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Electric Vehicle Charging Systems in the Helsinki Region

Master's Thesis submitted for approval for the degree of Master of Science.

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Supervisor Prof. Matti Lehtonen
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ABSTRACT OF THE
MASTER'S THESIS

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Global warming and efforts to reduce greenhouse gases have forced our community towards the use of alternative fuels. Due to recent developments, electric cars are becoming a respectable alternative to gasoline cars. This Master's Thesis is a part of a project, which aims to advance sustainable electric mobility in Finland. The thesis evaluates the current state of the industry in Finland and abroad. Also, the technology of electric cars and the batteries are reviewed. The primary target of the thesis is to develop solutions for electric vehicle charging, billing and metering in the Helsinki area. The billing and metering solutions are assessed from the end-user's point of view. In the thesis, charging and billing solutions for various locations are suggested and evaluated. Also, the effect of charging on the electricity consumption of individual households is examined along with medium voltage feeder studies. The examples from medium voltage feeders reveal that intelligent charging is desirable from the beginning and even mandatory in the long run. Lack of intelligence might result in exceeding the load capacity of the local network. The payment method evaluation notes the combination of mobile phone and RFID (Radio Frequency Identification) to be the most practical. RFID could handle the payment while the mobile phone offers the extra services. The mobile phone could operate as an optional instrument of payment.

Keywords: electric car, electric vehicle, plug-in hybrid, charging system, EV industry, impact of EV charging to the power network, basic solutions of charging, billing and metering

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Ilmaston lämpeneminen ja tavoitteet kasvihuonekaasupäästöjen vähentämiseksi ajavat yhteiskuntaamme kohti vaihtoehtoisia polttoaineita. Viimeaikaisen kehityksen johdosta sähköautoista on tullut varteenotettava vaihtoehto korvaamaan polttomoottoriautoja. Diplomityö on osa projektia, joka pyrkii edistämään sähköistä liikkuvuutta Suomessa. Työssä käsitellään aluksi sähköautoilun nykytilaa Suomessa ja maailmalla sekä tarkastellaan auto- ja akkutekniikkaa. Varsinaisena tavoitteena on pohtia mahdollisia ratkaisuja tuleville sähköautojen latausjärjestelmille sekä latauksen maksutapoja loppukäyttäjän näkökulmasta. Työssä esitetään ja arvioidaan ratkaisuja eri kohteiden lataustarkoituksiin sekä laskutustapoihin. Lisäksi tutkimuksessa tarkastellaan suppeasti sähköauton latauksen vaikutusta yksittäisen kotitalouden sähkönkulutukseen ja hieman laajemmassa mittakaavassa keskijänniteverkkoon. Esimerkkilaskut osoittavat älykkään latauksen olevan suotavaa jo muutoksen alkuvaiheessa ja miltei välttämätöntä sähköautojen yleistyessä. Sähköautojen yleistyminen ja älykkään latauksen puute saattavat johtaa verkon kuormitettavuuden ylittymiseen paikallisesti. Julkisten latauspaikkojen maksutapatarkastelussa todetaan, että matkapuhelimen ja RFID:n yhdistelmä olisi käytännöllisin vaihtoehto. RFID:n avulla voitaisiin hoitaa itse maksaminen ja matkapuhelin voisi tarjota lisäpalveluita kuluttajille. Matkapuhelinta olisi mahdollista käyttää vaihtoehtoisena maksuvälineenä.

Avainsanat: sähköauto, sähköajoneuvo, ladattava hybridi, latausjärjestelmä, sähköautoteollisuus, latauksen vaikutus sähköverkkoon, latauksen perusratkaisut, maksujärjestelmä

Preface

This Master's Thesis was completed in the Department of Electrical Engineering Aalto University. The thesis associates the SIMBe project involving companies showing interest in electric mobility in Finland.

I want to thank my supervisor Professor Matti Lehtonen for the interesting subject and guidance throughout the process. I wish to thank my instructor Eero Saarijärvi for valuable comments and ideas. I also express my gratitude to Pirjo Heine from Helen Sähköverkko Oy for all the materials, plans and comments for the power grid studies. Thanks to William Martin for proofreading the final version of my thesis.

I would also like to thank my colleagues, Leo Romana and Olli Vaittinen, for collaboration and good times over the year 2010. I thank my parents for all the moral support and financial assistance during my studies. Finally, my greatest gratitude goes to dear Katja for all the support over the years.

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Jani Lehtinen

Contents

Terms and Abbreviations

AC	Alternating Current
AMR	Automatic Meter Reading
BCG	Boston Consulting Group
BIT	Business, Innovation and Technology
CO_2	Carbon Dioxide
DC	Direct Current
DSO	Distribution System Operator
EEPROM	Electric Erasable Programmable Read-only Memory
EV	Electric Vehicle
HF	High Frequency
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
KTH	Royal Institute of Technology
LED	Light-Emitting Diode
$LiFePO_4$	Lithium Iron Phosphate
Li-Ion	Lithium-Ion
LPR	License Plate Recognition
MV	Medium Voltage
NiMH	Nickel-Metal Hydride
NOx	Nitrogen Oxide
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Vehicle
PIN	Personal Identification Number
RFID	Radio Frequency Identification
SMS	Short Message Service
TEPCO	Tokyo Electric Power Company
V2G	Vehicle-to-Grid
VTT	Technical Research Centre of Finland

Units

A	ampere
bbl	barrel
°C	Celsius
€	euro
g	gram
KB	kilobyte
km	kilometer
km/h	kilometers per hour
l	liter
m^2	square meter
Nm	Newton meter
$	United States Dollar
SEK	Swedish Krona
USD	United States Dollar
V	volt
Wh	watt hour
W	watt

1 Introduction

1.1 General

Constantly rising fuel prices and environmental consciousness have forced communities to consider alternative transport solutions. In the past, electric cars have not been a noteworthy alternative for cars with an internal combustion engine due to poor batteries. Lately, batteries and electric cars have developed to become a respectable alternative to gasoline powered cars. Although battery prices are high and driving ranges are low compared to the gasoline cars, electric vehicles entail several direct and indirect benefits to the society. Numerous projects concerning electric transportation around the world are in operation. Since most of these projects are at the initial phase, actual results are not available yet. The electric vehicle technology and business are, however, developing rapidly. Thus, it is vital to keep up with the pace and develop innovations and concepts further. After all, the Finnish industry has advantageous business opportunities after the transition really commences.

1.2 Scope and aim of the thesis

This Master's Thesis is a part of the SIMBe (Smart Infrastructures for Electric Mobility in Built Environments) project, started up in January 2010. The project is introduced further in Section 1.4. Chapter 2 presents the history, technology and features of electric cars. Additionally, battery technology is under study. The present state of the electric vehicle industry is assessed in Chapter 3. The primary aim of the thesis involves two points; to outline the possible charging solutions, and the feasible billing and metering methods for the electric cars in the Helsinki region. The fist aim is covered in Chapter 4 and the latter in Chapter 6. These solutions can be utilized at the implementing phase of the SIMBe project. The scope of the billing and metering evaluation was to consider this issue from the end-users viewpoint. Helen Sähköverkko Oy provided the research data used in Chapter 5 that handles the secondary target – to examine the effects of electric vehicle charging on the medium voltage network. In addition, the increase of an individual household's electricity consumption was assessed. At the end of the thesis, proposals for the basic solutions of charging are introduced. Also, convenient billing and metering methods from the user's viewpoint are suggested.

1.3 Methods

The thesis was started by familiarizing with the subject and gathering basic understanding about the state of the industry worldwide. After the introductory phase, a preliminary table of contents was prepared. Based on the table of contents, more accurate data about the chapter at issue was explored. The initial phase mainly included literature survey. Later, concepts from the world and ideas from the SIMBe project were partially modified and utilized into basic charging solutions. The billing and metering solutions were evaluated by assessing the current means of payment and ways of metering the electricity consumption. The effects of electric vehicle charging to the power grid based on the data received from Helen Sähköverkko Oy. By including own impressions about the charging load into the received data, a conception about the effects to the medium voltage network was acquired.

1.4 The SIMBe project

The overall aim of SIMBe is to accelerate sustainable electric mobility in Finland. SIMBe aims to prepare Finnish industrial parties and consumers for transition towards electric transportation. The project covers the state and opportunities of the industry in its entirety. The project focuses on built up environments and Helsinki will be the initial pilot city. Electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) lie within its scope, but not hybrids without plug-in capability. The scheduled time for the whole project is from January 2010 to December 2011 and the total budget is 1 M€. [1]

SIMBe starts with a stakeholder value analysis including industry, public authorities and end users. In the modeling and simulation phase, market-, traffic- and technology assessments as well as new and existing services will be integrated into concepts for strategic business models and earning logics. Further outputs include an infrastructure blueprint and guidelines for transition, uncertainty management and market entry. [1]

Electric vehicles are entering vehicle markets and dozens of car manufacturers have announced the launching of their own EV projects. Valmet Automotive has started to produce a Norwegian Think City electric vehicle (Figure 1). An American hybrid sports car, Fisker Karma, will also be produced by Valmet (Figure 2). Moreover, European Batteries is opening a factory for lithium batteries in Varkaus in 2010. [1] Finnish electro technical expertise merged with the electric car industry offers plenty of potential business opportunities.

Figure 1: Think City [2]

Figure 2: Fisker Karma [3]

1.4.1 Project participants

SIMBe will prepare the industrial partners to engage in new business opportunities built on electric energy sales and purchases, the increased sales of components, the provision of vehicles and mobility services as well as the provision of infrastructures. Both industrial partners, as well as Helsinki, will become forerunners in Finland in terms of electric mobility. Additionally, the partners are able to enlarge their image as environmentally friendly and sustainable suppliers and employers. [1]

The following parties are participating in the project:

- Aalto University School of Science and Technology
- Tekes
- Helsingin Energia
- Helsinki City Planning Department
- Nokia Siemens Networks Oy
- Finnish Parking Association
- Ensto Electric Oy
- O2 Media Oy
- Oliivi Autot Oy
- eCars Now!
- Puronovo Oy
- HOK-Elanto
- European Batteries Oy

International collaboration will involve complementary expertise from Stanford University, Harvard University, Royal Institute of Technology (KTH) and the Swedish Energy Authority STEM. National collaboration is generated with National Consumer Research Centre, Hanken and Technical Research Center of Finland (VTT). [1]

The project is divided into four work packages and this Master's Thesis enters into work package 4. Altogether four departments from Aalto University are involved in the project.

- The Business, Innovation and Technology (BIT) research centre operates as a coordinator
- The Department of Applied Physics, New Energy Technologies group (prof. Peter Lund)
- The Department of Civil & Environmental Engineering, Transportation Engineering group (prof. Timo Ernvall)
- The Department of Electrical Engineering: Power Systems and High Voltage Engineering group (prof. Matti Lehtonen).

Project Director Raphael Giesecke works as the project manager. The BIT research centre focuses on value networks and on value creation through electric mobility. Other departments focus on integrating their technological competences into the project. [1]

2 Electric vehicles and plug-in hybrids

2.1 History of electric cars

An electric car is an old invention. Electric vehicles were invented as early as in the 1830s. In the early 1900s electric cars were more popular than gasoline cars. Electric cars did not contain the vibration, smell and noise associated with gasoline cars. Electric cars also did not require gears, while in gasoline cars gear changing was the most difficult part of driving. Around the 1920s, internal combustion engines (ICE) started to gain dominance in the U.S. automotive markets. Decline of EV sales occurred for several reasons. First, by the 1920s, the system of roads required longer-range vehicles as distances were long. Second, the discovery of crude oil reduced the price of gasoline so that it was affordable to average consumers. Third, in 1912 the invention of an electric starter helped to start an ICE without an awkward hand crank. Finally, Henry Ford initiated mass production of internal combustion vehicles, which made these cars widely available and more affordable. Cars were no longer only for the upper class. By comparison, in 1912 the price of an electric roadster was $1750 while a gasoline car was sold for $650. [4]

Internal combustion engines have dominated car markets for the last 100 years for the previous and following reasons. It has been demonstrated that gasoline and diesel as a fuel contain better energy and power densities than batteries [5]. Moreover, refueling a gasoline tank takes a couple of minutes while recharging a battery takes several hours. Additionally, an ICE provides greater driving distance with a single refueling. In the past decades, the electric car has tried to enter car markets several times but the attempt has failed every time. Batteries have been the main reason why EVs are the not the vehicles we drive today [6]. Nevertheless, the mighty oil industry has had a major impact on the failure of EVs to gain a foothold in the market as well.

2.2 Demand for electric vehicles

In recent years, awareness of global warming and environmental issues has forced politicians to make decisions concerning greenhouse gases. In addition, the constant increase in crude oil prices has forced communities to search for alternative fuels and ways to get rid of oil dependency. Hydrogen and fuel cells provide one promising option for the fuel of the future. Hydrogen incorporates many advantages but also several unsolved problems. The fuel cells are expensive and hydrogen would require a totally new distribution network. Additionally, the storing of hydrogen arouses challenges as hydrogen is a very sensitive and explosive gas. Hydrogen does not exist in the form of pure hydrogen such as oil or coal. Also, hydrogen is in nature attached to some other element, for instance the compound of hydrogen and oxygen known as water. Therefore, pure hydrogen must be produced, similar to gasoline, which in turn requires energy. [7] Electricity provides another option for an alternative fuel. In turn, electricity has many advantages and disadvantages including the great challenge of storage. However, electricity is the most promising technology available because the basic infrastructure already exists and the technology is identified as being safe and dependable.

In order to protect nature and limit global warming, the reduction of CO_2-emissions is essential. The European Union's energy and climate convention states that Finland needs to reduce CO_2-emissions by 16% from the 2005 level. The aim for industrial countries is 60-80% reduction from the present level by 2050. [8] Such a reduction requires improvements in every sector. Road traffic causes 16% of all CO_2-emissions in Finland from which passenger cars produce 41% [9]. Hence, EVs are seen as a major part of the reduction plan. EVs can provide traffic without emissions if the electricity is produced with renewable resources. With the electric production currently in use, the CO_2-emissons of EVs are predicted to be around 50 g/km per car including emissions from power plants and losses in the distribution and transmission. At the moment, the average CO_2-emissions per car are around 180 g/km, including emissions from oil refinement and distribution. [8]

Along with CO_2-emission reduction plans, a constant rise in the oil price has assisted the rebirth of EVs [8]. As the world today is involuntarily dependent on oil, alternatives are needed. In recent times, the price of oil has greatly effected our everyday lives. In July 2008, the crude oil price rocketed to 147 USD/bbl, which is the highest price of all time [10]. These high crude oil prices naturally affected Finland as well. The prices of many products rose as transportation costs rocketed, people started to get rid of cars with high consumption, and people started to think carefully whether to drive or not. The peak occurred over the holiday season and many entrepreneurs suffered because people could not afford to travel. The consequences are long-lasting on both the general welfare and the economy, and it can take years to recover. Fortunately, EVs offer an energy efficient solution to reduce this oil dependency and ensure sufficiency of oil for future generations.

The price of a product strongly directs consumers towards certain choices. Consumers weigh receivable benefits against prices and usually the most valuable alternative is chosen. Thus, consumer selections can be influenced with taxation. On a larger scale, the same principle applies. In time, the most cost efficient solution to the whole society overshadows other options. Currently, electric cars are expensive due to batteries and the charging infrastructure requires major investments. Later, when the technology becomes less expensive and the infrastructure stands in place, EVs will become an attractive option to gasoline cars. However, development in the technology and financial assistance is required to kick off the transition.

2.3 Plug-in hybrid vehicle (PHEV)

A plug-in hybrid vehicle contains an internal combustion engine and an electric motor enabling long driving distance, relatively low fuel consumption and low CO_2-emissions. Plug-in hybrids can be divided in two main categories: parallel hybrids and series hybrids. In a parallel hybrid both engines can run the car (Figure 3). Typically, these engines run simultaneously, utilizing both their features. In parallel hybrids, a battery operates as energy storage for the electric motor. Batteries recharge while the car is braking or the engine is running free. Batteries can also be recharged from an external power source. When batteries run out of power, an internal combustion engine turns on and the driving continues without interruptions. In series hybrids an ICE operates as a generator to keep up the electric motor and the batteries. The electric motor runs the car alone (Figure 4).

Batteries are recharged the same way as in parallel hybrids. [8] The advantage of series hybrids is that they can utilize the combustion engine optimally. The ICE can run on its efficient revs and the batteries deal with the power adjusting. Of the major car manufacturers, Toyota uses a combination of two hybrid techniques called the series parallel hybrid system (Figure 5) [8].

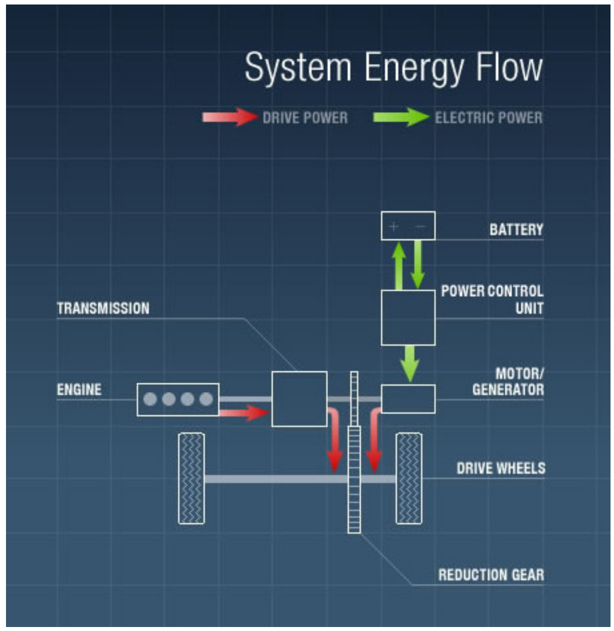

Figure 3: Parallel hybrid system [11]

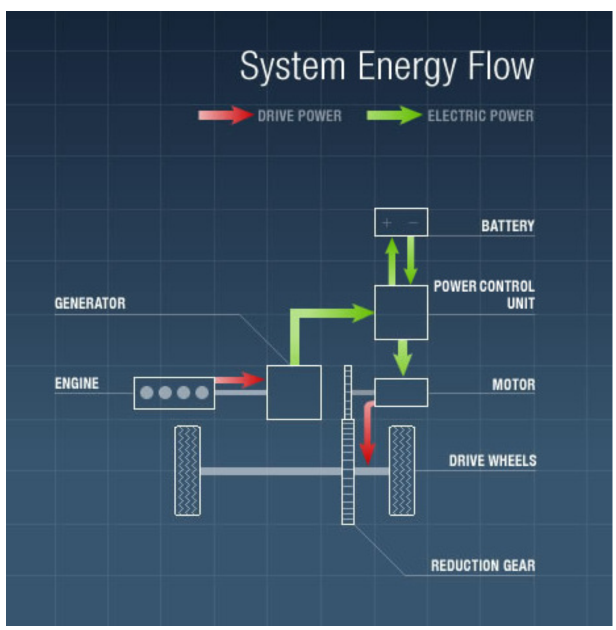

Figure 4: Series hybrid system [11]

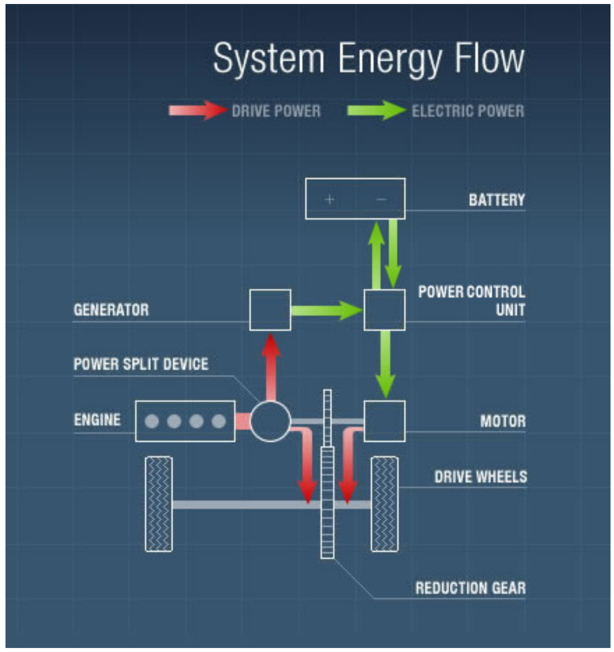

Figure 5: Series parallel hybrid system [11]

Contrary to EVs, driving distance is not a problem with plug-in hybrids. Additionally, heating and cooling of the interior can be dealt with an ICE like before. Thus, it is easier for consumers, for a start, to choose a plug-in hybrid instead of a fully electric car. However, in the long run plug-in hybrids are seen as an initial phase towards fully electric transportation. When charging stations start to appear, batteries develop further and prices go down, EVs are believed to start to become more widespread.

2.4 Electric vehicle (EV)

Electric vehicles require less service and the structure is less complicated than in plug-in hybrids. An electric car does not include an ICE as a motor or a generator. A battery and an electric motor operate as a power source. The power needed for the AC-motor is stored in the batteries. As in PHEVs, the batteries recharge while the car is braking. Also, the batteries can be recharged from an external power source. Chargers can be divided into two categories, on-board and off-board chargers. Chargers with less power are called on-board chargers because they are placed inside the car. High power chargers (off-board) are external DC-chargers. Because of the efficiency, an electric motor does not produce enough heat for the interior of the car. Hence, a distinct heater is required. Otherwise electric cars do not need to differ much from existing car types. Electric cars can be as fast and practical as cars today. Furthermore, electric cars offer a transport solution without local tailpipe emissions. [8] Conversion EVs are cars with an ICE changed to an electric motor and a battery pack. In Finland, only a few of such cars exist, mainly in business use. A Finnish community, called *eCars – Now!*, creates these conversions and their conversion Corolla has widely appeared in public. According to Jiri Räsänen from the *eCars – Now!* -community, a conversion for a standard Toyota Corolla costs some 30 000 €. [12] In the future, conversions will be cheaper as the batteries hopefully become less expensive.

Throughout the years, the battery has been the main obstacle to the widespread adoption of EVs. Costs and performance have typically been the key problems with the batteries. [8] Currently, performance is not an obstacle any longer. Electric vehicles can accelerate from 0 to 100 km/h in less than 4 seconds and driving distance can be almost 400 km [13]. To achieve such a performance and driving range, the price tag will be very high. Considering more conventional cars, EVs are much more expensive than most cars today. However, driving costs are many times lower with an EV. Therefore, the prices of EVs can be higher. The question is how much extra are consumers willing to pay? The battery is the most expensive part of an EV. For a medium sized electric car a battery pack costs ca. 20 000 € [8], which forms two thirds of the total price of the car [14]. In the future, ultra capacitors might replace batteries. Ultra capacitors are hoped to possess better energy density, smaller size and recharging could take only minutes. However, ultra capacitors are under testing and mass production might be still years away. In the future, ultra capacitors might revolutionize the storing of the electricity and, at the same time, electric motoring. [15][16]

2.4.1 Driving

The reputation that EVs have from the history is that they are mainly perceived as slow plastic boxes with wheels. New, modern EVs, however, can totally change the old image. Once people have driven these cars, they certainly change their conception. Modern EVs are quiet, fast, comfortable and easy to drive. EVs are quiet because an electric motor produces only a quiet buzz while running. At slow speeds, the actual noise merely comes from the tires. At higher speeds, the noise from tires is covered by the wind noise. When you learn to drive, the most difficult part of driving is usually gear changing. With an EV, driving is simple because clutch and gears are not required. Moreover, an electric motor offers plenty of torque instantly and throughout the revolutions. Hence, an electric car is even quicker than a car with an equal powered petrol engine. Driving distance, nevertheless, remains a challenge for EVs. Driving distance is proportional to the size of the battery pack. Reasonably priced EVs in production are capable of a 100-200 km driving distance, which serves most peoples' daily needs, as seen in Figure 6.

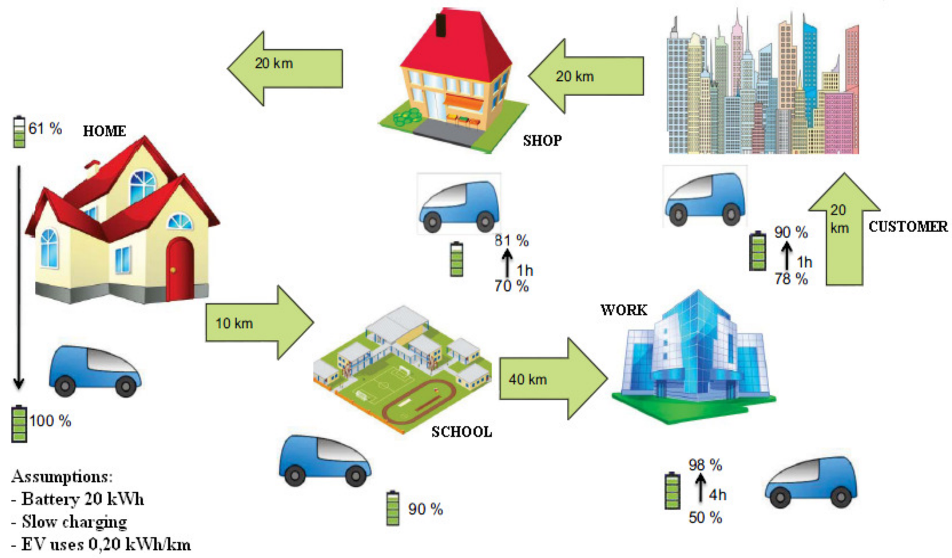

Figure 6: Peoples' daily mileages [17] *(Modified)*

Driving with an EV requires minor changes in peoples' driving habits. Regular visits to gas stations become unnecessary as you "refuel" the car during the day while the EV is idle. In the evening the car is plugged in and the battery will be fully recharged by the morning; simple. While driving, in the case of a low charging level, an electric motor reduces its output to save energy. This way batteries do not run down unexpectedly and the driver manages to drive to the nearest charging point. [5] Table 1 represents empty-to-full charging times with most probable charging levels. The size of the battery pack in calculations is 30 kWh and the efficiency of the battery and the charging process is assumed to be 80% [8]. With fast charging the charging power must be reduced after a charge level of 80%. Hence, Table 1 includes theoretical empty-to-full time and practical time for an empty-to-80% charge level. Charging levels above 20 kW are probably handled with off-board DC-chargers [8]. Similar calculations found on the Internet are usually over-optimistic and the losses are not taken into account.

Table 1: Charging times with most probable charging levels

Power (kW)	Time
3.7	10h
11	3.5h
50	45min
250	9min (theoretical)
250	7min (80% level)

2.5 Battery

The battery is the most crucial element of an electric car. The main characteristics of the battery are energy density (Wh/kg or Wh/l), power density (W/kg or W/l), price and lifetime (calendar or cycle stability). Power density and energy density are exclusive parameters. Therefore, a battery with short charging and discharging time cannot have appropriate energy storage capabilities and vice versa. The lifetime depends on the way the battery is used and charged. [8]

Recently, the development of Lithium-Ion (Li-Ion) batteries has enabled EVs to be respectable alternatives to gasoline cars. Historically, EVs have used a variety of batteries that have included many weaknesses, such as long recharging times and low driving ranges. In 1991, the Sony Corporation commercialized the first Li-Ion battery. Today, Li-Ion is the fastest growing and the most promising battery chemistry. Lithium is the best material for batteries because it is the lightest of all metals, contains the greatest electrochemical potential and provides the largest energy density per weight. As a result, lithium batteries possess high voltage and excellent capacity, resulting in high energy density. Additionally, Li-Ion batteries serve as low maintenance batteries without memory, and scheduled cycling is not required to maintain the Li-Ion battery life. Moreover, the self-discharge is less than half that of Nickel-Metal Hydride (NiMH) batteries. [18] Although batteries have developed more slowly than expected, Li-Ion batteries have been revolutionary in the battery industry. The characteristics of Li-Ion batteries are superior to the features of lead and nickel batteries. [6]

Li-Ion batteries, however, have their disadvantages as well. First, Li-Ion batteries are expensive to manufacture, at least for now. According to the Boston Consulting Group (BCG), battery costs will decline steeply as production volumes increase [16]. Second, Li-Ion batteries are subject to aging, even if not in use. Lastly, the batteries require a protection circuit to limit voltage and current. [18] If a Li-Ion battery is run fully empty, the battery might become useless. Also high temperature, air humidity and fast charging shorten the lifetime of the Li-Ion battery. Safety forms a very important aspect in battery technology as well. Lithium batteries might explode when short-circuited or overheated. Particularly while fast charging, batteries warm up significantly. Therefore, proper cooling of the batteries is important. [16][19]

The battery industry faces serious challenges. Batteries can be optimized to either high or cold temperatures, but it is difficult to fabricate batteries that function over a wide range of temperatures. Another major challenge is the capacity for storing energy. Battery cells today can reach nominal energy densities from 140 to 170 Wh/kg, compared to 13 000 Wh/kg for gasoline. Assuming that in the future the energy density reaches 200 Wh/kg, the driving range would be around 300 km. This kind of battery pack would weigh around 250 kg resulting in high delivery costs. [16] Thus, the battery industry will be bound closely to car manufacturers. Delivery costs need to be kept as low as possible because the battery is expensive already and it greatly determines the price of an EV. The cost of a battery pack plays a critical role in determining the commercial viability of EVs. The current original equipment manufacturer (OEM) cost of a battery pack ranges between $1 000 and $1 200 per kWh. The United States Advanced Battery Consortium has set a cost target of $250 per kWh by the year 2020. According to a BCG analysis, a 15 kWh battery pack that currently costs around $990 to $1 220 per kWh, will cost $360 to $440 per kWh in 2020. These are the OEM prices; the end consumers will need to pay a 40 to 45% premium. The possible price reduction depends on volume-dependent costs which include raw materials, labor rates and general machinery. BCG estimates that 70 to 75 percent of cell costs are volume dependent. The cell represents some 65 percent of the costs of the battery pack. The price of lithium has only a minor effect because lithium represents roughly two percent of cell costs. Therefore, the cost of the lithium forms only 1.3 percent of the total costs of the battery pack. [16]

2.5.1 Lithium Iron Phosphate ($LiFePO_4$)

At the moment of writing, $LiFePO_4$ batteries are one of the most advanced types of batteries suitable for EVs. $LiFePO_4$ has good chemical and thermal stability and the energy density per unit weight is rather high (110 Wh/kg). In addition, $LiFePO_4$ batteries can be recharged more than 2 000 times and the self discharge of one cell is less than 1% per month. $LiFePO_4$ batteries do not suffer any memory effect and they can be charged any time. Further, the batteries can be operated in any orientation, which is important in widespread everyday use. [20] A $LiFePO_4$ battery does not require full recharge and people can charge their battery, for instance, only 30 minutes while shopping. Among these benefits, $LiFePO_4$ incorporates several other advantages. First, the technology is stated safe, which is important for the market entry of new technologies. Second, the batteries are maintenance-free for their lifetime. Third, $LiFePO_4$ does not contain toxic heavy metals, making it the most environmental friendly battery chemistry available. Lastly, $LiFePO_4$ batteries can be safely recharged rapidly: when fully discharged, the battery can be 90% fully charged in 15 minutes. The $LiFePO_4$ technology has also disadvantages. The nominal voltage for one cell is 3.3 V. If the cell is discharged below 2.8 V, the durability may fall. Moreover, the cell voltage should not exceed 3.6 V during charging. [20] Another disadvantage is generated from the alternation of the capacity at different temperatures. A $LiFePO_4$ battery loses usable capacity both in cold and hot environments. Therefore, an appropriate thermal design is required to keep the battery at a suitable operating temperature. [21]

Carnegie Mellon University Pittsburgh has performed a test on $LiFePO_4$ cells produced by A123 Systems. Altogether 13 cells were purchased from four individual fabrication lots. The test examined the effects of combined driving and vehicle to grid (V2G) usage on the lifetime performance of commercial $LiFePO_4$ cells. The cells were kept at the ambient lab temperature of 24-27 ºC. Different degrees of continuous discharge were imposed on the cells to copy the V2G use. Additionally, a vehicle driving data and a vehicle physical model were used to create a daily battery usage pattern. The promising test results showed that more than 95% of the original cell capacity remains after thousands of driving days worth of use. Subsequent to 2 000 cycles, only a minor fraction of the initial capacity had been lost. In cells 95% discharged, the measurement predicted that 5 300 cycles will be needed to lower the capacity to 80% of initial capacity. [22] Therefore, if used and charged every day in an ideal environment, the battery would be in operational condition nearly 15 years. In reality, faulty usage, temperature alternation and fast charging would decrease the lifetime of the battery. Together with previous results, the test revealed that the cells from separate locations did not behave identically. Another observation was that higher rate cycling, involving fast charging, causes more capacity loss than slower cycling. [22] These conclusions are based on the laboratory circumstances. Thus, results certainly differ from the reality, although driving behavior and V2G simulations were used. Especially the cold Finnish winter decreases the capacity significantly. However, the test shows that $LiFePO_4$ batteries are suitable for EVs and that the advantages are definite.

2.6 Weight comparison

What is the weight difference between an ICE (internal combustion engine) and an electric motor plus a battery pack? By adding more batteries, the driving distance can be extended because the driving distance depends on to the size of the battery pack proportionally. This poses a problem as the battery packs are expensive and heavy. The battery pack for the Think City weighs 245-260 kg which constitutes one quarter of the kerb weight of the car [2]. Similarly, the battery pack for the Tesla Roadster weighs around 400 kg [13]. Ensto owns a conversion Volkswagen Passat that has a 24 kWh Lithium-ion battery pack of 240 kg. The car characterizes the driving range of around 100 km. The following figures are from Antti Ruusunen from *the eCars – Now!* – community. The internal combustion engine and transmission of their conversion Toyota Corolla weigh 150 kg, the tailpipe 20 kg and the gasoline tank 50 kg. According to Ruusunen, in other car models these parts can be heavier. The batteries of their conversion Corolla weigh nearly 300 kg, the electric motor 50-150 kg and the other parts about 50 kg. Thus, conversion to an electric car adds around 150-300 kg to the total weight of a car depending on the performance requirements. Although the battery packs are heavy, they can be attached to the bottom of the car, which in turn lowers the center of gravity of the car. The lower center of gravity improves the handling of the car and reduces the probability of rollover.

2.7 Redesign

The performance and the lightness of electric motors and batteries are developing all the time. Isis Innovation, the Oxford University's technology transfer company, has developed a new electric motor that outperforms the old ones. The motor is lightweight and it delivers a beneficial power to weight performance. The weight is only 13 kg but the motor delivers a peak torque of 130 Nm and a peak power of 50 kW. The overall efficiency is as high as 97%. One suitable application of the motor is in EVs and PHEVs, where mass and efficiency are critical. [23] When the motor is compact and the batteries can be placed at floor level, the car design can be more innovative.

Recently, Michelin has designed an active wheel that totally revolutionizes the car design (Figure 7). All essential components have been integrated into the wheel itself, including the electrical suspension and the electrical drive motor. The electrical suspension features extremely fast response time – just 3/1 000th of a second. Thus, all pitching and rolling motions are corrected automatically. [24]

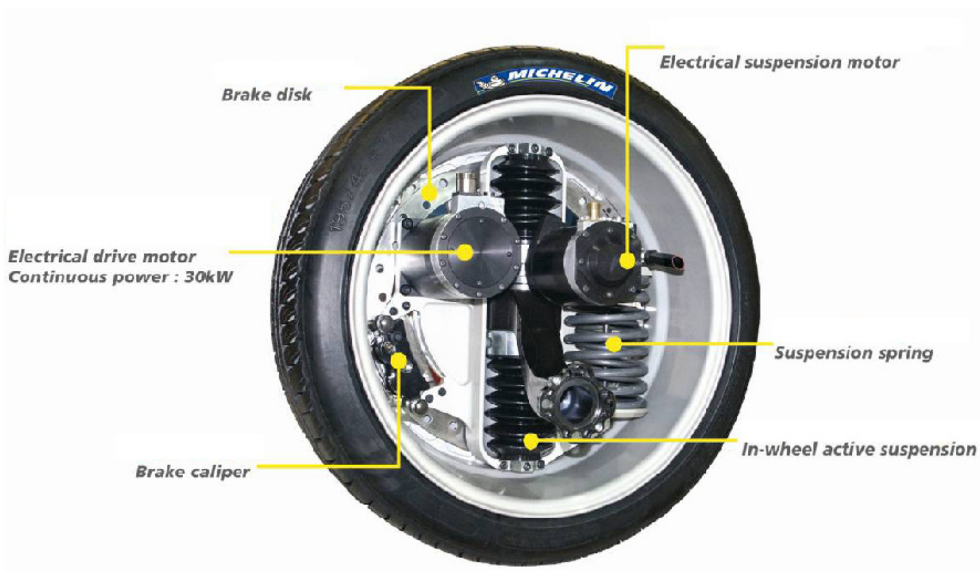

Figure 7: Michelin Active wheel [24]

The defining factors of present-day cars, the gearbox and the combustion engine, are not needed due to the active wheel. The technology enables a rethink of the automobile and it releases styling teams from certain constraints. New design possibilities include the elimination of the engine block, weight reduction, the possibility of totally flat floor cars, and chassis design that is fully focused on passenger safety and interior space. The invention accompanies other advantages as well. An active wheel system in each corner provides an active four wheel drive. [24] Furthermore, the car has plenty of space for batteries. Tire change can be performed as usual because the active part lies inside the wheel. [25] Undoubtedly, thrilling and exceptional car design will be seen in the future.

2.8 Advantages of EVs

Electric vehicles possess many advantages. First, an EV can have zero total emissions. In theory, if the electricity is produced with renewable resources the total CO_2-emissions are zero [5]. With the Finnish production structure, the total CO_2-emissions would be around 50 g/km, including the emissions of the electricity production and losses in the transmission of electricity. [8] Achieving zero emissions would require huge changes in the electricity production. In the real power system, electric vehicles increase the peak load that is mainly handled with coal combustion power plants. Thus, electric vehicles increase the CO_2-emissions of the electricity production and only the tailpipe emissions are zero. Compared to diesel vehicles, which produce harmful NOx-emissions, EVs lack the contamination of fine particles. Certainly, the tires will raise the fine particles from the road into the city air like before. Nevertheless, the total amount of pollutants in the city air will decrease. Hence, EVs could incorporate major indirect influences as well. The air quality in large cities would improve and respiratory disorders would decrease. The second advantage derives from the energy efficiency of electric motors. The total efficiency depends greatly on the way the electricity is produced. Third, an EV is quiet because an electric motor is almost silent. This reduces traffic noise in the city and urban areas, where driving speed is low and tire noise is insignificant compared to engine noise. On the other hand, quietness can be hazardous to pedestrians who cannot hear the approaching car. The fourth advantage is the cheapness of the upkeep. The operating and maintenance costs are low because the technology is very simple and the fuel (electricity) is cheap for now. [5] With an EV, driving is presently three times cheaper than with a gasoline car. In Appendix A, fuel costs per 100 km are calculated. At present, the Finnish government collects gasoline taxes worth 4 billion euro annually [26]. After EVs start to gain popularity, the government needs to compensate this lost gasoline tax income. Additional taxes might be somehow collected from EV users. Thus, driving an

EV will be more expensive in the future. In addition to affordability, EVs would reduce our dependency on oil. The electricity needed can be produced using many techniques and a sufficient amount of energy is constantly available. The structure of an electric car entails further financial advantages for the user. An EV is more maintenance-free than an ICE car (no oil, tailpipe, filters or spark plugs). In fact, an electric motor includes only one moving part. Therefore, maintenance costs would be only a fraction of present maintenance costs. Finally, an electric motor provides plenty of torque from a standing start and braking energy can be regenerated. For these reasons, EVs are functional in city areas, where traffic lights and traffic jams cause constant stop and go movement. [5]

2.9 Energy efficiency

In EVs all the energy comes from electricity. Therefore, EVs are not tied to any particular energy source. The electricity can be produced using the most cost efficient production method available. Electric motors with their efficiency outrun internal combustion engines. ICE vehicles generally run at about 20% efficiency, whereas EVs put approximately 80% of their input into running the car [27]. Additionally, the braking energy can be restored to batteries with regenerative braking. In the best scenario, an EV can have three times better energy efficiency than a gasoline powered car [8]. However, the actual total efficiency depends on many factors including; the electric motor, the battery, the power train, the power electronics, the electricity production method and the temperature of the outdoor operating environment.

The energy consumption of an EV is around 0.20 kWh/km excluding heating and cooling of the interior. Respectively, the energy consumption for a gasoline car is around 0.60 kWh/km (corresponds to a fuel consumption of 6.7 l/100 km). [8] In Appendix B, various production methods are compared in terms of primary energy consumption and CO_2-emission reduction. The reduction of CO_2-emission depends on the way the electricity is produced. It is noteworthy, that even if the electricity is produced purely with coal, the total CO_2-emissons still decrease. This occurs because electric motors are more energy efficient than internal combustion engines. [8] Overall, controlling and optimizing processes is easier in larger units, such as in power plants.

3 Present state and future outlook for the EV industry

3.1 Present situation

In many countries transition is at the planning phase or early implementation phase. Israel has announced its co-operation with Better Place and Renault-Nissan to be the first nation to achieve an all-electric infrastructure [28]. Portugal has a MOBI.E-project which will launch a nationwide electric mobility network by 2011 and liberates the country from dependency on oil. Previously, Portugal imported most of its energy. Currently, renewable energies account for over 43% of total energy electricity production. Hence, all 1300 charging points come into advantage in balancing load variations. [29][30] In parallel with these projects, activities are going on at least in Denmark, Sweden, Germany, Britain, U.S, Canada, Japan and China. [28] Despite many ongoing projects, empirical results are not available yet.

At the moment of writing, only a limited number of EVs are available and the demand has already exceeded supply. However, many car manufacturers have announced to bring EVs to the market in the near future. Appendix C introduces available and upcoming EVs. Some of these EVs should already be on the market (such as the Mini E and Toyota Prius PHEV), but delays have occurred. Hopefully car manufacturers will be able to release their EVs to the market while the public atmosphere is still favorable towards EVs. The website www.pluginamerica.org lists all upcoming and existing EVs monthly.

Presently, the standards for electric vehicles and charging technology are under preparation. Standards are essential in ensuring the success of the EV transition. In the following sections the present state of the EV industry in Finland is evaluated. Also, some forerunner companies and their projects outside Finland are covered.

3.1.1 Situation in Finland

Many key-technologies related to the EVs are developing rapidly. Companies within and outside SIMBe are actively seeking new business opportunities. In Finland several companies possess core competences in areas which are important in the EV technology, including the metal and the electrical industry. Additionally, Finland possesses skilled knowledge in the area of power electronics and in information technology, both of which are required in the charging technology. Thus, advantageous possibilities to create a profitable and sustainable industry around EVs will emerge. It is essential to manage to meet the demand directly at the initial phase. [8]

The factories of Valmet Automotive Oy and European Batteries Oy will bring fresh revenues already in 2010. Keliber Oy, a part of the Norwegian Mining Group, is opening a lithium mine in Finland. [8] Ensto, one of the key players in the Finnish EV industry, is developing charging systems for EVs. In 2009 Ensto developed a charging station in collaboration with Fortum (Figure 8) [31]. In the Electricity, Telecommunications, Light and Audio Visual 2010 exhibition, Ensto introduced a prototype for another charging station (Figure 9). In Finland, few charging stations are waiting for early adopters of electric vehicles. These charging stations have been installed at Kamppi Helsinki (Helsingin Energia), Stockmann Helsinki and Stockmann Oulu (Fortum), and the parking garage Kaupinkallio Espoo (Fortum). More charging points are forthcoming [32]. At the end of 2008, mere 85 EVs were running on roads, of which 7 were electric passenger cars. However, by 2020 there should be a notable amount of PHEVs and EVs on the roads of Finland. [8]

Figure 8: Charging station by Ensto and Fortum [31]

Figure 9: Charging station with kWh-metering by Ensto

3.1.2 Better Place

Better Place, founded in 2007 in California, is one of the leading EV service providers in the world. Better Place operates in the U.S., Israel, Denmark, Australia, Canada, Japan and Hawaii. Better Place's brand new primary research and development facility is located in Tel Aviv, Israel. [28] The EV projects that show the most progress are the

Better Place projects in Israel and Denmark. [33] In January 2008, Israel announced its partnership with Better Place and Renault-Nissan, making it the first nation to commit to an all-electric infrastructure. During the large-scale project, Better Place will build the recharge grid and Renault-Nissan will provide the EVs. Israel serves as an ideal place for EVs as the country is geographically small, with all major urban centers less than 150 km apart. [28] The weather in Israel is also very favorable for EVs. Contrary to Finland, the temperature remains substantially above zero all year round in Israel. As in Europe, Israel has high taxes on gasoline coupled with an economic policy that encourages people to buy low-emission vehicles. Moreover, Israel has a growing solar power sector that could be utilized for charging purposes. Israel is really on its way to achieving its stated goal of oil independence by 2020. [28]

The Danish project is even a little further along than the Israeli project. The largest power company in Denmark has partnered with Better Place to build a nationwide grid to support electric vehicles, composed of thousands of charging poles and battery switching stations. Similar to Israel, the government is firmly behind the Danish project. Early adopters can have tax breaks until 2012 and free parking in downtown Copenhagen. Better Place aims at having the first cars on Danish roads by the second half of 2011. By 2020 there will be more electric cars sold in Denmark than gasoline cars, Jens Moberg, the head of Better Place Denmark, believes. [33] Denmark has wind power capacity of 3150 MW. Wind power stands for 20% of the total Danish electricity production. Wind energy is renewable but cannot be stored. Therefore, in the case of a windless day, alternative energy sources are needed. Usually alternative energy comes from coal power plants which represent 50% of the total electricity production of Denmark. On a windy day, wind power plants produce even more energy than needed. Thus, Denmark needs to export excess energy with prices below the production costs. By estimation, between 2001 and 2008, 50% of the Danish wind energy was exported and the cumulative losses were almost one billion euro. For these reasons, Denmark is investing plenty of money to EVs. In the future, electric vehicles can operate as energy storages for wind energy, simultaneously balancing load variations. The majority of the batteries can be recharged at night when the energy consumption is low. As a result, EVs offer a win-win situation when the energy sellers can produce and sell electricity without losses and society obtains traffic without tailpipe emissions. [34]

3.1.3 *Elektromotive*

Elektromotive Ltd was founded in 2003 in the UK. Elektromotive is described as a small company dedicated to designing and installing technology for recharging. Their main product is the Elektrobay (Figure 10), a recharging station for on-street or multi-storey car park use. Elektrobay was introduced in 2006 and in 2008 Elektromotive installed 21 recharging stations in London. In December 2009, more than 250 Elektrobays were in operation in the UK. The number of Elektrobay charging stations will increase significantly in the UK during 2010. [35]

Figure 10: Elektrobay [35]

Elektromotive has business in various countries having exported Elektrobays to Belgium, Luxembourg, Sweden, Holland, Germany, Ireland, Iceland and Saudi Arabia. The company is expanding their business constantly in Europe, Asia and the Middle East. According to Electromotive Managing Director Calvey Taylor-Haw, it is critical that a cohesive and structured infrastructure is constructed now, as the EVs are on their way. The ambitious status of Elektromotive is “The world’s leading provider of EV recharging stations”. [35]

3.2 Future outlook in Finland

Electric vehicles are certainly on the way. The industry, however, still has many obstacles to overcome. First, the causality dilemma of the EVs and the charging stations. Companies are not eager to invest large sums on expensive charging stations before EVs emerge on the roads. But then, consumers will hesitate to buy EVs due to the nonexistence of charging units. The second problem is the price of EVs. The majority of consumers are not willing to spend over 40 000 € for a car that goes only 100 km with a single charge. Thus, the government needs to take actions to encourage people to buy EVs and to overcome the causality dilemma. In several countries governments provide incentives to early adopters of EVs. Some examples from foreign countries follow:

- In Sweden all environment friendly vehicles (less than 120 g/km CO_2-emissions and less than 5 mg/km particulate emissions for diesel engines) can have purchase incentives worth 10 000 SEK (ca. 1000 €). These vehicles can also have parking advantages in various cities. [8]
- Great Britain is giving incentives worth 25% (5 000 pounds at the maximum) from the purchase price of a new EV. The incentives are available from January 2011. [36]
- The government of Denmark has exempted EVs from car taxation until 2012. [8]
- The United States is investing $400 million into the development of EVs. The government of the U.S. offers $7 500 worth of financial assistance to the early acquirers of EVs. [8]

In Sweden, Fortum is collaborating with the city of Stockholm. Stockholm aims to be noiseless and almost CO_2-emissionless by the year 2030. Presently, Stockholm has 14 000 environmentally friendly cars and they will have 600 000 EVs by 2020. With these numbers, 15% of all cars would be electric in Sweden by 2020. [37] In Finland, Helsinki could be a forerunner similar to Stockholm. Citizens certainly want to be more ecologically sustainable and drive an EV. However, a large scale implementation requires proper incentives from the Finnish government.

The Ministry of Employment and the Economy has set up a working group to investigate the development and implementation of EVs in Finland. The priority of the research was on the business opportunities and the development of the EV industry. The working group suggests the following actions in order to develop the EV industry and enhance the adoption of EVs in Finland:

1. **Creating expertise and ensuring the availability of skillful labor**
   Finland must actively participate in international research and pilot projects related to the EV industry. EV technology must be included in basic education in technical colleges to the electric and car lines of study. The working group suggests starting education of EV systems, hybrid systems, and battery technology in Finnish universities.
2. **Developing business operations in the EV industry**
   New business possibilities are evaluated and solutions created under the lead of the companies in the industry. Special encouragement should be attached to the projects which are directed to the new market segments of the EV industry.
3. **Pilot projects and trials**
   The working group suggests electric transportation trials in the public-, delivery- and private sector. The government should provide half of the total funding and the first trial should start by the end of 2010. The government should share the risks of development with companies. The government should also provide incentives to the development of a Finnish EV concept and to the enhancement of exportation.
4. **Incentives of acquisition**
   Car taxation should be more progressively emissions-focused. Plus, the acquisition of an EV should be subsidized with state funds to begin with. The taxation value of company cars could be preferential towards EVs. In this way companies would acquire EVs for their employees, who would act as forerunners to the general public.
5. **Incentives of operation**
   The taxation of driving should be removed from EVs. At the moment, EVs are taxed in the same way as diesel vehicles, which does not promote the interests of

EVs. Transportation and parking benefits are also represented by the working group.

6. **Guidance of information**

   Public information has a significant influence on the selections of consumers. Hence, the information for consumers should include visible and available data concerning the EVs.

7. **Development of the charging infrastructure**

   A sufficient charging infrastructure must be available when EVs appear on the streets. Companies, municipalities and the government should co-operate to assist in the installation of the charging infrastructure.

8. **Influencing and observing standardization**

   International standards are being organized. The working group suggests that standardization should be actively observed and also influenced from the Finnish point of view. [38]

With the current taxation in Finland, the first rechargeable hybrids will be on the market during 2010. The number of PHEVs will increase continuously and in 2020 plug-in hybrids should represent 10% of the total cars sold. Additionally, EVs should cover 3% of the total car market in Finland. The working group has set a target that states the following: in 2020, of all the cars sold, 25% should be rechargeable (PHEVs or EVs) and 40% from these (10% from the total amount) should be EVs. Another target from the Ministry holds 1-2 billion euro revenues and several thousand workplaces by 2020. Such a development requires a sense of direction and successfully combined actions in the sectors of traffic, climate, energy, technology and industrial policy. With the right actions from the public sector, it should be possible to increase the demand. Sufficient demand would create the basis for development of the industry and terminate the causality dilemma. [38]

3.2.1 Early adopters

Early adopters are consumers who are quick to adopt new products. What kind of people would be the early adopters of electric vehicles in Finland? Many types of potential buyers exist. Attitudes towards the technology and the environment will drive early adoption. Thus, early adopters could be ordinary people interested in the new technology and the environment. These people are usually willing to pay more if they acquire the latest technology or they can live more ecologically. People, who want to be trendy and ahead of their time, can also be potential early adopters. Therefore, the brand of electric vehicles needs to be built with care.

A charging point or simply an electric plug or a preheating unit exists in many houses in suburban areas. Therefore, well-paid families in suburban areas, possibly with two cars, could be the first potential EV users. These families would have an EV for short daily trips and a gasoline car for longer trips. Lack of charging units would not be an issue because the EV could be recharged at home or at the workplace. Another suitable market segment would be company car drivers. An acquisition of EVs could be arranged easily by adjusting the taxation of company cars. Taxation could be adjusted to be preferential towards EVs. Electric cars could be more attracting if free charging at workplace could be a part of the employee benefits. This way a company could encourage their workers to be more "green" and at the same time improve their own image as an ecological company. All of these early adopters are important because they are the first users of EVs, leading the way for subsequent mass-market adoption. Based on early adopters' experiences and opinions, other people form their initial views about EVs.

3.2.2 Penetration of EVs

Predicting the speed of the penetration is challenging. The sources publish inaccurate estimations and usually three penetration levels are introduced: slow, basic and fast. Table 2 introduces the characteristics of the penetration levels. Small companies are estimated to have 30 employees, mid-sized companies 300, and large companies 3 000 employees. The average net sales are estimated to be 300 000 €/person/year. It might be reasoned to believe that a scenario between slow and basic penetration is the most probable one in Finland. This seems likely for several reasons. First, the battery technology is not practical enough for extensive usage in Finland. Batteries operate unreliably in the cold weather and the driving distances are long. Second, despite promises, the government has not yet taken any preparations assisting the purchase of EVs. The current taxation model does not encourage buying expensive EVs. The third challenge is the lack of education of the EV industry. For example, the maintenance of an EV requires an electricity license for a qualification and today's repair personnel are not qualified. Even if the education would start in the coming years, it would take several years to provide the first graduates to the labor market. Certainly, by re-educating today's mechanics, skilled maintenance personnel could be qualified slightly sooner. The lack of standards forms the fourth challenge impeding the spreading of EVs. Even if standards are being prepared, the implementation of standards does not occur immediately. Lastly, most people are unfamiliar with EVs. The government and companies should familiarize citizens with EVs so that people would not be suspicious towards the new technology. The threshold for transition should be as low as possible for consumers. However, the greatest restrictive factor globally at the moment derives from the lack of cars and batteries. By the time cars and batteries are widely on the market, the previously mentioned factors should have already been overcome.

Table 2: Assumptions of different penetration scenarios [8]

	Slow scenario	**Basic scenario**	**Fast scenario**
Technical development	Technical development restricts widespread adoption of EVs	Technical development does not restrict widespread adoption of EVs	Technical development does not restrict widespread adoption of EVs
The portion of EVs	The number of EVs is insignificant	The number of EVs is growing slowly	The number of EVs is growing fast
The role of Finnish industry	Finnish companies are operating in limited market segments	Innovations from abroad are adapted to fit to local requirements	Notable innovations are commercialized by Finnish companies
		The scale of the trade in 2020	
Car manufacturers			
Passenger cars	No manufacturing	One factory	One factory
Component suppliers			
Batteries	Only small production	One factory	3 factories
Electric motors and power electronics	2 midsized factories	3 midsized factories	6 midsized factories
Software and system integration	One midsized factory	2 midsized factories	3 midsized factories
Raw materials	No business	No business	One lithium mine
Infrastructure			
Building infrastructure	Some business	Infrastructure is developed gradually	Infrastructure is developed quickly
Knowledge about charging systems and distribution network	Some business	Some business	Charging systems and network technology also for export
Net sales (MEUR)	540	1530	2520
The amount of personnel	1800	5100	8400

4 Basic solutions of charging systems

4.1 Charging systems in general

Charging systems play a great role in making EVs more widespread in our society. Finnish power grid infrastructure is well-prepared for the EVs. The loading factor of the grid is high due to cold winters. In addition, 1.5 million existing engine preheating units can be utilized for charging to some extent. [38] Most of the houses possess a charging point when they have an electric socket outside. Usually this socket can be used for charging without modifications. A charging infrastructure is easy to implement in parking garages as the appearance is not positioned as the main point. City areas are more problematic because the entire charging infrastructure must be built up with strict restrictions.

The main point in the transition towards the new technology is to lower the threshold as much as possible. Charging is one of the everyday routines within EV usage. Therefore, the plugging needs to be an easy and quick procedure. In order to increase public interest towards EVs, charging should be as easy as fueling a gasoline car. The speed of charging is another question. The question is, how fast charging is needed? Cars can be charged while sleeping and during the day while the car is idle. In the case of a sudden need for charging, there could be possibility to drive to the battery switching or fast charging station. In the following sections charging solutions in conventional places are evaluated. Additionally, a variety of solutions for charging cables and charging units are considered.

4.2 Charging modes

EV charging can be roughly split into slow and fast charging. Both of these can be further divided into sub categories. These categories are defined by standards that are under preparation. IEC 61851-1 is the preliminary standard that specifies the specifications of EV charging. Table 3 lists the most probable upcoming charging levels of IEC 61851-1.

In the standard, mode 1 corresponds to slow, mode 2 to quick, mode 3 to fast, and mode 4 to ultra fast charging.

Table 3: Charging levels of the standard IEC 61851-1

Mode	A max	Phases	V	AC or DC	P (kW)
1	16	1	230	AC	3.7
	16	3	400	AC	11
2	32	1	400	AC	13
	32	3	400	AC	22
3	32	1	690	AC	22
	70	1	690	AC	48
	32	3	690	AC	38
	63	3	690	AC	75
	250	1	690	AC	173
	250	3	690	AC	300
4	400	-	1000	DC	400

4.3 Charging cables and sockets

The structures of the charging cables and the sockets are essential because charging cables will be used every day and the cable must be able to carry high currents. The cables need to be safe, robust and simple enough to use. The cable can be attached in several ways. The cable can be integrated to the charging unit itself or it can be integrated into the car. The cable can also be separated the same way as the preheating wires today. Each of these options has advantages and disadvantages. If the cable is integrated to the charging unit, it is exposed to vandalism and changing weather conditions. In addition, the car manufacturers would need to use the same kind of connectors, which is troublesome because of the deficiency of standards. As Figure 11 illustrates, various types of connectors are in use. The cable can be integrated into the car as well. In this case, the problem is the non-standardized socket of the charging unit. In case of damage, replacing of the cable would be difficult and expensive. For these reasons, neither of these options is useful. The third and the best option, for now, would be an unattached cable. It would be a little more time consuming for the user to plug both ends of the cable. However, the alternative has many advantages. First, standardization problems would vanish as the cable could be designed regardless of the connector solutions of the charging unit or the EV. Second, users would be responsible for the cable and they would treat the cables more carefully. As standards develop, a car-integrated cable for slow charging would be the best option. The cable would be self-replaceable and it could roll itself inside the bumper similar to the cable of a vacuum cleaner. This way the user would not need to store the cable inside the car and only one plugging per charging would be required. The cable should be easy to replace as it most probably strains over the years.

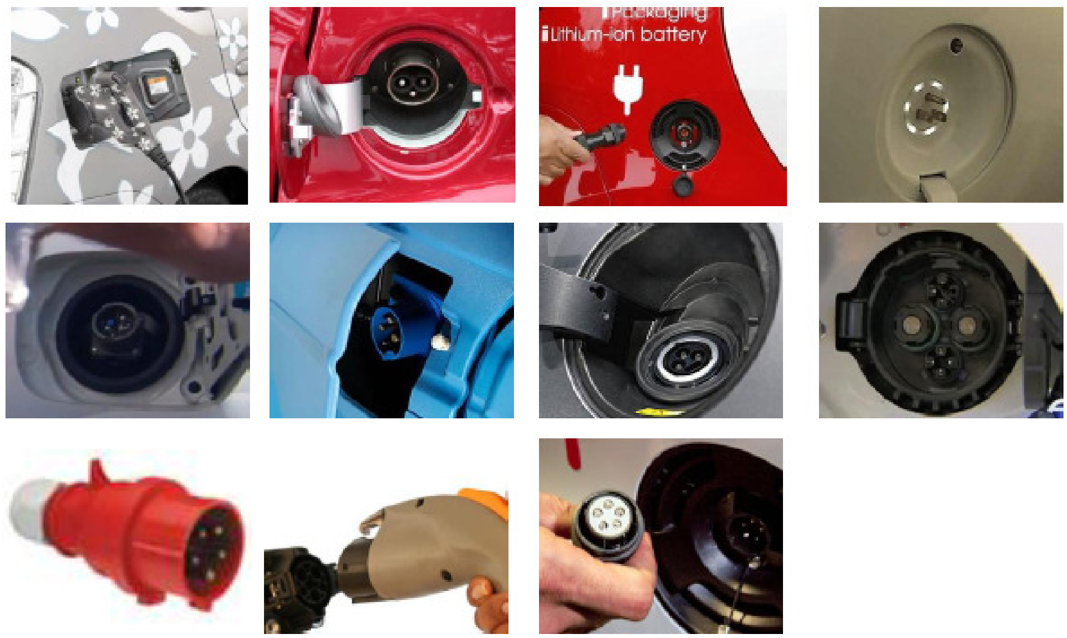

Figure 11: Some charging connectors [39]

4.4 Charging units

Several aspects must be taken into consideration while designing charging units situated on streets and other public places. The units must be robust to withstand the rough weather conditions and vandalism, well-designed to improve the cityscape, and illustrative to be user-friendly. The materials and the characteristics of the units should be chosen with care because the units cannot be unacceptably expensive. Charging units can be designed for specific purposes. Depending on the average parking time and the requirements, charging could be 1-phase or 3-phase with various voltage levels. The unit can be equipped with kWh-metering or mobile phone access. Ensto has built charging poles with these features. Ensto's and Elektromotive's charging units were introduced earlier in Figures 8, 9 and 10. GARO Finland Oy imports and markets electrical engineering products, including various charging stations (Figure 12). Their preheating unit can be easily modified to become a charging station by changing the inner module of the unit. Presently in Finland, GARO, Ensto and Fibox are the companies developing and selling charging stations.

Figure 12: GARO's charging station

ChargePoint, a charging station from Coulomb Technologies (Figure 13), works based on an RFID card. By showing the card to the receiver, the driver is identified and the station is unlocked for charging. ChargePoint has also an automatic SMS and/or email notification feature in case of a complete or an interrupted charging event. ChargePoint can be installed as a bollard type, pole mounted or wall mounted unit. [40]

Figure 13: Coulomb Technologies' ChargePoint [40]

4.4.1 Engine preheating units

There are approximately 1.5 million engine preheating units in Finland [38]. However, most of these units require modifications to match the charging requirements of EVs.

First, the timers need to be removed from the units. With the charging power of 3.68 kW (230 V and 16 A), the 30 kWh batteries are fully recharged in 10-12 hours [41]. Second, all the fuses less than 16 amperes need to be replaced. Some of the old preheating units contain only 6 A or 10 A fuses. In the worst case, the fuse is attached to two sockets, which splits the power in half. In the old preheating units the power is low because these units were originally designed for engine-block heaters which have output of around 500 W. For these dimensioning reasons, in some housing cooperatives external interior heaters are prohibited.

The fuses are not the only problem. Even if the weak fuses would be replaced, the electric wires inside the units might be too thin. The thinnest allowed wires inside the unit are 1.5 mm^2. These kind of wires are dimensioned for 10 A. Wires with cross-sectional area are of 2.5 mm^2, manage to carry sufficient 16 A. Even if the fuses and wires of the unit would be replaced, there might be a problem with the inadequate feeding cable and the group fuses of the housing cooperative. If the main fuses are strong enough and the connection to the power grid is sufficient, the problem can be solved by mounting a new supply cable with its own group fuses. Hence, if the fuses and the wires of the preheating units are inadequate, it is more logical for the housing cooperatives to purchase totally new charging units for the EVs and install a new supply cable only for the EV chargers.

4.5 Access points of the charging infrastructure

4.5.1 Charging at home

At home, a slow 1-phase or 3-phase charging (mode 1) should be sufficient. The EVs can be recharged while people are sleeping and charging time rarely poses a problem. In most of the houses people have electric plugs outside for preheating and outdoor equipment. In the case of weak fuses, investments are not excessive and a sufficient charging point is implemented easily. In suburban areas in Finland, housing cooperatives usually have engines preheating systems in their parking lots. Most of these preheating units require actions to be suitable for charging purposes. The required actions were introduced in the previous section. In cases where there is enough available space in the parking lot, charging units are easy to install by mounting new charging units, fuses and a feeding cable. The old preheating units can remain until more extensive need for charging units emerges. The situation becomes more complicated if the all the parking spots are reserved. The housing cooperative would need to convert some of the existing preheating units to charging units and redistribute the parking places. Some of the owners of these parking places would possibly resist the change, which would complicate rearrangements even more. The investment costs could be included in the maintenance charges of the housing cooperatives. After all, this kind of renovation raises the value of the apartments. Thus, parking lot renovations are comparable to television antenna network improvements. Not everybody uses the services but everybody gains benefits, at least through the value increase of their apartment. Possibly after a decade, the number of EVs is higher, resulting in a need for broader renovation. At this point the housing cooperatives' connection to the power grid might become inadequate. Then, all the cables and fuses must be reinforced to withstand the total load. This inevitable operation is expensive but it enables a wider use of EVs by the residents.

The actual increase in load to the power grid depends on the intelligence of the charging system. At first, intelligence would not be necessary due to the low number of EVs. Later, when EVs would represent a larger portion of the car fleet, intelligence becomes essential. The alternation of the loads is important in order to keep the load of the housing cooperative and the power grid in balance. The alternation could be arranged by alternating the start of the charging in different sections of the parking lot. But then, if an EV requires 10 hours of charging, all the EVs would recharge together at night anyway. In households, heated with direct electric heating, it might be easier to regulate warm water boilers and let people charge their cars whenever they want.

4.5.2 Charging at workplaces

Many workplaces have engine preheating units located in their parking lot. The capacity of the units varies from one place to another. Some workplaces forbid external interior heaters whereas others have no restrictions. Thus, the same principles apply to workplaces and housing cooperatives alike. If the company does not have preheating units or the units are low-powered, the company could provide new charging stations for their employees. An 8-hour working day is usually enough for a full charge because after the way to work, the batteries are not fully empty. Thus, mode 1 charging serves the needs of most workplaces. For visitors and urgent situations there could be a quick charging point greatly reducing the empty-to-full charging time.

At the initial phase, workplaces could be the primary charging places for employees living in city areas. Fast charging stations and public charging areas will not be ready for early adopters. Employees living in the city downtown area, typically use their cars for commuting because all the services lie nearby. Hence, these people could charge their EVs at work and drive back and forth with a single charging. Later, when public charging stations start to emerge, EVs can be used for other purposes as well.

4.5.3 Charging in park-and-ride areas

Park-and-ride areas connect passenger car traffic with public transport. Private cars can be parked in park-and-ride areas and the trip to the center of Helsinki continues by public transport. The service is mainly used for commutation and the car remains parked for the workday. Hence, the parking time allows slow charging (mode 1) to be the most convenient. In 2005, the Helsinki area possessed almost 5 700 spots for passenger cars in their park-and-ride areas. By 2020, there will be an additional 5 900 parking places in the Helsinki park-and-ride areas. [42] If one quarter of all these parking places would be electrified with 3.7 kW slow chargers, a power requirement of 10.7 MW would emerge. At the initial phase, only a few chargers per park-and-ride area would be required to meet the need of early adopters.

4.5.4 Charging in parking garages

Parking garages are favorable places from the charging point of view. The appearance is not an issue and the gutters for the cables are already in place. Additionally, weather is not a determining factor for installations. As a result, the implementing of the charging infrastructure is straightforward. The cables can be installed in the existing gutters and the units can be wall or pole mounted easily. The required speed of charging is determined by the purpose of the use. In shopping malls, charging needs to be more rapid than in residential parking garages. The Forum parking garage is mainly visited by shoppers. According to Sebastian Koreneff from the BK-group, the average parking time in the Forum parking garage is some two hours. The average parking time increases the further you go from Forum due to residents and other contract customers, Koreneff continued. Because people spend no more than a couple of hours shopping, shopping centers like Forum might require quick or fast charging. Slow charging (11 kW) takes circa 3 hours for a 30 kWh battery pack, and similarly less than an hour with fast charging (50 kW) [41]. The most convenient way of charging would be the user definable charging level. The user could select the most suitable charging level for one's purposes and budget. Such a system would be more expensive because the whole system would be dimensioned to withstand the highest charging level. At first, slow charging will be the most probable solution in the shopping centers because of the low investment demands and low utilization rate. On the other hand, 11 kW slow charging might be adequate because daily mileages of private cars are less than 30 km in the Helsinki region [43]. Hence, while entering the parking garage, the battery probably has plenty of charge left and less time is needed to fully recharge the battery. Fast charging would require strengthening of the existing power system and at the uncertain initial phase, minor investments are preferred. Shopping centers are usually connected to the MV-network, but their connection might still be inadequate for extensive EV charging.

Generally speaking, shopping centers are not prepared for EVs. An enquiry of three people responsible for electricity planning of separate shopping centers proved the unpreparedness. Electric vehicles were totally new for all and EVs were not included in any scenarios. A new shopping center is replacing the old mall in Martinlaakso, Vantaa. According to electricity specialist Voitto Laine from A-Insinöörit Oy, they have not included EVs in their electricity planning. They could, however, still have some capacity for 1-2 fast charging points, Laine replied. He promised to take the matter further into consideration. According to Property Manager Mika Lehtonen from Citycon Oyj, the shopping center Myyrmanni in Vantaa has no capacity for EV charging. By replacing incandescent light bulbs with LEDs and installing more efficient cooling, they might have some capacity in the future, Lehtonen says. Electricity designer Ilkka Suur-Nuuja from Gridon Oy is responsible from the electricity planning in the shopping center Itäkeskus. According to Ilkka, the total capacity of the transformers is 16 MVA. Depending on the charging level and the placement of the chargers, 1-3 fast charging points could be installed. In summary, the shopping centers are not ready for EVs. If the largest shopping center in the Nordic Countries, Itäkeskus, is only able to mount 1-3 fast charging points, major changes must be made to the existing electric systems of the shopping centers nationwide. After all, shopping centers are important places for people and, therefore, vital for EV adoption.

In residential parking garages slow charging serves the needs of the residents. Similar to private houses, EVs can be charged at night and charging time is not a limiting factor. The price of the charging system and the renovation requirement determine the type of the charging system. Thus, reasonable investment requirements are essential for the appearance of the charging systems and the EVs.

4.5.5 Charging on public streets

In the city downtown, 41% of the households own a private car. By comparison, 60% of the households in the suburbs possess a car. [44] Most residents in the city downtown do not have an opportunity for off-street parking. In order to get these people to purchase an EV or a PHEV, charging system needs to be placed on streets as well. For early adopters, a dense public charging network will not be a strong priority. Early adopters are ready to change their habits and park their car further away. [45] For masses, the charging units must be in place before these people even consider electric vehicles. Mode 1 or 2 charging would meet the need of citizens parking on-street. For more rapid charge, people could drive to a fast charging station.

The City Planning department of Helsinki opposes any kind of additional poles on the curb-sides. In recent years, the City Planning department has removed all unnecessary obstacles from streets to facilitate street cleaning and snow plowing. Therefore, alternative solutions for charging must be considered. Battery switching stations could be one solution for charging in city areas. However, citizens need plug-in charging units as well. In addition to the design of the batteries, the EVs and the switching stations are only at the early phase. Solutions that can be implemented easily with a short time span are the priority. Pole-mounted charging units are convenient for parking lot charging. Chargers could be installed in groups, which would minimize the extra nuisance for street cleaning. Small parking/charging areas intended for EV users could be established around the city. This way the EV users would not need to park on the streets and they would have no obstacles for EV acquisition. The drawback is that EV users would possibly have to walk a little further and that the space for parking is already limited. However, by centralizing the charging points, cost savings and other advantages would emerge. First, if charging areas would be near medium voltage lines, the amount of the connective cables would be minimal and sufficient amount of power would be available. Second, the charging units would not interfere with street cleaning. Some of these park-and-charge areas could be roofed, making wintertime cleaning unnecessary. Certainly, there is enough space available for the described little parking areas in the Helsinki area, at least at the initial phase.

Another option for roadside charging could be the underground parking garages. The city of Helsinki has several underground car parks that could be utilized for the urban EV users. At nighttime, the car parks are mainly empty. EuroPark Finland Oy has offered cheap nighttime parking (2 €/night) to the urban car users. The purpose is to ease the traffic flow and the rescue work. Also snow removal from the street would be easier if fewer cars would be parked on the streets. The EuroPark's trial has not been very successful and the car parks have still had plenty of vacant places at nights. [46] EVs could fill at least some of these vacant places at nighttime. The monthly price for parking and charging should be worth considering. EVs could be recharged in the parking garages at nights and street cleaning would not be disturbed. Hence, EVs could offer a win-win situation as the users would obtain an indoor charging spot and the car park owners would gain some profit at nights as well.

Altogether, people living in the city downtown area are not in a favorable situation in acquiring an EV at the initial phase. Lack of charging capability in the downtown area discourages the purchase of an EV. For these residents, one option will emerge – renting an EV. O_2 media Oy, a member of the SIMBe project, is the first car rental to provide electric cars in Finland. The driving range of these cars (100 km) will be sufficient for a daily demand. The rental price for the EV will be 19.95 € for 8 hours, including "fuel" and insurance. [47]

4.5.6 Fast-charging stations

Fast charging can be defined as any scheme other than slow charging. The real definition is, however, more complex. [48] Modes 3-4 of Table 3 include fast charging with various characteristics. In the EV world of the future, slow charging will be the most used charging method because of convenience and low costs. However, people need other charging solutions for sudden occasions and longer trips. (Ultra) fast charging can recharge the battery rapidly, the charging time depending on the power of the station. With fast charging, the battery can be only 80% charged due to battery chemistry. After this level, charging power must be reduced. Batteries from separate manufacturers hold various charging requirements. Without battery and charging standards there would be separate fast charging points for various types of batteries. Similarly, 95, 98 octane and diesel pumps exist today at the gasoline stations, so a couple of different fast charging units per station would not be that uncommon.

The Tokyo Electric Power Company (TEPCO) has been at the forefront of EV infrastructure development. The company conducted a study of fast charging infrastructure that began in October 2007 and ended a year later. TEPCO targeted the ICE service vehicles for substitution with EVs. The ICE service vehicles operated over the entire 8 * 15 km service area. When the EV service vehicles were introduced in 2007, they were recharged at the TEPCO facility using slow chargers at nights. However, subsequent to several months, TEPCO found that despite the sufficient driving ranges of the EVs, drivers accessed only a small portion of the service area. After the first fast charger was installed in March 2008, the EV drivers began accessing the entire service area, as did the ICE service vehicle drivers. This illustrates a phenomenon described as "range-anxiety". The case showed that because drivers were assured that they could recharge their cars during the day, they got rid of "range-anxiety" and started to drive further. Therefore, fast charging points have important psychological effects as well. The TEPCO study shows how limiting the slow charging-only system can be. If one fast charging point can have such a major impact on a set of drivers, a wide fast charging infrastructure will certainly enable wide adoption of EVs. [48]

The implementation of a fast charging network is not straightforward. Practical fast charging time is much less than 30 minutes. Hence, one fast charging point requires at least 50 kW. Recharging within minutes requires power from one charger 250 kW at minimum. Currently, gasoline stations have at least 4 fueling points. Similar stations for EVs would need 1 MW which is a considerable load for the local power grid. Thus, fast charging stations would require own connection point to the medium voltage network, and possibly energy storages to lower the load peaks. These storages could be recharged during off-peak and discharged during on-peak periods. These kinds of storages are expensive because of the need of the storage facilities and the batteries to store the energy.

The power required for public rail transport can easily consume the same amount of power as fast charging stations. The power for one train can be 6 MW and 3 MW for a subway train, respectively [49]. Even trams in Helsinki consume 300 – 500 kW each, depending on the age of the tram [49]. So, are the energy storages actually mandatory if the rail traffic has managed without them for decades? Probably, because the fast charging stations would replace some of the current petrol stations not having over 1 MW capacity on site. The most convenient way of building an energy storage would be attaching a battery switching station and a fast charging station. The switching station requires numerous batteries which could be utilized for load peaks and fast charging. The power for fast charging could be taken from the battery storage and the grid would not require major investments. The storage could also equalize the load of the grid by charging the batteries at nighttime and supplying the grid at daytime. The following section handles battery switching stations.

4.5.7 Battery switching stations

In order to achieve complete acceptance of EVs, fast charging solutions are required in parallel with slow charging. The problem is that fast charging requires major investments to the grid. The battery switching technology can overcome these problems. Additionally, the switch battery enables getting rid of several issues: battery ownership, battery lifecycle and battery cost. Moving the direct battery cost away from the consumer, from the purchase price, greatly changes the relation between an ICE vehicle and an EV: an electric car becomes more convenient and more affordable than a gasoline car. [50] Leasing the battery increases the operating costs but decreases the purchase cost. The consumers are more interested in the latter since people think how much money they have to spend on a car, less how much it costs to drive it. Nevertheless, EVs are more affordable despite leasing the battery because maintenance costs are unsubstantial.

Better Place has designed the battery switch process to take less time than a stop at the petrol station. The process is simple: the driver drives to the station and the robot changes the battery. Then, the robot takes the empty battery to the charging spot. The whole process takes less than five minutes and the driver and passengers may remain in the car throughout. [28] This way the batteries can be recharged slowly at off-peak times, which stresses less the batteries and the power grid. Better Place is building switching stations in Denmark and Israel in 2011 [51]. Additionally, Better Place is partnering with Tokyo's largest taxi operator, Nihon Kotsu, to bring the world's first electric taxis with switchable batteries to Japan. The pilot project began in January 2010. [28] A switchable battery is optimal for taxi and delivery traffic where the length of a single trip is low and the daily route is substantially similar. The problem from the Finnish point of view is that Better Place has tested the stations and the switching process only in warm countries. The Finnish company Puronovo develops switching stations as well. They produce battery switching stations for industrial machinery, and currently Puronovo is developing switching equipment for buses. Puronovo has proper knowledge regarding Nordic requirements in the switching process. Hence, if the Finnish industry acts efficiently, great business opportunities will emerge. Again, standards are the first key issue.

Battery switching stations can offer one solution to fast charging without high peak power changes. However, switching station-technology has many problems to solve. First, the standards for battery switching are not implemented. Battery switching requires co-operation between car and battery manufacturers. All the EVs would need to be built with the same kind of battery packs so that the robot can change the battery. The rough Finnish winter creates the second problem. If the battery is attached to the bottom of the car, the snow and ice would pile up under the car making the battery change impossible. Additionally, ice-control salt for the roads corrodes the bottom of the car. This requires a lot from the battery pack casing and attaching structures. The third problem is the storing of the batteries. One switching station would have to be able to store and recharge dozens of batteries, which develops a need for storage facilities. Free space is already limited in city areas and the land prices are very high. Therefore, some of the current petrol stations could be changed to the battery switching stations.

What about the price difference between a battery switching station and a fast charging station? The following price comparison is only suggestive but it gives something of a ballpark figure regarding the numbers. One battery switching station costs around $500 000 (excluding land price) [51]. Fast charging stations itself are estimated to cost $30 000 apiece, excluding the large investments in infrastructure [52]. A fast charging station would require its own connection to the primary substation [49]. In 2009, Helsingin Energia built a new 110/20 kV substation and a 110 kV switching station in Pukinmäki, Helsinki. The peak power of 60 MVA is distributed to 27 000 customers. The total cost of the station was 12.3 M€. [53] A fast charging station with four 250 kW chargers needs only a fraction of the power from the 60 MVA substation. An equivalent charging station would require 1/60 from the Pukinmäki substation's power and the price for the fast charging station would be around 300 000 € (plus the connection between substation and the charging station). As commented in the previous section, attaching both solutions in to one would be convenient and most cost-efficient. The benefits of this combined battery switching/fast charging station are evident.

5 Impact of EV charging on the power supply network

5.1 General

This chapter focuses on the impact of EV charging on the power network. The chapter handles Helsinki suburban and downtown areas, V2G, and studies from Lassila et al. and VTT. In the following sections, the effects of slow charging are examined in suburban areas whereas city downtown areas incorporate fast charging as well. In suburban areas a 20 kV voltage level is used, whereas 10 kV is used in the city central areas. In Helsinki, only underground cables are used in the medium and low voltage networks. The critical load of the underground cable type in use is approximately 10 MW on the 20 kV side, and approximately 5 MW on the 10 kV side, respectively.

For all the cases the following assumptions are included; if a consumer point has an EV, the daily mileage is 50 km and the average consumption is 0.25 kWh/km. Hence, an EV requires 12.5 kWh every day. The efficiency of charging is assumed to be 80% and the power of the charging is 3.7 kW. With these values, the daily charging time is around 4 hours. The user is assumed to charge only once a day, four hours without interruptions. The worst cases are the most interesting ones because they determine the dimensioning of the grid. The studied time period in the simulations was one week. Thereby, the weekends are simulated similarly as the weekdays because the worst cases occur at working days. Excluding the weekends would have deteriorated the study and complicated the preparation of the load graphs. Additionally, by including the weekend, the reader is able to see the load difference between the week days and the weekends.

The data used in the research was provided by Helen Sähköverkko Oy (Helen). Based on the data of the study cases, conclusions and various curves were drawn. In the figures, the power is active power, similarly to the data received from Helen. Rough estimations were included in the charging curves to achieve a conception of the effects of charging. Curves simulating the charging power were created by thinking of the worst and the best case scenarios.

5.2 Suburban areas

In this section of suburban areas, two study cases are dealt with: detached houses as customer connection points and a medium voltage feeder. In the first case, the load curves of houses with various charging periods are evaluated. In the second case, one MV-feeder of the suburban primary substation is selected and the increased peak load is examined with various charging characteristics.

5.2.1 Detached houses

Individual early adopters of EVs most likely live in suburban areas because of the convenient charging possibilities. Therefore, the electricity consumption of single customer points are examined with the charging power added. Two cases occur in the study; first data is from a 150m^2 house in Helsinki, built in 1967. The estimated annual electricity consumption is 6 700 kWh, which implies a slight usage of electronic equipment and that the house is possibly heated with district heat or oil. In the second case we have a 282 m^2 house, built in 1957. The annual electricity consumption is 39 600 kWh, which implies from a direct electric heating and heavy electricity consumption. The studied week is a winter week 5/2010.

Figures 14 and 15 illustrate increased electricity consumption with charging for the first detached house. In all figures, red curves represent the additional consumption due to EV charging. Blue curves represent the electricity consumption without charging. In Figure 14, charging is assumed to begin at 4 PM when the owner presumably arrives home from work. Likewise, Figure 15 illustrates the electricity consumption with EV charging starting at midnight. In reality, the charging load would mostly split up because the user would charge shorter periods of time within the day also. However, the worst case occurs when the user charges only after work, starting sharp at 4 PM. At worst, the total peak load is 59% higher with EV charging. Some days, the daily peak load almost triples. Without control, the situation in Figure 14 becomes reality and the peak load rises considerably. In Figure 15, charging starts at night and the daily peak load occasionally rises above the present, but remains near 4 kW. The overall load peak remains the same.

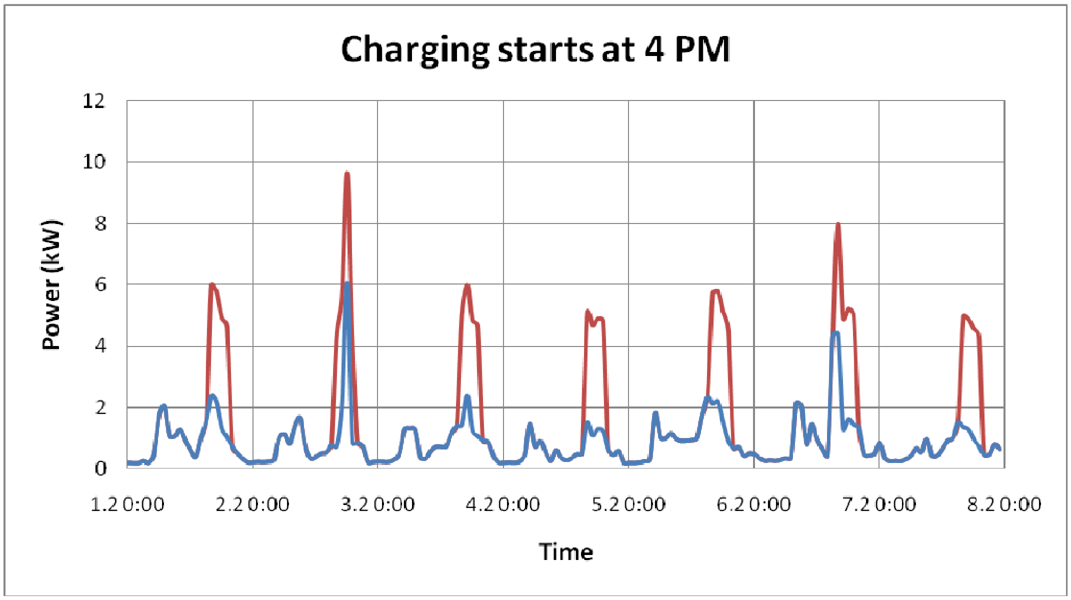

Figure 14: Small household. Electricity consumption with daytime EV charging

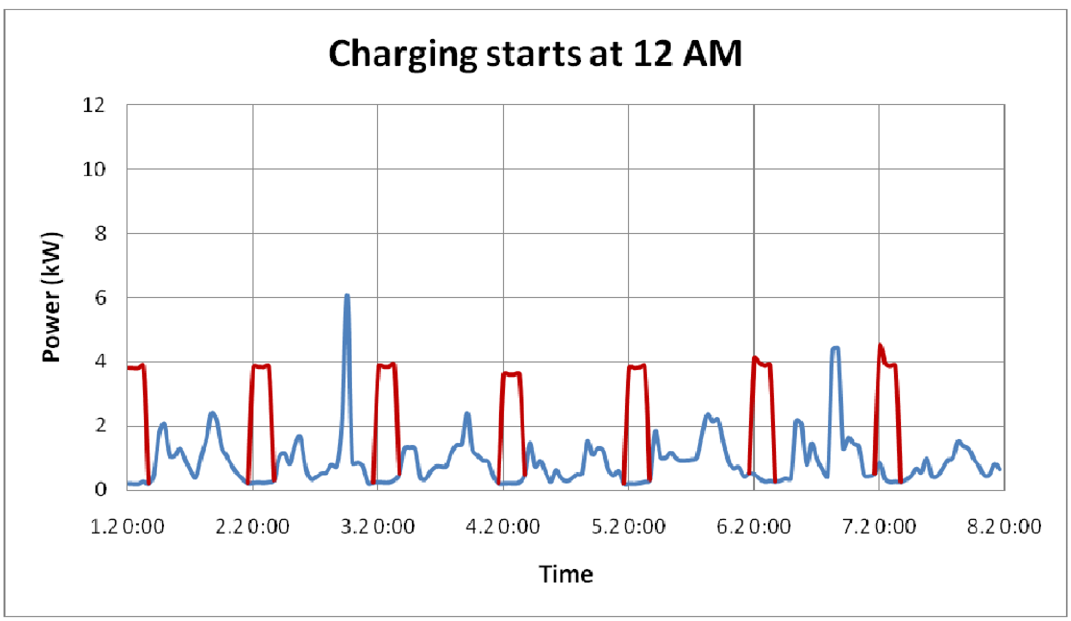

Figure 15: Small household. Electricity consumption with nighttime EV charging

For the second detached house, Figures 16 and 17 represent curves similar to those in Figures 14 and 15. The conclusions from these figures are similar to the first case. If charging starts at 4 PM the overall peak load rises 29% in the period under review. With a proper control, charging occurs at night and the daily peak load remains unchanged or at a tolerable level.

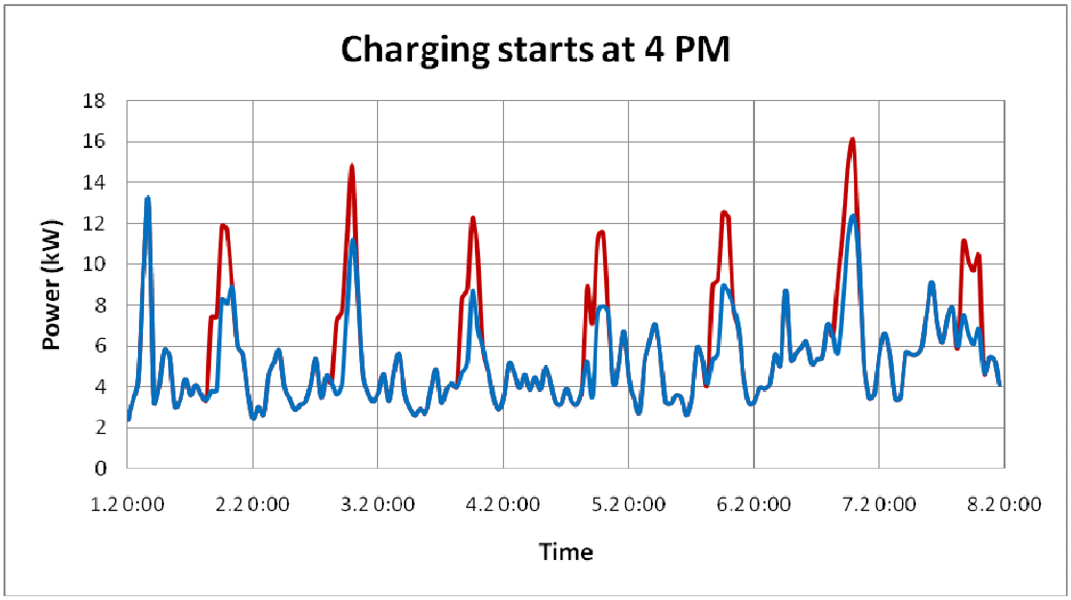

Figure 16: Large household. Electricity consumption with daytime EV charging

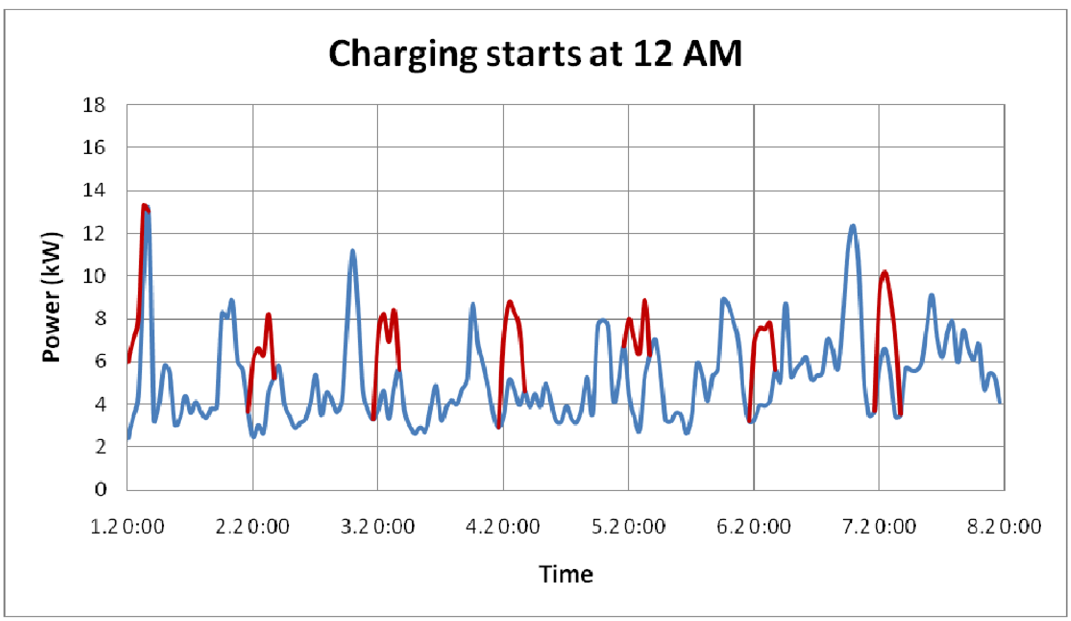

Figure 17: Large household. Electricity consumption with nighttime EV charging

These illustrations are only from two households in Helsinki. Nevertheless, the examples reveal that the time of charging has a remarkable effect to the daily peak loads. Dozens of similar households in the same area could have a significant combined effect.

Consumers are interested in how much it costs to drive 100 km and how much is their electricity consumption going to increase. An increase in the electricity bill depends mainly on the mileage. An average mileage for gasoline cars can be seen in the long-term statistics. However, it is challenging to specify the average mileage for EVs due to the non-existence of EVs and charging infrastructure. Thus, the following Table 4 exemplifies the amount of electricity consumed with various mileages. Table 4 includes the following assumptions:

- Energy consumption of an EV 0.25 kWh/km.
- Efficiency of charging 80%.
- 30 days/month.
- The price of the electricity 10.36 c/kWh.

Table 4: Increased monthly electricity consumption and costs of a household

Mileage/d (km)	Incr. electricity consumption/mo (kWh)	Incr. electricity costs (€)
10	94	9.7
20	188	19.5
30	281	29.1
50	469	48.6
100	938	97.2

Despite a 100 km daily mileage, an increase in the electricity cost is less than 100 € per month. Thus, driving with an EV is relatively cheap with current electricity prices. With these values, the “fuel” costs for 100 kilometers would be 3.2 €. With a gasoline car, similar costs rise close to 10 € (the average fuel consumption 7 l/100km and the fuel cost 1.353 €/l) [54].

5.2.2 Medium voltage feeder

The capacity of transformers and cables should also be assessed within EV charging. In the following case study, the power of one medium voltage feeder is examined with the charging power added. Overloading of the feeders is not allowed. If constantly overloaded, the lifetime of the equipment decreases and damages occur. Hence, the current of a feeder needs to remain below a certain limit. In Helsinki, the critical power to be supplied via a 20 kV underground cable is around 10 MW.

The time of the study is the winter week 4/2009. The average January temperature in Helsinki during 1900-2000 has been -4.7°C. Winter 2009 was relatively warm as seen in Table 5. The area supplied by the feeder consists of customers of public and private sector services, apartment houses and terraced houses. About 40% of the total load originates from the services and the rest from the apartments. The feeder in the study has 676 consumer points, of which 338 (50%) are expected to have a charging point and an EV.

Table 5: Average temperatures of the week 4/2009 [49]

Date	**Average temp (°C)**
19.1.09	-0.9
20.1.09	-1.3
21.1.09	0.8
22.1.09	-0.4
23.1.09	-2.5
24.1.09	-3.3
25.1.09	0.5

Figure 18 represents the effect of uncontrolled EV charging on the MV-feeder. The red broken line is the maximum capacity of one 20 kV feeder. When people after work charge their EVs, the peak load rises 16.6%. A similar study during summer time reveals that the peak load rises some 15% which does not differ much from the winter season. The charging load curve in Figure 19 is created by thinking of the worst case scenario, that is, when the majority of users start charging between 3 PM and 6 PM. Some charging occurs at nights, but the users are presupposed to charge their EVs mainly after work. In this example, the reinforcement of the MV network is not needed while the critical limit for an MV-feeder is about 10 MW. However, all the feeders cannot have a 10 MW load. Three 40 MVA transformers and over 20 feeders exists in the substation under study. Therefore, if every feeder incorporates many EV charging stations, the absolute maximum load of a single feeder decreases considerably from 10 MW. More accurate evaluation regarding the capacity would require more extensive research.

However, for the feeder under study, charging does not pose any problems. Nevertheless, intelligent charging is needed prior to EVs become more common.

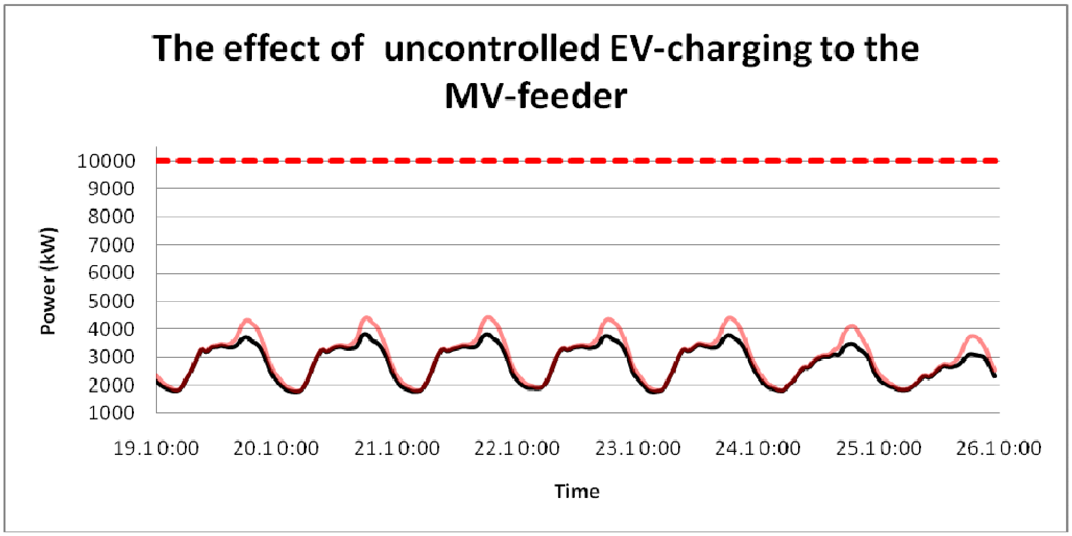

Figure 18: Charging in the suburban area without intelligence

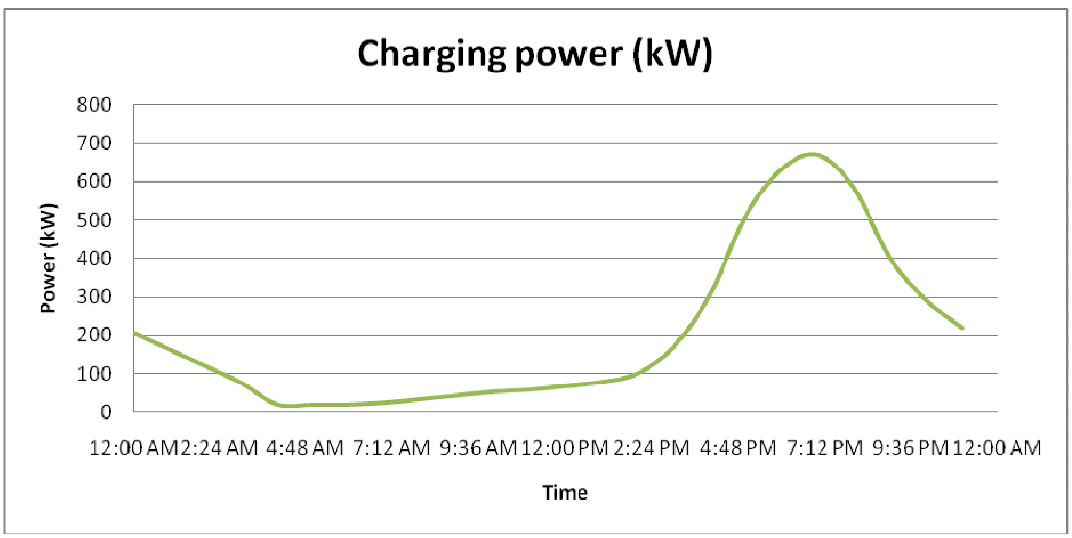

Figure 19: Charging load curve without intelligence

Extensive uncontrolled charging denotes increased daily peak loads. With control, the amount of charging points can be increased significantly without major problems. Figure 20 represents the result of controlled EV charging with the same MV-feeder. People need to charge during daytime but most of charging can be postponed to the nighttime when the load is lowest. Thus, the best case scenario occurs when charging mainly takes place at night (Figure 21). In Figure 20, in assistance with intelligent charging, the peak load rises only by 2.2%. The nighttime load grows closer to the daytime load, which is desirable from the power company's point of view when considering, for instance, the losses of the network. For a power producer, less power adjustment implies more constant production and less costs due to better utilization rate of installed capacity. Also, controlled EV charging supports the use of renewable energy whose power output cannot be stored or regulated. In this case, no reinforcement is needed in the MV network while the critical load limit is approximately 10 MW. However, intelligent charging is highly recommended when PHEVs and EVs start to generalize.

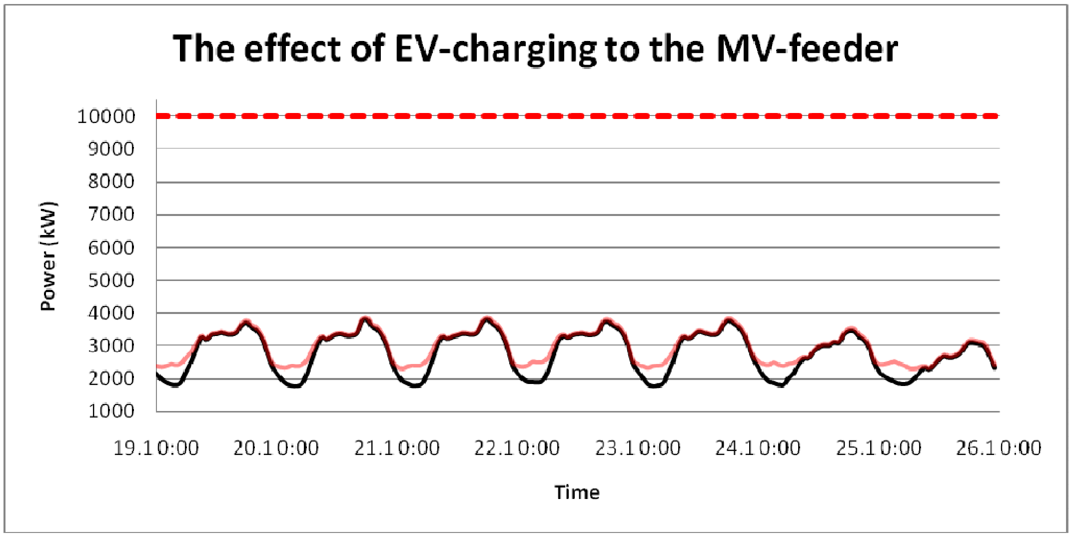

Figure 20: Charging in the suburban area with intelligence

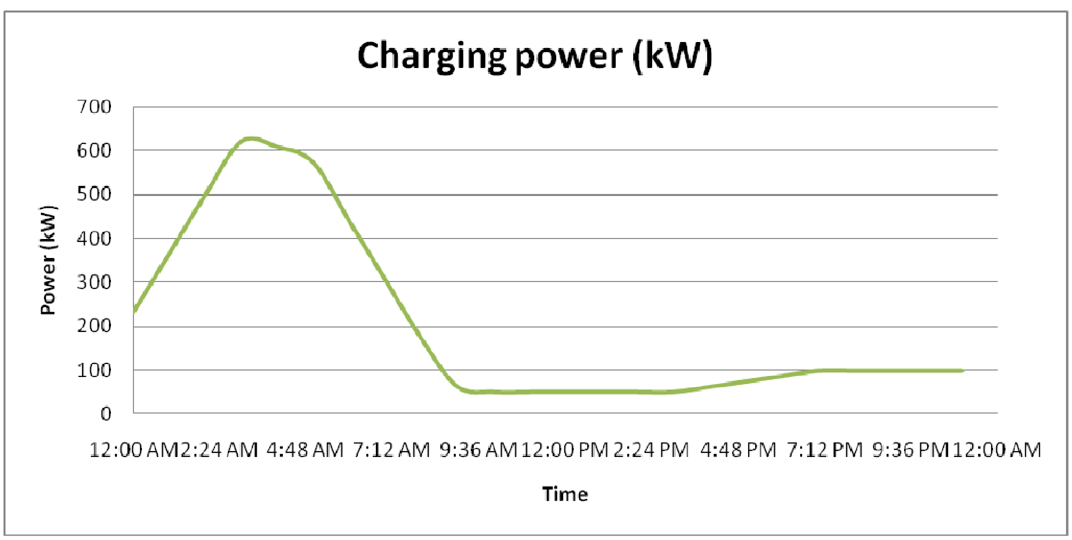

Figure 21: Charging load curve with intelligence

Smart charging provides remarkable charging opportunities without a significant increase in the peak load. Even if all 676 consumer points would have a charging point in daily use, the peak load rises only by 4.5% (Figure 22). The shape of the charging load curve is assumed to be similar to Figure 21 with the charging power doubled.

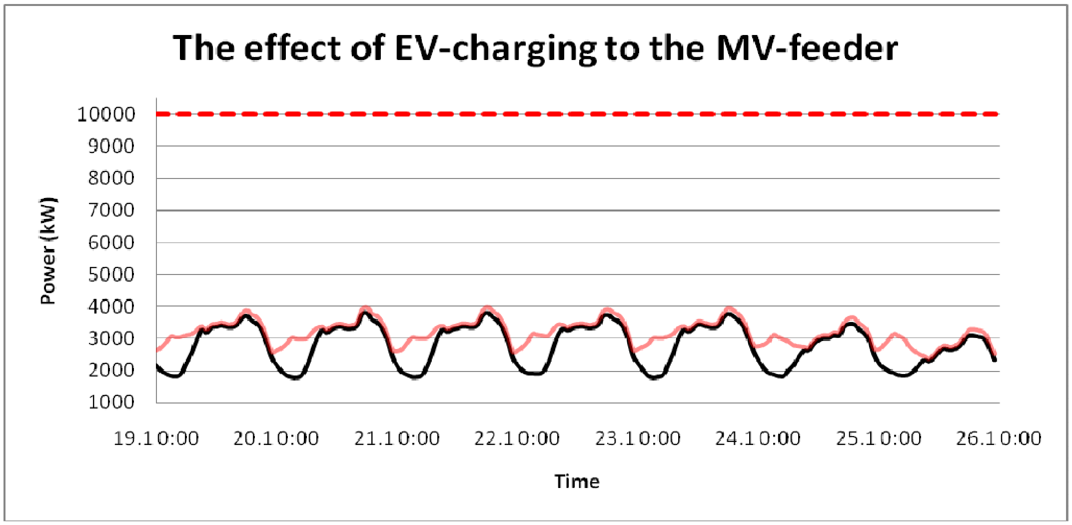

Figure 22: *Charging in the suburban area with intelligence*

Intelligent charging enables idealistic circumstances for the power company when the peak load does not rise significantly and the nighttime load remains higher. With V2G, load variations can be reduced even further. Presently, power companies are installing remotely readable meters to households. With automatic meter reading (AMR), it might be possible to control EV charging as well. Bi-directional data transfer between the household and the power company already exists. The meter needs to have means for controlling the charging relay and an override switch for the user's unexpected occasions. However, strict rules on charging and discharging should be legislated for the electricity contracts. Further AMR evaluation is passed in the thesis due to the large scale of the AMR aspect.

5.3 City downtown areas

In this study case, one MV-feeder of the downtown substation is evaluated with EV charging. In the area, one third of the consumption comes from the industry, the rest from the apartments (mainly heated with district heating) and private or public services.

In the city downtown with mainly district heated buildings, the outdoor temperature has only a minor effect on the power consumption. Thus, winter load does not differ considerably from summer load. Like in the previous case, the time of study is the winter week 4/2009. The area has 1 975 consumer points in its entirety. However, the industrial plant, that is only one consumer point among others, would probably have several charging points for the employees. Altogether 988 (50%) charging units are assumed to exist in the area. Figure 23 represents how the charging affects to the load of the feeder. The red broken line represents the maximum capacity of a 10 kV feeder. The charging load curve (Figure 24) is assumed to have two load peaks. The first peak occurs when people arrive at work and the second at evenings when people arrive home or start their evening shifts. Some charging takes place during the nights as well, but most of charging originates from the charging of the workers and visitors. With a 50% penetration level, the peak load rises to a noticeable 85%. An increase of this magnitude is not taken into account in the dimensioning of the transformer and the grid. However, in this example no reinforcements are needed as the maximum load on the 10 kV side is about 5 MW. Like the suburban case, all the feeders cannot have a 5 MW load. Thus, with higher EV penetration levels around the city, capacity problems would arise. With intelligent charging it would be possible, to a certain extent, to shift the charging peak towards the nighttime. This way it would be possible to get rid of the heaviest load peaks. However, if people need to charge while working, the full shifting of the peaks becomes impossible. Charging of the residents in the city area could take place at nights but workers and visitors need to charge during the daytime. Nevertheless, like in the suburban areas, the intelligence becomes essential round the year after EVs become widely accessible. Along with smart charging, some of the load peaks could be diverted by graded pricing.

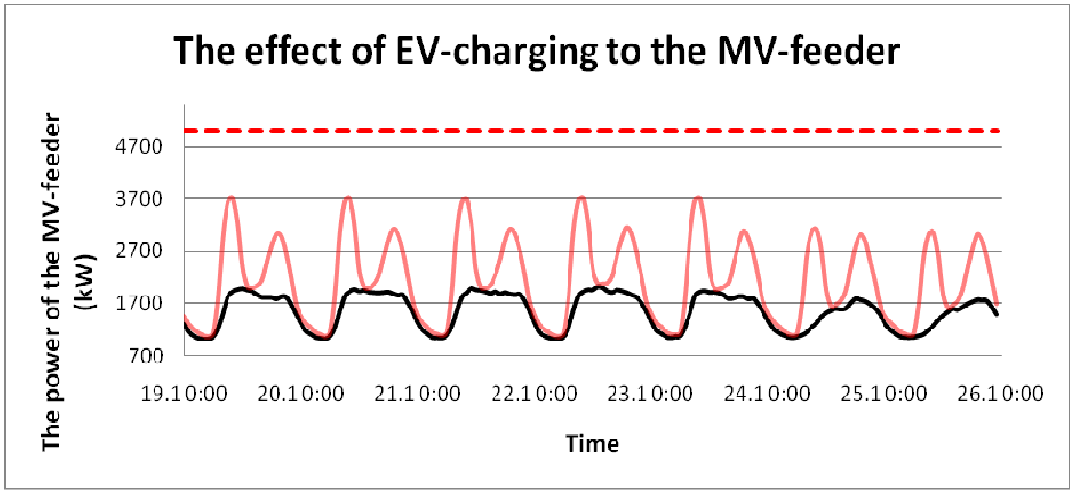

Figure 23: Charging in the city downtown without intelligence

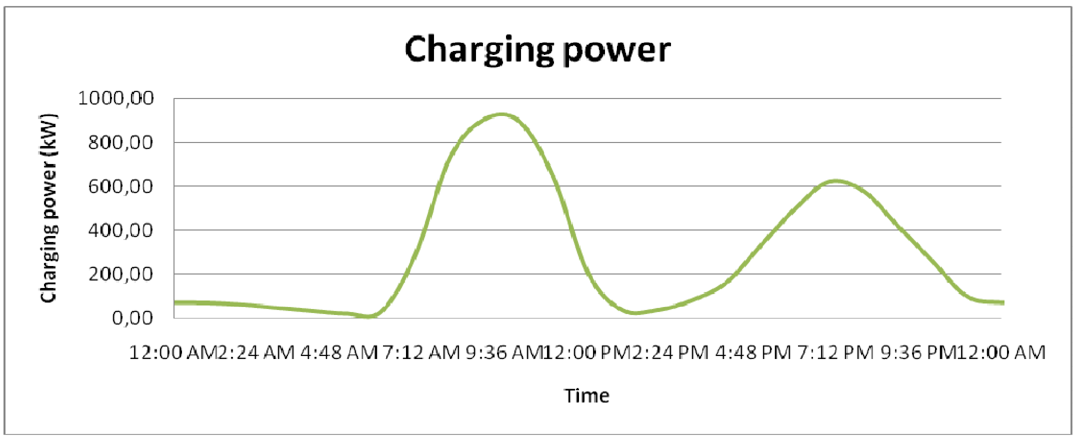

Figure 24: Charging load curve without intelligence

Fast charging stations might need their own MV-feeder because of high power demands. They might cause disturbances and worsening the quality of the electricity of other customers along the same feeder. The substation under study includes two 40 MVA transformers. [49] A fast charging station with four 250-400 kW chargers would be somewhat equivalent to a small petrol station. Figure 25 illustrates the active power of the city substation from the same week 4/2009. In this studied case, there is capacity for fast charging units at the substation level. However, in case of capacity problems, energy storages could handle the load peaks and the lack of capacity. An integrated battery switch/fast charging station could overcome the capacity problems and enable fast charging network. For example, as seen in Figure 25, during working days, the nighttime load is approximately 15 MW lower than daytime. A part of this gap could be equalized by loading the energy storages at nighttime.

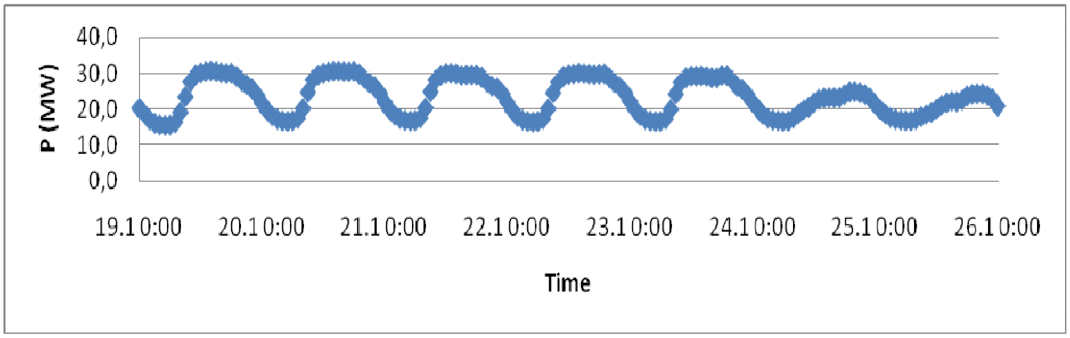

Figure 25: Active power of the city downtown substation

In summary, the areas of research in this Master's Thesis are capable of receiving EVs. In individual households, however, EVs increase the electricity consumption considerably. Without controlled charging the daily peak load may rise significantly. Nevertheless, the sizing of the fuses finally determines the charging capability of each household and housing cooperative. City downtown areas are more critical than suburban areas due to the 10 kV network. The load capacity is half of the suburban's and the present load is already high, which restricts the charging possibilities. In the city downtown substation, there is capacity for a couple of fast charging stations. However, energy storages are needed in order to implement a widespread fast charging network. In both areas of study, EV charging did not pose any problems. However, if all the areas of the substation have a significant amount of EV charging, problems would arise without intelligence in charging. Every MV-feeder cannot operate close to the maximum limit.

Comprehensive conclusions concerning EV charging in the Helsinki area would require more extensive studies about the impact of charging. Also low voltage network studies would be needed. This study confirmed that despite the available capacity, the intelligence is desirable at the initial phase and even mandatory in the long run. With intelligent charging the daytime load peaks can be equalized and nighttime load increased. Therefore, smart charging entails benefits to all parties. When the load alternation would decrease and the peak load would remain close to the same, the pressure to raise the electricity price would not emerge, which is important for the success of the EV transition.

5.4 *Vehicle to grid (V2G)*

Vehicle to grid is a concept where the power flow between an EV and a grid is controlled bi-directionally. The batteries can be recharged normally with power from the grid to the vehicle, but the power can also flow from the vehicle to the grid if necessary. This way during a shortage of power, the electric vehicles could deliver power to the grid. The EVs would act as controlled loads, while the grid would gain benefits in the form of reduced load variations. Therefore, electric vehicles can assist the adoption of renewable energy sources, which are primarily variable in nature. Wind and solar energy could be stored in the batteries during low demand times and the batteries can act as a buffer for the peak loads. Maintaining a sufficient amount of EVs connected to the grid can be assured by offering cheap tariffs to encourage storage utilization during peak times. [55] The time of charging could be regulated by pricing. Currently, day- and night-rate electricity is used which powerfully controls the operational time of hot water boilers of houses. Similar system, but with more resolution and dynamics could be used for EV charging as well. If high-priced charging would occur at peak times, people would mainly charge at low peak times and gain economic benefits by offering an energy storage capacity to the grid at peak times. Thus, electric vehicles are advantageous from the power company's point of view. However, V2G capability could be utilized in smaller scale as well. In rural areas short time power outages are common. During outages, an EV could keep up the households' necessary equipment.

Cars remain parked most of the day, even 95% of the time. Hence, EVs possess the potential to become an important power resource in the electricity system. [55] At the end of 2009, 200 000 passenger cars were registered in Helsinki [56]. If 10% of these cars would be EVs with a 30 kWh battery pack, and 80% of these EVs would be charging at the same time, we would have energy storage of 480 MWh. Of course, this amount of energy is not fully exploitable but a part of it can be used for occasional load peaks. At the initial phase, smart charging and V2G are not required because of the insignificant amount of electric vehicles. Later, when the penetration of EVs and PHEVs increases, at least smart charging and possibly V2G become paramount. Otherwise, considerable improvements to the grid would be needed to handle the increased peak loads. This in turn would raise the electricity price.

Most importantly, V2G technology has many obstacles to overcome. The V2G system requires extra equipment and data transmission standards between the EVs and the energy companies. The EVs would need information to know whether to charge or deliver energy. The second obstacle is the billing system which would be complex to implement. Individual billing and metering would require real time data regarding the location and the amount of energy received and delivered. EV users need to gain real financial benefits to let their cars to be exploitable. Otherwise people resist using their car as an energy storage for the public good. The major issue is that the EV is available whenever needed, not determined by the power company. A slight amount of energy can be taken from an individual battery but a battery with only a half the energy level in the mornings is inacceptable. Thus, well-defined rules concerning the rates and the level of utilization must be qualified. Some of the rules could be as follows:

- The power company has a permit to use 20% of the customer's battery capacity.
- The customer can override this permit 10 times a year for special occasions.
- For leasing the battery capacity to the power company, the customer receives a refund in the form of lower electricity bill. The refund could be dependent on the duration and the time of the day the car is plugged in.

5.5 Other studies

5.5.1 VTT: Future development trends in electricity demand

The main focus of the report was to study the future electricity demand and trends in Finland and Nordic countries in the transmission network level. The authors see industrial electricity demand, electric heating, heat pumps and electric vehicles as the most important individual factors affecting electricity demand in the future. A part of the study was to investigate the deployment of EVs and their effect on the electricity power system. The influence of EVs on the power system was studied with three separate cases:

- One million EVs in Finland.

- Five million EVs in the Nordic countries (excluding Iceland).
- Five million EVs with smart charging in the Nordic countries. [57]

For peak load comparison, the Nordel peak load week 16-22.1.2006 was used. The peak load of 67 800 MW took place on 20th January. Slow charging (12 A, 220 V) is assumed for all EVs and all cases. Heating and air conditioning, which increase the consumption of an EV, are excluded from the study. The share of different EVs is assumed to be shown as in Table 6. [57]

Table 6: Estimation of EVs' specific electricity consumption, average annual mileage, electricity consumption and share of various EVs on the roads in 15-25 years [57] *(Modified)*

	Electricity consumption kWh/km	**Trip km/a on electricity**	**Annual consumption MWh/a**	**Share of electric vehicles**
Electric vehicles	0.25	17 400	4.34	5%
Electric vehicles	0.17	17 500	2.97	15%
Plug-in hybrid vehicles	0.25	14 100	3.53	20%
Plug-in hybrid vehicles	0.17	14 000	2.38	60%

The effects of EVs on the system peak load in three cases are shown in Figures 26, 27 and 28. The results indicate that if 5-10% of cars in Finland were EVs, the electricity demand would rise less than 0.5-1%. If half (about one million) of all personal vehicles were EVs, realistically by 2030, the electricity consumption would rise 3 TWh (about 3%) in Finland and 15 TWh in Nordic countries. Nevertheless, changes to the system peak load management are not required if smart charging methods are adopted. [57]

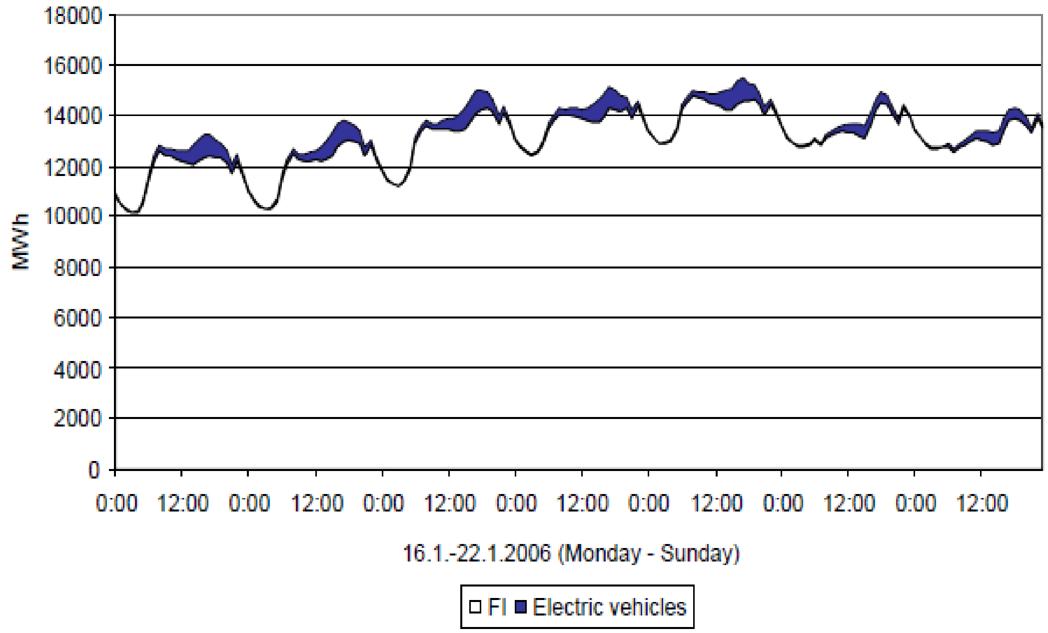

Figure 26: The effect of one million EVs on the system peak load in Finland. The peak load rises by 700 MW [57]

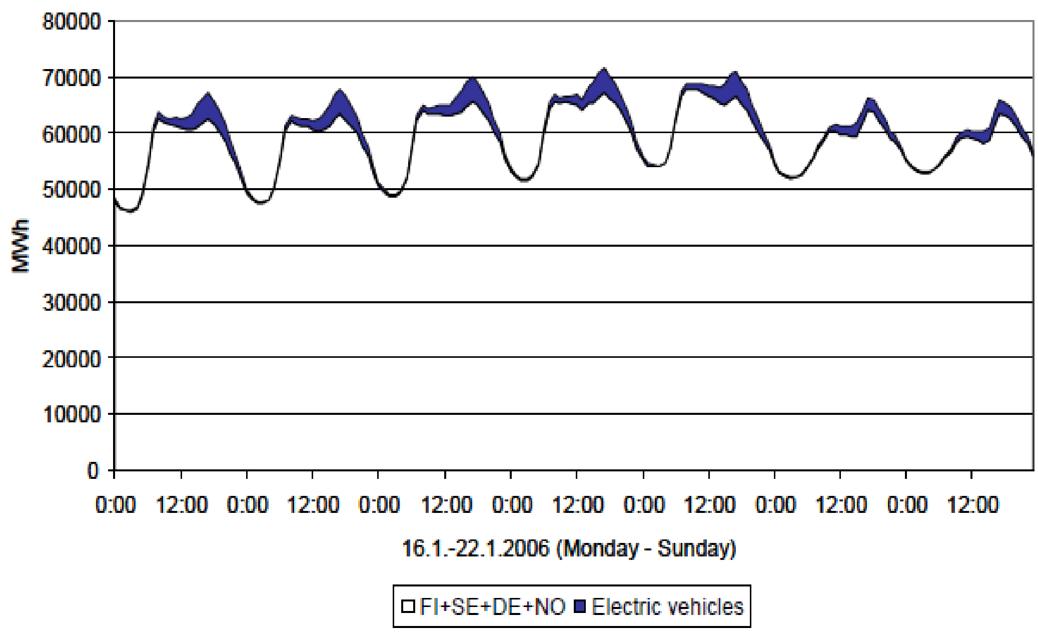

Figure 27: The effect of 5 million EVs on the electricity consumption in the Nordel system. Charging is assumed to occur as soon as vehicles plug in. The peak load increases by 3 800 MW [57]

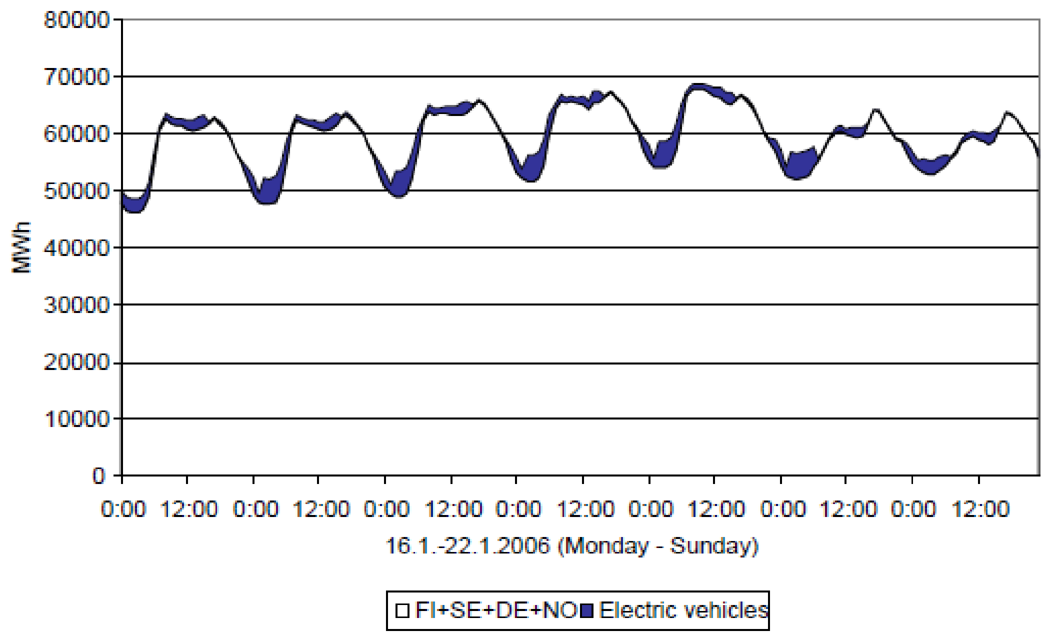

Figure 28: 5 million EVs with smart charging in the Nordic countries (excluding Iceland). The system peak load increases by 1 000 MW to 68 800 MW. The increase is less than 2%, although half of all personal vehicles were EVs [57]

5.5.2 Lassila et al.: Electric cars – Challenge or Opportunity for the Electricity Distribution Infrastructure?

Charging can effect on the power grid in all voltage levels. Lassila et al. have examined the effects of slow (3.7 kW) charging on the medium voltage network. In the study, the test area contains 20 000 residents, the level of cabling is 16% and the capacity of one battery pack is assumed to be 30 kWh. Figure 29 introduces the results on one MV-feeder. In the figures, blue curves represent the additional load caused by charging. [58]

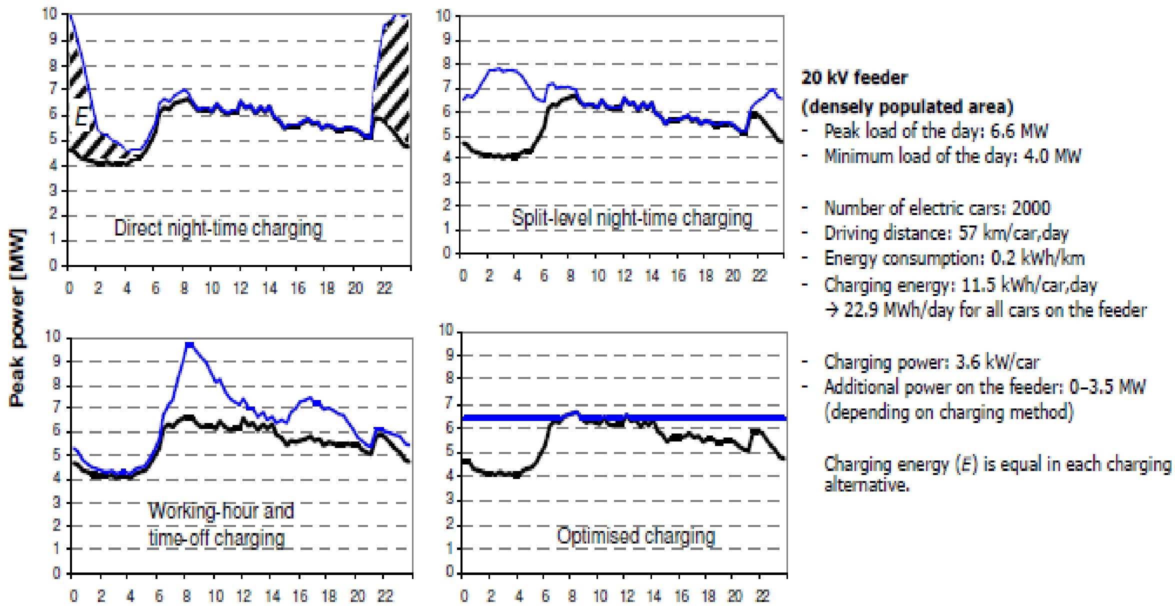

Figure 29: The effects of charging to the medium voltage load curve [58]

Notably, the time of charging is the most essential factor affecting the peak power. Therefore, alternation and controlling of the loads becomes essential. With proper control, additional investments are not required, the grid can be used more effectively and distribution fees may even drop. On the contrary, major investments are required if no control is implemented. [58]

The conclusions from VTT and Lassila et al. studies were that:

- Current power grid can withstand a huge amount of EVs without notable investments.
- The method of charging defines the peak loads. Significant investments are required if the charging is uncontrolled. With smart charging, the peak loads can be smoothened, the grid used more effectively, and the electricity distribution fees can even decrease.
- Need for energy for EVs does not create difficulties for the production capacity, if the charging is controllable. [8]

6 Billing and metering as a part of the charging infrastructure

6.1 General

In this chapter, billing and metering solutions are evaluated mainly from the end-user's point of view. Affordability and easy to use are the key characters to a large-scale success. Thus, charging and billing methods should be easy, affordable and safe to the user, as well as being cost efficient to owner. At the initial phase, charging could be free in public places to attract people to buy electric vehicles, but when the number of EVs starts to grow, charging becomes a subject to a fee. Companies are not willing to buy expensive and complicated systems during an unstable market situation. However, with EVs becoming more common, willingness to invest in new technology changes. Shopping centers and parking garages can attract customers by offering free charging. Similarly, workplaces can provide incentives to workers in the form of costless charging.

Fear of novelty is a familiar matter with new technologies. End-users tend to be skeptical towards new systems, particularly, if they are expensive, complex and require much learning. Therefore, charging units and billing methods should be designed with consumers in mind. Public charging units in all charging levels and battery switching stations should include close to similar user interfaces and billing systems to avoid confusion among users. Once again, standards are the key issue to keep customers satisfied and improve cost efficiency of the invention. Possible methods of payment are assessed with billing and metering solutions in the following sections.

6.2 Means of payment

A payment method for EV charging should be user friendly, that is; fast, simple and cheap. Parallel payment methods should be avoided to prevent avoidance by customers and to lower the threshold of the transition. However, specific sites possess separate requirement for payment. In public places though, the method of payment should be similar. In the following sections various means of payment in public places are introduced and evaluated.

6.2.1 Debit/credit card

Debit/credit cards are popular and convenient for shopping worldwide. For EV charging purposes, these cards include some beneficial characters. First, user identification accompanies with a card. Second, payment is familiar since similar systems already exist in, for instance, petrol stations. Lastly, the billing system is ready and waiting. On the contrary, debit/credit cards contain disadvantages as well. These cards require a data connection and a PIN-code for verification. That is why payment usually takes time. If charging takes place twice a day, it is not desirable to spend many minutes on plugging. Another problem arises when people without payment cards want to charge their EV. Some people are unwilling to obtain a payment card, so, other methods are needed. Debit and credit cards also fascinate misusers. There have been cases where cards have been copied by unauthorized copiers at petrol stations. Additionally, paying with a payment card might become liable to a charge in the future. Companies are currently legalized to collect the transaction costs straight from the consumer. Because of these reasons, payment card might not be a suitable instrument of payment for charging.

6.2.2 Mobile phone

A mobile phone as an instrument of payment is quite familiar, and the possibility for mobile payment is constantly becoming more general. Currently, you can buy travel tickets or pay your parking by the phone. In the future, we will see all kinds of services operated and paid for with mobile phones. Mobile phones possess several benefits as a payment instrument:

- Easy and safe payment.
- Identification of the user is simple.
- Almost everybody has a cell phone.

For previous reasons, cell phones are practical at least for paying tickets and occasional services. For EV charging purposes, mobile phones could enable various additional services as well. In addition, users could be able to select their own electricity seller, integrating their home and mobile energy bill. Users without a home energy supplier contract could sign a personal contract with the energy supplier. The users could buy the energy from the company they want and only the transfer price would be dependent on the charging spot. However, from the EV user's point of view, a mobile phone as an instrument of payment has some weaknesses:

- If the battery of the phone is empty, paying is impossible without a car charger for mobile phones.
- Calling or sending an SMS text message to the unit is rather slow, and if you charge daily, plugging becomes an effort.
- Company phone users are problematic. The employers possibly refuse paying for the charging, and separation of the charging fee might be complex.
- Charging with prepaid subscriber connection is impossible. Prepaid users would need another option for payment.

At the initial phase, a mobile phone could be a functional way to pay the charging. Early adopters are willing to adapt to the new system and mobile phone payment does not require considerable investments. Nevertheless, for the mass market more practical solutions are needed. Charging by sending an SMS or calling to the charging unit service consumes time. However, mobile phones could offer additional services to the user. The most functional system would include one application to handle all the services needed. This Internet based application could be in a mobile phone, laptop or car navigator. The application could possess the features presented in Figure 30.

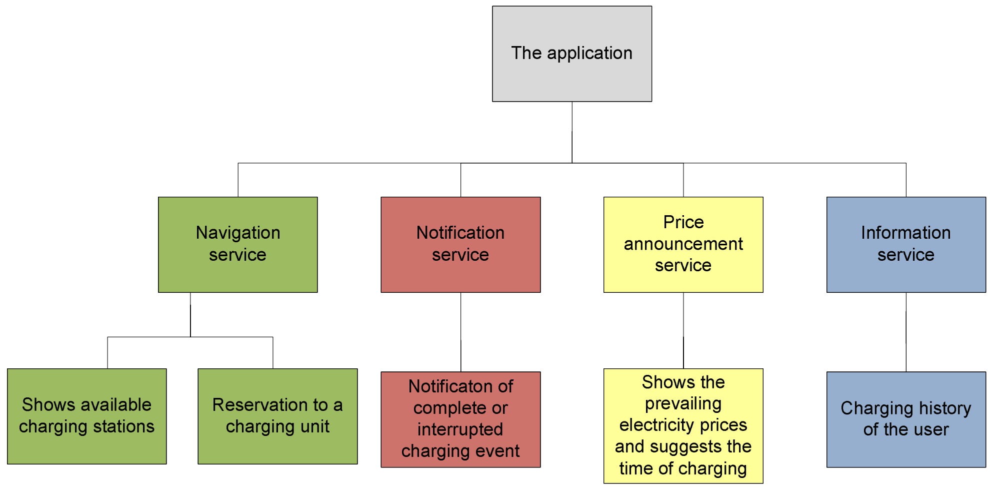

Figure 30: The possible features of the application

A navigation service would operate as navigators today but it would also show the available charging stations and driving distances. Via the application, a reservation to a certain charging unit could be made. After the reservation, the charging unit is reserved only for the user and charging should occur within ~15 minutes, otherwise the user is imposed a penalty (some 5€). The penalty is to prevent unnecessary reservations. Because smart charging would entail more dynamic tariffs, the user could utilize a price announcement service to check the prevailing price and the price forecasts. Because it would be annoying to constantly check the prices, the service could suggest the best charging times for the user. In addition to offering the additional services, a mobile phone could also operate as a secondary instrument of payment. The primary mean of payment could be RFID tag that is evaluated in the following section.

6.2.3 Radio Frequency Identification (RFID)

The RFID technology has been available for decades. The origins of the RFID technology relate to the invention of radar in 1935. The first RFID patent was granted in 1973 to the RFID active tag. The technology has developed in the course of time and presently the RFID is widely used. RFID technology is greatly standardized and developed. In Finland, many functional applications and solutions have been invented and Finland possesses world-class expertise in the RFID business. [59] Therefore, EV charging with RFID payment is worth studying and developing. A proper RFID system for payment could be a profitable export product as well.

RFID tags are cheap, only 0.06-5 € apiece, depending on the type of the tag. Three types of RFID tags exist; active, passive and battery assisted passive tags. The tag for EV charging should be passive. Passive tags require no external power source and the read range is low enough (0-10 cm). [59] The read range must be low to prevent misuse and to improve functionality. Presently, a high frequency of 13.56 MHz is widely used in low-range applications like key cards, travel cards and other smart cards [59]. The RFID tag for EV charging could be in the form of a card or a small key chain. A key chain-tag would be practical because people own too many cards already and a compact tag would easily follow with other keys. Furthermore, the user would not need to pick up one's wallet, which speeds up the whole charging process. The tag should be personal like mobile phones, allowing everyone to pay only for their own charging. Also, identification of the user could be arranged effortlessly. Similar to mobile phone payment, people could select their energy supplier and integrate their charging bill and home electricity bill.

Some people, however, are not interested in additional services. These people usually do not own a smart phone and want to perform the way they are used to. For these people RFID would offer an ideal functionality. Nevertheless, users interested in services could use additional services by mobile phone or via the Internet. For foreigners and visitors prepaid RFID tags could exist. These tags would include a certain value and after used empty, tags could be returned to the seller to be reused. Some consumers want to pay immediately, not afterwards by bill. For these people not willing to attach their EV charging to the home electricity bill, reload value RFID tags could be available. The actual charging process might be as follows:

- The user parks the car and places the RFID tag in front of the reader of the unit.
- The hatch of the unit opens and the user plugs in the charging wire.
- The user closes the hatch and the charging starts. The state of charging is clearly indicated with indicator lights.
- After businesses the user returns to the car and places the tag to the reader.

- The charging stops (if the battery is not already full) and the hatch opens.
- The user unplugs the car and is able to read the charging info from the display of the unit.
- The user leaves and, in case of an integrated bill, receives the bill from the charging afterwards.

With all new technologies, security is a major issue. Early stage safety problems may show to be very harmful for extending of a certain technology. RFID passive tags contain only an ID-number, which cannot be encrypted. Therefore, a tag's ID can be wire-tapped, copied and misused afterwards. The security of the user must be assured in other manners. A PIN-code could guarantee the safety but worsen the functionality of the charging process. With a PIN-code, the charging process would be nearly as slow as refueling today. NXP Semiconductors, founded by Philips, has developed MIFARE DESFire EV1 that is a smart card based on HF RFID technology. MIFARE DESFire EV1 is ideal for service providers wanting to use multi-application smart cards in transport schemes, e-government* or identity applications. In addition, it complies with the requirements for fast and secure data transmission, flexible memory organization and interoperability with existing infrastructure. DESFire EV1 is based on open global standards (ISO/IEC 14443). Key features also include up to 8 KB EEPROM memory with fast programming. [60] According to Kenneth Kronkvist from RFID Lab Finland, DESFire EV1 is already in use in various billing systems. DESFire EV1 is privileged in applications requiring high security. Thus, the EV1-chip could be suitable for EV charging purposes as well.

* e-government = the use of information and communication technologies, and particularly the Internet, as a tool to achieve better government.

6.3 Billing and metering in different locations

6.3.1 Billing and metering at home

People with own houses and yards in suburban areas commonly possess a socket outside. The electricity from these sockets accompanies in the residents' electricity bill.

Hence, the need for renovation and investments is unsubstantial and charging occurs without problems. These people presumably are early adopters as they might own two cars, of which one could be an EV. In suburban areas people have preheating units in their parking areas. These units can be modified to charging units quite easily. If the capacity of the cable is sufficient, a heating timer removal fills the requirements of EV charging. Some of the newest preheating systems are equipped with kWh-meters but usually residents are charged on a monthly basis. Billing on a monthly basis would arise problems as people are not willing to pay an additional fee for parking if a neighbor charges one's EV every day. Therefore, preheating units should be equipped with kWh-meters. Some person would need to read the meters, for example, once a month to know the amount of money to charge from a resident. For older households there can be seen another solution as well. If the house manager refuses to modify all the existing preheating poles, it would be easier at first, to use billing on a monthly basis. EV users would have to get their preheating poles modified (the timer removed) and this way the house manager would know who has an EV and who to bill more for parking. Later, when the amount of EVs exceeds the charging capacity of the parking lot, the whole parking lot could be renovated for EV purposes. That way, poles with kWh-meters could be attached and everybody would pay for the electricity used. The monthly basis billing might be considered unfair among some neighbors. Therefore, such a billing system might be suitable only for the initial phase.

6.3.2 Billing at workplaces

Charging and billing methods at workplaces should be easy to implement. The charging units manage without kWh-meters and 1-phase slow charging meets the needs of the employees. The units would require locks to prevent outsiders form stealing electricity. The workplace could pay the electricity bill and charge workers on a monthly basis or based on workdays. If the employer wants to be precise and monitor the electricity consumption, an employee could have their own parking place with a charging unit and a kWh meter. On this basis a company could charge the employee. The company could also offer incentives or bonuses to their workers by offering sponsored or totally free charging. Free charging would have a major impact on employees' car choices, which would assist the penetration of EVs. However, free daytime charging would not help the power grid to equalize load peaks. People would possibly avoid nighttime charging at home, which would even increase the daytime peak loads.

6.3.3 Billing at parking garages

Parking garages exist in many forms. In this section only commercial parking is considered. These garages often include ticket machines that could be modified to invoice for EV charging as well. The owner of the parking garage could gain extra profit by selling electricity to the customers alongside the parking fee. The payment for charging should be included in the parking fee, so that the system would be more customer friendly. Ensto and GARO Finland Oy sell ticket machines capable of these kinds of actions. GARO's old ticket machines can be modified to suit to EV billing purposes. Arriving customers have batteries with various charge levels. Thus, the energy used by the customer should be metered individually and correctly to charge a right amount of money, not by a fixed price. The actual charging and billing process for EV drivers could be as follows:

- The customer drives to the entry and receives the ticket.
- The customer drives to a parking spot intended only for EVs.
- The customer plugs the car to the charging unit.
- The customer walks to the ticket machine and activates the charging process by showing ticket to the main ticket machine and selecting "start charging on the unit x". The machine for activation could also be integrated with the charging unit.
- After businesses the customer comes back and places the ticket to the machine. The machine stops charging (if charging is still in progress).
- The machine displays the sum of the bill. Customer pays and leaves.

License plate recognition (LPR) is used in various countries by police officials. Also congestion charges and road tolls can be automatically collected from drivers. The system can be utilized for handling the billing in the parking garages as well. With the system, parking cards might become unnecessary. Nevertheless, the effortless payment for the user is the greatest benefit. LPR operates as follows:

- When the car arrives at the gate, the system recognizes the number plate and opens the gate. The system could direct the car to a certain parking spot.
- After businesses, the customer pays for the parking.
- When the car arrives to the gate, the system recognizes the number plate, opens the gate (if the payment is made) and lets the car go.

The process is even easier for customers with a parking contract. The contract customers can just drive away, the bill for parking is delivered afterwards. If the system could have access to the registry database, various additional features could be integrated. By linking EVs with LPR, the system could separate EVs and gasoline cars and direct an EV to a certain parking spot with a charging station. The charging unit would be connected to the database in order to identify the customer charging and the total cost to invoice for charging and parking. Because parking tickets would not exist anymore, the customer would enter the license plate number to the parking vending machine when paying. The payment event could occur as follows:

- The customer enters the license number to the machine. When the first letter is typed in, the vending machine lists all the license numbers in the garage starting with the same letter. Thus, remembering the whole combination is not required. After the user selects the license number, the system reveals the mark and model of the car. This way the customer assures the choice. Additionally, the system could report where the car is parked. These features would require a fast access to the national registry database.

In case of misuse or failure to pay, the system could utilize a blacklist. Members on the list could be later left outside or, let in, but not out. With harsh cases and constant offense, an automatic notice to the police could take place. The problem with the LPR system would be cars without plates and imported cars with sticker plates. Although these cars are the minority, they cannot be left outside. However, the LPR system entails benefits to the parking garage owner and the customer. To keep EV users satisfied, the charging fee should be included in the parking fee.

6.3.4 *Billing in park-and-ride areas*

The charging units in park-and-ride areas would be comparable to public places (upcoming in the following sections). The electricity to the charging units could be sold by the park-and-ride area owner. The parking and charging could be coupled with other public transport payment methods, such as travel card used in Helsinki public transportation. However, the travel card as payment method would create another parallel system to the EV billing system. Additionally, users would have to keep a significant amount of value on travel cards (the maximum value on the card is 400€) for charging purposes, which might become a hinder. Also, travel cards would be unsuitable for a nationwide instrument of payment. Therefore, travel cards would not be suitable for EV charging intentions. A more convenient way of paying would be by mobile phone or RFID payment. Similarly to the parking garages, the billing system could be based on the LPR system as well. Park-and-ride areas have regular customers who could sign parking contracts to utilize the LPR system.

6.3.5 *Billing options on public areas*

In this section, billing on public streets and parking lots of stores is assessed from the EV users' point of view. The charging units could be situated on streets, public parking areas or parking garages of shopping centers. Despite the location, the billing system and the user interface should be identical to avoid confusion. Electric cars and the transition require enough learning alone. Thus, the billing systems should be kept as simple as possible.

From the users point of view the whole charging process will be quite straightforward. The user charges one's car and pays or receives the charging bill afterwards. The problem is to find the right player to sell the electricity to the public charging poles. Depending on the location, the distribution system operator (DSO) transfers the electricity and charges a regulated fair fee for it. The energy producer can be selected separately. The competition between energy producers is believed to develop even without a regulation. After charging units and EVs start to appear, energy producers compete to get their electricity to be sold at the public charging units. In public areas people might want to know the greenness of the charging energy. Thus, the mobile phone or RFID card could be the solution overcoming these problems. People would have their own energy supplier and people could drive with green energy if desired.

6.3.5.1 Billing on streets

Residents living on city areas need charging points as well. Otherwise, the transition might fail. The billing should be arranged identically in public places all over the city. Mobile phone or RFID card could be the most suitable solution for charging because the electricity could be sold by the person's own energy company. The RFID tag or cell phone could be attached to the electricity bill of the apartment. Thereby, the consumer could select the energy supplier and only the DSO would be dependent on the location. The total price should be reasonable, so that price difference between on-street charging and home charging would be insignificant.

6.3.5.2 Billing in business parking areas

Business parking areas include large parking garages and parking areas of shopping centers. These places are essential for the breakthrough of EVs because people might drive dozens of kilometers to these shopping malls. With charging stations on sight, consumers do not have to consider whether to manage with an EV. Even if people would not need to charge while shopping, chargers have a psychological effect in assuring consumers to drive further.

The billing should be organized similarly to previous section, by mobile phone or RFID card. Despite the location, the consumer could charge "green energy" if desired. Of course, the shop owner would charge the premium from the user. The fee should be based on the energy consumed, which states the importance of metering also in the business parking areas. However, accurate metering is not necessarily required if the duration of the payment can be adjusted. With a certain charging mode, the energy consumption of a particular time span can be roughly calculated and kWh- meters are not required. As mentioned in the Section handling charging in the shop ing centers, the charging process in should be quick enough. Typically people spend a couple of hours shopping at maximum, while the car should be fully charged. Therefore, the actual price for charging would be slightly higher than with slow charging. Nevertheless, the price should be kept as low as possible to support the transition. The cost of fast chargers might be reasoned to be indirectly included in the expenditures of the shops upkeep. After all, the users could prefer shopping centers with low cost charging, thus bringing more profit to the centers.

6.3.6 Summary of the payment methods

Overall, the disadvantages of credit cards make it unsuitable for EV charging purposes, whereas RFID technology would offer the most practical way of paying. The RFID system might be expensive to build to begin with. However, the RFID system would be the most customer friendly billing system due to simplicity, speed and functionality. Meanwhile, the mobile phone could offer the additional services and an alternative payment instrument. Therefore, mobile phone and RFID solutions are not exclusive, they could operate in parallel. The features of these three instruments of payment are listed in Table 7 to conclude the comparison.

Table 7: Payment method comparison

	Credit card	**Mobile phone**	**RFID**
User identification	+++	+++	+++
Duration of the payment transaction	+	++	+++
Safety	++	+++	++
Additional services	+	+++	+++
Availability	+++	+++	+
Easy to use	+	++	+++

+ moderate ++ good +++excellent

7 Conclusions and recommendations

This thesis aimed to two primary objectives. The first was to find the main electrical engineering solutions for charging infrastructure. Billing and metering solutions from the end users perspective was the second. A secondary aim was to assess the effect of EV charging on the power grid. Despite a large amount of on-going projects worldwide, the non-existence of empirical results has complicated the study and completion of this thesis. Nevertheless, throughout the project, several concepts and inventions have been generated and documented in this thesis.

In the chapter handling basic charging solutions, people living in detached houses in suburban areas were stated to be in the most favorable position of having a charging capability. Unlike in suburban areas and most workplaces, EV charging poses challenges in the city downtown because the whole charging infrastructure has to be built from the outset. On the curb-sides, all kinds of poles are against the principles of the City Planning Department of Helsinki. Hence, small park-and-charge areas could be established or current parking garages utilized for EV users at nighttime. The available space needed for the park-and-charge areas should be estimated and the possibilities evaluated. The feasibility of utilizing the current parking garages for residents should be assessed as well. This set-up would require customized contracts between the garage owner and the residents. Early adopters of EVs include companies and people living in the outer city, making a wide charging network in the city downtown unnecessary at the beginning. However, to familiarize citizens with EV technology and to reduce the range-anxiety of the early adopters, some charging units must be implemented already at the early stage. Also for testing purposes a small-scale charging network, possibly including fast charging units, could offer essential research results and development plans for the future. The impact of fast charging on the quality of the electricity could be determined simultaneously. In the future, current gasoline stations in the city downtown could be equipped with fast chargers for busy EV users.

The chapter concerning the effects of charging to the medium voltage network stated the importance of smart charging in the long run. Timing of charging is the most crucial factor defining peaks loads. A more comprehensive study on the effects of charging on the power grid would require more extensive studies. A couple of case studies from the low voltage network side could offer useful data about the effect of charging as well. Despite the limited scope of this thesis evaluation, the significance of the intelligent charging became evident. At the initial phase intelligence is only recommended to lower the increased load peaks. However, smart charging is a development trend to be followed in the long run. The study also revealed that the grid has some capacity for fast charging stations. Nevertheless, the density of current petrol stations is not achievable without energy storages.

In the billing and metering chapter RFID technology is stated to bring the most convenient instrument of payment. The credit card, which is used in the automatic fuel pumps, was assessed to be an inconvenient instrument of payment for EV charging, mainly due to the slowness of the transaction. On the contrary, the quickness and easiness of the RFID payment are the most crucial factors to promote the RFID payment. However, the safety of the RFID payment must be assured prior to a wide introduction. A mobile phone, as a secondary instrument of payment, could entail the additional services for the EV users. One Internet-based mobile application could include all the desired services from navigation to notification services. These services could be used by a laptop or a car navigator as well. The RFID and mobile phone payment would require a new kind of personal electricity contracts, possibly integrated with the electricity bill of a household. Along with green home electricity, an environment conscious citizen could use renewable energy anywhere. Citizens willing to reduce their carbon footprint prefer renewable resources in the electricity production. In order to assure the possibility to low CO_2-transportation, electricity sellers should be prepared for such integrated contracts.

The infrastructure built today will be in service for decades. Thus, new construction production should include EVs and required charging infrastructure into construction blueprints all over. Surely, the lack of standards momentarily complicates implementing definite solutions for blueprints. The implementation of the charging infrastructure is strongly determined by the penetration level of EVs. Some charging units should be in place before EVs become widely accessible. The possible risk for investors derives from the unpopularity of EVs resulting in low utilization rates of the charging units. The risk can be reduced by installing the charging stations one by one and by observing the demand. Nonetheless, if the whole connection to the grid, possibly the transformer, or the feeding cable has to be reinforced, the risk can be only slightly minimized. The price of charging units is insignificant compared to the reinforcement of the electricity system. Indeed, incentives are needed in both public and private sectors to kick off the transition.

Before serious adoption, electric cars and various types of batteries should be tested to assure the functionality in the Finnish winter environment. Some batteries might require constant heating at extreme cold times to function in a proper way, which increases the required power output of the charging unit. The way of recharging the batteries affects the lifetime, which could be assessed at the same time with other studies. Once more cars and batteries are on the market, V2G pilot projects could be arranged. Various recharging/discharging methods to separate battery types should be tested. Simulating V2G in Finnish winter reveals the practicality of charging and discharging. The loss factor of the procedure needs to remain at a tolerable level in order to encourage building V2G systems.

Many ongoing projects around the world prove the entrance of electric vehicles. This thesis evaluated and proposed charging solutions for various locations, as well as solutions for billing and metering. Hopefully, some of these plans will become reality one day. Absolutely, lots of thrilling concepts and pilot projects worldwide will be seen in the upcoming years. Based on the project SIMBe that continues until December 2011, Helsinki and Finland will see real progress in electric transportation. All those involved in the project look forward to witness the beginning of the transition.

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Appendix A: Fuel cost calculations

In the following calculations the fuel costs of EVs, diesel and gasoline cars are compared. According to average prices at 21.2.2010, 95 octane fuel costs 1.353 €/l and diesel 1.058 €/l [54]. First, the fuel consumption is assumed to be 8 l/100 km for a gasoline engine and 5/100 km for a diesel engine. With these figures costs per 100 km are 10.824 €/100 km for gasoline and 5.29 €/100 km for diesel, respectively. For an EV the consumption is presumed to be 0.25 kWh/100 km and the efficiency of charging 80%. Helsingin Energia sells the electricity at 10.36 c/kWh [61]. Thus, costs per 100 km would be 3.24 €. A gasoline car is approximately three times and a diesel car almost two times more expensive to drive than an EV. These numbers are quite realistic in Finland because heating/cooling requires more power from the batteries and charging.

A modern gasoline car consumes less than previously assumed. A new VW Polo 1.2 TSI has an average fuel consumption of 5.3 l/100 km. Still, Polo TSI accelerates from 0 to 100 km/h in 9.7 seconds and the engine produces 105 hp. [62] For the new Polo, fuel costs for 100 km would be 7.17 € that still exceeds the costs of an EV. In the future, driving an EV will be more expensive. Considering that the Finnish government compensates the lost fuel tax income somehow, the burden of taxation falls on the EV users.

Appendix B: Electricity production method comparison in terms of CO_2-emission reduction

Electric vehicles significantly reduce pollution in city areas. The air quality improves as EVs do not generate local emissions at all. The following Figure 31 illustrates the influence of EVs on the CO_2-emissions with various penetration levels. In these calculations the term “EV” includes all plug-in vehicles. The Figure excludes the effects of emission trading. The number of vehicles in Finland is assumed to be 2.7 million and the average mileage per year is 17 000 km [8].

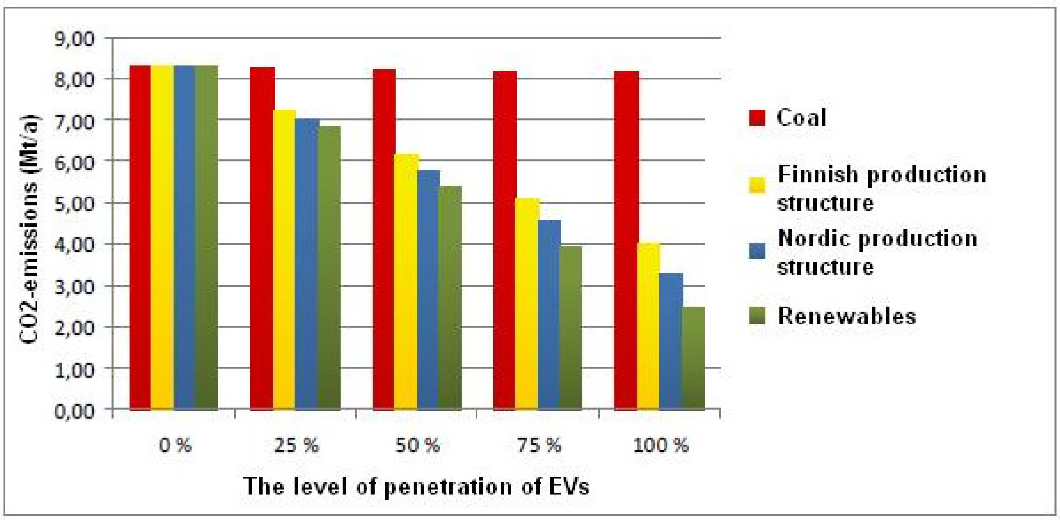

Figure 31: The total CO_2*-emissions in Finland with different electricity production methods* [8]

With renewable sources of energy, CO_2-emissions reduce considerably. With penetration level of 50% and with Nordic electricity production structure, CO_2-emissions would decline 30% compared to the present situation. Even with the coal-based production structure the total CO_2-emissions reduce slightly. [8]

With the same assumptions, we can calculate the reduction of primary energy in Finland. The following Figure illustrates the influence of EVs on the consumption of the primary energy.

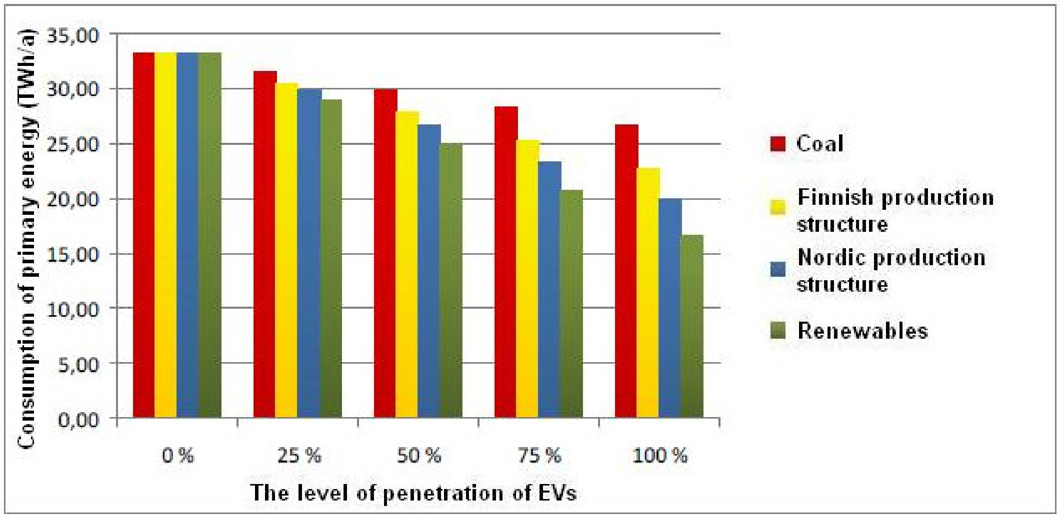

Figure 32: The consumption of primary energy by Finnish passenger cars with different production methods [8]

As seen in the Figure 32, the consumption of primary energy decreases 20% with a 50% penetration level of EVs when the electricity is produced with Nordic production methods.

Appendix C: Available and upcoming EV models

[41]