

Large Scale Testing of Wireless Charging in Sweden

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Summary

Wireless charging has the potential to simplify charging of electric cars, a technology that is now tested on a larger scale in Sweden in an ongoing project denoted WiCh (Wireless charging of electric vehicles). Inductive wireless chargers have been installed in a total of 20 electric vehicles located in Sweden, which means that so far the study is the largest demonstration activity of inductively charged vehicles in the world. The technology will be demonstrated and assessed during a year, and the experiences gained so far are outlined in this paper.

Keywords: EV (electric vehicle), PHEV, inductive charger, wireless charging, demonstration.

1 Introduction

Plugin electric vehicles, including both chargeable electric vehicles and plugin hybrid electric vehicles, have potential to reduce emissions, pollutions, oil dependency and traffic noise. The number of plugin electric vehicles and charging points increase in the world [1]. However, the market share of rechargeable vehicles is still modest, possibly with Norway as an exception, and there are several barriers pointed out; electric vehicles being more expensive than conventional fossil fueled cars, current battery technology, inadequate consumer knowledge and lack of charging infrastructure are some obstacles mentioned in [2]. In [3], the conclusion has been made that important real barriers to battery electric vehicle deployment are range, price, awareness and the availability of charging infrastructure. Range anxiety has earlier also been pointed out as a potential obstacle [4].

The charging cable can also be a potential barrier for electric car buyers. Therefore, several solutions have been proposed to make automated refueling systems for vehicles, both for fossil fueled cars, see e.g. Husky and Fuelmatics' Automatic Refueling System prototype [5], as well as for electrically charged vehicles, see e.g. Tesla's snakelike charger prototype [6]. However, an obvious drawback with these types of robotic fueling systems is high manufacturing costs, and it is unlikely that these products will be a mass-market home charging solution, if for anyone at all.

Another possibility is to charge plugin electric vehicles wirelessly without a cable or a cord between the charger and the charged vehicle. Charging with wireless technology is convenient and can be fully automated in the future, giving electric vehicles an advantage over fossil-fueled cars since they then can charge automatically when parked, e.g. at home in the garage, and there is no longer a need to go to the gas station. Furthermore, the wireless charger could potentially have lower lifecycle costs, due to the lack of a cable or plug which could be damaged or vandalized. Conductive charging [7] and inductive charging [8] are two types of wireless charging. Conductive charging uses a conductor to connect two electric devices in order to transfer energy, and requires contact between the charger and the charging device.

Inductive charging is a technology where a magnetic field is used to transfer energy between two objects. An alternating current in the primary coil creates an alternating magnetic field that induces an alternating

current in the secondary coil, see Figure 1a. In the case of charging vehicles, the primary coil is normally placed on top of, or mounted in the ground surface, and the secondary coil is mounted under the vehicle, see Figure 1b. As a technology, inductive charging has been known for a long time. However, transferring energy over a fairly long distance, e.g. from the ground to the underside of the vehicle, with high efficiency is challenging. A decade ago, a new technology with strongly coupled magnetic resonances was invented [9], which made it possible to transfer energy over distances up to several times the radii of the coils with high efficiency, opening up for efficient charging solutions for plugin electric vehicles.

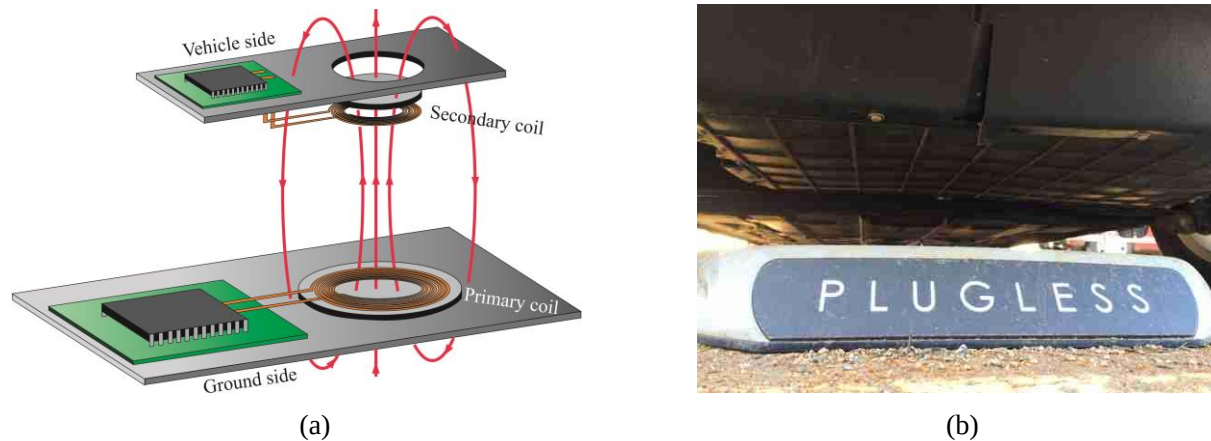


Figure 1: (a) Inductive charging where an alternating current in the primary coil generates an alternating magnetic field (indicated by red field lines) which induces an alternating current in the secondary coil. (b) In reality, the primary coil and its electronics are encapsulated and placed e.g. on the ground with the secondary coil and its electronics mounted underneath the vehicle, here under the square patterned guard.

Currently, even though several suppliers have stated that they are involved in the business of inductive charging, it is almost impossible to buy and test their equipment. Published news and personal contacts indicate that the suppliers try to sell the equipment directly to the car manufacturers, instead of testing it in a public environment. However, there is one exception described next.

WiCh – Wireless Charging of electric vehicles – is an ongoing project in Sweden [10], financed by the Swedish Energy Agency together with the project partners, where the purpose is to determine how the inductive charging technology works under Swedish real life conditions with for example cold temperatures, moisture and snow. During 2015, Evatran installed its **Plugless**[®] system of inductive wireless chargers in a total of 20 electric vehicles located in Gothenburg, Stockholm and Uppsala. This means that this Swedish study is the first large-scale demonstration of wireless charging outside North America [11]. Previous trials have only been performed in laboratory environments.

Wireless charging solutions can be convenient and have the potential to be an appreciated feature for electrically charged vehicles. Of course, the suppliers believe in future business, and so do several Original Equipment Manufacturers (OEMs), see e.g. [12] and [13]. However, it is important for other stakeholders as well to increase their knowledge by getting insights into the technology and find out what pros and cons users experience when handling the equipment as well as study how users interact with the new technology. This is the main reason for making this demonstration project around the new technology; the demonstrator will serve as a living lab research platform.

The electric cars with installed inductive charging are mainly used by municipality representatives, who use them in their ordinary daily operations. The main research objective of the WiCh-project is to answer the question if induction charging changes the users' charging behavior and if it causes more frequent connection of electric vehicles to the grid. However, before collecting data and answering this question, a phase of finding suppliers and installing the equipment has been performed. This paper focuses on this aspect and will highlight the experiences gained and the complexity of getting a project up and running. Some initial field trial results will also be given. Further project results can be found in [14] and [15].

The outline of the paper is as follows: First, a short description of the project is given including some of the project challenges. Technical Tests 3 explains the technical tests, followed by initial field trial experiences. The paper is ended with conclusions and future work.

2 Project Challenges: Setting up a Large-Scale Demonstration Trial

During 2011 a pre-study performed by Vattenfall and Viktoria Swedish ICT was granted by the Swedish Energy Agency, where different potential technologies that could facilitate automated and convenient charging of electric vehicles were studied. The potential charging solutions were evaluated by several overall criteria like accuracy, vandalism resistivity, estimated product cost, maintenance cost, efficiency, aesthetics, safety and sensitivity to snow and dirt. The main conclusion from the pre-study was that wireless charging by induction was deemed to have the greatest potential. Several suppliers of inductive wireless charging equipment were identified and contacted; some of them stated that they would be capable and willing to supply equipment to a demonstration project. Therefore, a demonstration project was formed and submitted as an application. The top row of Figure 2 indicates the phases of the pre-study, ending with a submitted application and an approved project, the WiCh-project that this paper is about.

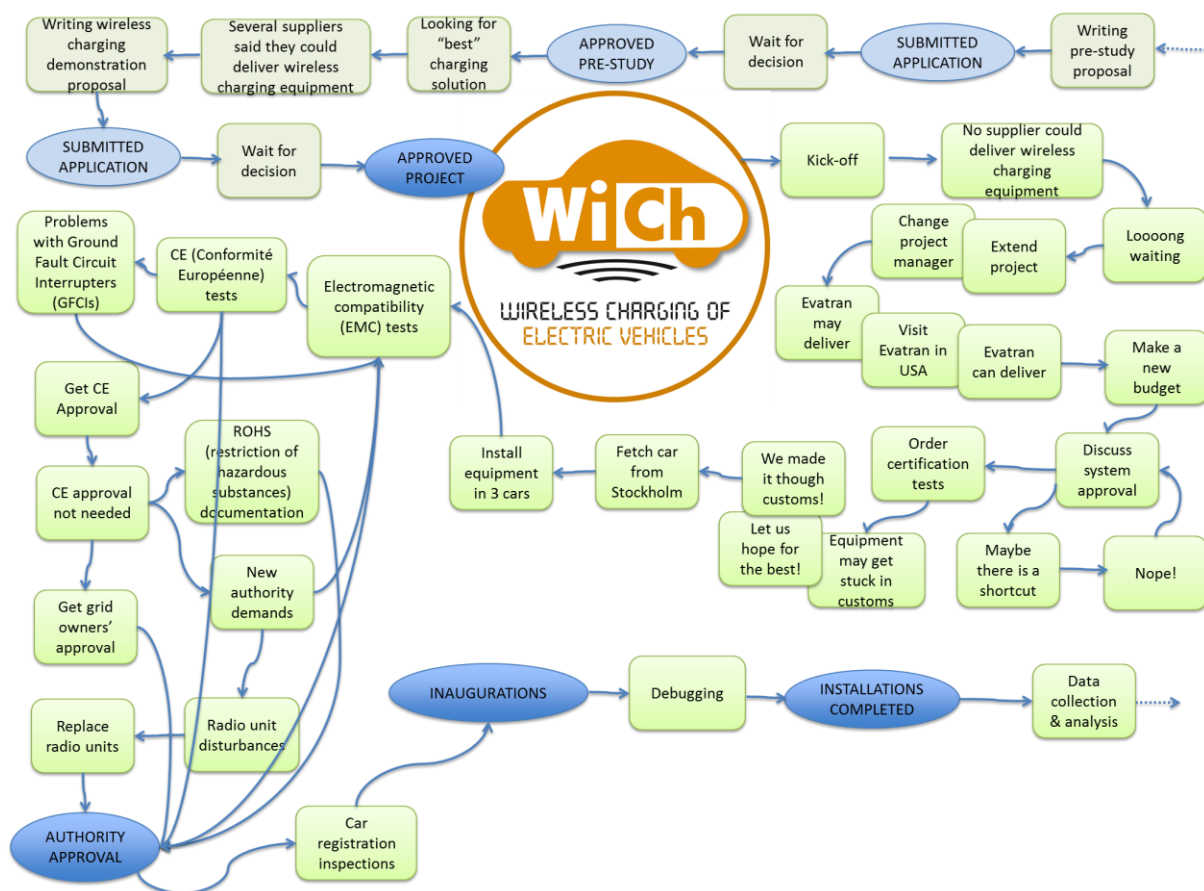


Figure 2: The main activities (green boxes) and milestones (blue ellipses) in the WiCh-project.

The aim of the WiCh project is to demonstrate and evaluate wireless charging with municipality users driving on public roads, to build knowledge and experiences both regarding technical issues like efficiency, EMC, electrical safety, radiation levels, robustness, costs, as well as user experiences and attitudes. The main hypothesis is that with wireless charging, vehicles will be more frequently charged compared to manually charging with cable. In addition, another hypothesis is that electric vehicle drivers will think that wireless charging is more attractive than charging with cable. We are furthermore interested in the possible concerns drivers may have regarding the safety aspects of inductive charging.

However, it turned out that to demonstrate and evaluate new technologies presented several challenges that had to be addressed, see Figure 2 for details, each of which with specific issues:

1. Acquiring and installing equipment
2. Getting approval for usage
3. Finding vehicles and users

2.1 Acquiring and Installing Equipment

Once the demonstration project WiCh had started in the autumn of 2012 and the suppliers were again contacted, it turned out that none of them were willing to deliver the charging equipment. We can only speculate about the reasons for this change, but it seems likely that both the technology had not matured as quickly as expected and that the suppliers prioritized future business with vehicle manufacturers over public demonstrations. Regardless of the reason, there was no other option than to put the project on hold and continue the dialog with the suppliers hoping for anyone to be willing to deliver the equipment.

During the spring of 2014, the American start-up company Evatran launched their Plugless[®] system to the American aftermarket for Chevrolet Volt and Nissan Leaf. Evatran was again contacted but hesitated to deliver their equipment since it only had been approved for the US market, which had required a lot of testing and approval from the authorities. After further discussions and a visit to Evatran, we all agreed to use their equipment in our project anyway, and 4 initial systems were ordered for certification tests in Sweden.

The delivery of these systems presented a specific challenge. According to custom regulations, non-certified equipment may only be imported for test and evaluations. The intention we had was to first use them for certification tests and then afterwards use them in the actual demonstration project. This double usage created a “Catch 22” situation: the systems could not be imported for demonstration use until they were approved, but we could not get them approved before they were imported. After several discussions with customs authorities and logistics companies, a few systems were first temporarily imported for testing, then temporarily exported. These systems and the remaining systems were then finally imported for usage when tests indicated they were approved (see Section 2.1 below).

The first systems were installed in 3 vehicles in December 2014. After receiving the approval for usage, an additional 17 systems were ordered and installed by Evatran and authorized Swedish electricians in May 2015. Finally, Stockholm and Gothenburg city officials could inaugurate the demonstration phase on May the 28th and 29th of 2015 respectively. In retrospect, the time from the first delivery of systems for certification to approval was 5 months, and the total time from project start to installed systems was 32 months – including 12 months during which the project was put on hold.

2.2 Getting Approval for Usage

In Sweden, to put any new technology on public roads requires approval from the Swedish Transport Agency. In this case, they in turn relied on statements from the Swedish National Electrical Safety Board, the Swedish Post and Telecom Authority and the certification laboratory at SP Technical Research Institute of Sweden.

In general, such equipment as this can be regarded as a “fixed installation”, which means that it does not have to be CE marked, although in principle the same requirements should be fulfilled. In this case, the complete system mounted in the car had to pass EMC tests, electrical safety tests and fulfil the RoHS (Restriction of Hazardous Substances) directive. The results and experiences from these tests are given in Section 3 below.

2.3 Finding Vehicles and Users

To get information about usage and getting access to 20 electric and plug-in electric vehicles together with users, a project consortium was built with the partners:

- City of Stockholm (5 vehicles in Stockholm)
- City of Gothenburg (14 vehicles in Gothenburg)
- Vattenfall AB (1 vehicle in Uppsala)
- Swedish Radiation Safety Authority
- Test Site Sweden (measurements)
- Viktoria Swedish ICT AB (project leading and research)

The vehicle owners were initially concerned that the warranties of the vehicles in the project would be void due to the modifications during the installation process. However, these concerns could easily be resolved since Evatran, as most other aftermarket suppliers, takes the warranty for any problems that occur due to their equipment.

The recruited users of the vehicles are people working with elderly care or parks, employees at the local energy company, volunteers in neighborhood watch, etc., and they use the vehicles in their day to day business. Vattenfall employs one user who also uses the vehicle for personal travels. All users are experienced electric vehicle drivers.

To ensure the users' safety, Swedish Radiation Safety Authority performed measurements of magnetic fields inside and around the vehicle. Since the fields measured were below the levels given by the Swedish Work Environment Authority, but above the requirements for public spaces, all charging stations (control box, primary coil, filters, etc.) were set up in closed parking spaces dedicated only to employees.

3 Technical Tests

In order for the project to be able to use the equipment within the European Union the following requirements were identified as necessary to be tested against:

- Conformité Européenne (CE) related tests:
 - Directive 2014/35/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits.
 - Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast):
 - Emission, EN 61000-6-3:2007/A1:2011
 - Radiated emission
 - Conducted emission
 - EN 61000-3-2 Harmonics
 - EN 61000-3-3 Voltage fluctuations and flicker
 - Immunity, EN 61000-6-1:2007
 - EN 61000-4-2 Electrostatic discharge
 - EN 61000-4-3 RF electromagnetic field
 - EN 61000-4-4 Fast transients
 - EN 61000-4-5 Surges
 - EN 61000-4-6 RF conducted disturbances
 - EN 61000-4-8 Power frequency magnetic field
 - EN 61000-4-11/34 Voltage dips and interruptions
 - Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).
 - Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS).
- E-mark related tests:
 - UN ECE Regulation No. 10.04. 04 series of amendments, including amendment 2:2013
 - Annex 4, radiated broadband emission 30-1000 MHz (CISPR 12:2009)
 - Annex 5, radiated narrowband emission 30-1000 MHz (CISPR 12:2009)
 - Annex 6, Radiated immunity (ISO 11451-2) 20-2000 MHz
 - Annex 11, Harmonics on AC power lines
 - Annex 12, Emission of voltage changes, voltage fluctuations and flicker
 - Annex 13, Emission of conducted RF on AC or DC power lines
- Swedish Post and Telecom Authority, Direction of Exemption from License Obligation, PTSFS 2014:5.
- Magnetic field strength, Swedish Work Environment Authority 2015/015968 and directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields).
- Swedish Transport Agency, Transportstyrelsens föreskrifter och allmänna råd om bilar och släpvagnar som dras av bilar (TSFS 2010:2). Loosely translated; Swedish Transport Agency's general rules and regulations on cars and trailers pulled by cars (TSFS 2010:2).

Since the charging equipment at least partly is mounted in the vehicle and as such might alter the behavior, it was also necessary to get an approval with regards to UN ECE Regulation No. 10:Rev4:2012, 04 series of amendments, including amendment 2:2013. One way to approach this regulation, and the one that was chosen, is to test the system installed in a specific car model. This will then not give a general approval, but instead only be relevant to the installed equipment in the specific model it's been tested on. Testing was done by SP Technical Research Institute of Sweden, see Figure 3, the Swedish Radiation Safety Authority and an accredited motor vehicle inspection facility.

Not all tests came back with a positive result necessitating a mix of actions in order to fulfill all regulations:

- Directive 2014/35/EU (more commonly known as the low voltage directive): Minor deviations from the requirements which a risk analysis performed by SP Technical Research Institute of Sweden showed could be mitigated with an amendment to the documentation and a change in operating temperature. As an example the analysis showed that a relay in the charger could overheat if the surrounding temperature was approaching the specified 50°C maximum operating temperature. Since the temperature in Sweden very seldom exceeds 30°C and most chargers are mounted either in basements or under a roof this was deemed to be acceptable during the project. Other examples include a non-EU standard electrical cable color, a minimum electrical creepage distance on the lower side, as well as a lacking marker for the electrical ground.
- EN 61000-6-3:2007/A1:2011, radiated emissions: Minor deviations, and a radio module not specified to the newly mandatory regulation ETSI 300 328 v.1.8.1 was detected, leading to the project replacing the radio modules to a newer version specified to the new regulation.
- UN ECE Regulation No. 10.04. 04 series of amendments, including amendment 2:2013, Annex 5: A peak in horizontally polarized radiated emissions at approximately 203MHz, see Figure 4, prompted the need for an exemption, which was granted by the Swedish Post and Telecom Authority (PTS) and the Swedish transport agency.
- Conducted emission, EN 61000-6-3:2007/A1:2011 and UN ECE Regulation No. 10.04. 04 series of amendments, including amendment 2:2013 annex 13: Test results indicated radiated emissions exceeding the regulatory limits. By treating the electrical installation as a fixed installation and installing an RF filter on the incoming power cable the emissions could be negotiated.
- Harmonics, EN 61000-3-2 and UN ECE Regulation No. 10.04. 04 series of amendments, including amendment 2:2013 annex 11: Large deviations from the required limits. Exemptions from the regulation were acquired by the electrical transmission system operators (TSO) after a safety analysis done by the local TSO for each installation site.
- RoHs and WEEE: During the necessary timeframe in the project it was not possible to guarantee that all the components were RoHs compliant. There are somewhat less stringent rules when it comes to equipment used for research, but as a way to mitigate the uncertainty with regards to RoHs compliance a contract with the supplier was established where the equipment will be exported back to the supplier for proper disposal.

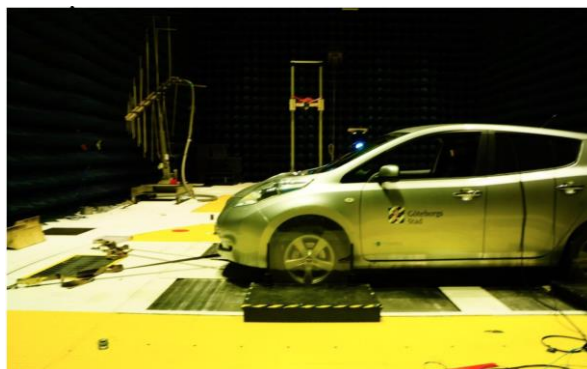


Figure 3: Test setup measuring radiated emission, 30-1000MHz, charging right side, horizontal polarization.

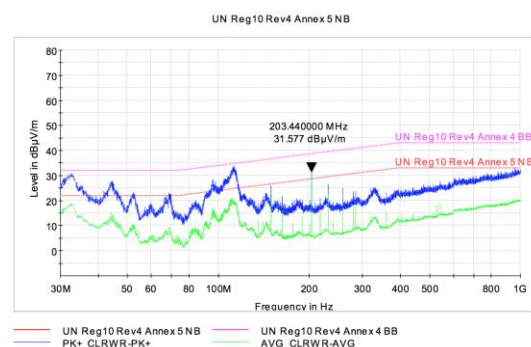


Figure 4: Result measuring radiated emission, 30-1000MHz, charging right side, horizontal polarization.

Due to the above deviations from the requirements, the approval from the Swedish Transport Agency that was received on April 30, 2015 was only temporary for about 2 years.

4 Field Trial: the Effect of Introducing Wireless Charging for Electric Vehicle Drivers

The WiCh-project is now in the stage of data collection and analysis; see the lower right milestone in Figure 2, and will continue until the autumn of 2016. The project will then be summarized and finalized. The remaining part of this paper will describe the study performed to fulfil the main research objective of the project and some initial field trial results gained so far.

The study was carried out as a comparative study of charging with cable (Stage 1) and charging with inductive wireless charging (Stage 2) to explore change in attitudes towards practical use, attractiveness and perceived safety when introducing wireless charging. Stage 1 of the study also captured drivers' expectations of inductive charging.

4.1 Data Collection

The data collection consisted of logged driving and charging data from the 20 vehicles together with a specially developed digital survey (see [14] for further details) to collect the experiences and attitudes of the drivers throughout the trial period. So far, approximately 200 survey responses have been collected. The data collection has been complemented with a set of transcripts from interviews performed in Stage 1. Interviews for Stage 2 are yet to be performed. The first interview study (I1) involved 11 experienced drivers using either battery electrical vehicles or plug-in hybrid vehicles. The drivers used the vehicles either for private errands (i.e., a vehicle owned by themselves) or as transport vehicle in their daily work (i.e., a vehicle owned by their employer). The second interview study (I2) involved key users at each of the participating sites to identify expectations on inductive charging. The first digital survey (Q1) (N=65) was distributed to the drivers in May 2015, before the introduction of inductive charging. The second survey (Q2) (N=56) was distributed approximately two months after installation, and the third survey (Q3) (N=44) about four months after installation of inductive charging. The age distribution among the drivers was 26 to 76+ years for all three surveys and the main part of respondents were between 36 and 55 years of age. All respondents can be considered as experienced electric vehicle drivers while using the vehicles regularly in their daily work tasks. A majority of the drivers had more than 12-months experience of driving electric vehicles. All participants came from the project partner organizations within WiCh. The distribution of responses from each site was roughly 5-15% of total responses with one deviating organization with much higher (35-55% of total) response rate for the three surveys.

4.2 Results

In this paper, an overview of the results from performed interviews in Stage 1 and data from the first 3 digital surveys are presented.

4.2.1 Stage 1: Before the Introduction of Wireless Charging

Experience of charging with a cable

A grounded theory analysis of the first interview study (I1) identified that the charging of electric vehicles can be considered as an easy task to perform. Several isolated and integrated factors were identified to contribute to this positive experience. First of all, all drivers had not experienced any major negative experience related to the charging activity. In addition, respondents also highlighted that charging becomes easy when compared to "booking and accessing the electrical vehicle and drive the vehicle to a destination". This is further emphasized in the questionnaire study (Q1) which showed that 90% of the respondents were positive towards the design of the process of charging with cable. Also, 92% of the respondents were positive regarding the usability of the charging equipment when charging with cable. The interview study (I1) also identified that charging is a highly motivational activity which differ in such a way that organizational motivational factors (a routine written down and the decision made by someone other than yourself) is more prominent in electric vehicle (cooperate) drivers and individual motivational factors (price, environment, technology) is present in drivers of plug-in hybrid vehicles (private use). Common motivational factors for all respondents include the severity of not performing the activity. The decision 'to charge or not to charge' the vehicle is most often determined by physical constraints such as location of the parking space, or the management of the vehicle in terms of, time available, (current/future) needs and the routines/organizational structure in use. This was further emphasized by the questionnaire (Q1). When asked about the most tedious aspect with charging with cable examples of quotes are: "If the

cable is dirty”, “When colleagues don’t connect the cable”, “To connect and not forgetting to disconnect the cable” and simply “I don’t think it is tedious”. Another comment relates to charging as a part of the electric vehicle experience as a whole: “I drive the car two-three times per month. To connect and disconnect the cable is a minor thing to deal with”. That is, the charging part is minor, while their use also involves administrative tasks that are perceived as more time consuming.

Expectations on inductive charging

The analysis of the first interview study (I1) identified that it would be attractive to take away the cable if possible. It was highlighted that the lack of a cable may reduce some of the negative practical aspects of handling the cable including: “easier”, “more robust”, “less vandalism (no parts sticking up)”, “no one can use the electricity for other purposes”, “more automatic process”, “access at inconvenient places (e.g., not practical to have a charging pole in the middle of a large parking space)”, “less parts to handle”, “more practical”, “no need to handle a cable”, “weather independent”, “charging even during short stops at home”, “more approachable for new users”, “efficient use of time”, “no parts that require storage or moving between vehicle and charging point”. In addition, it was argued that the wireless charging could allow for charging while driving (in the future); this is in particular appealing for some of the interviewee. The interview results were further confirmed with expectations expressed in the first questionnaire (Q1). One of the respondents expressed expectations as “Cable works fine, but imagine the day we can say ‘Remember the time when you were supposed to REFUEL the car!?’ Now you just have to go without handling dirty stuff or spending any time on that [i.e. charging]”. The interviews performed with the representative at each site (I2) highlighted that the introduction of wireless technology could eliminate the risk of arriving at a vehicle that has not been charged. It is also highlighted that wireless charging could be perceived as a more attractive option compared to the handling a cable. All respondents said that they expected it would be an easier charging process when eliminating the cable: “the vehicle will charge itself”. This was confirmed in the questionnaire (Q1): “All improvements are good. Even if I am happy with charging with cable, it is better and more convenient if I could just get into the car and drive.” In particular, it would be easier to attract new users with wireless charging, also confirmed in questionnaire comments, e.g.: “Ultimately it would be beneficial to not having to use the cable, one thing less to think about in one’s stressed daily life, saves time, no dirty hands, reduced risk of sabotage and more harmonic as a car owner (I think). This is another argument for buying an electric car.”. Respondents (Q1) also believed that the vehicle would be charged more, as well as used more often. Some concern regards the safety of the equipment placed on the ground. Also participants were concerned whether or not it would be difficult to park over the charging spot. Limited concern was raised regarding electro-magnetic radiation from the inductive chargers. The respondents argued that inductive charging is common today (e.g., stove, toothbrush, etc.) and the installed technology is tested.

4.2.2 Stage 2: Introducing Wireless Charging

The questionnaire (Q2) highlights that after introduction of inductive charging, the number of positive respondents regarding the usability of the charging equipment was reduced to 72% (Q1: 90%). The analysis of the written comments identified that the difficulty of parking correctly over the charging pad was the main reason for the drop. When asked about the most tedious thing about inductive charging the following type of comments emerged (Q2): “To succeed in parking correctly. ... A better and more forgiving docking of the car would have been good” and “It is difficult to get the car in the correct position at once. It takes some adjustments to get the charging to work”. There were however also respondents who had no perceived problems with the inductive charging (Q2): “None”. The change in opinions related to the time it takes to handle the charging equipment showed a similar pattern as the usability and procedure, showing a drop in positive responses with inductive charging (Q1:86%, Q2:70%). However, the minimum parking time to feel motivated to start the charging was judged to be lower when using inductive technology. That is, the respondents stating that they needed to park at least ten minutes or more before starting the charging dropped from 44% in Questionnaire 1 (Q1- cable charging) to 7% in Questionnaire 2 (Q2- inductive charging)). This despite the decreasing rate of positive answers regarding the time it takes to perform the charging procedure. The experience of having to make several attempts to park the car correctly seems to cause annoyance affecting the answers related to practical use. One respondent expresses the problems as: “To hit the right spot ... I have been forced to reverse back and forth many times to start the charging”. Also, on the multiple-choice question “At the following occasions I have not started the charging despite available charging”, the alternative “The car is parked too short period of time” dropped from 36% (Q1- cable charging) to 3% (Q2) and 8% (Q3) for inductive charging indicating that the

parking time becomes less of an issue with induction when deciding to start charging or not. The inductive charging thus seem to have a potential of leading to more charging occasions, if used in a working context with many short stops (and available inductive charging at the destinations).

4.2.3 Stage 2: Experiences of Wireless Charging

On the question if the electric vehicle is an attractive mode of transport the positive answers increased from 75% (Q1) to 88% (Q2) after introduction of inductive charging. This figure dropped to 68% (Q3) after having used the technology for four months. Similarly, the positive respondents of the charging process dropped to 64% (Q3) (Q2: 72%). Thus, the first impression of inductive charging seems very positive but due to technical issues it did unfortunately not meet the expectations of the users. This is in line with comments such as "Since it has been so much trouble with the technology I can't be positive" (Q3). However, in written comments the respondents also have positive things to say about the technology as such, although not satisfied with the implementation at their specific workplace. For example, respondents state, "It only takes development of the technology, the idea is great" and "Inductive charging as such is good. However it is not suitable always and in all locations...".

Briefly said, the technology is good when it works but there is room for improvements. On the question of preferred mode of charging, the preference for cable charging is almost unchanged between surveys two and three. The preference for inductive charging dropped from 49% (Q2) to 34% (Q3) between surveys, while the indifference alternative increased slightly.

4.2.4 Discussion of Initial Results

The aim of the field trial was to see the effect of introducing inductive wireless charging on charging behavior, perceived attractiveness and safety.

Emerging changes in charging behavior

The results from surveys indicate that new charging patterns are likely to appear when introducing inductive charging. The drivers say that the parking time to motivate a start of charging is shorter compared to cable. Interestingly, when using inductive charging, the task of connecting the cable is replaced by the task of parking correctly over the charging pad (at least in the evaluated charging solution). Since the parking task will still be made, there should be a reduced effort required from the driver. However, the evaluated technology needs refinement for an optimal user experience helping the driver to hit the precise charging spot. (With future autonomous vehicles or integrated automatic parking aid this issue might disappear.) Yet, our results show that the users think it is convenient to get rid of the cable, which promotes use of inductive charging. Combining these results tells us that there is a potential for an increased number of charging opportunities given that the charging infrastructure is present. This means that the charging behavior will be different with inductive charging. Exactly how the charging behavior will change is yet to be studied.

Perceived attractiveness

The initial positive attitude towards the charging process is gradually reduced over time. Based on the written comments, the explanation to this pattern is most likely the difficulties of parking the car correctly over the inductive charger pad in the first attempt. With several attempts needed to find the exact spot for the charging to start, the perceived benefit of not having to handle the charging cable was very much reduced. One reason for the difficulty is the design where the charging pad is placed in the rear of the vehicle, which makes it difficult to make small changes of the car's position to achieve the correct placement for charging. Also, several users complained about the technical malfunctions that plagued the project with problems related to installation (ground circuit breakers), faulty chargers and problems with charging some of the vehicles' 12V batteries.

According to our results, the first impression of inductive charging seems to be perceived very positively. The technical problems in the project however caused the technology not to live up to the expectations of many of the drivers. Also, the difficulties of parking the car correctly over the inductive charger pad in the first attempt, with several attempts needed to find the exact spot for the charging to start, the perceived benefit of not having to handle the charging cable was very much reduced. The positive comments in the free text answers of the technology *as such* still points to a positive attitude although being discontent with the implementation. Other free text answers also points to perceived convenience of inductive charging, not having to handle the cable. The results as a whole point to the importance of a well-designed driver-charger

interaction where the evaluated solution has room for improvements. When the technology works, the drivers also see clear benefits of inductive charging, which reasonably also makes the electric vehicle more attractive. As our study shows, poor interaction design can have the opposite effect.

Perceived safety

The survey result shows that the positive opinions regarding perceived safety drops over time. However, the negative side does not increase accordingly. Instead the opinions seem to have shifted to “No opinion”. An explanation for this could be that the safety aspects regarding electro-magnetic radiation from the inductive chargers are difficult to assess as an individual user. The radiation is invisible and it is impossible to know if you are being exposed while starting or stopping the charging, which might be a source of anxiety.

Despite the drop from the positive side of the perceived safety ratings, very few users have reverted to feeling more negative regarding their perceived safety. In general there is a predominance of positive ratings. Malfunctioning equipment could also add to the insecurity of if the equipment is safe or not, in other aspects than electromagnetic radiation. In the study, we have not seen any substantial evidence that perceived safety should be a hindrance for wider adoption of inductive charging. However, the case could be different for home users where children and pets will be closer to the charging equipment.

5 Conclusions and Future Work

So far, the demonstration of inductive wireless charging shows that the tested charging technology has potential to provide a more convenient way of charging, and hence, never having to “re-fuel” the vehicle. According to the surveys, the most difficult thing compared to charging with cable is to park correctly over the charging pad on the first attempt. Due to the placement of the charging pad at the rear of the vehicle, exact positioning can be difficult. However, the tested equipment still seems somewhat immature to provide an optimal user experience. So far in the study, it is evident that technical problems (e.g. malfunctioning ground circuit breakers, parking difficulties, charging of 12V batteries) affect the attitudes towards inductive charging in a negative way.

The minor difficulty in positioning the vehicle over the charging pad is reinforced by the fact that the inductive charging system is placed in the rear of the vehicle behind the rear wheels (where the spare wheel usually is located), see Figure 1b. The reason for this is that this is the only place underneath the vehicles where there is enough space to mount an aftermarket inductive charging equipment. From a parking point of view, driving into a parking space trying to fit the center of the rear wheels over a point on the ground is trickier than fitting the center of the front wheels [16]. Automatic parking most likely makes parking easier for most drivers. In combination with inductive charging, there is a potential to provide drivers with a convenient automatic parking and charging functionality, thus making electrically charged vehicles more attractive.

Evatran works in relatively quick iterations to improve their Plugless[®] inductive charging system. The feedback from this project gives them valuable input to improve their system. There is no surprise that working early with new technologies leads to technical problems. Even though the user experience is far from optimal, interesting results and experiences can still be gained as this paper shows.

The project is on-going and the final results will be presented at a later stage.

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