MANTECH Publications

Journal of Power Electronics and Drives
Volume 11, Issue 1, January-April 2026

# *Wireless Power Transfer and Contactless Energy Systems*

***Abhinav Kulkarni[1], Deepali Saxena[2]***

*Associate Professor[1], PG Scholar[2]*

*Department of ECE*

*Maharshi Dayanand University – Rohtak, Haryana*

***Corresponding Author Email:*** *Abhinavkulkarni161@gmail.com[1]*

***DOI:*** *https//doi.org/10.5281/zenodo.19279755*

## *ABSTRACT*

*Wireless Power Transfer (WPT) and contactless energy systems have gained considerable attention in recent years due to their ability to deliver electrical energy without physical connectors. From early experiments in electromagnetic induction to modern resonant coupling and microwave transmission systems, the technology has evolved significantly. This paper presents a comprehensive review of the principles, classifications, design considerations, recent advancements, and practical applications of wireless power transfer systems. The study discusses inductive, resonant inductive, capacitive, microwave, and laser-based power transfer techniques. Applications in consumer electronics, biomedical implants, electric vehicles, and industrial automation are examined. Key challenges such as efficiency, safety, misalignment, cost, and electromagnetic interference are also analyzed. A comparative analysis table is included to provide clear understanding of different methods. The paper concludes that although WPT systems are not yet replacing wired infrastructure fully, they are rapidly improving and likely to play a critical role in future smart grids, IoT ecosystems, and sustainable energy systems.*

***KEYWORDS:*** *Wireless Power Transfer, Contactless Energy Systems, Inductive Coupling, Resonant Coupling, Microwave Power Transmission, Electric Vehicle Charging, Energy Efficiency*


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

## INTRODUCTION

The idea of transferring electrical energy without wires has fascinated researchers for more than a century. Conventional energy transmission relies on conductive wires, which suffer from losses, wear and tear, and safety issues in certain environments. Wireless Power Transfer (WPT) provides an alternative method where electrical energy is delivered through electromagnetic fields instead of direct physical connection.

Contactless energy systems are especially useful in situations where connectors are impractical, dangerous, or expensive to maintain. For example, implanted medical devices, underwater sensors, rotating machinery, and electric vehicle charging systems benefit greatly from wireless solutions.

In recent years, rapid development in power electronics, semiconductor materials, and control systems has accelerated research in WPT technologies. Improvements in switching devices such as MOSFETs and GaN transistors have allowed higher frequencies and better efficiency. Although still facing limitations in long-distance high-power transmission, WPT has become commercially viable for short-range applications like smartphone charging pads.

This paper reviews fundamental concepts, classifications, technical challenges, and emerging trends in wireless power and contactless energy systems.

## HISTORICAL BACKGROUND

The concept of wireless power transfer is not a completely new idea; in fact, its roots go back more than a hundred years. The foundation was established in the late 19th century when scientists began to understand the relationship between electricity and magnetism. The formulation of Maxwell’s electromagnetic theory by James Clerk Maxwell provided the mathematical explanation of how electric and magnetic fields propagate through space. His equations proved that electromagnetic waves could travel without a physical medium, which indirectly opened the possibility of transmitting energy wirelessly.

One of the most important early contributors to wireless power concepts was Nikola Tesla. In the 1890s, Tesla conducted several experiments demonstrating high-frequency alternating currents and resonant transformer systems, commonly known as Tesla coils. He envisioned a


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

global wireless energy transmission system that could deliver power over long distances without wires. His ambitious Wardenclyffe Tower project was designed to transmit both information and power through the Earth's atmosphere. Although the project was never completed due to financial and technical limitations, it inspired future generations of researchers.

During the same period, the invention and development of transformers significantly influenced wireless power studies. Transformer theory, based on electromagnetic induction, demonstrated how energy could be transferred efficiently between coils without direct electrical connection. This principle later became the backbone of modern inductive wireless charging systems. However, early technologies were limited by low efficiency, bulky components, and insufficient understanding of high-frequency power electronics.

In the early 20th century, research focus gradually shifted toward radio frequency (RF) and microwave technologies. The invention of vacuum tubes and later semiconductor devices allowed generation of higher frequency electromagnetic waves. During the 1960s and 1970s, microwave power transmission experiments were actively studied, especially in the United States and Japan. Scientists explored the possibility of transmitting power from space-based solar panels to Earth using microwave beams. The concept of the rectifying antenna (rectenna), which converts microwave radiation into DC electricity, was introduced and experimentally demonstrated. Although large-scale implementation was not realized, these experiments proved that long-distance wireless power transmission was technically feasible.

Another significant milestone was the development of contactless charging systems for low-power consumer products in the late 20th century. Electric toothbrushes became one of the earliest commercial examples of inductive charging. These devices used sealed enclosures and avoided exposed metal contacts, making them safe in wet environments such as bathrooms. This practical success demonstrated that wireless charging could solve real-world problems.

The rapid miniaturization of electronic components in the 1980s and 1990s, driven by advances in semiconductor technology, further increased interest in wireless energy solutions. Portable electronics such as mobile phones, pagers, and early laptops created demand for convenient and reliable charging methods. However, battery technology and power management circuits


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

at that time were still limited, so wired charging remained dominant.

A major breakthrough occurred in 2007 when researchers at the Massachusetts Institute of Technology experimentally demonstrated efficient mid-range wireless power transfer using strongly coupled magnetic resonance. In their experiment, a 60-watt light bulb was powered over a distance of about two meters with relatively high efficiency. This demonstration revived global interest in resonant inductive coupling and proved that energy could be transferred efficiently beyond very short distances. It also showed that resonance significantly improves performance compared to simple inductive coupling.

Following this milestone, research and industrial development accelerated rapidly. International standardization efforts began to ensure compatibility among devices. Organizations such as the Wireless Power Consortium introduced the Qi standard, which became widely adopted for smartphone charging. This allowed interoperability between chargers and devices from different manufacturers, encouraging mass adoption.

Over the last two decades, wireless charging technology has transitioned from laboratory prototypes to mainstream commercial products. Smartphones, smartwatches, wireless earbuds, and wearable health trackers now commonly use short-range inductive charging pads. Automotive manufacturers have also started integrating wireless charging systems for electric vehicles. These systems typically operate at kilowatt power levels and use resonant inductive coupling to achieve higher efficiency even with slight misalignment.

In the biomedical field, wireless power has enabled significant improvements in implantable medical devices. Pacemakers, cochlear implants, and neural stimulators benefit from transcutaneous energy transfer, reducing the need for repeated surgical battery replacements. This advancement has improved patient comfort and device longevity.

Recent research is focusing on dynamic wireless charging for electric vehicles, where coils embedded in roadways can charge vehicles while they are moving. In addition, drone energy replenishment systems using wireless pads are being developed to enable autonomous landing and charging cycles. These systems could support applications such as surveillance, delivery services, and disaster monitoring.


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

In summary, the historical development of wireless power transfer reflects a gradual progression from theoretical electromagnetic principles to practical consumer and industrial applications. Early visionary experiments laid the groundwork, mid-20th century microwave studies expanded the possibilities, and modern power electronics and materials science have transformed WPT into a commercially viable technology. The field continues to evolve, with ongoing research aiming to increase efficiency, range, and safety while reducing cost and complexity.

## FUNDAMENTAL PRINCIPLES OF WIRELESS POWER TRANSFER

Wireless Power Transfer (WPT) is mainly based on the interaction of electromagnetic fields between a transmitting unit and a receiving unit. Instead of using metal conductors to carry current, WPT systems use time-varying electric or magnetic fields to deliver energy across an air gap or even larger distances. The performance of the system strongly depends on the operating frequency, transmission distance, alignment between transmitter and receiver, and environmental conditions.

The mechanism of energy transfer changes depending on whether the system operates in the near-field region (non-radiative) or far-field region (radiative). Near-field techniques are typically used for short distances and rely on magnetic or electric coupling, while far-field methods use electromagnetic waves that propagate through space.

## ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the most basic and widely used method for wireless power transfer. It is based on Faraday’s law of electromagnetic induction, which states that a changing magnetic field within a closed loop induces an electromotive force (EMF) in that loop. This principle was experimentally demonstrated by Michael Faraday in 1831, forming the backbone of transformer theory.

In an inductive WPT system, alternating current (AC) flows through a primary coil (transmitter coil). This AC creates a time-varying magnetic field around the coil. When a secondary coil (receiver coil) is placed within this magnetic field, a voltage is induced across it. If the secondary circuit is connected to a load, current flows and power is delivered.


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

Wireless chargers for smartphones and small electronic devices operate on this principle. Essentially, they function as loosely coupled transformers where the magnetic core is replaced by air. Because air has much lower magnetic permeability than iron cores, the coupling between coils is weaker, which reduces efficiency compared to conventional transformers.

The efficiency of inductive coupling depends on several factors:

- **Coupling coefficient (k):** Represents how much magnetic flux from the transmitter links to the receiver. A higher value means better energy transfer.
- **Coil alignment:** Misalignment reduces magnetic flux linkage and decreases efficiency.
- **Operating frequency:** Higher frequency can improve power transfer but increases switching losses.
- **Quality factor (Q-factor):** A higher Q-factor indicates lower energy losses in the coil.

Inductive systems are highly reliable and safe for short distances, typically a few millimeters to a few centimeters. However, efficiency drops rapidly as the gap increases.

**RESONANT INDUCTIVE COUPLING**

Resonant inductive coupling is an improved form of inductive power transfer that allows energy transfer over relatively longer distances with higher efficiency. This method uses the concept of resonance in electrical circuits.

A resonant circuit consists of an inductor (L) and a capacitor (C) connected in such a way that energy oscillates between magnetic and electric fields at a particular frequency called the resonant frequency. When both the transmitter and receiver circuits are tuned to the same resonant frequency, strong energy exchange occurs even if the coupling is weak.

The resonant frequency is given by:

f=12πLCf = \frac{1}{2\pi\sqrt{LC}}f=2πLC1

At resonance:

- Reactive power is minimized.
- Voltage and current can increase significantly.
- Energy transfer becomes more efficient compared to non-resonant systems.


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

A major experimental demonstration of resonant coupling was performed by researchers at the Massachusetts Institute of Technology in 2007, where power was transferred over a distance of about two meters using strongly coupled magnetic resonance. This experiment showed that mid-range wireless power transfer is practically achievable.

Resonant inductive coupling is widely used in:

- Electric vehicle wireless charging systems
- Industrial robotics
- Biomedical implants
- Consumer electronic charging pads

Although more complex than simple inductive coupling, it provides better tolerance to misalignment and moderate distance variations.

**CAPACITIVE COUPLING**

Capacitive power transfer (CPT) works on the principle of electric field coupling rather than magnetic field coupling. In this method, two conductive plates form a capacitor at the transmitter side, and corresponding plates form another capacitor at the receiver side. When high-frequency AC voltage is applied to the transmitter plates, a displacement current flows through the electric field between the plates and induces voltage at the receiver.

Unlike inductive systems, capacitive systems do not require bulky coils. However, they generally require higher operating frequencies to achieve reasonable power transfer levels. The coupling capacitance is usually small, which limits power capability.

Advantages of capacitive coupling:

- Lightweight structure
- No magnetic materials required
- Reduced electromagnetic interference in certain conditions

Limitations:

- Sensitive to plate spacing
- Lower power handling capability
- Electric field exposure concerns


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

Capacitive systems are mostly used in low-power applications such as sensor networks and small electronic modules.

## MICROWAVE POWER TRANSMISSION

Microwave power transmission (MPT) is a far-field wireless power technique that uses electromagnetic waves in the microwave frequency range (typically GHz range). In this system, electrical energy is first converted into microwave radiation using an oscillator and power amplifier. The microwave energy is transmitted via a directional antenna toward a receiving antenna known as a rectenna (rectifying antenna).

The rectenna converts the received microwave signals back into DC electricity using diode rectifiers. The concept of microwave transmission was explored extensively in the 20th century, especially for space-based solar power systems.

Advantages:

- Suitable for long-distance transmission
- Can transfer high power levels
- Potential for space-to-earth energy transmission

Limitations:

- Requires precise line-of-sight alignment
- Atmospheric attenuation
- Safety and radiation exposure concerns
- Lower overall system efficiency compared to near-field methods

Microwave transmission remains mostly in experimental or specialized applications due to these challenges.

## LASER-BASED POWER TRANSFER

Laser-based wireless power transfer is another far-field technique. In this method, electrical energy is converted into a coherent laser beam using laser diodes or solid-state lasers. The beam is directed toward a photovoltaic (PV) receiver that converts light energy back into electrical energy.


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

Laser systems can achieve very long transmission distances and high directionality. Because laser beams are highly focused, they can deliver energy to specific targets with minimal spread. This makes them suitable for applications like powering unmanned aerial vehicles (UAVs), satellites, or remote sensors.

However, there are several significant concerns:

- Safety risks due to high-intensity beams
- Atmospheric absorption and scattering
- Conversion losses in both laser generation and photovoltaic reception
- Need for accurate tracking systems

Overall system efficiency is often limited by multiple energy conversion stages (electrical → optical → electrical).

## CLASSIFICATION OF WIRELESS POWER TRANSFER SYSTEMS

Wireless power systems can be classified based on distance and technology.

**1. Near-Field Techniques**

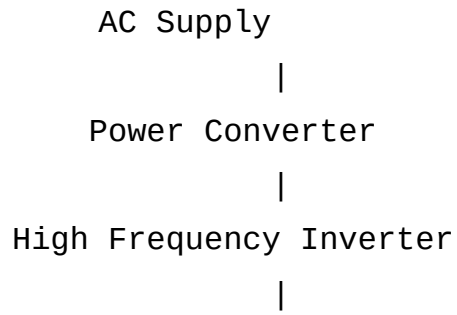
- Inductive coupling
- Resonant inductive coupling
- Capacitive coupling

**2. Far-Field Techniques**

- Microwave transmission
- Laser power transfer

## SYSTEM ARCHITECTURE

A typical wireless power transfer system consists of the following blocks:





Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

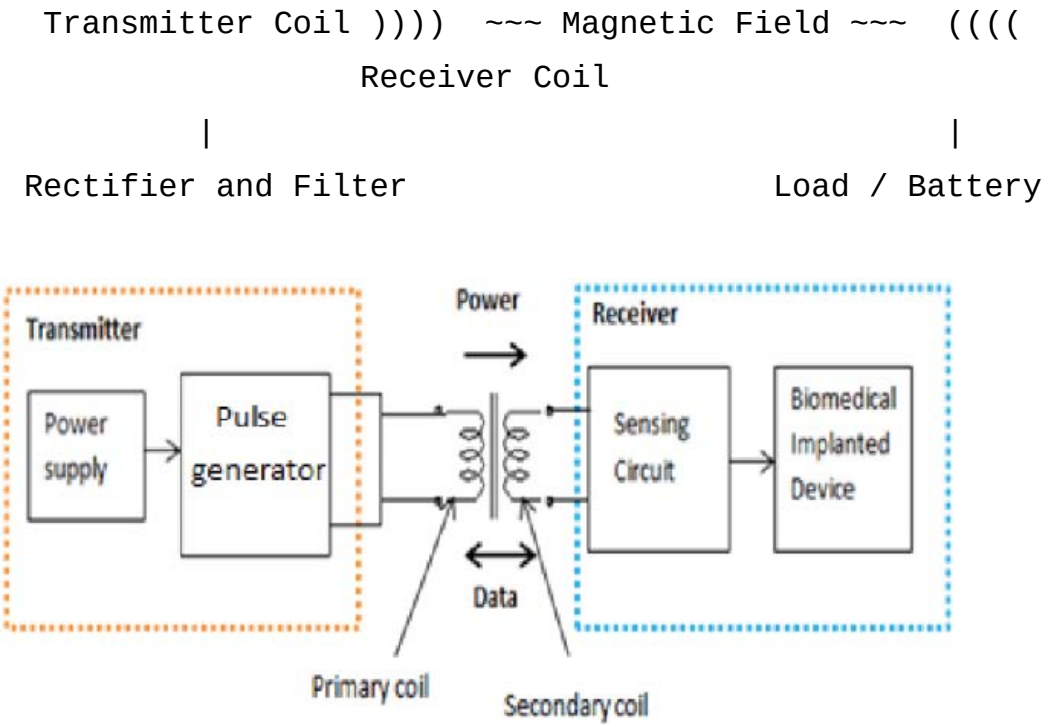



***Figure 1: Basic Block Diagram of Inductive Wireless Power System***

The inverter converts DC to high-frequency AC to reduce coil size and increase efficiency. On the receiver side, rectifier and filter convert AC back to DC for charging the battery or powering load.

## DESIGN CONSIDERATIONS

Design of a WPT system requires optimization of several parameters:

### 1. Frequency Selection

Higher frequencies allow smaller coil size but increase switching losses and electromagnetic interference.

### 2. Coil Geometry

Coil shape, number of turns, wire gauge, and spacing influence coupling coefficient and efficiency.

### 3. Compensation Networks

Series or parallel compensation capacitors are used to achieve resonance and reduce reactive power.

### 4. Efficiency

Overall efficiency depends on:

- Power electronics efficiency


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

- Magnetic coupling
- Rectifier losses
- Alignment accuracy

**5. Safety Standards**

Human exposure to electromagnetic fields must remain within safety limits. Shielding and frequency regulation are important.

## COMPARATIVE ANALYSIS OF WPT TECHNIQUES

***Table 1: Comparison of Wireless Power Transfer Methods***

| Technique | Range | Efficiency | Power Level | Complexity | Applications |
|---|---|---|---|---|---|
| Inductive Coupling | Few cm | 70–90% | Low-Medium | Low | Phone charging |
| Resonant Inductive | Up to 1 m | 60–85% | Medium | Medium | EV charging |
| Capacitive Coupling | Few cm | 50–70% | Low | Medium | Sensors |
| Microwave Transmission | Long distance | 40–70% | High | High | Space solar power |
| Laser Power Transfer | Long distance | 30–60% | Medium | High | Drones |

From the table it is clear that near-field methods provide higher efficiency at short distances, while far-field methods are better suited for long-range but lower efficiency scenarios.

## APPLICATIONS OF WIRELESS POWER TRANSFER

**1. Consumer Electronics**

Wireless charging pads for smartphones and wearable devices are now widely available. These systems eliminate wear on connectors and improve user convenience.

**2. Electric Vehicles**

Contactless EV charging is a rapidly growing area. Static charging pads installed in garages or parking spaces allow automatic charging without cables. Research on dynamic charging


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

(charging while vehicle is moving) is ongoing.

### 3. Biomedical Implants

Implantable devices such as pacemakers and neural stimulators require reliable power sources. Wireless charging reduces need for surgical battery replacement.

### 4. Industrial Automation

Rotating machinery and robotic arms benefit from contactless power transfer as it avoids mechanical wear of slip rings.

### 5. Internet of Things (IoT)

Small sensors in remote or hazardous environments can be powered wirelessly, reducing battery replacement frequency.

## ADVANTAGES AND LIMITATIONS

### 1. Advantages

- Eliminates physical connectors
- Reduced maintenance
- Enhanced safety in wet or hazardous conditions
- Improved user convenience
- Enables sealed and compact designs

### 2. Limitations

- Efficiency decreases with distance
- Alignment sensitivity
- High initial cost
- Electromagnetic interference
- Safety concerns at high power

Though the technology is promising, these limitations must be addressed for wider adoption.

### 3. Recent Advances

Recent research focuses on:

- Use of gallium nitride (GaN) devices for high frequency operation


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

- Adaptive impedance matching
- Multi-coil systems to reduce misalignment effects
- Magnetic shielding materials
- Integration with renewable energy systems

Machine learning algorithms are also being used to optimize tuning and load adaptation in real time.

## CHALLENGES AND FUTURE SCOPE

Wireless power transfer still faces engineering challenges.

1. **Distance vs Efficiency Trade-off** – Increasing distance reduces coupling.
2. **Standardization Issues** – Multiple standards create compatibility problems.
3. **Thermal Management** – High power systems generate heat.
4. **Economic Feasibility** – Infrastructure cost is high for large-scale deployment.

Future research may focus on:

- Smart grid integration
- Road embedded charging coils
- Wireless powered drones
- Underwater wireless energy networks

If these developments continue, WPT systems could become part of daily infrastructure in coming decades.

## CONCLUSION

Wireless Power Transfer and contactless energy systems represent an important shift in energy distribution technology. From small electronic devices to electric vehicles and industrial automation, the demand for cable-free power solutions is increasing. Near-field inductive systems are already commercially successful, while far-field methods are still under research for practical large-scale implementation.

Although there are limitations in efficiency, cost, and safety, continuous improvements in power electronics, magnetic materials, and control strategies are making wireless systems more


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved

reliable. In future smart cities and IoT ecosystems, contactless energy transfer will likely become common infrastructure. The technology is not meant to fully replace wired transmission, but to complement it where flexibility and safety are required.

Overall, wireless power transfer is evolving from an experimental concept to a realistic engineering solution, and further interdisciplinary research is necessary to overcome existing challenges.

**REFERENCES**

1. Kurs, A., Karalis, A., Moffatt, R., et al., “Wireless Power Transfer via Strongly Coupled Magnetic Resonances,” Science Journal, 2007.
2. Sample, A. P., Meyer, D. A., and Smith, J. R., “Analysis of Resonant Inductive Coupling,” IEEE Transactions on Industrial Electronics, 2011.
3. Covic, G. A., and Boys, J. T., “Modern Trends in Inductive Power Transfer,” IEEE Journal of Emerging Technologies, 2013.
4. Shinohara, N., “Power Without Wires,” IEEE Microwave Magazine, 2014.
5. Zhang, W., Mi, C. C., “Compensation Topologies in Wireless Power Transfer Systems,” IEEE Transactions on Power Electronics, 2016.
6. Lu, X., Wang, P., Niyato, D., et al., “Wireless Charging Technologies: Fundamentals and Applications,” IEEE Communications Surveys & Tutorials, 2018.
7. Bi, Z., Kan, T., Mi, C., et al., “A Review of Wireless Power Transfer for Electric Vehicles,” IEEE Transactions on Industrial Informatics, 2019.
8. Liu, C., Chau, K. T., Wu, D., Gao, S., “Opportunities and Challenges of Wireless Power Transfer,” Renewable and Sustainable Energy Reviews, 2020.
9. Ahmad, S., Alam, M., Chabaan, R., “Review of Inductive Power Transfer Systems for EV Charging,” Energies Journal, 2021.
10. Kumar, P., and Singh, R., “Recent Advances in Contactless Energy Systems,” International Journal of Power Electronics, 2022.

**Cite as:**

Abhinav Kulkarni, Deepali Saxena. (2026). Wireless Power Transfer and Contactless Energy Systems. Journal of Power Electronics and Drives. 11(1), 45-58. https//doi.org/10.5281/zenodo.19279755


Page 45-58 © MANTECH PUBLICATIONS 2026. All Rights Reserved