Wireless Charging is Now

- Bringing automated wireless charging to accelerate EV adoption -

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ABSTRACT: For many years, people talked about wireless power transfer (WPT). Since Nikola Tesla's time in the late 1800s, wireless power transfer (WPT) has been used in applications such as telemetry, satellite communications, and radio frequency identification (RFID) tags. Most of these applications transfer low amounts of power, in the range of microwatts to milliwatts, for data transfer. For higher-power applications, from a few watts to several kilowatts – over moderate distances – WPT has become the focus of industrial developments and electric vehicles. But, until recently, wireless charging of electric vehicles has only been a dream. Now, it's reality.

KEY WORDS: electric vehicle, wireless charging, wireless power transfer, V2G, vehicle-to-grid, level 2 charger

1. INTRODUCTION

For many years, people talked about wireless power transfer (WPT). Since Nikola Tesla's time in the late 1800s, wireless power transfer (WPT) has been used in applications such as telemetry, satellite communications, and radio frequency identification (RFID) tags. Most of these applications transfer low amounts of power, in the range of microwatts to milliwatts, for data transfer. For higher-power applications, from a few watts to several kilowatts – over moderate distances – WPT has become the focus of industrial developments and electric vehicles. But, until recently, wireless charging of electric vehicles has only been a dream.

Now, it's reality.

Over the past year, several high-profile car OEMs have brought EV wireless charging to market as a factory-installed option. This paper explores those that are currently available. In addition to enabling autonomous electric vehicles, wireless charging enables fully autonomous warehouses. It also enables dynamic charging, an area of interest for many communities. With dynamic charging, wires located under the road wirelessly transmit electric power to a receiver in the car. As OEMs prepare to bring wireless charging to their factory-installed vehicles, the WiTricity Halo™ system, built on WiTricity's core magnetic resonance charging, peripheral systems, and software developed over a decade of innovation, provides the opportunity to upgrade modern EVs to showcase the experience to consumers. But it's not just personal vehicles that are transforming. Fleets are also impacted by the EV craze … trucks, buses, vans, and taxis. There are many impacts to a fleet's costs and efficiency with charging being an integral part of the solution. Lastly, wireless charging is also transforming the landscape by enabling vehicle-to-grid (V2G) technology, the operating mode in which the parked vehicle is able to transfer energy back into the grid.

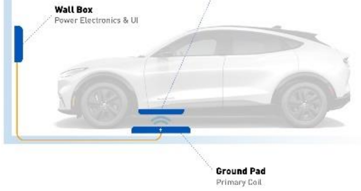
Please see the white paper on wireless charging https://witricity.com/wp-content/uploads/2021/11/WiTricity_Highly-Resonant-Wireless-Power-Transfer.pdf

2. APPLICATIONS

2.1. Factory-installed wireless charging

Wireless EV charging from WiTricity is safe and efficient. Using magnetic resonance to transfer power over distance, any electric and magnetic fields are kept below the well-established and long-standing human safety limits that regulate all electromagnetic consumer devices, like cell phones, wireless routers, Bluetooth headphones, radio transmitters, and more.

The efficiency of wireless charging is the same as a Level 2 charger. As many know, plug-in charging is not 100% efficient. Energy loss, primarily in the form of heat, occurs every step of the way from grid to battery. What's more, regardless of the brand, a plug-in EV charger is made of many components, any one of which may be more or less efficient than similar components in another charger. So, the "efficiency" of the transfer of energy from the grid all the way to battery encompasses a range; a typical Level 2 home charger operates in the range of about 83-94% efficiency grid-to-battery depending on which one you buy. Wireless charging operates within a narrow band of efficiency (88-93%) that is equivalent to Level 2 plug-in charging, plus you get the added efficiency of not having to spend time plugging and unplugging the vehicle. Last but not least … every time you park and charge wirelessly, you're more likely to be operating in the 20-80% state of charge (SOC) range that the battery likes – and is the most efficient. With plug-in charging, it's less likely that the 20-80% SOC range will be maintained since drivers tend to forget to plug-in, or don't bother when they know they have enough battery left for their next journey. In fact, many people plug in once a week, drive all week, and then plug in on the weekend. Not only is this less efficient but it's harder on the battery.



With the power output of 11kW, the Hyundai Genesis GV60 starts charging automatically when a vehicle equipped with a receiver pad is parked over a ground pad at the wireless charging station. Ground pads will be made available for consumers to charge at home.

2.2. Wireless charging makes autonomy possible

Another manufacturer bringing wireless charging to market is China's FAW. The HongQi E-HS9 takes wireless charging even further by using it to power true autonomy. No driver. No charging plugs. No human involvement. As you'll see in this video, it even backs in on its own. Another manufacturer is IM Motors Zhiji with its luxury L7 vehicle as shown here.

Evidence of wireless charging enabling autonomy is YuTong Bus, the first-ever commercial application of wireless charging for an autonomous e-bus. In this video, the YuTong bus charges wirelessly. This is true autonomy – something that would not be possible without wireless charging.

In addition to enabling autonomous electric vehicles, wireless charging enables fully autonomous warehouses. One of our licensees, DAIHEN, built wireless chargers for Autonomous Guided Vehicles (AGVs), ultra small EV, and small EV in Japan. Now, warehouses can run operations 24/7 with our technology used both inside and outside the warehouse in small autonomous robots and larger electric vehicles. This will enable automated charging for an upcoming explosive growth of autonomous valets, robo-taxis, and delivery robots. As autonomy progresses, the logistics of charging and servicing will become even more critical. As EVs are getting adopted from small vehicles in Japan, DAIHEN's wireless charging will help accelerate the adoption of small EVs.

2.3. Upgrading current vehicles for wireless charging

But the excitement doesn't stop in Asia. It continues over to Europe where WiCET is trialing wireless charging in its taxis. The UK's first wireless charging electric taxi demonstration is taking place in Nottingham. Nine electric taxis have been retrofitted with wireless charging systems, and five wireless charging pads have been installed at the Trent Street taxi rank to demonstrate the application and impacts of wireless charging technology for electric vehicles. The outcomes of the demonstration will be to prove the technical and commercial case for the wireless charging of Hackney Carriages in medium and large cities. It also endorses the UK as an international leader in demonstrating the potential of new and emerging technologies in the field of clean mobility.

In addition, WiTricity has been engaging in a successful trial with Florida Power & Light (FPL), the largest power utility in Florida. As America's largest electric utility, Florida Power & Light Company serves more customers and sells more power than any other utility, providing clean, affordable, reliable electricity to more than 5.7 million accounts, or more than 12 million people. In an effort to expand its green efforts, FPL is growing its fleet of electric vehicles and testing wireless charging – both at employee homes and at the headquarter offices.

In early 2022, WiTricity announced plans to offer an aftermarket wireless charging upgrade package for owners of select EV models. The solution, WiTricity Halo™ Charging, offers a complete end-to-end, and hassle-free charging experience: just park and charge. The WiTricity Halo™ upgrade will deliver 11 kW wireless charging, enabling a charge rate that provides up to 35-40 miles of driving range per hour of charging time, a speed and efficiency on par with today's Level 2 AC plug-in chargers. The WiTricity Halo™ upgrade includes three key components: the power receiver that is installed on the vehicle, the wall box that connects to electric power, and the charging pad that is installed on- or in-ground. WiTricity Halo™ Charging availability is scheduled for later this year.

The WiTricity Halo™ system is built on WiTricity's core magnetic resonance charging, peripheral systems, and software developed over a decade of innovation. As a preliminary step in developing the WiTricity Halo™ solution, WiTricity has upgraded modern EVs to showcase the experience to consumers. WiTricity's Tesla Model 3, sporting its distinctive "This Tesla Charges Wirelessly" skin, has been a common sight in our headquarters town, Watertown, Massachusetts since October 2021 when it was outfitted with wireless charging. WiTricity's upgraded Tesla fully charges in less than 6 hours using the WiTricity Halo™ system, just as fast and efficiently as plugging in at home. WiTricity engineers have also upgraded a Ford Mustang Mach-E, with more vehicles in the pipeline This video demonstrates what it is like to wirelessly charge in the Ford Mach-E

2.4. Dynamic Charging

Dynamic charging continues to be an area of interest for many communities. With dynamic charging, wires located under the road wirelessly transmit electric power to a receiver in the car. Dynamic charging differs from another kind of wireless charging, static charging, in one important way: dynamic charging implies that the vehicle is moving. Frequent charging on the road allows car makers to reduce the size of batteries and, therefore, cuts the cost of the car while elongating the lifespan of batteries themselves. In 2017, the Halo Division of Qualcomm – now part of WiTricity – demonstrated dynamic charging on a track outside Versailles. The track was operational for two years and proved the legitimacy of dynamic charging and the benefits it could bring.

2.5. Wireless Charging for Fleets

But, it's not just personal vehicles that are transforming. Fleets are also impacted by the EV craze … trucks, buses, vans, and taxis. Trips, slips, and falls are the most common workplace injuries. With large, heavy charger cords at your employees' feet, accidents are waiting to happen. Safer working conditions are realized by eliminating trip hazards and the need to wrangle these unwieldy cords and cables. And employees are happier not having to remember to plug in. Contributing to a more efficient fleet is wireless charging easily integrated into existing vehicle workflows for additional convenience, without the need to hire additional personnel or build out charging robots. With wireless charging, drivers don't need to worry if their vehicle isn't charged due to the previous driver forgetting to plug in. Charging starts as soon as the vehicle is parked over the charging pad and stops when the vehicle is fully charged.

There are many impacts to a fleet's costs and efficiency – charging is one of them. In a recent study, the relative total cost of ownership (TCO) of adopting and running an electric fleet for last-mile parcel delivery saw a 50% savings in TCO by using wireless power transfer built on technology developed by WiTricity. The dramatic savings in electricity costs come from:

- Opportunity charging vehicles in depot operations, which doubles the duration of the charging operations and thus does not rely on DC fast charging to keep the vans up and running.
- Reduced labor costs. Electric vehicles that need to be plugged in to charge inherently need someone to do that plugging and unplugging. Because no human intervention is required for opportunity charging connection or disconnection, a higher level of autonomy can be enabled
- Low maintenance. Wireless charging incurs very low maintenance because there are no serviceable parts, active cooling is not required, and there are no mechanical connectors that wear out or need replacement.
- Less stress on the electrical grid with wireless charging
- Reduced trip and fall injuries from not having to deal with unwieldy cords and plugs

2.6. Enabling V2G with wireless charging

Wireless charging is also transforming the landscape by enabling vehicle-to-grid (V2G) technology. V2G is the operating mode in which the parked vehicle is able to transfer energy back into the grid. It is difficult to maintain a balance between renewable energy availability and the peak energy demand placed on the grid. Distributed energy storage, in the form of parked electric vehicles that are connected to the grid and capable of bi-directional energy flow, is seen to have excellent potential for stabilizing the balance between supply and demand on the power grid. When EVs are enabled with wireless charging, connecting to the grid for V2G becomes automatic and seamless, and can facilitate the large-scale introduction of V2G technology into the market. Without wireless charging, an EV owner must remember to always plug in to enable V2G to work.

With the increase in electric vehicles, one of the big issues facing utility companies is maintaining the energy grid and providing energy during peak demand periods. V2G enables the use of renewable energy by allowing electric vehicles to store electricity and deliver when needed. This source of electricity provides needed support to utility companies who can reduce their CAPEX by not needing to provide as much energy during peak capacity periods. With EVs storing electricity and providing it to the house, grid, or business, both the utility and EV owner benefits.

Please see the paper published in SAE international in 2019 : https://www.sae.org/publications/technical-papers/content/2019-01-0870/

2.7 Standards

SAE International announced publication of the first global standard that specified, in a single document, both the electric vehicle- and supply equipment (EVSE) ground-system requirements for wireless charging of electric vehicles (EV) on October 22, 2020. The new standard, **SAE J2954** paved the way for charging without the need for plugging in – widely considered to be a key enabler for accelerating the adoption of EVs and autonomous vehicles. The technology is a safe and efficient method for transferring power from the AC grid supply to the electric vehicle. Tests using a 10-in. (250-mm) ground clearance have shown that WPT systems operate at grid-to-battery efficiencies of up to 94%. WPT with additional alignment elements in SAE J2954 also fulfills the charging requirements for autonomous EVs to charge themselves without human interaction.

The standard was more than a decade in the making. SAE kicked off its pioneering pre-competitive research at a time when few contemporary electric cars existed and wireless power transfer (WPT) systems for EVs were an unproven concept. The SAE J2954 Wireless Power Transfer and Alignment Taskforce worked since 2007 to thoroughly vet and test the technology, in partnership with government agencies, regulatory bodies and private-industry groups including the American Association of Medical Instrumentation (AAMI), U.S. Dept. of Energy (DoE), the U.S. Food & Drug Administration (FDA), automotive OEMs, Tier 1 suppliers and many others, including WiTricity, to ensure global harmonization.

A critical issue addressed early in the SAE J2954 process was to classify products in terms of charging levels, vehicle ground clearance and systems interoperability. Three power levels were established: WPT1 (3.7 kW), WPT2 (7 kW), and WPT3 (11 kW). The WPT system consists of two “sides.” The Ground Assembly (GA) encompassing the charging hardware which is wired into the grid. The other side includes the on-vehicle equipment known as the Vehicle Assembly (VA).

SAE J2954 establishes a universal Ground Assembly for WPT3, critical especially for public infrastructures. It is downward-compatible to charge vehicles also at WPT1 and WPT2. The goal is that the WPT-GAs will be installed in publicly available parking spaces, per the setup in today’s plug-in charging infrastructure. Installation with WPT3 will allow downward compatibility.

For ease of use, SAE J2954 specifies the requirements to make the GAs and VAs fully interoperable – so that any vehicle will be able to charge when it is parked in an SAE J2954 GA-equipped parking location. There is also the possibility to have specific designs for captive fleets; as described in SAE J2954, in this case a GA would only be expected to fully operate with a specific group of vehicles.

To validate its performance targets, safety limits and methodologies, the SAE J2954 standard includes key parameters such as minimum efficiency, EMI and EMF (electromagnetic interference and field) limits as well as foreign object detection. There are three overlapping ranges of vehicle ground clearances from 100 to 250 mm (3.9 to 9.8 in.) and three levels of grid input to the GA up to 11.1 kVA. Parking tolerances are ±75 mm (3.0 in.) in the direction of travel and ±100 mm (3.9 in.) in the lateral direction.

The SAE J2954 task force concluded that to ensure interoperability, the ability of systems to transfer power, as designed by different manufacturers, must be validated in both bench and vehicle testing. SAE J2954 standardizes a WPT GA/VA test station, along with coil specifications to evaluate the requirements for safety, interoperability and performance. This allowed OEMs and Tier 1s alike to prove their vehicles and charging sub-systems were compatible with SAE J2954 requirements and guidelines.

The baseline bench testing of the WPT Systems was carried out at both the DOE's Idaho National Laboratories and TDK RF Solutions, evaluating the GA side and the VA sides. Since these were prototype systems, the SAE J2954 defined VA/GA test station was built to allow for consistent tests conditions over the range of parking alignments, output voltages and ground clearances.

First paired GAs and VAs provided by the same manufacturer – a so-called "matched subsystem" was tested. Performance data (input power, power factor, output power, efficiency, maximum power presented to the load) at various output voltages, along with misalignment conditions and vehicle ground clearances was evaluated. The results of the bench testing showed that the performance targets were realistic and different suppliers, following SAE J2954, could meet requirements.

The second phase of testing was performed with GAs and VAs from different manufacturers to establish non-matched interoperable configurations. The goal was to demonstrate that these different system sub-components could work together; even though there had been no prior verification. The results showed that with competitor interoperable configurations, performance could be reached similar to matched systems, hence proving interoperability between competitor GA/VA following SAE J2954. The work was published under "Bench Testing Validation of Wireless Power Transfer up to 7.7kW Based on SAE J2954," SAE Int. J. Passeng. Cars - Electron. Electr. Syst. 11(2):89-108, 2018.

With the initial bench performance test results, the coil specifications for the GA and VA – the factors to enable interoperable power transfer – were validated. Further testing was done related to safety and emission aspects, as well as the transition from test-bench measurements including real vehicle measurements. A final test-bench study was done to evaluate the impact of WPT on Cardiac Implantable Electronic Devices (CIED) was considered in consultation with the AAMI and ISO. WPT systems of different coil topologies were brought to the FDA laboratory for evaluation of the impact on actual medical devices (running pacemakers) during WPT. The results of the FDA tests resulted in agreements on limits and system requirements and solidified that the public infrastructure GA would be circular topology, proven to be within SAE J2954 and AAMI limits.

Thereafter, vehicle systems were to be tested. A group of companies including Aptiv, BMW, Continental, Ford, General Motors, Hevo, Honda, Hyundai, IHI, KAIST, Lear, Qualcomm, Toyota, and WiTricity, under SAE leadership, created a Cooperative Research Project (CRP) with industry-committed funds for additional vehicle and emissions testing. In those tests conducted at TDK RF Solutions near Austin, Texas, automakers and suppliers brought vehicles. Different suppliers brought GAs that were tested for performance, interoperability, and EMI/EFI emissions.

The focus of those tests was to determine the field emissions using calibrated and certified equipment and industry standard procedures so that equipment developers could determine areas of improvement and to correlate with their own laboratory test results. These tests were done in both matched and interoperable configurations, verifying that the integration of the VAs onto the vehicles and the results in final validation of SAE J2954. The work was published under "Validation of Wireless Power Transfer up to 11kW Based on SAE J2954 with Bench and Vehicle Testing," SAE Technical Paper 2019-01-0868, 2019.

SAE spearheaded harmonization with numerous Standards Development Organizations (SDOs) and regulatory agencies including FCC, FDA, ITU-R and CEPT. To help harmonize worldwide standardization and ensure as much compatibility as practical across these documents, SAE established an MOU with ISO and Underwriters Laboratories for their UL 2750 Document for EVSE Certification.

In 2019, the SAE J2954 team hosted a joint meeting with leadership from ISO, IEC, and the GB/T standards groups to ensure international compatibility of standards. Incompatibilities between the documents in development were identified and actions were given to each of the organizations to modify their documents to minimize differences. As a result, a homologation agreement was made so that systems compliant with these standards will work around the globe.

In 2020, ISO 19363 created a vehicle-side standard (VA only), and IEC/ISO continue in development of standards with its four-document series (IEC-61980-1, -2 and -3, plus ISO 15118-8 and ISO 15118-20). China published part of the GB/T 38775-series of documents in 2020 and 2021 and continues work to complete the series. SAE J2954, published in 2020 and updated in 2022, also enables worldwide harmonization of WPT. Looking to the future, the SAE J2954 Taskforce has begun a new effort for higher power WPT with SAE J2954/2 also for busses and heavy-duty vehicles.

Wireless communication for control of the WPT charging process had been proprietary for each supplier until SAE J2847/6 [https://www.sae.org/standards/content/j2847/6_201508/] was published in 2015. In 2020, the SAE Hybrid/ EV communications taskforce updated the J2847/6 document by leveraging the work of the SAE J2954 Alignment and Controls Sub-Team extended a JSON-based message set (protocol) originally developed to bench test wireless energy transfer interoperability between unmatched GA and VA systems.

In addition to SAE International, **China** also set a national standard for wireless charging of electric vehicles based on WiTricity technology. WiTricity worked closely with the GB standards committee on several technical issues, including efforts for harmonization. For inductive charging, there was a gap that is beginning to close as the China Electricity Council (CEC) ratified and published a set of four national standards for the wireless charging of EVs. Eighteen are planned in total.

The four-part set of the now available standard with the designation GB/T 38775 regulates the following: the general requirements, communication between onboard chargers and external chargers, special requirements, and limit values and test methods for electromagnetic environmental influences. It also formulates requirements for transmission and system functions that must be met during product design and testing – including basic safety requirements.

For equipment to meet this new standard, WiTricity's patented technology has become instrumental. WiTricity worked closely with the GB/T standard committee (CEC), the China Electric Power Research Institute (CEPRI) and the China Automotive Technology and Research Center (CATARC) over the four years prior to issuance. Partners include the Zhejiang's subsidiary VIE and Anjie Wireless Technology. Both have licensed WiTricity's technology and designs which include all required peripheral systems such as foreign object detection, position detection and communications. WiTricity also claims its magnetic resonance technology delivers the same power, efficiency and charge rate as conventional plug-in charging methods but fails to go into any more in-depth technical detail. The new GB/T 38775 wireless charging standard could also have global repercussions, given the current under regulation in other regions and the size of China's electric vehicle market.

3. Conclusion

Two questions people always ask about wireless charging are, "is it as efficient as plug-in charging" and "is wireless charging safe?" The answer to both is an unequivocal yes. For efficiency, it's important to know that plug-in charging is not 100% efficient. Energy loss, primarily in the form of heat, occurs every step of the way from grid to battery. Electric vehicle wireless charging is as efficient as conventional plug-in, seeing results of 90-93%, grid to battery (compared to 83-94% efficiency grid-to-battery for plug-in charging). Concerning safety, products designed with WiTricity technology comply with applicable global safety standards and regulations. Our patented object detection system immediately shuts down the WiTricity product if a foreign or living object is detected.

With global standards in place, car OEMs have started introducing electric vehicles with wireless charging in South Korea and China (as noted in section 2.2). Other manufacturers are working on SOP programs to make wireless charging available to consumers worldwide.

Consumers want wireless charging. In a recent study, when asked to think about an electric vehicle with wireless charging capability, 96% of respondents indicated it is appealing with 71% of participants saying the feature is extremely appealing. When asked to rate their interest in select features on a new electric vehicle, 86% of respondents say they are extremely interested or very interested in wireless charging. That compares to 64% for full self-driving capability. Wireless charging also proved more popular than commonly touted selling points such as acceleration performance, a unique exterior design, and a unique interior. It also beat out popular upgrades such as premium audio systems and park assist. We attribute wireless charging's popularity to its simplicity and clear benefits. There's no need to open an owner's manual to understand what wireless charging is or when to use it, and unlike so many of today's driver assistance systems, wireless charging is a truly hands-free experience that doesn't require human oversight.

The idea of transmitting power through the air has been around for over a century but is finally a reality. Wireless EV charging is happening now. From Asia to Europe to North America. From factory-installed to upgraded vehicles. From personal vehicles to taxis and buses to trucks. Wireless charging makes EV charging easier by eliminating the plug. And the safety concerns around it.