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THE MEMBERS OF THE TESLÁSOK.ÓE TEAM ARE *NÁNDOR RÓJA*, *ANDRÁS CSERNA*, *TAMÁS MIHELIK*, *ZSOLT NÁNDOR VÍGVÁRI*, *ISTVÁN MARTIN SÜLI*, *BENCE PÁLOK*, AND *DÁNIEL BASA*.

Abstract: One of the most critical issues of our time is energy saving, which can be seen because of rising energy prices and accelerating environmental changes. One way to do this is to bring electric cars to the fore. Unfortunately, in our current situation, the use of conventional cars with internal combustion engines provides a significantly greater feeling of comfort for the average user. Our work aims to offer the reader an alternative that reduces inconveniences and gives motivation to the indecisive ones toward the choice of electric cars. Because of the combination of these factors, we chose the topic of wireless vehicle charging possibilities. Our goal is to achieve this by comparing and reinterpreting existing concepts.

Keywords: energy saving, energy prices, environmental changes, electric cars, wireless charging possibilities

1. Introduction

As the title of our article highlights, the main idea of our project was the wireless charging of electric cars.

It is worth mentioning that considering the survey released by the Central Statistical Office in September 2021, pure electric cars and plug-in hybrids accounted for 5% of the new car sales in Hungary and the figure is on the rise. Without any exaggeration, we are able to say that the progression is unstoppable.

The reason for which we have chosen this project was that we are all interested in cars, and in the developments related to them. As it can easily be revealed by the reader, our main focus as electrical engineers of the future is especially the functionality of electric cars. After our research, we found ourselves entering the deepest waters of the automotive industry. The subject would have been one size too large for us, so we narrowed it down to the matter of their wireless charging.

As the recent trends show, wired solutions are part of our present but the future will be characterized by the wireless solutions. Many different electronic devices had already been using this method of charging such as smartphones and smartwatches. Nowadays technology has reached a level at which these chargers are almost as efficient as if they had used wired chargers. 20 years ago, nobody would have dared to think that this would ever be possible, so that begs a new question: why wouldn’t this be possible for electric cars as well?

In this project, we were attempting to rely on Hungarian references as well as on international ones. We questioned whether our conception will be able to be implemented in the Hungarian industry in the next few years. In our work, we also covered the current projects of the Swedish luxury car manufacturer Volvo Cars in Gothenburg and the scientific research of the Stellantis Group in Italy. Finally, we talked about the challenges of environmental protection.

The main aim of our project was to introduce the reader to the current image of what charging electric cars looks like and to compare this conventional model to the latest conceptions. We were looking for viable solutions to level these two technologies, which are based on completely different standards. We aimed to do so both in finance and convenience.

Nándor Rója

2. Wireless charging – is there a need for it?

2.1. What is wireless charging? [2]

Wireless charging, also called wireless power transfer (WPT), is the technology that enables a power source to transmit electromagnetic energy to an electrical load through an air gap without interconnecting wires. This relatively new technology can be applied and used in many ways, from toothbrushes, to electrical vehicles, because of its highly convenient method.

„In 2014, many leading smartphone manufacturers, such as Samsung, Apple, and Huawei, began to release new-generation devices featured with built-in wireless charging capability. IMS Research envisioned that wireless charging would be a 4.5 billion market by 2016. Pike Research estimated that wireless powered products will triple by 2020 to a 15 billion market.”- [Wireless Charging Technologies: Fundamentals, Standards, and Network Applications]

2.2. PROS & CONS [3]

Wireless charging has advantages as well as disadvantages. The purpose of the developments of the WPT, is to reduce the inconveniences and disadvantages.

Advantages:

1. Without the cords and cables, wireless charging provides better user experience and makes charging simple and convenient. Furthermore, multiple devices (different brand etc.) could be charged at the same time on the same charger.
2. The problem regarding cables being worn and broken will be solved.
3. It provides better durability for contact free devices. (dustproof, waterproof etc.)
4. It enhances flexibility, especially for the devices for which replacing their batteries or connecting cables for charging is costly, hazardous, or infeasible (e.g., body implanted sensors).
5. Wireless charging can provide the power required by charging devices on demand, making it more flexible and energy efficient.

Disadvantages:

1. Wireless charging is much more expensive, as it incurs an approximately 30 percent higher implementation cost than traditional wired charging.
2. It is much slower, especially compared to the fast-charging possibilities. In case of a mobile phone, it can be 30-80% less efficient.
3. The metal parts produce more heat as through heat, energy is wasted.
4. In the procedure the positioning of the different parts is also vital as if the device is not positioned properly, the charging might not start.

After all, we are able to say that in some conditions, wireless charging is a huge drawback from the recent form of wired charging. As it stands, wireless charging is far from being perfect, but it is getting there. Many companies are trying to overcome these drawbacks to present the best charging device from their side to the consumers.

2.3. Summary

In the future, this technology will probably replace a huge part of nowadays current cable technologies.

The disadvantages are as follows the compatibility of plug-ins and charging stations, the limited lifespan of the connectors and the resulting errors (oxidation, contact errors, etc.) and the low tolerance of the charging cable to environmental influences (which can even result in a serious accidents).

On the other hand, wireless technology has its own advantages, such as the technology of V2G and the standardization of charging systems. We must mention also that the WPT charging system is more resistant to mechanical damage.

2.4. Cars [4][5]

The technical development of hybrid and electric cars had been outstanding in the recent years, both in terms of performance and comfort. A huge part of them is able cover hundreds of kilometres on the road without even a single recharge. With the increasing number of electric vehicles (EVs) on the road, their efficient and effective charging method (which has a significant impact on the electric grid) remains a challenge.

Almost all existing electric vehicles can be charged through the wired way. No matter whether at home or on the petrol stations, cables must be physically connected to charge EVs. These physically connected cables can be dangerous, especially in bad weather conditions.

A much more flexible and convenient charging method attracted attention. Several companies such as Tesla, BMW, and Nissan have already started developing electric vehicles that can be charged wirelessly without the need for cables. Instead of a physical cable connection, a wireless (inductive) connection effectively avoids sparking. In addition, wireless charging opens new possibilities for dynamic charging.

Wireless parking pads could make possible for an EV to be charged while parked for a short or a long period.

2.5. V2G (Vehicle to grid), decentralisation of energy distribution [1]

In the recent decades, one of the most urgent problems to be solved is environmental pollution.

The idea of V2G allows bi-directional flow between the vehicle and the power grid. This new concept is especially important with the presence of renewable energy sources and the increasing use of them, because in many cases the production of renewable energy is unreliable, difficult to calculate and constantly fluctuating.

Battery-based electricity storage is perfect for "smoothing out" these waves, and then recharging from there when renewable energy decreases.

As for now, inductive charging is less efficient and more expensive than conductive charging. For this reason, wired charging is used almost everywhere. Nevertheless, wireless charging is developing rapidly. It is crucial to point out that the significant evolution of electronic cars has only started less than twenty years ago. (For reference: Traditional cars has been around for more than a hundred years).

Nándor Rója

3. Home ground issues

This technology is quite widespread by today’s standards. It has many forms of application, and a rentable, active market but only in smaller, portable devices. The technology is also in use in the charging procedure of micro-mobility vehicles, such as electric scooters. An excellent example of these days is the Rollin Technologies company created by an enthusiastic group of Hungarian university students. They have also developed charging and docking stations that have already made the e-scooter sharing system more efficient. Their innovation is now being tested on the ZalaZone test circuit as you can see in the following picture.

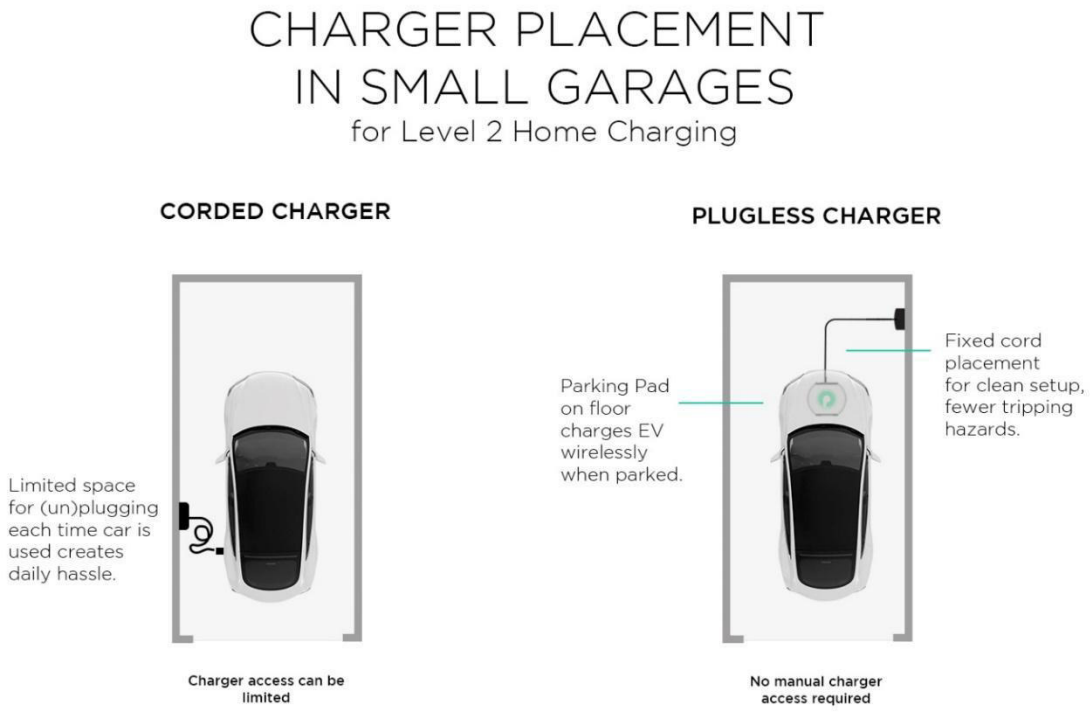
1. Figure – Rollin Technologies, Zalaegerszeg [6]

We have to admit that for the larger devices, the technology is still fresh and immature and begs more questions for which the answers are continuously being looked for. There would be a fundamental demand for the technology as it could replace the current well-honed variant without its disadvantages.

It is perceptible that wireless technology would have a huge market in the automotive industry, but some obstacles need to be overcome such as developing the fitting technology for the connection between charger and vehicle. By today's standards of an average electric car (that would have 30 cm or 11.81 inches of airspace), this would require an estimate of 11 kilovolts (KV) AC charging (being the most used method of charging), but not on 50 Hz of frequency. The efficiency of energy transfer could be reached by the increasement of the frequency to radiofrequency levels (of about 100 kHz) since it is the most important factor of transfer. With these parameters using a well-tuned transceiver unit, the charging performance can function with an estimated deficit of 10-15%.[13]

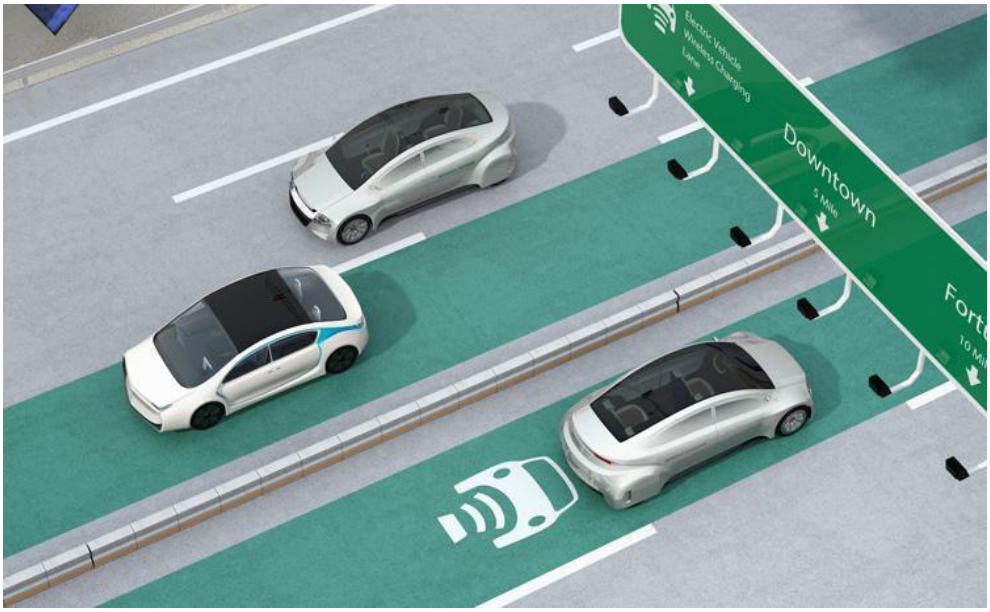
The biggest problem, however, is that there are no up-to-date standards for this charging system and the construction of a charging point involves a lot of risk factors, the solutions of which make the technology even more expensive. So, this technology is feasible, but it is still in the experimental phase. There have already been attempts at experiments, and test plants for passenger cars, buses and even road-integrated systems, but there are solutions that can make our lives easier in other ways. It takes up space to connect the vehicle itself to the charging device, and it also matters where the charging connector is located on the vehicle. Because of this, in a small garage, charging with a wired charger can cause an unsolvable engineering problem.

The solution is to build a wireless charging device since it would be located on the floor, so you only need to find the right position between the car and the charger, and you can get it going. The other important point is that the unit does not have to be installed in a specific position if there is a demand for it, so its implementation is much simpler than with the wired version.



2. Figure – Charger Placement in Small Garages [7]

If we get ourselves a little above ground level and look at the matter from a different perspective, it may even be conceivable that in the future, vehicles will be able to be charged while moving through a system integrated into the road. That would be the ideal solution as it is well represented below. With even more refined technology in the future, it may be possible to utilize the vehicle's kinetic energy in such a way that not only the vehicle, but also the system in which it is moving around could use it (similar to the KERS - Kinetic Energy Recovery System that had been in Formula 1 cars, and since then, in many road-legal hybrid super- and hypercars). In this way, a two-way energy flow would be created (the car would also be able to charge its excess energy back into the network and not only play the role of energy storage and consumer).



3. Figure – Dynamic Wireless Charging [8]

Hungary would not necessarily be the primary receiving market. In Hungary, many difficulties can hinder the installation of the system, such as the outdated electrical network (which would not be able to withstand this kind of overload), the poor quality of the road network, the fact that it does not have adequate standards and not to mention the fact that the culture of electric cars is only just emerging and now filling station systems are built, thus this technology would still be very early for larger mobility devices. In the short term, the implementation of wireless charging systems installed in private households is a possible and real goal, which may even have a market soon.

István Martin Süli

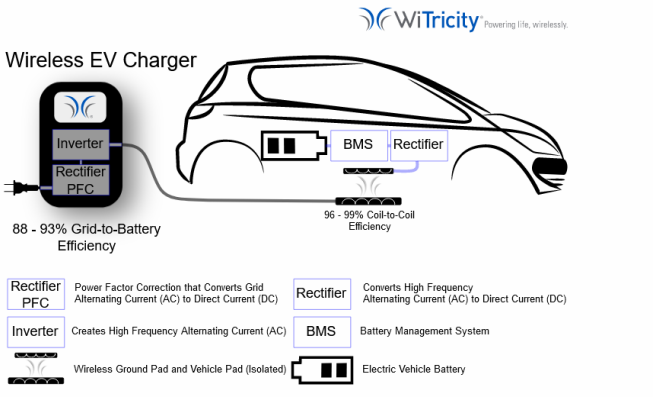
4. How Do They Do It? – Wireless Charging

4.1. Wireless charging

Wireless transmission of electrical energy was developed by Nikola Tesla. Its operation is quite simple: the coil (or coils) in the charger head creates an electromagnetic field, the resulting field gets converted into electric current by the coil in the car parked on the charger. From an electrotechnical point of view, it does not produce an induced current, but rather an induced voltage. Due to the voltage difference, an electric current is generated in the circuit. The efficiency of charging depends largely on the distance between the coils, therefore most of the developments are focused on overcoming this problem. There are developments that take several coils into consideration in a given car. Research has shown that it is worth placing receiving coils both on the floor plate of the vehicles and in the nose of the vehicle, so that the car can also utilize the chargers that would be built into roads, in which case the coils are approximately 15-20 cm apart. Even in this case, an efficiency of 93-95% can be achieved, which ranges from 400 to 3600 W of charging performance, Also, there are chargers that can be mounted walls, which would offer a better solution in terms of them being much easier to reach the smaller distance between the two coils, and as a result, they can achieve better efficiency by placing the charger in this way.

4. Figure -Wireless EV Charger [10]

4.2. The structure of the charging system:



5. Figure – Wireless Power Transfer [9]

"According to the developers of the SAE J2954 standard, the advantage of this technology compared to the usual charging method is that it is fully automatic and therefore simpler - you just have to park over a compatible charging panel and the charging process starts. A magnetic field is generated between the panel connected to the network and the receiving device mounted on the bottom of the car, through which energy is transferred in the form of alternating current (AC), which the vehicle then converts into direct current (DC) to charge its battery. The standard currently supports three performance levels: 3.7 kW, 7 kW and 11 kW, but the organization previously mentioned 22 kW, which is expected to be introduced in the future.

This regulation still has its limitations, for example it was developed only for one-way charging, i.e., energy transfer from the network to the car, and this will probably change in the future. As of its current state, the SAE J2954 standard can only be applied for stationary vehicles, and we have already seen examples of the development of mobile electric cars and underground wireless charging devices with charging pads placed above the ground, so it is almost certain that a unified criteria system will be prepared for these later as well." [1]

Bence Pálok

5. Industrial implementation

There are many companies researching and developing wireless charging solutions. Most of these projects are, however, in test phase only. The companies making the biggest steps forward

in the field are the Stellantis N.V. and Volvo Cars, latter having developed the XC40 Recharge, a wireless-rechargeable car.

Furthermore, it seems like that the commercial vehicle industry is also getting interested in the technology.

6. Figure - Volvo XC40 Recharge [17]

5.1. Wireless charging in stationary position [16]

The Volvo XC40 Recharge:

Volvo's main concept intends on testing the XC40 purely electric SUV over the span of 3 years, equipping them with wireless charger receivers.

The testing will happen at the Swedish city, Gothenburg, where the cars will be operating as taxicabs. The charging of the cars will take place in the city centre, at wireless recharging stations. This test is one of the various tests conducted in Gothenburg's Green City Zone, an initiative to provide a testing space for green transportation solutions.

The charging stations are developed and manufactured by Momentum Dynamics.

Docking the charging station, the driver will be assisted by a 360° camera system, and they will have to position their vehicle correctly over the charging pads that are recessed below the road's surface. The charging procedure will begin automatically when the car is in place. This allows drivers to charge their car without having to exit them.

The charging station sends power to the wireless transmitter under the car, that transmits to the car's receiver. The entire charging session is trackable, and the car will display the battery percentage and the approximate remaining time till a full charge. The driver is free to drive

away anytime they desire without the need to disconnect a wire, when they feel like their car is sufficiently charged.

The XC40 Recharge's wireless power transmission can reach up to around 40 kW, which is quadruple of that of a normal household car charger, and almost as fast as a 50 kW DC charger.

The test cars will be used 12 hours a day, and they will have travelled around 100,000 kilometres in a year's time. This is going to be Volvo's first large scale test of BEVs (Battery electric vehicle) on the consumer market.

5.2. Charging while on-the-go [14]

The Arena del Futuro (Arena of the Future) is a circuit built for wireless-rechargeable electric vehicles with a ring of wireless transmitters all along the road, built through a partnership between several companies, chief amongst them being Stellantis. The circuit is to test a system where the drivers can charge their cars without ever stopping, by receiving power from the recessed wireless transmitters. [18]

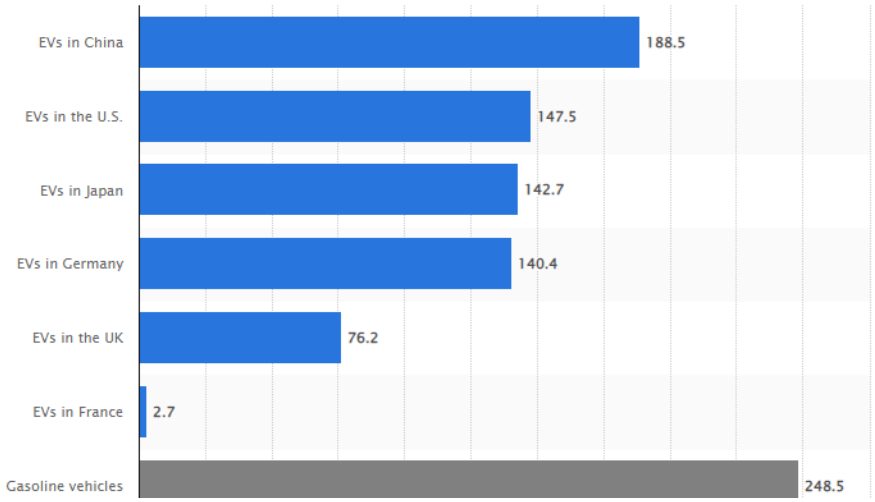
Stellantis' special charger is located in the outermost lane of a multi-lane road, where the EVs would operate. The test subject was a Fiat 500E. [15]

The objective is to provide the cars with enough power to maintain a constant battery level at constant speed and enough power for comfort features. It is also important that neither the car's, nor battery's weight increases with the developments.

Bence Pálok

6. Environmental and health-related issues of the wireless charging technology

One of the most pressing concerns about electric vehicles is their questionable ability to reduce carbon emissions and their cost compared to a combustion engine-based vehicle. The most frequently criticized factors are the expensive, and environmentally unfriendly materials in the batteries (such as lithium), and the fact that the vehicle's zero-emission operation is irrelevant if the electricity stored in the vehicle comes from fossil fuels, such as coal or oil. This makes high-efficiency circuits important, to waste as little energy as possible.[19]



7. Figure- Emisson of electric cars in different countries [26]

AS YOU CAN SEE HERE, THE CARBON EMISSION OF ELECTRIC VEHICLES IS HIGHLY DEPENDENT ON THE COUNTRY THEY OPERATE IN. FOR EXAMPLE, CHINA MOSTLY USES FOSSIL FUELS TO GENERATE ELECTRICITY, WHEREAS FRANCE MOSTLY USES NUCLEAR POWER. (SOURCE: STATISTA.COM)

The introduction of wireless charging could come with several factors of comfort, such as the elimination of the charging cable, but from an environmental and financial perspective, the technology might just be less feasible than the wired alternative.

6.1. Time consumption

Modern charging technologies enable EV (electric vehicle) owners to charge their vehicles with tens of kilowatts of power, making the charge time low, and with new concepts, such as plug-and-charge [1], charger manufacturers can provide consumers with a more comfortable and easier charging experience. Saving time is nearly as important in the field as saving energy.

But wireless charging would be a detriment to both aspects. Since wireless charging technology has more physical limits than wired charging, the performance of the charger would be significantly less, thus the charge time would increase. Even with our superchargers, the time

to charge an EV takes significantly more time than fuelling an ICE-based vehicle. Increasing the charge time only makes combustion engines more appealing to people with busy schedules.

6.2. Power losses and weight

Wireless power transmission is done with two coils, galvanically isolated, such as in a conventional transformer.[2] The difference, however, is that conventional transformers have solid iron cores, and both coils are wrapped around the same core, whereas the same cannot be done in wireless charging since it would re-introduce the solid physical connections between the charger and receiver. Iron cores are important to confine and guide the magnetic fields in transformers, to minimize power losses due to electromagnetic radiation. [20]

The transmitter and receiver coils could have their own, separate coils, and the coils could be brought close together with a lift mechanism. That would also lower the losses. However, the introduction of a coil and an iron core to the vehicles has some unfavourable consequences.

For example, the received power would come in the form of alternating current, which cannot be used to charge a battery, so the vehicle must also contain a high-power rectifier circuit, making the two circuit elements heavy and spatially dependent. This would both take away space from batteries and require more batteries since a heavier vehicle requires more energy to move forward. The extra power conversion circuit would also introduce its power losses.

This increase in weight would also make more energy-dense batteries more likely to be used (such as lithium-ion (Li-Ion) or lithium-polymer (Li-Po)), as opposed to potentially more environmentally friendly, future technologies (such as the sodium-ion (NIB or SIB) battery technology, by companies such as CATL [21]) that are not necessarily as energy dense.

This circuit design would not only lower efficiency but the maximal charging power, due to the potential damage to the environment caused by high-power electromagnetic radiation.

	Lithium-ion	**Sodium-ion**
Volumetric energy density	200–683 Wh/L	250–375 Wh/L
Specific energy	120–260 Wh/kg	75–165 Wh/kg

8. Figure – Energy Density of Popular Battrey technologies [28]

6.3. Induction heating, electrical interference, tissue heating

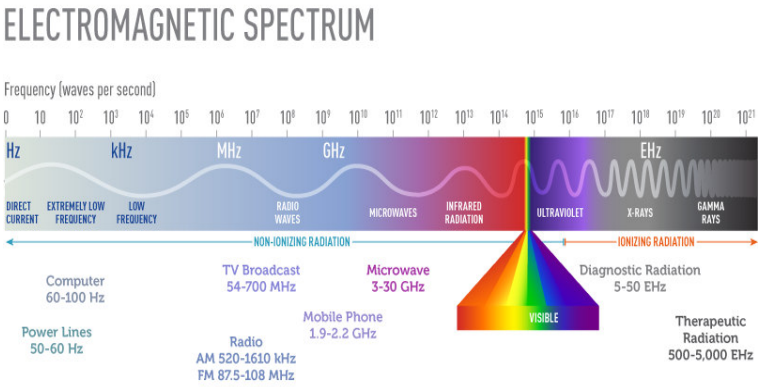
When alternating current (generally high frequency) passes through a conductor, the rapid change of magnetic fields generates electric currents, called eddy currents in a conductor. These eddy currents will flow through the resistance of the conductor, and create heat, due to resistive heating. The heat is generated inside the conductor itself, and, generally, ferromagnetic

materials, such as iron, create more heat during the process.[22] This is the concept on which induction cookers are based.

This wouldn't only mean that the iron core of the receiver heats up from the large power transmitted, but any ferromagnetic material found in the vehicle will heat up considerably due to leakage from the transmitter circuit. This would require the minimalization of ferromagnetic materials in the vehicle's design, at least in the coil's proximity. The heat losses would also lower efficiency since a portion of the transmitted energy would be used to heat the iron core.

Another issue with radiations is that they can interfere with electrical circuits, for the same reason induction heating occurs. The eddy currents flowing through the circuits' resistances will generate stray voltages, which can cause glitches in circuits that may result in permanent damage. The same concept is used in EMP devices,[23] used to remotely interfere with- or destroy circuits. This makes the need for shielding against radiation more important, which can add more weight to our vehicle. Also, an external circuit or device in proximity of a charger, such as a mobile phone, or medical device worn by a person standing nearby may fall victim to the radiation.

Furthermore, since the charger needs to run on high frequencies for more efficient power transfer, tissue heating can be an issue, meaning that a person standing close to the charger can experience a sensation of heat in their body, or, if the energy is high enough, the charger can cause burn damage to the person, as if they were inside a microwave oven. The lowest frequency at which this occurs is around 100 kHz.[24] Fortunately, according to studies, [8] these frequencies are unable to cause DNA damage, and thus cancer, since that requires high-



9. Figure – Electromagnetic Spectrum [27]

IONIZING RADIATIONS HAVE MUCH HIGHER FREQUENCIES THAN WHAT A WIRELESS CHARGER WOULD OPERATE AT, THUS THEY ARE UNABLE TO CAUSE CANCER. (SOURCE: CANCER.GOV)

frequency ionizing radiation, such as UV, X-ray or Gamma-ray. In my opinion, it is also possible, that a pet, for example, a cat, a species that likes being close to warm and tight places,

such as the charger's surroundings) wandering near the charger could sustain adverse health effects due to tissue heating.

6.4. Conclusion

While wireless charging seems like the technology of the future in the average onlookers' eyes, the increasing energy prices and tight schedules of people make the wired alternative more appealing, not even taking the effects of it on the environment and on the user into consideration.

The engineers may come up with a more viable technology, but in the current state, wireless charging would be a disadvantage to the electric vehicle industry and consumers.

Tamás Mihelik

7. Concluding Words

Would electric cars and other vehicles be suitable for wireless charging? – was raised the question by our enthusiastic team a little while ago.

To briefly answer it, the time is not here yet for the realization.

Over the past few weeks, we have been able to take part in an interesting and far from closed journey. During this period, an interesting depth of the electrical engineering was revealed for us.

Our work aimed to offer the reader an alternative that reduces the inconveniences and gives motivation to the indecisive ones toward the choice of electric cars.

At the beginning, our idea was that this could be achieved by the wireless vehicle charging.

Now, we can clearly see that the project requires further technological development for widespread, everyday use. The base of the concept is basically suitable for a future implementation, but there are still many obstacles for the engineers to face.

Daniel Basa

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