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Economical potential of controlling charging of electric vehicles by using price signal

Sami Tolonen

Kandidaatintyö
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Sami Tolonen
Kaupallinen potentiaali käytettäessä hintasignaaliohjausta sähköautojen latauksessa

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Sähköautojen määrä kasvaa jatkuvasti, joten tulevaisuudessa tärkeäksi kysymykseksi nousee sähköautojen latauksen toteuttaminen. Sähköautojen lisääntyvä määrä voi nostaa jakeluverkon huippukuormia aiheuttaen verkolle ongelmia. Nykyään sähköautojen lataus on ohjaamatonta, mutta sähköautojen määrän kasvaessa niiden älykäs lataaminen (ohjattu lataus) tulee olemaan yksi mahdollinen ratkaisu tilanteen hallitsemiseksi.

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ABSTRACT

Lappeenranta University of Technology
Faculty of Technology
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Sami Tolonen
Economical potential of controlling charging of electric vehicles by using price signal

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Bachelor's Thesis.
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The number of electric vehicles grows continuously and the implementation of charging electric vehicles is an important issue for the future. Increasing amount of electric vehicles can cause problems to distribution grid by increasing peak load. Currently charging of electric vehicles is uncontrolled, but as the amount of electric vehicles grows, smart charging (controlled charging) will be one possible solution to handle this situation.

In this thesis smart charging of electric vehicles is examined from electricity retailers` point of view. The purpose is to find out plausible saving potentials of smart charging, when it´s controlled by price signal. Saving potential is calculated by comparing costs of price signal controlled charging and uncontrolled charging.

CONTENTS

ABBREVIATIONS AND SYMBOLS

EV	Electric vehicle
OTC	Over the counter-trading
TSO	Transmission system operator

1. INTRODUCTION

The amount of electric vehicles (EVs´) is growing fast worldwide and there are no signs that this trend is going to end. In the future, great amount of vehicles would be electric vehicles and it also concerns electricity retailers and distributors. Charging of the electric vehicles will be a new component at the electricity consumption of the end users. Hence electricity retailers and distributors have to find out best ways to implement it.

This thesis examines the issue from electricity retailers´ point of view. The aim of this thesis is find out if there is saving potential when using price signal controlled charging. This is done by comparing price signal controlled charging to uncontrolled charging.

Thesis is divided into two different parts. First one presents the idea of smart charging and introduces Nordic electricity markets and second one presents background data, calculation methods and results of calculations for the potential savings.

2. SMART CHARGING

Smart charging means the communication of information and services between electric vehicles, smart grid technologies, service providers and operators. Charging of an electric vehicle is called smart charging if charging cycle can be altered by external events such as implicit chances of grids physical properties and communication of information and services between electrical vehicles and smart grid. Altering charging cycle allows adapt charging habits, which helps reach more efficient management of power demand and energy used during charging. This also leads to more grid friendly behaviors and enables more efficient management of power demand and used energy during the charging process. (E-mobility smart charging 2012)

“Value Added Service” is also part of smart charging concept. It includes things like location of charging spots, possibility to reserve charging spots, easy and secure identification methods and other services that add value to service and makes charging event easier to customers. (E-mobility smart charging 2012)

2.1 Aim of smart charging

The main target of smart charging is to satisfy the needs of an electric vehicle users and at the same time create conditions that allow an optimal charging process that adjust charging behaviors considering systems capacities, grid stability and efficient management of power demand and energy use. In order to achieve these targets the smart charging concept should consider electrical systems constraints and costs, energy price, energy mix, demand side management, bandwidth management and grid quality management. At the same time some background objectives and conditions must be taken account. Systems and components must be compatible and have smart cooperation between them. Smart charging should satisfy needs (such as charging time and costs of charging) of EV users, achieve sustainable transport system, reduce CO_2 emissions when using EVs and achieve targets cost-effectively. These may apply simultaneously or not. (E-mobility smart charging 2012)

2.2 Smart charging types

Uncontrolled charging is the case, when as the electric vehicle is connected the battery management system determines the charging profile by itself. Smart charging is the case when charging cycle can be altered by external events. Price signal controlled charging means that charging is controlled by energy price (e.g. low hour tariff). In price signal controlled charging customer has a possibility to not to use it. Charging could be also controlled by power consumption and energy production. The aims are avoid overload risk and imbalance between consumption and production or peak demand exceeding the capacity of a grid. (E-mobility smart charging 2012)

3. ELECTRICITY MARKETS

Electricity markets are divided to wholesale and retail markets. This chapter introduces functioning of markets and points out reasons to use controlled charging for electricity vehicles from retailers´ point of view.

3.1 Wholesale markets

Most of the power trade is done on power´s wholesale markets, where the amount of produced electricity and it`s price are determined. Finland is part of market area, which other members are Denmark, Norway, Sweden, Estonia, Latvia and Lithuania. Producers, retailers and large users of electricity are buying and selling power at the market. Elspot trade covers 70 % of total electricity used in Nordic countries. (Energiateollisuus 2013a)

Elspot-prices are known at least 12 hours before beginning of hour, which gives retail sellers possibility to use load controlling in order to reduce usage of electricity during high spot-prices. This is the main reason for using Elspot-price in thesis while calculating possible savings of price signal controlled charging. The timeframes of Nordic physical electricity markets is presented at Figure 3.1

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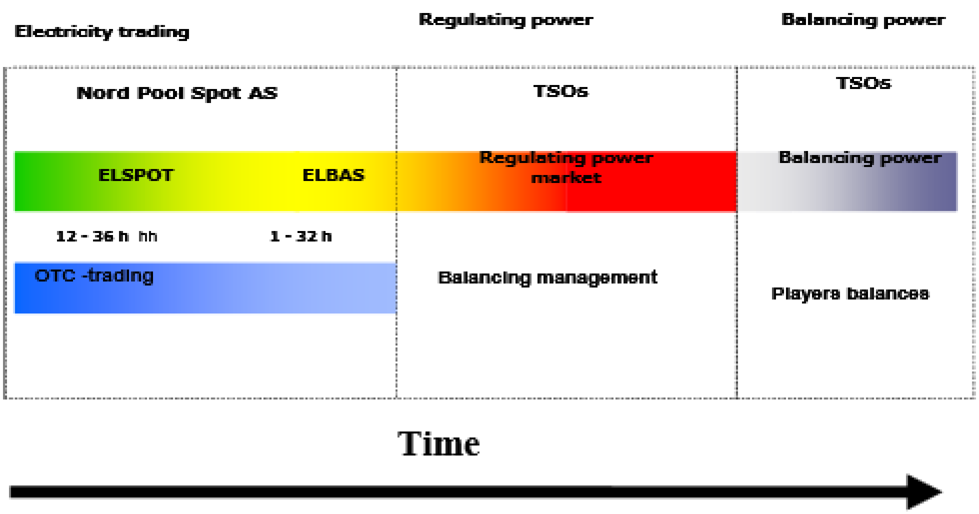

Figure 3.1 Timeframes for Nordic physical electricity markets. (NordREG 2010)

Elspot is the main arena for power trading. Elbas, regulating power and balancing power are meant to balance supply and demand. Over the counter-trading (OTC) is trade that happens outside the market and it supplements electricity markets. (Nordpool)

3.1.1 Elspot

Elspot, the day-ahead market is the place where next day´s wholesale price (spot price) for power is determined. Elspot includes most of power trading in the Nordic region and it´s the main arena for power trading. In the Elspot, sellers (for example power plant owners) have to decide how much energy they can deliver and at what price, as buyers need to decide the amount of power they are ready to buy and make offer for the price. Offers has to be left before 12:00 CET, which is the deadline for submitting bids for power that is delivered at the following day.

Figure 3.2 presents how the system price is set where the curves for the supply price and the demand price meet. Calculations are done for each delivery hour based on offers. (Nord Pool)

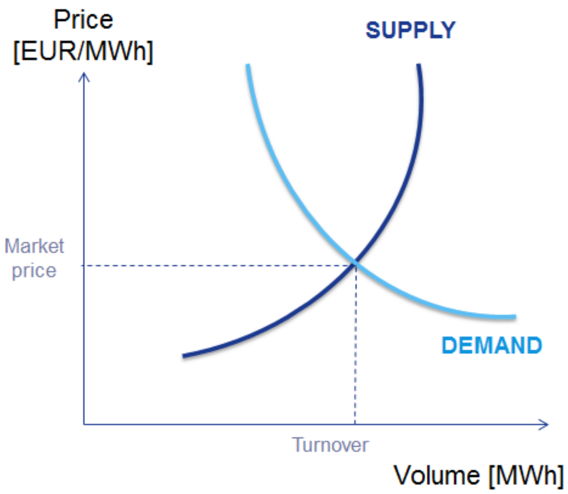

Figure 3.2 Elspot price determination. (Nord Pool)

Elspot´s market mechanism aims to use production methods which variable costs are lowest. The system price is the variable cost of most expensive production method that is need to cover the demand. Figure 3.3 shows electricity demands at summer and winter.

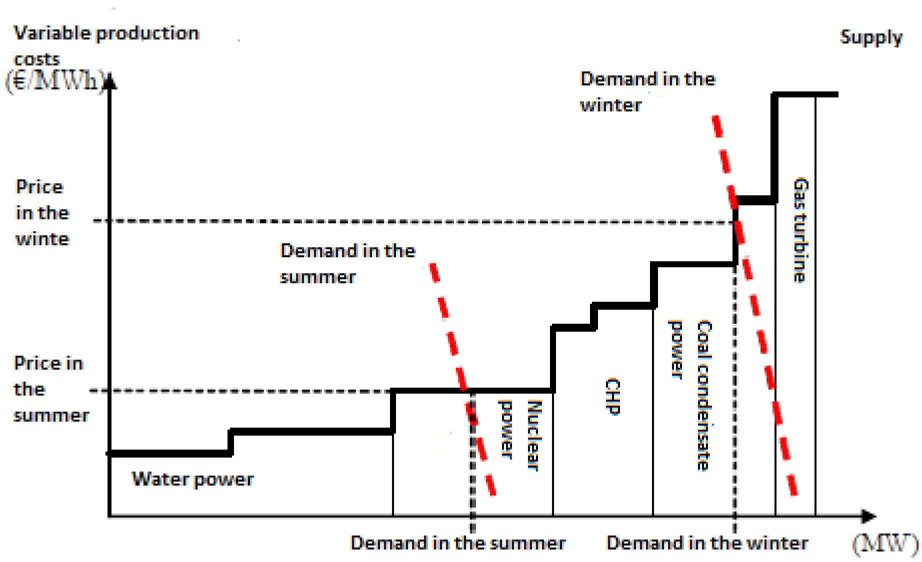

Figure 3.3 The formation of electricity`s market price. (Partanen & al. 2012)

In the summer, the demand of power is lower than in the winter. Therefore, demand can be covered by lower variable cost energy sources such as water and nuclear power, leading to lower market price of electricity. In the winter, demand is larger and usage of condensate power, even gas turbines is needed to cover the demand. Because of larger variable production costs, the market price of electricity is much higher. (Nord Pool) and (Partanen & al. 2012)

Markets have been divided into 15 bidding areas. Norway has five, Sweden has four, Denmark has two and the rest of the countries including Finland have one bidding area. All members submit their orders and after that the system price and the area prices are calculated for all bidding areas. The system price is same for whole Nord Pool Spot area and it works as a reference price at the Nordic area. (Nordpool)

At the Nordic market the spot price is same for each area only short period of a year. The area prices are different because of so called bottleneck situations, meaning trading capacity limitations between bidding areas. If power flows between bidding areas don´t exceed the trading capacity the system price is same for both areas, otherwise area prices are calculated. This is presented in Figure 3.3.

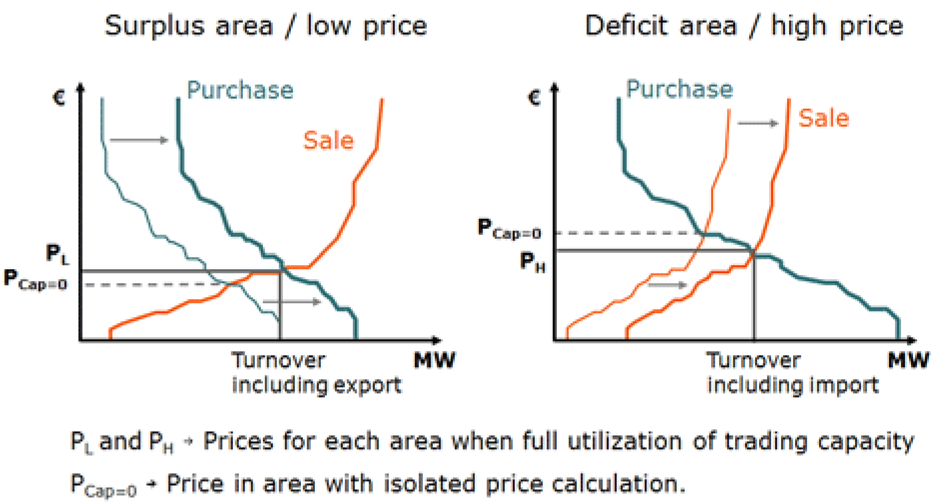

Figure 3.3 Area price calculation. (Nord Pool)

In the Surplus area price goes down and in the deficit area price rises. The equilibrium points are determined after the addition of power flow between these areas. The price mechanism balances itself with area prices by relieving grid congestions. (Nord Pool)

3.1.2 Elbas

Elbas is an intraday market for Nord Pool Spot, which has same market area as Elspot, but it also includes Germany. It supplements Elspot by helping to secure the balance between supply and demand in the power market. Trading happens close to real time, because of balancing purpose of Elbas. Day-ahead market covers majority of trade and for the most part the balance between supply and demand is secured there. Intraday market is used balancing supply and demand when for some reasons Elspot has not done it. There might have happened incident, for example some major power plant has stopped operating or wind turbine plants produce less or more power than predicted. (Nord Pool)

The importance of intraday market is growing. Wind and solar power use is increasing and because they are unpredictable by nature, they will cause unbalance situations between demand and supply. (Nord Pool)

3.2 Retail markets

At the retail markets electricity, purchased on the wholesale market, is sold by retailers to the end consumers. Most of the contracts between retailers and the end consumers are fixed-price contracts leaving all risk from electricity price volatility to retailers (Energiateollisuus 2013b). In these cases retailers benefit from lower consumption during high price hours.

4. BACKGROUND DATA

In this chapter the data used in calculations is presented. First selecting the year which spot price is used in calculations and second presenting case areas traffic flow which is used to simulate the customers having EVs.

4.1 Selecting used spot price

The objective of price signal controlled charging is to reduce charging of EVs during high spot price hours and to charge at lower prices. In this thesis calculation period is one year and used spot prices are from 2010, because of its high average spot price and exceptional amount of high price peaks. The Table 4.1 shows the average spot prices from past 5 years.

Table 4.1 The average elspot prices. (Nordpool)

Year	Average elspot price [€/MWh]
2012	36,64
2011	49,30
2010	56,64
2009	36,98
2008	51,02

As Table 4.1 shows that the average spot price from year 2010 higher is than any other year from past 5 years. Figure 4.1 presents 2010 spot price (Nordpool) compared to average spot price of that year. Comparing is done by reducing the average spot price from each hour`s spot price. Hours` which are under the zero have spot price less than average price and hours` which are above it have spot price higher than average.

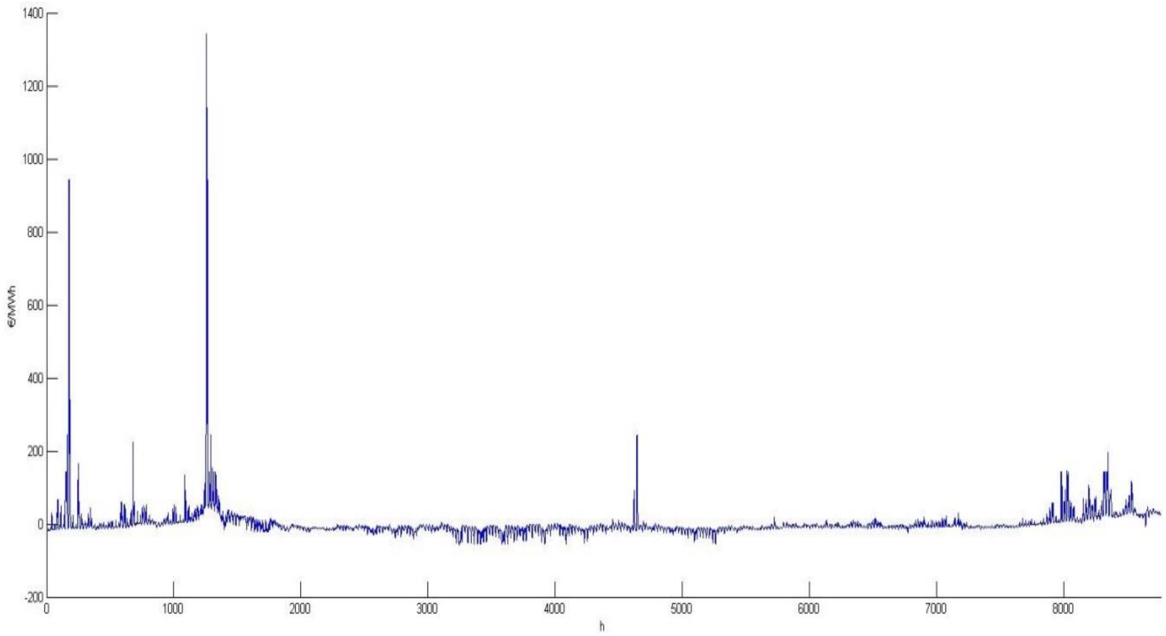

Figure 4.1 The difference between spot price and average spot price 2010.

As Figure 4.1 shows, year 2010 includes lots of hours when spot price is above average and some of those peaks are exceptional high (highest 1400.11 €/MWh during one hour). Exceptional high peaks were caused by varied reasons. During high price periods prevailed cold weather, maintenance shutdowns of some Swedish nuclear plants were longer than expected, inelastic demand of Nordic markets and also the way how transmission system operators (TSO´s) calculate the available transmission capacity between the countries (Energiamarkkinavirasto). These high peaks include high saving potential if the charging during the peak hours could be moved/shifted to lower price hours.

4.2 Case Pikisaari

In this thesis calculating possible savings is done by using traffic flow data from Pikisaari district of the City of Lappeenranta. To simplify average workday traffic flow based on actual traffic flow measurement (Ville Tikka & al.) is used to calculate amount of cars that are staying in Pikisaari per hour (Figure 4.2).

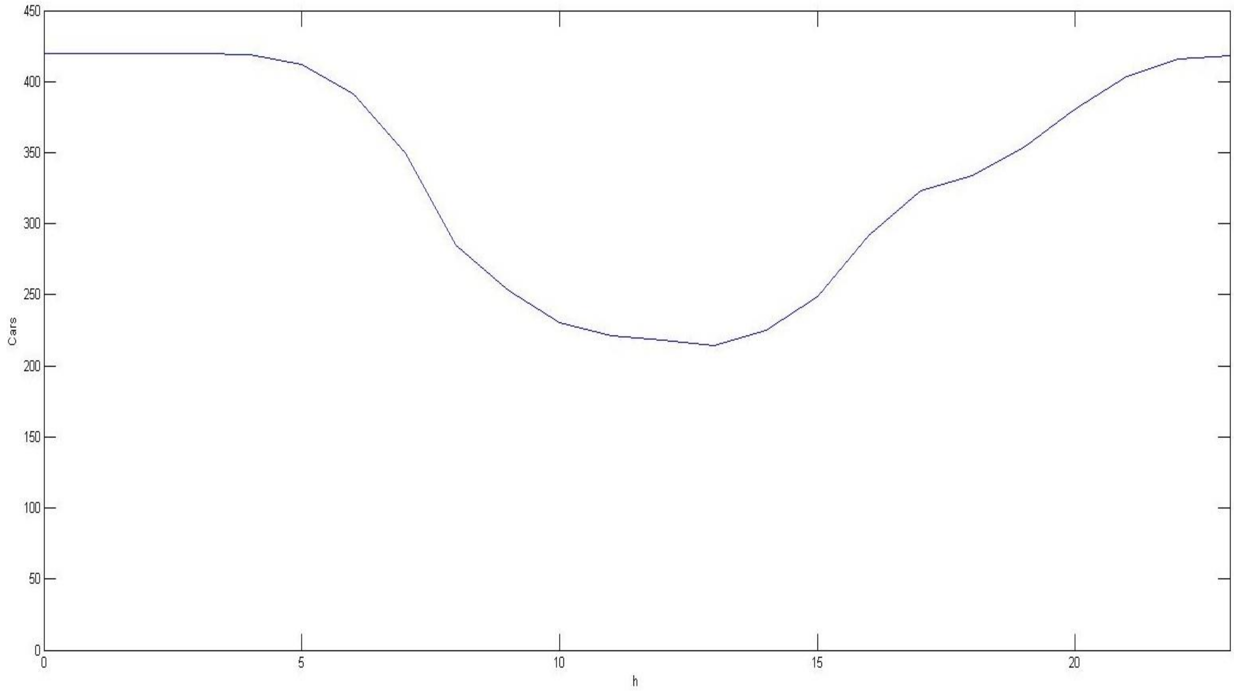

Figure 4.2 Number of cars in Pikisaari at average workday.

As seen in Figure 4.2, the amount of cars drops when people are leaving to work and rises back when they are coming back. It is assumed that there are 420 cars in Pikisaari.

In this thesis the goal is find out the saving potential when using price signal controlled charging. The saving potential is calculated by comparing the energy costs of uncontrolled charging and price signal controlled charging. Uncontrolled charging data is presented on Figure 4.3 with baseload (load without EVs` charging) of Pikisaari area (Ville Tikka & al.). To simplify, some assumptions are made when uncontrolled charging data is formed. Cars drive 50 km/d, consumption of energy is 0.2 kW/km and charging capacity is 3.6 kW/h.

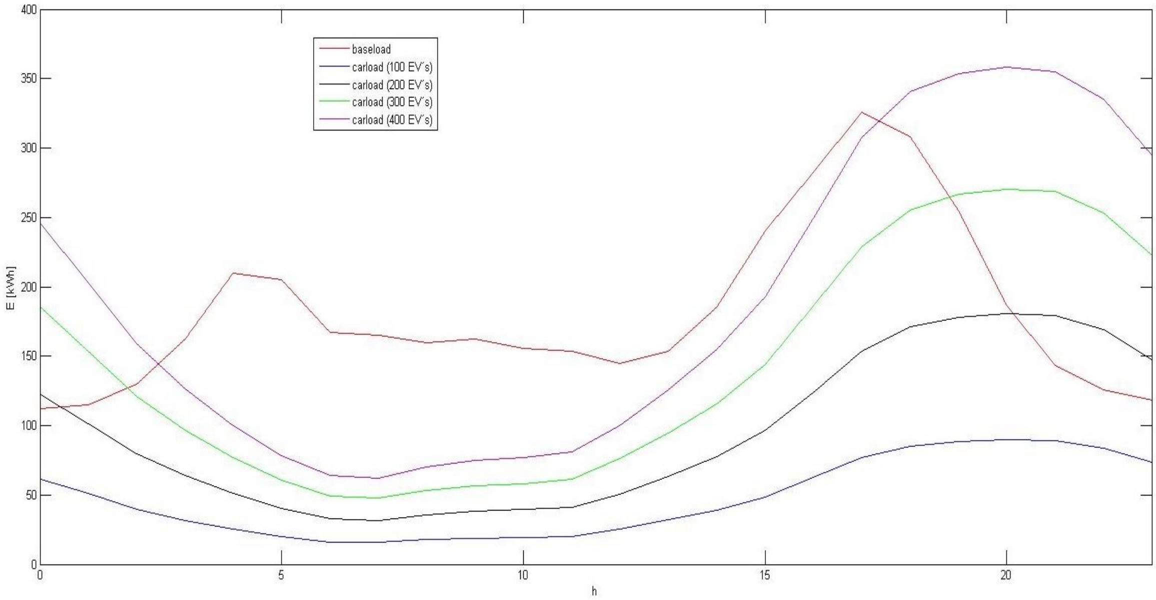

Figure 4.3 Uncontrolled charging of EVs and baseload of the case area.

In the Figure 4.3 is presented four different cases, which are used in the calculations. Only variable is amount of EVs which is 100, 200, 300 or 400.

5. SAVING POTENTIAL OF PRICE SIGNAL CONTROLLED CHARGING

This chapter demonstrates used methods, results and analysis. The goal is to find out what kind of saving potential there is when using price signal controlled charging in electric cars. This is done by comparing costs of price signal controlled charging and uncontrolled charging. The calculations are made by using Matlab-software.

5.1 Uncontrolled charging

Costs of uncontrolled charging (Figure 4.3) are calculated by multiplying the energy of uncontrolled charging by spot price. This is done hour by hour and the uncontrolled charging data is same at each day. Calculations are done for four different cases presented in Figure 4.3. Costs of uncontrolled charging are presented in Table 5.1 with costs of theoretical case when costs of charging are calculated by using 2010 average spot price.

Table 5.1 Costs of uncontrolled charging and costs of charging when using average spot price (2010).

Number of EVs	**Costs of uncontrolled charging [€]**	**Costs of charging when using average spot price [€]**
100	23200	23386
200	46500	46872
300	69754	70350
400	92500	93243

The uncontrolled charging costs less than charging with average spot price, meaning that great amount of uncontrolled charging happens outside of high spot price hours, for example during at night as shown in Figure 4.3.

5.2 Price signal controlled charging

Controlling EVs` charging with price signal means that charging is moved from high price hours to lower price hours. In order to simulate this, boundaries for reducing the charging need to be set. Boundaries are set by comparing 2010 spot price (Figure 4.1) to 2010 average spot price. To simplify calculations, cars are handled as an amount of energy. Hence, Matlab only uses data about how many EVs are in Pikisaari to calculate maximum power of charging by multiplying number of EVs by 3.6 kW power and the amount of energy which is moved from high price hours and the amount of energy that is charged in the case of uncontrolled charging (Figure 4.3). To simulate situation where customers may have different kind of controlled charging deals, three stages are set:

- If the spot price is under 65 €/MWh all cars are charging with 3.6 kW power if necessary.
- If the spot price is 65-75 €/MWh, 80 % of EVs stop charging. 90 % of EVs stop charging
- If the spot price is 75-85 €/MWh and if the spot price is higher than 85 €/MWh all EVs stop charging.

Calculations are also limited by the goal to get all cars charged before 4:00 AM. The calculation method is presented in Figure 5.1.

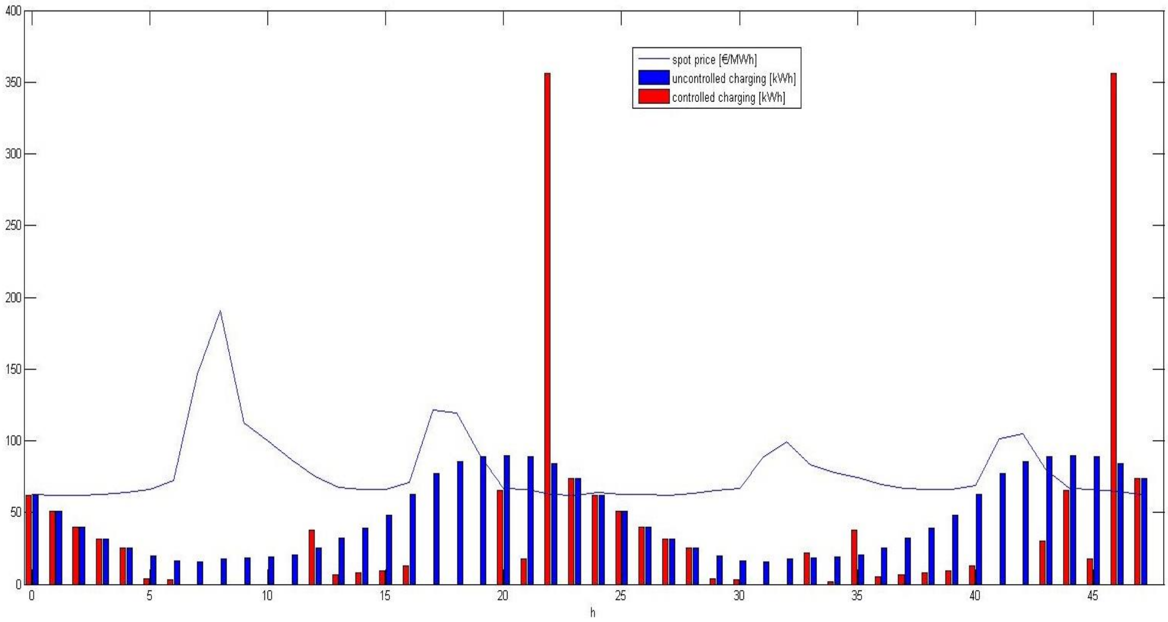

Figure 5.1 Presenting calculation method (spot price 14.-15.2.2010).

As seen in Figure 5.1 price signal controlled charging reduces or stops charging when spot price boundaries are exceeded. In this scenario price signal controlled charging cannot be used for the whole year because of uninterrupted period of high spot prices. During four periods 16.2-27.2, 4.3-7.3, 30.11-1.12 and 7.12-31.12, price signal controlled charging is changed to uncontrolled charging. This method´s costs and savings compared to uncontrolled charging are presented in Table 5.2.

Table 5.2 Costs and savings of price signal controlled charging (2010).

Number of EVs	**Costs of un-controlled charging [€]**	**Costs of price signal controlled charging [€]**	**Savings of price signal controlled charging [%]**	**Savings/EV [€]**
100	23200	22415	3.38	7.85
200	46500	44926	3.38	7.87
300	69754	67400	3.37	7.85
400	92500	89371	3.38	7.83

Savings are low, only 3.38 % when compared to uncontrolled charging. This is because of four periods when price signal controlled charging cannot be used. As seen in Figure 4.1 most of highest price peaks are inside of these periods. Other reason is that as mentioned before, high amount of EVs´ charging happens outside of the high price hours. In periods, where price signal controlled charging with parameters mentioned before is able to use, only 7.4 % of hours are above lowest boundary (65 €/MWh).

In order to use price signal controlled charging during the whole year, some modifications to calculation method need to be done. To simplify and because of high spot prices during problematic periods, only one boundary is set to each period. When spot price is above this limit, all EVs quit charging. Outside of these periods calculations are done same as before. To exploit price signal controlled charging effectively, different boundaries are set to each period. Boundaries are set by using average price signal of period if possible and by raising it from average spot price if all EVs do not have time to get charged before 4:00 AM. Boundaries of each period are presented in Table 5.3.

Table 5.3 Spot price boundaries of problematic periods.

Period	**Boundary [€]**
16.2-27.2	132.20
4.3-7.3	80.00
30.11-1.12	115.00
7.12-31.12	94.00

New calculations are made by using modified calculation method. Price signal controlled charging is used during 24 % of hours inside these periods. This method´s costs and savings when compared to uncontrolled charging are presented in Table 5.4.

Table 5.4 Costs and savings of modified price signal controlled charging (2010).

Number of EVs	**Costs of uncontrolled charging [€]**	**Costs of modified pricesignal controlled charging [€]**	**Savings of modified price signal controlled charging [%]**	**Savings/EV [€]**
100	23200	21669	6.60	15.31
200	46500	43431	6.60	15.35
300	69754	65164	6.58	15.30
400	92500	86396	6.60	15.26

With modifications price signal controlled charging is used throughout the year. This leads to higher saving percent 6.6 %, which is almost double compared to earlier case. This shows that it is possible to gain reasonable savings when using price signal controlled charging. Possible savings could be much higher if price boundaries are set individually day by day after spot prices are known. In this thesis calculations are based on 2010 spot prices, which are exceptional when compared to past 5 years. Average spot price is higher and there is more high price peaks than on the other years. In those years savings could be lower. In reality, EV owners might want to charge their EVs at different times possible during high price hours, which also decrease possible saving. Rising saving percent is plausible by lowering boundaries and modifying them day by day.

6. CONCLUSION

In this thesis the goal was to find out if there is any saving potential when using price signal controlled charging to charge electric vehicles instead of uncontrolled charging. Calculations were made by comparing costs of uncontrolled charging to costs of price signal controlled charging by using Matlab-software.

According to results it is possible to gain reasonable savings (6.60 %) by using price signal controlled charging. Amount of savings is dependent on amount of spot price peaks, level and duration of those peaks and possibility to control charging of EVs. Simplifications used in this thesis might have decreasing effect to possible savings. By modifying price signal boundaries, higher saving percent can be plausible.

Savings per EV were low (15.30 €) even calculations based on 2010 spot prices, which should been good year to gain saving because of its high average spot price and large amount of high price peaks. Possibility to profitably exploit price signal controlled charging depends on number of EVs and costs of building the system. In Finland, distributors and retailers of electricity are not the same companies. And as the grids are managed by distributors, it is probable that smart charging is planned from their point of view which could lead to lower savings.

Currently it seems that the possible saving gain by using price signal controlled charging could be significant but calculations needs to be done by using data from several years. In order to use price signal controlled charging in practice it is necessary to solve the effects of different price boundaries and the utility of price signal controlled charging from electricity distributors point of view. The script developed in this thesis could be used to calculate savings from other years.

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