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Effects of electric vehicles charging on the power system

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1 Introduction

Oil is very important for transportation vehicles today, but the availability of oil reserves and transportation fuels will become a problem in the future, since oil reserves are constantly decreasing and transportation fuels cause greenhouse gas emissions. One possible solution to this problem in the future is the use of electric vehicles (EVs). However, large scale use of different EVs has an effect on distribution systems, as they are plugged in for charging to the already loaded grid. Smart charging of EVs can offer a possible solution by controlling charging operations during suitable time.

2 Oil reserves

According to the International Energy Agency (IEA), the global share of oil consumption used by road traffic was 95 % in 2009. According to the “New Policies Scenario”, traditional oil production will be more difficult in the future. Oil fields currently in production will not be enough in the future. They will only account for 15 % in year 2035. This causes uncertainty and pressure for the oil price as well as a possible increase in the price in the future. Figure 1 describes the different oil reserves and changes up to year 2035. [1].

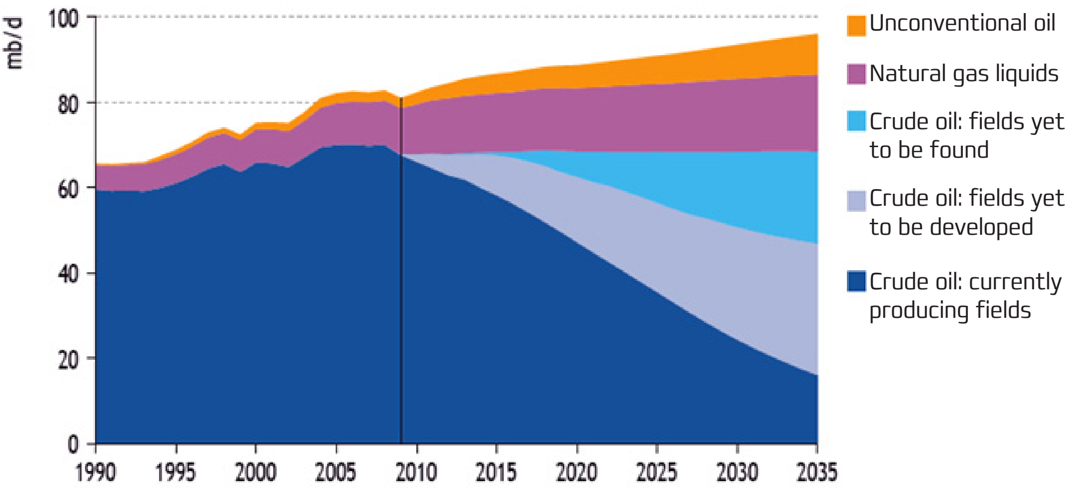
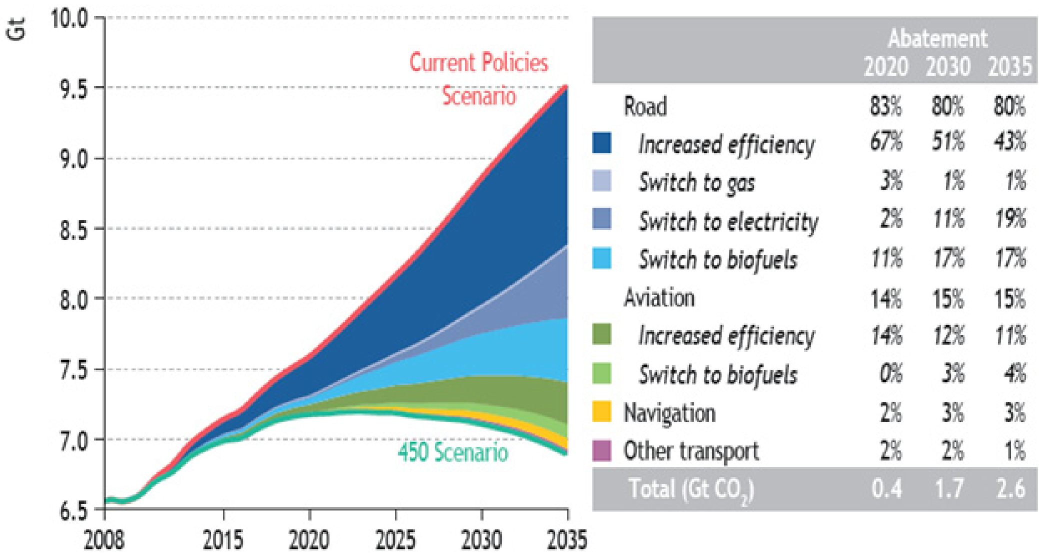


Figure 1. *Oil reserves up to 2035 according to World Energy Outlook (WEO) [1].*

2.1 REDUCING OF GREENHOUSE GAS EMISSIONS

As the oil reserves are decreasing, other sources of electric energy, such as wind energy, biomass and other renewable energy sources, increase their popularity, as stated by the WEO. However, greenhouse gas emissions will not automatically be reduced when replacing oil with electricity in transportation. The best way to reduce greenhouse gas emissions is to improve energy efficiency and the saving of energy. By using nuclear energy or renewable energy (hydropower, wind energy, solar energy, biomass) for reducing greenhouse gas emissions, it is possible to achieve remarkable results. By using electric vehicles in Finland and in Nordic countries, it is possible to reduce greenhouse gas emissions remarkably because of the form of electricity production. Figure 2 shows how different operations affect the reduction of greenhouse gas emissions in transportation. [1].



	Abatement 2020	2030	2035
Road	83%	80%	80%
Increased efficiency	67%	51%	43%
Switch to gas	3%	1%	1%
Switch to electricity	2%	11%	19%
Switch to biofuels	11%	17%	17%
Aviation	14%	15%	15%
Increased efficiency	14%	12%	11%
Switch to biofuels	0%	3%	4%
Navigation	2%	3%	3%
Other transport	2%	2%	1%
Total (Gt CO_2)	0.4	1.7	2.6

Figure 2. *IEA 450 scenario shows how different operations affect greenhouse gas emis¬sions in transportation [1].*

Figure 2 shows that 80 to 83 % of greenhouse gas emissions are caused by transportation. The increased efficiency of EVs can affect the percentage rising up to 24 % by year 2035 and the electrification of transportation will overtake biofuel by 2030. The reduction of greenhouse gas emissions to about 80 % by year 2050 means that the majority of all cars must be electric. On global scale, this means a remarkable changing of electricity production forms compared to present. [1].

3 Electric vehicles

Electric vehicle (EV) categories include Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). PHEVs are divided into three categories as seen in the next figure. [1].

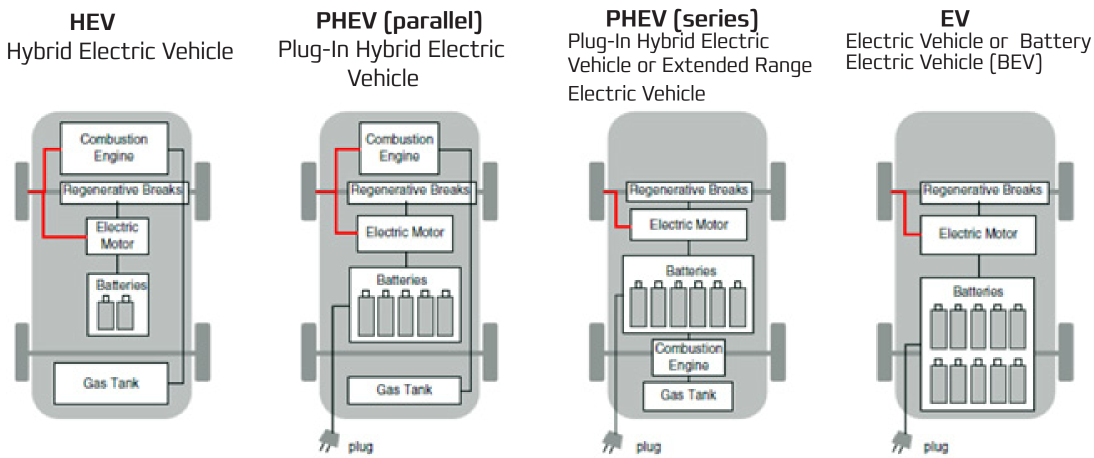


Figure 3. *Different categories of electric vehicles [1].*

The basic difference between HEVs and PHEVs is that PHEVs can be charged with an external electricity source, which is not possible for HEVs. In parallel PHEVs, the engine and the motor are connected to the drive train. In series PHEVs, the generator produces electricity and charges the battery or runs the electric motor, but the engine is not connected to the drive drain. [2].

3.1 BATTERY TECHNOLOGY

Batteries are very important components of EVs. The most essential characteristics of batteries include energy density, capability for fast charging, life cycle, and the ratio between power and energy. Battery technologies develop constantly and batteries are becoming cheaper, so a longer all-electric range in PHEVs and FEVs is more possible. Nowadays, lithium-ion (Li-ion) batteries are very efficient, about 95 % of electricity storage. The efficiency of a good charger is about 95 % and a good motor average over 90 %. Braking energy is partially recovered by using the motor as a generator. [2]. The next table shows the typical characteristic of different battery types [1].

Table 1. *Characteristics of different battery types according to European Batteries (EB). For relative safety and relative environmental effect, number one is the best and number four is the worst. [1].*

	Lead Acid	NiCd	NiMH	Li-ion LiCoO2	Li-ion LiFePO4
Battery/back specific energy, Wh/kg	30-50	45-80	60-110	110-200	100-180
Cycles	200-300	1500	300-500	500-1000	3000+
Charge time, hr	2-5	1	2-3	1-3	1-2
Self discharge/mo, %	5	20	30	3	2
Avg operating Voltage	2	1,2	1,2	3,6	3,2
Relative battery/pack cost	1X	3-4X	3-4X	4-5X	3-4X
Relative safety	2	1	1	4	1
Relative environmental	3	4	2	2	1

Table shows that all ranges of Li-ion batteries are better compared to the traditional lead acid battery. In comparison, Li-ion batteries are 3-5 times more expensive [1].

3.2 DIFFERENT CHARGING METHODS

Charging of EVs must view at least on next levels as electric vehicle, charging place, service level and the easiness of charging, electric network and its different parts, energy production and the electricity market [1]. Mainly, the charging infrastructure and battery properties set limits to the charging of EVs; how much charging power can the EVs/batteries withstand without harmful effects and household wirings can limit the charging power because of a limited current. Typically, many parking spaces in the Nordic countries have electric outlets for the pre-warming of car engines before use, so they could be used for the charging of EVs. Typical charging methods for batteries include normal charging, fast charging and ultra-fast charging (Fig. 4). [2].

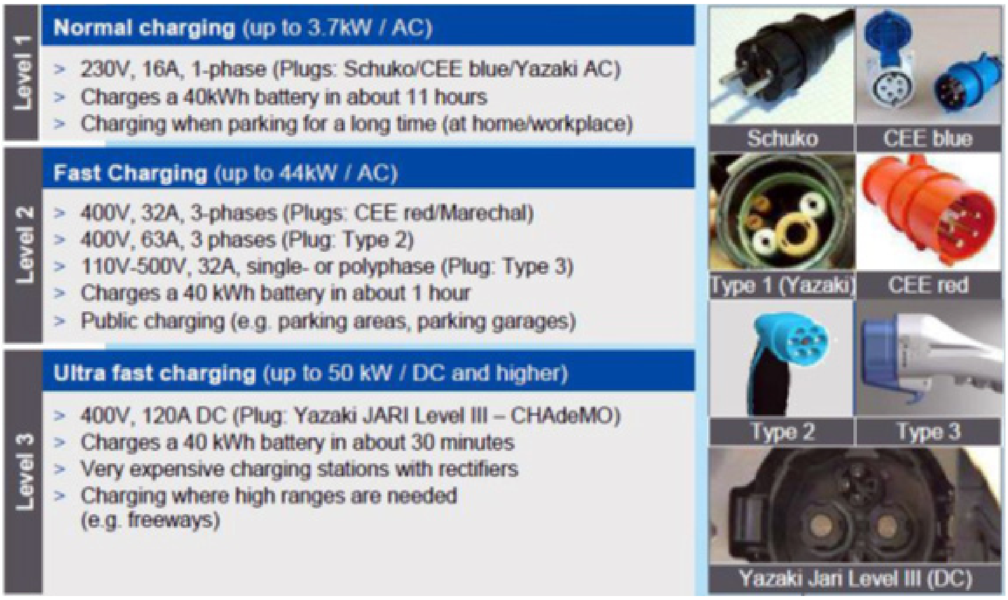


Figure 4. *Different charging methods and plug types for EVs according to RWE Electro-Mobility [1].*

Normal charging is a typical method at home and in the workplace. If EVs start to become more common, normal charging is commonly used first [1]. When the requirement of charging rises from normal to fast charging, it is no longer possible in residential buildings because too much power is needed in a short time. Therefore, parking areas and parking garages could be possible charging places for public charging. The ultra-fast charging needs very expensive charging stations with rectifiers. [2].

4 Impact on the power system

The impact of the charging of EVs on the power system depends on the extent of the use of different EVs in the future. The electricity consumption of EVs is about 0.15-0.3 kWh/km. This means that lower level consumption EVs have the properties of low speed, light weight and aerodynamics. Higher level consumption EVs are bigger cars which are more driven too in exacting circumstances. If an average consumption is about 0.2 kWh/km, the consumption of EVs according to fast scenario will be in total about 0.6 TWh in 2020 (0.2 million cars) and about 3.9 TWh in 2030 (1.23 million cars), assuming that 80 % of the kilometres driven are covered by electricity. [3]. However, an exact prediction is impossible, since the speed of change depends on the cost of competitiveness of the cars, performances of the batteries and lithium mining, since the start of new mining operations takes many years [2].

4.1 PEAK LOAD SITUATION IN NORDIC COUNTRIES

It is possible to describe the influence of the charging of EVs on the power system by using the Nordel simultaneous peak load week (16.-22 January 2006). The peak load on 20th January 2006 between 8 am and 9 am (Scandinavian time) was 67.8 GW. All EVs are assumed to use slow charging of max. 12 A, 220 V, without heating or air-conditioning. Figure 5 shows the increase of annual electricity consumption by 14 TWh, or 15 TWh with the transmission system losses, assuming a half of all personal vehicles in Nordic countries were EVs. [2].

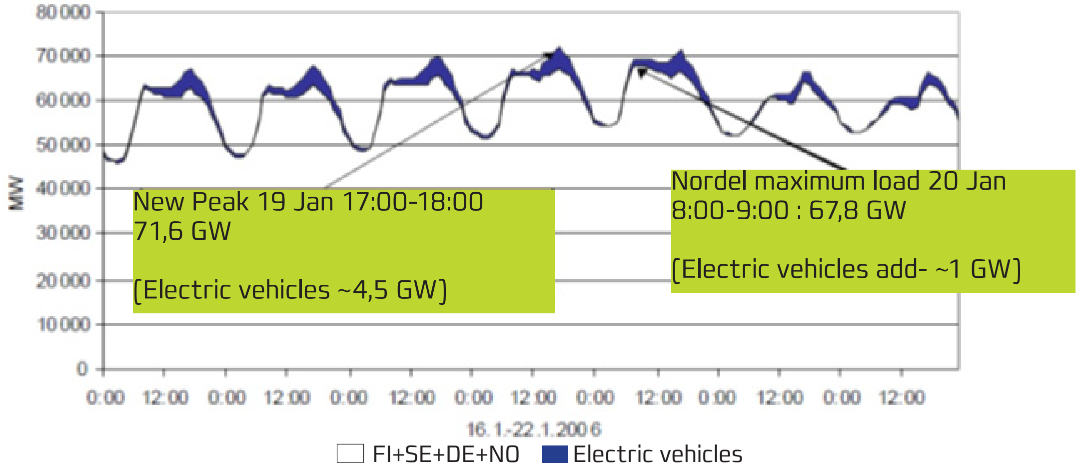


Figure 5. *The effect of five million EVs in the Nordic countries (Nordel system) are charging as soon as possible as the vehicles are plugged in [3].*

Figure 5 shows how peak load moves from Friday morning between 8 am and 9 am to Thursday evening between 5 pm and 6 pm and increases from 67.8 GW to 71.6 GW with five million EVs as normal (slow) charging typically at home or in the workplace. Without the charging of EVs, the Thursday evening load decreases with ~ 4.5 GW. [2].

4.2 SMART CHARGING

Smart charging of EVs can offer relief to the peak load situation because of charging control during the hours when the electricity is cheaper and/or the demand is the lowest. However, the difference between day and night electricity is quite small on the Nordic market (Nord Pool), so the financial advantage is rather insignificant for an individual EV owner, some dozens of euros per year. Figure 6 shows how smart charging of EVs decreases the peak load, assuming a half of all personal vehicles in Nordic countries were EVs. The results are based on a simple algorithm. [2].

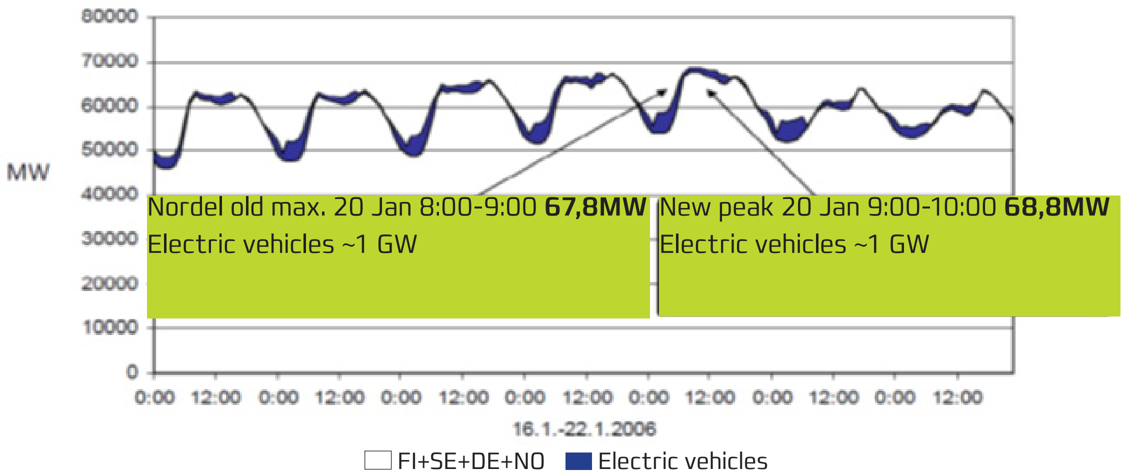


Figure 6. *The effect of five million EVs in the Nordic countries (Nordel system) are smart charging [3].*

In Figure 6, evening charging between 4 pm and 11 pm are moved in time when the electricity is cheaper, at night between 12 am and 7 am. In this case, peak load moves from Friday morning between 8 am and 9 am to 9 am - 10 am, i.e. only one hour, and EVs increases new peak load ~ 1 GW, so the new peak load is 68.8 GW. The peak load decreases about 2.8 GW, less than 2 %, because of smart charging. With smart charging, because EV owners are assumed to be able to override the postponement, only 90 % of evening hour loads are moved later. Night time loads are limited to the maximum defined by the maximum load from the previous day, assuming that smart loads are no worse for the system. In this case, there are no rules between 7 am and 4 pm. Rules in Finland follow the Finnish time and in Scandinavia the Scandinavian time. [2].

With smart charging, controlling of charging behavior according to the electricity price indicator, e.g. spot price, could be possible. Controlling charging by real time price signals using two-way communication is not a problem. However, charging at night is not necessary, if the power system consists of large amounts of variable production, such as wind power. In this case, charging could take place accordingly within the limits of plug-in periods and the user's needs. The power system balance between production and consumption at all times has to be taken into account and the role of EVs could be very important due to reserve production, e.g. if a transmission line suddenly goes down or more production is needed because of power system imbalance. However, at up regulation times EVs charging could be get down or stopped. A useful benefit of EVs could be the discharging capability, e.g. during disruptions or at times when power prices are at a very high level. The benefits of EVs could offer support in case of blackouts in the local or residential micro-grid or in case of high peak loads. [2].

5 Conclusion

The speed of the spread of different EVs depends on many circumstances, such as how fast battery technologies improve and batteries become cheaper, different driving patterns of EV owners, and changes in the oil price and the impacts of greenhouse gas emissions. Maybe electric vehicles become more popular when battery technologies make it possible to drive longer distances than nowadays. However, these scenarios depend on many facts, and whether the different types of EVs really become common without an advanced charging technology such as smart charging are dependent on many issues. Figures 5 and 6 show that the peak load could be bigger without smart charging and cause problems mainly to the local network, if five million EVs in the Nordic countries are charging as soon as possible as the vehicles are plugged in. In this case, some strengthening operations at the distribution network level are needed or otherwise it could result in system overload. With smart charging, the role of EVs could be reserve production and support, e.g. in case of malfunctions or power system imbalance. Furthermore, it is important to consider that typically, network companies transfer investment costs as strengthening costs to customer prices and thus, electricity becomes more expensive. Otherwise, smart charging as a part of the smart grid technology could be a very interesting alternative in the future.

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Oil is very important fuel for transportation vehicles, but oil reserves are decreasing in the future. Furthermore, transportation fuel causes greenhouse gas emissions, so renewable energy sources are needed. Using of Electric Vehicles (EVs) offers one solution for this problem. Remarkable reducing of greenhouse gas emissions in the world level require that the majority of all cars should be electric cars. Large-scale charging of different EVs cause problems on power system peak load and charging methods are very important part of solving this problem. Advanced charging technologies such as smart charging could be an interesting method to control EVs charging during hours when electricity is cheaper and/or demand is lowest.

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