CHALMERS

Svenskt Hybridfordonscentrum

www.hybridfordonscentrum.se

Pre-study of Charging Connections- Convenient charging while parked

MIKAEL ALATALO

Department of Energy and Environment

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2013

Pre-study of Charging Connections- Convenient charging while parked

Technical Report No. 2013:2
Department of Energy and Environment
Division of Electric Power Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
SE-412 96 Gothenburg
Sweden, 2013

Cover page: Hybrid bus, pantograph belongs to the tram in the background.

Abstract

The electric vehicles of today have limited driving range, but we can expect incremental improvements towards 250-300 km / per charge and even longer if the work on new battery chemistry will succeed. It might be a solution for passenger cars. I.e. the operating range will be long enough for the costumer and the need for opportunity charging will disappear. This will take some years.

However a big investment in the infrastructure could kick-start the electric vehicle market. If slow and fast chargers will be available on several locations the drivers will be more confident in the car itself.

There are several techniques for charging of electric vehicles, the most promising is conductive charging and inductive wireless charging. These two techniques are already available and there is a common core technology using high frequency switching at high power level. A further development is the ability to deliver energy back to the grid in the future. The report finds that research on inductive charging is the most important.

Capacitive, radio frequency or micro wave, conductive power transfer are possible ways to charge the vehicle when it stops at home, for shopping or at work. These technologies are not mature but it is interesting to investigate their potential.

Even a hydrogen system may be regarded as charging of a vehicle as long as the hydrogen is produced from electricity. There are two good benefits of this system, the vehicle may be used in the same way as an ordinary car. It is driven until the fuel is almost gone and then you fill it up in a couple of minutes. The other benefit is that the hydrogen system may be used for balancing the electricity production from wind or solar.

Preface

This report is a survey over different techniques for charging of electric vehicles. Some information is gathered from scientific publications and some from internet with the intention to highlight both scientific activities and the activities that are ongoing at different companies. The information from internet have to be seen as a not fully trustworthy source.

Thanks to Torbjörn Thiringer and Sonja Lundmark for valuable discussions and comments on the text. Robert Karlsson and Eva Palmberg have broaden my knowledge of antennas. It is also acknowledged that Bengt Axelsson and Börje Grandin at VCC and Conny Börjesson at VI have been helpful in finding information and good ideas.

The financial support of Svenskt Hybridfordonscentrum, Statens Energimyndighet and participating companies is gratefully acknowledged.

Mikael Alatalo

Gothenburg, Sweden, 2013

Table of Contents

1. Introduction

This report investigates different ways to charge electric vehicles and the possibility to increase the use of electricity for powering mainly cars. In the future we may have access to electricity along the roads for powering trucks and buses and perhaps this can also be used by the cars.

There is an ambition to increase the use of electricity and minimize the use of fossil fuels in the transport sector. One way is to electrify the trucks, buses and cars that travel on the road and along the highways install an electrical feeding system, (Electric Road System, ERS).

A main problem today is the limited range of battery electric vehicles (BEV). A typical BEV has the range of 150 km under good conditions, but it can be substantially decreased in cold weather or when the air conditioner must be used. Some sports cars, such as the Tesla will have relatively long range due to a large battery and a small sized car, which could be a solution. The cost of such a large battery is not an option for main stream cars. The cost of the battery must in that case be lowered.

If we have to accept a small battery in the car, charging during driving may be a solution but this has to be done in a convenient way. Opportunity charging is a way to increase the actual driving range of the car.

Tests have started on buses and trams where inductive charging is used along the routes of the bus / tram.

This study investigate different ways to charge the cars mainly at standstill. For instance while shopping, the car can be placed over an inductive charging plate and when the driver returns to the car, a good amount of energy has then been charged to the car. If possible, the car could get use of the systems that are installed for the buses, while driving.

2. Transport

2.1. Passenger transport

In Sweden around 80 % of passenger travel is done by car or motorcycle. The rest is almost equally split between railway travel and buses/ trams/subway. A minor part is done by flight, [17]. Figure 1 shows two of the most modern trains in Sweden, double decked, X40, and Regina regional trains.

One way to lower the use of fossil fuels is to increase the travel by train and cars on train. The latter is called Motorrail or Auto Train, [32]. It would be possible to equip the trains with charging fascilities and during the travel the car is charged. The train travels to a place near the destination and the car is unloaded with a charged battery and travels the last few km's using energy from the battery.

Figure 1. Passenger transportation on train. Göteborg central station.

2.2 Freight transport

About 22 000 Mtonkm per year is transported on railways in Sweden and 33 000 Mtonkm on trucks, i.e. it should be possible to increase the amount of goods on railways. We may compare to Switzerland, who have extensive use of railways. The statistics are relatively good, about two third of the traffic that cross the Alps are transported on trains. Unfortunately the trend is declining [1] and the reason for this is probably that smaller companies need to plan their transports by themselves and with short notice.

Increasing railway traffic will need large investments in the infrastructure. The railways in Sweden have some weak spots that are heavily used today. This concerns especially the areas around the big city's Stockholm, Göteborg and Malmö and also lines near Helsingborg, Gävle and Kristinehamn. The freight yard in Malmö and the line to Göteborg harbor, see Figure 2 and 3, are also parts of the system that is on the limit of their capacity. [2].

Figure 2. Container on train, Hisingen Göteborg.

Figure 3. Loading of container, Gothenborg railway yard.

2.3 Electric Road System

The idea of an Electric Road System (ERS) is that electricity could be available along main routes and the vehicles may then have a smaller battery that only have to supply the cars for shorter distances outside of the main routes.

Two tests have been done in Sweden:

*conductive charging to trucks and a bus has been tested by Volvo

*inductive charging have been tested by Scania.

Conductive charging can be done in the way envisioned by Siemens, [18]. It is a system using two conductors above the road and pantographs. The electricity may also be fed via strips along the road surface, [19].

Inductive coupling have been investigated for some time. Already in 1978 ideas where tested in the USA, [16]. Bombardier has an inductive system with power rating of several hundreds of kW, Primove.

3. Electric vehicles and alternatives to charge

The battery electric vehicles (BEV) of today have a limited operating range, the Japanese cars from Nissan, see Figure 4, and Mitsubishi have as well as the cars from Renault an operating range of 150-200 km in the summertime. In the winter the range are lower, due to decreased battery capacity and the use of heating. At warm weather and solar radiation the cars have to be cooled by air-conditioner that also draws a significant amount of power. With the ability to charge the battery during travel the operating range can be theoretically unlimited.

Some efforts are also made on increasing the operating range of the vehicle. Some prototypes of the car SIM (Shimizu In wheel Motor-Drive), [21, 22], has been evaluated. The latest iteration has an operating range of 333 km (Japanese city driving) and an impressive performance. The acceleration from 0 to 100 km/h is managed in just 5.4 s and the market introduction is planned to 2014. Compare with the EV1 which had almost the same battery size (26.4 kWh, NiMH) and a range of up to 235 km [25].

Figure 4. Two Nissan Leaf charging at CTH. Volvo C30 at Lindholmen.

Further Mitsubishi have claimed an operating range of 300 km for their next generation of electric vehicles. A concept is shown during the Geneva Auto Show. Some points compared to the i-Miev are improved, the weight is lowered, aerodynamics are better and the drive-line have better efficiency. The battery-size is also increased to 28 kWh, [20].

The Renault ZOE has an operating range of 210 km on the NEDC cycle, [33], and the next generation of Nissan Leaf have also increased the driving range, so we can anticipate small incremental improvments towards at least 300 km.

Taking into account new battery technology and an optimized vehicle, it may not be necessary to charge the vehicle when driving. It may be possible that the car is charged during night and stand still and it will be sufficient for 99 % of all travels the next day. Of course some vehicles are on an extreme long journey and have to charge, but with an operating range of say 400-500 km it's reasonable to have a break during which charging takes place. Better battery chemistry is on the way, for instance Wang et al. [15] indicates an 80 % increase of energy to weight. Other work that is worth mentioning is the efforts for Li-air systems, research on a sulfur-silicon-lithium cell at Frauenhofer Institute that expect to reach 500-600 Wh/kg, [27,28,29] and Toyota's trials on the next generation of batteries that are based on Mg.

There is also other ways to increase the use of electric vehicles. The rental services, BlueCar in France and Move About, see Figure 5, in Sweden are two interesting alternatives for city driving.

Other interesting projects are the Renault Twizy and Toyota's Iroad, which are small and relatively safe vehicles that can compete with scooters and mopeds. The Twizy have sold well in France and also relatively well in Germany and several thousands of them are already on the road.

Figure 5. Move About's charging station Lindholmen, Göteborg.

3.1. Fast chargers

Normally an onboard-charger is mounted in the battery electric vehicle for easy access to the electric grid. The power rating is however low, 2-3 kW, which is sufficient for night-time charging at home. When driving longer distances there is a need to charge either very quickly or whenever possible. Quick charge means that high power has to be installed at the charging spot. The fast chargers used in Japan have the power rating of 50 kW, which is enough to charge 80 % of the battery in half an hour. SAE J1772 specifies a standard for charging with up to 90 kW that ideally could charge a typical battery in 15 minutes. The charging time is although long and the operating range is short. Probably electric cars will not be used for long journeys, it will be used for city driving as a start. Figure 6 shows the schematics of the on board charger and a fast charger.

The fast DC-charger communicates with the BMS (Battery Management System) and controls the battery current to an appropriate level.

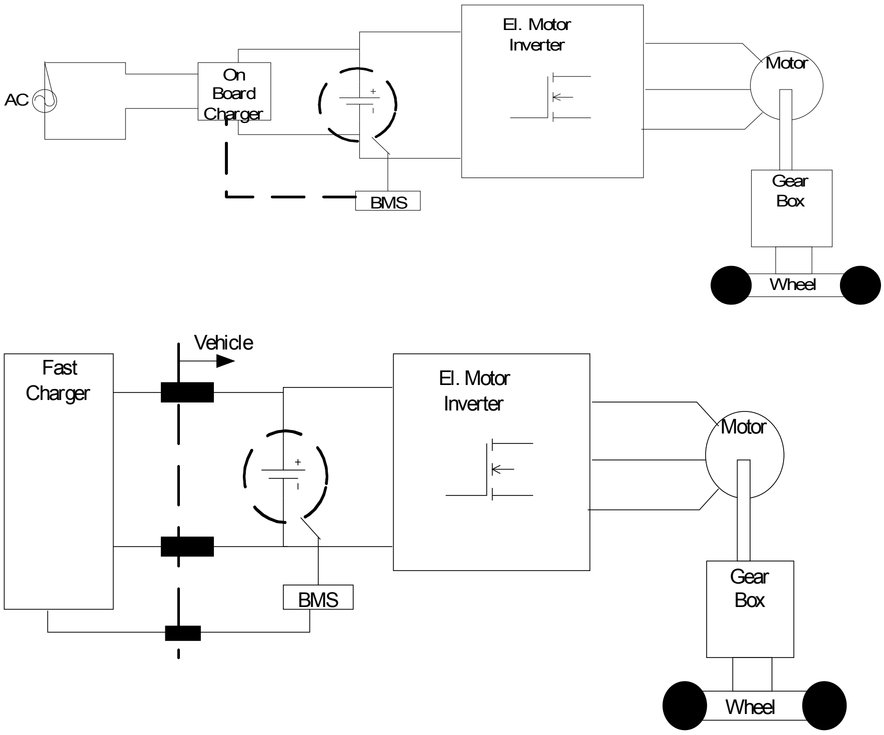

Figure 6. Onboard charger and fast charger

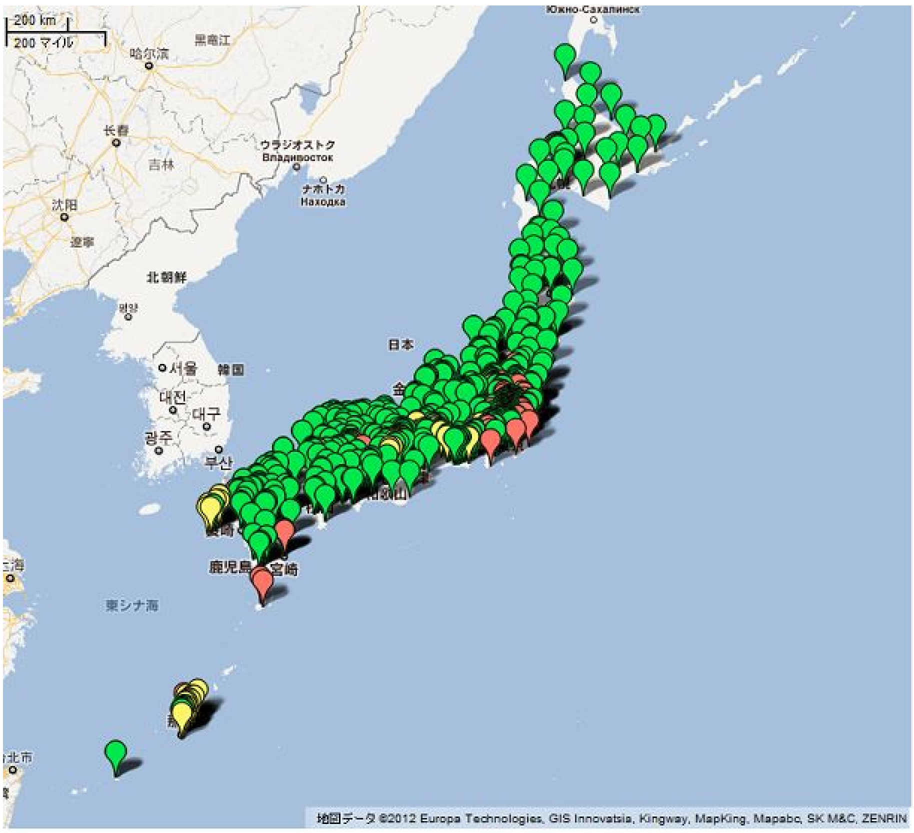

Figure 7. Fast charger locations, Google maps.

In Japan a lot of effort has been done to install fast chargers. As a start fast chargers were placed in and around Tokyo. At the time beeing there are fast chargers all over Japan. Figure 7 shows that today there are fast chargers available within short distance, wherever the driver is in Japan. Experience from Tokyo showed that the range anxiety(the driver doesn't trust the battery capacity) were almost gone when the fast chargers come available, [3]. A significant increase of the battery-capacity was used during the trips when the driver knew that there is a fast charger available in the neighborhood.

Estonia have officially opened a net of 165 fast-chargers from ABB.

Approximately ten chargers are available on different locations in Sweden, for instance the one at Ringön in Gothenborg. See Figure 8.

Figure 8. Fast charger Ringön, Göteborg.

The DC fast charger is a relatively expensive solution and inside the charger a high frequency converter and transformer guarantee a galvanic insulation between the grid and the car. From the perspective of the car owner, this system has probably the lowest initial cost. The car has only a connector to the DC-link and a communication between the charger and the battery management system. It would be possible to make systems that automatically connect the car to the charger for easy access. Similar systems are available for busses, [37,38].

In Europe fast chargers with the rating of 22 kW and connection to the AC-grid gain interest.

Renault call it Chameleon and it is similar to the method developed at SHC, [29]. The motor converter are used via the motor windings, but in the Renault patent they use a separately magnetized synchronous machine.

To use the motorconverter is an economical way to solve the charging. It is already installed in the vehicle and a simpler equipment may be used to connect the grid to the car. The downside is that extra switches must be installed to rearrange the motor windings and the motor cannot freely be optimized. The charger has high power rating and it can be used for both charging and discharging the battery. The discharge capability could be used in smart grids and for stabilising the grid when a high penetration of renewable energy is present.

3.2. Inductive chargers

This technique is made up on a winding that is placed under the road surface and a pick-up coil placed under the floor of the vehicle acts as a high-frequency transformer. The road-side coil is fed by a high frequency converter. Since the distance between the coils is long (> 10 cm) the leakage flux is high and this is mostly compensated for by resonant capacitors.

The permissible flux density that can affect people in the vicinity of the coils shall be limited to 6.25 uT, and this can in some cases lead to a shielding problem, [5]. Of this reason it is important to keep the distance between the coils as low as possible and try to direct the flux to the right place.

Several manufacturer are close to market introduction and the most important are OLEV (Korea), and Bombardier, who have ongoing test operation with busses and trams, [5,6, 7].

OLEV uses 20 kHz as operating frequency and reports on a transmission of 60 kW with an efficiency of 80 %.

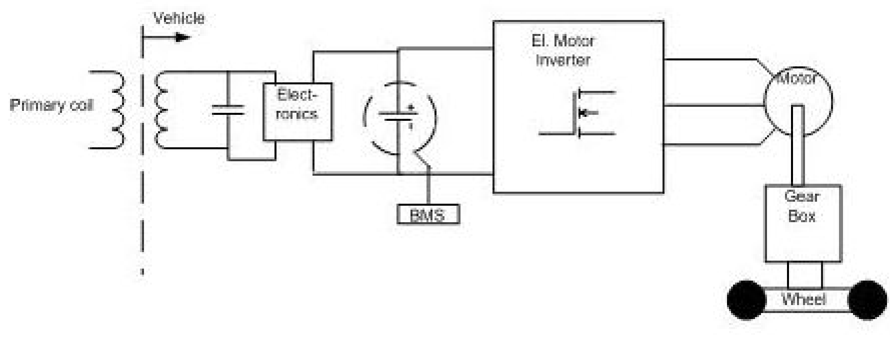

Figure 9. Inductive charger.

Bombardier uses a higher frequency, 40 kHz, at high power levels but applications on 145 kHz is also used. The transformer is made with a minor difference compared to OLEV. No clear information has been found but it looks as Bombardier directs the flux vertically similar to the case in Fig 10. A winding made of Litz-wire is placed on the surface of a ferrite core while OLEV have a horizontal direction of the flux. NOT verified data.

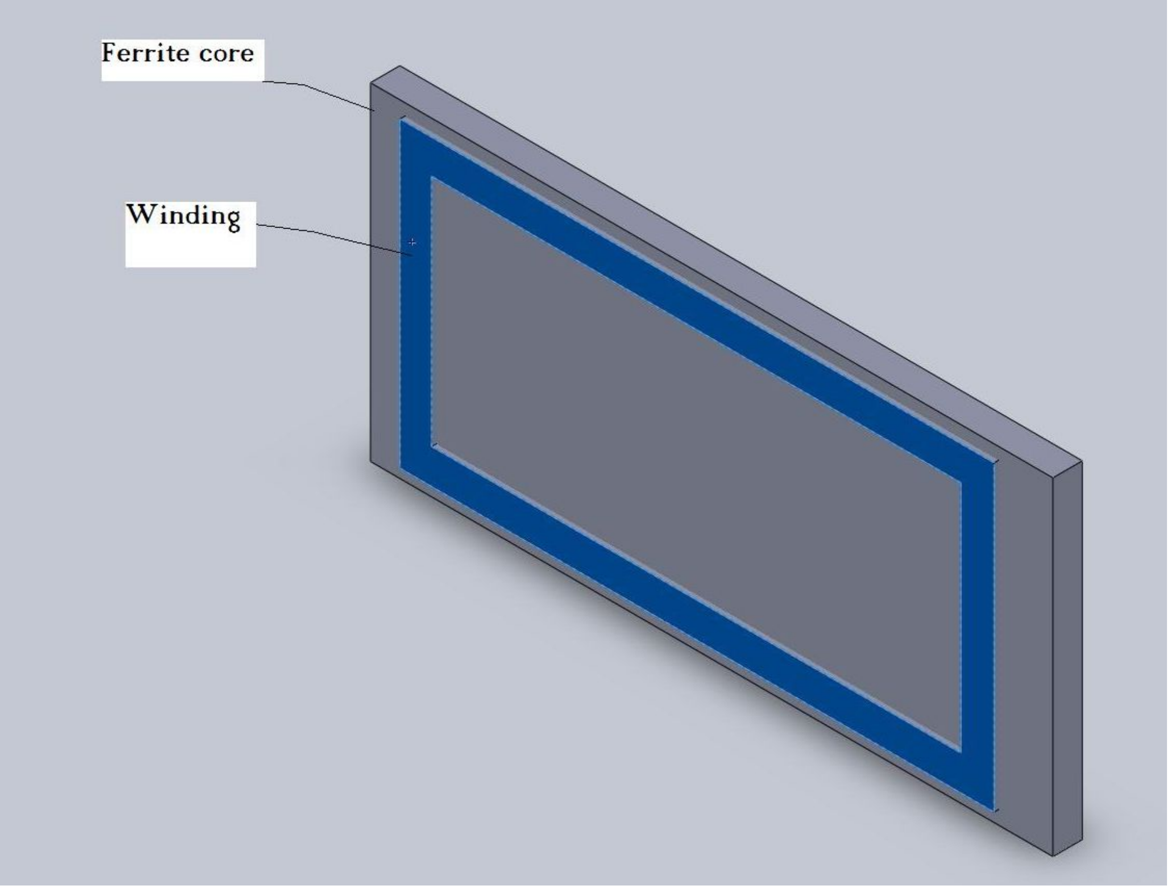

Figure 10. Inductive power transfer coil. One of two coils.

The real pioneer in this area is Conductix-Wampfler who have delivered equipment to buses in Genoa and Turin. The buses have been in operation for 10 years, where a system with two primary coils feed the bus. The latest version have the total power of 60 kW and the magnetic field are 'very located in the area'. Probably this stands for low radiated emissions, [30].

Fig. 11. Conductix-Wampfler.

The technology suits bus operation very well, the buses follow a specified route and the operator may plan where the best place is for the inductive charger. In this way the size of the battery can be rather small.

3.3. Capacitive Power Transfer

An idea that has been investigated by LTH, [9], is to use the steel cords in the tires of the car as a capacitor. Tests have been performed but the transferred power level was relatively low. The work has concluded that a shift of frequency and change of material in the tire could increase the possible power transfer.

The energy density of the magnetic field in vacuum is:

$dW_m = \frac{B^2}{2\mu_0} = 400\, kJ/m^3$ if the flux density B = 1 T.

The energy density of an electric field may be written as,

$W_e = \varepsilon \int E^2 dV = 8.85\, pJ/m^3$.

In the case of a uniform field with the strength of the electric field $|E| = 1\, V/m$ in vacuum. Even if the electric field is increased to 1000 V / m the energy content is much lower than in the magnetic field. However if an effective coupling can be achieved between sending and receiving side it could be interesting.

As an example 200 pF was measured in [9] and at 100 kHz this will imply an impedance of 8 kΩ. A reasonable voltage level is below 1 kV corresponding to a current of 0.125 A, which in best case will correspond to 125 VA. We will need a voltage level of 1kV working in a frequency around 1 MHz to transmit something near 1-2 kW.

3.4. Microwave transmission

Several studies have been performed on transmission of solar power, from satellites down to earth. This technology has also been studied for vehicle charging. Oida et.al. at Kyoto University have studied micro-wave transmission to a small vehicle. [14].

Other recent work is from a company in Japan, *quote from greencarcongress.com*:

"

> Nihon Dengyo Kosaku and Volvo Technology Japan wirelessly transmit 10kW of electricity 4 meters using rectification of microwave signals

17 July 2012

Tech-On. Nihon Dengyo Kosaku and Volvo Technology Japan have demonstrated the wireless transmission of 10kW of electricity a distance of 4 meters using a prototype high-efficiency rectenna—a microwave rectifying antenna that converts microwave energy into direct-current electricity.

The 10 kW rectenna was made by combining eight rectennas the output of which is about 1.3 kW each; overall efficiency of the conversion is about 84%. Dengyo announced its first rectenna product last year.

The output power per area is 3.2kW/m^2 or higher, which Dengyo claims is the "world's highest output." The frequency of the microwave is 2.45GHz.

Volvo Technology Japan was established by Sweden-based AB Volvo in 2012 in Tokyo as its R&D base in Asia. The Volvo Group plans to apply the newly-developed wireless power transmission technology to commercial vehicles such as buses and trucks, Volvo Technology Japan said.

The rectification of microwave signals for DC power has been researched and developed for decades for a wide range of applications, especially for satellites. (Japan is exploring the possibility of developing a Space Solar Power Station/Satellite (SPS) that would use rectennas for power transmission to Earth. Earlier post.)

The basic rectenna was patented in 1969 by William Brown.

" *End of quote.*

Compared to other work the efficiency is very high at the Dengyo-experiment. Oida et. al., [14] reports on an overall theoretical efficiency of 44 %, when using a magnetotron as source and a rectenna as receiving antenna. The test done in [14] results in an efficiency of 5 %, so with this in mind 84 % as said by Nihon Dengyo is very high. Possibly they speak about the efficiency for conversion in the rectenna.

3.5. Hydrogen and fuel cells

Hydrogen can be produced in many ways but if we want to compare it to electric mobility, then the hydrogen should be produced from electricity via electrolyzers and 'charged' to the car at a fuelling station. In this sense it's another way of utilizing electric energy for transportation.

There are still a lot of efforts done on this technology and a commercial break-through are relatively near. Honda and several other producers will launch fuel cell cars or in 2015. Hyundai iX30 Fuel Cell is a car that is already available for fleet operation and it will be available for ordinary costumers in 2015. The benefits are of course that almost the same behavior as with petrol can be utilized, you drive the car and fill it up in a few minutes when needed.

Germany has decided to close their nuclear plants and have an ambition to completely rely on renewable energy. A lot of effort has been done to change their energy supply. Solar panels are installed on many roof tops and on midday of Saturday May 26, 2012, solar energy provided over 40% of total electricity consumption in Germany, and 20% for the 24h-day. Wind energy production in Germany is also relatively high and there is a need to store energy from day to night and from sunny days to days with cloudy weather.

Germany will install 50 hydrogen stations, which should be able to support the expected 5000 vehicles in the year 2015, [12]. Also in California the number of hydrogen stations are relatively high. Siemens are developing electrolyzers using PEM-membranes and have delivered the first unit, which have the power rating of 100 kW. They claim to produce 33.3 kWh of hydrogen from 50 kWh of electricity.

Hydrogen has the capacity to store the amount of energy that is needed for Germany. The electrolyzers have a good transient performance and can follow the random behavior of for instance wind power, [11]. With this technology two problems are solved, energy used for transportation can be produced and it is also possible to store the surplus energy from renewable energy. Germany have a storage capacity of 40 GWh in pumped hydro and in order to have a comparable size of other storing options it should be at least greater than 10 GWh. Hydrogen serves this capacity and as a comparison Germany have the possibility to store more than 200,000 GWh in their net of gas pipes. When storing the energy in the gas pipes the hydrogen has to be converted to methane or e-gas as Audi calls it. Audi are near starting operation of a site for converting wind energy into hydrogen via an electrolyzer. After that the hydrogen is converted to e-gas via a process where surplus CO_2 from a waste to biogas plant is used to methanate the hydrogen. The CO_2 would otherwise be emitted to the air. The gas can be fed into the gas net or power converted ICE-cars. This could be a way to gradually shift from the use of fossil natural gas to gas produced by renewable and sustainable processes.

The down side is a lower well to wheel efficiency compared to the BEV-alternative. A factor of 3-4 differs when hydrogen produced from renewable energy sources are compared to the case where renewable energy are directly charged to a battery-car, [4]. If Methane is produced it will lower the efficiency by 10 %. Further on if we compare the storage capability, 10 GWh corresponds to 400 000 cars with a battery of 25 kWh. It isn't an extreme number but they have to be connected to the grid and also have to be equipped with V2G-capability (Vehicle to grid). In addition there is also a cost involved when energy is cycled to a battery, due to a decreased life length of the battery. The life length may be enhanced if the used SOC-variation is limited, which means that millions of electric cars have to be available in order to absorb a high penetration of wind-power.

3.6 Range extender

One solution for extending the range of the vehicle is to use a small motor and generator that charge the battery. The power rating of this device can be relatively small, a typical midsized car need 10-15 kW for maintaining constant speed at 100 km/h. I.e. If the battery have high power rating and sufficient energy content for long hills or other extremes the range extender can be small. The system is very much like a plug-in hybrid vehicle and no clear difference can be stated. See Figure 12.

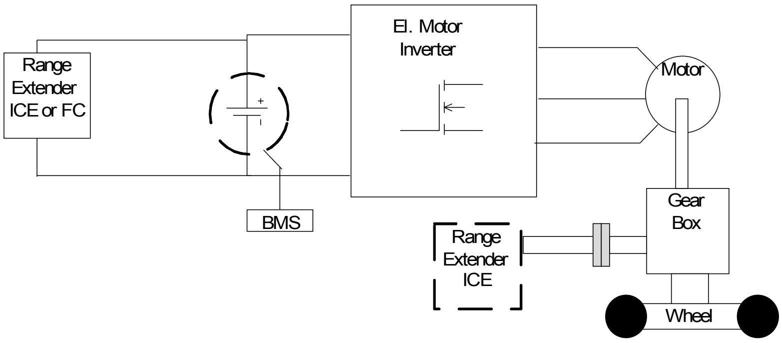

Figure 12. 'Charging' from range extender.

Some near commercial products have been tested with ordinary ICE-technology. Other ideas have been proposed such as free piston engines, wankel engines and fuel cells, [23,24].

This report handles electro-mobility and in this case the range extender should be powered by electricity or some fuel derived from electricity. Two examples is the previously mentioned e-gas from Audi or a fuel cell powered by hydrogen produced from electricity. The range-extender can also be powered by gas or fluids that are produced from bio-mass but that is beside the scoop of electromobility.

4. Minor investigation on inductive transmission

4.1 Frequency

The frequency used in the transmission affects the performance and a study of this has partly been performed by Cederlöf [10].

In order to find how the chosen frequency influences the system we must however calculate the whole system and iterate it for every frequency. However some conclusions may be drawn from start.

Positive effects:

1. Induced voltage is proportional to frequency and flux which means increased frequency decreases the size and the amount of used material. The voltage is

   $$E = j\omega\psi = j\omega BAN \qquad (1),$$

   where B is the flux density, A is the enclosed area of the winding. The voltage is also proportional to the number of turns, N.

2. Tuning frequency is:

   $$\omega_0 = \frac{1}{\sqrt{LC}} \qquad C = \frac{1}{\omega_0^2 L} \qquad (2)$$

   The latter function shows that the capacitor, C, decreases when the frequency is elevated. The inductance, L, is mainly related to the leakage flux.

Negative effects:

1. The skin effect is more protruded as shown in [10].
2. When the size goes down the relative flux that is leaking will be higher.
3. It will be more strain on the power electronics.
4. Electromagnetic interference will be more difficult to avoid.

The negative effects tend to be dominating but the possibility of minimising the size is important. It's an economical tradeoff between low size and dealing with the high frequency problem aspects.

The work to find a standard in size and frequency has just started and for now the differenet companies are sticking to their solution. This means that a set of frequencies between 20 and 145 kHz are discussed, see Appendice A.

4.2 Case study

An inductive power transformer is assumed to be made of a plate of ferrites on which a winding is fixed, see Figure 13, a cross section of the transformer is shown and the lower part conducts current in the layers representing the winding. This is handled using 2D-analysis and is of that reason only qualitative and used for discussing the behavior.

The major part of the flux goes through the upper winding layers showing that relatively good mutual coupling is present. A part of the flux is leaking outside of the upper winding and it is denoted by leakage flux.

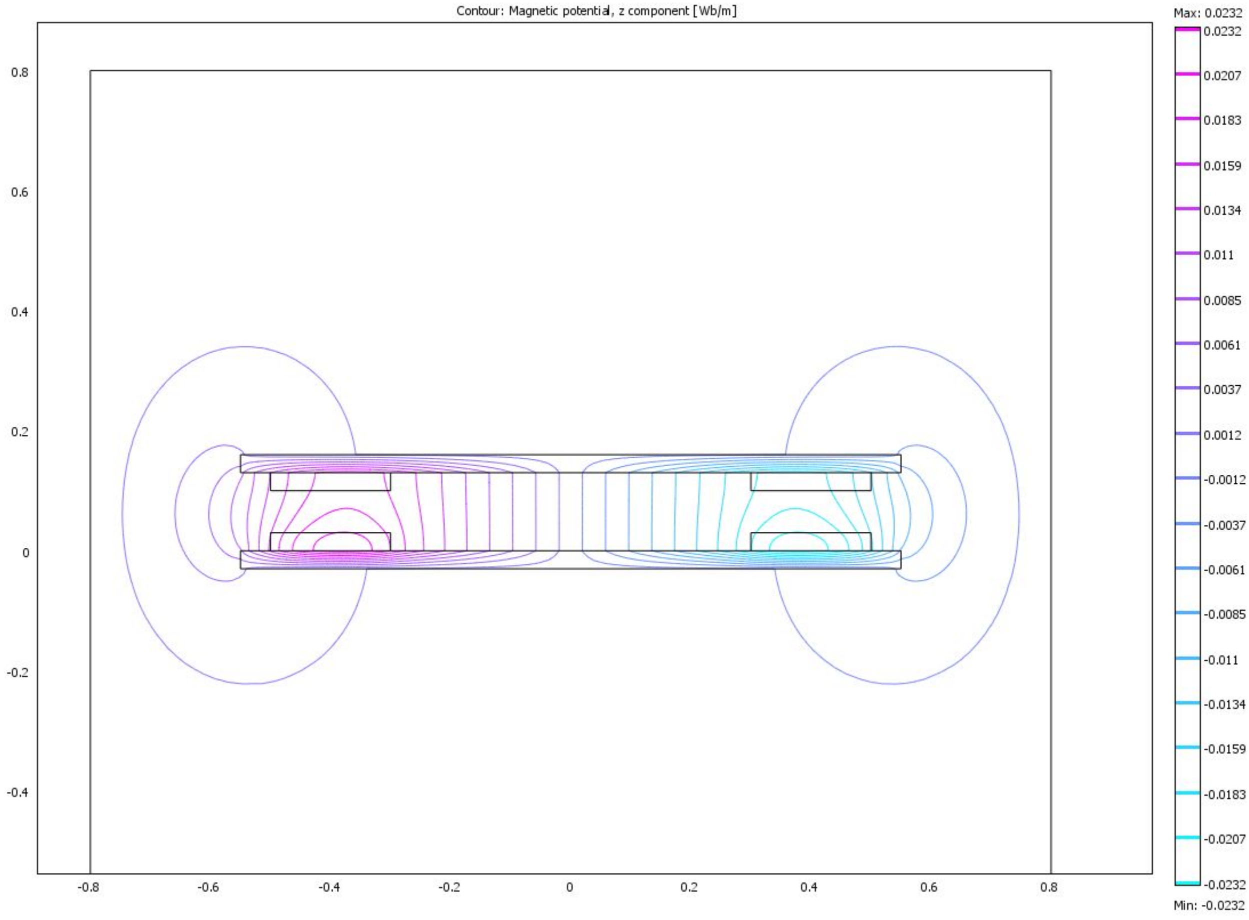

Figure 13. Two big coils.

In Figure 14 a smaller pick-up is present above the original exciting coil and it can be seen that a lot of flux is spread outside of the secondary coil. This means that the impedances of the circuit is changed.

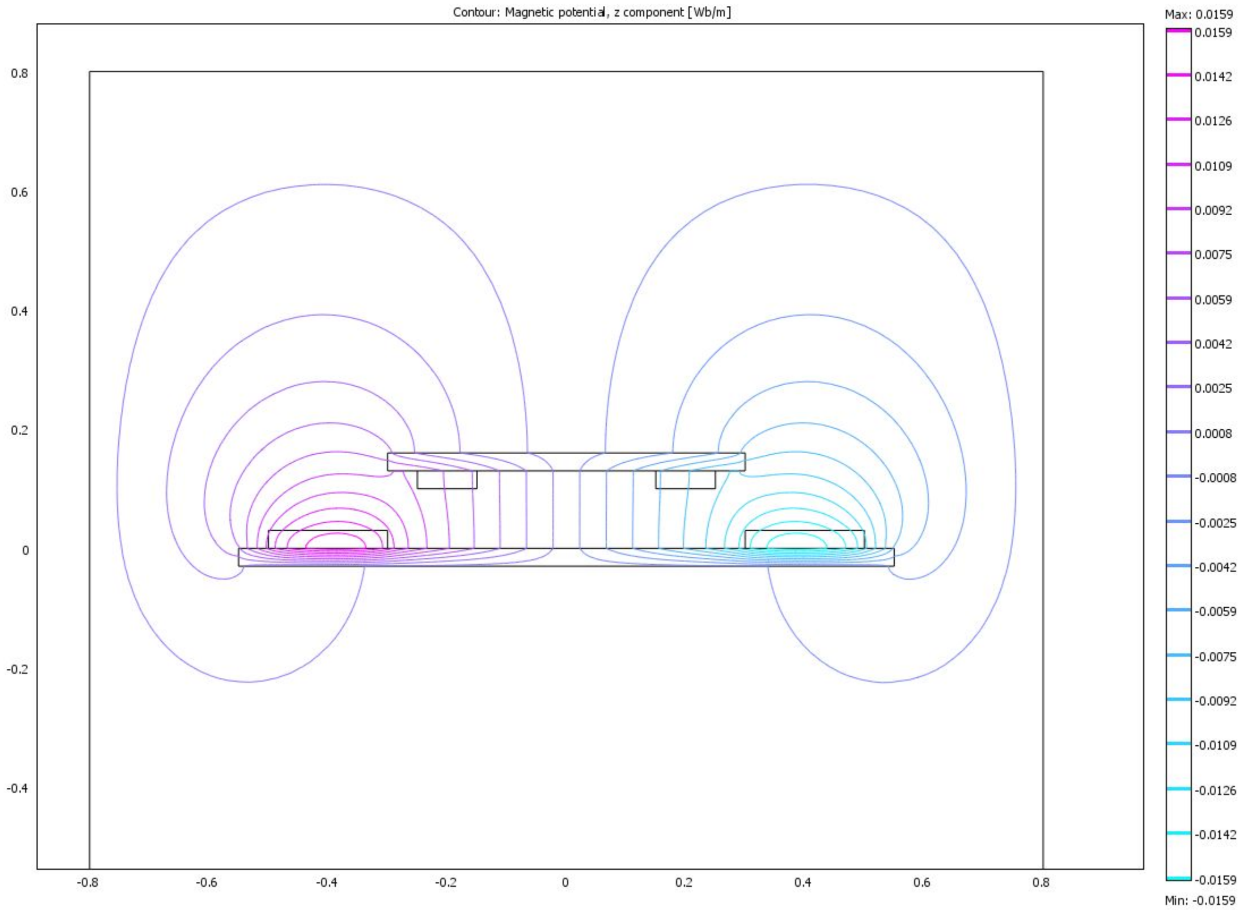

Figure 14. Smaller receiving coil.

If we compare the situation in Figure 13 and 14 the leakage flux is increased from 20 % of the total flux to 70 %.

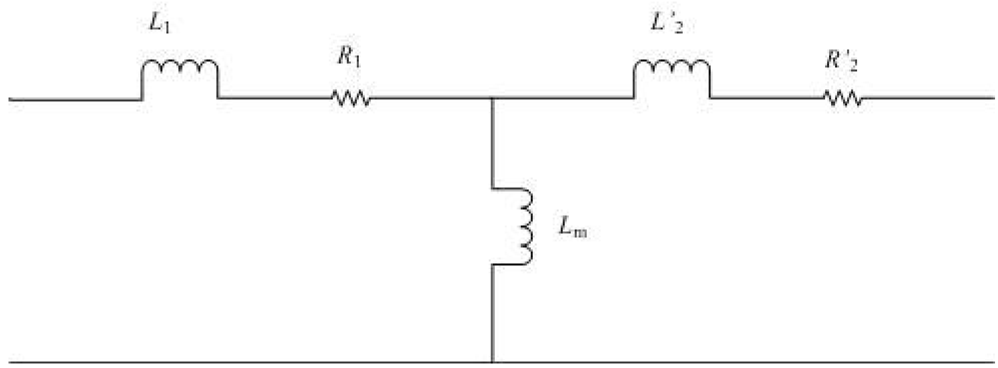

Figure 15. Circuit representing the two coils.

The two windings can be represented by a transformer model, according to Figure 15. The magnetizing inductance L_m is however relatively small. Refering to Figure 15 the impedances change according to Table 1, when the coils are located at different places. The leakage inductance changes a factor of 2.7 between the most favourable position.

It is assumed that the number of turns is the same in the primary coil as in the secondary coil. In this case it is just one turn in each coil. The inductance value is per meter of the parts. Position 3 and 4 are the same as Position 0 and Position 2 but with a smaller air gap of 0.02 m.

Tabell 1. Inductance at different positions

	Position 0	Position 1	Position 2	Position 3	Position 4
L1	0.86 uH/m	2.3 uH/m	1.04 uH/m	0.50	0.99 uH/m
Lm	1.21 uH/m	0.12 uH/m	0.8 uH/m	1.98 uH/m	0.85 uH/m
L2'	0.86 uH/m	2.07 uH/m	1.52 uH/m	0.50 uH/m	1.97 uH/m

The different positions are shown in Figure 16.

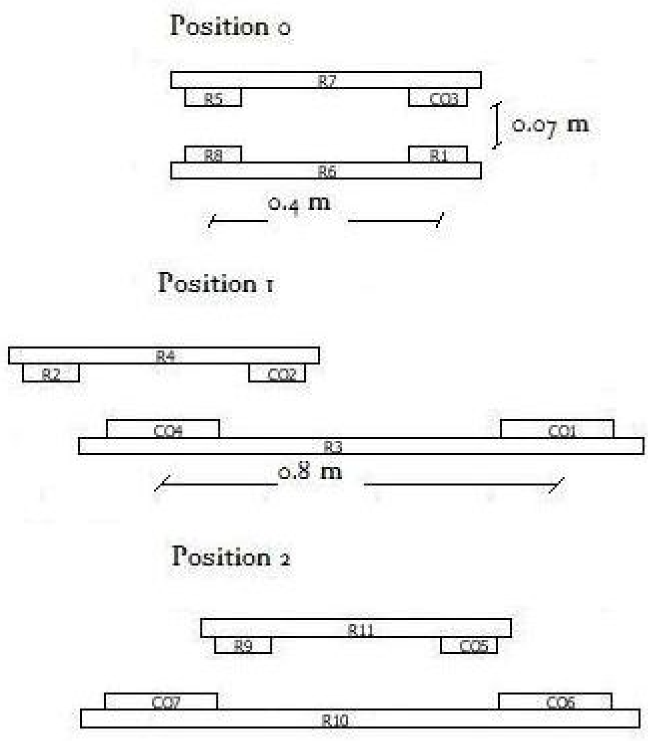

Figure 16. Evaluated positions of two coils

The best is of course two coils with a smimilar size and with as low airgap as possible. Position 1 is the worst but even in this case a certain mutual inductance is present.

We investigate the transfer characteristic for a series parallel resonant circuit according to Figure 17 and adapt the size and winding turns so the coils correspond to the case studied in [34]. The resulting transfer function, *H*, of the circuit is shown in Figure 18.

$$H = \frac{|U_2|}{|U_1|}$$

U_1: Input voltage from the inverter

U_2: Output voltage to the (active) rectifier

The peak of the transfer function is moved towards a lower frequency compared to position 0. The change in frequency is about a factor of 2, which must be handled in some way to get a proper energy transfer.

The amplitude of the transmitted voltage differs several dB at the original tuning which means crucial impact on the available power. On the other hand a shifted frequency may achieve a fairly good transmission. The study is done under the assumption of constant load resistance, which is a simplification. It remains to find the peak power transfer for each of the positions by means of finding the optimal load resistance. (Load current).

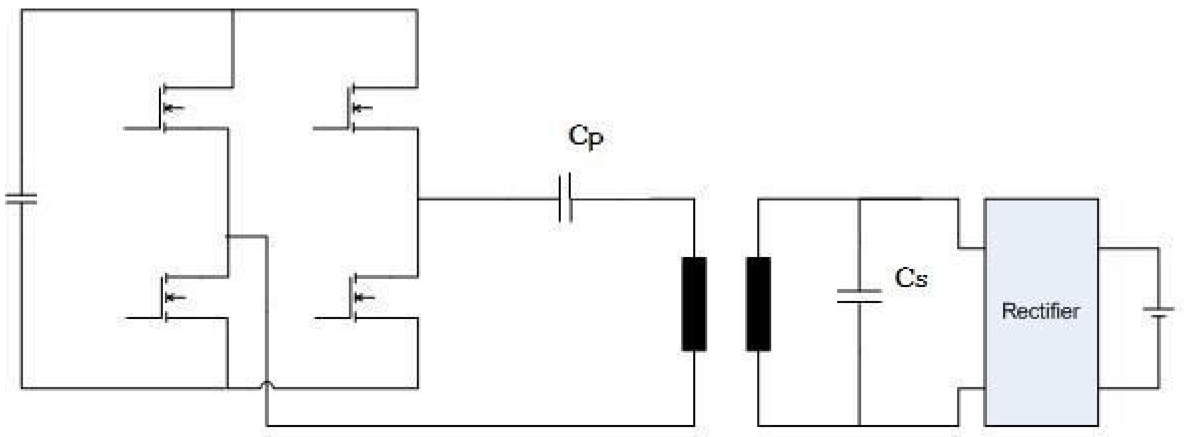

Figure 17. Inductive power transfer, main power circuit.

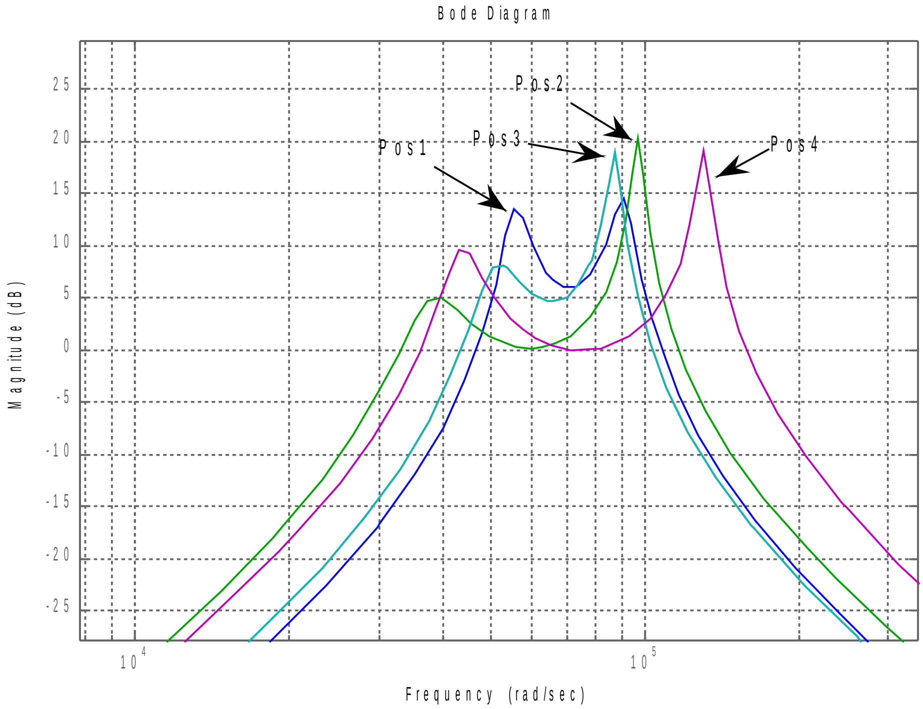

Fig. 18. Transfer characteristics , *H*. Logarithmic scale.

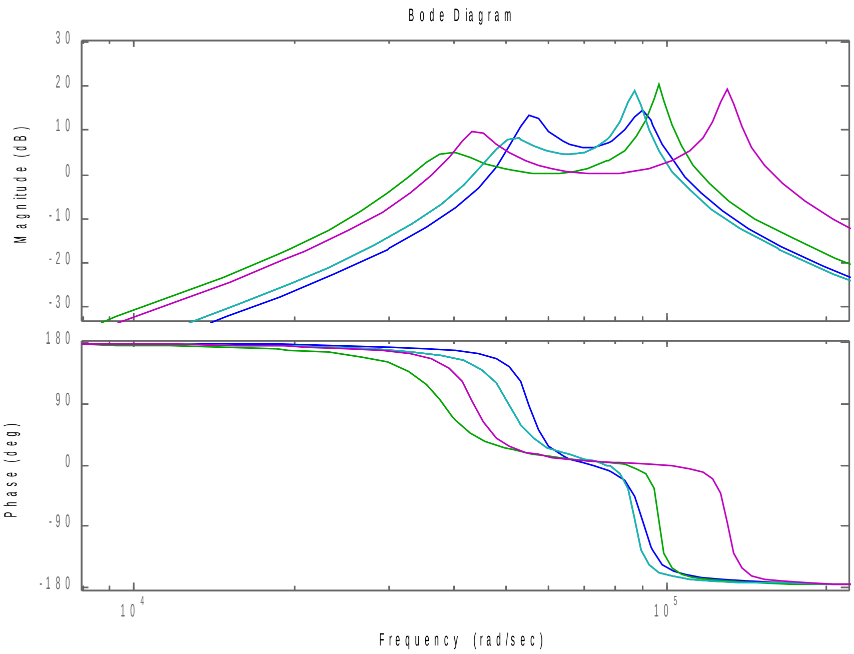

Figure 19. Bode plot, including the phase

5. RF / Microwave Transmission

Beside the micro-wave experiments mentioned in this report, many scientist reports on power transfer at 1-100 MHz.[36]. Normally it is for low power but some write about near field antennas for charging of electric vehicles.

I see some problems in this frequency range. The wavelength is much larger than the antennas and a fact that is hard to avoid is that with increased frequency we will also increase the electric field. As an example the 2D-structure according to Figure 20 is analyzed for different frequencies.

Under and above the current carrying coil there is a shielding plate made of copper and it is supposed that the receiving coil is adjacent to this shield. The total current (number of turns times the current) fed into the lower coil is 390 A. And the field is measured at a position that possibly could be a place for a foot or a face. The resulting flux density and electric field is shown in Figure 21.

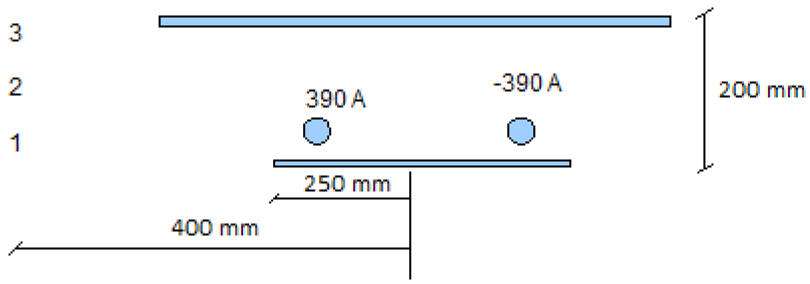

Figure 20. Analyzed antenna

In this calculation the displaement current in Maxwell's equations are considered as neglible.

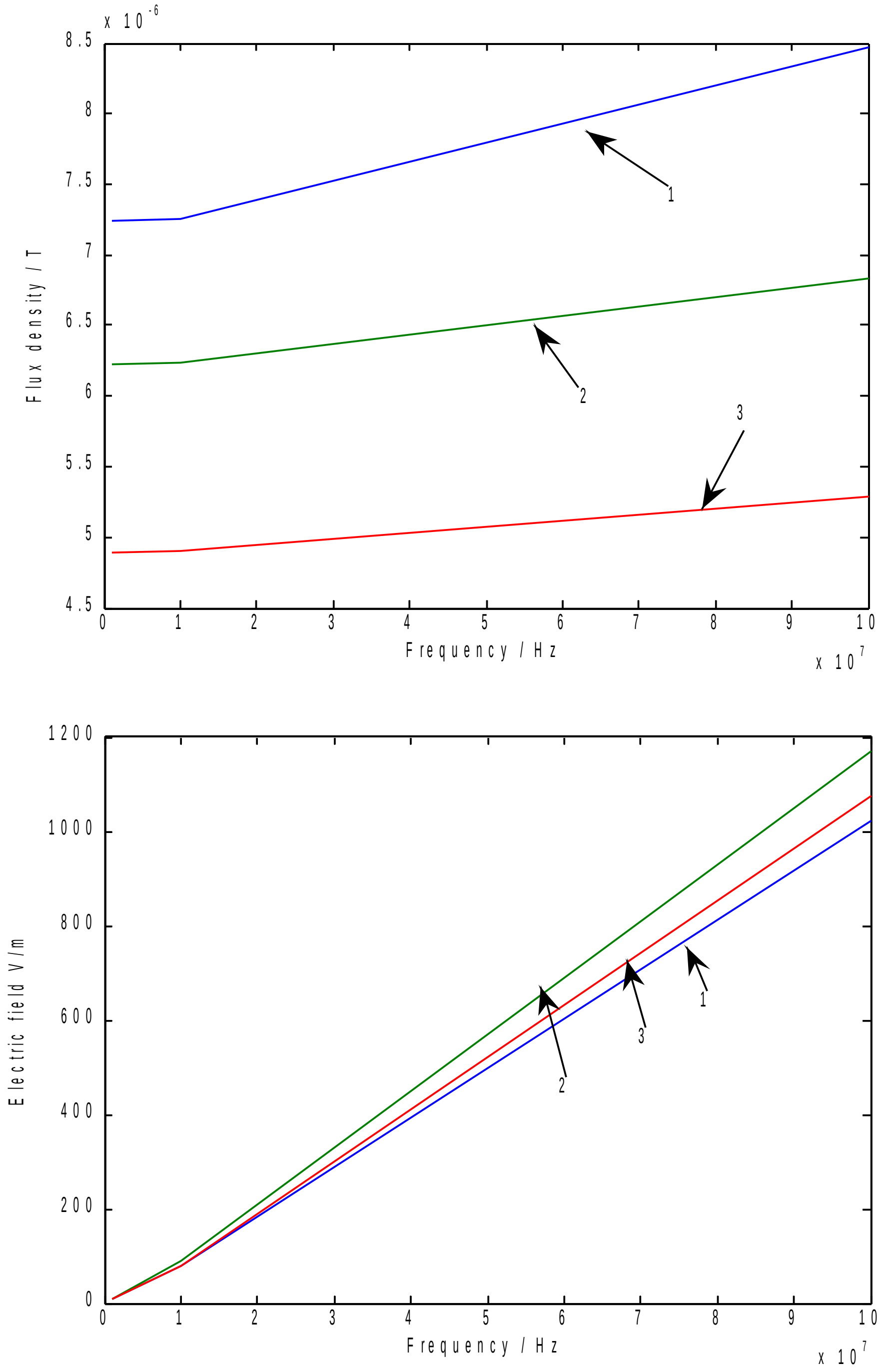

Figure 21. Flux density and electric field at the positions 1,2 and 3.

The magnetic flux density should be possible to handle. It's in the same range as the limit of today, but the electric field is very high. A figure of what is permitted is the SAR rating specified by Strålsäkerhetsmyndigheten, see Figure 22.

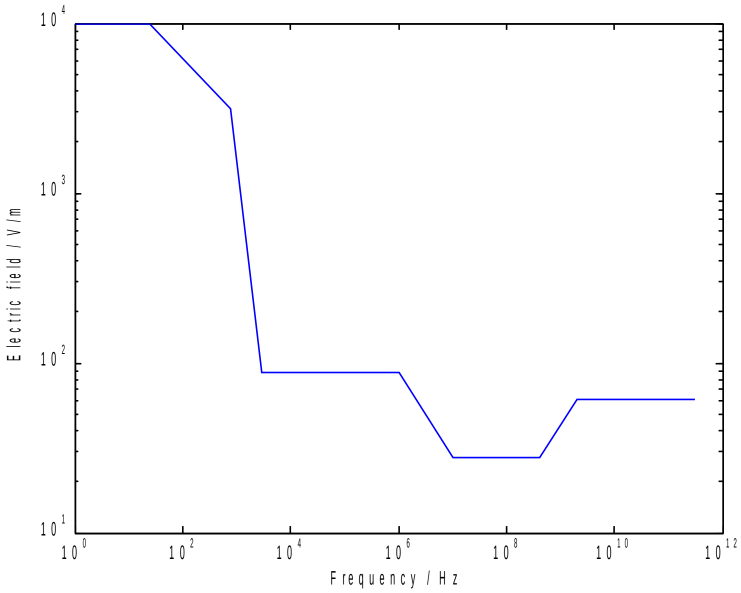

Figure 22. Limits of electric field amplitude.

Relatively high electric field-strength is permitted at low frequency but in the mid range 1MHz to 2 GHz the limit is lower than 100 V/m.

6. Parameters

A lot of parameters have to be taken into account when discussing a standard for charging connections. The work towards a standard for the inductive power transfer is described by Conny Börjesson, see Appendix A which is a copy of SHC News letter. An attempt to summarize the most important parameters:

* Power Levels

* Frequency

* Size and shape of the coils

* Number of coils.

* Direction of the magnetic flux density

* Type of tuning on the sending side. Series or parallel capacitor.

* Safety

* Position of the secondary coil

* Air gap length

* Shielding of magnetic and electric field

* Communication, some sort of signal should start the system when an authorized vehicle is above the charger and also disengage the system when the vehicle isn't present any more.

* A billing system has to be incorporated if charging points should be utilized in public areas.

* The communication could also be helpful when the driver tries to position the vehicle in the right spot.

7. Summation

The electric vehicles of today have limited driving range, but we can expect incremental improvements towards 250-300 km / per charge and even longer if the work on new chemistry will succeed. It might be a solution for passenger cars. I.e. the operating range will be long enough for the costumer and the need for opportunity charging will disappear. This will take some years.

However a big investment in the infrastructure could kick-start the electric vehicle market. If slow and fast chargers will be available on several locations the drivers will be more confident in the car itself. There are already fast DC-chargers up to 50 kW, fast AC-chargers up to 43 kW and there are inductive chargers that can be installed to the Nissan Leaf and Chevrolet Volt. The ERS, could at least power a major part of freight transportation beside the rail-way system. If the ERS have inductive power transmission the cars could use the infrastructure as well, and it is likely that future cars will anyway have some sort of inductive power device for charging. It could be an excellent way to power electric cars for long way travel. It would also make it possible to lower the battery size and the cost of the vehicles.

There are several techniques for charging of electric vehicles, the most promising is conductive charging and inductive wireless charging. These two techniques are already available and there is a common core technology using high frequency switching at high power level. A further development is the ability to deliver energy back to the grid in the future.

Conductive charging along the highways, ERS, is developed for trucks and buses. Until now it is solved via pantographs, which are not considered as an alternative for the cars. It is to big distance between the car roof and the power lines. Tests are done on feeding the trucks from conductors on the ground, which may also be useful for the cars.

The conductive charging stations have a drawback compared to the other types. A cable and connector has to be handled which can be messy and inconvenient. There is also a risk that the cable is not connected when the driver comes back to the car. As well as installing high frequency inductive plates it should be possible to develop automatic systems that connects to the car and secure that charging takes place. As well as for the other systems it's important to agree upon global standards that will increase the production volume of critical components, which will lower the cost of the vehicles and the charging equipment.

Inductive wireless charging is already an alternative for standstill charging. Opportunity charging of busses are tested and even charging of the battery when the bus moves. The vertical distance between the coils is large and the magnetic field may exceed what is regarded as healthy for the people near the bus or the car. It has been mentioned that it is of interest to minimize the air gap in the coils of the IPT. This can be seen as a mechanical problem but there is an alternative with a coil that levitates on the magnetic field, (source prof. Alaküla). A smart solution in this way could reduce the other problems mentioned in chapter 4.

The capacitive power transfer has until now achieved rather low power rating. In my opinion it would be possible to make an effort in this area. In order to increase the capacitance it would be possible to optimize the tire. One point is to maximize the surface of the tire that is in near contact with the ground (exciting plate). This is opposite to what is needed in low friction high pressure tires, which is desirable for cars with low rolling resistance. Another part is the possibility to change material in the tire to lower the losses in power transfer, [9].

It seems probable that fuel-cell cars will be an option in 2015. If major investments are done in USA, Japan and Germany a significant part of the future cars will be made in this way. Toyota which has an consequent and well defined strategy, names fuel cell vehicle as the ultimate eco-car and probably the vehicle will have plug-in capability. The hydrogen production works as a complement to renewable energy, which I see as an important factor. Germany for instance doesn't have the ability to balance wind and solar power with hydro power as the Swedish energy system can do.

Based on the tests in Japan, [13], microwave transfer may be of interest but as I see it transfer in the frequency range 1-100 MHz is of no interest due to the disturbances with other systems, and also a conflict with the SAR-ratings.

Based on the collected information and presented work a number of research suggestions have been identified. An attempt to rate different technologies are made and a brief description of the technology is done:

IPT tuning	Research on inductive power transfer from ERS to the vehicle. How misaligned coils and coils that are not fully matched will influence the power circuits. Invent different ways to tune the circuit in a case of mismatch and maximize the power transfer. Investigate optimal coil shape and optimal frequency.
IPT minimize	Research on inductive power transfer where the secondary coil is 'free' to move and come as close as possible to the primary coil. The air gap is minimized. The research will be concentrated to coils that levitates on the magnetic field.
Microwave/RF	A work mainly on antenna theory and high frequency. Verify the conclusion about the frequency range from 1 to 100 MHz and if that is verified concentrate on micro-waves. How to make antennas that can direct the power to the receiving antenna without disturbances to people and surrounding equipment. How to generate and rectify the power with high frequency and high efficiency.
Capacitive	As suggested in [9] investigate if a change of the tire-material would result

	in higher transmitted power. Another matter to address is that the secondary power will be received in the rotating wheel. The power has to be transmitted to the stationary car body and how this shall be done is not solved. Slip rings ?
Fast DC charger	In the fast DC charger several conversions take place, that includes high power and high frequency converters as well as transformers. Some parts of the technology is the same as in IPT. Important parts to develop is high efficiency and cost effective power electronic circuits and methods for switching.
Fast AC charger	Used as reference and it is not endorsed from SHC for further work.
Hydrogen	As a start a thorough economical analysis of the difference between building an infrastructure for hydrogen and compare it to ERS. Further investigate if a PHEV with a fuel cell range extender could be a better solution than IPT. The range extender is in this case a relatively small fuel cell. Shorter trips is made using electricity and the battery. Long trips utilize the fuel cell.

A rating system is used where green is good and red is bad.

Best, 5	Good, 4	Neutral, 3	Bad, 2	Worst, 1

	Potential Power	Efficiency	Infrastructure cost	Vehicle cost	Emission (Electromagnetic noise)	Rating
IPT tuning						16
IPT minimise						18
Microwave/RF						11
Capacitive						16
Fast DC charger						22
Fast AC charger						21
Hydrogen				*		20

*Assumed that a smaller battery compensate for fuel cell cost

The highest rating is from the conductive charging, but no value has been added for convenience and what the user would prefer. Hydrogen has also a high rating and I see it as an important area. It is however not the main focus in this report.

Among the wireless chargers inductive and capacitive have almost the same rating and RF/microwave have the lowest. The latter is a reflection of the possible problems with radiated disturbances and cost for safety and construction of the charging 'stations'.

Based on the information in this report I would recommend research and development on:

A. Optimal coil system and tuning. Coil systems and tuning of the circuits for inductive charging. Optimal coil system in terms of shape, magnetic layout and frequency. As an extension ways to minimize air gap and ways to avoid disturbances.

B. Capacitive charging. Investigate the potential of capacitive charging. Study the influence of material change and eventually other changes that could increase the power level.

C. High frequency power electronics. High frequency circuits for high power (Power > 50 kW, 40 < switch freq. < 150 kHz). It's a common technology that is important both in fast chargers and inductive chargers and maybe the good switching characteristic of silicon carbide components can be of interest.

D. Antennas. Micro-wave transfer. A smaller feasibility study on antennas, generation and handling of micro-waves.

8. Abbreviations

IPT	Inductive Power Transfer
BEV	Battery Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
FCHEV	Fuel Cell Hybrid Electric Vehicle
ICE	Internal Combustion Engine
RF	Radio Frequency
SHC	Swedish Hybrid Vehicle Centre
BMS	Battery Managment System
V2G	Vehicle to Grid
SOC	State Of Charge
SAR	Specific Absorption Rate
ERS	Electric Road System
SiC	Silicon carbide

9. References

[1], 'Shifting freight traffic to rail proves daunting', by Daniele Mariani and Christian Raaflaub, swissinfo.ch Jun 24, 2012

[2] 'Godstransporter i Sverige redovisning av ett regeringsuppdrag', Rapport 2012:7.
[3] 'PHEV09-S12-3_TakafumiAnegawa', Tepco, **http://ebookbrowse.com/phev09-s12-3-takafumianegawa-pdf-d320835715**

[4] ' Fuel Cell or Battery: Electric Cars are the Future', J. VanMierlo, G.Maggetto, FUEL CELLS 07, 2007, No. 2, 165–173

[5] 'Magnetic Field Design for Low EMF and High Efficiency Wireless Power Transfer System in On-Line Electric Vehicles', S. Ahn, J. Y. Lee, D. H. Cho, J. Kim, **http://olevtech.com/technology/literature/**
[6] 'Application of Shaped Magnetic Field in Resonance (SMFIR) Technology to Future Urban Transportation', I. S. Suh, **http://olevtech.com/technology/literature/**
[7] http://primove.bombardier.com/media/news/show/134/#134-primove-e-bus-in-mannheim-successfully-homologated
[8] Conductix-Wampfler
[9] 'CAPACITIVE POWER TRANSFER TO CAR THROUGH WHEEL - IS IT POSSIBLE?' Hall S. , Master Thesis LTH.
[10] 'Inductive Charging of Electrical Vehicles', M. Cederlöf, XR-EE-ETK 2012:001, KTH
[11] 'Elektrolyse-neue Potentiale in eiener sich verändernden Energielandschaft', Manfred Waidhas, **http://www.dwv-info.de/aktuelles/Pressemeldungen/2012/pm1201_wai.pdf**
[12] http://www.hybridcars.com/50-hydrogen-filling-stations-germany-47346/
[13] **http://techon.nikkeibp.co.jp/english/NEWS_EN/20120708/227131/**
[14] 'Development of a new type of electric off-road vehicle powered by microwaves transmitted through air', Oida, Nakashima, Miyasaka, Ohdoi, Matsumoto, Shinohara, **http://dx.doi.org/10.1016/j.jterra.2007.10.002**
[15] http://www.nature.com/srep/2013/130307/srep01401/full/srep01401.html, Wang et.al., open paper in Nature.
[16] 'Inductive Power Coupling for an Electric Highway System', Bolger et.al., 28th IEEE Vehicular Technology Conference
[17] 'Transportarbete 1950-2011', www.trafa.se (Regeringens Trafikanalys)

[18] http://www.mobility.siemens.com/mobility/global/en/interurban-mobility/road-solutions/electric-powered-hgv-traffic-eHighway/the-ehighway-concept/Pages/the-ehighway-concept.aspx

[19] https://www.viktoria.se/projects/slide-in-electric-road-system#description

[20] http://www.autocar.co.uk/car-news/geneva-motor-show-2013/geneva-motor-show-mitsubishi-ca-miev-crossover-concept

[21] http://www.sim-drive.com/english/index.html

[22] http://green.autoblog.com/2012/04/04/new-sim-wil-electric-prototype-has-218-mile-range-in-wheel-moto/

[23] http://gglotus.org/blog/2009/09/lotus-range-extender-engine-revealed/

[24] http://en.wikipedia.org/wiki/Elect%27road

[25] http://en.wikipedia.org/wiki/General_Motors_EV1

[26] M. Hagen, S. Dörfler, P. Fanz, T. Berger, R. Speck, J. Tübke, H. Althues, M.J. Hoffmann, C. Scherr, S. Kaskel (2013) Development and costs calculation of lithium–sulfur cells with high sulfur load and binder free electrodes, *Journal of Power Sources*, Volume 224, Pages 260-268, doi: 10.1016/j.jpowsour.2012.10.004

[27] M. Hagen, S. Dörfler, E.Q. González, H. Althues, J. Tübke, H. Föll (2012) High energy cells: Lithium-sulfur and lithium-sulfur-silicon. Honolulu PRiME 2012.

[28] Arumugam Manthiram, Yongzhu Fu, and Yu-Sheng Su (2012) Challenges and Prospects of Lithium–Sulfur Batteries. *Accounts of Chemical Research* doi: 10.1021/ar300179v

[29] Saeid Haghbins, 'Integrated Motor Drives and Battery Chargers for Electric or Plug-in Hybrid Electric Vehicles', ISBN 978-91-7385-811-3

[30] http://www.wampfler.com/data/files/downloads/PRB9200-0019-IPT%20Charge%20for %20Buses.pdf

[31]http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Forfattning/SSMFS/2008/SSMFS2008-18.pdf, Tabell 2

[32] http://www.bahn.com/i/view/GBR/en/prices/europe/motorail.shtml

[33] http://blog.renault.com/en/2012/03/06/renault-zoe-quite-simply-revolutionary-and-yet-a- reality/

[34] Thiringer, Lundmark, Palmberg, Karlsson, Alatalo, 'Wireless charging-some key elements', Technical report - Department of Energy and Environment, Division of Electric Power Engineering, Chalmers University of Technology; nr 2013:1

[35] http://www.toyota-global.com/innovation/environmental_technology/fuelcell_vehicle/

[36] Xiaofang Yu, Sunil Sandhu, Sven Beiker, Richard Sassoon, and Shanhui Fan, 'Wireless energy transfer with the presence of metallic planes', Applied Physics Letter 99

[37] http://patentscope.wipo.int/search/en/detail.jsf?docId=WO2011139680&recNum=80&docAn=US2011033915&queryString=%28energy%2520and%2520%28hydro%2520or%2520wind%2520or%2520bio*%2520or%2520geotherm*%2520or%2520solar%2520or%2520hydrogen%29%29&maxRec=194680

[38] http://www.proterra.com/index.php/products/productDetail/C23/

Appendix A.

From Magnus Karlströms Newsletter 130310

Standardiseringsarbete inom trådlösa energiöverföringssystem för elfordon
skrivet av Conny Börjesson, Swedish ICT Viktoria

Utvecklingen av induktiv laddning för elbilar har på allvar tagit fart under 2012. Ett stort antal samarbeten har annonserats och standardiseringsarbetet har påbörjats. Tekniken står inför en nära förestående lansering och det är hög tid att hänga med utvecklingen för den som har intressen i tekniken.

De tre mest aktiva nationerna är USA, Tyskland och Japan som alla har en stor bilindustri och flera stora underleverantörer.

Standardiseringsarbetet inom trådlösa energiöverföringssystem (Wireless Power Transfer systems - WPT) för elfordon startade under 2012 och fokuserar i nuläget primärt på personbilar och stationär överföring. Enligt tidsplan skall generella krav fastställs i IEC 61980 innan sommaren 2014 för att därefter underhållas parallellt med att specifika krav tas fram, vilka planeras att vara fastställda hösten 2017. För att utföra arbetet har två arbetsgrupper skapats, ledda av Audi respektive Toyota. Tidsplanen diskuteras aktivt och justeras i takt med att nya aktiviteter tillkommer arbetet.

- Arbetsgrupp 1 (“Specific requirements for communication between electric road vehicle (EV) and infrastructure with respect to wireless power transfer (WPT) system”) leds av Audi och fokuserar på specifika krav för kommunikationen som sker mellan fordonet och den infrastruktur som är involverad vid trådlös energiöverföring.
- Arbetsgrupp 2 (“Specific requirements for the magnetic field power transfer systems”) leds av Toyota och fokuserar på specifika krav för de trådlösa energiöverföringssystemen.

Nu är standarden ute på remiss i CD-version (Committe Draft) [1]. Det finns tid till och med den 22 mars 2013 att ge synpunkter på innehållet innan dokumentet fastställs som CD-version inom IEC (International Electrotechnical Commission) (om du vill veta mer om IEC gå in på deras hemsida [2].

CD-dokumentets omfattar följande kapitel: Level, beskriver olika effektnivåer vid trådlös laddning och skall förutom effektnivåer i personbilar även täcka in effektnivåer i tyngre fordon. Ansnittet som behandlar Tuning är inte fullständigt definierat i dagsläget, men är tänkt att avhandla aspekter med avseende på primär- och sekundärsidans avstämning av resonansfrekvens. Vid korrekt avstämning av resonansfrekvens fås på ett avstånd lika med fordonets markfrigång en mycket hög verkningsgrad, till skillnad från teknik som inte tar hänsyn till resonansfrekvensen och därmed har mycket låg verkningsgrad på samma avstånd. I avsnittet Magnetic coupling beskrivs primärt spolarnas geometriska dimensioner och placering. Rubrik Frequency beskriver val av frekvens(er) för energiöverföringen och EM radiation skall täcka det viktiga området säkerhet med avseende på störningar, påverkan på människor och djur samt värmealstring vid energiöverföringen.

Strax före jul 2012 hölls ett möte i Achen i Frankrike där följande företag och institutioner var på plats:

- Nissan
- Toyota
- JARI (Japan Automobile Research Institute)
- Sumitimo
- Qualcomm
- Audi
- Siemens
- SEW
- Schneider

Hela standardiseringsarbetet leds av Eduard Stolz från Park-charge som har många års erfarenhet när det gäller processer för standardisering och som även har ett stort internationellt kontaktnät. I arbetet har JARI tagit huvudinitiativ inom skydd och mätmetoder för EMF (Electro Magnetic Fields) och EMC (Electro Magnetic Compatibility). Nu har även Renault börjat uttala sig och föreslår att en expertgrupp bildas innan dessa områden. Qualcomm gjorde ett inlägg med avseende på värmealstring vid användning av tekniken. Bland annat på grund av den rådande juridiska situationen i USA är amerikanerna extra vaksamma vad gäller brandsäkerheten kring den nya tekniken och lägger därför extra kraft och energi på detta.

Nästa möte kommer att ske i Tokyo under februari. Man skall då fortsätta att diskutera planeringen av arbetet och även starta diskussioner angående tekniska detaljer. Nu i närtid fokuseras arbetet på insamling av relevanta dokument i området. Man samlar även in förslag på vilka frekvenser som ska användas vid energiöverföringen. Nästa steg blir att försöka enas om något gemensamt vad gäller dessa frekvenser. Interoperability, det vill säga att olika företags produkter skall kunna fungera tillsammans kommer att vara den övergripande frågan. Vems koncept som skall bli tongivande, och blir de andra företagen tvungna att anpassa sig efter detta koncept, är frågor som återstår att besvaras. Just nu lutar det åt en lösning med två separata frekvenser, en frekvens ur den lägre delen av det aktuella frekvensspannet och en frekvens ur den högre delen av spannet.

Hur viktigt är då IEC-arbetet? Standarden är endast en rekommendation, men om till exempel EU antar den så finns det ekonomiska påtryckningsmedel för att följa standarden i samband med upphandlingar. Om flera tongivande företag ansluter sig till standarden så blir det ett faktum att andra företags produkter och tjänster måsta vara kompatibla, det vill säga passa med standarden, för att de skall kunna vara med och konkurrera på marknaden.

[1] På IEC hemsida kan man läsa följande angående CD-stadiet i standardiseringsarbeten:

”The committee stage is the principal stage at which comments from national bodies are taken into consideration, with a view to reaching consensus on the technical content. National bodies shall therefore carefully study the texts of committee drafts and submit all pertinent comments at this stage. As soon as it is available, a committee draft is circulated to all members of the technical committee or subcommittee for consideration, with a clear indication of the latest date for submission of replies.”