UNIVERSITY OF VAASA

THE SCHOOL OF TECHNOLOGY AND INNOVATIONS

COMMUNICATIONS AND SYSTEMS ENGINEERING

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IMPLEMENTATION OF A SYSTEM TO FIND SUITABLE CHARGING STATIONS FOR ELECTRIC CARS

Master's thesis for the degree of Master of Science in Technology submitted for assessment, Vaasa, 27 June, 2018.

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ACKNOWLEDGMENT

I would like to take this opportunity to express my deepest gratitude to those people who have helped accomplish my goals. Foremost, I would like to thank my instructor Tobias Glocker who helped me choose a topic that is challenging and new learning experience. He pushed me to do the best and he shared his knowledge and experience throughout the thesis work. I would also like to thank my supervisor Professor Timo Mantere for the support he gave in doing the thesis.

Throughout my study, I never lost support of my boyfriend Hailesilassie. I am grateful for his constant love, support and encouragement. I would also like to acknowledge my dad for always believing in me and pushing me to do better in life. Last but not least, I want to pass my gratitude to my family and friends for their love and encouragement. And University of Vaasa for giving me the chance to study and accomplish my dream.

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ABBREVATIONS

AC – Alternating Current

API – Application Programming Interface

BMS - Battery Management System

CCS – Combined Charging System

CENELEC - European Committee for Electrotechnical Standardization

CHAdeMO – CHArge de Move

DC – Direct Current

SOC – State of Charge

UNIVERSITY OF VAASA
The School of Technology and Innovations

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Topic of the Thesis:	Implementation of a System to Find Suitable Charging Stations for Electric Cars.
Supervisor:	Professor Timo Mantere
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Degree:	Master of Science in Technology
Degree Programme:	Degree Programme in Communications and Systems Engineering
Major:	Communications and Systems Engineering
Year of Entering the University:	2015
Year of Completing the Thesis:	2018 **Pages:** 69

ABSTRACT:

Charging station is an electrical system infrastructure designed to recharge electric cars. And there are different types of charging stations based on the type of connector/plug it uses and the mode of charging it operates in. Therefore, electric car users have to choose a station compatible to their cars.

The thesis has presented a thorough research on how public charging stations work and the elements involved in electric car charging process such as battery capacity, charging modes, plug types and charging station power output. It also provides a comprehensive research from several sources on the electric cars currently (as in May 2018) available in the market, their battery size and the manufacturer provided plug type.

To achieve better user experience of charging stations, an app was developed as a system implementation for eleven hypothetical charging stations located in four places in the city of Vaasa, Finland. The app has successfully simulated the availability status check for the stations. It also calculates the estimated charging time and charging costs specific for any electric car. The app was developed using android studio and it can be launched in any android phone with API 15 and above.

KEYWORDS: Charging station, Electric cars, Charging mode, Plug, Android App, Java, Activity

1. INTRODUCTION

Nowadays, our world is facing existential threats like climate change. It is assumed that cars are one of the main contributors to this cause. Thus, changing the car industry to use clean energy would be a big step towards reversing climate change.

Electric cars are easy to drive and zero emission cars. The number of internal components is small which makes diagnostics and maintenance easy. The most adhering limitation of an electric car is the limited range because of the compromise the manufacturer has to make between high battery capacity and the price of the car. High battery capacity leads to a longer range but at same time to a much higher price.

Batteries are very expensive component of the car. In order to make the cars affordable, most of them have a short range. Most people use their car to drive to work, home or school and this distance is shorter than the range of one battery charge. Also, most of the users charge their car overnight at home.

Home charging is a slow process that takes about twelve hours to achieve a full charge. Thus, public charging stations are established for fast charging. Public charging stations can be operated in two modes i.e. AC fast charging mode and DC fast charging mode. And different plugs are used for each charging mode.

Electric cars were popular before gas cars controlled the market. Because of its limited driving range, its popularity declined shortly. In recent years, the market for electric cars is reviving and people are showing interest to buy. Some of the reasons to its revival is the advancement and price fall of the battery costs.

The range of electric cars has been increasing due to battery technology development throughout the years. But they still have to come long way to have competitive range as gas cars. Meanwhile, users have to charge their cars often. And this leads to the establishment of number of public charging stations.

There are several standards surrounding electric cars like standard of plugs, charging modes and output power. Thus, the car users are expected to know such details in order to use services like charging. This makes it difficult to charge in any charging station so one must find a station compatible to his/her car's specifications.

This thesis is a research on modern electric cars and public charging stations. Its aim is to provide access to information about public charging stations of certain areas and the charging information for your car, then deliver it to the electric car users through an android app. It combines functionalities such as locating and checking the availability of charging stations with the estimation of charging time and costs.

There are several apps that provide location and availability checks to users. But the estimation of charging time and cost is not accessed because it is dependent on the specifications of the car. This thesis provides research on the modern electric cars currently (as in May 2018) in market. This enabled us to formulate calculations for charging time and cost estimation ahead, so that users would know and decide how much time they would spend on charging and how much it would cost them.

Our city Vaasa is an industrial city found in Western Finland. It has four electric car charging stations in different areas. The charging stations were taken as inspiration to build the app and simulate eleven charging stations located in four places (same address as the stations in Vaasa). The app provides location, availability status, charging time estimation and cost estimation.

The app is developed using android studio platform and it is functional in android smartphones and tablets with API 15 and above. Android was chosen because it is an open source platform with many users all around the world.

2. LITERATURE REVIEW

Civilization of the human race is solely dependent on social interactions. As the world grew bigger, our social circle grew wider and it was no longer limited by distance. So, we needed to travel distances to meet people. This became a reason to facilitate fast mobility. People started using animals for transport, then realized it is not efficient and scalable, so scientists started to experiment on the notion of creating better way of transportation. Through time they were able to build cars, trains, ships, planes and rockets. And cars became the most popular and widely used way of transport in the world. Human beings are very ambitious and started to work on perfecting the technology of cars to make it reliable, safe and fast. Since then several types of cars were produced and among those are electric cars.

2.1 History of electric cars and Charging Station

Along the years, several methods were used to power this mobile machine commonly called a car. Some of the early discoveries were cars powered using steam. Steam power was popular source of energy during the 1800s after the industrial revolution. It was needed between factories, trains and several machines. Following the trend of using steam as power source, steam cars were built.

Using steam to power cars is highly inefficient because it required lots of huge and heavy components, such as burner furnace and boiler, which had to be installed in the car. The furnace is used to burn coal that will heat the boiler containing water to produce steam. And the steam is used to run the motor. In addition to the heavy components, it has long starting time because the coal in the furnace takes time to burn and produce enough heat. Likewise, having a burning coal and very pressured steam makes it dangerous to drive with. Considering the types of materials used to build the pressure holder, it is highly unreliable. It could dismantle anytime the car shakes badly or gets to accident. This raised the risk of fatal accidents. (Matulka 2014) So, with the long start up time and unsafe structure, steam powered cars had more disadvantages over its advantages. And people were desperate to find other energy sources to power cars.

The exact date or identity is unknown for who created electric car. But the first practical production electric car was built by Thomas Parker in London in 1884. Thomas Parker is English man who is also known for his invention of the coalite, an easy to burn and less smoky type of coal, and the modifications he made on the use of dynamo. (Guarnieri 2012: 1-3)

The electric cars that have been developed were less noisy, had very little contribution to air pollution and less risky to drive comparative to other types of cars which were available at that time. Although it had limited traveling distance, at that time it was the best choice of transport. Users had only to drive short distances before recharging due to the battery storage capability. There were no dedicated charging stations even though at that time the distribution of electricity was spreading fast. Lots of big cities were getting power for residences and factories. Most users charged their car at their own home with the common electric outlet. The technology back then was very immature and the use of cars among population was also very small in number. Hence no one cared to establish public charging stations.

The decline of electric cars started when Henry Ford started the mass production of the Model T gasoline powered car in 1908. The Model T car was less than half of the price. On the other hand, a rapid development of road infrastructure and widening of cities was undergoing in now developed countries. This got people to acquire cars which can travel longer distance without having to stop for long hours of recharge. Additionally, the discovery of crude oil in vast areas of the Middle East made petroleum and gasoline widely available to public. So, the popularity of gas powered cars increased while the sales and development on electric cars dramatically declined. From that time till the late 20^{th} century, electric cars were out of the market competition.

Gas powered cars use combustion engine to drive the car. Throughout the years the evolution of combustion engine has been remarkable. Several car manufacturers have innovated their engines to utilize less fuel and produce less exhaust fumes. Hence, they became the most popular car. For many years until now, they have proven to be very convenient to society's lifestyle for many reasons. For instance, the average family sedan with full tank of gas can be driven 800km without stop for refueling. This enabled people to drive long distance without having to worry where and when to refuel constantly.

Gas cars have by-product exhaust gas because of the combustion of fuel. And the emission of exhaust gas has been found to be harmful to human respiratory system and the environment. It has enormous contribution to climate change by increasing the temperature of Earth's atmosphere. Scientists have proven the negative effects of climate change can lead to devastating outcomes to the extent of species extinction. Due to the alarming effects, people are forced to use an alternative to power their cars. Also, fuel is a finite resource that will grow to be scarce in the future, so it is necessary to prepare for what can happen.

One of the clean energy source that is relatively easier to implement is electrical energy. Car manufacturers and researchers started to work on developing efficient high-capacity batteries and ultimately electric cars capable of long distance travel without recharge. Hence the development of electric cars recovered from long hibernation.

In 2006, a company called Tesla Motors announced they will be producing electric cars that can travel around 320 km in one full charge. This captured the attention of many people especially the ones who cared about the environment. Ever since the company has produced different models of electric cars. Their cars have got wide popularity and acceptance by the public despite the high sales price. Figure 1 shows the first production electric car made by Thomas parker and Figure 2 presents the new Tesla Roadster electric car.

Figure 1. Early electric car built by Thomas Parker (Guarnieri 2012)

Figure 2. New Tesla Roadster car (Tesla 2018)

The success of Tesla models pushed several car manufacturers to make full electric cars. Soon after the success of first tesla models, several other brands of electric cars, such as Chevy Volt from Chevrolet, Nissan LEAF and Zoe from Renault started to emerge in the market.

At the end of last year 2017, Tesla has announced a Tesla Roadster which will be in market in 2020. The Tesla Roadster is a full electric car that has top speed 250 mph and that can travel up to 1000 km at highway speed with one full charge. The company also announced a semi-truck, the first of its kind that is fully electric. The semi-truck will have 800 km range in highway speed with maximum weight and it is promised to last a million miles drivetrain guarantee. (Tesla 2018)

This new emerging development in the electric car industry is attracting attention of many. With the increasing risks of global warming and undeniably attractive features, electric cars seem to be the future of cars. Countries like Estonia and Norway have put laws to encourage their citizens to buy electric cars. As a result, Norway has the most number of electric cars to population ratio.

2.2 How Different Type of Cars Operate

Simply cars are machines that convert energy from one form (fuel, electric...) to kinetic energy. Based on the type of energy used to drive the car, different car types and performance levels exist.

2.2.1 Gas Cars

Gas powered cars use fuel that is extracted from crude oil (petroleum). Petroleum is a natural resource found in deep underground. It is extracted and refined to get several petrochemical products such as diesel, gasoline, naphtha, jet fuel and many others. And some of the extracted products are used as fuel. Crude oil is a very important resource because it is expensive and has no by-product or waste from the refinery process. For such reason, countries go into war over the need to own oil reservoirs. A research in the US indicated that 47% of the petroleum refine product is used to power cars. (US Energy Information Administration 2018) And that is huge amount considering millions of barrels of petroleum are refined everyday around the world and shipped to be used by gas cars. This gives a little insight of how much exhaust fume is burned and released to the air.

The combustion engine is the main part of a car that is responsible for conversion of chemical (petroleum) energy to mechanical energy. It is complex process which can take place in two strokes, four strokes, six stroke engines or Wankel rotary engine. For example, in one of the most common engine, a four-stroke engine, it has four main steps. These steps are intake stroke, compression stroke, power stroke and exhaust stroke. (Woodford 2018) Intake stroke is when the inlet valve opens to put mixture of air and fuel (from fuel tank) to a cylinder. The mixture is then compressed by the piston. When maximum compression is achieved, a spark is ignited to fire the mixture. The energy released from the burn moves the crankshaft and the by-product/exhaust gas is released to the exhaust pipe. And this process repeats as we continue to drive the car. Total components involved in this combustion process are approximately 2000. Thus, the it maintenance is difficult and expensive.

2.2.2 Hybrid Cars

Hybrid cars operate in between and as combined entity of electric and gas-powered cars. They were built to compromise between the high oil consumption of gas cars and the repetitive need to recharge electric cars.

Hybrid cars mainly have the following parts: combustion engine, electric motor, fuel tank, battery pack, generator and transmission. Each part work together to get a great deal of travel distance while producing less pollution. In most of the hybrid cars, the electric motor run on the electric power stored in the battery pack when starting the car for takeoff and at low speeds. Then on higher speed and acceleration the combustion engine kicks in and take over. The combustion engine is smaller and more efficient than regular gas cars. So, when the car gets in difficult situation that requires much engine power like going uphill, the electric motor steps in. (Nice & Layton 2008)

The battery pack in hybrid cars can be recharged using the energy from the combustion engine or in case of plug-in hybrid cars by plugging it in electrical power source. And when the user forgets to recharge the car, the plug-in hybrid acts like the default hybrid and recharges its own batteries using the combustion engine as generator.

2.3 Modern Electric Cars and How They Operate

Electric cars convert electric energy to kinetic energy to mobilize the car. The electric energy is transferred from electric power source to the car battery using a charger. The charger rectifies the voltage and converts the current from AC to DC among other functionalities. Then the DC electric power is transferred to the battery pack to be stored. The battery management system makes sure of even distribution of charge among the battery cells among other monitoring and controlling for safe charging system.

The exterior of electric car might be similar or in some case close to identical to gas cars, but the interior construction is vastly different. Electric cars operate using the coordinated functions of the electric motor, motor controller and battery pack.

While a driver is stepping on the accelerator pedal of electric car, the variable resistors located under the pedal send signals to the motor controller. Those signals indicate the level of acceleration required. Accordingly, the controller calculates the amount of power needed and delivers it from the battery pack to the electric motor. Most motors operate using AC power, so in such cases the controller converts the DC power to AC power.

Electric car has much less moving parts than another car type. So, it uses fewer lubricants and fluids liberating the driver from regular constant check in and changes. Though regular maintenance will be needed for parts such as the brakes, motor, battery pack, controllers and others. Especially the brake is far less worn out as compared to gas cars because of a system of regenerative charging. Figure 3 illustrates the skeleton or internal structure of the BMW i3 electric car.

Figure 3. BMW i3 internal structure (Duchene 2013)

Electricity is widely used clean energy all over the world. Using it to power cars has created zero emission gas which made it very environment friendly. Even better, electricity nowadays is generated through renewable energy such as wind, solar and water craft. These sources of energy produce no harm to the environment. For such reasons, many public stations operate using solar panels and wind turbines independent of the grid power.

Currently electric cars are more expensive than any other types of cars. And the main reason is the cost of the battery pack. A battery pack of mid-range electric car can cost more than half of the price of the car. According to Tesla, these prices would eventually decrease when production of batteries worldwide increases. In the past six years, we have seen steady drop of price for lithium-ion batteries. These are the most widely used type of batteries in electric cars. And there is increase in demand for batteries not only in the car market but also in different electronics technologies. This is attracting investors to build battery manufacturing industries. Figure 4 demonstrates the constant decrease of lithium-ion battery price from the year 2010 until 2016.

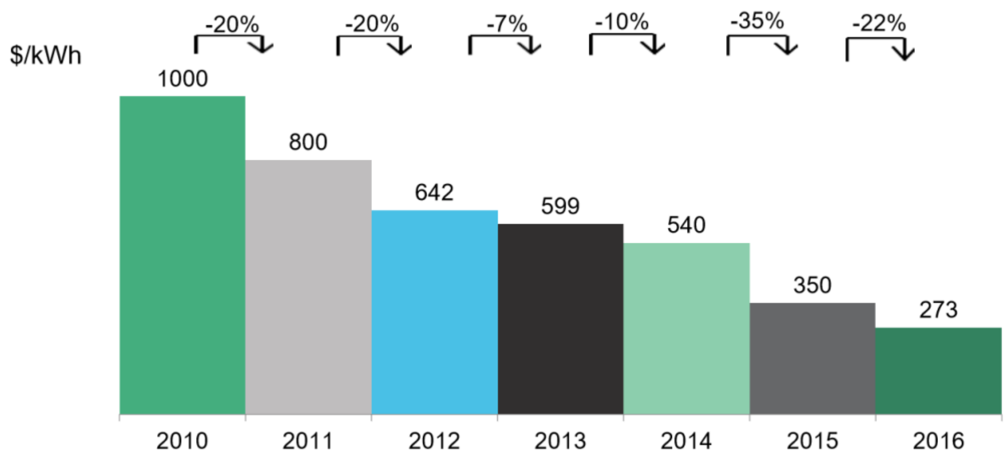

Figure 4. Lithium-ion battery prices per kilo watt hour from 2010-2016 (Curry 2017)

2.4 Charging Stations

Following the trend, the future will be having a majority of electric cars on the road. People would like to recharge their cars not only at their homes. And charging stations are the infrastructure built specifically for such purposes.

There are several types of charging stations based on the amount of power withdrawn. Slow charging station uses 11kW – 22kW power and it is built in household garage and parking lot. Building it requires changes on the electrical system that a local electrician can adjust. While fast charging stations require a coordinated work of engineers and electricians to build and install. It withdraws up to 120kW.

Most countries in Europe and North America are investing great deal of money on establishing public charging system. Especially fast charging stations are being deployed along highways and roads. There are two major obstacles for spreading fast charger station. The grid is not originally designed to handle a huge load like a charging station. Thus, adjustments that are mostly expensive are enforced. Secondly, there is no universal charger standard. Each standard has unique structure and protocol that makes it incompatible with others. Even though there are adapters and connectors designed to work across different standards, several charging stations must be built for each standard. Figure 5 displays the DC fast charging station in the city of Vaasa.

Figure 5. DC fast charging station in Vaasa (picture by Marda)

3. THEORY AND BACKGROUND

3.1 The Charging System

Electric cars can be recharged in two different ways. The first is conventional charging using electricity from the grid. The other one is regenerative braking which is accomplished when the car is braking or decelerating while driving on the road. It seems an odd principle given that all ordinary cars refuel only while at rest. Although it does not provide a large amount of charge to the car, it elongates the usage of the brakes. In other car types, when the car decelerates the kinetic energy of the moving car is converted to heat and friction on the brakes. Instead electric cars use the kinetic energy to run a generator that converts it to electric energy that is stored in the battery pack.

The charging system of electric cars transfers electric power from the grid to the batteries. And according to Purwadi, Dozeno and Heryana, it has three main functions. (Purwadi, Dozeno & Heryana 2013:2)

I. AC to DC conversion: Electric power in the grid exists in AC form, while batteries operate in DC form. So, the charger converts it before delivering it to the battery pack.

II. Voltage Regulation: Noise is a constructive or destructive signal that causes the expected voltage to be higher or lower than the expected limit respectively. Although lots of measures are taken to reduce the effect, it is impossible to completely avoid it. Hence, the voltage is regulated to get steady level by the charger.

III. Coupling: The charging system is also responsible for the establishment of physical connection of the electric car and the charging station using a coupler.

The main part of the charging system is the charger. It is responsible for the AC to DC conversion and voltage regulation. And based on location of installation, there are two types of chargers: On-Board charger and Off-board charger.

- On-Board Charger: It is installed in the car and used for lower power transfers in AC mode. It is small in order not to add much weight on the car.
- Off-Board Charger: It is installed in the charger station that enables to bypass the on-board charger and charge the batteries directly. It is developed to enable the EV to recharge within short period of time using high power. It is also equipped with a communication system that enables the car to interact with the grid. Development of off-board charger infrastructure is way more expensive compared to on-board charger because a lot of times, it requires modification on the existing grid.

Modern electric cars are manufactured with built in on-board charger. This has enabled users to charge their cars without additional electric systems. Thus, any electric car can charge using ordinary electric outlet.

Charging systems are divided into two categories based on its construction and methods of operation. These are Inductive and Conductive charging systems.

I. Inductive Charging System

This is a wireless means of charging electric cars using inductive power. The charging station is embedded on the ground. It contains a primary coil along with other electronic components to generate alternating magnetic field. In order for electric car to charge using this system, it has to be equipped with secondary coil and it has to be physically parked over the station. The secondary coil is used to induce electricity when it comes in contact with the magnetic field generated by the primary coil. Then the induced electric power is stored in the battery pack.

Inductive charging system is a new and growing area of charging systems. It creates the possibilities to charging while in motion and more. But it is expensive to deploy and has low charging efficiency. Figure 6 shows inductive charging system on electric car.

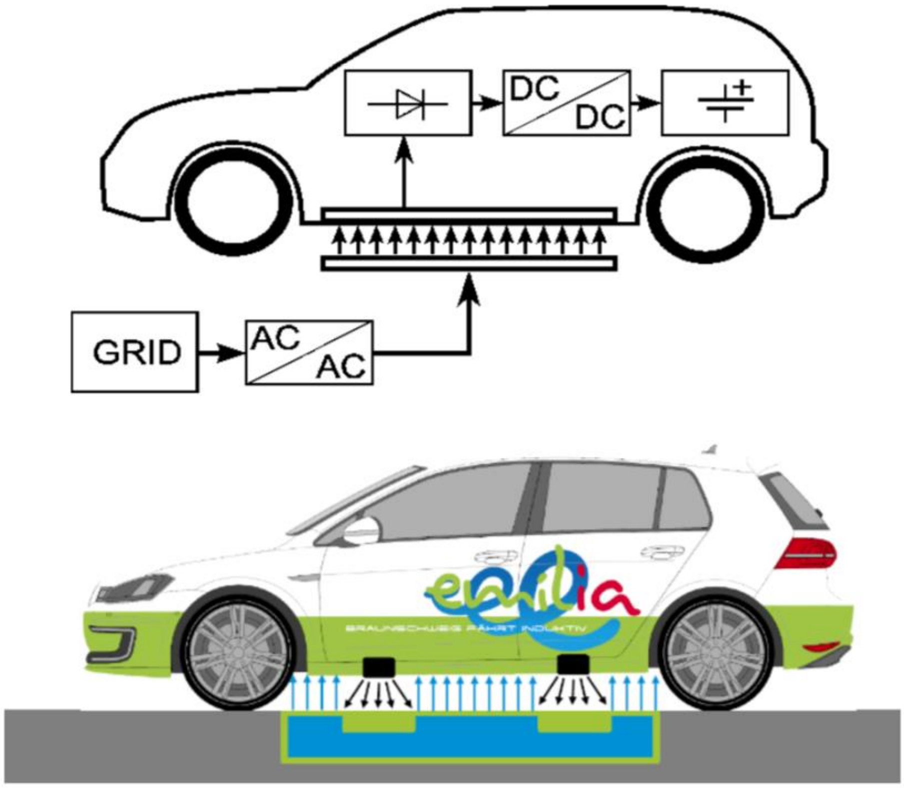

Figure 6. Inductive charging system of electric cars (Henke & Dietrich 2017:2)

II. Conductive Charging System

This is a plug-in charging system where an electric car is plugged into electric outlet or charging station. It uses on-board charger to transfer power to the battery pack. It is the widely deployed and used type of charging system.

3.2 Battery Pack

The battery pack of electric cars is compilation of battery cells connected to create bigger capacity energy storage. Individual cells are first connected to form modules that collectively create the pack. A module can be of any size depending on the car manufacturer. The main importance of grouping it in modules is to make the battery management easier.

There are several types of rechargeable batteries in the market, but the recent most commonly and widely used type is lithium-ion battery. Lithium-ion battery uses lithium cobalt oxide as a cathode and graphite as an anode. It can achieve energy density of 200+ Whr/kg and 80-90% of charge/discharge efficiency. (Wikipedia 2011) It is commonly used in electronics such as laptops.

The battery pack come in all sizes depending on the electric car model. The bigger it is, the more range the car has where range is the distance that can be covered by one full charge. But with bigger battery comes more cost and added weight. The added weight affects the performance of the car because it creates high inertia. On the other side, it is beneficiary since it gives the car low center of gravity. Most electric cars place their battery pack spread on the bottom center of the car. This helps the car from easily flipping in case of accident. Also, it is very hard and heavy structure so when the car is hit from side, the pack can absorb the force and prevent excessive damage to the passenger and driver. Figure 7 shows the battery pack of a Tesla electric car.

Figure 7. Tesla battery pack (Teslaupdates 2016)

Batteries are sensitive to temperature. For instance, lithium-ion batteries don't recharge below freezing point. To avoid harsh environment impacts, the battery is sealed and covered well. But extreme weather conditions still affect it and consequently the car's performance and range are affected. The level of impact differs from one car model to another. Some electric car models have relatively steady performance throughout the year regardless of weather conditions. That's why we see countries with predominant winter (harsh weather) using significant number of electric cars. For example, Norway has a weather with dominant and sometimes harsh winter. Yet, it is the top electric car sales per total car sales ratio in the world.

The lifetime of a battery is limited. And with electric cars having huge size and expensive battery pack installed scares many users from buying one. Since modern electric car technology is relatively recent phenomena, the research done so far might not be realistic but more a prediction. For instance, Nissan Leaf is a bestselling electric car as of December 2016. And in 2015, Nissan stated that they only replaced 0.01% of batteries for failure/damage reasons inflicted by external damage. And there are vehicles with 200,000km mileage with no battery problem. (Wikipedia 2011)

3.3 Battery Management System (BMS)

The charging system of electric car needs close control and monitoring. The components can be deadly if not handled well. It is easy for fire to break out in an environment with high power electricity and mobility. Even a small error in a single battery cell can cause damage that can spread to the other cells. To prevent potential harms, a system that closely monitors and enforces corrections to the damages is required.

Battery Management System(BMS) can be called the brain of the system. It manages the battery pack, battery monitoring, maintenance, battery optimization and failure detection. It uses microprocessor-based electronics to collect and analyze data from the battery cells. Hence, the BMS can come up with information such as the state of charge, distance prediction and battery conditions that are displayed on the board computer. (Bradford 2010) It interconnects commands from the user to the battery system and from the battery system to the user. This guarantees reliability. It also executes necessary electrical power management commands to determine the speed of the car.

During emergency such as car accident, active battery can be deadly. The battery pack is heavy and high powered. Hence an accident on the car could expose it to conductive objects such as metals and water. And lithium-ion battery is known to explode in fire which adds up to the risk. That is why BMS is very important as it is responsible for isolating the battery pack in extreme situations.

BMS can be different for different car models. Manufacturers develop BMS and algorithm that can best serve the system of that particular model. And one car model can be very different like in battery pack size from other cars which forces them to develop unique systems.

3.4 Modes of Charging

Electric car can be charged using several but defined amount of power and speed. According to the European Committee for Electrotechnical Standardization or CENELEC, specifically the standard CENELEC EN 61851-1 on wired charging of electric vehicle classifies four different charging modes. (CEN-European Committee for Standardization 2011.)

3.4.1 Mode 1 - Slow Household Charging

Electric cars can be recharged in residential house using the usual wall socket that is 120/240V outlet because every electric car is manufactured with a built-in on-board charger.

This mode of charging uses less than 11kW power and 16A current in 250V single phase or 480V three phase socket. Hence it is the slowest of all charging modes. Total charging time would be between ten to fifteen hours, depending on the battery size of the car.

For a number of reasons, this mode is very widely used by electric car users. The user is not required to make any modifications to the home electrical system. Secondly most users drive their car to move to places in the daytime and park it when they are going to sleep. This sleeping time gap is estimated to be seven to eight hours per day, which is enough time for most electric cars to fully charge. The night time charging is most effective and cheap due to less electric usage at night. So, this doesn’t create overload on the power grid.

3.4.2 Mode 2 - Modified Household Charging

This mode of charging is also used in residential house and garage. Any residence that wants to accommodate this mode of charging needs modification on the house electric box, fuses and cables which requires professional electrical installation using a dedicated electrical circuit. It is faster than mode 1 charging but overall it is still slow charging mode.

It uses less than 32A current and 22KW power in single phase or 480V three phase. An average electric would take around six to ten hours to fully charge.

3.4.3 Mode 3 – AC Rapid Charging

It requires a dedicated charging station and cable. The charging station must be permanently connected to the main AC and control communication between vehicle and the grid. One of the charging cable component is used for control pilot that enables communication between the station and onboard charger. It is used to verify the connection, enabling and disabling electric flow from supply and selecting the charging rate. (Electrical and Mechanical Services Department of Hongkong 2015) It uses about 64A current and 43kW power. AC rapid charging charges the battery completely in four hours.

3.4.4 Mode 4 – DC Fast Charging

This is the fastest way of charging electric car. It uses an off-board charger to charge the batteries directly in DC by bypassing the onboard charger. The energy is directly transferred to the batteries. Since the on-board charger is not used, there is no additional loss of energy during the charging process. Hence this charging is more efficient. On the other side, since the system is bypassing the onboard charger, it is necessary to provide information about the type and state of charge (SOC). For such reasons most DC charging stations only let you charge for 20 - 30 minutes.

Charging using this mode can add you in average of 80-100 miles range in a 30 minutes of charging time. The IEC 62196 standard allows it to charge up to 400A current. This type of charging uses very high power from 50kW up to 120kW and Direct Current. (Kettles 2015:7)

This mode of charging requires to build charging stations which are more expensive than the other modes. It draws large amount of power from the grid so there will be needed adjustments to strengthen the ordinary grid infrastructure.

Mode 4 is the most convenient way of charging in times of hurry, such as charging in between road trip and on the side of a highway. For these reasons large companies such as Tesla are investing a huge amount of money in establishing these charging station in selected key places throughout long country roads.

3.5 Types of Chargers (Plugs)

Any electric car can be charged in all charging modes using specifically designed chargers or plugs. And different plugs are designed depending on the type of the car and charging mode. Countries such as US, Japan, China and European countries have been working on establishment of standardized plugs for their countries. So far, some standards have been established which we can categorize into two groups: AC chargers and DC fast chargers.

The modes of charging 1, 2 and 3 input AC current to the on-board charger. So, they use AC charging plugs. And there are many AC plugs in the market today. Focusing on the popular AC public charging stations, which uses mode 3 charging, there are 2 widely used standards: SAE J1722 and Mennekes (IEC 62196) type 2 connector. (Longo, Maffezzoni, Zaninelli, Lutz & Daniel 2017:2)

DC fast charging plugs are used in charging mode 4. Since the mode 4 uses very high power to charge in a short amount of time, these plugs are designed to accommodate high current and voltage flow while being safe for the user. There are four standard DC fast charging plugs available: Combined Charging System (CCS), CHAdeMO, Tesla Supercharger and GB/T 20234 plug.

3.5.1 SAE J1722 Plug

It is a single-phase coupler widely used in the US, Japan and other countries which have mainly a single-phase distribution network. It is used by several versions of Nissan Leaf and Chevrolet Volt.

It has 5 pins: AC line 1 pin, AC line 2 pin, ground pin, proximity detection pin and control pilot pin. Figure 8 illustrates different views of SAE -J1722 plug. This plug has 2 charging levels AC level 1 and AC level 2. AC level 1 uses 120V single phase with maximum current of 16A. It is used as mode 1 charging. AC level 2 uses 208V and 48A on leg to leg 3-phase or 240V on split phase. (Wikipedia 2015)

Figure 8. SAE J1722 plug (Longo, Maffezzoni, Zaninelli, Lutz & Daniel 2017)

3.5.2 Mennekes (IEC 62196) Type 2 Connector

It is a single and 3-phase coupler manufactured by a company called Mennekes which is widely used in Europe. It was chosen as official charging plugin within European Union in January 2013. Then more countries accepted this connector, including New Zealand. Meanwhile it was tested and standardized by the German Association of the Automotive Industry (VDA) as VDE-AR-E 2623-2-2. (Wikipedia 2016)

IEC 62196 is round shaped with seven pins of different sizes and functionalities. It can handle a power supply up to 40kW. Figure 9 presents the front view of a type 2 connector.

Figure 9. Mennekes (IEC 62196) Type 2 Connector (Wikipedia 2016)

3.5.3 CCS - Combined Charging System

CCS is a combination of AC coupler with DC coupler that is derived from SAE J17722 designed to be used for a fast charging. It was a collaborative design of an American and German company in intention of producing a faster charger than the AC chargers.

This plug is capable to charge with the power of 350kW power of charging. The high power can be deadly if it is mismanaged, so the CCS has a lock mechanism to prevent from being suddenly unplugged. However, the CCS charging stations use only 50kW output power because most cars can’t charge with more than 50kW.

The CCS has been chosen as international standard fast charger as described by IEC 61851. (Gjelaj, Træholt, Hashemi and Andersen 2017:2) It is widely used in vast areas of Europe and also in parts of the US. Since it was a collaborative design of US and Germany, it is the widely chosen charger in cars like Audi, Volkswagen, BMW, Ford and General Motors. Figure 10 shows picture of CCS charger.

Figure 10. CCS charger (Eldis 2015)

3.5.4 CHAdeMO

CHAdeMO is the short for "CHArge de MOve" which can be translated to ‘move by charge’. It is originally developed by a Japanese company and it is capable of charging with 62.5 kW power, 500V/125A.

The plug is big in size as compared to other fast charger plugs. Figure 11 presents picture of CHAdeMO plug held by a person. It is the charger of choice for the Nissan Leaf, Kia Soul EV, Mitsubishi EVs and Citroen. Tesla cars can use it by applying Tesla adapter. Tesla adapters are an add-on product developed by Tesla to allow its vehicles to charge in CHAdeMO stations. In Spite of different models of CHAdeMO chargers, all are designed to fit to Tesla adapters.

Figure 11. CHAdeMO (Wikipedia 2011.)

3.5.5 Tesla Supercharger

This is a plug designed to charge Tesla electric cars in the fastest way. The supercharger is located in stations that are deployed in US, Europe and other countries by the Tesla motors company.

This plug can charge a car using up to 120kW of power and it can charge a Tesla model S car, fully in 75 minutes. So far, this plug is only used by Tesla cars only because other electric vehicle chargers don't fit it and no adapter has been made to unify the different chargers. Figure 12 presents a picture of Tesla supercharger plug.

Figure 12. Tesla supercharger plug (Spang 2014)

3.5.6 Chinese GB/T 20234 Charger

It is the standard electric car charger in China. There is not much research done on the charger except it is similar to the German charger Mennekes IEC 62196 only with few alterations. It can be used also for AC fast charging. It charges up to 400V on DC.

The Chinese market for electric car has a huge potential. The country has shown interest in implementing environment friendly technologies and introducing electric cars to the vast majority. Thus, the electric cars that are imported to China have to have the GB/T 20234 plug. Since there is a huge market, companies are showing interest to produce their cars with GB/T 20234 standard.

DC fast charging was developed by several companies to overcome the slow charging process that can be inconvenient for electric car users. Hence, there are four standards rather than having a single universal standard. Having four standards have forced companies to spend lots of money. Several countries have several dominant standards although all standard chargers can be used anywhere in the world with the right infrastructure. For instance, Tesla superchargers are only used by Tesla cars which makes it expensive and lowers profit.

3.6 Power Grid and Electric cars

The grid is an electrical network that interconnects power plants with customers. Electricity is often generated in remote areas and travels long distance to reach the customer. It travels in very high voltage and low current on the long transmission lines in order to reduce the power loss. But the high voltage to low current ratio is not needed by regular consumers, thus transformers change the voltage and current levels to defined standard levels. The consumer electric systems are commonly defined as loads.

Electric cars can have different roles on the grid depending on the type of interaction. There are four types of electric car and grid interactions:

I. Grid-to-Vehicle: Is the most widely used and simplest form of interaction. The current flows from grid to the batteries of the electric car. And there is only one-way communication from grid to the car.
II. Vehicle-to-Grid: In a system where, two-way communication between the car and grid can be established, the stored energy in the battery pack is used to contribute electricity to the grid upon request. It is very helpful in stabilizing the grid during peak hours.
III. Vehicle-to-Home: Most electric car owners park their car in their garage. And while it is parked it can be used to provide electricity to the house.
IV. Vehicle-to-Building: Similar to the two mentioned methods above, the energy from battery pack can be used to provide electricity to a building.

3.6.1 Grid-to-Vehicle Interaction

Electric car is considered as a high-power load while recharging from the grid. And this is the most widely used interaction because communication is not required, and less modification is needed.

The current electric grid systems are not designed for charging electric cars. Although in many cases enough power could be generated to accommodate a growing number of electric cars, the local, especially residence area distribution network is not ready to accommodate the fast-growing demand. And most users use this electrical network to charge their car overnight. Figure 13 describes the distribution of electricity from power plant until it reaches the charging station. The picture was drawn using free picture sources.

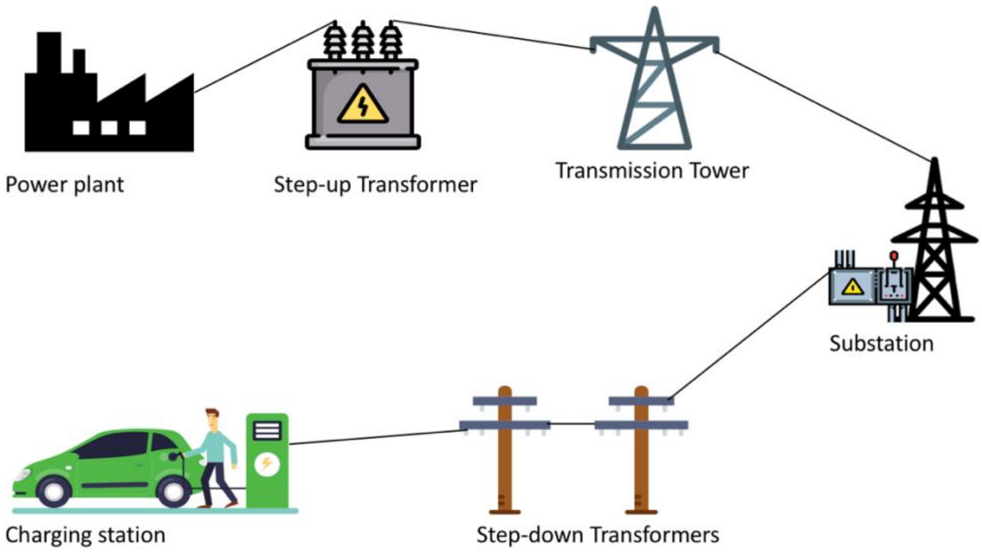

Figure 13. Electricity distribution from power plant to a charging station

Transformers are one of the main components in the grid that are highly affected by electric car charging stations. For instance, charging modes 1 and 2 usually occur in the household. The electric grid distribution system for residential area often include a transformer that can handle 10-50KVA. Let's say a few families in the area that share a transformer use level 2 charging with 240V which is in average around 7KVA. Hence, a few electric cars would easily overload the transformer.

Charging modes 3 and 4 require constructing a dedicated charging station because it draws high power from the grid. This includes significant alterations on the existing transformers to make them accommodate on higher power or total replacement with the new capable ones.

Power quality is the creation of constant and regular power supply, free of noise. It is dependent on both the power supplier and the load. From the power supplier side, we have seen how transformers can affect the system. Since transformers can be very expensive, we need to come up with alternative solutions that can be applied to the loads.

Charging regulation can be placed on the system to increase the power quality. Charging regulations monitor the amount of energy withdrawn by the electric car chargers especially during peak hours. Peak hours put lots of loads on the grid that the power quality is forced to decrease. Adding high power load during that time affects the power quality even in a much worse way. A research in California found out when electric cars are simultaneously charging, significant power degradation is experienced. It showed that the Total Harmonic Distortion of the current has varied from 3% to 28.11%. This means that the power factor has dropped from 1 to 0.96. (Monteiro, Gonçalves, Ferreira & Afonso 2012.)

3.7 Energy Sources

The electricity that powers electric cars is generated from several energy sources. Its distributed to users via the grid which is fed by several power plants. Power plants are industries used to utilize one form of energy and convert it to electrical energy. The electricity production process can be very complicated or relatively simple depending on the energy source. For example, nuclear energy requires big powerplant because of the complicated processes. Meanwhile, solar power requires little setup.

There are 2 types of energy sources: renewable sources and non-renewable sources

- Renewable Sources: These are energy sources that have unlimited supply. It consists of solar, wind, hydro, geothermal and others. These sources are usually environment friendly.
- Non-renewable sources: These are limited or finite sources. It includes coal, petroleum, natural gas, nuclear energy and others.

There are number of energy sources used to generate electricity. Some of the commonly used sources are solar, wind, hydro, nuclear and fossil fuel.

3.7.1. Solar Power

The sun is very powerful source of energy which has been used for years. It has been utilized in different areas of life. One aim of solar energy is to generate electric power.

The sunlight is converted to electric power using solar panels. Solar panels are smooth plane panels that absorbs sunlight to generate electricity. It is made up of smaller units called solar cells. Solar cells are usually constructed from two silicon layers, one positively and the other negatively charged. When sunlight hits the cell, the negatively charged silicon electrons fall to the positively charged layer. This creates direct current flow.

Number of solar cells are connected and mounted together to create a module. And modules are grouped together to form an array. This array of solar panels generates direct current. The generated current is incompatible with the grid because the grid uses AC power input. So, the generated power passes through inverters and step-up transformer. Solar panels get sunlight in the daytime, so power generation occurs only in the day time.

Solar power is usually used in small power applications such as water heating system, water pumping and lighting. It is rarely implemented to energize high power applications because in order to produce high power, more modules are needed. And this requires large area to setup. Additionally, the panels have to get direct sunlight, so it has to be set in clear area. Such conditions are hard to fulfill in urban settings where buildings can shadow and block sunlight. Thus, such barriers make solar power less desirable.

Some electric car charging stations are built under solar panel. The panel generates power when sunlight is available. In the absence of sunlight, most stations use power from the grid or from energy storage component. Most solar system have energy storage component where electric power is stored in the day time and dispensed in the absence of sunlight. Figure 14 shows the 3D animated picture of future Tesla supercharger station that is powered by solar panels and disconnected from the grid.

Figure 14. Tesla supercharger station powered by solar panels (Hanley 2017)

3.7.2. Hydro Power

Hydro power plant takes advantage of gravity and uses the energy of water fall to generate electricity. The idea of this came from old system of grinding grain using a while that turns by flow of a river. Then the idea evolved to using waterfall which has much kinetic energy.

A hydro power plant consists of a dam or waterfall, turbine and generator. Most power plants have built dams around the river to accumulate the running water. By doing so, it creates potential energy. The dam has mechanism to control the amount of water it releases. This enables the plant to control the potential energy and generate the desired amount of power. Thus, the natural flow of water has minimum impact on the consistency of electricity generation.

When the water falls from the dam, it hits the turbine that it will start to spin. The turbine size is dependent on the height of the waterfall and volume of water. The end of the turbine is connected to a generator. Then the generator converts the kinetic energy to electrical energy.

Hydroelectric power is the most used renewable energy source to generate electricity in the world. (World Energy Council 2016.) Even though the initial construction cost is high, it is a cost competitive source of energy. And compared to other renewable sources, it is highly reliable.

Most hydro power plants are located in a remote area. Thus, the electricity generated is delivered to customers after passing through transformers, substations and long-distance transmission lines.

3.7.3. Wind Power

Wind power is one of the most applied energy sources in the world. It uses turbines to generate electricity. Wind turbines have blades attached to the rotor on top. Inside the rotor is a generator which connected to the blade rotation. Thus, whenever the blade rotates, electricity is generated.

The height of the wind turbine is directly related to the amount of energy it produces. At high attitude, the wind power is stronger and free from turbulence. The stronger wind would turn the rotor blades at higher speed which implies higher power production. Figure 15 shows the relation between the height of the turbine and amount of power produced. The 35-50 feet wind turbine produces 400W power while the 80-120 feet wind turbine produces 10kW power.

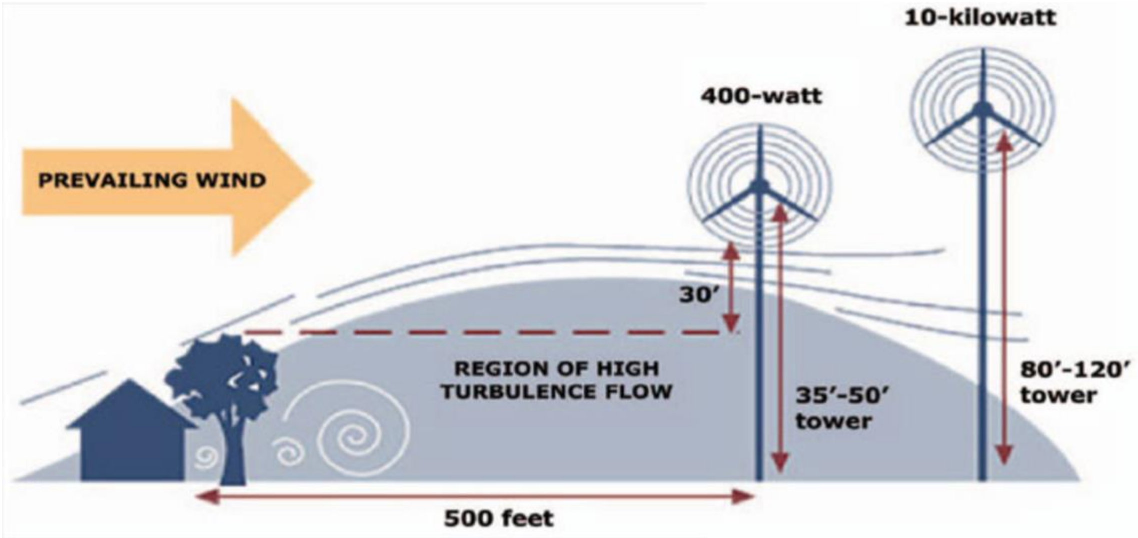

Figure 15. Wind turbines height and power relationship (Stankiewicz, Dvorak & Froese 2009)

Wind power is currently evolving sector in the world. It is inexhaustible and resilient source which makes it environment friendly. It needs less space for deployment. But it has some disadvantages such as: it has high initial investment and it can pose threat to birds.

3.8 Public Charging Stations

Most electric car users charge their car at home garage or parking space with charging station. These types of charging are slow and can take up to eight hours for the car to fully charge. This can be inconvenient at times. So public charging stations are built to achieve faster charging i.e. less than four hours.

Building charging station has its challenges. Several factors such as limited adoption of electric cars have a huge contribution. In comparison to gas cars and hybrid cars, the number of electric car is very small. So, deploying number of charging stations may not be profitable in a short period of time. On top of that, electric cars have short range. This implies that the charging stations should be built many in number and in close distance with each other.

There are different standards surrounding the charging system of electric cars. Countries like US, Japan, China and European union members have established their own charger standard.

Big car companies in Europe such as Volkswagen manufacture their electric cars with CCS charger, while other companies like Nissan use CHAdeMO for DC fast charging standard. Meanwhile, Tesla Motors, a company that only manufactures electric cars, have established their own charger standard, the Tesla supercharger. These has created huge challenge in building uniform standard charging stations.

The three standards: CCS, CHAdeMO and Tesla supercharger are in competition to become the most dominant in markets of US and Europe. At the beginning of the vast charging station deployment in US and Europe, the Nissan Leaf car was the most sold electric car in the world. And Nissan Leaf uses the CHAdeMO charger, so that made CHAdeMO charging stations to be deployed in mass ahead. At that time, it was the most deployed charging station compared to the CCS and Tesla chargers. But in the long run, other car manufacturers started to produce electric cars which used the CCS standard. Hence, more CCS stations where built especially in European countries. (Wikipedia 2011.) Figure 16 and 17 show the distribution of CHAdeMO chargers and CCS chargers in Europe respectively.

Figure 16. Distribution of CHAdeMO chargers in Europe (Longo, Maffezzoni, Zaninelli, Lutz & Daniel 2017)

Figure 17. Distribution of CCS chargers in Europe (Longo, Maffezzoni, Zaninelli, Lutz & Daniel 2017)

Tesla cars are currently (by April 2018) the most sold electric cars. And the company is making investment on deploying supercharging stations. Thus, the supercharging stations could become the most deployed DC fast charging stations in few years. (Lambert 2018.) Figure 18 shows the distribution of Tesla supercharger stations in Europe.

Figure 18. Distribution of Tesla supercharger stations in Europe (Longo, Maffezzoni, Zaninelli, Lutz & Daniel 2017)

Nowadays, DC fast charging stations are being built with 2 charger/plug options one CHAdeMO and the other CCS so that any car with either charger type could use it at a time. Tesla model cars can also use this station using CCS adapter. Such stations can charge more than 80% of electric cars present in Europe, US and Japan.

Public charging stations often times are AC fast charging (mode 3) or DC fast charging (mode 4). The building process and cost of each structure is different. Deploying AC fast charging station requires high power cable for the outlet and modified electric system to control the high-power transfer. This requires minor or none modifications on the electrical components such as transformers on the local grid distribution.

DC fast charging stations are the most expensive of all to deploy. One of the reasons is because it requires change in the transformer of the local grid to support the huge power surge. Such alteration require consent from local authority and electricity distributing company which might be subjected to monetary cost. Also, DC fast charging stations require electronics components such as AC to DC converter, voltage rectifier and controller in its system because it has to convert the AC power from the grid before passing it to the car system. Since the charging mode bypasses the on-board charger of the car, offboard charger is installed as part of the charging station.

4. IMPLEMENTATIONS OF THE SYSTEM

4.1 Overview of the system

Our city Vaasa and surrounding area has four electric car charging stations which are operated by different companies. In this thesis, the functions of these charging stations is acquired as inspiration to simulate a system for eleven hypothetical charging stations located in those four locations. It gives users access to information about these stations. using a mobile app. The app provides full information about the stations and it connects the users to find compatible ones for their car.

To develop the app, the first step is laying out problems the app intends to solve. Then it continues to the design of the system architecture, activities and the definition of the core functionalities or methods.

Modern electric cars are a recent phenomenon and the problem surrounding users in relation to charging stations is growing through time. The access of charging stations to users such as the urgency to locate the nearby charging station with compatible plug type is necessary. Electric cars have a small range. Thus, they need to be recharged frequently. Even though there are few electric cars, the charging stations can often be busy. On top of this, the station can be occupied for hours, especially in cases of AC fast charging. Hence, users need to know the availability, charging time and the location of a station compatible to their car's plug type.

The app in a way solves the problem in hand using these main functions which are locating charging station, establishing availability status, estimating charging time and charging cost.

The app is developed using android studio and integrated Google maps API. Android studio is a platform used to create/code and simulate mobile apps for android phones while the google maps API enables to display map and map data. The API is integrated to the app using unique API key which has to be fetched from a specified website and put on the google_maps_api.xml file. Hence, the map of Vaasa is displayed on the opening of the app where charging stations are marked clearly so that users can see the locations on the map. The station's detailed information is provided on snippet, which appears when the user clicks on the marker.

Availability information is one of the most important features included on the app because charging electric car on public stations can be time consuming (between 0.5 to 4 hours). By opening the app any user would know which stations are occupied or free at any given time on the map. Since the charging stations connection is simulated, there is no way to get the real time availability information of a station. So, the availability check on the system is generated using random number to simulate the availability of the station at any given time.

Electric cars operate on several standards which make it nearly impossible to use any given charging station. Information about the standard charging mode and type of plug is the most important information required to know beforehand. The app enables users to choose their desired charging mode and plug type of their car, then it returns the available charging station which fulfills the criteria. By clicking on the result, they can also view details about the charging station like its source of energy and precise location.

One of the unique features of the app is to read the input information such as charging mode, car model and state of charge (SOC) from the user and it calculates the estimated charging duration and the charging cost. Figure 19 illustrates how the app works and shows the main functions in the app.

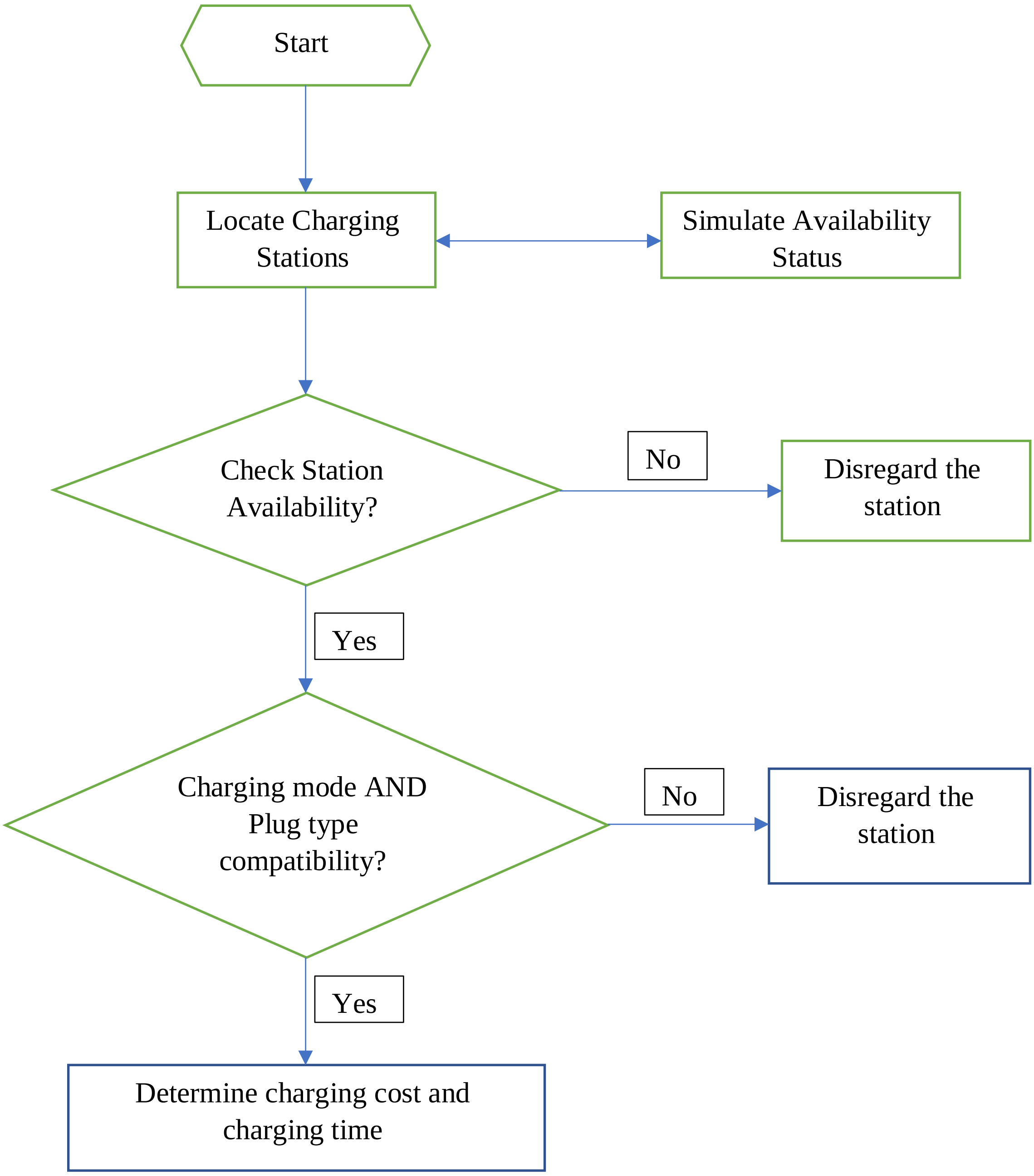

Figure 19. System design flow chart

4.2 System Design

The app that has been developed is using the data first approach. The data is encoded in a data source file for a lookup during processes. Figure 20 explains the system design in the form of Use Case Diagram.

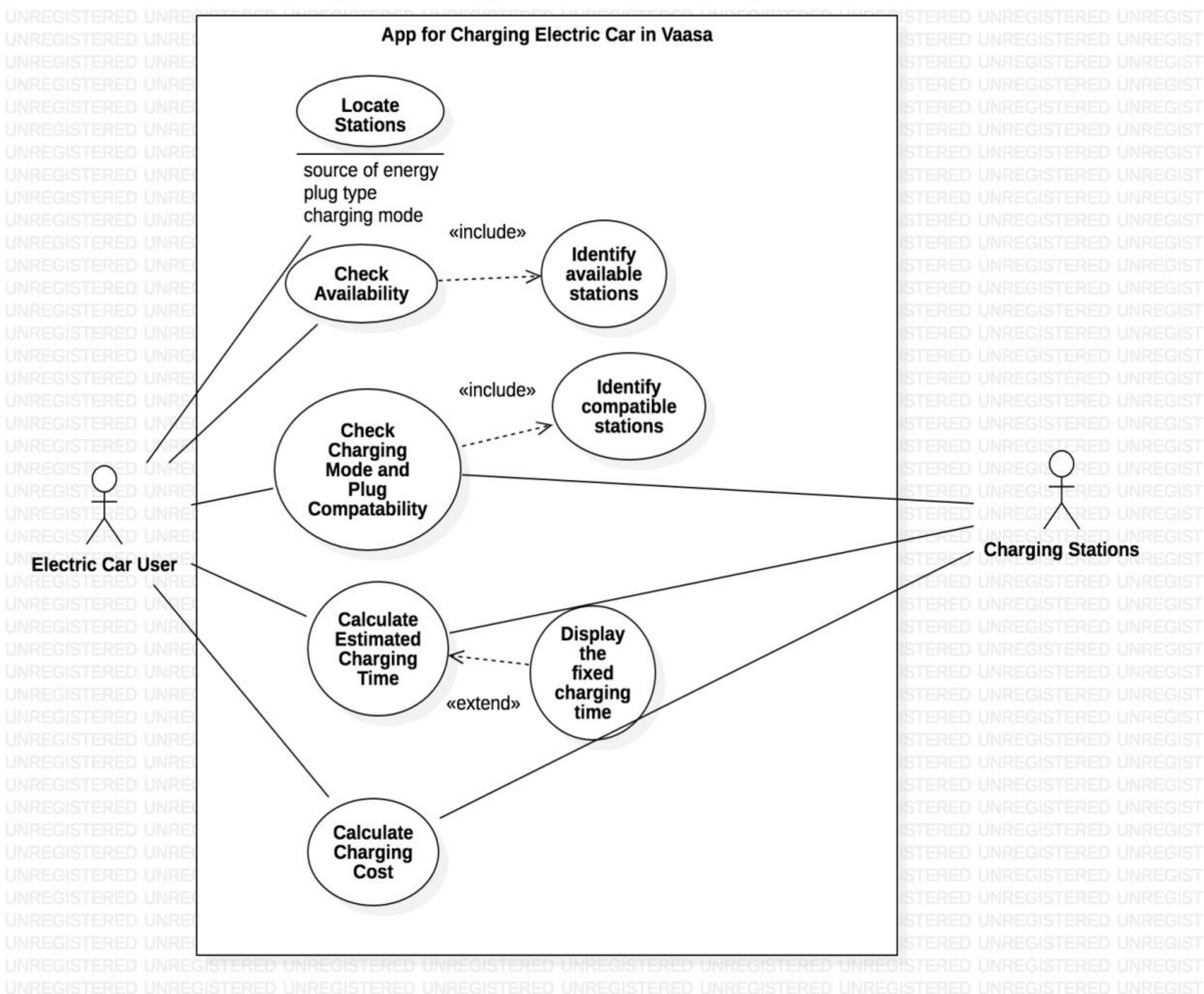

Figure 20. Use case diagram for the app

4.3 Main Functions of the App

4.3.1 Locating Charging Stations and Availability Check

Charging stations are first located on the map of Vaasa using red markers on the exact positions. Their location, source of energy, charging mode and type of plug is hard coded on the app. User can see it by clicking on the marker where a snippet appears with thus information.

Availability check is simulated when the app is first opened to indicate if a given station is occupied or free. In a real life deployed system, this data would had been obtained from the stations but in a simulated case, the status is set by using modulo 2 operators on generated random number in the data source file. The modulo 2 operator results in 0 or 1, where 0 is used to indicate the station is free and 1 is for occupied.

4.3.2 Charging Time Estimation

Charging time depends on several factors such as car battery capacity, charging point power output, battery condition or age, temperature and state of charge. And getting exact estimation is difficult because a lot of parameters are unpredictable and thus their relationship is not exactly defined. For example, a battery charging is charged faster from 10% to 80% than from 80%-100%. This is because the battery controller gets to “trickle mode” which is very slow. For such reason DC fast charging only, charges cars up to 80% of charge in a short period of time (usually 0.5 hours).

To calculate the estimated charging time of AC charging, the app takes the input for the current SOC, target SOC and car model from the user. The battery capacity is retrieved by referencing the input car model. Then the three components are computed to achieve it. The following equation shows how the calculations are computed.

$$ECT = (T.SOC - C.SOC) * (BC\ (kWh) / Pout(kW)) \qquad (1)$$

Where ECT is estimated charging time, T.SOC is target or desired state of charge, C.SOC is current state of charge, BC is battery capacity and Pout is charging station power output.

4.3.3 Cost of Charging

Electricity is a cheap energy source in comparison to gas or oil. In addition, it is environment friendly. The cost mainly varies based on the hour of the day and the energy source used to generate. The power load is high in the day time which makes it more expensive to charge. But since public charging stations are widely used in the day time, the app will consider day time cost analysis. Table 1 below shows the cost of electricity in Finland that has been generated using the specified energy source.

Table 1. Cost of electricity for different source of energy in Finland (Helen 2018.)

Source of Energy Generated	Average Price in c/kWh
Basic electricity (mix)	4.67
Wind power	5.05
Hydro power	4
Solar power	8

To determine the cost of charging, the user input data for current and target SOC as well as the car model, which in return gets battery capacity, are used.

$$CC = (T.SOC - C.SOC) * (BC\ (kWh) * EC\ (c/kWh)) \quad (2)$$

Where CC is the charging cost in cents, T.SOC is target or desired state of charge, C.SOC is current state of charge, BC is battery capacity and EC is cost of electricity. Table 2 describes the list of electric cars currently (as of May 2018) on market, the type of plug that is provided by the manufacturer and their battery capacity. The list is accessible in the app where users can find and select their car model. It is to mention that Table 2 relies in multiple internet sources.

Table 2. List of electric cars, their battery capacity and plug for AC and DC charging

Full-Electric Cars	Battery Capacity (kWh)	Plug type provided by Manufacturer	
		AC Fast mode	DC fast mode
BMW i3	33	SAE-J1772	CCS
BYD e6	60	Type 2 Mennekes	CCS
Chevrolet Bolt	60	SAE-J1772	CCS
Citroen C-Zero	16	SAE-J1772	CHAdeMO
Fiat 500e	24	SAE-J1772	CCS
Ford Focus 2012	23	SAE-J1772	CCS
Ford Focus 2018	33.5	SAE-J1772	CCS
Honda Clarity	25.5	SAE-J1772	CCS
Hyundai Kona Electric	64	Type 2 Mennekes	CCS
Hyundai Ioniq Electric	28	Type 2 Mennekes	CCS
Kia Soul EV	27	SAE-J1772	CHAdeMO
Luxgen S3 EV+	33	-	GB/T 20234
Nissan Leaf I	24	SAE-J1772	CHAdeMO
Nissan Leaf II	40	SAE-J1772	CHAdeMO
Mitsubishi i-MIEV	16	SAE-J1772	CHAdeMO
Renault Fluence Z.E.	22	Type 2 Mennekes	Type 2 Mennekes
Renault Zoe	22	Type 2 Mennekes	Type 2 Mennekes
Smart EQ Fortwo EV	16,7	Type 2 Mennekes	Not applicable
Smart EQ Forfour EV	16,7	Type 2 Mennekes	Not applicable
Tesla Model S	94	Type 2 Mennekes	Tesla Supercharger
Tesla Model X	94	Type 2 Mennekes	Tesla Supercharger
Tesla Model 3	70	Type 2 Mennekes	Tesla Supercharger
Toyota RAV4 EV	42	SAE-J1772	Not applicable
Volkswagen e-Golf Mk7	32	Type 2 Mennekes	CCS

5. EXPERIMENTS AND RESULTS

In this chapter, different case scenarios are implemented and discussed to reflect how the system works. These scenarios are designed to get deep insight to the services of the app. At each case, specific requirements are given to the app and the results are presented here.

5.1 Scenario 1: Checking Available Stations

Checking available stations using the app is one click away. When the app is opened, the first activity that is presented is MapsActivity. Figure 21 displays the home screen of the app which is the map of Vaasa with markers on the location of the charging stations. The activity has two buttons.

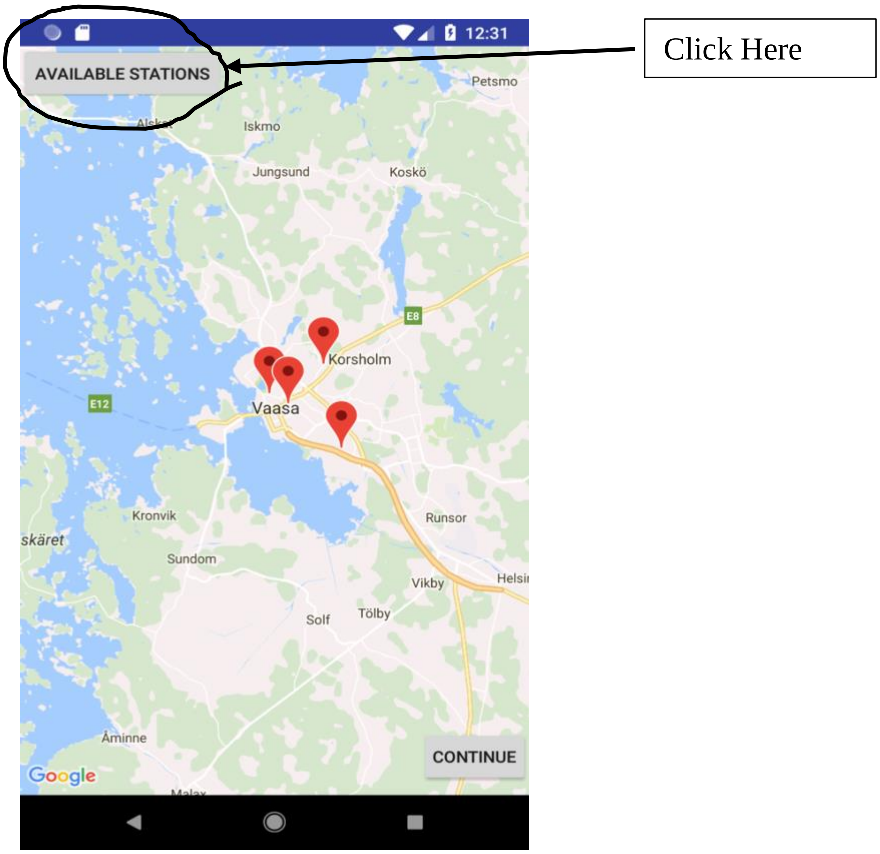

Figure 21. Home screen of the app

When the one on the top left corner “AVAILABLE STATIONS” is clicked, a method in MapsActivity.java is called. The called method implements an Intent object that launches AvailabilityActivity. This activity is used to display the list of available stations including their location, address, charging mode, plug type and energy source.

AvailabilityActivity uses layout activity_availability.xml. The layout uses recycler view GUI component to display the list of available stations. The availability status of the stations is generated and assigned in the data source file Chargst.java when the app first opened. So AvailabilityActivity uses the if conditional statement to filter the available ones and publish the list through the recycler view. Figure 22 presents the detailed list of available stations.

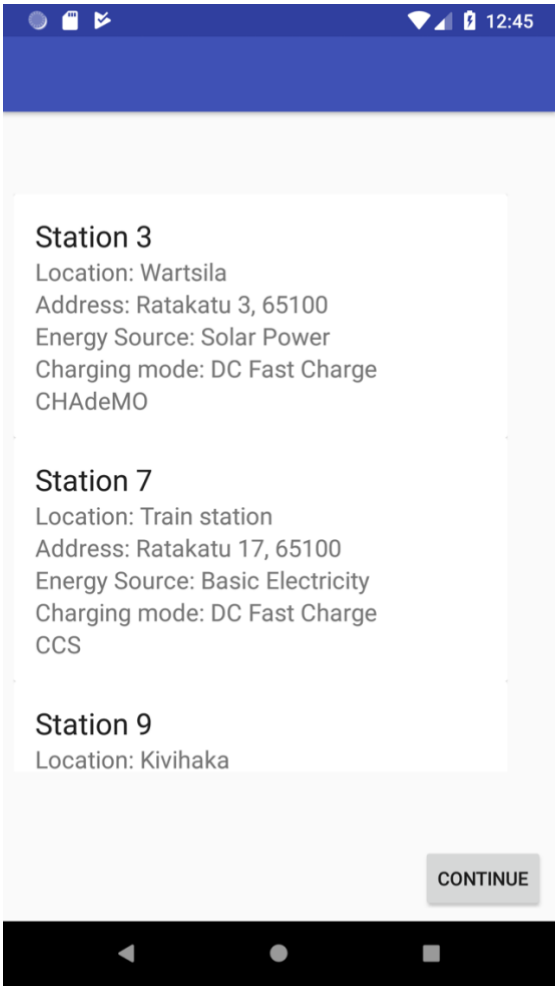

Figure 22. Detailed list of available stations

5.2 Scenario 2: Charging Nissan Leaf II on AC Mode Using Clean Energy Source

Nissan Leaf II is a popular electric car that is manufactured with SAE-J1772 charger. In order to charge on AC mode, one should find a charging station that uses SAE-J1772 plug. Additionally, if a user chooses to charge in stations that use clean energy source, the selections are wind energy, solar energy and hydro energy. Thus, the charging station should fulfill three requirements: available station, SAE-J1772 plug and clean energy.

Step 1: A user can access the selection section of the app i.e. SignUpActivity in two ways. The “CONTINUE” button in MapsActivity and AvailabilityActivity launches the SignUpActivity. It provides alternative to users who first want to see available stations before continuing on. Figure 23 shows how to launch SignUpActivity from MapsActivity (left) and from AvailabilityActivity (right).

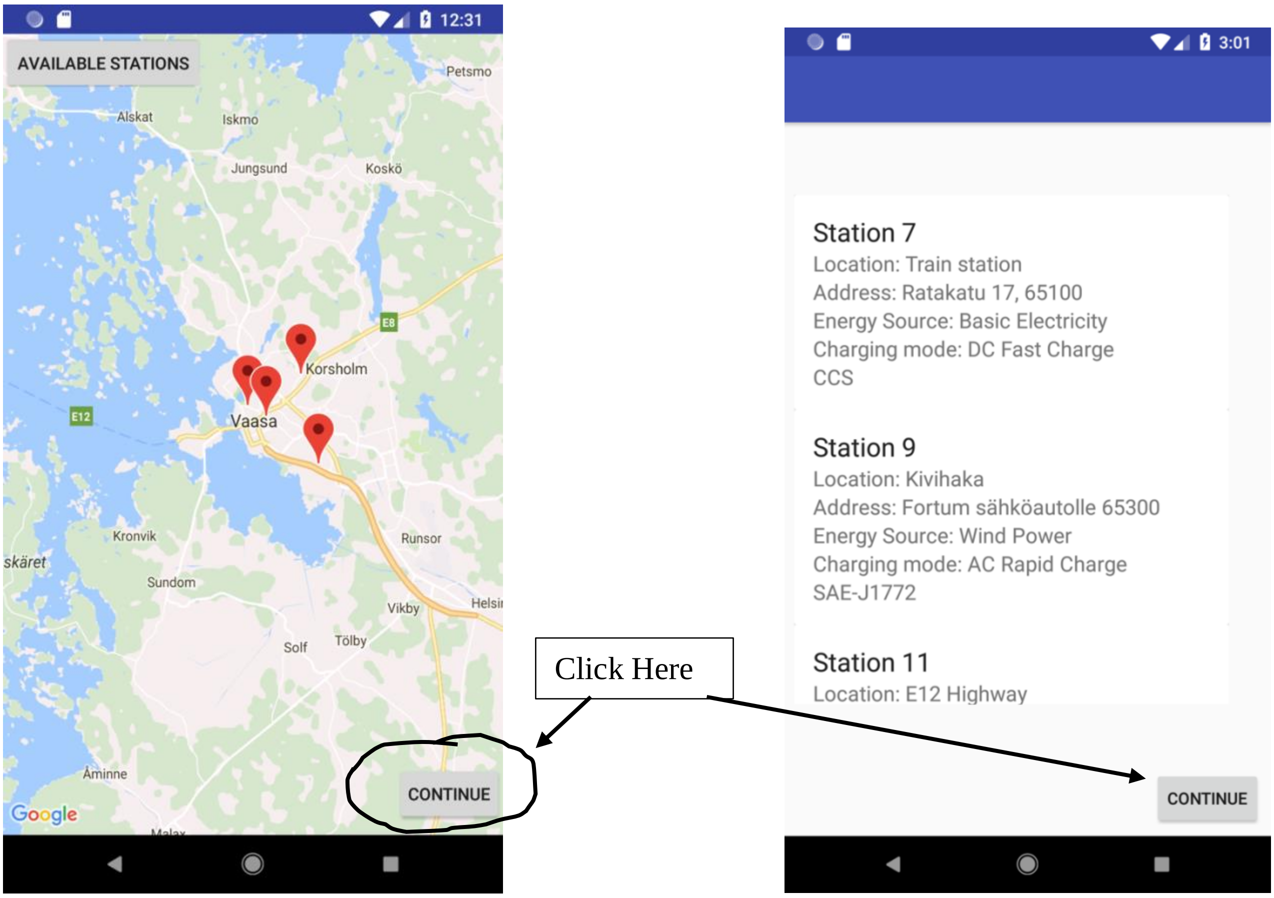

Figure 23. Launching SignUpActivity from MapsActivity (left) and from AvailabilityActivity (right)

Step 2: SignUpActivity uses layout activity_sign_up.xml. The layout uses GUI components a spinner for choosing availability status, five checkBoxes for selecting plug and another Spinner for selecting energy source. The methods in SignUpActivity.java retrieve the selected items of each GUI components because an instance OnClickListner is implemented. Then the selections are cross referenced with the charging station values stored in the data source file, Chargst.java. Thus, the matching stations are identified, and their station name is saved in the form of array of strings. Figure 24 illustrates how to choose the desired plug, availability status and energy source.

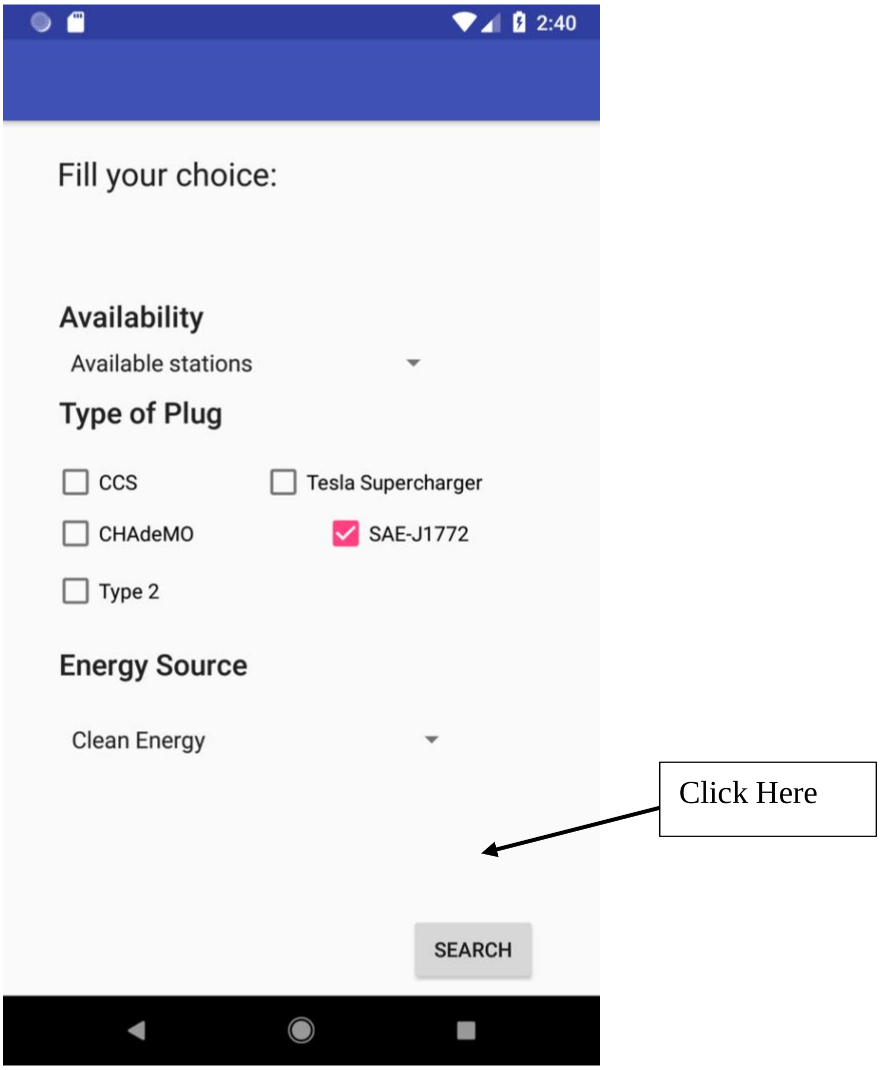

Figure 24. User selections for Nissan Leaf charging in AC mode

Step 3: When the “SEARCH” button on SignUpActivity is clicked, intent.putExtra() method is implemented. This method launches the ResultsActivity and passes the resulting matching stations array list at the same time.

ResultsActivity has a layout activity_results.xml which uses GUI components six textViews and one spinner. The entries of the array list from SignUpActivity is passed to each textView and spinner. Thus, user can choose desired station from the spinner. The selected item is then passed to CalculationsActivity. Figure 25 shows the result of the matching station search.

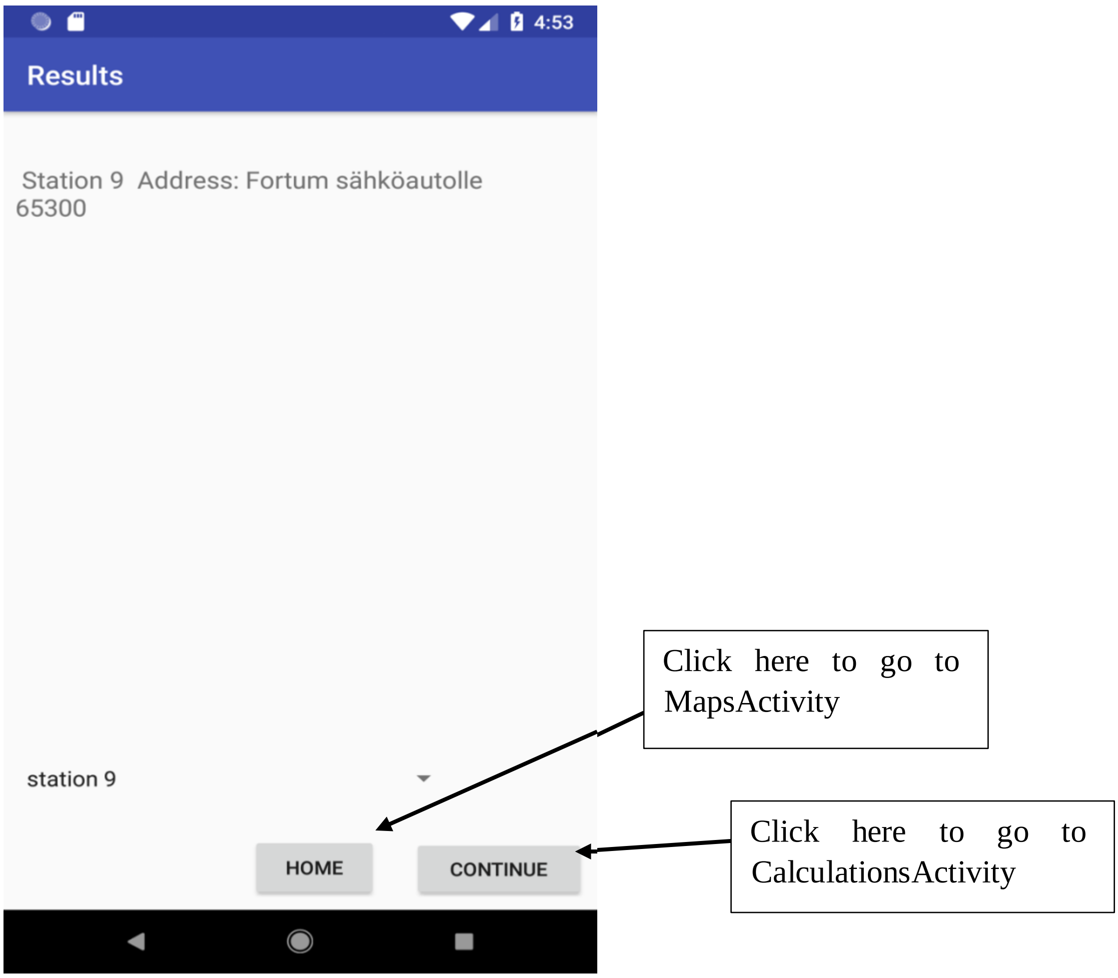

Figure 25. Charging stations compatible to Nissan Leaf that uses SAE-J1772 plug

Step 4: After the user gets to choose a station, there are two options to go to. One can go back home to MapsActivity or continue to calculate the estimated charging time and cost.

The "CONTINUE" button launches CalculationsActivity. Meanwhile, the station name selected from the spinner in ResultsActivity is passed to CalculationsActivity and saved. This activity has a layout file activity_calculations.xml which contains the GUI components a spinner and two seekBars. The spinner is used to choose the car model you want to charge. The first seekBar takes the current SOC and the second one takes the target SOC from the user. Figure 26 illustrates how to choose the car model, the current SOC and target SOC in the CalculationsActivity.

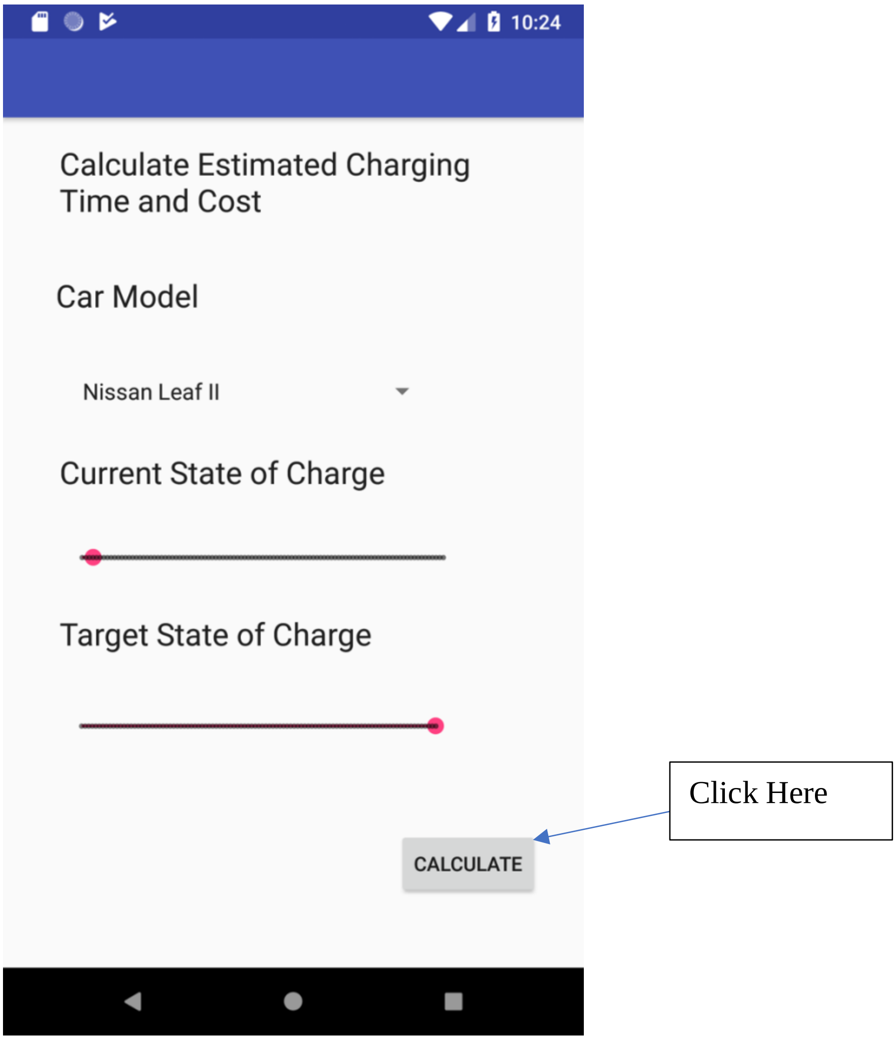

Figure 26. Choosing car model, current SOC and target SOC for charging Nissan Leaf

Step 5: After choosing the car model and setting values of the current and target SOC, the “CALCULATE” button is clicked. Upon the click, a method is called that the calculations is doing. The calculations for the estimated charging time and costs require values of current and target SOC, battery capacity of the car model and power output of the selected charging station.

The battery capacity of each car model is saved in array of float datatype sequentially. Using the position id of the selected item in the spinner as array entry index, the battery capacity of the selected model is claimed. Meanwhile, the selected station name which is passed from ResultsActivity spinner is used to access the power output attribute. Since all necessary variables are available, the calculation can be done and the result of the estimated charging time, charging cost and station name are passed to the DetailActivity.

DetailActivity uses a layout activity_detail.xml. It has three textView GUI components to display the 3 results. Figure 27 presents results of charging time and cost estimation calculations

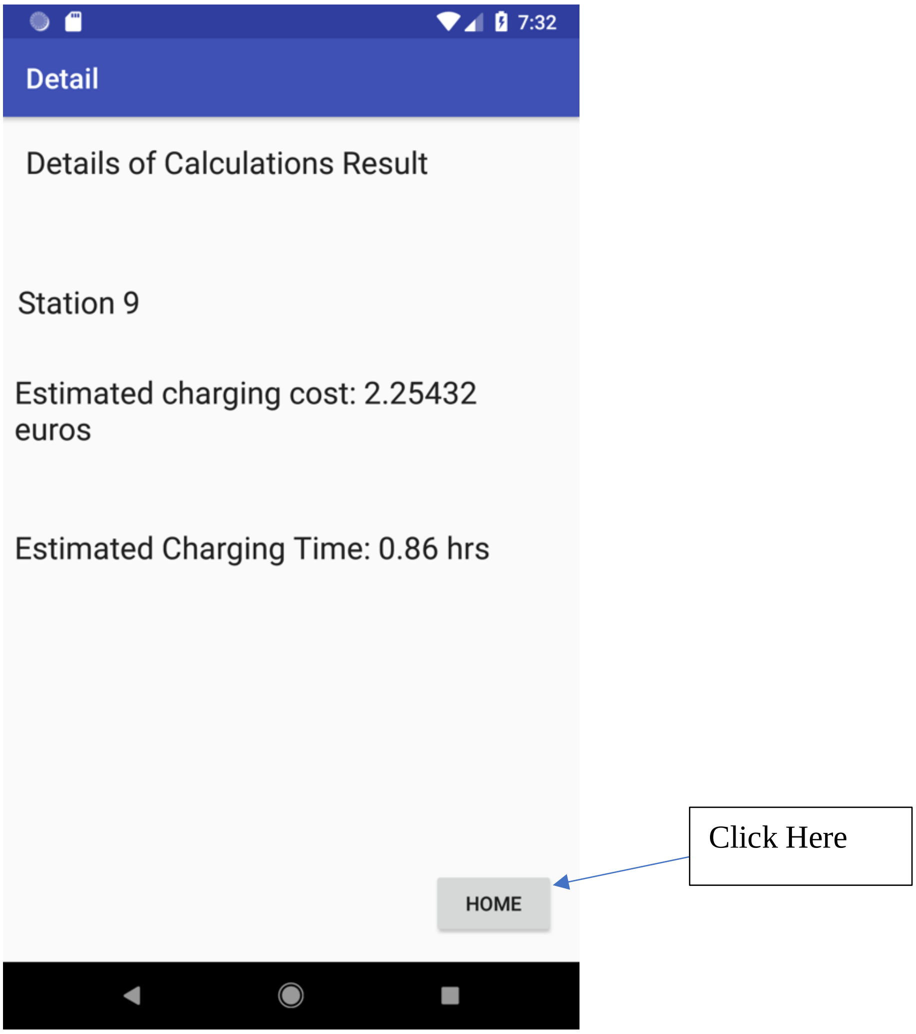

Figure 27. Results of charging time and cost estimation calculations for Nissan Leaf charging in AC mode

5.3 Scenario 3: Charging Tesla Model X on DC Charging Mode

Tesla Model X cars are manufactured to use Tesla super charger in DC mode charging. But there is a Tesla Model X CHAdeMO adapter that enables Tesla cars to be charged in CHAdeMO stations. Hence, CHAdeMO or Tesla Supercharger plug are both chosen.

Step 1: While opening the app, the first activity MapsActivity is displayed and then click the “CONTINUE” button to launch SignUpActivity. In other way, one can click

"AVAILABLE STATIONS" button to see the currently available stations. Figure 23 shows how to launch the SignUpActivity from MapsActivity and AvailabilityActivity.

Step 2: In the SignUpActivity, the user puts the desired requirements in the spinners and checkBoxes. The values are retrieved upon the selection using the instance OnClickListener. Then the selections are cross referenced with the charging station data source file Chargst.java. And the matching stations' name is passed into an array list of strings, which is passed to the ResultsActivity. Figure 28 shows the SignUpActivity and selections according to the scenario requirements.

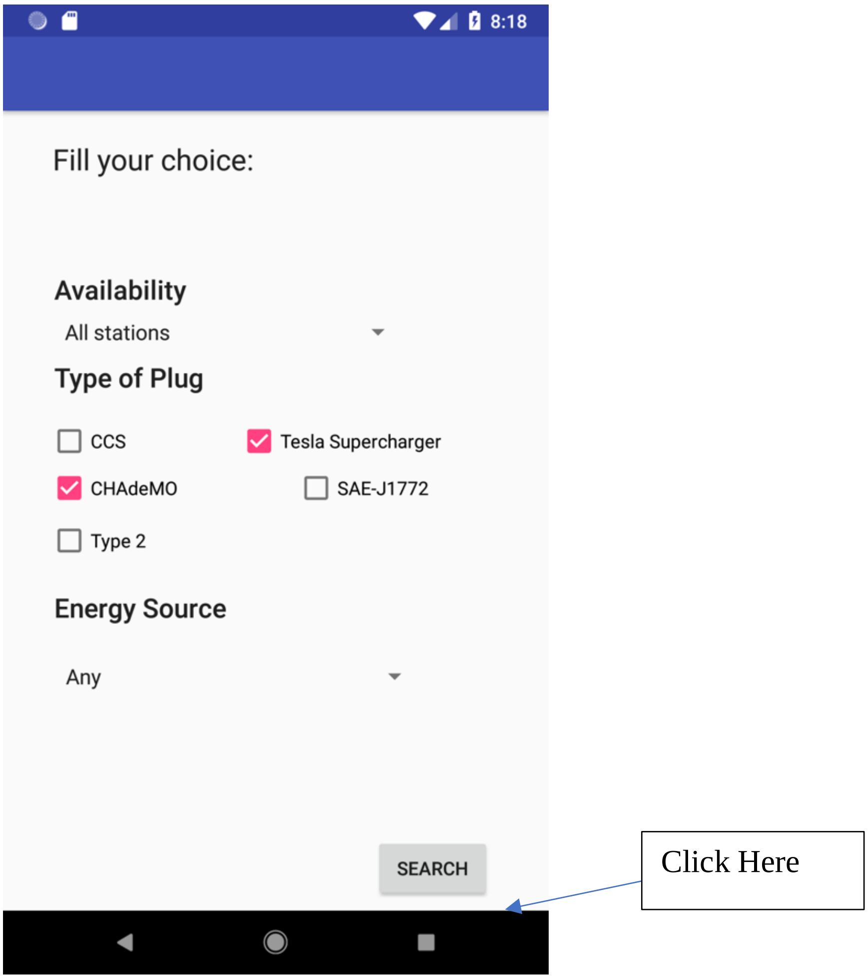

Figure 28. User selections for Tesla Model X charging in DC mode

Step 3: When the "SEARCH" button on the SignUpActivity is clicked, the array list of the matching charging stations is passed to ResultsActivity where it is displayed on the textView GUIs and at the same time entered into the spinner. Then the user chooses a station to charge in between the matching stations presented in the spinner. In this case, there are four matching stations found and let's choose 'Station 6' from the spinner. Figure 29 demonstrates the search results of Tesla Model X that can charge using Tesla supercharger and CHAdeMO.

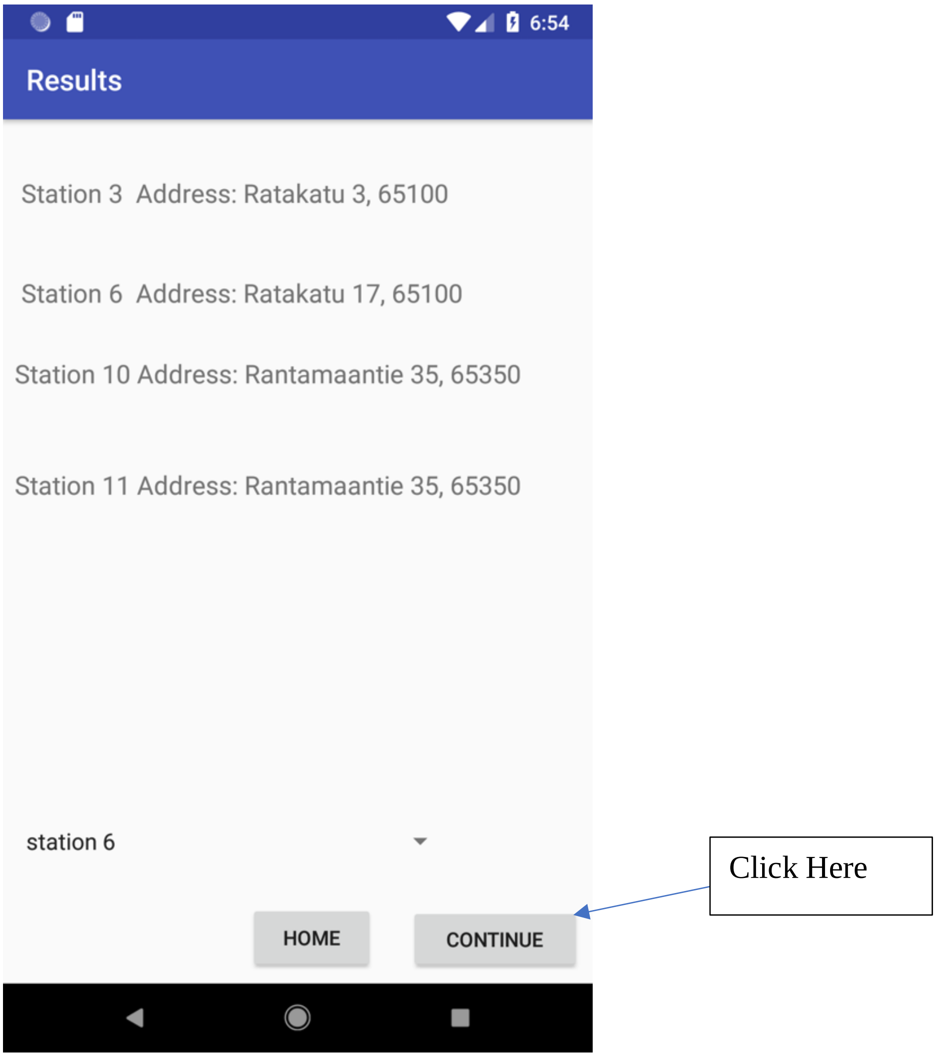

Figure 29. Charging stations compatible to Tesla Model X that uses CHAdeMO or Tesla supercharger

Step 4: The CalculationsActivity is launched when "Continue" button in ResultsActivity is clicked. Meanwhile, the selected spinner value i.e. a charging station name is passed to the activity. Since the selected station is DC fast charging, the charging time calculation is overridden and set to 0.5hrs. And the maximum of target SOC is set at 85%, because more SOC level is not achievable in 30 minutes DC fast charging. So only the electric car cost calculation is implemented. Figure 30 illustrates the CalculationsActivity for charging Tesla Model X.

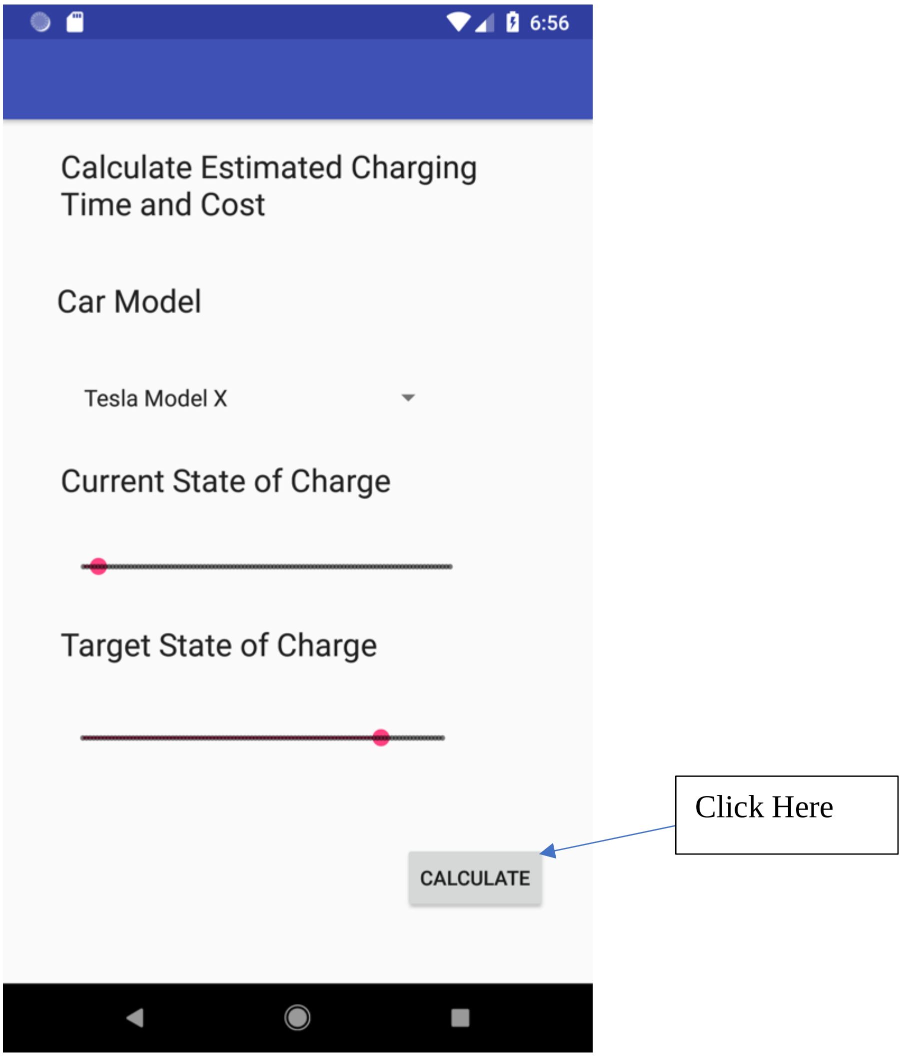

Figure 30. Choosing current and target SOC for Tesla Model X

Step 5: The result of electric cost calculation and preset value of charging time is passed to ResultsActivity and its displayed on the textView GUI. Figure 31 shows the details of the calculated charging cost and charging time.

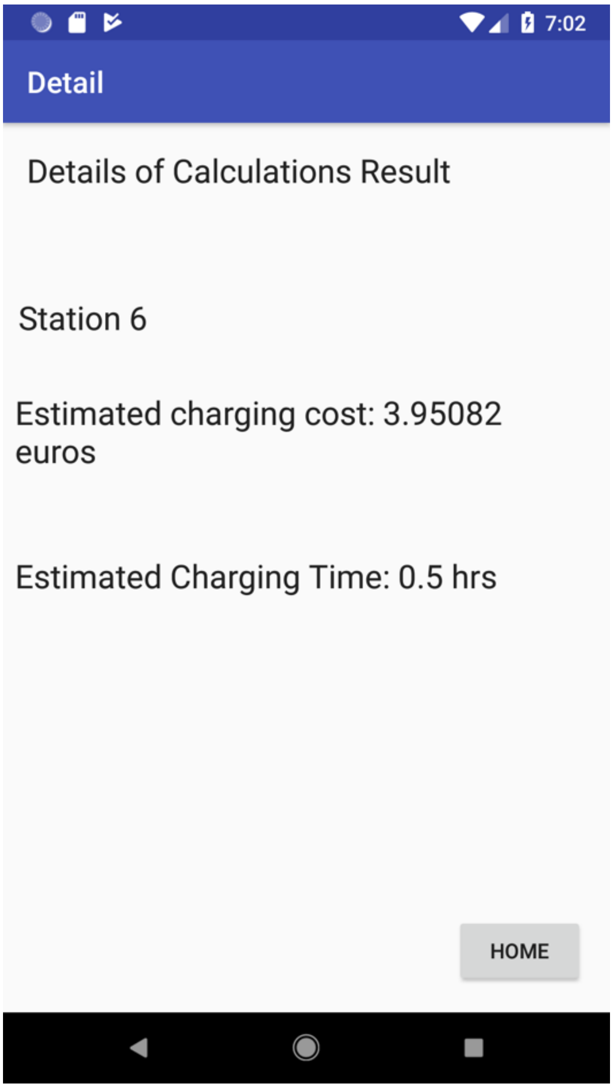

Figure 31. Results of charging time and cost estimation calculations for Tesla Model X charging in DC mode

6 CONCLUSION AND FUTURE WORK

This thesis has explored the areas regarding charging stations and electric cars in detail. As a result, it successful system that enables electric car users effectively access real time (simulated) status of charging stations and also estimate the charging time and charging cost specifically for their car type.

The app can be applied for real life application after enacting some altercations such as introducing the use of a server or database instead of a data source file. Then the real time data, the availability status of charging stations can be entered for instance to the server. The server can process and provide the availability status among other information to users through the app. This is a very important feature which can be extended to be used for services like booking charging stations ahead.

The implemented system has a significant importance in easing electric car users' charging experience. It is a marketable system that can easily be accessed and used. There is plenty room for expansion of the system. The app was designed in such a way that it can be easily modified with more charging stations that cover a larger area.

The app calculates the estimated charging time using a simple equation that is mainly dependent on the car battery capacity, current SOC, target SOC and charging station power output. In real life, the charging time is affected by a number of factors that has not been taken into consideration in the equation. Those components include battery quality, efficiency of the charger, SOC (battery charges slower at 80-100%) and temperature. Thus, the charging time estimation can be longer or shorter.

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