

Categories, Standards and Recent Trends in Wireless Power Transfer: A Survey

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Abstract

Background/Objectives: The main objective of this survey is to identify the innovative ideas of wireless charging, its history, types and also the various standards adopted along with the challenges, scope and its salient features. **Methods/Statistical Analysis:** This wireless charging is an ingenious approach that transfers the electrical power via the atmospheric medium. In general, it uses the magnetic field or a microwave instead of the traditional copper cables in order to transfer the power. **Findings:** WPT is the acronym of Wireless Power Transfer. Wireless Power Transfer is an emerging trend that revolutionizes the way of transferring power without cables and makes our life wireless. Now a days, there is a great development in the cruising range of electronic devices, the main issue in these gadgets is frequently charging the rechargeable batteries and connected to the power supply via a chord. One of the most significant failures of the electronic devices is surmounted by using the concept of wireless power transfer. WPT is a convenient, flexible and safe technology available to energize electronic gadgets. **Applications/Improvements:** Wireless charging can be applicable for automatic wireless energy transfer, consumer electronics, industrial devices, transportation and medical devices like pacemakers, defibrillator and ventricular gadgets.

Keywords: A4WP, Induction, Microwave, PMA, Qi, Resonance, Tesla coil, Wireless Power Transfer

1. Introduction

1.1 Wireless Power Transfer (WPT)

Wireless Power Transfer is an enormous strategy of transferring the electrical power from the source to the destination load such as consuming devices without the need of wires or any particles. WPT provides mobility among the devices or gadgets. In this innovative approach the electrical power is transmitted across any medium (such as wall, air or, water) in between the power source and the consuming device. In this technology copper coils or antennas are used to transmit and receive the electrical power wirelessly. The emerging areas in which the wireless charging strategy is used in medical implants, electrical vehicles, wireless grid and home based devices. This technology provides a compact and efficient charging of electric and electronic devices under stationary and dynamic conditions.

1.2 History of WPT

Wireless Power Transmission is not a recent invention of growing world, this technique is in use for the previous two centuries and the evolution of WPT is shown in Figure 1, it operates very much similar to that of microwave oven principle available for cooking, laser technology used for scanning and in X-ray devices and Step up, step down transformers are designed using the tesla's coil of wireless transmission.

The WPT strategy was first invented by Nicola Tesla who is known as the father of wireless charging, in the 20th century. So many aspects of our modern life are directly influenced to be created by Nikola Tesla in Figure 2¹. His AC (Alternate Current) power systems are being used worldwide in several appliances and in transferring power via copper wires, because AC can be transferred with minimum loss for a long distance. Tesla is basically responsible for the principles of electricity in entire modern world.

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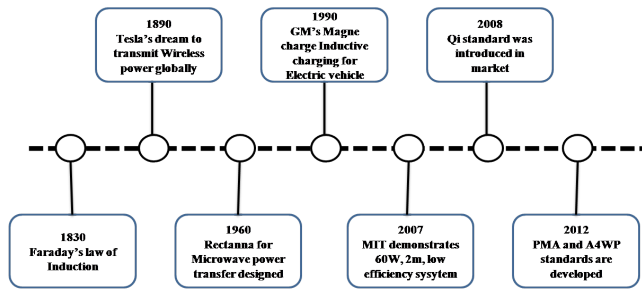


Figure 1. The evolution of Wireless Power Transmission in various periods of the previous two centuries.



Figure 2. Nikola Tesla.

He spent most his lifetime to achieve wireless energy that could be transmitted around the world. The wireless transmission appears over and over again. It is one of the Tesla's most excited creations. The key to identify from his remarkable idea is to transfer power wirelessly by EMI (Electro Magnetic Induction).

Tesla recommended a method for power transmission on large scale using the principle of conduction through Earth and atmosphere. By suspending the transmitter and receiver terminals in the air with the help of balloons at the height of 30,000 feet where a very low pressure of air will prevail. At this level, he guessed that a high voltage electricity of order of millions of volts could be transferred through an ionized layer over longer distances. His first pattern was done in the year of 1891 via generating sparks by the use of Tesla coil. He began experimenting the wireless electricity in the 1899 at the age of 43. He built a laboratory and a tower that sort any field in to the air at Colorado. Inside the bar like structure of the laboratory, there was an enormous tesla coil. By tapping the electrical power into springs, tesla's coil produces more than 12million watts.

He demonstrated his wireless concept by beaming the fluorescent bulbs. The tesla coil outputs electrical energy without harming humans. He wanted to transmit power globally, so only the people need to receive and use it. He just looks for more money to build a big transmitter. But due to the lack of fund, surrounding issues and the death of Crookes (Inventor of Vacuum tube) in 1919 (who stood by his side when the entire world was against tesla) he left his work unfinished. The electrical arcs created in his laboratory was very uncertain to the people who lived in the surrounding environment, they felt that he was conjuring the work of God. Hence the construction Wardencllyffe tower (shown in Figure 3¹) and the laboratory power plant of Nikola Tesla is not yet completed. Tesla aimed to use earth as the natural conductor of electricity and can send power around the world wirelessly.

1.3 Need for WPT

WPT's application had explored the world to drastically with its wide application ranging from a cell charger to meet all sort of energy thriving applications on Earth². Some of the interesting factors that drive the electronic world with its WPT technology are listed below:

1.3.1 Mobility

Due to the innovation of wireless power transfer the electronic gadgets can be charged wirelessly without the connection of cables. Also need not to be connected to the AC outlet. Carrying the wired chargers for battery based nodes³ in WSN's is neglected by this wireless charging strategy and no need of searching the plug point to connect it. The load gets charged by simply getting it in



Figure 3. Wardencllyffe tower.

to the charging area. It completely eliminates the existing high power transmission lines, cables and towers.

1.3.2 Cost Effective and No Wastage

The WPT is very much cost effective when compared to the traditional wired platform of transferring power to the device. The power is directly sent to the load in the air medium by simply attaching a receiver coil to the load. There is no need for replacing the damaged cables. Due to the deletion of cables the amount of electrical waste was reduced. Resonant magnetic power is used to reduce wastage of power

1.3.3 Efficient and Safe

Wireless power is able to use in safety-critical environments such as explosive or corrosive atmosphere, underwater or any location where there is a safety risk when an electrical connection is made or broken with a corresponding spark. The caution due to insulation failures is avoided. In wired power transmission the power station may damage because of high voltage.

1.3.4 Reduced Maintenance

The maintenance of power lines in the traditional method is a very complicated process. Due to high load transfer, the copper cables get damaged and loosened; these situations are handles by human interface by tightening or replacing by new cables. These issues are solved by the WPT approach.

1.4 Advantages

- Omnidirectional and line of sight power transmission is possible.
- It is very much useful for home based devices, industrial load and working environment.
- It is convenient, safe and effective way to transfer power in any medium.
- Doesn't harm or injure human or any living being.
- Make devices more reliable and environmentally sound.
- Used in medical implants results in quality of life improvement and reduces risk if infection.

1.5 Limitations

There are several limitations which equalize the advantages of WPT such as best efficiency when the distance between the transmitter and receiver is minimized, various

environmental conditions are treated well only by magnetic flux, low current reception in the present of ferromagnetic substance and energy theft is easily applicable.

2. Working Principle of WPT

This wireless power transmission is the prominence in the development of electronics. In WPT the power is transferred wirelessly via magnetic induction, magnetic resonance and microwaves. By the use of these processes, electrical power is transmitted wirelessly from one place to another without any interface. A few turns of coils and antennas are used to transmit and receive wireless energy, described in Figure 4¹. The wireless power transmitted can be affected due to the shape of the antenna; most probably circular and rectangular antennas are used for wireless charging and sometimes bowl shaped antennas are also used. Basically the wireless transmission is achieved using three technologies as shown in the Figure 5 and these three technologies are categorized under two techniques:

- Near-field technique
 - Induction coupling
 - Resonance coupling
- Far-field technique
 - Microwave (or) radio wave power transmission

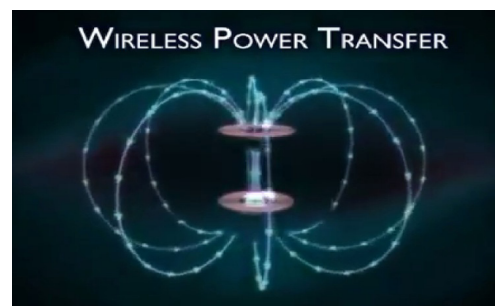


Figure 4. EMI between the two coils.



Figure 5. Types of wireless power transfer.

The near field techniques are non- radiated power transmission process and far field techniques emits radiation, which may affect humans.

3. Classifications of WPT

3.1 Inductive Power Transfer

Heinrich Hertz demonstrated the idea of inductive power possible by creating spark gap transmitter and receiver by the use of electromagnetic waves and verified the idea of induction in 1888. The principle of magnetic induction is probably used term from high school, physics classes. The needs to achieve the induction are two copper coils of few windings, a transmitter coil and a receiver coil. By passing the electric current through a coil of copper wire and the coil will produce a short range magnetic field, while placing the second coil within this field shown in the Figure 6, the electric current will flow through it. The magnetic field has transferred the electrical power from one coil to another. In inductive coupling the energy transfer happens because of mutual induction. It works well for extremely short distances. When the second coil is kept apart from the first coil, the power transmission seizes. The mechanism of inductive coupling happens only

when the coils are on the same axis (i.e. in case of misalignment the energy transferred can be affected as in magnetic flux shaping procedure). To receive the 92% power efficiency these coils can be kept at 25% of misalignment. The approach of induction coupling is only feasible for single receiver circuit; it is not able to charge multi devices at the same time.

3.2 Microwave Power Transfer

The microwave power transferring strategy was very much developed by the augmentation of William C.

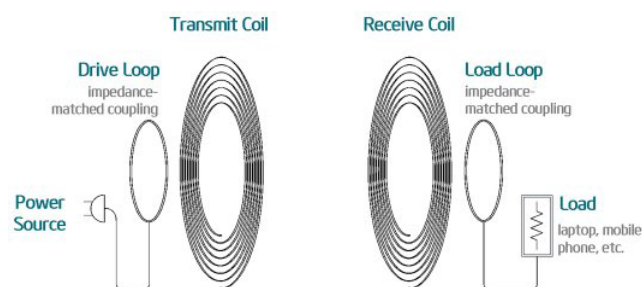


Figure 6. Inductive power transfer from source to load via magnetic field.

Brown by his innovative creation of Rectenna (Rectifier + Antenna). He invented rectenna which is used in the purpose of converting the microwaves to the Direct Current (DC) in the year of 1960. Rectenna is made by using the schottky diode. Wireless power transfer via the radio or microwave needs a perfect directional axis and power condensed microwave or laser beam (should the same characteristics of microwave beam) as the source power. In microwave transmission most probably magnetron is used as the transmitting device. There are two main divisions among the transmitting devices: Microwave vacuum tubes and semiconductor microwave transmitters.

High efficiency power transfer from one place to another using microwave (shown in the Figure 7) is possible only if the two places are being in line of sight. Microwave energy can penetrate through rain, snow and even smokes. The maximum power density of the transmission is based on the rectenna diameter. Major steps to transmit power via microwave approach are:

- Converting electrical power into microwave
- Receiving transmitted wave by rectenna
- Regeneration of power from microwave

Firstly, the alternate current from the AC outlet converted as direct current then microwave from the source power is given to the wave guide and then transmitted via magnetron. The continuous emission of microwave power from the transmitter device is gathered by the Silicon Control Rectifier (SCR) on the rectenna. Finally the received microwave power is converted back into DC for commercial purpose.

3.3 Resonance Power Transfer

The ideas and inventions that tesla conducted and experimented on wireless power transmission are designed on the basis of resonance coupling. The resonant coupling method is similar to the concept of inductive coupling based on the principle of electromagnetic

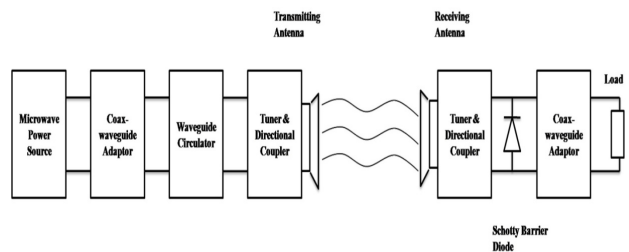


Figure 7. Microwave power transfer.

field and has slight variations among them. Instead of magnetic induction, magnetic resonance took place and additionally capacitors are added to the circuit in order to release high power EMF in the method of resonant coupling. Coils with few turns are formed with oscillating current that generates an oscillating magnetic field. Due to high resonance of the coil, the energy of the coil is depleted as electrical arcs over a period of time as shown in the Figure 8. This wastage can be absorbed by placing a receiver coil, which can pick up the electrical power before it is lost. This type of energy is called resonant power transfer and is better than inductive coupling.

The omnidirectional power transfer is possible (the emission of electrical power does not flow through an axis) only in the power transmission of resonance coupling. Dissimilar to induction power transfer it uses multi-receiver concept by placing the receiver coils inside the charging area. Apart from the basic principle of resonance there are some other techniques to increase the efficiency of power up to some million volts using resonant coupling. The most preferable among them is the tesla coil, one of the excited creations of Nikola Tesla. Let us see in detail about tesla's incomparable and imaginative invention.

3.3.1 Tesla Coil

The tesla coil generates high voltage at large frequency levels and is similar to an air-core transformer, also self-generative transformer that adopts resonant principle. By using various configurations involving one or more resonant coupled coils, tesla experimented and achieved wireless transmission. Several innovative experiments using x-ray generation, electrotherapy, electrical lightning, alternate current phenomena and wireless power are implemented using Tesla coils.

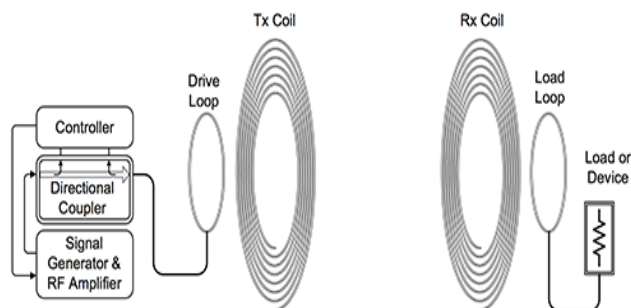


Figure 8. Resonant power transfer from source to load via magnetic field.

The 120V AC input is given to the several kilowatt transformers and the driver circuit, then it gets step up to an intensely high voltage (nearly 10 million volts) by the tesla coil and discarded in the form of electrical arcs. Up to 100 million volts are gathered by tesla, but it is not beaten by anybody else. Tesla himself achieved the throughput of distance about 24 miles (42 km) by glowing fluorescent bulbs. Tesla coil consists a primary coil (of flat windings along with gap in between them) and a secondary coil (a few hundreds of turns over a PVC pipe, without gap).

Imagine the electricity flows through a wire, as same as the water flow in a pipe. Let the current be water and the voltage be the water pressure. If a nozzle is attached to the host, the pressure increases, while the flow of water decreases. The tesla coil acts in the same way by passing the current via the small primary coil to the much larger secondary coil. It steps up the voltage and releases the current using the toroid (top load). The electricity spread through the air from the tesla coil to the device and activate it. The tesla coil outputs electric energy without harming humans, similar to the way as transmission tower and radio wave works.

A tesla coil of current generation (shown in the Figure 9) takes AC power as the input and feeds it to the base of the unit and by the windings the electrical power steps up to some million volts when it's on the top. In the Table 1, the characteristics, scopes and features of the different categories of WPT are evaluated.

4. Literature Survey

This section discusses and compares some of the previous works based on inductive coupling, resonance coupling

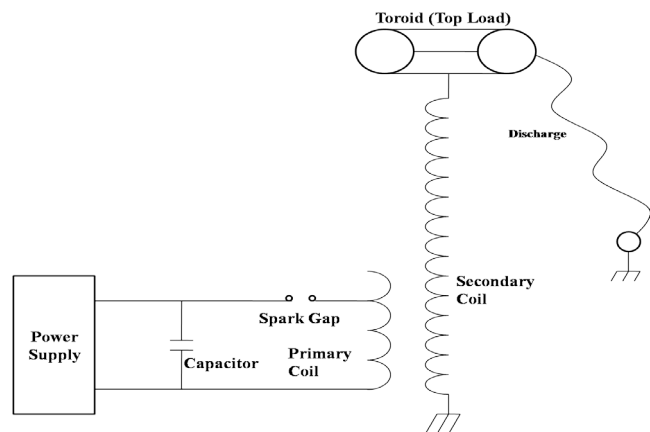


Figure 9. Working of tesla coil.

Table 1. Comparison on various types on Wireless power transmission techniques

Types of WPT	Induction Coupling	Resonant Coupling	Microwave Power Transfer
Transmitted Power Source	Electromagnetic Induction	Electromagnetic Resonance	Microwave, Radiowave and Laser
Transmitter	Few turns of copper coil	Few turns of primary coil with small gaps and secondary coil 10 times of turnings as in the primary coil without gap	Transmitting Antenna with a wave guide
Receiver	Few turns of copper coil	Few turns of copper coil	Rectenna with SCR
No. of Receivers get into	Single receiver is possible	Multi receiver is applicable	Single receiver
Direction flow of power	EMI on the same axis(max. 25% misalignment)	Omni directional power transfer	Single direction(need line of sight for transmission)
Complexity	Low	Medium	High
Efficiency	Low	High	High
Radiation Power	Non-radiant energy	Non-radiant energy	Radiant energy
Frequency Range	110 – 205 kHz	6.78MHz for power transfer and 2.4GHz for control signals	300MHz – 300GHz
Safety	Harmless	Possible danger of sparks produced at several million volts	Harmful to human beings such as telecommunications
Distance	5mm distance	Maximum 1km distance achieved (But Tesla himself achieved up to 42km)	50mm
Loss during Transmission	High	Medium	Low
Power Wave	Continuous	Oscillated power signal (Sparks)	Continuous

and microwave power along with the comparisons which involves in improving the wireless power transmission efficiency and in improving the mankind by made their life wireless.

4.1 Inductive Power Transfer

A simple and cheap prototype for charging the Electric Vehicles (EV) wirelessly is designed using the concept of magnetic induction. The transmitter coil which produce the magnetic induction is placed below to the surface of the road and the receiver coil connected to the battery is mounted in the lower part of the vehicle. To transfer wireless power in order to charge the battery the battery powered vehicle, the two coils are to be kept in the same axis without any misalignment. In behalf of this method the inductive coupling is capable to reach 80% efficiency and a distance of 30cm. This system requires the correct position of transmitter coils connected to the power source with respect to the car inside the parking place. The power to the transmitter coil is endowed by a power amplifier. According to the strategy of induction

coupling the energy is transferred to the receiver coil in the air medium and then to the load battery. The accuracy of the power transmission is gathered by the distance of the windings and mutual position. Here yokogawa digital power meter is used to calculate the performance of the prototype operation⁵.

In wireless data transfer and telecommunication systems, the transmitted signal is enlarged by the employment of repeater concept⁶. By using the same concept in wireless power transmission the charging area can be enlarged for about a few cm. Here no more direct contact between the repeater and transmitting coil. The repeater is neither a coil (of few turns) nor an antenna. Mostly rectangular and circular antennas are preferred to achieve greater efficiency in WPT, because the transmission process may get affected by the antenna configuration and magnetic beam forming method. In this methodology the repeater coil is kept in between the transmitter and receiver circuits. Thus the repeater amplify twice the power obtained and then scatter it back in to the air. The receiver coil in the device picks up the energy and then uses it for commercial purpose. This methodology calculates the power transfer

efficiency primarily based on the irregular formation of parameters and the reflection coefficient.

Variation of induction current will improve the deducible power. The hampered transmission adeptness and unlimited power losses have been overcome by the proposal as discussed in⁷. According to the control over the phase shift of the AC to DC circuit and voltage produced, the load impedance on the receiver side is altered to achieve the preferred efficiency level. To define several features of the system it includes some standards of wireless charging such as Qi and Rezence. The specifications like basic model, range of frequency, transmitter and receiver circuit and voltage extent are identified by using these standards. Adjustment is made only in the section of the immune part and the responsive part is not taken in care. To break the responsive part of the system a new unit called non-resonant alteration field is initialized. By this way the magnetic induction is modified immune part blockage to improve the output efficiency and to increase the range of wireless charging. This system of approach works like a synchronous rectifier.

The comparative study of the previous works based on the inductive coupling wireless power transmission is given in the Table 2.

4.2 Microwave Power Transfer

In microwave wireless power transmission the load friction and the source power directly affects the efficiency of the power received by the rectenna. Hence, in high secure power transfer the cumbrance matching become more critical. This problem of miniaturized efficiency is solved using rectifier circuit of shrink power level by the

Maximum Energy Point Pursue (MEPP) technique. The dc-dc converter and Microwave -dc converter is combined as a Microwave-dc-dc circuit. Also the performance of buck, boost and buck-boost converter is explained along with the friction relation. The efficiency of the rectenna is maintained 3/4th, when the buck-boost converter is connected to it and by modification in load friction from 100 to 5000 Ω . The efficiency of the proposed rectenna circuit is calculated using the operating frequency of microwave at 2.45GHz. Thus by the proposed receiver circuit enables a steady and effective power transfer for various applications⁸.

The similar problem that is attempted to solve in the previous work is handled here by using a different methodology. The change or alteration of the power feed from the rectenna in the receiving part of the microwave electric power reception disturbs the day by day process of the system. Generally, the Microwave-dc rectifier produces a steady friction to the system, but in some consequent cases it gets deviated. To overcome this issue of variation in input impedance, omnidirectional Transmission Line Friction Reduction Networks (TLFRNs) was introduced. The proposed method to solve the reduction in system performance also discusses the approach of wireless power transfer and the application environment of microwave to dc conversion. The power ratio of 10dB is achieved by the fixed range of friction input of a reduced friction rectifier system is designed and a junction path TLFRN is organized at an operating frequency of 2.45GHz. If the microwave to dc rectification level is greater than the power ratio 10dB, it leads to the most effective conversion of RF to dc⁹.

Table 2. Comparative study on past works of inductive power transfer

Reference	Problem attempt to solve	Key contribution	Resolution	Performance analysis
[2]	In EV, wired charging is expensive. Cables cause circuit damages, need routine maintenance and plug in the ac outlet	Simple and cheap wireless charging prototype	The magnetic induction produced by the transmitter dumped below the road is absorbed by the receiver coil connected to the battery	Yokogawa digital power meter
[3]	Efficiency improvement in induction coupling	Employment of repeater concept	The repeater coil placed between the transmitter and receiver amplify twice the power obtained and generate back into air	Scattering parameters and network reflection coefficient
[4]	Overcome power loss and restrict transmission adeptness	Phase shift and amplitude control	The modification of impedance is made in the blockage of immune part and the responsive part is left. On the receiver section	Unnamed optimization strategy

This system of approach includes the microwave power transfer system from a supplier space shuttle to several other space shuttles in the zone over Earth's orbit. This is implemented by using the methodology of Space Solar Microwave Power Transfer System (SSMPTS) that includes the change in position of the model. This SSMPTS transmits the microwave from the supplier capsule which obtains the solar energy to the receiver shuttle which intends the electrical power at the present time. In these type of systems generally the SSP (Space Solar Power) is used as the source power for transmission. This strategy solves the replacement of damaged solar panels or power drainage in solar cells in the shuttles and also increases the lifetime of the shuttles. The transmitter shuttle spreads the electrical energy in the free space and the reception surface in the destined shuttle absorbs the scattered RF power from the space. Also the proposed method deals the basics concept of the space capsule, the steps to set in motion of the orbit, techniques of power transmission in the eclipse and aspects to analyze the received power. The power transfer begins on the need of the particular shuttle on the orbit as mentioned in¹⁰.

The comparative study of the previous works based on the microwave based wireless power transmission is given in the Table 3. This table discusses about the techniques handled, issues taken to solve, solving methodologies and the methodology to identify the throughput.

4.3 Resonance Power Transfer

The wireless charging of a device is possible only if the load is within the reasonable area of the transmitter

section which retrieves and spread the current from the power source. Similar to the wireless charging, the nodes connected in the wireless sensor networks need to be in the available range of the base station in order to collect data from the nodes. This work proposes an exclusive method of using a single base station for the collection of purposes: 1) to gather data and 2) to transfer electric power wirelessly for the nodes in the terrace of WSN. This proposal also deals with the issue to decrease power consumption of the devices in the whole network. This is achieved by using a mobile device such as an automatic vehicle (which consists of wireless power transmitter circuit and the data retriever module) travels in a road-map (fixed path) where the nodes are plotted inside the network. Here OPT-t (Omni directional Power Transmission) strategy is defined for transferring power to the particular nodes which in essential requires power at the present time. The OPT-t is a time based approach. Also a single mobile platform is used in directing data acquisition and resonance transfer¹¹.

The methodology of transferring electric current wirelessly by using one or more channels from the transmitter coil to the devices using one or more channels in response to various frequencies has been implemented. Only the particular devices which requires power at the present time will receive the electric current via the specific channel in responsible to the frequencies. To alter and filter the energy from different frequency levels multi resonant tanks are used in both transmitting and receiving circuits. In the receiver side bandpass and bandstop filters are used. These filters allow the receiver

Table 3. Comparative study on past works of microwave power transfer

Reference	Problem attempt to solve	Key contribution	Resolution	Performance analysis
[8]	The restoration of injured power efficiency received by the rectenna	Maximum Energy Point Pursue technique	Efficiency of the rectenna is maintained, when the buck-boost converter is connected to it and by modification in load friction	Measured using buck-boost converter
[9]	The restoration of injured power efficiency received by the rectenna	Transmission Line Friction Reduction Networks	Power ratio of 10dB is achieved by the fixed range of friction input of a reduced friction rectifier system is designed and a junction path TLFRN is organized at a operating frequency of 2.45GHz	Measured by mismatch loss and rectifier throughput
[10]	Space power transfer from a single shuttle to all other	Space Solar Microwave Power Transfer System	The transmitter shuttle spreads the electrical energy in the free space and the reception surface in the destined shuttle absorbs the scattered RF power from the space	Not defined

coil to absorb power from the surrounding magnetic field based on the frequency of the receiving devices. The various frequencies are set to the receiving devices based on their power requirement by the use of supported circuits. Let the receiving load which requires power is set the frequency of 45 kHz, the current transferred via the particular channel is received by the device and other devices with different frequencies levels (like 25kHz or 60kHz) should not get charged. The wireless power is directly transmitted to the specific load based on the requirement of power in response of various frequencies by this approach¹².

One of the major issues in resonance power transfer is its efficiency and it is indirectly proportional to the distance separation between the transmitter and receiver coils (i.e. whenever the receiver is far away from the transmitter, the power reception declines quickly. Thus in resonance wireless power transmission, due to multi receiver connected platform the load which is closest to the transmitter circuit consumes high current and the load farthest will consume low current. This problem of wireless power distribution is recovered by using the impedance matching and electric current division strategy by designing the receiving devices with attachment of impedance inverters. A chance of several receivers and repeaters connected to a single transmitter coil is achieved by utilizing few arithmetic derivations proposed. These equations are easily understood by their similarities. By this proposal there is no need for changing the position of load to improve power transfer efficiency¹³.

The comparative study of the previous works based on the resonant coupling wireless power transmission is given in the Table 4.

Table 4. Comparative study on past works of resonant power transfer

Reference	Problem attempt to solve	Key contribution	Resolution	Performance analysis
[5]	Single base station for both data collection and power transfer in WSN	Automatic charging mobile vehicle	automatic vehicle travels in a road-map where the nodes are plotted and OPT-t transfers power for required nodes	OPT-s and OPT-t
[6]	Efficiency improvement in induction coupling	Multifrequency unwired power transmission system	Particular device which requires power will receive the electric current via the predefined channel, with respect to frequencies	-
[7]	The close and distant loads to the transmitter circuit receives the same energy	Impedance matching and electric current division strategy	Arithmetic derivations are proposed to utilize the connection of several repeaters and resonators	Power division method

5. Standards Used in WPT

There are several standards used in wireless charging based on the three types of power transmitting process. Most preferable wireless charging standards used worldwide are Qi, A4WP (Rezence) and PMA. Let discuss them in detail and their comparisons under the scope and features are given in the Table 5.

5.1 Qi or WPC (Wireless Power Consortium)

The Qi was the first introduced wireless charging standard in the year of 2008. This WPT standard works on the principle of magnetic induction. Qi is used to charge compatible devices such as mobile phones, tablets, etc. It is suitable in transferring 5W to 10W electric current to the load. The power transfer is established by using digital communications. The power transfer begins by simply placing the device over the charging pad. Few companies utilized this standard for charging their devices are Samsung, LG, Philips, Toyoto, Microsoft and Sony¹⁴.

5.2 PMA (Power Matters Alliance)

The PMA is similar to the Qi standard, both works on the principle of magnetic induction technique. In the year of 2012 PMA standard was introduced by Procter & Gamble and Powermat. This uses tightly coupled coils for charging the batteries of mobile devices. Likewise Qi, PMA also transfers power up to 5-10W. Some companies utilizes the principle of this standard are Powermat, Witricity, Flextronics, Teavana and FCC.

Table 5. Comparison on various standards on Wireless power transmission

Standard	Qi	PMA	A4WP
Principle	Magnetic Induction (Tight coupling)	Magnetic Induction (Tight coupling)	Magnetic Resonance (Loose coupling)
Communication Technique	In-Band	Bluetooth	In-Band
Frequency Range	110 – 205 kHz	277 – 357 kHz	6.78MHz for power transfer and 2.4GHz for control signals
Distance	5mm	5mm	50mm
Power Transmitted	Continuous	Continuous	Oscillated power signal
Products available in Market	Over 500 products and used in more than 60 cellular phone companies	1,00,000 powermats at starbucks	No product is launched, but combined with PWA

5.3 A4WP (Alliance Wireless Power)

A4WP was established in the year of 2012 by the Samsung and Qualcomm. This standard is also called resonance and is based on the principle of magnetic resonance, the transmitter and receiver coils are loosely coupled¹⁵. A4WP overcome the drawbacks on the previously defined standards such as a single load can absorb the power at the present time and placing the device over the source circuit. Multireceiver system is applicable in A4WP; several individual devices can absorb electric current wirelessly from the transmitter coil at the same time. Few companies took support of A4WP on their product are HTC, Intel, LG, Qualcomm, Samsung and Tedia Tek. It actively performs in various fields like industrial, scientific and medical environments.

6. Summary and Conclusion

WPT is deliberated as aspiration to the power source for growing mobile electronic devices and an inspiration

to the future technology. This study highlights different methodologies available for enabling wireless transmission of electricity, along with its history that presents the evolution, standards, advantages, disadvantages, scopes and limitations. The key working principle of WPT methodology was also emphasized. An extensive survey have also been made on the previous works carried out in this domain that performs transmission of power by using Induction coupling, resonant coupling and microwave transmission. The various components used for transmission, reception, number of such receivers used and the admissible frequency range, losses incurred are tabulated. The complexity of these approaches with their efficiency have also been analyzed and presented in the table. Recent trends and various standards available for wireless transmission strategies have been examined along with their performance implications. Most frequently adhered standards adopted by the leading companies in the market have also been identified and listed.

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