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Comparative Analysis of High-Power Wireless Power Transfer Systems Using TOPSIS Methodology

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Abstract: *The first generation of the Qi wireless power transfer (WPT) standard, introduced in 2010, featured a diverse array of transmitter and receiver designs to enhance compatibility and encourage widespread adoption among manufacturers. This focus on interoperability led to the involvement of over 400 companies in the Wireless Power Consortium (WPC), contributing to a rapidly growing wireless power market over the past decade. Currently, the WPC is broadening the scope of WPT applications to include mid- and high-power uses, with capabilities reaching several kilowatts. Meanwhile, the Society of Automobile Engineers (SAE) has established standards for wireless charging of electric vehicles (EVs), accommodating power levels of up to tens of kilowatts. The authors advocate for a transition from prioritizing compatibility to optimizing performance, focusing on maximizing energy efficiency and reducing charging times. This shift is essential to meet the increasing power requirements of WPT applications. The paper highlights essential technologies pivotal for the transition to high-power wireless power transfer (HPWPT), which is critical for supporting battery electric vehicles (BEVs). As this technology continues to evolve each year, efforts for standardization and commercial collaborations have increased. Substantial research has advanced high-power charging, with new techniques and devices driving further developments. This review examines current high-power WPT systems, detailing the progress made in passive components, devices, subsystems, and methods that have facilitated higher power levels. Energy limitations are often perceived as significant barriers for wireless and mobile devices, with limited battery life hindering performance and posing challenges for large-scale sensor network deployment. However, wireless power transfer has recently emerged as a viable solution to address energy and lifespan constraints in sensor networks. This article reviews the evolution and recent breakthroughs in wireless power transfer, illustrating how these technologies can help alleviate energy challenges in sensor networks.*

Keywords*: Dynamic wireless charging, inductive power transfer, high power charging, transportation electrification, wireless power transfer, power electronics*

1. INTRODUCTION

The idea of wireless power transfer (WPT) has its origins in the early 20th century, even before the establishment of electric power grids. After successfully transmitting the first electrical signal across the Atlantic, Nikola Tesla, a groundbreaking electrical engineer, envisioned large-scale wireless power distribution. He built the world's first power station, known as Wardenclyffe Tower, on Long Island, New York, with the aim of transmitting both signals and electricity without wires. However, Tesla's invention ultimately failed to achieve practical application due to the extensive electric fields it generated, which significantly hindered the efficiency of power transfer.

In the late 20th century, the demand for wireless power transfer (WPT) surged with the proliferation of mobile electronic devices, including laptops, cell phones, PDAs, and tablets. The increasing popularity of electric and plug-in hybrid vehicles in the automotive sector also contributed to the growing need for wireless power solutions. WPT represents a transformative technology that allows energy transmission without the need for cords, fundamentally changing traditional energy usage across various applications. These applications include portable electronics, implanted medical devices, integrated circuits, solar-powered satellites, electric vehicles (EVs), and unmanned aerial vehicles (UAVs). With its significant advantages of flexibility, position independence, and mobility, WPT is emerging as a promising solution for powering electric devices in specific settings, particularly in smart home applications in the near future.

Wireless power transfer (WPT) technologies play a crucial role in addressing two significant challenges faced by battery-powered devices: limited battery life and high initial costs. For example, while many electric vehicle (EV) manufacturers assert that their vehicles can travel over 120 km on a single charge, drivers often experience range anxiety, resulting in trip limitations to around 100 km. Although extending the driving range to over 400 km is possible by adding more batteries, this approach substantially increases the initial cost, making EVs less accessible to the general public. Rather than relying on future advancements in energy storage technology, WPT is gaining traction as a viable solution to overcome these battery limitations. With WPT, battery-powered devices can wirelessly harness energy from electromagnetic fields in the environment, enabling them to charge without cords—even while in motion. This innovative technology has the potential to resolve the issues of short battery life due to limited storage capacity and to lower the high upfront costs linked to installing multiple batteries.

In recent years, the field of inductive or wireless power transfer (WPT) has experienced substantial growth, particularly with the annual development of higher-power systems. While WPT encompasses a wide range of applications, the domain of high-power wireless power transfer (HPWPT) has become a distinct area of focus as industries and researchers investigate its potential for use in buses, automobiles, trains, and other modes of transportation. These systems are being proposed as technological solutions to overcome the challenges of electric storage and driving range that currently limit the electric transportation sector. For the purposes of this paper, HPWPT is defined as systems capable of wirelessly delivering at least 20 kW of power to a battery.

The development of higher-power chargers is essential for the widespread adoption of electric vehicles (EVs). Whether through wired or wireless systems, the infrastructure needed to support large-scale EV implementation must be robust, convenient, and adaptable to minimize the reliance on large onboard energy storage—currently a significant barrier for battery electric vehicles (BEVs). Public surveys consistently reveal concerns about driving range and charging times associated with EV usage. High-power charging is crucial for reducing the long charging durations, which can take approximately 8 hours to cover 100 miles of driving using a Level II charger. Larger electrified vehicles, such as delivery trucks or tractor-trailers, may require up to 140 kW of battery power, necessitating even higher charging capacities to ensure reasonable charging times. Although most high-power wireless power transfer (HPWPT) systems currently operate at around 50 kW per unit, it is possible to connect multiple modules in parallel to achieve charging capacities of up to 200 kW. Cost-effectiveness is vital for industry adoption, and many real-world applications of these systems are already found in electric buses, which charge while stopping over dedicated charging coils during their routes. In many cases, these systems have demonstrated greater affordability than traditional diesel buses while providing a more environmentally friendly option for urban areas.

Multi-criteria decision making (MCDM) has emerged as one of the fastest-growing fields in recent decades, driven by changes in the business landscape. Decision makers frequently seek support tools to rapidly evaluate alternatives and efficiently eliminate less favorable options. The rise of computer technology has facilitated the widespread adoption of decision-making methods across various domains. MCDM has found particular resonance in operations research and management science, resulting in the development of numerous methodologies. In recent years, the growing availability of computer resources has greatly simplified the application of MCDM methods for decision makers, who often encounter complex mathematical processes in their analyses.

2. MATERIAL AND METHODS

In high-power wireless power transfer (HPWPT), design decisions are heavily influenced by the specific application at hand. Key trade-offs include the magnetic coupling coefficient (k) in relation to the airgap (the distance between the primary and secondary coils), the design of the coupler and tuning compensation, switching frequency, core and shielding losses, thermal management, and stray electromagnetic fields. These factors are particularly important when designing systems for various modes of transportation, such as automobiles, buses, or trains, each of which has different spatial and airgap requirements. For example, magnetic coupling, which improves with larger couplers and shorter airgaps, significantly affects the system's energy transfer efficiency. However, compact designs—often necessary in vehicles—can limit the power transfer capacity by constraining the size of the secondary coupler. Buses, for instance, can support multiple integrated coils, effectively increasing the coupler area and enabling higher power transfer, whereas cars typically have less space, limiting power to around 50 kW. Furthermore, if the vehicle's onboard battery or battery management system (BMS) is not equipped to handle high input power, especially in retrofitted systems, this can further restrict the ability to achieve greater power levels.

The overall design of high-power wireless power transfer (HPWPT) systems is heavily influenced by the intended application, whether static or dynamic. The concept of transferring energy to moving vehicles has been a key focus in this area, as highlighted by early pioneering research. Nevertheless, static charging remains appealing due to its efficiency and cost-effectiveness. Ideally, both charging approaches should utilize interoperable, factory-installed couplers that operate on the same frequencies and standards. Alternatively, dual-frequency systems could be developed to switch between two frequencies depending on operational requirements, though this would require additional components like switches and tuning capacitors. For HPWPT to succeed, gaining acceptance from major industry stakeholders, automakers, and regulatory agencies is crucial. Without widespread industry adoption, aftermarket systems—currently available from only a handful of companies—are likely to remain niche products, restricting the technology's broader impact. To fully develop HPWPT, substantial capital investments from key stakeholders are essential, and several companies have already begun taking steps toward this goal. A brief overview of such systems relevant to transportation, including examples from both commercial and academic institutions, is presented in Table 1.

TABLE 1. Recent High-Power Wireless Power Transfer Systems

Institute/Company	Power per Pickup (kW)	Airgap (mm)	Efficiency (%)	Frequency (kHz)
KAIST	22	200	71	20
WAVE	50	178	92	23.4
ETH Zurich	50	100-200	95.8	85
Fraunhofer	22	135	97	100
KRRI	818	50	82.7	60
INTIS	30	150	90	35
Showa Aircraft Co	30	150	92	22
NYU	25	210	91	85
Conductix Wampfler	120	40	90	20

Table 1 presents recent high-power wireless power transfer (HPWPT) systems from various institutes and companies, showcasing their respective specifications. KAIST achieves a power output of 22 kW with an airgap of 200 mm and an efficiency of 71% at a frequency of 20 kHz. WAVE demonstrates a higher power output of 50 kW, operating at an airgap of 178 mm with impressive efficiency of 92% at 23.4 kHz. ETH Zurich also provides 50 kW, with an airgap ranging from 100 to 200 mm and a remarkable efficiency of 95.8% at 85 kHz. Fraunhofer offers a power output of 22 kW with a 135 mm airgap and a high efficiency of 97% at 100 kHz. The Korea Railroad Research Institute (KRRI) stands out with an impressive power per pickup of 818 kW, although its efficiency is 82.7% at a close airgap of 50 mm and a frequency of 60 kHz. INTIS and Showa Aircraft Co both provide 30 kW, with airgaps of 150 mm, efficiencies of 90% and 92%, and frequencies of 35 kHz and 22 kHz, respectively. New York University (NYU) produces 25 kW with a 210 mm airgap and an efficiency of 91% at 85 kHz. Lastly, Conductix Wampfler showcases the highest power output of 120 kW, with a minimal airgap of 40 mm, achieving 90% efficiency at 20 kHz.

TOPSIS method: Today, the TOPSIS technique is applied across various fields, including energy, medicine, engineering and manufacturing systems, safety and environmental studies, chemical engineering, and water resource management. Chen and Hwang expanded on the TOPSIS method, introducing a new model. Zulqarnain et al. developed a graphical representation of the TOPSIS method to facilitate the selection of medical clinics for disease diagnosis. Additionally, to address uncertain data, Chen modified TOPSIS for Group Decision Making in a fuzzy context, employing this new approach for decision-making. In this context, the importance weights of multiple criteria and the ratings of alternatives concerning these criteria were treated as linguistic variables and assessed by a group of decision-makers. TOPSIS is a widely utilized evaluation method for addressing multi-criteria decision-making (MCDM) problems. It finds applications in various fields, including comparing company performances, analyzing financial ratios within industries, and evaluating financial investments in advanced manufacturing systems. However, TOPSIS does have certain limitations. Many improvements to the original method have centered on refining the weighting system to better adjust the R value, while others have focused on enhancing the R value formula, such as through the "Miqiezhi" method. Given the complexity of evaluation problems, there is a demand for a more accessible approach to understanding the relationship between the R value and alternative evaluations. This report presents a novel modified TOPSIS (M-TOPSIS) method, which calculates the distance between alternatives and reference points in the D+ D− plane and constructs an R value to assess the quality of the alternatives. Decision making is the optimal process for selecting the best alternative among various feasible options. In many situations, the number of criteria involved in decision making is significant, leading to the challenge that these criteria often conflict with one another, making it impossible to satisfy all criteria at once. To address such challenges, decision-makers turn to multi-criteria decision-making (MCDM) methods. One approach for solving MCDM problems, introduced by Hwang and Yoon, is known as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The fundamental principle of this technique is that the selected alternative should be the one that is closest in geometrical distance to the Positive Ideal Solution (PIS) and farthest from the Negative Ideal Solution (NIS).

3. RESULTS AND DISCUSSIONS

TABLE 2. Normalized Data

	Power per Pickup	Air gap	Efficiency	Frequency
KAIST	0.0264	0.4411	0.2648	0.1134
WAVE	0.0601	0.3926	0.3432	0.1327
ETH Zurich	0.0601	0.3308	0.3573	0.4819
Fraunhofer	0.0264	0.2977	0.3618	0.5670
KRRI	0.9834	0.1103	0.3085	0.3402
INTIS	0.0361	0.3308	0.3357	0.1984
Showa Aircraft Co	0.0361	0.3308	0.3432	0.1247
NYU	0.0301	0.4631	0.3394	0.4819
Conductix Wampfler	0.1443	0.0882	0.3357	0.1134

Table 2 presents the normalized data for various high-power wireless power transfer (HPWPT) systems, focusing on four key parameters: power per pickup, air gap, efficiency, and frequency. KAIST has a normalized power per pickup value of 0.0264, with an air gap of 0.4411, an efficiency of 0.2648, and a frequency of 0.1134. WAVE exhibits higher values with a power per pickup of 0.0601, an air gap of 0.3926, an efficiency of 0.3432, and a frequency of 0.1327. ETH Zurich shares the same power per pickup value of 0.0601, but benefits from a smaller air gap of 0.3308, a higher efficiency of 0.3573, and a significantly improved frequency of 0.4819. Fraunhofer mirrors KAIST's power per pickup at 0.0264, with a reduced air gap of 0.2977, an efficiency of 0.3618, and a frequency of 0.5670. The Korea Railroad Research Institute (KRRI) shows a remarkable normalized power per pickup of 0.9834, accompanied by an air gap of 0.1103, an efficiency of 0.3085, and a frequency of 0.3402. INTIS and Showa Aircraft Co both have a normalized power per pickup of 0.0361, with identical air gaps of 0.3308, efficiencies of 0.3357 and 0.3432, respectively, and frequencies of 0.1984 and 0.1247. New York University (NYU) registers a power per pickup of 0.0301, an air gap of 0.4631, an efficiency of 0.3394, and a frequency of 0.4819. Finally, Conductix Wampfler has a power per pickup of 0.1443, the smallest air gap of 0.0882, an efficiency of 0.3357, and a frequency of 0.1134.

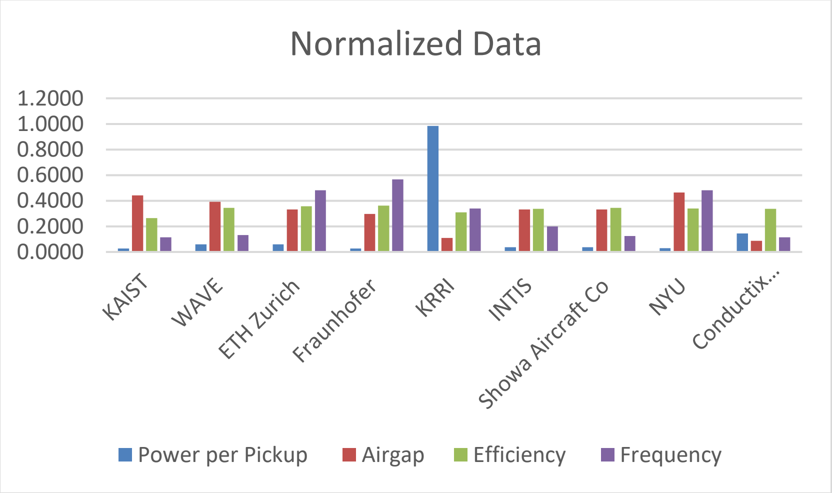

FIGURE 1. Normalized Data

The figure 1 normalized data presented in the table highlights key performance metrics for various institutes involved in research or development related to energy systems. Each metric—Power per Pickup, Air Gap, Efficiency, and Frequency—provides insight into the capabilities and operational efficiency of the different entities. For instance, KRRI stands out with a significantly higher value in Power per Pickup (0.9834), indicating its strong performance in harnessing energy. In contrast, Conductix Wampfler has the lowest Air Gap value at 0.0882, suggesting a potentially tighter operational design. Overall, the data reflects a diverse range of efficiencies and operational characteristics among the institutes, emphasizing the varying approaches to energy optimization in their respective fields. This comparative analysis can serve as a valuable foundation for further research or decision-making in selecting suitable partners or technologies in energy-related projects.

TABLE 3. Weight

	Power per Pickup	Airgap	Efficiency	Frequency
KAIST	0.25	0.25	0.25	0.25
WAVE	0.25	0.25	0.25	0.25
ETH Zurich	0.25	0.25	0.25	0.25
Fraunhofer	0.25	0.25	0.25	0.25
KRRI	0.25	0.25	0.25	0.25
INTIS	0.25	0.25	0.25	0.25
Showa Aircraft Co	0.25	0.25	0.25	0.25
NYU	0.25	0.25	0.25	0.25
Conductix Wampfler	0.25	0.25	0.25	0.25

Table 3 illustrates the weights assigned to the key parameters of various high-power wireless power transfer (HPWPT) systems, including power per pickup, air gap, efficiency, and frequency. Each of the systems—KAIST, WAVE, ETH Zurich, Fraunhofer, KRRI, INTIS, Showa Aircraft Co, New York University (NYU), and Conductix Wampfler—has been assigned an equal weight of 0.25 for all four parameters. This uniform weighting reflects a balanced approach to evaluating these systems, suggesting that each criterion is considered equally important in the assessment process. By maintaining this equal weight distribution, decision-makers can comprehensively analyze the performance and characteristics of each HPWPT system without bias towards any single parameter.

TABLE 4. Weighted normalized decision matrix

	Power per Pickup	Airgap	Efficiency	Frequency
KAIST	0.0066	0.1103	0.0662	0.0283
WAVE	0.0150	0.0981	0.0858	0.0332
ETH Zurich	0.0150	0.0827	0.0893	0.1205
Fraunhofer	0.0066	0.0744	0.0905	0.1417
KRRI	0.2458	0.0276	0.0771	0.0850
INTIS	0.0090	0.0827	0.0839	0.0496
Showa Aircraft Co	0.0090	0.0827	0.0858	0.0312
NYU	0.0075	0.1158	0.0849	0.1205
Conductix Wampfler	0.0361	0.0221	0.0839	0.0283

Table 4 presents the weighted normalized decision matrix for various high-power wireless power transfer (HPWPT) systems, quantifying their performance across key parameters: power per pickup, air gap, efficiency, and frequency. The values have been calculated by applying the weights from Table 3 to the normalized data from Table 2. For instance, KAIST exhibits a weighted value of 0.0066 for power per pickup, 0.1103 for air gap, 0.0662 for efficiency, and 0.0283 for frequency. Similarly, WAVE shows weighted values of 0.0150 for power per pickup, 0.0981 for air gap, 0.0858 for efficiency, and 0.0332 for frequency. ETH Zurich and Fraunhofer also present competitive figures across the metrics, with ETH Zurich achieving notable scores of 0.0150 for power per pickup and 0.1205 for frequency. This weighted normalized decision matrix provides a comprehensive view of how each system performs relative to the established criteria, enabling informed comparisons and evaluations among the different HPWPT technologies.

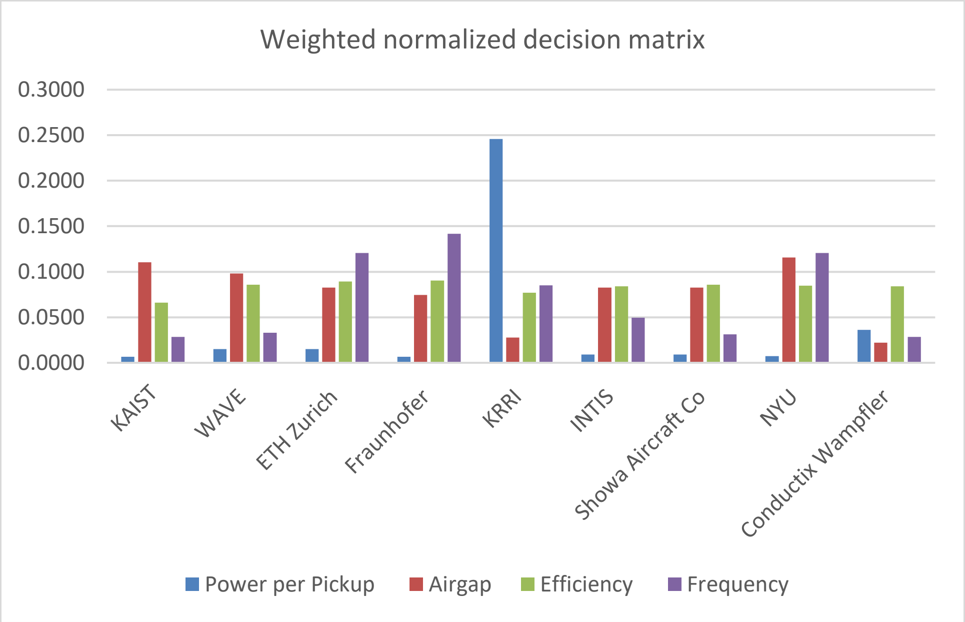

FIGURE 2. Weighted normalized decision matrix

The figure 2 showed weighted normalized decision matrix presented in Table 4 illustrates the performance of various institutes across four critical metrics: Power per Pickup, Air Gap, Efficiency, and Frequency. Each entry reflects the relative importance of these metrics in the context of decision-making for energy systems. Notably, KRRI has a dominant value for Power per Pickup at 0.2458, underscoring its exceptional capability in energy harnessing compared to other institutes. Conversely, Conductix Wampfler exhibits the lowest scores in both Air Gap (0.0221) and Power per Pickup (0.0361), indicating potential limitations in its design and operational efficiency. Fraunhofer stands out with a strong performance in Frequency (0.1417), suggesting its effectiveness in maintaining operational consistency. Overall, this matrix enables a comprehensive comparison of the institutes, facilitating informed decision-making regarding collaboration or investment in energy technologies based on their weighted performance across critical criteria.

TABLE 5. Positive Matrix

	Power per Pickup	Airgap	Efficiency	Frequency
KAIST	0.2458	0.1158	0.0905	0.1417
WAVE	0.2458	0.1158	0.0905	0.1417
ETH Zurich	0.2458	0.1158	0.0905	0.1417
Fraunhofer	0.2458	0.1158	0.0905	0.1417
KRRI	0.2458	0.1158	0.0905	0.1417
INTIS	0.2458	0.1158	0.0905	0.1417
Showa Aircraft Co	0.2458	0.1158	0.0905	0.1417
NYU	0.2458	0.1158	0.0905	0.1417
Conductix Wampfler	0.2458	0.1158	0.0905	0.1417

Table 5 outlines the positive matrix for various high-power wireless power transfer (HPWPT) systems, representing the ideal performance levels across key evaluation parameters: power per pickup, air gap, efficiency, and frequency. In this table, all entries for each system are uniformly set at 0.2458 for power per pickup, 0.1158 for air gap, 0.0905 for efficiency, and 0.1417 for frequency. This uniformity suggests a theoretical benchmark that serves as a reference point for evaluating the performance of each system against an optimal scenario. The positive matrix facilitates the assessment of how closely each HPWPT system can approach these ideal values, allowing decision-makers to gauge potential areas for improvement and identify systems that align most closely with the desired performance standards in the field.

TABLE 6. Negative matrix

	Power per Pickup	Airgap	Efficiency	Frequency
KAIST	0.0066	0.0221	0.0662	0.0283
WAVE	0.0066	0.0221	0.0662	0.0283
ETH Zurich	0.0066	0.0221	0.0662	0.0283
Fraunhofer	0.0066	0.0221	0.0662	0.0283
KRRI	0.0066	0.0221	0.0662	0.0283
INTIS	0.0066	0.0221	0.0662	0.0283
Showa Aircraft Co	0.0066	0.0221	0.0662	0.0283
NYU	0.0066	0.0221	0.0662	0.0283
Conductix Wampfler	0.0066	0.0221	0.0662	0.0283

Table 6 presents the negative matrix for various high-power wireless power transfer (HPWPT) systems, which captures the least favorable performance levels across critical evaluation parameters: power per pickup, air gap, efficiency, and frequency. Each entry in this table is uniformly recorded as 0.0066 for power per pickup, 0.0221 for air gap, 0.0662 for efficiency, and 0.0283 for frequency. This uniformity establishes a benchmark for the lowest acceptable performance, allowing for a clear comparison between the HPWPT systems and a standard for underperformance. The negative matrix is essential for assessing the shortcomings of each system, as it enables decision-makers to identify areas needing improvement and understand how closely each alternative deviates from the desired performance thresholds. This comparison ultimately supports more informed decision-making in the evaluation of HPWPT technologies.

TABLE 7. SI Plus and Si Negative values

	SI Plus	Si Negative
KAIST	0.2659	0.0882
WAVE	0.2557	0.0792
ETH Zurich	0.2341	0.1130
Fraunhofer	0.2428	0.1272
KRRI	0.1057	0.2462
INTIS	0.2563	0.0667
Showa Aircraft Co	0.2635	0.0638
NYU	0.2393	0.1327
Conductix Wampfler	0.2563	0.0344

Table 7 displays the SI Plus and SI Negative values for various high-power wireless power transfer (HPWPT) systems, highlighting the performance metrics used for evaluation. The SI Plus values represent the idealized performance for each system, with KAIST achieving the highest score of 0.2659, followed closely by Showa Aircraft Co at 0.2635. On the other hand, the SI Negative values indicate the least favorable performance, with KRRI registering a notably low score of 0.2462, signifying areas where improvement is necessary. Other systems such as Fraunhofer and ETH Zurich show SI Negative values of 0.1272 and 0.1130, respectively, suggesting they are more aligned with acceptable performance thresholds. This dual representation of SI Plus and SI Negative values facilitates a comprehensive understanding of each system's strengths and weaknesses, aiding decision-makers in assessing overall system efficacy and guiding future improvements in HPWPT technology.

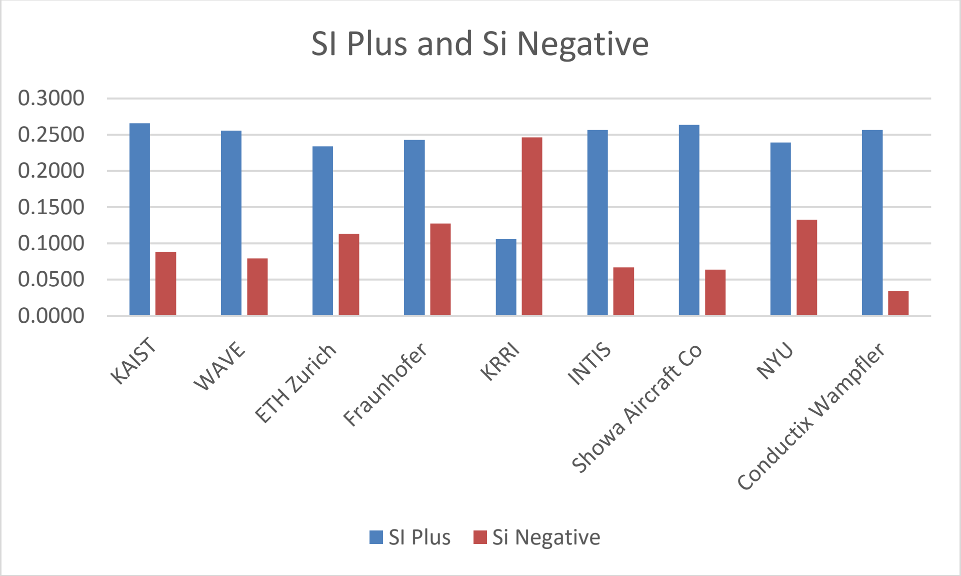

FIGURE 3. SI Plus and Si Negative values

Figure 3 showed presents the SI Plus and SI Negative values for various institutes, offering a nuanced perspective on their overall performance metrics. The SI Plus values represent the strengths of each institute, while the SI Negative values highlight their weaknesses. Among the institutes, KAIST leads with the highest SI Plus value of 0.2659, indicating its strong performance and positive attributes in the context of energy systems. In contrast, KRRI has the lowest SI Plus value at 0.1057, suggesting a need for improvement in its capabilities. On the other hand, KRRI also shows the highest SI Negative value of 0.2462, reflecting significant challenges or weaknesses that could hinder its operational efficiency. Conductix Wampfler, with the lowest SI Negative value at 0.0344, demonstrates a more balanced performance, suggesting fewer weaknesses relative to its strengths. This analysis of SI Plus and SI Negative values provides valuable insights for stakeholders seeking to identify potential collaborators or areas for development within the energy sector.

Table 8. Ci values

	Ci
KAIST	0.2491
WAVE	0.2364
ETH Zurich	0.3255
Fraunhofer	0.3439
KRRI	0.6996
INTIS	0.2065
Showa Aircraft Co	0.1950
NYU	0.3568
Conductix Wampfler	0.1182

Table 8 presents the CiC_iCi values for various high-power wireless power transfer (HPWPT) systems, which serve as a crucial metric for evaluating their overall performance. Among the systems listed, KRRI exhibits the highest CiC_iCi value of 0.6996, indicating a significant advantage in its operational efficiency and performance. Following closely, Fraunhofer and NYU show CiC_iCi values of 0.3439 and 0.3568, respectively, reflecting their strong capabilities as well. In contrast, Conductix Wampfler has the lowest CiC_iCi value at 0.1182, suggesting it may have areas that require considerable enhancement to compete effectively with the other systems. The CiC_iCi values provide valuable insights into the relative performance of each system, assisting decision-makers in identifying the most effective HPWPT solutions and highlighting opportunities for improvement in less competitive systems.

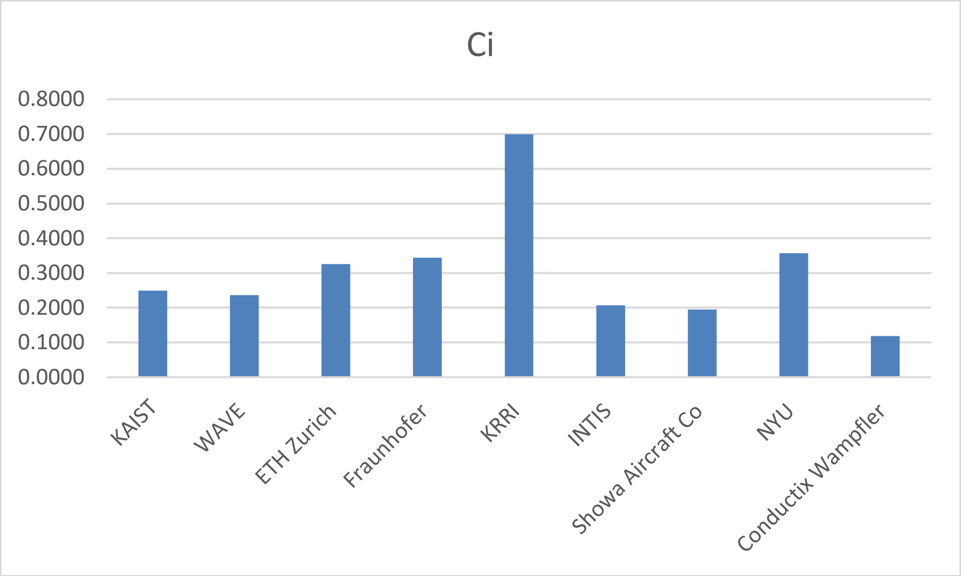

FIGURE 4. Ci values

Figure 4 displays the Ci values for various institutes, serving as a critical indicator of their overall performance in the context of energy systems. The Ci values reflect a composite score that integrates the strengths and weaknesses identified in previous analyses. Among the institutes, KRRI stands out with the highest Ci value of 0.6996, suggesting a significant competitive advantage or effectiveness in its operational capabilities. Conversely, Conductix Wampfler has the lowest Ci value at 0.1182, indicating potential challenges or inefficiencies that may need to be addressed. Notably, Fraunhofer and NYU also demonstrate strong performance with Ci values of 0.3439 and 0.3568, respectively, highlighting their relative strengths in the field. This evaluation of Ci values provides valuable insights for stakeholders looking to prioritize investments or collaborations in energy technologies, as it effectively summarizes the overall performance and competitive positioning of each institute.

Table 9. Ranking

	Rank
KAIST	5
WAVE	5
ETH Zurich	3
Fraunhofer	2
KRRI	1
INTIS	6
Showa Aircraft Co	8
NYU	2
Conductix Wampfler	9

Table 9 displays the ranking of various high-power wireless power transfer (HPWPT) systems based on their CiC_iCi values. KRRI is ranked first, indicating it as the most efficient system among those evaluated. Fraunhofer and NYU share the second position, demonstrating strong performance capabilities. ETH Zurich follows closely in third place, showcasing its competitive edge. WAVE and KAIST are both tied in fifth place, reflecting similar performance levels. INTIS ranks sixth, while Showa Aircraft Co occupies the eighth position, indicating areas for improvement. Lastly, Conductix Wampfler is ranked ninth, suggesting it may require significant enhancements to elevate its performance relative to the other systems. This ranking provides a clear hierarchy of the systems, aiding stakeholders in decision-making and future development efforts.

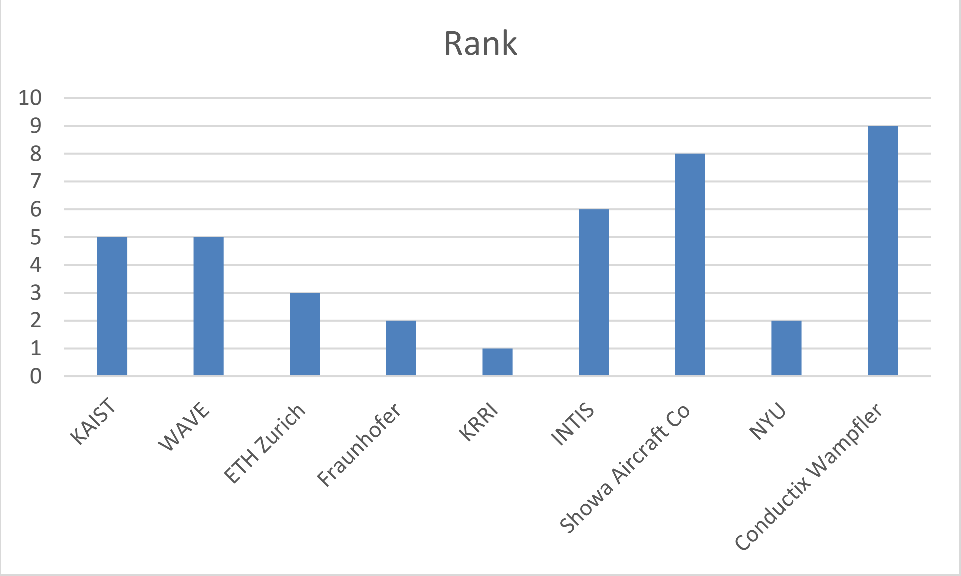

FIGURE 5. Ranking

Figure 5 presents the ranking of various institutes based on their performance in energy systems, as indicated by their composite Ci values. In this ranking, KRRI emerges as the top performer, securing the first position with its robust capabilities and effective operational strategies. Following closely are Fraunhofer and NYU, both tied for second place, reflecting their competitive strengths in the field. ETH Zurich ranks third, indicating a solid performance but slightly lower than the top three institutes. WAVE and KAIST are both tied for fifth place, demonstrating comparable effectiveness but falling short of the leading positions. Meanwhile, INTIS and Showa Aircraft Co rank lower, at sixth and eighth respectively, while Conductix Wampfler occupies the ninth position, suggesting significant room for improvement in its overall performance. This ranking provides a clear hierarchy of the institutes, enabling stakeholders to identify potential partners and areas for development in the pursuit of advancements in energy technologies.

4. CONCLUSIONS

In conclusion, the evaluation of high-power wireless power transfer (HPWPT) systems demonstrates significant variability in performance across different institutions. The ranking of these systems, led by KRRI, highlights the importance of various design and operational factors, including power per pickup, airgap, efficiency, and frequency. The modified TOPSIS method effectively identifies and ranks these systems based on their relative performance metrics. The insights gained from this analysis not only assist in identifying the most efficient systems but also inform future design considerations and potential improvements in HPWPT technology. As the demand for efficient energy transfer solutions grows, particularly in the transportation sector, the findings underscore the necessity for continued research and collaboration among academic and commercial entities to enhance the performance and adoption of HPWPT systems. This research highlights the critical role of High-Power Wireless Power Transfer (HPWPT) systems in the transition toward sustainable electric mobility. By employing the modified TOPSIS methodology, we evaluated various HPWPT technologies based on key performance indicators such as power per pickup, airgap, efficiency, and frequency. The findings reveal that the KRRI system outperformed others, demonstrating superior power output and efficiency, while Conductix Wampfler ranked lower due to its limitations.

These results emphasize the importance of a structured decision-making framework for stakeholders, including automotive manufacturers and policymakers, to identify and invest in optimal charging solutions. Furthermore, this study underscores the need for ongoing research to enhance HPWPT technologies, focusing on advanced materials, dynamic charging capabilities, and integration with renewable energy sources. As electric vehicle adoption accelerates, the insights gained from this analysis will facilitate the development of efficient and effective charging infrastructures, ultimately contributing to a sustainable transportation ecosystem. Continued collaboration among industry stakeholders will be essential to overcome challenges and fully realize the potential of HPWPT systems in supporting the electrification of mobility.

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