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A Comparative Analysis and Review of Application Prospects of Wired and Wireless Power Transmission Technologies

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Abstract. Power transmission technology is crucial to modern society. Wired and wireless transmission technologies have their own advantages and complement each other. Wired transmission relies on physical conductors. After a century of development, it has formed a mature system with large capacity and high reliability. It is the backbone of the current power grid, which can realize long-distance and large-scale power transmission, but also faces challenges such as line loss and corridor occupation. Wireless transmission uses electromagnetic induction, magnetic resonance and other principles to get rid of the limitations of cables and has excellent flexibility. It is suitable for power supply of mobile device and special environments, but there are still problems such as efficiency decreases with distance and electromagnetic safety. The two are not to replace each other, but will be deeply integrated in the future to build an intelligent transmission network of "wired backbone + wireless access". This integration will expand its application in electric vehicles, the Internet of Things, medical care and other fields, and contribute to the global energy transformation and the realization of the "dual carbon" goal.

Keywords: Wired Power Transmission, Wireless Power Transmission, Power Transmission Technology, Energy Transmission System, Wireless Charging Application

1. Introduction

Today's world is electrically powered by electricity and it is the most important source of power for any developed world. The proper, safe, and efficient transfer of such energy is an important component for the economy as well as day-to-day life [1,2]. Although traditional cabled power transmission networks have been developed more than one century to provide safe and reliable grid connectivity ,newer wireless energy transfer techniques, which is changing the game [3].

Traditional power delivery systems use tangible electrical connections to transmit electric energy between power producers and consumers. Traditional grid technologies have high capacity and reliability,which constitutes the backbone of current power grids [4]. On the other hand, WPT uses electromagnetic effects such as inductance, magnetic resonance,and microwaves for wireless power transfer at short-to-moderate distances [5].

This study proposes novel approaches to provide power to mobile electronic devices and enable device operation under special conditions [6,7]. This paper will provide an overview on the principles, properties, state-of-the-art applications, as well as limitations for wired and non-wired

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electrical energy transmission technologies; it will also investigate their possible integration and development trends for future smart grid systems.providing meaningful direction to both technological deployment and policy choices [8].

2. Wird power transmission technology

Conductors electricity distribution means transport of generated electric energy on the grid, then distributed to customers via metal wires (or cable with insulation). That is how it's done since at least the late nineteenth century,that provide power for much of our modern electric grid [4]. its main attraction is its capacity for transmitting large volumes of electric power great distances at high voltage,which is now the predominant means of delivering electric power throughout the globe [9].

2.1. Basic principles and structure

Power systems are mainly composed by plants, transmission lines and transformers,and distribution networks to consumers [4]. Power plants transform many types of primary energy sources like coal, hydropower,and nuclear energy for electrical generation.The power is then stepped up by means of a transformer to higher and very high voltages,reducing the amount of energy that needs to be dissipated in transmitting it [7] .

The types of conductive paths include overhead lines (OH) and underground cables (UC) [9]. OH lines are strung over the ground by means of poles,while landmines and antipersonnel mines lie on the ground or under soil, sand, mud, water, or ice, respectively, and all have unique technological features which render them suitable in particular circumstances.Higher voltage line reduces amperage and since Q=I2Rt , it is a square law relationship,significantly reduces the losses in power transfer [7].

During this delivery step, substation transformers are used for voltage control purposes and for distributing electric energy [4]. Transformers reduce transmission voltages to low-more usable levels for consumer applications.

Transformers are used in the electric power system to raise or lower voltages as required by end-users,while the protection switching is applied for detecting and isolating the faults in systems for maintaining network's reliability and security [9].

2.2. Key technical features

Wired power transmission is characterized by high capacity, high stability, and high reliability [4]. First, its transmission capacity is almost not limited by distance. By increasing the voltage level and using split conductors, it can achieve power transmission at the level of several gigawatts [9]. Second, due to the stability of the physical connection, the quality of electric energy transmitted by wired means (such as frequency, voltage harmonics) is easy to control and can meet the high-reliability power needs of both industrial and residential users [4]. In addition, with the progress of material science and manufacturing processes, the conductor materials (such as steel-cored aluminum stranded wire, carbon fiber composite core conductor) and insulating materials of modern transmission lines are continuously optimized, which significantly reduces line resistance and environmental losses [10]. The application of smart grid technologies, such as Wide Area Measurement Systems (WAMS), Flexible AC Transmission Systems (FACTS), and High Voltage Direct Current (HVDC) transmission, has further enhanced the flexibility, controllability, and transmission efficiency of wired transmission systems [9].

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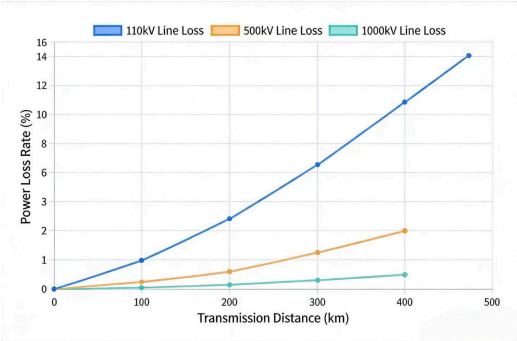


Figure 1. Schematic diagram of relationship between transmission distance at different voltage levels

2.3. Challenges faced

Although wired power transmission technology is mature, it still faces many challenges during long-distance and large-scale transmission [4]. First, line losses are inevitable physical phenomena, including resistive losses, corona losses, and insulation losses, among which resistive losses increase significantly with the square of the current [7]. Second, the occupation of transmission corridors and the impact on the environment are important limiting factors, especially in ecologically sensitive areas, where line construction needs to balance economic considerations with environmental protection [9]. In addition, extreme weather and natural disasters (such as lightning strikes, ice coating, and typhoons) pose a serious threat to the safe operation of transmission lines, requiring the use of advanced monitoring and protection technologies [10]. Finally, with the large-scale integration of renewable energy, the traditional unidirectional power flow transmission system needs to evolve towards a bidirectional, flexible smart grid, which puts higher demands on the upgrading and transformation of existing infrastructure [8].

3. Wireless power transmission technology

Wireless power transfer technology refers to the transmission of electrical energy from a transmitter to a receiver without the use of physical conductors, using media such as electromagnetic fields or electromagnetic waves [5-11]. In recent years, this technology has developed rapidly and is regarded as an important component of the future energy internet, offering flexible and convenient power solutions for mobile devices, special environments, and distributed energy systems [12].

3.1. Basic principles and classification

There are essentially three ways of transferring wireless energy namely, electromagnetic induction [3], resonance-based magnetic coupling [13] and far-field radiation approaches [5-11]. EM induction relies on an oscillating magnetic field inducing a current within the receiving coil,enabling wireless power transfer in the very short-range regime (typically, a few mm up to cm) [3].This is the most common method used in current industry such as mobile phone chargers or electronic brushes [12]. The principle of resonance magnetic coupling is to make resonant circuits with the same frequency on both sides for the transmitting coil and receiving coil,where the coupling is very effective for intermediate distances (a few cm to a few m), if both coils oscillate with same frequency [5-11]. In turn, long range radiative techniques are based on focused EM wave (microwave antenna or laser

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beam) transport of power at larger distance (up to few kilometers),although they tend to be less efficient, requiring higher technology levels [13].

Wireless Power Transfer (WPT) is classified as a nearfield or far-field system depending on the frequencies used and the distance from the transmitter to receiver [3]. Nearfield systems typically operate with low-power, short-range,high-efficiency near-field coupling, whereas the latter is used for specific applications that require longer distance and lower power [14].

3.2. Key technical features

The advantages of WPT are mainly flexibility and ease-of-use since it does not require any plug-in:this technology enables continuous charging of mobile devices and electric vehicles, drones,and smart wearables [12]. These features render it an enabling technology of the upcoming "Mobile Energy Network" idea [6-8]. for special-purpose situations like underwater and underground systems or in medical equipment,wireless energy systems can be considered as a solution that overcomes all disadvantages associated with traditional wire-based approaches such as the lack of electrical isolation,maintenance; and safety of operation [11].

With advances in materials technology [11], circuit design, and control strategies, recent research on WPT has significantly improved efficiency and reliability for wireless charging applications [12]. Recent MR designs have reported theoretical efficiencies greater than 80% [13]. Some efficient techniques are using low-loss resonators, [3-14]. advanced winding topologies, and active impedance tuning techniques [14].

The recent advances in technology that enables multiple devices to be charged from a single wireless source, and power transfer independent of relative device location, have significantly increased the applicability of wireless power transfer for practical applications [12] .

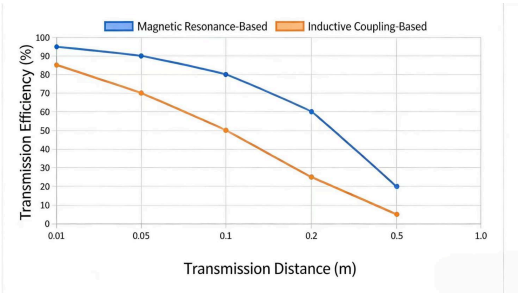


Figure 2. Comparison of efficiency variations with transmission distance for different wireless power transfer technologies

3.3. Challenges faced

The wireless powering technology has tremendous potential but many challenges still need to be overcome [12]. When increasing the distance between a transmitter and a receiving coil,there is a significant loss of energy coupling efficiency as a result of basic physics constraints, and for off-resonant operation,the performance is poor due to large losses and heat dissipation [5].

Additionally, there are some important issues such as EM disturbance and health hazards [11]. High-frequency radiation produces intense EM field which can disturb other electrical appliances in the vicinity and pose threat to humans' health,requiring strict compliance with international safety standards like the ICNIRP guidelines [3].

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A second level is the technical challenge for frequency and power control at many devices,foreign object detection, and coordinated charging of multiple devices—all challenges that need to be addressed before wider deployment is possible [14].

Finally, there are some economic and standardisation challenges: Advanced wireless power transfer systems remain costly,and that better standardisation would be necessary in order for this technology to become more widely adopted [15].

Interoperability between different producers and specs (Qi vs. AirFuel) also has its own implications [12].

4. Comparison between wired and wireless power transmission technologies

The differences between the wired and wireless power transfer technologies are quite significant from a conceptual point of view , performance ,real-world applications, and challenges that arise in real life scenarios [8]. They are not necessarily alternatives of each other but rather complementing each others for better performance [1].

4.1. Comparison of principles and performance

Conventional cable-based power transmission relies on electric current flowing through conductors to deliver electrical energy [4]. In practical applications, its transmission efficiency can reach approximately 95%, and the transmission distance has only a marginal impact on efficiency [9]. By contrast, wireless power transfer is based on magnetic field coupling, and its performance is constrained by multiple factors, including transmission distance, relative alignment, and operating frequency [5]. For short-range transmission on the order of centimeters, wireless power transfer can achieve efficiencies of around 80%; however, when the transmission distance increases to the meter scale, the efficiency typically drops to below 20% [13]. Although wireless power transfer exhibits lower efficiency compared with wired methods, it offers several distinctive advantages, such as ease of installation and reduced dependence on environmental conditions, which are difficult to achieve with conventional transmission technologies [12].

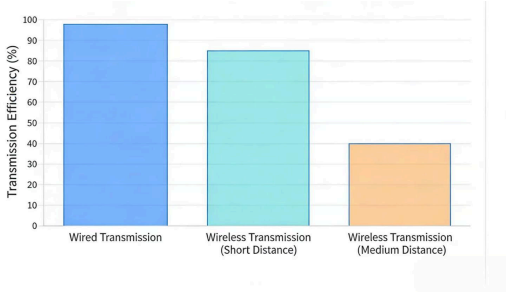


Figure 3. Comparison of power transmission efficiency between wired and wireless transmission

4.2. Comparison of application scenarios

Tightly-coupled power transfer is best suited to large scale point-to-point electrical grid applications [4], for example, urban electrical grids or regional transmission lines. They are robust in capacity and reliable so they can keep businesses running and homes electrified [9]. On the other hand, wirelessly transferring energy is more suitable to use in distributed or mobile power scenarios, including wireless charging of personal electronics as well as portable or fixed-base EV chargers, energising medical implants, and powering connected sensor networks in the Internet of Things

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(IoT) applications [12]. In smart home applications, wireless energy transmission can be a convenient way of charging cell phones, tablets and wearables [3]. For electric cars, there are touchless chargers for automatic recharging.stationary charging and even charging while vehicles are in motion, significantly improving customer convenience [6]. In biomedical systems, wireless power transfer enables continuous functioning of implanted medical devices including pacemakers and cochlear implants [11], thus avoiding repeated surgery required for battery replacement.

Requirement for periodic surgical replacement of the energy source.

4.3. Comparison of economic efficiency and reliability

Wired power distribution involves substantial costs in wiring infrastructures, but is more economically efficient in moving power over greater distances and carrying higher quantities of electric output [4]. Conventional transmission lines are also long-lived and relatively cheap to maintain [9].In near-term and low power use cases, such as close-range WET systems, cost-effective designs for implementing WET are becoming available, largely as a result of lower costs from scale production and ongoing technology advances [12], but for very long transmission ranges or extremely large power demands, wireless solutions are not yet cost-effective compared to wired counterparts [15]. In terms of reliability,wireline power transfer has mature standards in systems engineering and operations,and maintenance over more than one century of evolution leading to excellent service reliability [4]. On the other hand,wireless power transfer that is still rather new and requires more field testing prior to being deemed trustworthy enough for extended use [13].

5. Application prospect and future development trend

A further development is integration of wired and wireless charging technologies [1]. As global smart grids and electric power systems are being developed,the two different strategies will complement each other in most respects [8].

5.1. Trend toward technological integration

In future power networks, we expect that wired and wirelessly communication technologies will be fully integrated [3]. In power grid applications,existing high-voltage alternating current (HVAC) or direct current (HVDC) powerlines will be integrated with wireless power transmission networks to create an overall topology referred to as "wired backbone and wireless edge" [1]. In smart grid communities for example, traditional power lines provide uniform baseline power to all residents in a neighborhood [4], whereas wireless chargers placed, for example, at parking spots or on roads can be used to charge mobile phones flexibly, especially electric vehicles [6]. Fixed robots are connected directly to the grid via cables, whereas mobile or free-running machines get their electricity from wireless transmission [6,7]. thus also enhancing operable flexibility and automation of the production processes [8].

With the development of electronics and telecommunications, we are moving toward smart grid technology that can automatically control how electric energy is distributed by routing it as needed:external environment, and economy indexes which will optimize the whole system [9] .

5.2. Emerging application scenarios

Wireless energy transfer (WET) is expected to play a key role in several emerging applications [12]. In the context of electric vehicle, roadway-based dynamic wireless energy transfer, which involves

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the installation of inductive loops on roadways to charge moving vehicles, is considered one way to alleviate range anxiety [3-14]. Several demonstration projects or field tests have been implemented around the globe [3-8].In smart homes or the Internet-of-Things (IoT), with many distributed sensors and edge nodes, perpetual operation is possible via scavenged energy, which may result in free-standing self-sustaining networks [12]. In aerospace and space applications, WET can be used to power satellites in orbit, spacecrafts, and drones without having to save electric power inside a battery [13]. Contactless power transfer is also useful in medicine, where it can offer a reliable and convenient means for providing power to an implant or some other medical instrument [3].

5.3. Policy and standards support

Several nations around the world have identified wireless power as a matter of national interest for which they enact policy and regulation to encourage progress on the technology [2]. For instance, China,the United States, and the European Union (EU) have all made explicit references to wireless charging infrastructure as part of smart grid initiatives [8] ,making it a core part of the way we pursue clean energy [2].International organizations such as the International Electrotechnical Commission (IEC), are currently updating international wireless charging standards [12], where the Qi protocol is now universally accepted for use in personal electronics and meanwhile evolving standards are being developed that can support higher power levels,increased range of operation, and improved operating safety [14]. In addition to these issues, efficient allocation and management of the available frequencies is also an important aspect in order to make large scale adoption of wireless power transmission possible [11].

Spectrum must be allocated efficiently by the government so as to minimize interference among different types of wireless communications [12].

6. Conclusion

Wireless and wireline power transmission both have advantages [1]. Traditional electrical grid,is strong, sturdy, and durable, so that is why it has become an everyday feature in todays' world [4]. By contrast,wireless power transmission offers flexible, convenient options that change the way in which electricity is delivered [12]. The above two directions are not necessarily competing paths to a solution, but complementary building blocks of future energy systems [8]; with further advances in materials science,electronic power conversion, digital communications, and automatic control schemes will continue to improve the efficiency and reliability of wireless power transmission [13]. Its application will not only extend to individual portable electronics but also critical areas such as industry,vehicles, transportation networks, healthcare etc [11]. Future power grids will be able to integrate wireline and wireless technologies seamlessly,enabling efficient, flexible, secure power flow [1].

Smart power grid is an important way to achieve global energy revolution [9], the goal of reducing carbon dioxide emissions can be achieved by using smart power grid technology provides strong support to reach the peak of carbon dioxide emissions and carbon neutral goals [2]. It is recommended that industry stakeholders remain aware of future trends for technology adoption, participate actively in standards development and market deployment processes so as to facilitate further advances in transmission technologies [8].

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References

[1] Ming Chatang. Principles and Processes of Electric Power Transmission [J]. Electronic Technology, 2024.
[2] Xuan Xin Wei Technology. AC Power and Power Transmission Efficiency: An Introduction to Key Influencing Factors [J]. Electronic Technology, 2025.
[3] ResearchGate. Output performance of the wireless power transfer [EB/OL]. 2013.
[4] Scientific.Net. Wireless Power Transmission [M]. 2023.
[5] Cui S X, Zhang Z J, Liang X M. Characteristic Research on Wireless Power Transfer Based on Magnetic Coupling Resonant [J]. Scientific.Net, 2021.
[6] Electronic Technology Applications. Issues Related to Wireless Charging for Electric Vehicles [J]. 2015.
[7] Institute of Wireless Power Transfer Technology, Chongqing University. A Method for Achieving Wide-Range Zero-Voltage Switching in Magnetically Coupled Wireless Power Transfer Systems [J]. 2025.
[8] IJRET. An Overview of Technological Advancements and Future Possibilities in Wireless Power Transmission [J]. 2013.
[9] MATLAB Answers. Wireless power transfer efficiency [EB/OL]. 2023.
[10] Nature. Scientific Reports. Wireless power transmission system with enhanced efficiency by using frequency reconfigurable metamaterial [J]. 2021, 11(5): 898.
[11] Cannon B L, Hoburg J F, Stancil D D, et al. Magnetic Resonant Coupling As a Potential Means for Wireless Power Transfer to Multiple Small Receivers [J]. IEEE Transactions on Power Electronics, 2009.
[12] Nature Electronics. Body-coupled power transmission and energy harvesting [J]. 2021, 4(6): 562-567.
[13] ResearchGate. How do I improve the efficiency of a wireless power transmission system? [EB/OL]. 2023.
[14] arXiv. SwinFi: a CSI Compression Method based on Swin Transformer for Wi-Fi Sensing [EB/OL]. 2024.
[15] ResearchGate. A cost-effective system for wireless power transmission [M]. 2013.