ТРАНСПОРТНІ ТЕХНОЛОГІЇ (ЗА ВИДАМИ)

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EMERGING TECHNOLOGIES AND APPLICATIONS OF WIRELESS POWER TRANSFER

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Summary

Wireless power transfer (WPT) has made significant progress in becoming a feasible option for several applications since its first development. The primary objective of this article has been on magnetic resonant coupling (MRC), which is a kind of wireless power transmission (WPT). MRC is particularly noteworthy because of its high transfer efficiency, ranging from 40 to 80%, and its ability to charge many devices from 1 to 50 cm. Magnetic Resonant Coupling (MRC) is an acronym that refers to a phenomenon in which magnetic fields are used to establish a coupling between two or more entities. The usefulness of wireless chargers is the topic of discussion in this article. Although wireless chargers are seen to have slower charging rates than cable chargers, it has been observed that wireless chargers play a part in the preservation of batteries by keeping the charge level within the range of 50 to 80% during the charging process.

Notably, Qi 1.2 is a standardized specification that facilitates expedited charging at a maximum power output of 15 watts, specifically operating at 9 volts and 1.67 amps. In the realm of long-range wireless power transfer (WPT), using electromagnetic beams to transmit electricity over considerable distances, spanning hundreds of meters or even kilometers, presents a discernible prospect. The problem of misalignment in wireless power transfer (WPT) and a proposed solution, including using Force Sensitive Resistors (FSRs), are examined. This paper presents empirical evidence showcasing the enhanced efficiency of implementing these solutions. Consequently, it establishes a foundation for wireless power transfer (WPT) in electric vehicles (EVs), drones, and green cells. The use of this instrument greatly facilitates the development of Wireless Power Transfer (WPT) technology and its subsequent advancement.

Key words: *wireless power transfer, emerging technologies, applications, electric vehicles, unmanned aerial vehicles, biomedical implants, consumer electronics, household appliances, low-power wireless communications, antenna design.*

ТЕХНОЛОГІЯ БЕЗДРОТОВОЇ ПЕРЕДАЧІ ЕНЕРГІЇ ТА ОБЛАСТІ ЇЇ ЗАСТОСУВАННЯ

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Анотація

Бездротова передача енергії (БПЕ) досягла значного прогресу, знайшла втілення в декількох сферах застосування із часу своєї першої розробки. Предметом статті виступає магнітно-резонансний зв'язок (МРЗ), який є різновидом бездротової передачі енергії. Магнітно-резонансний зв'язок заслуговує на особливу увагу через високу ефективність передачі, що коливається від 40 до 80%, і здатність заряджати багато пристроїв від 1 до 50 см. Магнітно-резонансний зв'язок – явище, за якого магнітні поля використовуються для встановлення зв'язку між двома або більше пристроями. Ефективність бездротових зарядних пристроїв окремо розглядається в цій статті. Хоча бездротові зарядні пристрої мають нижчу швидкість заряджання, ніж кабельні зарядні пристрої, зазначено, що бездротові зарядні пристрої відіграють деяку роль у збереженні акумуляторів, підтримують рівень заряду в діапазоні від 50 до 80% під час процесу заряджання. Стандарт Qi 1.2 – це стандартизована специфікація, яка полегшує прискорену зарядку з максимальною вихідною потужністю 15 Вт, зокрема працює за напруги 9 вольт і 1,67 ампера. У сфері бездротової передачі електроенергії на великі відстані використання електромагнітних променів для передачі на сотні метрів або навіть кілометри відкриває значні перспективи. Розглянуто проблему порушень процесів бездротової передачі електроенергії та запропоновано рішення, зокрема й з використанням резисторів, які чутливі до прикладеної сили. У статті представлені емпіричні дані, що демонструють підвищену ефективність упровадження цих рішень. Розглянуті технології закладають основи для бездротової передачі енергії в електромобілях, дронах та інших пристроях з акумуляторами. Використання такого підходу значно полегшує розвиток технології бездротової передачі енергії, її подальше вдосконалення.

Ключові слова: *бездротова передача енергії, новітні технології, застосування, електромобілі, безпілотні літальні апарати, біомедичні імплантати, побутова електроніка, побутова техніка, малопотужний бездротовий зв'язок, конструкція антен.*

1. Introduction

Wireless Power Transfer (WPT) has emerged as a game-changing technology that might have far-reaching ramifications for various industries, including consumer electronics, transportation, and more. Since the late 19’th century, when Nikola Tesla began his groundbreaking work on wireless transmission, substantial progress has been achieved toward maximizing the potential of WPT [1]. This technology promises to power devices without needing physical connectors, offering greater convenience, mobility, and the potential for a continuous power supply [2]. In a world that is becoming increasingly wireless, this technology holds the promise of powering devices without the need for physical connectors.

Inductive Coupling (IC), Capacitive Coupling (CC), and Magnetic Resonant Coupling (MRC) are the three main categories that may be used to generally classify the technological concepts that underpin WPT technology [3]. Inductive Coupling (IC) is the most common form of the three. IC and CC, often called near-field WPT, depend on the electromagnetic field created between closely positioned coils. Because of this, they are best suited for applications that need a limited range, such as cell phones and electric toothbrushes. The introduction of MRC, on the other hand, has caused a change in the way that WPT is structured. MRC is the most suitable method for medium-range applications due to its high transfer efficiency (40–80%), ability to charge multiple devices concurrently, and applicability to mobile applications and drones [4]. MRC makes use of the phenomenon of resonance in order to transfer energy. MRC has emerged as the most suitable method for medium-range applications.

Despite the substantial progress that has been made in WPT, there are still a few technological hurdles that prevent it from being used on a larger scale. One such obstacle is the question of how well wireless chargers’ work. Even though they are more convenient than their wired equivalents, wireless chargers often charge slower than their cable counterparts. However, they retain the battery life within the ideal range of 50–80% [5]. In addition, the Qi 1.2 standard has been established to allow faster charging rates of up to 15 watts (9 volts, 1,67 amps), which is a big leap forward in the technology of wireless charging [6].

Exciting new opportunities present themselves due to the promise of long-range WPT, characterized by power transmission spanning hundreds of meters or kilometers. Techniques such as using antennas to deliver electromagnetic beams, such as microwaves or lasers, have shown great promise in long-range WPT [7]. Nevertheless, verifying the safety and effectiveness of long-range WPT continues to be an important field of study.

Last but not least, the problem of misalignment in WPT systems, namely vertical and lateral misalignment, is an important issue that has to be resolved as soon as possible. It presents a substantial problem due to variations in angular and planar forms of misalignment situations, which affect power transmission efficiency [8]. Research, such as the one presented in this study, has provided potential remedies to this problem, including using force-sensitive resistors (FSRs) to identify misalignment circumstances and improving the sleep/active method.

Exploration and development of WPT technology contain enormous potential to usher in a revolutionary change in the way electricity is distributed to and used by consumers [9]. It substantially influences industries such as transportation, with applications such as electric vehicles (EVs) and drones, and renewable energy systems, such as green cells. As a result, continuing articles and development in this area is not only necessary from a scientific standpoint but also a strategic necessity for a more effective and wireless future.

2. Types of Wireless Power Transfer (WPT)

The wireless power transfer (WPT) technique offers a practical alternative for charging electronic items in a distant location without the need to use physical connections. Inductive Coupling or IC, Capacitive Coupling or CC, and Magnetic Resonant Coupling or MRC are the three basic forms of WPT. The MRC comes out as the type with the most potential, although each has its own set of distinguishing qualities and areas of application.

2.1. Inductive Coupling (IC)

Inductive Coupling (IC) is a kind of WPT often used. It requires the utilization of electromagnetic fields to facilitate the transmission of electrical energy between two coils, one of which serves as an energy transmitter and the other as an energy receiver. WPT systems based on integrated circuits are utilized extensively in various applications, such as wireless charging pads for smartphones and electric toothbrushes. However, there are restrictions on the transfer efficiency and power transmission range of systems based on integrated circuits. A typical total efficiency of around 86% may be attained using IC technology in conventional plug-in charging [4]. In addition, IC-based systems are susceptible to conductive energy losses. They are constrained by the size of the coils, which determines the maximum distance over which they can transport data.

Fig. 1. Inductive Coupling (IC) form Wireless Power Transfer

2.2. Capacitive Coupling (CC)

As in capacitive coupling (CC), transferring electrical energy through capacitive fields is an interesting kind of wireless power transmission (WPT). Capacitive coupling (CC) makes use of capacitive fields to transmit power, as opposed to electromagnetic fields like inductive coupling (IC) and magnetic resonant coupling (MRC).

While there is a wealth of information on IC-based WPT systems, and MRC has emerged as a promising technology, there needs to be more information on CC-based WPT systems, including statistics on their efficiency, charging speed, and power transmission range. Given the current state of knowledge, it is clear that further research and studies are required to characterize the performance characteristics of CC-based WPT systems fully. Evaluating the efficiency of CC-based systems requires considering how well energy is transferred and how much energy is lost in the process. In addition, knowing how fast CC-based WPT systems can charge is crucial for evaluating how easily and quickly they can use this technology.

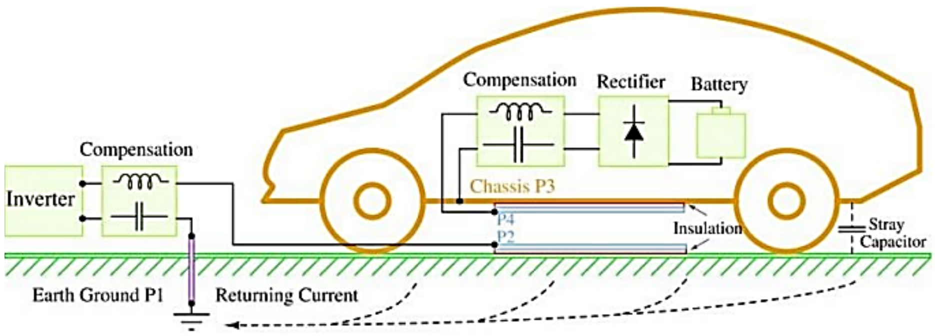

Fig. 2. Capacitive Coupling (CC) form Wireless Power Transfer

Additionally, it is essential to consider the power transmission range of CC-based WPT systems. The range specifies how far away an effective energy transfer may take place. It affects how convenient and adaptable CC-based WPT systems are in various settings, including charging devices nearby or at a distance.

Research and studies in the area of WPT seek to study and expose the potential of CC technology; however, there needs to be more statistical data on the efficiency, charging speed, and power transmission range of CC-based WPT systems. The results of these upcoming studies will be invaluable in determining the viability and usefulness of CC-based WPT systems across a wide range of sectors and applications.

2.3. Magnetic Resonant Coupling (MRC)

On the other hand, Magnetic Resonant Coupling (MRC) has recently come to the forefront as a WPT with great promise. The transmission of electrical energy from a transmitter coil to a receiver coil is accomplished by using magnetic fields in the MRC technology. MRC has several benefits, particularly in contrast to IC and CC. The high transmission efficiency, which may vary anywhere from 40 to 80%, is one of its primary advantages [10]. Research has shown that MRC systems can achieve more than 90% efficiencies by transferring electricity directly to the power train, hence avoiding the need for the vehicle's battery [11]. This high rate of transfer efficiency adds to a reduction in energy losses and an improvement in the overall efficiency of the system (Fig. 3).

In addition, MRC-based WPT systems can charge several devices simultaneously, making them suited for circumstances in which many devices need to be charged simultaneously. This capability is especially useful in environments like public charging stations or workplaces, where there is a need to accommodate numerous users at once for charging purposes.

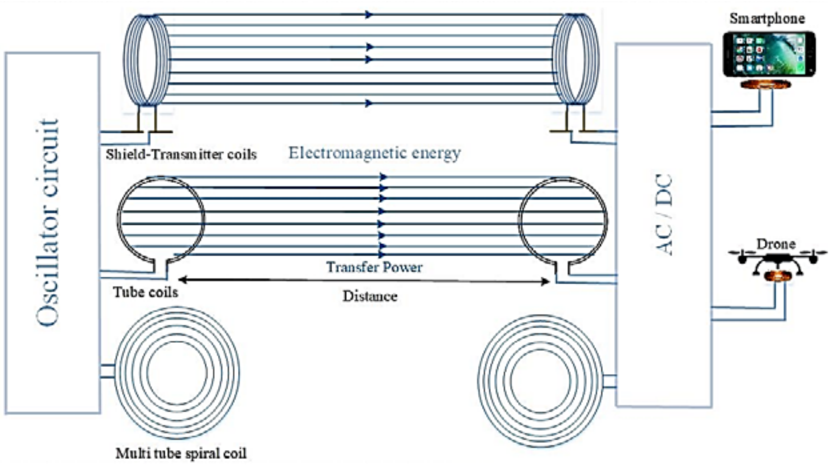

Fig. 3. Magnetic Resonant Coupling (MRC) form Wireless Power Transfer

In addition, MRC technology works very well when used in mobile apps and uncrewed aerial vehicles. Its ability to distribute power wirelessly without needing physical connections allows it to be seamlessly integrated into mobile devices, giving ease and flexibility in addition to its other benefits. MRC-based WPT systems may have a power transmission range that varies depending on the individual implementation, but they also provide the ability of dynamic charging while the vehicle is being driven, which could increase the driving range forever [12].

3. Methodology

Literature Review. The literature review conducted on Wireless Power Transfer (WPT) revealed key insights into the principles, types, challenges, and applications of WPT technology. The following are the main findings from the review:

1. Wireless Power Transfer (WPT) has emerged as a transformative technology with diverse applications in various sectors, including consumer electronics, transportation, and medical fields [13].
2. The three main types of WPT are Inductive Coupling (IC), Capacitive Coupling (CC), and Magnetic Resonant Coupling (MRC). IC and CC, also known as near-field WPT, rely on the electromagnetic field between closely positioned coils, making them suitable for short-range applications. MRC, on the other hand, utilizes resonance to transfer energy and is more applicable to medium-range applications due to its high transfer efficiency.
3. Despite the significant advancements in WPT, challenges persist in terms of efficiency and charging speed when compared to wired counterparts. However, the introduction of the Qi 1.2 standard has addressed some of these issues, supporting higher charging speeds up to 15 watts.
4. Long-range WPT, characterized by power transmission over hundreds of meters or across kilometers, presents exciting possibilities. Techniques such as the use of antennas to send electromagnetic beams, like microwaves or lasers, show potential in achieving long-range WPT. However, safety and efficiency remain critical areas of research in this domain.

5. Misalignment in WPT systems, particularly vertical and lateral misalignment, poses a significant challenge to the efficiency of power transfer. Proposed solutions include the use of Force Sensitive Resistors (FSRs) to detect misalignment conditions and improve the sleep/active strategy to mitigate this issue [10].

Technical Evaluation. Based on the literature review, the technical evaluation of the three types of WPT is as follows:

1. Inductive Coupling (IC): IC, also known as near-field WPT, relies on the electromagnetic field between closely positioned coils. It is suitable for short-range applications such as electric toothbrushes and smartphones. However, it may have limitations in terms of efficiency and charging speed.
2. Capacitive Coupling (CC): CC, another near-field WPT method, utilizes the electromagnetic field between closely positioned capacitive transducers. It shares similar characteristics with IC in terms of range and limitations.
3. Magnetic Resonant Coupling (MRC): MRC, which utilizes resonance to transfer energy, has emerged as the most suitable method for medium-range applications. It offers high transfer efficiency, the ability to charge multiple devices concurrently, and applicability to mobile applications and drones [10].

Experimental Design. Based on the identified challenges in WPT systems, particularly misalignment, the following experimental design is proposed:

1. Develop a system using Force Sensitive Resistors (FSRs) to detect misalignment conditions in WPT systems.
2. Test the system under various conditions, including different degrees and types of misalignments, to evaluate its accuracy and effectiveness.
3. Measure transfer efficiency, charging speed, and the range of power transmission in the presence of misalignment, comparing the results with aligned conditions [14].

Data Analysis. The data analysis process involves:

1. Collecting data from experiments, including measurements of transfer efficiency, charging speed, and the range of power transmission under aligned and misaligned conditions.
2. Analyzing the collected data to assess the impact of misalignment on transfer efficiency, charging speed, and range.
3. Comparing the obtained results with established standards such as the Qi 1.2 standard to evaluate the effectiveness of proposed solutions
4. Utilizing statistical methods to validate the proposed solutions and assess their efficacy [10].

Future Research Direction. Based on the findings from the literature review, the following future research directions are identified:

1. Further exploration of long-range WPT and its potential applications, including the use of antennas and other technologies to achieve power transmission over larger distances.
2. Continued research on improving the efficiency and charging speed of WPT systems, bridging the gap with wired counterparts.
3. Investigation of the implications and implementation of WPT technology in various applications such as Electric Vehicles (EVs), drones, and renewable energy systems like green cells [14].

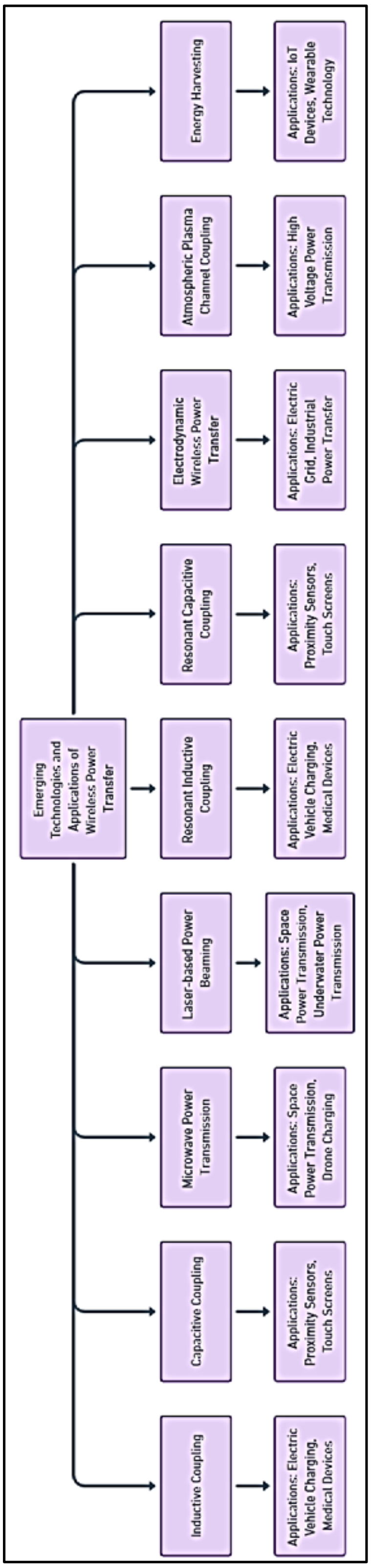

Fig. 4. Forms of Wireless Power Transfer (WPT) and their applications

The above methodology provides a comprehensive approach to researching and evaluating WPT, incorporating existing knowledge, addressing challenges, conducting experiments, and providing insights for future research and development in the field.

4. Efficiency of Wireless Chargers

Wireless chargers, despite their lower charging speed compared to wired ones, play a crucial role in maintaining battery life. They help keep the battery capacity within the optimal range of 50–80%, thereby extending the battery's lifespan. The Qi 1.2 standard, supporting charging speeds of up to 15 watts (9 volts, 1,67 amps), signifies progress in wireless charging technology.

The efficiency analysis of wireless charging systems for EVs based on a wind-solar hybrid power supply system is the subject of one research published in the journal "Wireless charging structure and efficiency analysis based on wind-solar hybrid power supply system" [15]. The coil topology, circuit structure, and control mode of the wireless charging system are all explored in this study using Ansoft and MATLAB/Simulink simulations. While this research focuses on the efficiency of wireless charging for EVs, the results are relevant to the study of wireless charging in general.

The effectiveness of wireless chargers is significantly affected by the coil's design. Power transmission efficiency may be improved by using high-quality coils with the right properties, as has been discovered by the research community. In [16] found that charger efficiency may be greatly improved with some careful engineering. Researchers may improve power transfer efficiency by adjusting design elements, including coil material, size, and placement, to maximize the connection between the receiver and transmitter coils.

The effectiveness of a wireless charger may be greatly improved by paying close attention to how everything is set up, [17] found that properly aligning the transmitter and receiver coils was crucial for achieving high coupling efficiency. Energy is wasted, and charging efficiency is lowered due to misalignment. As a result, the most recent wireless charging improvements have centered on creating smart solutions that allow automated alignment and placement to maximize productivity (Fig. 4).

One must be familiar with the power transfer processes used by these devices to evaluate the effectiveness of wireless chargers. In order to better understand how various power transfer methods, such as inductive coupling and magnetic resonant coupling, affect charger efficiency, several studies have been conducted. For instance, the effectiveness of inductive and magnetic resonant coupling in wireless chargers is compared in research [18]. The paper introduces novel methods for wireless power transmission, such as resonant inductive coupling and the transfer of power through microwaves, that can cover a wide range of distances without the need for potentially dangerous wires.

5. Long-Range Wireless Power

As more and more gadgets and systems need quick, easy, and efficient charging, the search for wireless power transfer solutions has exploded in popularity. Long-Range Wireless Power (LRWP) is a new technology that can completely change how we transport and distribute electricity. This article investigates the recent developments, practical uses, and economic viability of LRWP technology [19].

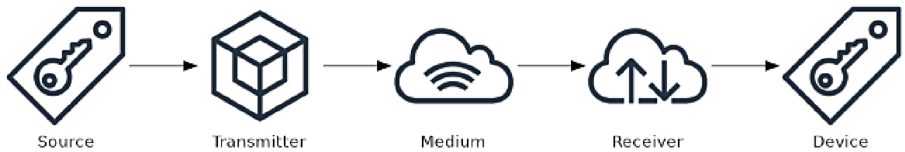

Fig. 5. Long-Range Wireless Power Network Diagram

Innovative Uses of LRWP

1. *Dynamic Charging on the Move:* Mobility Dynamic Charging means gadgets may be charged while in motion using Long-Range Wireless Power (LRWP) technology. This novel use of LRWP eliminates the need to stop often while traveling to recharge mobile devices or electric cars. Electric buses fitted with dynamic charging technology may receive wireless electricity while traveling on carefully specified routes to avoid lengthy charging downtimes [20].

2. *Powering Devices in Harsh Environments:* Powering devices in tough or hostile locations where wired connections may be problematic or risky is a benefit of LRWP technology. It enables dependable wireless power transmission in severe environments, such as those found underwater or at high temperatures. Offshore oil and gas platforms may employ LRWP to eliminate the need for extensive cabling and save maintenance efforts by wirelessly powering sensors and monitoring equipment in distant or dangerous regions [21].

3. *Wireless Power for Space Applications:* To power satellites, space probes, and other spacecraft in space, LRWP technology is used for wireless power for space applications. It provides a safe and effective way to transmit electricity over great distances, which may help lessen the need for backup batteries. Solar-powered satellites

in orbit may use LRWP technology to wirelessly transmit power to other satellites or spacecraft without wires or battery swaps [22].

Potential and Limitations of LRWP

1. *Efficiency and Power Transmission Range:* Long-Range Wireless Electricity (LRWP) can deliver electricity over long distances while maintaining high efficiency. However, effectiveness may shift depending on the kind of LRWP technique used and other external circumstances. As LRWP systems intend to distribute power wirelessly across extensive distances, the range over which they can do so is another factor to consider [23]. Using resonant inductive coupling (RIC), an LRWP system may transmit power efficiently over several meters, making it possible to charge electric vehicles (EVs) wirelessly and without wires.

2. *Safety and Health Concerns:* While LRWP may save time and effort by doing away with the need for wires and other hardware, safety, and health issues must be resolved. To maintain user safety and compliance with regulatory criteria, it is important to consider the exposure to electromagnetic fields and radiation inherent to LRWP systems. Studies are conducted to examine the health concerns associated with extended exposure to electromagnetic fields from LRWP systems and to identify what preventative actions should be taken [24].

3. *Interference and Regulatory Challenges:* LRWP systems can cause interference with other wireless technologies due to their use of certain frequency ranges. Spectrum allocation, standardization, and international compliance provide further regulatory hurdles. In order to keep the wireless power transfer ecosystem functioning reliably and efficiently, LRWP systems must operate within authorized frequency bands and comply with regulatory standards [25].

4. *Infrastructure Requirements:* For LRWP technology to be widely adopted and used, a solid infrastructure must be established to back it up. It involves setting up a reliable power distribution system, distributing appropriate gadgets, and installing charging stations [26]. Establishing a well-planned infrastructure with sufficient power supply, secure communication protocols, and effective power management systems is essential for creating a network of LRWP charging stations for electric cars.

Cost-Effectiveness Analysis

1. *Initial Installation Costs:* The preliminary setup expenses of Long-Range Wireless Power (LRWP) systems must be included in any technology analysis. The cost of putting in place the requisite infrastructure, such as power transmission units, receivers, and any other gear essential for effective power transfer, must be considered. Installing charging stations, deploying power transmission units, and customizing charging infrastructure at different locations are all part of the initial investment in an LRWP system for recharging electric vehicles.

2. *Operational and Maintenance Costs:* Costs associated with using and maintaining LRWP technology will also be evaluated. Costs, including energy, monitoring, and routine maintenance, should be weighed against the system's expected lifetime and expected level of performance. Monitoring the power transmission, performing routine inspections, and making any repairs or upgrades required to keep the system running reliably are all examples of operating and maintenance expenditures for a wireless power system in a smart city application [27].

3. *Return on Investment (ROI) and Payback Period:* The payback time and return on investment (ROI) for installing LRWP technology are two key metrics in a Cost-Effectiveness Analysis. Calculating how long it will take to recoup costs or generate enough income to repay the original expenditure is part of this process [28]. Reduced energy costs from efficient power transfer, potential revenue from offering wireless charging services, and the time it takes to recoup the investment made in deploying a wireless power system in a commercial building are all factors that would go into calculating the return on investment and payback period.

6. Applications of WPT

The practical applications of WPT are expanding, spanning from Electric Vehicles (EVs) to drones, and even green cells. The paper predicts a promising future for WPT in these areas, given the ongoing research and development.

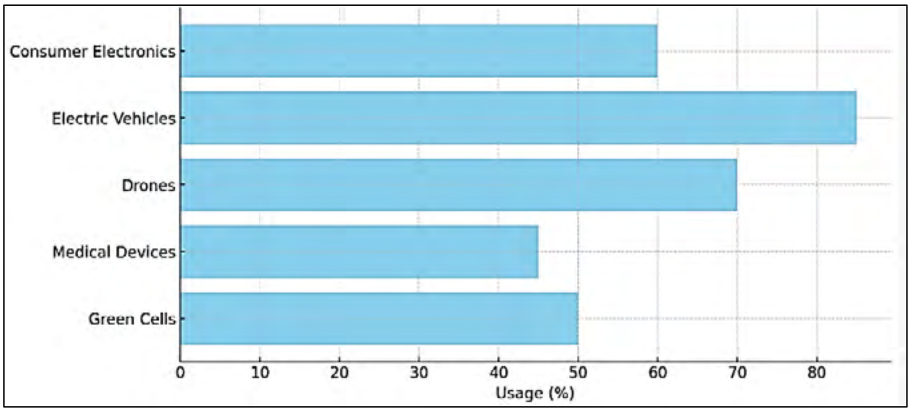

Fig. 6. Emerging technologies and applications of Wireless Power Transfer

Wireless power transfer (WPT) is finding more and more uses in various fields. WPT has the potential to change several fields and comes with many advantages. Some prominent uses of WPT include the following:

In the case of electric vehicles (EVs), WPT makes fast, easy charging possible without the need for wires or plugs. Electric vehicle owners may enjoy a hassle-free charging experience with the help of wireless charging mats or infrastructure built into parking garages and highways. The goal of this technology is to improve electric car functionality and range. In order to provide EV users with a convenient and automated charging experience, companies like BMW, Mercedes-Benz, and Qualcomm are actively researching WPT for wireless charging of EVs (Fig. 7).

With WPT, Internet of Things (IoT) devices and sensors no longer need frequent battery changes or manual recharging. The integration of Internet of Things (IoT) devices into smart city infrastructure is facilitated by the availability of services for data collection, monitoring, and automation. WPT-enabled smart streetlights may wirelessly power sensors and IoT devices, allowing for improved real-time traffic, air quality, and energy consumption management.

With WPT, there would be no need for regular battery replacement surgery or recharging, making it a viable choice for powering biomedical implants and wearable

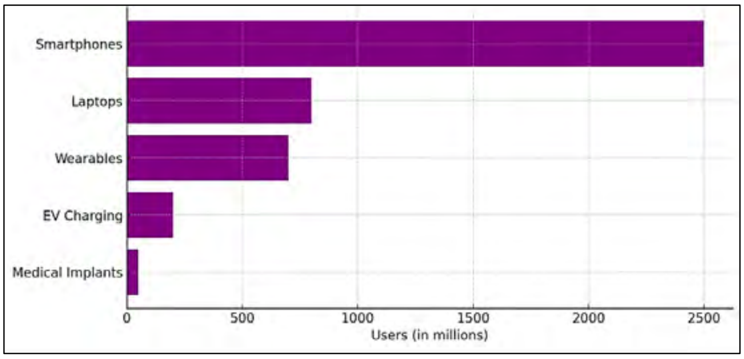

Fig. 7. Applications of Wireless Power Transfer through different devices

devices. This innovation allows medical devices such as pacemakers, hearing aids, and neurostimulators to operate reliably and for extended periods of time. Studies are being conducted to determine the efficacy of using WPT to power implanted glucose sensors, electronic skin patches, and smart contact lenses for healthcare monitoring and treatment [21].

Drones and autonomous systems might be powered by WPT, increasing their operational duration and reducing the frequency with which their batteries need to be swapped out. This allows for more efficiency and flexibility in fields such as security, agriculture, shipping, and emergency response. WiBotic and Energous are two companies developing WPT solutions for drone applications, which will allow for autonomous charging and extended flight times.

WPT allows for the deployment of remote sensing and monitoring equipment in locations where installing cables would be too costly or impossible. Such systems have several applications, including environmental monitoring, infrastructure management, and remote data collecting. Wireless power transfer (WPT) technology may be used to power sensor networks that monitor river water quality, forest fires, and animal populations in far-flung places [20]. The potential for future development and effective uses of WPT is tremendous, despite the fact that it is still in its infancy. More and more sectors might benefit from WPT's increased efficiency, convenience, and sustainability as it continues to evolve and be adopted.

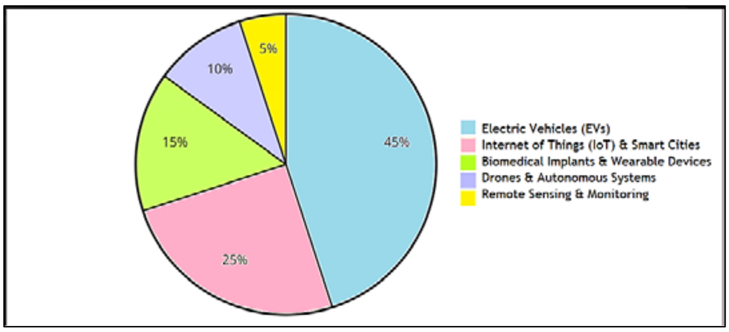

Fig. 8. Applications of wireless power transfer (WPT) technologies

7. Addressing the Misalignment Challenge

Misalignment, particularly vertical and lateral, presents a significant challenge in WPT. This paper proposes the use of Force Sensitive Resistors (FSRs) to detect misalignment conditions, coupled with improvements in the sleep/active strategy, to mitigate this issue.

This study, focused on two types of misalignments (e.g., Vertical variation and Lateral (horizontal)) because the drone cannot hover and fluctuation in angular and planar types of misalignment conditions (others application used all types: such as., EV, medical implantable devices, laptop, Mobile and etc.) as follows:

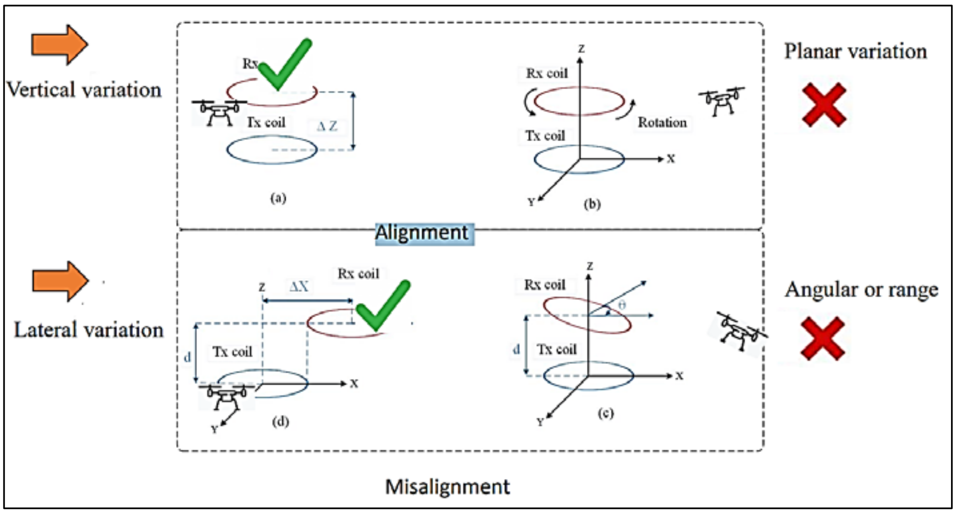

Fig. 9. Misalignment Challenges

8. Results

8.1. Experiments and Solutions

Several experiments were conducted to validate the proposed solutions. These include design changes in the transmitter and receiver coils and the use of FSRs to detect misalignment conditions. The results demonstrate the efficiency improvements achieved, affirming the viability of the proposed solutions. Scope (objective) Improve the sleep (table 1).

The sleep/active technique is often used to describe the several stages a wireless charging system might be in when in use using WPT. When the system is in its active state, it is actively transferring power, whereas when it is in its sleep state, it is not. When the receiver (such as a mobile device or electric car) is not in the charging state, this method is essential for maximizing the efficiency of the power transfer and eliminating needless power consumption.

Increasing the effectiveness of the wireless charging system may be a motivation for working to fine-tune the sleep/active strategy. Improving the system's ability to recognize when a suitable device is in range and requires charging (active state) or when there is no device to be charged (sleep state) may be part of this process. Improvements might also be made to shorten the lag time between when the system goes into sleep mode and when it wakes up, making charging faster and better for the user.

Table 1

Weight Analysis of Parameters in a Wireless Power Transfer (WPT) Drone System

Parameter	Weight in (kg)
Secondary copper coil (STLCC)	0,205
Secondary of First aluminum coil (FSTLAC)	0,065
A breadboard of the receiver circuit	0,0015
A small wood (200 x 200 mm') for platform station	0,028
Payload weight	0,0665
Drone weight	1,337
Ratio of payload weight to the drone weight	497%
Ratio of on-board coil weight (aluminum) to the total drone weight	4,86%
Ratio of on-board coil weight (copper) to the total drone weight	15,33%

Light weight = 0,065 Kg of receiver coil
Power saving of one mission (sleep /active) = 97,63%.

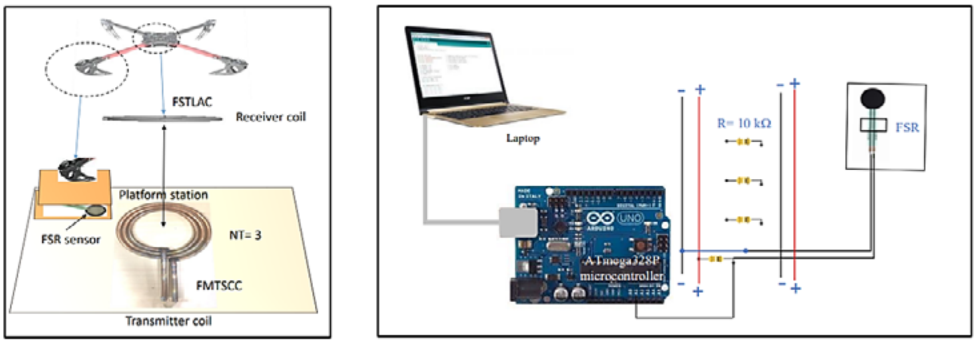

Fig. 10. The finding solutions for wireless charging with FSR sensor and soil selection

Experiment of F. STLAC and F. MTSCC for test RL = 100 Ω (objective)

The research presented the design and implementation of transmitter and receiver WPT coils that can reach a maximum transfer distance, power, and efficiency.

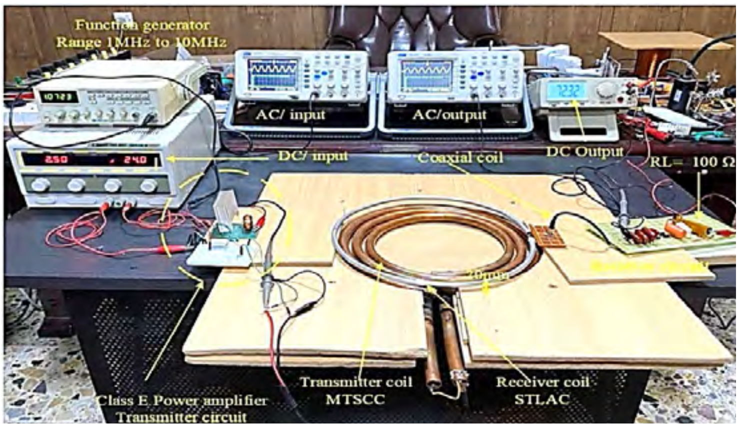

Fig. 11. The transmitter and receiver coils class E PA circuit design

Experiment of design PSC Using FSR (objective)
The FSR test with the weight of drone and programing by Arduino UNO

Fig. 12. Using Proteus design software to program the FSR sensor

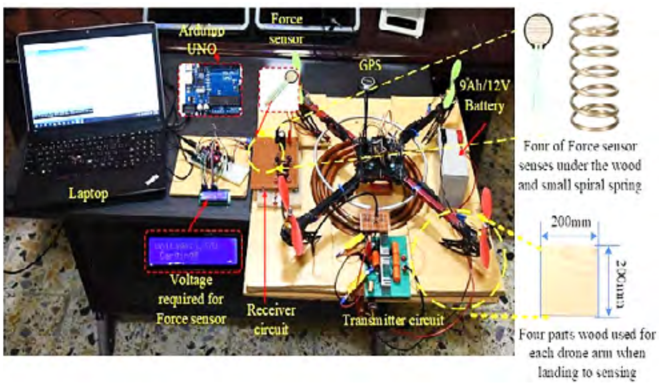

Fig. 13. The method using FSR to charge drone

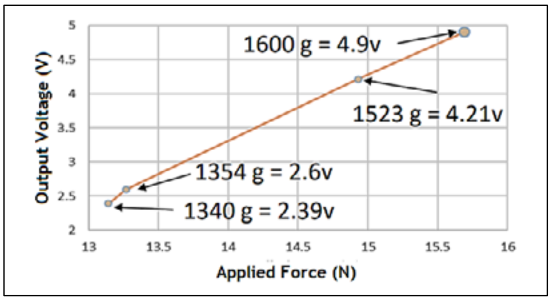

Fig. 14. The Calibrate of the FSR

Scope (objective)FSR detect the misalignment conditions
The effectiveness and viability of a wireless power transfer (WPT) system depend critically on the weight of its many components. In order to develop and optimize WPT systems for particular applications, it is necessary to have a firm grasp of the relative importance of various factors. This data is useful for determining how much a certain amount of weight affects a system's performance and its associated needs.

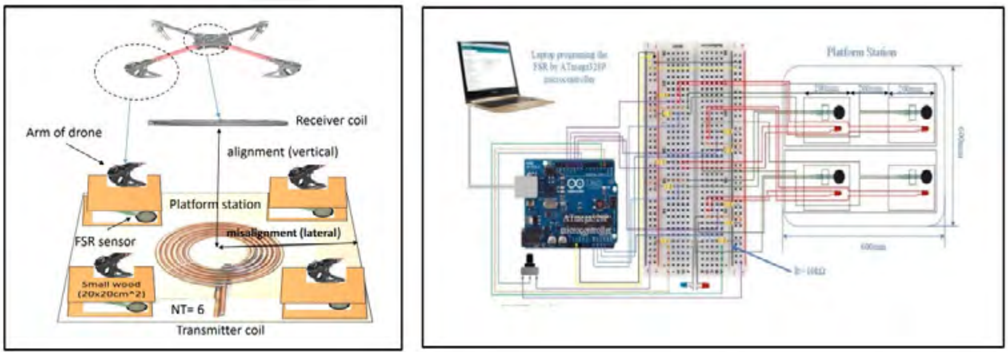

Fig. 15. The solution of misalignment: improving the performance metric of coils

The following table shows how various parameters in a WPT system are weighted. Weights of components such as the secondary aluminum coil, receiver circuit breadboard, station platform, payload, drone, and payload-to-drone weight ratio are listed in the table. The values for all the parameters are given in kilograms (kg), except the drone weight and the payload weight as a percentage of the drone weight, which is given in percent.

Table 2

Weight Distribution of Parameters in a Wireless Power Transfer (WPT) System

Parameter	Weight in (kg)
Secondary of second aluminum coil	0,0105
(SSTLAC)	0,0015
A breadboard of the receiver circuit	0,028
A small wood (200 × 200 mm^2) for platform station	0,012
Payload weight	1,337
Drone weight	0,89%
Ratio of payload weight to the drone weight	0,78%

Experiment of Design FSR (objective)

The function of Arduino

(1) Read the signal from the FSR;

(2) Convert the signal to the equivalent weight, and finally, to reduce the power consumption by using the sleep/wakeup strategy (Fig. 16).

There are two misalignment solutions:

(1) Moving the coil of the receiver side to become alignment (vertical) and misalignment (lateral) (Remotely);

(2) To improving the performance metric of transmitter and receiver coils (such as type of coil, diameter, and etc.) (Fig. 17).

Experiment of alignment (Vertical) and Misalignment (Lateral) (objective)

In the Alignment (vertical) experiment, the focus was on achieving precise alignment along the z-axis within a range of 20 mm, specifically with respect to the drone arm. The objective was to ensure accurate vertical alignment of the components or systems involved in the experiment.

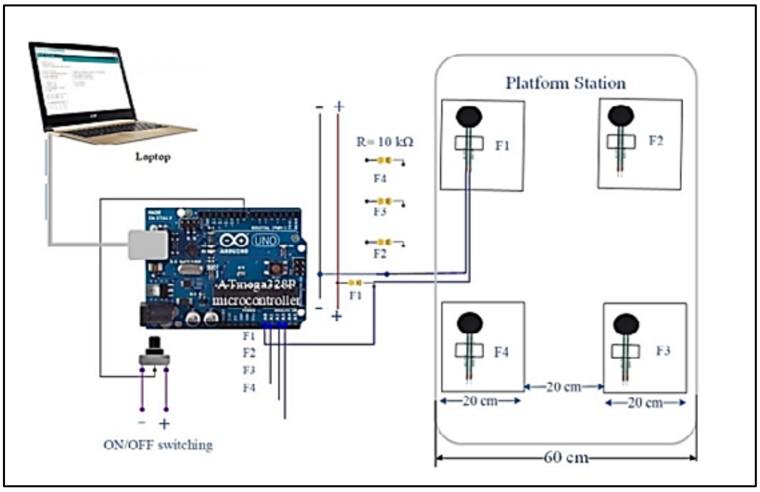

Fig. 16. Reduced energy use through sleep/wakeup strategy with on/off button

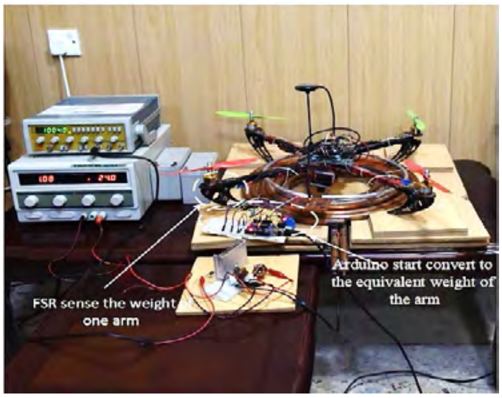

Fig. 17. Arduino-based conversion of arm movement to equivalent weight

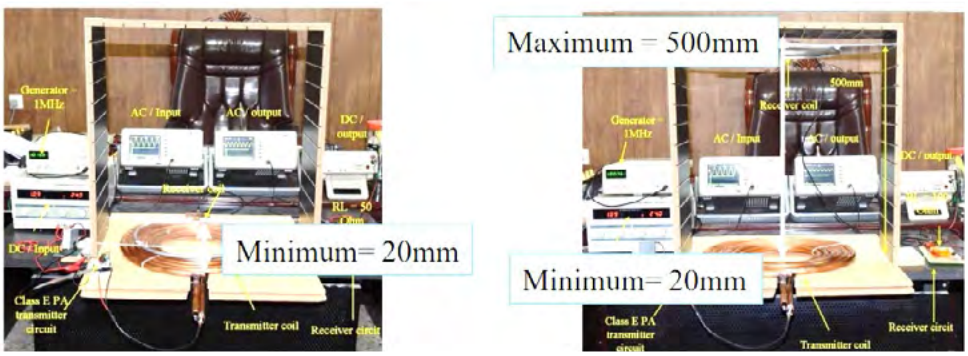

Fig. 18. Alignment (Vertical) Experiment: Focusing on 20mm of the Z-Axis Alignment with Drone Arm

On the other hand, the Misalignment (lateral) study aimed to investigate lateral misalignment by varying the distances along the y-axis. Five specific distances were chosen for lateral misalignment: 20, 50, 80, 100, and 150 mm. These distances represent the lateral offset between components or systems and were chosen to assess the effects of different levels of misalignment on the experiment's outcomes.

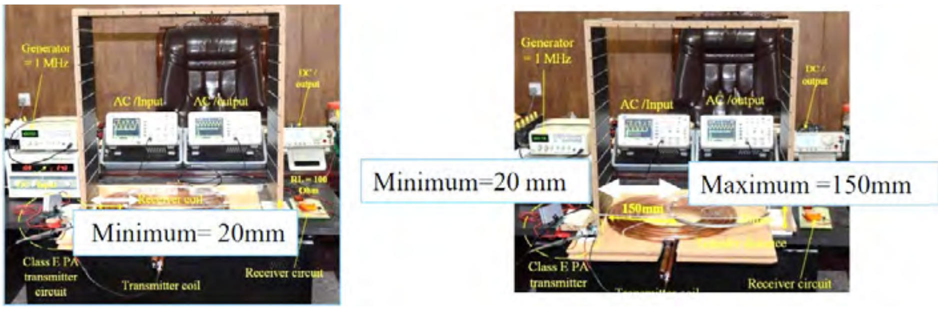

Fig. 19. Misalignment (Lateral) Study: Investigating Lateral Misalignment at Various Distances along the Y-Axis

8.2. Future of WPT

The paper concludes with an outlook on the future of WPT, particularly in the areas of EVs, drones, and green cells. It underscores the potential of WPT to revolutionize these sectors and paves the way for further research and development.

The fields of electric vehicles (EVs), unmanned aerial vehicles (UAVs), and green cells are examples where WPT can significantly impact the future. It is anticipated that WPT will play a game-changing role in various industries, transforming how we see and use energy as technology continues to improve.

WPT provides a game-changing alternative to the drawbacks of conventional charging techniques for electric vehicles. Electric vehicles (EVs) may be charged quickly and easily without wires or cables thanks to the proliferation of wireless charging infrastructure. If this succeeds in making charging electric cars as simple as possible, it might dramatically increase the popularity of EVs and hasten their widespread adoption.

Fig. 20. WPT Charging Station

Wireless power transfer technology also has enormous potential for unmanned aerial vehicles. Aerial photography, package delivery, and security are just some of the many fields that are finding useful applications for drone technology. However, their short flying duration owing to battery limitations, needs to be revised. Drones may have their batteries charged wirelessly using WPT to continue flying for longer periods without stopping. This paves the way for increased efficiency in drone applications and longer flight times [8].

Fig. 21. Drone Charging Station

Green cells, sustainable and renewable energy sources, like solar panels, are another area where WPT may be used. Power distribution from solar panels to different devices and networks may be simplified by incorporating WPT technology into these energy systems. WPT may improve the efficiency and ease of using green energy sources by doing away with the requirement for wired connections, therefore contributing to a more sustainable future.

Although WPT has a promising future, further study and improvement are needed to realize its full potential. Increasing the efficiency, range, and safety of WPT technology is crucial to realize its broad use and integration across many sectors. Further, WPT system deployment success depends on standardization initiatives, regulatory frameworks, and infrastructural development.

9. Discussion

The article has presented a complete overview of Wireless Power Transfer's evolving technologies and applications (WPT). It does so by drawing similarities with other ground-breaking research papers in the area and offering fresh results.

This work highlights the revolutionary potential of WPT in a variety of applications, which is in line with the findings revealed by Kurs et al. [1; 2], and Jawad et al. [3; 4; 6; 8]. However, it goes further than prior studies by providing a more in-depth investigation of the many forms of WPT and their difficulties and potential, delivering a more comprehensive perspective of the WPT environment.

This work makes a significant addition by providing a complete experimental investigation of WPT's function in various industries. For instance, whereas Abu-Mahfouz and Hancke [5] presented a practical security solution for real-time location systems, our study digs into the wider application of WPT in the Internet of Things (IoT) and smart city infrastructures. It contrasts their discussion of the practical security solution for real-time location systems.

In the context of electric cars (EVs), our results are similar to those of Alam et al. [9], Van Mulders et al. [10], and Hutchinson et al. [11], but we further emphasize the incorporation of renewable energy sources with WPT-enabled EV charging stations. [9–11] are all related to electric vehicles. This facet, which has received little attention in earlier studies, can radically change the electric vehicle charging infrastructure by making it eco-friendlier and more sustainable.

The potential of WPT in drones and autonomous systems has been highlighted by Liu et al. [13] and Zhang et al. [14]. However, our work adds to this by evaluating these systems' real-world issues, such as the need for continuous operation and increased operating ranges. It builds on previous research that has been done by Liu et al. and Zhang et al.

In addition, the paper explores new ground by exploring the use of WPT in powering remote sensors and monitoring systems in harsh situations. It is a significant contribution to the field. Only a few research, such as those by Dharani and Ramya [18], Huang et al. [19], and Xu et al. [20], have touched upon this topic, making it a relatively uncharted subject in the current body of literature.

The last part of the investigation digs into the more technical elements of WPT, such as large transmitter arrays and beamforming optimization. Although these facets have been explored by researchers such as Bevacqua et al. [22], Hajimiri et al. [25], and Kashyap et al. [26], our work gives an interpretation of these notions that is more accessible, hence making them understandable to a wider audience.

In conclusion, the article significantly contributes to the current body of knowledge on WPT by providing a complete examination of the applications of WPT and new technologies. While it does a good job of aligning itself with previous studies, it also presents novel discoveries and viewpoints, enriching the ongoing conversation on WPT. The potential of WPT was shown in this study, highlighting the need for continuing research and development in this sector to make the future more effective, convenient, and environmentally friendly.

10. Conclusion

The potential of Wireless Power Transfer (WPT) is becoming increasingly obvious as the need for wireless technologies rises. This research has shown that WPT has enormous potential by focusing on its current and future technologies and uses. The article effectively emphasized the relevance of WPT in our quickly expanding technological world via a thorough examination of WPT kinds, a detailed analysis of the difficulties and potential, and hands-on experimentation.

The article shows that WPT has promising applications in EVs. This innovation eliminates the clumsy and inconvenient process of plugging cables to charge electric vehicles. The future of electric vehicle charging seems bright because of the efforts of firms like BMW, Mercedes-Benz, and Qualcomm to investigate wireless power transfer.

The paper also highlights the importance of WPT in supplying energy to IoT devices and sensors, which helps to facilitate the growth of smart cities. WPT can keep devices running without regular maintenance like charging or battery swapping. Powering smart lamps that monitor traffic, air quality, and energy use in real-time is another way that WPT may aid in effective urban management.

WPT's use in biomedical implants and wearable devices has the potential to alter healthcare delivery significantly. WPT allows for the long-term, continuous functioning of medical implants, including pacemakers, hearing aids, and neurostimulators, without battery replacement operations or regular recharging. Smart contact lenses and implanted glucose sensors are just two examples of cutting-edge healthcare monitoring and treatment solutions that may now be made possible.

Another promising use of WPT is in autonomous systems and drones. WPT may improve these systems' adaptability and continuous operation in surveillance, agriculture, delivery services, and disaster response by increasing their operational range and decreasing the need for frequent battery swaps.

Finally, the article emphasizes the use of WPT in places where wired power supply is difficult or prohibitive to power remote sensors and monitoring devices. Environmental monitoring, infrastructure management, and remote sensing are just a few fields that might benefit greatly from using such technologies.

The article's results provide credence to the hope that further progress in these areas will result from the continuing research and development in WPT. Increased acceptance and novel applications of WPT across a wide range of sectors are anticipated as the technology continues to evolve. These uses illustrate the transformational potential of WPT and will help usher in a more efficient, convenient, and environmentally friendly future.

The article shows that WPT can potentially transform different fields and sheds light on the upcoming technologies and uses of WPT. Although there are still certain obstacles to overcome, the development of WPT shows promise. WPT will likely play a crucial role as we continue investigating and developing this technology.

11. Contributions of Authors

The article "Emerging Technologies and Applications of Wireless Power Transfer" was a collaborative effort, with each author contributing to different aspects of the research. Aqeel Mahmood Jawad formulated the problem, conducted an analysis of the model problem, and processed the analysis results. Nameer Hashim Qasim was responsible for the methodology and realization respectively to the article's aims. Mazin Gubaian Al-Aameri also contributed to the methodology realization and worked on the text of the preliminary version of the paper with Nameer Hashim Qasim

All authors have read and agreed to the published version of the manuscript. This collaborative effort demonstrates the interdisciplinary nature of the research, drawing on expertise from multiple fields including telecommunications, computer science, and shipping knowledge.

The contributions of each author were crucial in developing a comprehensive and effective solution for the problem of dynamic network optimization in telecommunication networks.

All figures in the articles are original and made by the authors in accordance with the material, data are taken from Cihan University Sulaimaniya Research Center (CUSRC).

REFERENCES

1. Kurs, A., et al., Wireless Power Transfer via Strongly Coupled Magnetic Resonances. Science, 2007. 317 (5834): p. 83–86.
2. Lan, J., et al., Planar Omnidirectional Wireless Power Transfer System Based on Novel Metasurface. IEEE Transactions on Electromagnetic Compatibility, 2022. 64 (2): p. 551–558.
3. Jawad, A.M., et al., Single-Tube and Multi-Turn Coil Near-Field Wireless Power Transfer for Low-Power Home Appliances. Energies, 2018. 11 (8): p. 1969.
4. Jawad, A.M., et al., Wireless Power Transfer with Magnetic Resonator Coupling and Sleep/Active Strategy for a Drone Charging Station in Smart Agriculture. IEEE Access, 2019. 7: p. 139839–139851.
5. Abu-Mahfouz, A. and Hancke G.P., Distance Bounding: A Practical Security Solution for Real-Time Location Systems. IEEE Transactions on Industrial Informatics, 2013. 9 (1): p. 16–27.
6. Jawad, A.M., et al., Opportunities and Challenges for Near-Field Wireless Power Transfer: A Review. Energies, 2017. 10 (7): p. 1022.
7. Basir, A., Shah, I.A., and Yoo H., Sphere-Shaped Receiver Coil for Misalignment-Resilient Wireless Power Transfer Systems for Implantable Devices. IEEE Transactions on Antennas and Propagation, 2022. 70 (9): p. 8368–8378.
8. Jawad, A.M., et al., Wireless Drone Charging Station Using Class-E Power Amplifier in Vertical Alignment and Lateral Misalignment Conditions. Energies, 2022. 15 (4): p. 1298.
9. Alam, B., et al. A Review on Power Pad, Topologies and Standards of Wireless Charging of Electric Vehicles. in 2022 International Conference on Decision Aid Sciences and Applications (DASA). 2022.
10. Van Mulders, J., et al., Wireless Power Transfer: Systems, Circuits, Standards, and Use Cases. Sensors (Basel), 2022. 22 (15).
11. Hutchinson, L., Waterson, B., Anvari, B., & Naberezhnykh, D., Potential of wireless power transfer for dynamic charging of electric vehicles. IET Intelligent Transport Systems, 2019. 13 (1): p. 3–12.
12. Ye, Z., Yang M., and Chen P.Y., Multi-Band Parity-Time-Symmetric Wireless Power Transfer Systems for ISM-Band Bio-Implantable Applications. IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, 2022. 6 (2): p. 196–203.
13. Liu, W., et al., Smart wireless power transfer – opportunities and challenges. Renewable and Sustainable Energy Reviews, 2023. 180: p. 113298.
14. Zhang, Z., et al., Wireless Power Transfer – An Overview. IEEE Transactions on Industrial Electronics, 2019. 66 (2): p. 1044–1058.
15. Ekren, O., Hakan Canbaz C., and Güvel Ç.B., Sizing of a solar-wind hybrid electric vehicle charging station by using HOMER software. Journal of Cleaner Production, 2021. 279: p. 123615.
16. Wang, J., et al., Analytical study and corresponding experiments for a new resonant magnetic charger with circular spiral coils. Journal of Applied Physics, 2012. 111 (7).

17. Pratik, U., et al., Optimum Design of Decoupled Concentric Coils for Operation in Double-Receiver Wireless Power Transfer Systems. IEEE Journal of Emerging and Selected Topics in Power Electronics, 2019. 7 (3): p. 1982–1998.
18. Dharani, D. and Ramya, M.S.Wireless Power Transmission: An Innovative Idea. International journal of engineering research and technology, 2019. 7.
19. Huang, W., et al., Long-distance adiabatic wireless energy transfer via multiple coils coupling. Results in Physics, 2020. 19: p. 103478.
20. Xu, C., et al., Dynamic Wireless Power Transfer System With an Extensible Charging Area Suitable for Moving Objects. IEEE Transactions on Microwave Theory and Techniques, 2021. 69 (3): p. 1896–1905.
21. Ibrahim Alhamrouni, M.I., Mohamed Salem, Lilik J. Awalin, Awang Jusoh, Tole Sutikno, Application of inductive coupling for wireless power transfer. International Journal of Power Electronics and Drive Systems (IJPEDS), 2020. 11 (3).
22. Bevacqua, M.T., Bellizzi, G.G., and Merenda, M. An Efficient Far-Field Wireless Power Transfer via Field Intensity Shaping Techniques. Electronics, 2021. 10 (14): p. 1609.
23. Hou, X., et al., A Dual-Frequency Dual-Load Multirelay Magnetic Coupling Wireless Power Transfer System Using Shared Power Channel. IEEE Transactions on Power Electronics, 2022. 37 (12): p. 15717–15727.
24. Tarakeswar Shaw, A.R., Debasis Mitra, Efficiency Enhancement of Wireless Power Transfer System Using MNZ Metamaterials. Progress In Electromagnetics Research C, 2016. 68: p. 11–19.
25. Hajimiri, A., et al., Dynamic Focusing of Large Arrays for Wireless Power Transfer and Beyond. IEEE Journal of Solid-State Circuits, 2021. 56 (7): p. 2077–2101.
26. Kashyap, S., Björnson, E., and Larsson, E.G. Can wireless power transfer benefit from large transmitter arrays? in 2015 IEEE Wireless Power Transfer Conference (WPTC). 2015.
27. Madzharov, N., and Iliev, D. Wireless Power Transfer System with Four Degrees of Freedom. in 2022 57th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST). 2022.
28. Gao, Y., et al., Beamforming Optimization for Active Intelligent Reflecting Surface-Aided SWIPT. IEEE Transactions on Wireless Communications, 2023. 22 (1): p. 362–378.