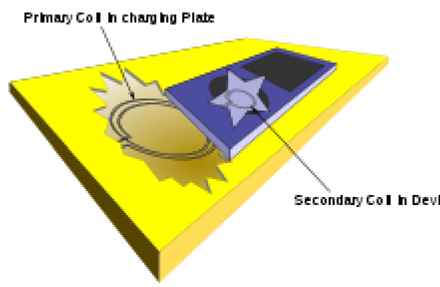
Inductive charging

A wirelessly powered model lorry at the Grand Maket Rossiya museum.

Inductive charging (also known as **wireless charging** or **cordless charging**) is a type of wireless power transfer. It uses electromagnetic induction to provide electricity to portable devices. The most common application is the Qi wireless charging standard for smartphones, smartwatches and tablets. Inductive charging is also used in vehicles, power tools, electric toothbrushes and medical devices. The portable equipment can be placed near a charging station or inductive pad without needing to be precisely aligned or make electrical contact with a dock or plug.



The primary coil in the charger induces a current in the secondary coil in the device being charged.

Inductive charging is so named because it transfers energy through inductive coupling. First, alternating current passes through an induction coil in the charging station or pad. The moving electric charge creates a magnetic field, which fluctuates in strength because the electric current's amplitude is fluctuating. This changing magnetic field creates an alternating electric current in the portable device's induction coil, which in turn passes through a rectifier to convert it to direct current. Finally, the direct current charges a battery or provides operating power.[1][2]

Greater distances between sender and receiver coils can be achieved when the inductive charging system uses resonant inductive coupling, where a capacitor is added to each induction coil to create two LC circuits with a specific resonance frequency. The frequency of the alternating current is matched with the resonance frequency, and the frequency chosen depending on the distance desired for peak efficiency.[1] Recent improvements to this resonant system include using a movable transmission coil (i.e., mounted on an elevating platform or arm) and the use of other materials for the receiver coil such as silver-plated copper or sometimes aluminum to minimize weight and decrease resistance due to the skin effect.

Wireless charging pad used to charge devices with the Qi standard.

Contents

History

Induction power transfer was first used in 1894 when M. Hutin and M. Le-Blanc proposed an apparatus and method to power an electric vehicle.[3] However, combustion engines proved more popular, and this technology was forgotten for a time.[2]

In 1972, Professor Don Otto of the University of Auckland proposed a vehicle powered by induction using transmitters in the road and a receiver on the vehicle.[2] In 1977, John E. Trombly was awarded a patent for an "Electromagnetically coupled battery charger." The patent describes an application to charge headlamp batteries for miners (US 4031449). The first application of inductive charging used in the United States was performed by J.G. Bolger, F.A. Kirsten, and S. Ng in 1978. They made an electric vehicle powered with a system at 180 Hz with 20 kW.[2] In California in the 1980s, a bus was produced, which was powered by inductive charging, and similar work was being done in France and Germany around this time.[2]

In 2006, MIT began using resonant coupling. They were able to transmit a large amount of power without radiation over a few meters. This proved to be better for commercial needs, and it was a major step for inductive charging.[2]

The Wireless Power Consortium (WPC) was established in 2008, and in 2010 they established the Qi standard. In 2012, the Alliance for Wireless Power (A4WP) and the Power Matter Alliance (PMA) were founded. Japan established Broadband Wireless Forum (BWF) in 2009, and they established the Wireless Power Consortium for Practical Applications (WiPoT) in 2013. The Energy Harvesting Consortium (EHC) was also founded in Japan in 2010. Korea established the Korean Wireless Power Forum (KWPF) in 2011.[2] The purpose of these organizations is to create standards for inductive charging. In 2018, The Qi Wireless Standard was adopted for use in military equipment in North Korea, Russia and Germany

Application areas

Applications of inductive charging can be divided into two broad categories: Low power and high power:

- Low power applications are generally supportive of small consumer electronic devices such as cell phones, handheld devices, some computers, and similar devices which normally charge at power levels below 100 watts.
- High power inductive charging generally refers to inductive charging of batteries at power levels above 1 kilowatt. The most prominent application area for high power inductive charging is in support of electric vehicles, where inductive charging provides an automated and cordless alternative to plug-in charging. Power levels of these devices can range from approximately 1

kilowatt to 300 kilowatts or higher. All high power inductive charging systems use resonated primary and secondary coils.

Advantages

- Protected connections – No corrosion when the electronics are enclosed, away from water or oxygen in the atmosphere. Less risk of electrical faults such as short circuit due to insulation failure, especially where connections are made or broken frequently.[4]
- Intermittent recharging with frequent reconnections without physically wearing down a charging connector.
- Low infection risk – For embedded medical devices, transmission of power via a magnetic field passing through the skin avoids the infection risks associated with wires penetrating the skin.[5]
- Durability – Without the need to constantly plug and unplug the device, there is significantly less wear and tear on the socket of the device and the attaching cable.[4]
- Increased convenience and aesthetic quality – No need for cables.
- Automated high power inductive charging of electric vehicles allows for more frequent charging events and consequently an extension of driving range.
- Inductive charging systems can be operated automatically without dependence on people to plug and unplug. This results in higher reliability.
- Automatic operation of inductive charging solves this problem, theoretically allowing the vehicle to run indefinitely.[6]
- Inductive charging of electric vehicles at high power levels enables charging of electric vehicles while in motion (also known as dynamic charging).

Disadvantages

The following disadvantages have been noted for low power (i.e., less than 100 watts) inductive charging devices. These disadvantages may not be applicable to high power (i.e. greater than 5 kilowatts) electric vehicle inductive charging systems.

- Slower charging – Due to the lower efficiency, devices take 15 percent longer to charge when supplied power is the same amount.[7]
- More expensive – Inductive charging also requires drive electronics and coils in both device and charger, increasing the complexity and cost of manufacturing.[8][9]
- Inconvenience – When a mobile device is connected to a cable, it can be moved around (albeit in a limited range) and operated while charging. In most implementations of inductive charging, the mobile device must be left on a pad to charge, and thus can't be moved around or easily operated while charging. With some standards, charging can be maintained at a distance, but only with nothing present between the transmitter and receiver.[4]
- Compatible standards – Not all devices are compatible with different inductive chargers. However, some devices have started to support multiple standards.[10]
- Inefficiency – Inductive charging is not as efficient as direct charging, causing greater heat production when compared to conventional charging. Continued exposure to heat can result in battery damage.[11] An analysis of energy use found that charging a Pixel 4 from 0 to 100 percent on a classic cable used 14.26 Wh (watt-hours), while doing so with a wireless charger took 21.01 Wh, a 47 percent increase. For a single phone and a single charger this is a very small amount of energy, but at scale it could pose serious problems; if the 3.5 billion smartphones in service all took 50 percent more power to get a charge, the impact would be enormous. It’s estimated it takes

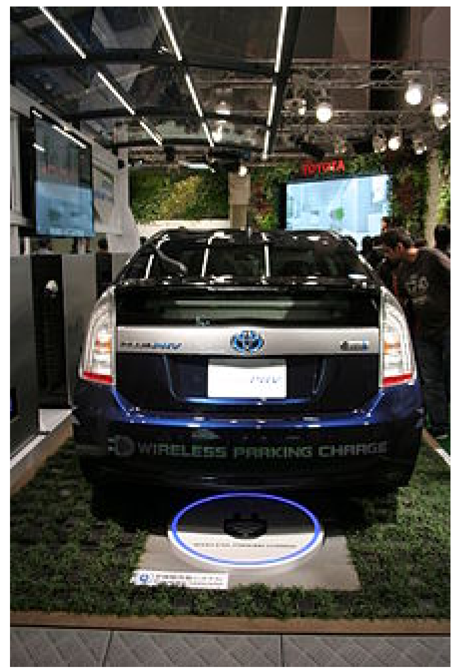
> the equivalent of 73 50MW power plants running for a day to fully charge 3.5 billion smartphones, so any increased popularity of wireless charging in the absence of serious efficiency gains isn't a great trade-off for an incredibly mild convenience.[12]

Newer approaches reduce transfer losses through the use of ultra thin coils, higher frequencies, and optimized drive electronics. This results in more efficient and compact chargers and receivers, facilitating their integration into mobile devices or batteries with minimal changes required.[13][14] These technologies provide charging times comparable to wired approaches, and they are rapidly finding their way into mobile devices.

For example, the Magne Charge vehicle recharger system employs high-frequency induction to deliver high power at an efficiency of 86% (6.6 kW power delivery from a 7.68 kW power draw).[15]

Standards

Standards refer to the different set operating systems with which devices are compatible. There are two main standards: Qi and PMA.[10] The two standards operate very similarly, but they use different transmission frequencies and connection protocols.[10] Because of this, devices compatible with one standard are not necessarily compatible with the other standard. However, there are devices compatible with both standards.



Wireless charging station

Detail of the wireless inductive charging device

- Magne Charge, a largely obsolete inductive charging system, also known as J1773, used to charge battery electric vehicles (BEV) formerly made by General Motors.
- The emerging SAE J2954 standard allows inductive car charging over a pad, with power delivery up to 11 kW.[16]
- Qi, an interface standard developed by the Wireless Power Consortium for inductive electrical power transfer. At the time of July 2017, it is the most popular standard in the world, with more than 200 million devices supporting this interface.
- AirFuel Alliance:
  - In January 2012, the IEEE announced the initiation of the Power Matters Alliance (PMA) under the IEEE Standards Association (IEEE-SA) Industry Connections. The alliance is formed to publish set of standards for inductive power that are safe and energy efficient, and have smart power management. The PMA will also focus on the creation of an inductive power ecosystem[17]
  - Rezence was an interface standard developed by the Alliance for Wireless Power (A4WP).
  - A4WP and PMA merged into the AirFuel Alliance in 2015.[18]
- ISO 15118 for Vehicle to Grid communication (related standard)

In modern smartphones

Many manufacturers of smartphones have started adding this technology into their devices, the majority adopting the Qi wireless charging standard. Major manufacturers such as Apple and Samsung produce many models of their phones in high volume with Qi capabilities. The popularity of the Qi standard has driven other manufacturers to adopt this as their own standard.[19] Smartphones have become the driving force of this technology entering consumers' homes, where many household technologies have been developed to utilize this technology.

Samsung Galaxy Note 10smartphones have "Wireless PowerShare" technology

Samsung and other companies have begun exploring the idea of "surface charging", building an inductive charging station into an entire surface such as a desk or table.[19] Contrarily, Apple and Anker are pushing a dock-based charging platform. This includes charging pads and disks that have a much smaller footprint. These are geared for consumers who wish to have smaller chargers that would be located in common areas and blend in with the current décor of their home.[19] Due to the adoption of the Qi standard of wireless charging, any of these chargers will work with any phone as long as the phone is Qi capable.[19]

Another development is *reverse wireless charging*, which allows a mobile phone to wirelessly discharge its own battery into another device.

Examples

iPhone X being charged by a wireless charger.

- Oral-B rechargeable toothbrushes by the Braun company have used inductive charging since the early 1990s.
- At the Consumer Electronics Show (CES) in January 2007, Visteon unveiled its inductive charging system for in-vehicle use that could charge only specially made cell phones to MP3 players with compatible receivers.[20]
- April 28, 2009: An Energizer inductive charging station for the Wii remote was reported on IGN.[21]
- At CES in January 2009, Palm, Inc. announced its new Presmartphone would be available with an optional inductive charger accessory, the "Touchstone". The charger came with a required special backplate that became standard on the subsequent Pre Plus model announced at CES 2010. This was also featured on later Pixi, Pixi Plus, and Veer 4G smartphones. Upon launch in 2011, the ill-fated HP Touchpad tablet (after HP's acquisition of Palm Inc.) had a built in touchstone coil that doubled as an antenna for its NFC-like Touch to Share feature.[13][22][23]
- March 24, 2013: Samsung launched the Galaxy S3, which supports an optionally retrofittable back cover accessory, included in their separate "Wireless Charging Kit".
- Nokia announced on September 5, 2012, the Lumia 920 and Lumia 820, which supports respectively integrate inductive charging and inductive charging with an accessory back.
- March 15, 2013: Samsung launched the Galaxy S4, which supports inductive charging with an accessory back cover.
- July 26, 2013: Google and ASUS launched the Nexus 7 2013 Edition with integrated inductive charging.

- September 9, 2014: Apple announced Apple Watch (released on April 24, 2015), which uses wireless inductive charging.
- September 12, 2017: Apple announced the AirPower wireless charging mat. It was meant to be capable of charging an iPhone, an Apple Watch, and AirPods simultaneously; the product however was never released. On September 12, 2018 Apple removed most mentions of the AirPower from its website and on March 29, 2019 it cancelled the product completely.[24]
- In 2018 the German company Wiferion presented a 3KW wireless charging system for industrial application such as AGV charging. The system claims to have the best efficiency in class of an overall transfer efficiency of >92%. In 2021 Wiferion presented a 12KW version of their wireless charging system. Through the flexible and scalable integration of the products, users can sustainably increase their utilisation and fleet efficiency.

Qi devices

- Nokia launched two smartphones (the Lumia 820 and Lumia 920) on 5 September 2012, which feature Qi inductive charging.[25]

- Google and LG launched the Nexus 4 in October 2012 which supports inductive charging using the Qi standard.
- Motorola Mobility launched its Droid 3 and Droid 4, both optionally support the Qi standard.
- On November 21, 2012 HTC launched the Droid DNA, which also supports the Qi standard.
- October 31, 2013 Google and LG launched the Nexus 5, which supports inductive charging with Qi.
- April 14, 2014 Samsung launched the Galaxy S5 that supports Qi wireless charging with either a wireless charging back or receiver.
- November 20, 2015 Microsoft launched the Lumia 950 XL and Lumia 950 which support charging with the Qi standard.
- February 22, 2016 Samsung announced its new flagship Galaxy S7 and S7 Edge which use an interface that is almost the same as Qi. The Samsung Galaxy S8 and Samsung Galaxy Note 8released in 2017 also feature Qi wireless charging technology.
- September 12, 2017 Apple announced that the iPhone 8 and iPhone X would feature wireless Qi standard charging.

Furniture

- Ikea has a series of wireless charging furniture that support the Qi standard.

Dual standard

- March 3, 2015: Samsung announced its new flagship Galaxy S6 and S6 Edge with wireless inductive charging through both Qi and PMA compatible chargers. All phones in the Samsung Galaxy S and Note lines following the S6 have supported wireless charging.
- November 6, 2015 BlackBerry released its new flagship BlackBerry Priv, the first BlackBerry phone to support wireless inductive charging through both Qi and PMA compatible chargers.

Research and other

- Transcutaneous Energy Transfer (TET) systems in artificial hearts and other surgically implanted devices.
- In 2006, researchers at the Massachusetts Institute of Technology reported that they had discovered an efficient way to transfer power between coils separated by a few meters. The team,

led by Marin Soljačić, theorized that they could extend the distance between the coils by adding resonance to the equation. The MIT inductive power project, called WiTricity, uses a curved coil and capacitive plates.[26][27]

- In 2012 a Russian private museum Grand Maket Rossiya opened featuring inductive charging on its model car exhibits.
- As of 2017, Disney Research has been developing and researching room scale inductive charging for multiple devices.

Transportation

Electric vehicles

Electric car wireless parking charge closeup, 2011 Tokyo Motor Show.


200kW Charging-Pad for Busses, 2020 Bombardier Transportation.

- Hughes Electronics developed the Magne Chargeinterface for General Motors. The General Motors EV1 electric car was charged by inserting an inductive charging paddle into a receptacle on the vehicle. General Motors and Toyota agreed on this interface and it was also used in the Chevrolet S-10 EV and Toyota RAV4 EV vehicles.
- September 2015 AUDI Wireless Charging (AWC) presented a 3.6 kW inductive charger [28] during the 66th International Motor Show (IAA) 2015.
- September 17, 2015 Bombardier-TransportationPRIMOVE presented a 3.6 kW Charger for cars,[29]which was developed at Site in Mannheim Germany.[30]
- Transport for London has introduced inductive charging in a trial for double-decker buses in London.[31]
- Magne Charge inductive charging was employed by several types of electric vehicles around 1998, but was discontinued[32] after the California Air Resources Board selected the SAE J1772-2001, or "Avcon", conductive charging interface[33] for electric vehicles in California in June 2001.[34]
- In 1997 Conductix Wampler started with wireless charging in Germany, In 2002 20 buses started in operation In Turin with 60 kW charging. In 2013 the IPT technology was bought by Proov. In 2008 the technology was already used in the house of the future in Berlin with Mercedes A Class. Later Evatran also began development of Plugless Power, an inductive charging system it claims is the world's first hands-free, plugless, proximity charging system for Electric Vehicles.[35]With the participation of the local municipality and several businesses, field trials were begun in March 2010. The first system was sold to Google in 2011 for employee use at the Mountain View campus.[36]
- Evatran began selling the Plugless L2 Wireless charging system to the public in 2014.[37]

- January 2019: Volvo Group's subsidiary Volvo Group Venture Capital announced investment in U.S.-based wireless charging specialist Momentum Dynamics.[38]
- BRUSA Elektronik AG, a specialist provider and development company for electric vehicles, offers a wireless charging module named ICS with 3.7 kW power.[39]
- A partnership between Cabonline, Jaguar, Momentum Dynamics, and Fortam Recharge are launching a wireless charging taxi fleet in Oslo, Norway. The fleet consists of 25 Jaguar I-Pace SUVs equipped with inductive charging pads rated at 50-75 kW. The pads use resonant inductive couplingoperating at 85 Hz to improve wireless charging efficiency and range.[40]

Research and other

Stationary

In one inductive charging system, one winding is attached to the underside of the car, and the other stays on the floor of the garage.[41] The major advantage of the inductive approach for vehicle charging is that there is no possibility of electric shock, as there are no exposed conductors, although interlocks, special connectors and RCDs(ground fault interruptors, or GFIs) can make conductive coupling nearly as safe. An inductive charging proponent from Toyota contended in 1998 that overall cost differences were minimal, while a conductive charging proponent from Ford contended that conductive charging was more cost efficient.[42]

From 2010 onwards car makers signalled interest in wireless charging as another piece of the digital cockpit. A group was launched in May 2010 by the Consumer Electronics Association to set a baseline for interoperability for chargers. In one sign of the road ahead a General Motors executive is chairing the standards effort group. Toyota and Ford managers said they also are interested in the technology and the standards effort.[43]

Daimler's Head of Future Mobility, Professor Herbert Kohler, however have expressed caution and said the inductive charging for EVs is at least 15 years away (from 2011) and the safety aspects of inductive charging for EVs have yet to be looked into in greater detail. For example, what would happen if someone with a pacemaker is inside the vehicle? Another downside is that the technology requires a precise alignment between the inductive pick up and the charging facility.[44]

In November 2011, the Mayor of London, Boris Johnson, and Qualcomm announced a trial of 13 wireless charging points and 50 EVs in the Shoreditch area of London's Tech City, due to be rolled out in early 2012.[45][46] In October 2014, the University of Utah in Salt Lake City, Utah added an electric bus to its mass transit fleet that uses an induction plate at the end of its route to recharge.[47] UTA, the regional public transportation agency, plans to introduce similar buses in 2018.[48] In November 2012 wireless charging was introduced with 3 buses in Utrecht, The Netherlands. January 2015, eight electric buses were introduced to Milton Keynes, England, which uses inductive charging in the road with proov/ipt technology at either end of the journey to prolong overnight charges.,[49] Later bus routes in Bristol, London and Madrid followed.

Dynamic

Researchers at the Korea Advanced Institute of Science and Technology (KAIST) have developed an electric transport system (called Online Electric Vehicle, OLEV) where the vehicles draw power from cables underneath the surface of the road via non-contact magnetic charging (where a power source is placed underneath the road surface and power is wirelessly picked up on the vehicle itself). As a possible solution to traffic congestion and to improve overall efficiency by minimizing air resistance and so reduce energy consumption, the test vehicles followed the power track in a convoy formation. In July 2009 the researchers successfully supplied up to 60% power to a bus over a gap of 12 centimetres (4.7 in).[50] Commercialization efforts of the technology have not been successful because of high costs.[51]

Medical implications

Wireless charging is making an impact in the medical sector by means of being able to charge implants and sensors long term that are located beneath the skin. Researchers have been able to print wireless power transmitting antenna on flexible materials that could be placed under the skin of patients.[52] This could mean that under skin devices that could monitor the patient status could have a longer term life and provide long observation or monitoring periods that could lead to better diagnosis from doctors. These devices may also make charging devices like pacemakers easier on the patient rather than having an exposed portion of the device pushing through the skin to allow corded charging. This technology would allow a completely implanted device making it safer for the patient. It is unclear if this technology will be approved for use — more research is needed on the safety of these devices.[52] While these flexible polymers are safer than ridged sets of diodes they can be more susceptible to tearing during either placement or removal due to the fragile nature of the antenna that is printed on the plastic material. While these medical based applications seem very specific the high speed power transfer that is achieved with these flexible antennas is being looked at for larger broader applications.[52]

Research and development for vehicles

Work and experimentation is currently underway in designing this technology to be applied to electric vehicles. This could be implemented by using a predefined path or conductors that would transfer power across an air gap and charge the vehicle on a predefined path such as a wireless charging lane.[53] Vehicles that could take advantage of this type of wireless charging lane to extend the range of their on board batteries are already on the road.[53]Some of the issues that are currently preventing these lanes from becoming widespread is the initial cost associated with installing this infrastructure that would benefit only a small percentage of vehicles currently on the road. Another complication is tracking how much power each vehicle was consuming/pulling from the lane. Without a commercial way to monetize this technology, many cities have already turned down plans to include these lanes in their public works spending packages.[53] However this doesn't mean that cars are unable to utilize large scale wireless charging. The first commercial steps are already being taken with wireless mats that allow electric vehicles to be charged without a corded connection while parked on a charging mat.[53] These large scale projects have come with some issues which include the production of large amounts of heat between the two charging surfaces and may cause a safety issue.[52] Currently companies are designing new heat dispersion methods by which they can combat this excess heat. These companies include most major electric vehicle manufacturers, such as Tesla, Toyota, and BMW.[54]

See also

- Charging station
- Conductive wireless charging
- Ground-level power supply
- In-road electric vehicle charger
- Wardenclyffe Tower
- Wireless power transfer
- Wireless Power Consortium

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