozawa (Eds.), *Lithium-Ion Batteries, Science and Technologies*, Springer, 2009, 452 p.

[7] A. Rautiainen, S. Repo, P. Järventausta, A. Mutanen. "Statistical charging load modeling of PHEVs in electricity distribution networks using National Travel Survey data". Proposed for IEEE Trans. Smart Grids. 10 p.

[8] Fortum Oyj. 2011. "Recommendation to plug-in vehicles in internal networks of real estates", [Online] Available: http://www.fortum.com/gallery/press/Ladattavat_autot_sahkoverkoissa_suositus.pdf [in Finnish]

[9] A. Rautiainen, C. Evens, S. Repo, P. Järventausta. "Requirements for an interface between a plug-in vehicle and an energy system", IEEE Powertech 2011, 8 p.

[10] A. Rautiainen, S. Repo, P. Järventausta. "Intelligent charging of plug-in vehicles". NORDAC 2010, The 9th Nordic electricity distribution and asset management conference, Aalborg, Denmark, 2010, 11 p.

[11] E. Sortomme, M. M. Hindi, S. D. J. MacPherson, S. S. Venkata. "Coordinated Charging of Plug-In Hybrid Electric Vehicles to Minimize Distribution System Losses", IEEE Trans. Smart Grids, vol. 2, 2011, pp. 198–205.

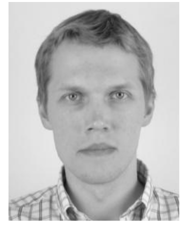
[12] E. Sortomme, M. A. El-Sharkawi. "Optimal Charging Strategies for Unidirectional Vehicle-to-Grid". IEEE Trans. Smart Grids, vol. 2, 2011, pp. 131–138.

[13] K. Clement-Nyns, E. Haesen, J. Driesen. "The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid" IEEE Trans. Power systems, vol. 25, 2010, pp. 371–380.

[14] M. D. Galus, G. Andersson. "Demand Management of Grid Connected Plug-In Hybrid Electric Vehicles (PHEV)", IEEE Energy2030, 2008, 8 p.

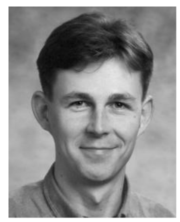
[15] J. Lassila, T. Kaipia, J. Haakana, J. Partanen, P. Järventausta, A. Rautiainen, M. Marttila. "Electric cars – challenge or opportunity for the electricity distribution infrastructure?". European Conference SmartGrids and Mobility, 2009, Würzburg, Germany. 8 p.

[16] J. Kiviluoma, P. Meibom. "Methodology for modeling plug-in electric vehicles in the power system and cost estimates for a system with either smart of dumb electric vehicles", Energy (2011), doi: 10.1016/j.energy.2010.12.053.



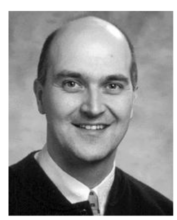
A. Rautiainen received his M.Sc degree from Tampere University of Technology in 2008. He is now working as a researcher towards doctoral degree at Tampere University of Technology. His main interest focuses on the effects of plug-in vehicles to electric power systems, ancillary service possibilities of plug-in vehicles and new load control schemes.

K. Vuorilehto received his M.Sc. and Dr.Tech. degrees in Electrochemistry from Helsinki University of Technology in 1990 and 1997 respectively. At present he is an adjunct professor for Electrochemical Energy Solutions at Aalto University (formerly Helsinki University of Technology), Helsinki. Additionally, he works as a battery consultant for the industry. His main interest is the electrochemistry of lithium ion batteries.



S. Repo received his M.Sc. and Dr.Tech. degrees in Electrical Engineering from Tampere University of Technology in 1996 and 2001 respectively. At the present he is an associate professor at the Department of Electrical Energy Engineering of Tampere University of Technology. His main interest is the management of active distribution network including distributed energy resources.

A. Mutanen was born in Tampere, Finland, on June 10, 1982. He received his Master's degree in electrical engineering from Tampere University of Technology in 2008. At present, he is a Researcher and a post-graduate student at the Department of Electrical Energy Engineering of Tampere University of Technology. His main research interests are load research and distribution network state estimation.



P. Järventausta received his M.Sc. and Licensiate of Technology degrees in Electrical Engineering from Tampere University of Technology in 1990 and 1992 respectively. He received the Dr.Tech. degree in Electrical Engineering from Lappeenranta University of Technology in 1995. At present he is a professor at the Department of Electrical Energy Engineering of Tampere University of Technology. The main interest focuses on the electricity distribution and electricity market.