# CHARGING TECHNOLOGIES AND ITS FUTURE DEVELOPMENT OF ELECTRIC VEHICLES

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Degree Programme in Automation Engineering

Valkeakoski, Spring 2017

Anton Frolov

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES



Automation Engineering
Valkeakoski

| | | |
|---|---|---|
| **Author** | Anton Frolov | **Year** 2017 |
| **Subject** | Electric vehicle charging technologies and its future development | |
| **Supervisor(s)** | Katariina Penttilä | |

ABSTRACT

The main goal of this thesis was to design an automated charging station for electric vehicles. Easy and convenient charging can solve the range anxiety issue - worry that a car's battery is depleted before reaching the desired charging point.

The first part of the thesis examines the history and types of electric cars. The next part is a study about future plans of different car manufacturers including start-ups and major corporations as well as governmental plans of different countries. The final part contains the design description of an automated charging station with information about its possible users and customers.

As an outcome of the project, it can be stated that technologies are already advanced enough to actually take the designed charging station into use in real life with some small exceptions about fully autonomous cars.

**Keywords** Electric vehicles, EVs, charging, automated charging station.

**Pages** 27 pages

CONTENTS

# 1 INTRODUCTION

## 1.1 Objective of thesis

Electric Vehicles hereinafter referred to as EV, are one of the fastest growing parts of the car market. A lot of existing car manufacturers, as well as some start-ups, are spending a great amount of money on research and development of EVs.

It is impossible to imagine Earth's green future without zero-emission cars. Electric vehicles in their great variety of forms are exactly what will be used everywhere soon.

However, not everything is that good about electric cars nowadays. Unfortunately, EVs still cannot deliver the same level of usability compared to conventional cars that are widely used now. One of the reasons is that modern technologies still cannot provide a good maximum range for electric cars. So, possible EVs buyers can suffer from the so-called range anxiety. "[Range anxiety is a] worry on the part of the person driving an electric car that the battery will run out of power before the destination or a suitable charging point is reached." (English Oxford Living Dictionaries, n.d.)

The target of this thesis was to provide a concept design for a modern automated charging station that will be easy to use and will help future EVs buyers to eliminate potential range anxiety. My thinking in this project was influenced by the extensive reading of the literature in the field.

## 1.2 History of electric cars

### 1.2.1 19th century

EVs were invented even earlier than the traditional Internal Combustion Engine cars, hereinafter referred to as ICE cars. The first ever working prototype was created in 1828 by Ányos Jedlik, a Hungarian who invented the very early type of electric motor. However, first practical EV was built only after the invention of rechargeable lead-acid battery in 1881. In 1899 Baker Electric was the first production EV in the history. Also in 1899 Hyppolyte Romanov, Russian inventor and engineer created first fully electrical bus with 17 seats. It was built using the same type as horse-powered carriage where the driver's seat was on top behind the passengers. The bus could do 64 km on one charge with a maximum speed of 37.4 km/h. Unfortunately, H. Romanov could not find investors so he switched to the other parts of Electrical Engineering.

During the April/May in 1899, EV La Jamais Contente broke the max speed record of 100 km/h even earlier than ICE cars. Famous American inventor Walter Baker later built an EV with a top speed of 130 km/h. Also, Borland Electric EV did a journey from Chicago to Milwaukee (167 km) on one charge, and after the charging, it drove back with an average speed of 55 km/h.

### 1.2.2 1st half of the 20th century

Originally maximum range of EV and ICE cars was approximately the same. The biggest disadvantage of EV was complicated charging system – it used an electric motor powered by AC current to generate electricity for car batteries. The invention of an easy-to-use electrical rectifier in 1906 did not completely solve this problem. That's why steam powered cars were very popular – almost half of the cars in the USA in 1900 were steam powered.

### 1.2.3 2nd half of the 20th century

The rrevival of interest for EV occurred in the 1960s due to ecological problems and in 1970s after the energy crisis and rise of the gas prices.

However, after 1982, interest in EV fell again. It was caused by a rapid change in the oil market conditions and weak performance of current EVs due to shortcomings of existed chemical energy sources.

In 1990s California was the most air-polluted region in the US, so California Air Resources Board (CARB) made a law that 2% of all cars sold in California by 1998 and 10% by 2003 should have zero emissions. General Motors started producing model EV1 as well as few other car manufacturers started their own sales. The main mass of EV1 buyers was the Hollywood bohemian audience.

In total, up to 5500 EVs were sold in California by the year 2002. Later zero emissions restriction was replaced by low-emissions one, so almost all EVs were confiscated and destroyed by manufacturers. They even refused to leave some of them for those who wanted to buy them after the lease period. (Deeter, 2006)

### 1.2.4 21st century

During the last few years gas prices are going high again, so EVs are becoming more and more popular again.

In 2008, Tesla Motors started production of Tesla Roadster – first EV that was not inferior in driving performance (acceleration dynamics and maximum speed) to conventional ICE cars.

On 22-23rd of May 2010, Daihatsu Mira EV (ICE car converted to EV by a local Japan EV Club) made 1003,184 km on one charge.

Later, on 24th of August 2010, EV Ventura Jamais Contente set the EV max speed record to a 495 km/h on a 1 km distance.

On 27 of October 2010, EV *lekker Mobil* converted from conventional Audi A2, made a record-breaking trip from Munchen to Berlin (605 km) using public roads and having all necessary systems such as heating, lights etc. working. The car was built by *lekker Energie* using the LiPo battery Kolibri by DBM Energy. The battery had 115 kWh stored, which allowed completing the whole trip with an average speed of 90 km/h (max speed was 130 km/h) and it had 18% of charge left after the finish.

EV Nissan Leaf won the European Car of the Year award in 2010. More than 250,000 cars were sold by end of 2016.

In January 2017 EV Rimac Concept_One won a drag race against one of the fastest production ICE vehicles Bugatti Veyron.

# 2 CURRENT STATUS OF ELECTRIC VEHICLES

## 2.1 Types

### 2.1.1 Rechargeable battery

Rechargeable batteries are the most common type of EV. They were used since the end of XIX century. The basic scheme of the rechargeable EV is generally the following: the battery connected to the electric motor through the power wiring and control system. Electric motor transfers the torque to the main gear using the universal shaft. Sometimes electric motor can be installed directly into the wheel.

Car characteristics mostly depend on battery type – total range is directly proportional to the ratio of the battery weight to the total car weight.

Batteries are mostly located on the bottom of the car, in easy access places – for faster maintenance or battery change.

### 2.1.2 Fuel cell

A fuel cell (FC) vehicle is a type of EV which uses a fuel cell to power its motor. All fuel cells consist of 3 parts: an electrolyte, an anode, a cathode. A hydrogen FC works as a battery, producing electricity to run an electric motor. The fuel cell can be easily refilled with hydrogen instead of charging.

The main characteristic feature of EVs using fuel cells is that the mass of power system does not change with a change in its capacity, thus range increase can be achieved by increasing the mass of fuel in the fuel tanks.

On the one hand, a fuel cell can greatly increase EV's maximum range, but on the other hand, fuel has a high cost and can be toxic and harmful for the environment while produced.

Each fuel cell works as a compact reactor that generates electricity by chemical reaction. Hydrogen inside the fuel cells contacts with the electrode (its platinum covering surface). Following reaction is the fission of hydrogen atoms into protons and electrons. Electric current is just a flow of electrons, so electrode is used to get the electricity from that fuel cell. Protons, however, without leaving the fuel cell move to the second electrode through the so-called proton-exchange membrane, performing the functions of the electrolyte. It is made of a polymer that allows protons to penetrate it, but blocking the access of electrons. The second electrode (also a platinum-coated plate) is located on the opposite end of the electrical circuit through which electrons run, so protons and electrons are again connected to it. They cannot connect by themselves, you need to add oxygen to the second electrode, so then negatively charged atoms connect with positively charged hydrogen protons. And this chemical reaction leads to the formation of inoffensive exhaust – just water. Water is so clean, that human can actually drink it – Chevrolet and US Army created a hydrogen vehicle that can be used in combat, but in a case of water shortage, they can collect up to 7,5 liters of water every hour. (Auto Vesti, 2015) (Stewart, 2016)

### 2.1.3 Hybrid vehicles

In the end of 60s first EVs with a combined power system were developed. In Great Britain EV based on DAF 44 was built – it had combined power system using batteries and fuel cells. During the acceleration power system used batteries, but for all other modes fuel cells were used, they also were charging the battery.

In the USA one of the earliest combined type EV was made by conversion of conventional Austin A-40. Maximum range was exceeding 300 km.

Nowadays, combined fuel type cars are called hybrids. Hybrid Electric Vehicle (HEV) uses the combination of conventional ICE and electric drivetrain. Current hybrid cars can be differentiated by the hybrid system type, fuel type and the mode of operation. Gasoline engines are the most popular type for hybrids, but there are some diesel engine hybrids as well as some biofuels.

Car manufacturers can use the hybrid system for two different purposes – increase fuel economy or increase performance. Considering the first option, the most known hybrid car is Toyota Prius (it is also the world’s best-selling hybrid). Current HEVs are using all existing modern technologies that can increase efficiency. Such as regenerative brakes (converts kinetic energy into electric energy when braking, not just wasting it into heat), the start-stop system (stops the ICE at idle when electric motor only is enough) etc.

The second way to develop hybrids is to increase performance. Such systems are used in a modern super and hypercars as well as some other everyday cars. For example, in McLaren P1 electric motor boosts propulsion, fill in gaps in torque in order to keep car’s performance at the maximum possible level. The same system is used in a world’s fastest racing cars – Formula One (it’s called KERS there). McLaren competitor Ferrari used 2 electric motors – one for the wheels and second for its electric system. Plus, all the batteries located on the floor. It resulted not only in additional 60 kilograms but also in a power increase of 163 horsepower. Third hypercar’s manufacturer Porsche used almost the same system but also allowing their 918 Spyder to go up to 20 kilometers in a fully electric mode (it can also help the car to enter some city centers where only electric cars are allowed, for example in Freiburg, Germany). (Okulski, 2013)

Of course, not only supercars are using latest technologies in hybrid systems. Most of the HEVs nowadays and plug-in hybrids, it means that they can be connected to an external power source to charge its batteries. A plug-in hybrid has pros and cons of both electric and conventional ICE cars. It still needs to be filled with gas and in addition should be charged. But that system combined provides a way better fuel economy and lacks so-called “range anxiety” because car’s ICE works as a backup power source when batteries are depleted.

Modern hybrids vehicles that can be seen on the streets include Toyota Prius, Honda Insight, Ford Fusion Hybrid, Volkswagen Jetta Hybrid and first ever hybrid that was mass-produced in Europe, Toyota Auris Hybrid.

More than 12 million hybrid EVs were sold worldwide by January 2017. Japan was named as the market leader with total sales of over 5 million hybrids. The USA comes second with more than 4 million units sold. Europe is not too advanced in hybrids – only 1,5 million cars sold in total.

#### 2.1.4 Other

There are a lot of different solar-powered cars, powered only by solar energy. Its main disadvantage is solar panels low efficiency (10-15% only), while the most advanced developments can have up to 30% efficiency. However, it is still too low, compared to normal electric motor and battery which can have up to 96,5% and 99% respectively. Also, solar panels are useless during the night or bad weather (and almost completely useless in some regions). The second big disadvantage is solar panel's high cost.

The most efficient solar car called SolarWorld GT – it has 2 wheel-motors (total 11,4 total horsepower). Thanks to extremely low weight (260 kg) it has a range of 275 km and max speed of 120 km/h.

There is a Trans-Australian rally "World Solar Challenge", where teams are mostly formed by engineering students, doing it as their Thesis project.

### 2.2 **Manufacturing and usage**

#### 2.2.1 Manufacturing process

EV's manufacturing process requires as much design consideration as the vehicle itself – that design includes modern high-end approaches as well as some simplifications where possible. The EV's assemblers work in build-in station teams, while all needed parts are stored on special modular racks, where it is easier to find correct part to use. However, assemblers also use high-tech tools – only one torque wrench with different heads, where computer decides itself the correct torque setting.

EV's body is made the same way as in the manufacturing of conventional ICE cars. First, separate parts of the car are prepared for welding – engine compartment, front floor, rear floor, side and the bottom of the body. Then the automated robot forms the body. After geometry is formed, the roof is installed on the other bodywork. This is mostly done using a video system. Possible errors are displayed on monitors, and this helps to correct the work.

After the body is ready it is time to start putting correct electronics there. EVs have more wires to fit than ICE cars. Electronics part includes body wiring, propulsion control module, motors, integrated drive unit etc.

Next step is interior that includes flooring, carpets, seats, front dashboard. These parts are the same as used in normal cars. During interior install, air conditioning and heating are also mounted on a car.

The following step is to install batteries and later suspension with axles and wheels. Batteries in modern EVs are mostly located under the floor – to lower the center of gravity and increase car's safety. After that step car can move using its own power.

Finally, all other components are installed, such as windows, previously assembled doors, remaining exterior panels. After this step car is going to be completely checked and test-driven to make sure that everything has been done correctly.

Of course, the order of these steps can change from manufacturer to manufacturer, but the main concept remains the same.

### 2.2.2 Possible additional usage of electric cars

There is a concept called Vehicle-to-Home which is created to integrate EVs and living homes. For example, old batteries can easily work as portable power supplies. While connected together and equipped with a power inverter, 5 to 10 batteries from Chevrolet Volt can supply electricity for several houses during the emergency blackout.

CHAdeMO charging standard also allows using a car as a charger. So, connected for charging EV can actually work as an emergency power supply.

## 2.3 **Batteries**

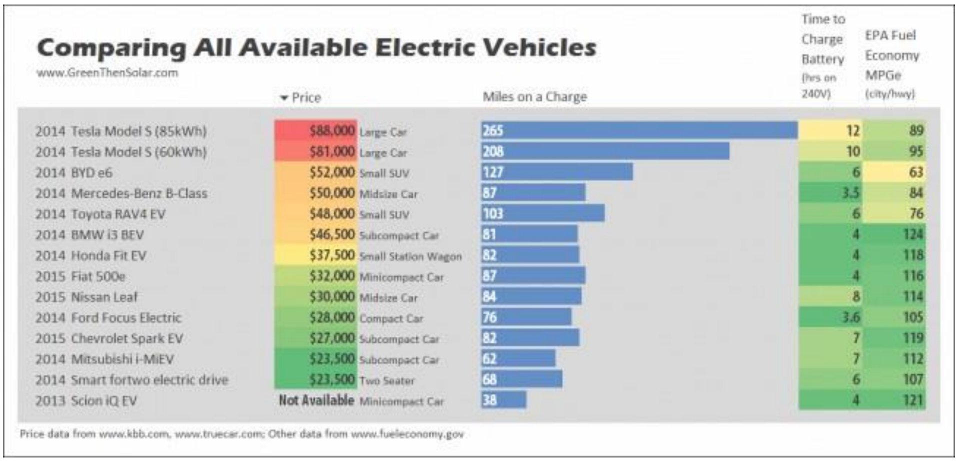
Most current EV designs use Lithium-ion and other lithium-based batteries, but there are a number of different variants that are used. Lithium-based batteries are well known for its high power and energy density, but they also have a very limited cycle lifetime. Different variants like Lithium-iron-phosphate or Lithium-titanate batteries try to increase its durability compared to traditional Lithium-ion ones.

Another type is lead acid batteries, which a still used in conventional cars to power on-board electric system. The initial costs can be significantly lower than Lithium-based batteries, but power-to-weight ratio is way lower. Nickel metal hydride (NiMH) are heavier and not that efficient as Lithium-ion, but they are also more inexpensive.

There are few other types of battery chemistries in development, for example, zinc-air that will be lighter than Lithium-ion. Chemists are also developing liquid type batteries, that can be refilled almost instantly, without spending any time to charge it. (Battery Universe, 2016)

### 2.3.1 Range

Maximum EV range depends on type and size of batteries that are used. The weight and type of vehicle also affect the maximum range, just as they do on the conventional ICE vehicles. The range can also be reduced while using a car in a cold weather. Figure 1 shows the approximate range of different electric vehicles.


Comparing All Available Electric Vehicles
www.GreenThenSolar.com

| | Price | | Miles on a Charge | Time to Charge Battery (hrs on 240V) | EPA Fuel Economy MPGe (city/hwy) |
|---|---|---|---|---|---|
| 2014 Tesla Model S (85kWh) | $88,000 | Large Car | 265 | 12 | 89 |
| 2014 Tesla Model S (60kWh) | $81,000 | Large Car | 208 | 10 | 95 |
| 2014 BYD e6 | $52,000 | Small SUV | 127 | 6 | 63 |
| 2014 Mercedes-Benz B-Class | $50,000 | Midsize Car | 87 | 3.5 | 84 |
| 2014 Toyota RAV4 EV | $48,000 | Small SUV | 103 | 6 | 76 |
| 2014 BMW i3 BEV | $46,500 | Subcompact Car | 81 | 4 | 124 |
| 2014 Honda Fit EV | $37,500 | Small Station Wagon | 82 | 4 | 118 |
| 2015 Fiat 500e | $32,000 | Minicompact Car | 87 | 4 | 116 |
| 2015 Nissan Leaf | $30,000 | Midsize Car | 84 | 8 | 114 |
| 2014 Ford Focus Electric | $28,000 | Compact Car | 76 | 3.6 | 105 |
| 2015 Chevrolet Spark EV | $27,000 | Subcompact Car | 82 | 7 | 119 |
| 2014 Mitsubishi i-MiEV | $23,500 | Subcompact Car | 62 | 7 | 112 |
| 2014 Smart fortwo electric drive | $23,500 | Two Seater | 68 | 6 | 107 |
| 2013 Scion iQ EV | Not Available | Minicompact Car | 38 | 4 | 121 |

Price data from www.kbb.com, www.truecar.com; Other data from www.fueleconomy.gov

Figure 1. The range of electric vehicles (Stobing, 2016).

Tesla Roadster has a maximum range of 394 km on one charge. Tesla Model S can do up to 426 km with 85 kWh battery. Nissan Leaf (most selling EV) has a range of 172 km, using the 30-kWh battery. Low-range urban EVs like Volkswagen XL1 or Renault Twizy can do up to 100 km with a 5-6 kWh battery. According to the study made by California Center for Sustainable Energy that is shown in Figure 2, 50% of drivers are doing only 25 to 50 kilometers per day, while 32% of respondents marked 160 to 240 kilometers as the desired range of an EV. (Berman, 2013)

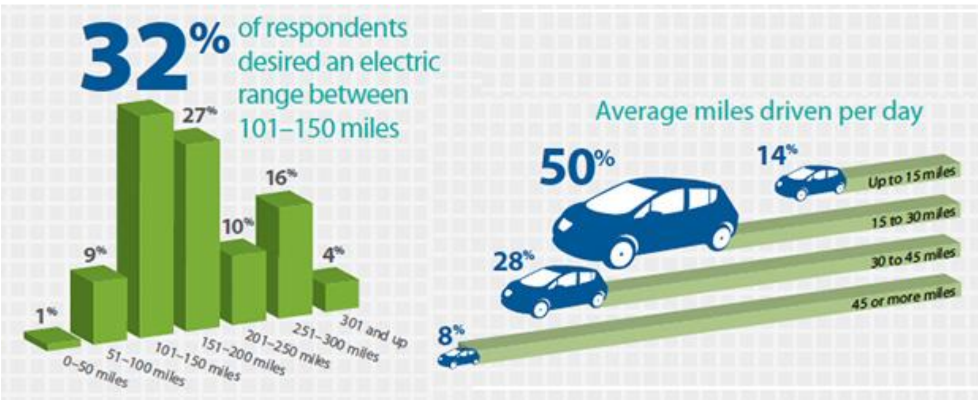



Figure 2. A survey made by *California Center for Sustainable Energy*. (The California Center for Sustainable Energy, 2013)

Every EV nowadays has an expected range display. Those displays consider almost every factor that affects maximum range – battery charge, driving style, air conditioning system, sometimes even local traffic conditions. However, a lot of EV's drivers are still worried about getting to their destination without any problems. It is called range anxiety. All EVs manufacturers call it one of the most serious problems that can affect EVs sales.

### 2.3.2 Charging

Range anxiety is one of the reasons why EVs cannot be used without widely spread charging stations network. EVs have lesser maximum range on one charge than typical ICE vehicles, and they should spend considerable time to recharge. However, EVs can be charged at home at night – option not available for ICE vehicles. More than 70% of all daily drives in Europe and North America are less than 60 km per day.

As an example of home charging, Nissan Leaf and Tesla should be considered – Leaf has a 3.3 kW charger, while Tesla can accept 16.8 kW using its own High Power Wall Connector. Home charging is still slow compared to an average petrol/diesel pump, which has effective power delivery rate of 5000 kW.

Of course, there is a more rapid way to charge EVs – Fast Charging. For a long-distance travel, there are Fast Charging stations with high-speed charging capability using industrial three-phase outlets. They can charge most EVs to 80% in 30 minutes. It still requires more time compared to gas refill, but in practice, it works well – after few hours of driving, passengers can make 30 minutes stop for eating/drinking and resting, giving car enough time to be charged.

In December 2013, Estonia was the first country to deploy countrywide charging network, with fast chargers installed every 40 to 60 km along the main highways and higher density in urban areas. Mostly all EVs manufacturers have plans to cover great areas with their charging networks. Tesla has its own Superchargers network, giving its vehicles an additional 290 km in half an hour.

### 2.3.3 Range extenders

Some manufacturers offer different ways to extend car's range. For example, BMW has an option to install a built-in gasoline-powered extender engine for i3 model. Such cars are called plug-in hybrids, and they can eliminate the range anxiety concerns using additional ICE (usually, it is a small engine with a low fuel consumption).

There are 2 types of hybrids – parallel and series. Parallel hybrid, shown in Figure 3, has ICE and electrical engine that can both power the car individually or jointly if needed. While series hybrid can use ICE only for charging its battery, where ICE works as a generator. This structure can be seen in Figure 4. Such hybrids more commonly have bigger available range on battery only than parallel hybrids, whose full electric range can be almost nominal, like a 50 km on a Chevrolet Volt (also known as Opel Ampera in Europe) or 18 km for a Toyota Prius. While series hybrids can do more than 150 km, BMW i3 does up to 200 km. (Colin, 2014)

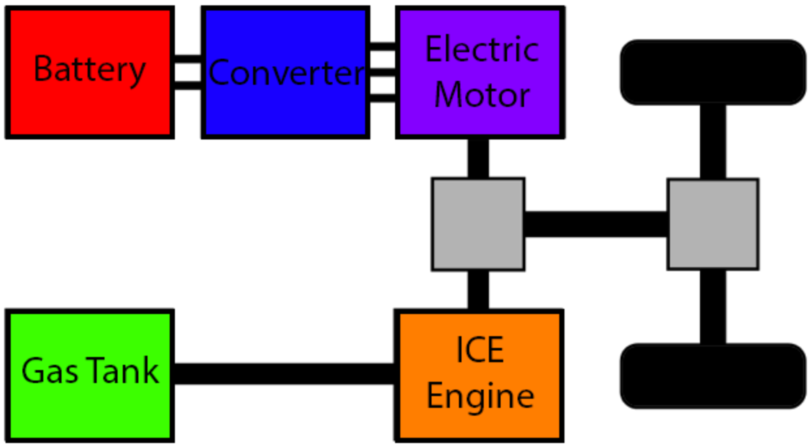



Figure 3. Parallel hybrid structure.

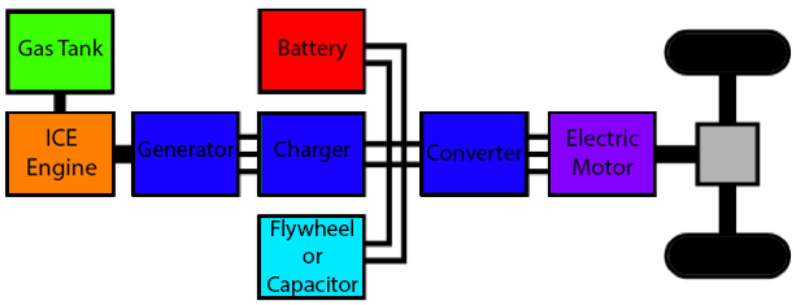



Figure 4. Series hybrid structure.

There is a third plug-in hybrid type called power-split or series-parallel and it is shown in Figure 5. They allow power delivery from the ICE to the wheels can be both types – electrical or mechanical.

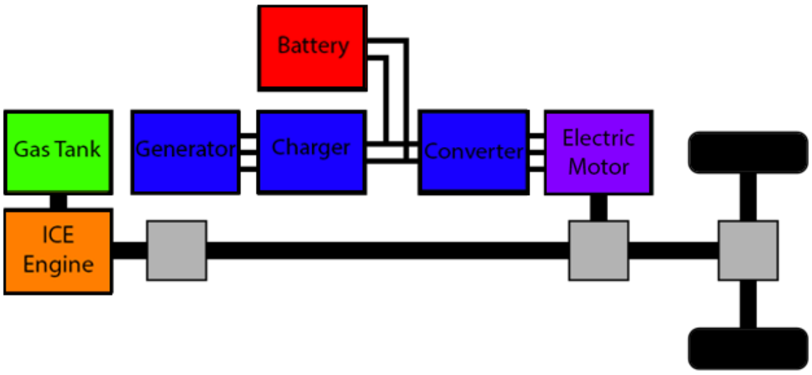



Figure 5. Combined hybrid structure.

### 2.3.4 Swappable batteries

Another way to extend vehicle's range is using swappable batteries. An EV can go to a battery swapping station and change it in a few minutes.
Tesla Motors engineered Model S with battery swapping in mind – battery can be changed in 90 seconds, faster than a gas tank refill. Tesla plans to start installing battery swap stations in each of its Superchargers, starting with Interstate 5 in California, where many Tesla EVs making the San Francisco to Los Angeles and back trip regularly. Then Washington, DC to Boston highway will be equipped with battery swap stations. Each charging station will have approximately 50 batteries available at any time. Figure 6 is presenting possible battery changing concept.

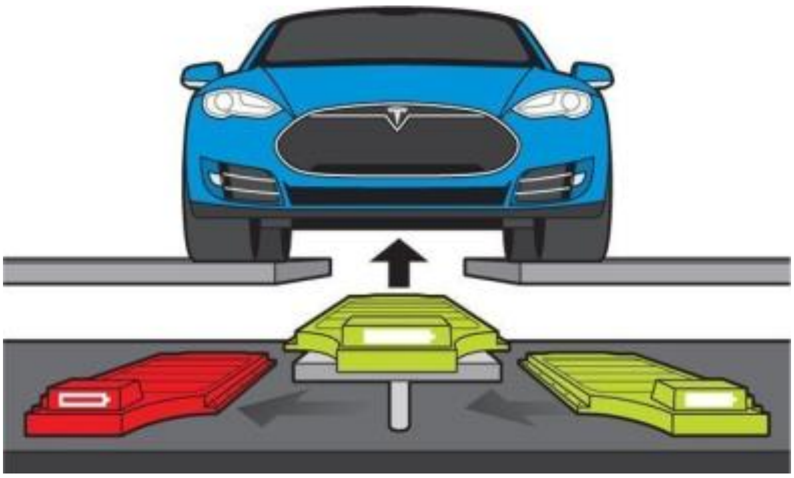


Figure 6. Swappable batteries concept sketch. (Philpot, 2013)

### 2.3.5 Lifespan

Battery lifespan should be taken into consideration when calculating the total cost of ownership of EV, as batteries wear out and should be replaced. Many types of batteries can be damaged by depleting them beyond a minimum recommended level. Lithium-ion batteries shouldn't be stored or used at high temperatures. To prolong batteries life, they shouldn't be rapidly charged and charged to its maximum limit. That is why many EV's users charge their cars to 80% for daily use and charging to 100% for longer trips only.

Unfortunately, there is a chance that battery may fail even during its planned life cycle, however, failure rate is as low as 0.003% for some types of batteries. Nissan made a press-release in 2015 that only 0.01% of batteries had problems or failures, some of them because of externally inflicted damage. Mostly all modern batteries will last for at least eight years or/and one hundred thousand miles.

It is still unknown exactly how many cycles batteries will last. According to latest researches, Lithium-ion batteries should be good for 300 – 500 cycles. That's not much, for example, Tesla Models S with 85 kWh battery can achieve up to 480 kilometers. After simple calculation, we can see that battery lifespan will be 144,000 to 240,000 km, while conventional ICE cars can last for millions of kilometers. But total battery life will actually be longer – after 500 cycles of 100 percent depth of discharge, cells' capacity will drop to 70%, which will give additional 500 – 1000 cycles. But in that case, maximum range will be dropping continuously. Battery lifespan problem can be easily solved by using the battery swap stations, where companies will have only batteries in good condition, recycling all others.

Battery replacement can be costly, also it cannot be done by the driver in his own garage. Thanks to recycling options available, old batteries still have a significant trade-in value, so EVs owners can get some money back.

### 2.3.6 Future

Lithium-ion batteries and electric motors, used in a many modern EVs, use rare-earth elements such as neodymium, boron, cobalt etc. Demand for these materials is expected to grow greatly due to the future increase of EVs production. Latest estimation shows that there are enough rare materials to power up to four billion EVs in near future, however, some of the largest world reserves located in countries with unstable governments and hostility to US interests.

There are some experiments with supercapacitors and flywheel energy storage nowadays. The FIA (mostly known as governing body for many auto racing events) included them in regulations for Formula One racing.

Unfortunately, not everything is that great with electrical car manufacturing. Devonshire Research Group said that electric cars, Tesla as an example, still creating some pollutions and carbon emissions in other ways than from exhaust pipe. Each stage of electric car's life has some impact on our environment. For example, if you use electricity made with carbon burning, then EV are not better than conventional ICE car in terms of greenhouse effect. So, to be really green and ecological, an electric car should use electricity from renewable sources like wind, solar, water etc. However, final $CO_2$ emissions are almost four times lower compared to ICE cars. (Wade, 2016)

## 2.4 **Infrastructure**

### 2.4.1 Charging stations

Batteries in EVs must be charged almost every day, but unlike traditional ICE cars, they can be charged overnight at home without going to a gas station. Also, EV can be charged using a street, garage or shop charging station. Electricity for charging purposes generated from different sources: nuclear, hydro, coal etc. Nowadays power sources like solar panels or wind are also used, as they a good for our environment.

The more electrical power network can give – the faster car will be charged. Power is limited by the total capacity of grid connection and car's charger. In Europe (and other countries with 230V supply) outlets have 3 kW, while in North America (and countries with 110V supply) outlets are up to 1.5kW. The main connection to a house can have additional 10 to 20 kW, except normal everyday loads.

There are several charging machines types: Japanese CHAdeMO is used by Toyota, Mitsubishi and Nissan, while BMW, Volkswagen, Ford and GM are using the Society of Automotive Engineers' (SAE) International J1772 Combo standard. Both systems use direct current to charge EV up to 80% in less than half an hour. Unfortunately, two different systems are not interchangeable, so as experts say, EVs market will be restricted unless these 2 companies cooperate. Also, there is a Tesla Supercharger standard that is not compatible with others too, but Tesla sells additional adapter allowing Tesla drivers to use CHAdeMO chargers. Chinese car manufacturers use its own standard as well. This situation looks a bit the same as mobile devices and laptops charging – there used to be a lot of different charging standards, but finally, USB Type C is used mostly everywhere. (Herron, n.d.) Research nowadays is mainly focused on reducing the charging times for EVs.

### 2.4.2 Charging standards

In North America, in 1998 California Air Resource Board classified levels of power that have been codified in title 13 of the California Code of Regulations, the U.S. 1999 National Electrical Code section 625 and SAE International standards. So, four standards were developed, named AC Level 1, Level 2, Level 3 and Combo Charging System.

Recently, Level 3 standard has been used by the SAE J1772 Committee for a possible future fast charging AC standard. Table 1 presents different charger types that are used nowadays.

Table 1. Charger types.

| Level | Definition | Connectors |
|---|---|---|
| AC Level 1 | 120 V AC;<br>16 A (1.92 kW). | SAE J1772,<br>NEMA 5-15 |
| AC Level 2 | 208-240 V AC;<br>12-80 A (2.5-19.2 kW). | SAE J1772,<br>IEC 62196,<br>IEC 60309,<br>IEC 62198,<br>etc. |
| AC Level 3 | 208-240 V AC;<br>11.6-96 kW. | SAE J1772. |
| Combo Charging System (CCS) | 200-450 V DC;<br>up to 90 kW. | SAE J1772. |

Nowadays these standards can be a bit outdated, as some cars are providing options that don’t fit under them.

In Europe, the IEC 61851-1 charging modes are used to classify charging equipment. IEC 62196 includes 4 different charging modes:

- Mode 1 (16 A, 250 V AC or 480 V three-phase),
- Mode 2 (32 A, 250 V AC or 480 V three-phase),
- Mode 3 (63 A (70 A in the US), 690 V AC or three-phase),
- Mode 4 (400 A, 600 V DC).

(Herron, n.d.)

### 2.4.3 Connectors

Most cars are using the conductive coupling to supply electricity for charging purposes after California Air Resources Board standardized the SAE J1772-2001 as the main charging interface for EVs in California. However, European ACEA (the automobile manufacturers’ trade association) decided to use the Type 2 connector from the IEC 62196 standard for conductive recharging of EVs in the European Union as the

Type 1 connector (SAE J1772-2009) is not suitable for three-phase charging. (BBC, 2011)

Another available type is the inductive charging connector developed by Delco Electronics around 1998 for the General Motors EV1. However, inductive charging has more loses, so it’s not used in a modern EVs.

Figure 7 shows the typical CHAdeMO inlet and connector that are used in Japan, while Figure 8 presents so-called Combo Charging System that is used by most European and USA manufacturers.

Figure 7. CHAdeMO standard inlet and connector. (www.e-station.it)

Figure 8. J1772 SAE Combo Charging System. (www.e-station.it)

# 3 FUTURE DEVELOPMENT

## 3.1 Plans of car manufacturers

Today, there are a lot of different manufacturers that are interested in development and producing EVs – some of them are big corporations, while others are still start-ups.

### 3.1.1 Start-ups

The most well-known EV start-up is Faraday Future, company located in Los Angeles. It was established in April 2014. However, their biggest and most important partner and investor is Jia Yueting, the Chinese entrepreneur and businessman. First company's model FF91 was already presented in January 2017 on a CES trade show. It has 4 electric motors with a maximum power output of 1050 horsepower combined. Batteries are 130 kWh, maximum range up to 600 km on one charge.

Henrik Fisker, automotive designer, who is well known as an author of such iconic cars as BMW Z8 and Aston Martin DB9, founded Fisker Inc. as a manufacturer of plug-in hybrids. However, it didn't work out. The company was closed after few years of production, but in 2016 Henrik Fisker announced that his company will soon start selling fully electric vehicle, which should become Tesla's competitor. The car will have graphene battery because they are less expensive, lighter and more efficient than traditional Lithium-Ion batteries. Charging is also faster, the only problem is that it's manufacturing started not so long ago, and it's still in development.

Jia Yueting is also a founder of LeEco company. LeEco has a plan to sell up to 400 000 EVs every year, but it's still a plan. They introduced concept car LeSee Pro, without any additional technical details yet. LeEco is in a partnership with Faraday Future, so some critics say that LeSee was developed by Faraday Future's engineering and designing team. The main car usage scenario is an autonomous car-sharing, where anyone can use this car for a fee.

Lucid Motors is another company where Jia Yueting has his share. The company was founded 10 years ago originally named as Atieva. Its first steps were to develop better battery types. Their first prototype was built using the Mercedes-Benz van, and it was capable of doing 100 km/h in under 3 seconds. In 2016, Lucid Motors has signed an agreement with authorities of Casa Grande city in Arizona. The main idea of this agreement is to build a plant where up to 120 000 EVs can be produced in a year. Also, this company is the strategic partner of McLaren Applied Technologies and Sony, together they will produce batteries for Formula E racing series.

Of course, not only small road cars are being transferred to electrical energy. Nikola Motor presented electric truck *One*. It uses hydrogen to power its batteries containing 32 000 Lithium-ion cells. Maximum range – up to 1500 km. The most interesting thing – is the torque: 2700 Nm originally, but using gearbox it can be increased up to 100 000 Nm theoretically. (Guriev, 2017)

### 3.1.2 Major corporations

There are a lot of start-ups developing EVs nowadays, however, major corporations are doing it as well. There are several already in production cars made by big corporations, such as BMW, Chevrolet, Ford, Honda, Nissan, Renault, Tesla, Toyota, Volkswagen etc.

BMW introduced 2 previous EVs in 2013 and 2014, i3 and i8 respectively. i8 is more like prestigious EV for those, who need to show off, while i3 is a practical small hatchback, that is meant to be used every day. Next EV is planned in 2020 only, but the automaker will not just leave this 7-year gap empty. According to company's CEO Harald Kruger, BMW is planning to introduce new all-electric MINI (the company owned by BMW since 1994) in 2019, following by all-electric BMW X3 in 2020. BMW's plan to make 15 to 25% of their sales being electric by 2025. It will be a significant increase, as nowadays BMW sells only 5% of electric cars. By that year batteries should reach capacity and cost parity with ICE before fuel cost according to most researches. (Lambert, 2017)

Tesla's plans for the following 4 years include building its own Gigafactory, which will help the company to dramatically decrease the price of its batteries. Tesla estimates that factory will reduce battery prices by 30% once it is fully operational in 2020. Next big thing is to bring its mass-market Model 3 into production. Model 3 will cost around $35,000 in the USA. Production should begin by the end of 2017, with first deliveries in the beginning of 2018. Also, Tesla plans to increase maximum range of their cars up to 1000 km per one charge by end of 2018. (Thompson, 2016)

Volkswagen announced that it wants to be the world leader in electric cars by 2025 after the huge "dieselgate" emissions cheating scandal. VW brand chief Herbert Diess said that by 2025 VW plans to sell one million EVs every year and become a global market leader in electromobility. Currently, VW sells only 2 EVs – *e-Golf* and *e-Up!*. *e-Golf* was presented at the 2013 Frankfurt Motor Show. Its original maximum range was only 190 km, but in February 2017, VW announced an updated version with increased range (up to 201 km) and more power. (The Guardian, 2016)

There are many other companies that produce or willing to produce EVs in the near future. Next 5 to 7 years will be crucial in electric cars industry, especially while gas prices are going up.

## 3.2 **Plans of governments**

### 3.2.1 In Europe

European Economic Recovery Plan includes the electrification of transport. DG MOVE (Directorate-General for Mobility and Transport) is fully supporting European project on EVs as part of the Green Car Initiative with a total budget of 50 million euros. Most of the European Union countries already provided tax incentives for EVs. These incentives consist of tax reduction and bonus payments for the EVs buyers.

Finnish Ex-Prime Minister (2003-2010) Mr. Matti Vanhanen stated (2008) that he wants to see as many EVs as possible in the nearest future. It was determined that charging at home using normal motor and cabin heating outlets to be a possible load on the grid. Considering all cars in the country run on electricity it will add approximately 8 TWh per year, and this amount is 10% of Finland's consumption every year. (Taloussanomat, 2008)

Germany is one of the most advanced countries in aspects of electric mobility. In 2011, German government started a program for the development of production of EVs. The goal of the program is to increase the number of cars with electric batteries in the country to 1 million by 2020, and by 2030 that number should raise up to 6 million. At the same time, this program suggests several points to stimulate demand for EVs. For example, owners of the EVs are exempt from taxes on the vehicle for the first 10 years. In addition to special parking places for EVs, it is also planned to create special driving lanes for them.

German government allocated more than 2 billion euros before 2013. A special group was created to coordinate their work with the government. Up to 1400 charging stations were already built by 2017, and up to 7100 more stations are planned before 2020. It is planned to bring to the country's roads 1 million EVs by 2020. Serial production started in 2011, and additional 500 million euros were allocated for these purposes. ((NPE), 2015)

There were some problems with Great Britain's plans on switching a proportion of car fleet to EVs. The original plan was to have 9% of all cars being electric, but latest studies show that figure by the end of the decade is likely to be 5% only. (Harvey, 2016)

Great Britain's government provides a grant up to 5000 pounds to every EV buyer, if their car is on the special list of eligible vehicles. Also, there is a network of charging stations across the main routes.

Ireland plans to have 10% EVs out of all number of cars in the country in the near future.

In Norway, Tesla Model S was the most sold car in 2014, even compared to traditional ICE cars. Norway's government waived annual registration fee, tools and gave an access to special traffic lanes. For those who drive for a living (taxi drivers, deliverers etc.), electric cars will get them an income-tax deduction. (Ballaban, 2014)

### 3.2.2 In North America

In North America, Canada is providing some additional benefits for EVs buyers. Ontario will pay back up to 8500 CAD for the first 10,000 people who qualify. Province presented special green-coloured license plates for EVs, which allow EVs to use special carpool lanes regardless of a number of passengers inside.

Of course, USA is one of the leaders in EV production and usage. In 2011, President Obama set the goal to have 1 million cars by 2015, however, EVs sales were lower than expected, so this goal was unattainable. Approximately 542,000 EVs were sold by December 2016. According to 2012 study by Pike Research, an overall number of EVs in the USA will reach the initial goal by 2018 only. One of the biggest problems for EVs development – low gas prices in the country. Of course, the government provides tax credits for EVs buyers – up to $7,500. What is more important, US government also provided a tax credit for home-based charging stations. And same as in Canada, EVs have an access to carpool or high-occupancy lanes. (Green Car Congress, 2012)

### 3.2.3 In Asia

In Japan, where the fleet of EVs is the third largest after the US and China, electric car's sales also rising. But their strategy focuses on hydrogen cars, instead of plug-in EVs in Europe and Northern America. This trend is supported by both local government and domestic car manufacturers. Toyota's vice chairman Takeshi Uchiyamada said that current technologies do not meet society's needs, so it is better to focus on fuel-cell cars.

Not only cars are being switched to hydrogen energy. Japan's plan is to have 5,3 million households to be covered by residential hydrogen fuel cells by 2030, while 100,000 fuel cells were already installed before 2015. According to The Guardian, Japan also has more EV charging points than petrol stations, however, it also includes a lot of private stations. (McCurry, 2016)

Chinese EV market is also growing rapidly. Chinese plans are mostly represented by a various number of start-ups located there. But the Chinese government is also trying to make China a world leader in battery production. According to CATL's plans (one of the biggest local companies producing Lithium-ion batteries), China should become a world's leader by 2020, having 84% of the mass production of Lithium-ion batteries.

One of the biggest advantages of the Chinese market is access to raw materials – local companies were buying up mining assets with a goal to reduce the total price. They have stakes in different companies all over the world – Argentina, Chile, Democratic Republic of Congo etc. (Sanderson, Hancock, & Lewis, 2017)

# 4 AUTOMATED CHARGING STATION

## 4.1 Target

Today, car charging stations look the same as normal gas stations with only small exceptions. But in a modern world, everything is being optimized and automated. And there is a way to make electric cars charging easier and more convenient for its users. It will include fully automated charging, so drivers will not need to do anything on their own.

The target of this concept is to help electric car drivers with easier charging and, in addition, solve the range anxiety issue that may stop future EVs' users from buying an EV. Nowadays, an electric car can be charged with help of its driver, which includes opening the charging port, connecting the power cord to a car and after the charging doing it in a reverse order. It might not be a problem in a sunny California, but electric cars are used in different weather conditions already. For example, in Nordic countries, the daily temperature during the winters can be as low as -30 Celsius. It is not too pleasant to go outside and connect the car to the charger. While the fully automated system can easily solve this problem.

Next problem that can be solved by using fully automated station is a charging of autonomous cars, for example, those that are used in car-sharing programs. In future, autonomous cars will not be parked near our houses, they will be used all day by different people who use this car sharing program. But in a car's free time it should be charged. How to do it without the driver? The automated station can help. Autonomous cars will have a list of all possible stations where they can be charged automatically. So, they will drive there and charge while not in use.

It is easier to charge EVs using automated station – driver will not need to care about charging, there is even a way to schedule autonomous car charging during the night, while driver is sleeping (and car will drive to the charging station, charge itself and then return before the morning, so its user will be able to use it when needed).

## 4.2 Potential customers and users

Automated charging stations can be built in a number of different locations – starting with already existing charging stations (or gas stations that also have a possibility to charge EVs) to big shopping malls. Some parking lots may also install automated charging station.

Potential users include people who drive EVs every day or for longer trips. Finding right location for each station will be crucial for its success. Automated charging stations will be one part of a big plan to deal with range anxiety. This plan should include increasing the maximum range of

EVs by developing new and better types of batteries and making electric cars way more efficient. The second part is to have a convenient way to charge EVs. Stations should be located almost everywhere, so drivers can easily access it. Nowadays, gas stations can be found in every part of the big city, and charging stations must be too.

## 4.3 **Operating principles**

### 4.3.1 General information

Automated charging station should be as easy as possible. The driver should just drive in, stop the car, open an app on his phone and press “Start”. Then he is free to go for a while (depends on how long charging takes – and it depends on how soon batteries will be improved).

Automated charging station’s overall design will be very similar to today’s gas station. However, it should be upgraded to increase its efficiency. For example, solar panels must be added as many as possible. There are some technologies to increase its efficiency, like an automatic solar tracking system for solar panels developed by Hanlog Oy engineer, also a HAMK student Fatbardh Xhemajili. This system tracks the sun’s location and adjusts solar panels position according to it, so they are always at 90 degrees to the sun.

### 4.3.2 Applications

Cell phones should not be the only option to use the charger (as they might run out of battery, break etc.). Almost 100% of modern produced EVs have a built-in multimedia pack, which includes a possibility to install different applications there. So, one part of the charging system should include different applications for various Operational systems.

In the case of autonomous cars, an application should also have an option to send the car to charge itself and return back. However, it is not possible with current technologies and laws. There are 6 levels of autonomous cars by SAE:

- Level 0: Driver controls everything.
- Level 1: Most functions are still controlled by the driver, but specific functions like steering or accelerating can be done automatically by a car.
- Level 2: At least one driver assistance system of both steering and acceleration/deceleration is automated, like cruise control and line centering. The driver must still always be ready to take control of the vehicle if necessary.

- Level 3: Drivers are still needed, but can completely shift “safety-crucial functions” to a vehicle, under certain traffic or environmental conditions.
- Level 4: Fully autonomous vehicle. However, it is limited to the Operational Design Domain of the vehicle – meaning it does not cover every aspect of possible driving.
- Level 5: Fully autonomous vehicle, that doesn’t need any supervision and has equal to human performance – including various environments like snow, dirt or any other extreme conditions.

(Torchinsky, 2016)

Today’s cars achieved only level 2, so sending the car to be charged can only be done after technologies get to Level 4 (or 5 if the car is somewhere outside the city where no asphalt roads are available).

### 4.3.3 Specifications

The most important part is to develop a future standard that will be used all the time. Charging port on a car will have only 2 additional sensors (diodes) to align charger correctly. While charger connector will have receivers to check correct position according to diodes. Also, that connector will need to have additional sensor for Z axis, it can be simple ultrasonic sensor or laser distance sensor for increased accuracy (it should be tested before – ultrasonic is cheaper, but there is a need to check if its accuracy is enough, or use a laser distance sensor, which is way more expensive, but also a way more accurate).

The second way to make it work is to use a full laser scanning of charging port and do aligning according to it. It may require additional computing power and usage of neural networks, which we lead to increasing the overall system price.

There are a lot of things to consider, like how exactly system will identify where charging port is located. We can add few photosensors, which will scan the side of the vehicle and determine where the port is located. Currently, there are only a few standards of charging ports, so it is easy to find them.

Next thing to consider is a design of charger with its arm. Tesla already made a prototype with a snake-like arm. It hides the cable inside, which is making it more reliable. The second option is to add a robotic arm that will use normal charging cable. Both concepts can be used, but the final design should be selected after a lot of testing.

Considering possible costs, a snake-like design will be more expensive (also for developing), while the additional arm is easier to develop and a robot made by ABB or KUKA can be easily used.

### 4.3.4 Usage with existing cars

The first issue with already existing cars is that mostly all of them cannot open their charging port completely by pressing only one button inside. So, the driver is still needed to go outside and open it. Anyway, it is still easier than also connecting the charging cord, which can be wet, dirty or frozen.

Next problem is how to locate charging port. Nissan Leaf has it under the front mask, while Tesla has it in the back, built into the rear lights. During the first launch of the application, the user will set the correct side of car’s charging port (left, right, front or rear). It is impossible to add specifications of all cars because there are too many possible combinations (including some DIY conversions that can switch mostly every car to electric energy).

One way to solve it is to develop a small adapter with needed sensors that will be connected to car’s charging port. This adapter will be slim, so it can be connected all the time, even when charging port door is closed. The adapter will have 2 diodes that will help to align charger position on X and Y axes (left and right), while everything else will be located on a charger itself. That will allow using the same standard for existing and future cars (where needed sensors are built-in).

These adapters can be sold when subscribing for the charging plan or using the vending machines located on a charging stations. Production price should be small, as it only has few sensors on it. According to current production prices in China, each item should be approximately 1-2 euro. While it can be sold for 10-20 euro (still a small price for customers, considering that they only need to buy it once).

## 4.4 **Advantages and disadvantages**

One of the biggest advantages of this system is that autonomous cars will be able to use it in a near future. Also, it will be perfect for some harsh environments where going outside for charging might be a problem.

Next advantage is that market is still not yet created. With a correct management and development team, it is possible to become a leader in automated charging systems industry. It is also needed to patent all developments that are made.

Of course, there are might be some problems and challenges also. First of all, manufacturers are still using different charging stations, so they need to start using the only one for more extensive EVs expansion. Otherwise, the automated charging system will be different for various markets.

Next problem is the price – electric chargers are not cheap nowadays, so automated system will only increase the price. However, in near future electronics price will go down, so total system price should decrease also.

It can be hard to convince future customers to use this system now, but it will not be a problem later when autonomous cars are common. It is almost impossible to create this system without cooperation with different car manufacturers, as they will need to add few sensors to their car, which is going to cost additional money.

# 5 CONCLUSION

The objective of this thesis was to make a research on current charging technologies for electric vehicles and design a possible concept of the automated charging station.

The first part of this thesis was mostly focused on current technologies that are already in use nowadays. Main research sources were websites, as well as one documentary film, report and personal communications with an ex-BMW engineer.

One of the most challenging task was to find an up-to-date information about technologies and companies. This industry is developing so fast, that sometimes one-year-old information is not fresh anymore. So, research about every topic was made using at least 2 different sources. And sometimes, 2 sources had absolutely opposite information about the same topic. Also, some information was available only in different languages – English, Russian and Finnish. First two were not a problem, but I was forced to ask a Finnish-speaking person to translate that article for me. However, in the end, correct information was found for every topic covered in this thesis.

Concept part of this thesis is just a design proposal of the automated charging station, but it has a great opportunity to become real in a near future. Today, no companies have 100% ready to production prototype of automated charging station, while it is possible to create one using today's technologies. With some additional technical explanations, this thesis might be a subject to patent.

## REFERENCES


(NPE), G. N. (2015). *Charging Infrastructure for Electric Vehicles in Germany.* Berlin: German Federal Government Joint Unit for Electric Mobility (GGEMO).

Auto Vesti. (2015, Nov 3). *КАК РАБОТАЮТ ТОПЛИВНЫЕ ЭЛЕМЕНТЫ?* Retrieved Dec 14, 2016, from Auto Vesti: http://auto.vesti.ru/news/show/news_id/656221/

Ballaban, M. (2014, Oct 27). *Here's Why The Tesla Model S Is The #1 Selling Car In Norway*. Retrieved Dec 28, 2016, from Jalopnik: http://jalopnik.com/heres-why-the-tesla-model-s-is-the-1-selling-car-in-no-1651261025

Battery Universe. (2016, Jul 07). *BU-104a: Comparing the Battery with Other Power Sources*. Retrieved Feb 13, 2017, from Battery Universe: http://batteryuniversity.com/learn/article/comparing_the_battery_with_other_power_sources

BBC. (2011, Sep 22). *European electric car charging standards agreed*. Retrieved Jan 24, 2017, from BBC: http://www.bbc.com/news/business-15024153

Berman, B. (2013, May 17). *Survey: To Be Satisfied, Electric Car Drivers Want 150 Miles of Range*. Retrieved Feb 20, 2017, from PlugInCars: http://www.plugincars.com/survey-be-satisfied-electric-car-drivers-want-150-miles-range-127255.html

Colin, A. (2014). *Inside EVs*. Retrieved Mar 25, 2017, from Just How Far Can A Chevrolet Volt Go On Electricity? How About 81.8 Miles: http://insideevs.com/far-can-chevrolet-volt-really-go-ev-mode-81-8-miles/

Deeter, J. (Producer), Paine, C. (Writer), & Paine, C. (Director). (2006). *Who Killed the Electric Car?* [Motion Picture]. United States: Sony Pictures Classics.

English Oxford Living Dictionaries. (n.d.). *range anxiety*. Retrieved Dec 28, 2016, from Oxford Living Dictionaries: https://en.oxforddictionaries.com/definition/range_anxiety

Green Car Congress. (2012, Jul 2). *Pike Research projects plug-in sales to fall short of US 2015 target; strong growth through 2020*. Retrieved Feb 1, 2017, from Green Car Congress: http://www.greencarcongress.com/2012/07/pikepev-20120702.html

Guriev, L. (2017, Jan 30). *Электрические старты*. Retrieved Jan 30, 2017, from motor.ru: https://motor.ru/articles/2017/01/30/electricstarts/

Harvey, F. (2016, Sep 1). *UK government 'falling behind' on electric car pledge*. Retrieved Feb 14, 2017, from The Guardian:

https://www.theguardian.com/environment/2016/sep/01/uk-government-falling-behind-on-electric-car-pledge

Herron, D. (n.d.). *EV DC Fast Charging standards – CHAdeMO, CCS, SAE Combo, Tesla Supercharger, etc*. Retrieved Dec 19, 2016, from GreenTransportation.info: https://greentransportation.info/ev-charging/range-confidence/chap8-tech/ev-dc-fast-charging-standards-chademo-ccs-sae-combo-tesla-supercharger-etc.html

Lambert, F. (2017, Mar 22). *BMW explains its electric vehicle plans in more details and it's going in the right direction*. Retrieved 04 15, 2017, from electrek: https://electrek.co/2017/03/22/bmw-electric-vehicle-plans/

McCurry, J. (2016, May 10). *Japan now has more electric car charge points than petrol stations*. Retrieved Apr 3, 2017, from The Guardian: https://www.theguardian.com/world/2016/may/10/japan-electric-car-charge-points-petrol-stations

Okulski, T. (2013, Mar 5). *This Is Why Ferrari, Porsche, And McLaren Went Hybrid With Their New Hypercars*. Retrieved Jan 17, 2017, from Jalopnik: http://jalopnik.com/this-is-why-ferrari-porsche-and-mclaren-went-hybrid-w-451213585

Philpot, C. (2013, Oct). Tesla Across America: How Elon Musk is Building an EV Infrastructure. *Article*.

Sanderson, H., Hancock, T., & Lewis, L. (2017, Apr 05). *Electric cars: China's battle for the battery market*. Retrieved Apr 10, 2017, from Financial Times: https://www.ft.com/content/8c94a2f6-fdcd-11e6-8d8e-a5e3738f9ae4

Stewart, J. (2016, Oct 03). *Chevy's Making a Hydrogen-Powered Pickup for the US Army*. Retrieved Jan 19, 2017, from Wired: https://www.wired.com/2016/10/chevys-making-hydrogen-powered-pickup-us-army/

Stobing, C. (2016, Feb 4). *What to Consider Before Buying an Electric Car*. Retrieved Feb 4, 2017, from How to geek: https://www.howtogeek.com/239948/what-to-consider-before-buying-an-electric-car/

Taloussanomat. (2008, Aug 5). *Matti Vanhanen puhui sähköautojen puolesta*. Retrieved Jan 27, 2017, from Taloussanomat: http://www.is.fi/taloussanomat/art-2000001582541.html?page=showSingleNews&newsID=200820199

The California Center for Sustainable Energy. (2013, May). Survey: To Be Satisfied, Electric Car Drivers Want 150 Miles of Range. *Survey*. San Diego, California, USA.

The Guardian. (2016, Nov 22). *VW shifts focus to electric cars with US expansion plan*. Retrieved Mar 1, 2017, from The Guardian:

https://www.theguardian.com/environment/2016/nov/22/vw-shifts-focus-to-electric-cars-with-us-expansion-plan

Thompson, C. (2016, Jul 17). *Tesla has big, big plans for the next 4 years*. Retrieved Jan 20, 2017, from Business Insider: http://www.businessinsider.com/everything-tesla-promises-to-accomplish-by-2020-2016-7?r=US&IR=T&IR=T/#complete-its-giant-gigafactory-1

Torchinsky, J. (2016, Aug 18). *What's A 'Level 4' Autonomous Car? This Chart Explains Everything*. Retrieved Feb 20, 2017, from Jalopnik: http://jalopnik.com/whats-a-level-4-autonomous-car-this-chart-explains-eve-1785466324

Wade, L. (2016, Mar 31). *Tesla's Electric Cars Aren't as Green as You Might Think*. Retrieved Mar 8, 2017, from Wired: https://www.wired.com/2016/03/teslas-electric-cars-might-not-green-think/

www.e-station.it. (n.d.). La prima colonnina FAST DC pronta all'uso!