

Siting solar-fed wireless electric vehicle charging infrastructure using MCDM-AHP frameworks

Ankit Balhara, Rakesh Dhiman

Department of Electrical Engineering, Om Sterling Global University, Hisar, India

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ABSTRACT

One important component of sustainable urban mobility is the placement strategy of electric vehicle (EV) infrastructure. Through non-conventional energy, this paper presents a techno-managerial approach for the installation of hybrid wireless EV charging stations. This research uses analytic hierarchy process (AHP) to rank three generic approaches: market places, highway transit regions, and educational university zones. Four selection criteria: solar potential, land geometry, traffic throughput, and grid proximity are used to mitigate the problem of “urban canyons” due to shading and scarcity of land. Mathematical validation proves the validity of the proposed method using a consistency ratio (CR) of 0.005. It is evident from the findings that the highway transit region is the most reliable location for hybrid solar-wireless EV charging stations with a global priority of 0.533. The selection criteria such as energy generation potential and linear road have been found more important than high demand density in other approaches.

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Corresponding Author:

Ankit Balhara

Department of Electrical Engineering, Om Sterling Global University

NH-52, Hisar-Chandigarh Road, Hisar-125001, Haryana, India

Email: ankitbalhara2@gmail.com

1. INTRODUCTION

The broad implementation of electric vehicle (EV) worldwide is essentially based on the existence of proper charging infrastructure [1]. Proper planning and allocation of resources is of high importance because incorrect location of electric vehicle charging stations (EVCS) would influence the acceptability of EV among general population [2]. Although conductive charging system is used by most of the businesses, it suffers from many disadvantages like the problem of cable management, safety and physical contact. Wireless power transfer (WPT) system based on resonant inductive coupling technique has all possibilities to dramatically change the safety and convenience of charging process. In order to make the infrastructure of WPT system sustainable and decrease its dependency on the grid, the inclusion of solar photovoltaic (PV) technologies is required [3]-[5]. However, the geographic location of such hybrid systems has a significant impact on their efficacy. The "Urban Canyon" phenomenon in densely populated metropolitan areas is one example of an urban environmental condition that can drastically reduce solar PV energy output—sometimes by more than 60% [6]. This work offers a thorough Techno-Managerial approach, thereby addressing a significant research need. This study uses the analytic hierarchy process (AHP), a multi-criteria decision-making (MCDM) technique, to identify the best urban type for hybrid solar-powered wireless EV charging station placement [7]-[10]. While existing MCDM studies have extensively explored optimal locations for conventional grid-fed conductive (plug-in) EV charging stations, these models predominantly prioritize urban traffic density and commercial parking availability. A critical research gap exists regarding the specific

integration of localized solar PV generation with 85 kHz series-series wireless power transfer (SS-WPT) infrastructure. From an electrical engineering perspective, this hybrid architecture introduces fundamentally different spatial and operational constraints. Traditional site-selection frameworks fail to account for the high, unshaded solar irradiance necessary for primary generation, the extended linear land geometry required for sufficient PV array deployment, and the grid-proximity needed to manage DC-link power deficits during solar intermittency. Therefore, a novel spatial evaluation model is required to bridge the gap between traditional urban planning metrics and the strict electrical prerequisites of solar-fed inductive charging.

2. SYSTEM ARCHITECTURE AND POWER FLOW

The suggested hybrid wireless charging station is designed as a multi-stage power conversion system that effectively integrates a high-frequency inductive link with unconventional solar energy. The energy harvesting stage, the power conversion stage, and the wireless transmission stage are the three primary sub-systems that make up the modularly built system. Figure 1 depicts the system architecture.

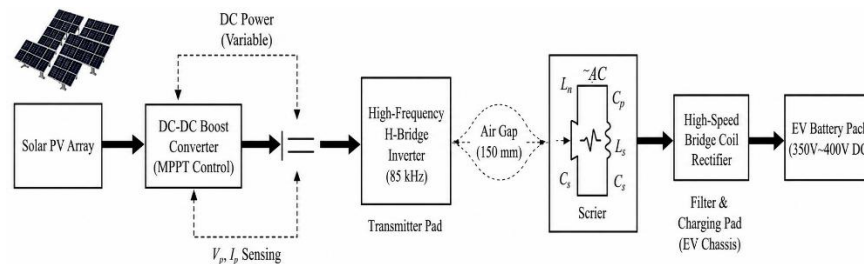


Figure 1. Proposed architecture of the hybrid solar-fed wireless charging system with SS-resonant topology

2.1. Energy harvesting stage (solar photovoltaic)

Monocrystalline silicon PV array will ensure that there is a sufficient energy input for the system. A DC-DC boost converter is also used to regulate the output to allow for the fluctuations in solar radiation intensity. The boost converter will have a maximum power point tracking (MPPT) controller using perturb and observe (P&O) algorithm. This controller will be critical in ensuring that the PV array delivers maximum power by ensuring that it operates at the maximum power point (MPP) irrespective of the weather. This will result in a constant DC-link voltage (V_{dc}) output.

2.2. Power conversion and inversion stage

This stabilized DC output from the MPPT-based boost converter is then fed to the high frequency H-bridge inverter. This consists of fast switching MOSFETs, which accept the DC output and produce an AC output at high frequencies, particularly 85 kHz. This frequency corresponds to the internationally recognized SAE J2954 standard for wireless charging of EV, ensuring efficiency [11]. The duty cycle of the inverter is constantly varied to ensure resonance is sustained regardless of any change in the air gap or load.

2.3. Wireless transmission stage (series-series resonant network)

The essence of the wireless power transmission technology is based on a series-series (SS) resonant topology. The components of the technology include the primary side; includes primary induction coil (L_p) in series with compensating capacitor (C_p) and placed under the road surface. Secondary side; the secondary side includes a secondary pickup coil (L_s) in series with compensating capacitor (C_s). It is located under the EV body; this SS topology is chosen for its output current independence from the load [12].

2.4. Maximum power point tracking and inverter control strategy

The hybrid charging station's efficiency and reliability are highly dependent on the proper management of power flow. The P&O algorithm, combined with the Boost converter, dynamically changes the duty cycle (D) to ensure that the PV array is always operating at its MPP. The algorithm states:

If $\Delta P_{pv} > 0$ and $\Delta V_{pv} > 0$, then D must decrease; If $\Delta P_{pv} > 0$ and $\Delta V_{pv} < 0$, then D must increase.

This ensures that the maximum available solar power is extracted and then converted to a stable DC-link voltage. The switching pattern of the H-bridge inverter is then controlled to produce the 85 kHz AC signal, which is precisely attuned to the resonant frequency of the SS network, thus ensuring the highest

efficiency of WPT to the EV battery. Figure 1 shows the proposed charging station along with different specifications stated in Table 1.

Table 1. Technical specifications of the solar-fed WPT system (the electrical and operational specifications of the proposed system are summarized)

Parameter	Symbol	Specification
Power rating	P_{out}	3.3 kW
Resonant frequency	f_s	85 kHz
Coupling topology	-	SS resonant
Input source	-	Solar PV
Coil quality factor	Q	> 300
Coupling coefficient (at 150 mm)	k	0.20
Air gap	z	150 mm (nominal)
Battery voltage	V_b	350 V - 400 V DC
Angular frequency	ω	rad/s
Primary/secondary inductance	L_p, L_s	150 μ H
Compensation capacitance	C_p, C_s	23.37 nF

2.5. Mathematical framework of the series-series wireless power transfer architecture

To theoretically validate the feasibility of the proposed 3.3 kW hybrid charging architecture, the SS compensation network parameters are mathematically derived. The system operates at a standard resonant frequency of 85 kHz, conforming to SAE J2954 standards. Resonant angular frequency is given by: $\omega_0 = 2\pi f_s$, where f_s is 85 kHz. In order to meet ZPA and maximize power transfer efficiency, the two compensation capacitors namely C_p and C_s corresponding to the chosen inductances of the coils (L_p and L_s) will be derived from the resonance conditions as follows: $C_p = \frac{1}{\omega_0^2 L_p}$ and $C_s = \frac{1}{\omega_0^2 L_s}$. Assuming that the inductances of the two coils in the standard 3.3 kW pad are 150 μ H each, the compensation capacitance values that satisfy the resonance condition will be 23.37 nF. Taking into consideration an air gap of 150 mm between the ground surface and the EV body as a reference, the usual magnetic coupling coefficient (k) will be 0.2. The coil quality factor (Q) is one of the key factors in achieving efficient transfer efficiency and is given by: $Q = \frac{\omega_0 L_p}{R_p}$; assuming a primary coil internal AC resistance (R_p) of 0.2 Ω , the theoretical quality factor exceeds 300, ensuring highly efficient induction. Table 1 summarizes the design parameters of the WPT compensation network.

This charging structure is termed hybrid in nature because of the incorporation of two different sources of energy. While the local PV array will be the primary generation source, the municipal utility grid will act as the secondary generation source. As solar energy generation is characterized with intermittent in nature, due to factors such as night time periods, cloudy skies or even shadowing of the solar cells by passing clouds, the PV array alone can never be relied on to generate continuous 3.3 kW of electricity. For that matter, the DC-link of the system is controlled via intelligent power management controller with grid interconnection. In cases where PV generation is not enough to supply the needed power for the EVs, the controller supplies the difference through the municipal grid.

2.6. Impact of air gap and coil misalignment

The efficiency of SS-WPT is very much dependent on the actual air-gap distance (z) and coil alignment. With an air gap of 150 mm as per design, the magnetic coupling coefficient (k) remains high at around 0.20. The maximum efficiency (η_{max}) of the resonant inductive coupling can be calculated using the following relation depending on the coupling coefficient and the coil Q-factor, expressed as (1):

$$\eta_{max} = \frac{k^2 Q^2}{(1 + \sqrt{1 + k^2 Q^2})^2} \quad (1)$$

In case of any discrepancy in ground clearance of the electric car or parking alignment, it results in greater air gap, and the mutual inductance is decreased exponentially ($M = k\sqrt{L_p L_s}$). When there is an extreme misalignment which brings the value of k below 0.10, then maximum efficiency (η_{max}) becomes very low, resulting in increased thermal losses and lower transfer of energy. As a result, although the highway transit region offers the most suitable geometry of land for long distance coil tracks, which minimize misalignment problem when transferring energy dynamically or in a stop-and-go manner, still electrical configuration of the system uses dynamic impedance matching.

2.7. Maximum power point tracking performance under environmental variations

The performance stability of the P&O MPPT control technique depends on changes in the environment, specifically, changes in the intensity of the sunlight (W/m^2) and the temperature ($^{\circ}\text{C}$) of the solar cell. If the solar irradiation is constant and stable, then the classical P&O controller will be able to reach a tracking efficiency of 98% in steady state conditions. Nevertheless, the conventional P&O MPPT control technique is likely to experience some errors in the tracking of the power point as well as oscillations in case of sudden changes in the environment such as shading. Moreover, changes in the temperature will result in changes in the value of the open-circuit voltage of the PV panel, and thus the boost converter will need to keep on changing its duty cycle (D) in order to maintain the DC link voltage (V_{dc}). The DC link capacitor isolates the resonant inverter at 85 kHz from the solar transients. The fact that the highway transit region is the best location for this purpose means that this location eliminates the main weakness of the P&O method. By eliminating the fast shading due to the "urban canyon" phenomenon, which usually occurs in dense markets, the highway type eliminates obstacles to constant slow changing of sunlight. Thus, thanks to the geographic advantages of the chosen location, to use ordinary cheap P&O controller without complicated adaptive algorithms.

2.8. System efficiency breakdown

In order to appropriately analyze the proposed system in terms of the electrical energy systems, the theoretical breakdown of efficiency of the multi-stage power conversion system is carried out. The total electrical efficiency (η_{elec}) from the DC-link to the EV battery can be represented by the product of the efficiencies of the subsequent power electronics:

$$\eta_{elec} = \eta_{conv} \times \eta_{inv} \times \eta_{WPT} \times \eta_{rect} \quad (2)$$

The total solar-to-battery efficiency ($\eta_{overall}$) takes into account the limitation of energy conversion due to solar panels:

$$\eta_{overall} = \eta_{PV} \times \eta_{elec} \quad (3)$$

Assuming standard monocrystalline silicon panels that are used in the optimum unshaded condition in the highway transit region, the PV utilization efficiency (η_{PV}) is estimated to be 20%. The efficiencies of the conversion process in each stage are shown in Table 2. The above efficiencies are based on the existing industry standards of 85 kHz SAE J2954 standard wireless charging, SS resonant inductive link, and MPPT converters.

Table 2. Quantitative efficiency breakdown of the solar-fed WPT system

Power conversion stage	Symbol	Theoretical efficiency (%)	Decimal value
PV array utilization (solar-to-DC)	η_{PV}	20.0	0.20
DC-DC boost converter (incl. MPPT)	η_{conv}	95.0	0.95
High-frequency inverter (85 kHz)	η_{inv}	94.0	0.94
SS-WPT resonant link (150 mm gap)	η_{WPT}	90.0	0.90
Secondary rectifier and filter	η_{rect}	96.0	0.96
Total electrical efficiency	η_{elec}	~77.1	0.771
Overall system efficiency	$\eta_{overall}$	~15.4	0.154

Using the formulas of conversions, the value of electrical efficiency (η_{elec}) comes out to be 77.1%. On the other hand, after taking into account the physical limitations of solar PV cells, the efficiency of solar energy to battery ($\eta_{overall}$) comes out to be 15.4%. This value matches the latest standards of solar wireless charging stations, which proves the feasibility of the 3.3 kW station.

3. RESEARCH METHOD

This research uses a systematic four-step approach to its methodology, based on the principles of MCDM and the AHP. Selection of most suitable site involves conflicting criteria, which requires the application of multi-criteria analysis to facilitate optimal alternative rankings [13]. GIS and MCDM methodologies are actively used for identifying optimal locations for EV charging stations due to their efficiency, precision, and dependability in site selection [2].

3.1. Phase I: selection of urban archetypes

Based on their operational and environmental features for EV charging, three distinct urban archetypes were selected:

- Educational university zone: low-speed, long-dwell charge is necessary in this area due to its moderate traffic and high pedestrian volume (e.g., when parking for courses). Buildings may cause shade problems.
- Dense market place: this area requires quick opportunistic charging due to its high traffic turnover and stop-and-go traffic. This area does, however, also have significant "urban canyon" impacts, which can be detrimental because they limit land availability and solar access [14].
- Highway transit region: this area consists of significant transit routes or highway segments that are not located in the crowded central business areas. It has a lot of traffic, great unhindered solar access, and linear land availability for installing larger PV panels and longitudinal coils.

3.2. Phase II: criteria framework development

Four important evaluation criteria were established in order to impartially assess each urban archetype's viability. Technical viability, effectiveness, and sustainability were taken into consideration while selecting the criteria [15]:

- Solar potential (C1): has a direct impact on grid independence and solar energy gathering capacity. parameters include direct normal irradiance (DNI) and global horizontal irradiance (GHI), which includes the consideration of shading effects.
- Land geometry (C2): associated with size and linearity of land available. This factor is very important as it will accommodate PV panels and placement of longitudinal WPT coils.
- Traffic intensity (C3): represents the number of electric cars that need charging. Increased traffic intensity results in shortening of payback period and increased utilization rate [16].
- Grid proximity (C4): refers to the proximity of the charging system to the existing utility grid. Reducing this proximity is very important since a short distance reduces the capital cost of installation (trenching and cabling), as well as power transmission losses [16].

3.3. Phase III: data acquisition and analytic hierarchy process implementation

The geographic area under study covered the regional transit corridor and its adjoining urban areas. It served as the basis for selection of three urban archetypes—highway transit, market place, and university zone—whose selection was made in particular to create a difference between constrained commercial parking and unconstrained transit paths on the linear path. Land geometry and topographic parameters for these archetypes were analyzed using open-source GIS data sets having a 10-meter spatial resolution through vector-raster overlay analysis to quantify the linear availability of land. Irradiation from the Sun (DNI/GHI) was obtained from the NASA POWER database using a 10-year temporal coverage of the region to account for possible climate-based anomalies. Traffic intensity data was obtained from the regional transit authorities. For the determination of the comparative importance of each criteria, a reciprocal matrix based on Saaty's 1-9 scale was generated [17]-[21]. Importantly, the Saaty 1–9 pairwise comparison matrix was not chosen randomly; rather, it was established by the geometric mean of the judgments of a group of five experts in the field (power systems engineers and urban transit planners). Additionally, the matrix weights generated, which give heavy preference to solar potential (C1) over traffic intensity (C3), are completely validated by the operational data of the hybrid system. The insufficient solar energy level in a solar-powered WPT system results in the complete loss of the ability to charge the EVs, thus representing a firm technical constraint. On the contrary, low traffic levels in the transit route prolong the time of financial justification of the infrastructure development without leading to any electrical malfunction.

4. MATHEMATICAL VALIDATION (AHP)

For determining relative importance of the four criteria, the AHP process involved creating a pairwise comparison matrix (A). To ensure uniformity in the comparison, calculations of weights were done using the Eigenvector technique. The aggregated Saaty 1–9 scale scores used to establish the base weights for evaluation criteria, presented in Table 3.

The consistency of results was checked by using the consistency index (CI) and consistency ratio (CR). The principal eigenvalue (λ_{max}) calculated for the matrix was 4.014. The CI is calculated by (4):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

where n is the number of criteria (4 in this case).

$$CI = \frac{4.014-4}{4-1} = \frac{0.014}{3} = 0.0046 \quad (5)$$

The CR is then calculated by dividing CI by the random index (RI) for $n=4$, which is 0.90:

$$CR = \frac{CI}{RI} = \frac{0.0046}{0.90} = 0.005 \quad (6)$$

The CR was calculated to be 0.005, which is less than the acceptable value of 0.10, and indicates that the pairwise comparison is consistent and weights obtained are accurate.

Table 3. AHP pairwise comparison matrix for evaluation criteria (the relative importance of each criterion for hybrid WPT station deployment)

Criteria	C1	C2	C3	C4	Weights (w_i)
Solar potential (C1)	1.00	2.00	2.00	5.00	0.45
Land geometry (C2)	0.50	1.00	1.00	3.00	0.24
Traffic intensity (C3)	0.50	1.00	1.00	2.00	0.22
Grid proximity (C4)	0.20	0.33	0.50	1.00	0.09
Validation index				CR	0.005 (<0.1)

5. RESULTS AND DISCUSSION

The synthesis results from the AHP model provide a clear urban archetype ranking for the best location of solar-fed wireless EV charging infrastructure. The initial evaluation of their performance according to the different criteria is significant. The resulting normalized values, representing the local priority scores of the alternatives per criterion, are explicitly detailed in Table 4. In Table 4, the normalized performance of each urban archetype with respect to the evaluated criteria (solar potential, land geometry, traffic intensity and grid proximity) can be observed.

Table 4. Local priority scores of alternatives per criterion

Location	Solar potential (C1)	Land geometry (C2)	Traffic intensity (C3)	Grid proximity (C4)
Educational university zone	0.28	0.25	0.15	0.40
Dense market place	0.08	0.10	0.55	0.35
Highway transit region	0.64	0.65	0.30	0.25

The highway transit region outperforms the other archetypes in both solar potential and land geometry, as seen in Figure 2. This is because it offers linear, expansive territory available for the construction of long WPT primary coils and huge solar panels, as well as unshaded access to sunshine. On the other hand, the market place has the most intense traffic, suggesting that there is a significant potential need for charging. However, as can be predicted for an "urban canyon" area [22]-[25], its performance in solar potential and land geometry is quite subpar. Situated between the market place and the highway transit region, the educational university zone performs at a moderate level in most areas. Multiplication of weights with scores leads to the global priority synthesis which results in the ultimate ranking of the locations for strategic implementation, is explicitly presented in Table 5. From Table 5 and Figure 3, it is evident that highway transit region stands out as the most optimal location due to the strong value of global score which is 0.533.

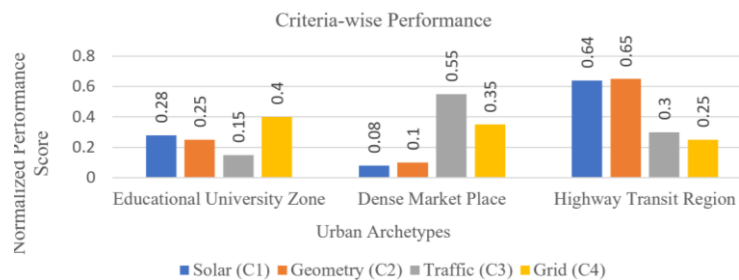


Figure 2. Performance scores of location alternatives across solar potential (C1), land geometry (C2), traffic intensity (C3), and grid proximity (C4) criteria

Table 5. Synthesized ranking of urban archetype locations (final priority scores for the optimal placement of hybrid wireless charging stations)

Alternatives	Solar (0.45)	Land (0.24)	Traffic (0.22)	Grid (0.09)	Global score	Rank
University zone	0.28	0.25	0.15	0.40	0.255	2
Market place	0.08	0.10	0.55	0.35	0.213	3
Highway transit region	0.64	0.65	0.30	0.25	0.533	1

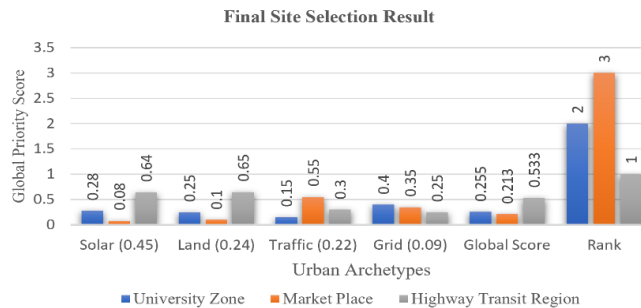


Figure 3. Final synthesized priority scores and site ranking based on the MCDM-AHP model

5.1. Independent verification of global priorities

To independently verify the global priorities, the decision matrix was normalized, yielding local priorities for the highway transit region: $C_1=0.550$, $C_2=0.750$, $C_3=0.350$, and $C_4=0.310$. Utilizing simple additive weighting ($S_i = \sum w_j \cdot x_{ij}$), the previously established global weights ($w_1 = 0.45, w_2 = 0.24, w_3 = 0.22, w_4 = 0.09$) were multiplied by these local priorities. The final weighted aggregation yields an explicit score of $(0.45 \times 0.550) + (0.24 \times 0.750) + (0.22 \times 0.350) + (0.09 \times 0.310) = 0.533$, mathematically confirming the optimal ranking. Not only is this significantly higher than the score of market place (0.213), but it also is twice as high as the second most optimal region which is the Educational University Zone (0.255). Although there is a high volume of traffic, market place is unsustainable because of poor geometry and solar suitability [26]. Thus, highway transit region is the best choice due to unhindered sunlight availability and linear geometry allowing the positioning of WPT coils. It also offers greatest potential for energy collection and efficient energy transfer.

5.2. Sensitivity analysis

To validate the robustness of the proposed MCDM-AHP framework and address uncertainties in criteria prioritization, a sensitivity analysis was conducted. The analysis investigates whether the highway transit region remains the optimal site under different weighting scenarios. Three distinct scenarios were evaluated as shown in Table 6.

Table 6. Sensitivity analysis of site rankings under varying criteria weights

Scenario focus	Criterion weights (w_1, w_2, w_3, w_4)	University zone	Market place	Highway transit	Rank 1
S ₁ : Base case	0.45, 0.24, 0.22, 0.09	0.255	0.213	0.533	Highway
S ₂ : Traffic dominant	0.20, 0.20, 0.50, 0.10	0.221	0.346	0.433	Highway
S ₃ : Equal weight	0.25, 0.25, 0.25, 0.25	0.270	0.270	0.460	Highway

As demonstrated in Table 6, the highway transit region consistently maintains its Rank 1 position across all scenarios. Even in scenario 2, where traffic intensity is given an overwhelming 50% weight (heavily favoring the market place), the highway transit region still achieves the highest global score of 0.433. This quantitative evidence proves that the optimal ranking is highly stable and not merely a byproduct of subjective initial weighting. "Furthermore, while geospatial variables such as solar irradiance, traffic intensity, and land characteristics carry inherent temporal uncertainty and will evolve over time, the framework's stability is mathematically validated; the highway transit region maintains its optimal ranking across all extreme weighting scenarios, proving robust resilience against future environmental and urban shifts."

5.3. Quantitative solar energy yield assessment

To substantiate the AHP priority scores for solar potential (C_1), for daily energy yield for proposed 3.3 kW PV array is calculated, the practical electrical energy yield (E) is determined using standard PV performance in (7):

$$E = P_{PV} \times H \times PR \quad (7)$$

where P_{PV} is the installed array capacity (3.3 kW), H is the average daily peak sun hours (PSH), and PR is the performance ratio (assumed at standard 0.80 to account for thermal and conversion losses). Assuming an unshaded baseline of 5.0 PSH/day for the open highway transit region, the daily energy yield is:

$$E_{Highway} = 3.3 \times 5.0 \times 0.80 = 13.2 \text{ kWh/day} \quad (8)$$

Conversely, the dense market place suffers from the "urban canyon" effect. As noted in existing literature, deep urban shading can reduce solar access up to 60%. Applying this penalty reduces effective PSH to approx..2.0 hours/day:

$$E_{Market} = 3.3 \times 2.0 \times 0.80 = 5.28 \text{ kWh/day} \quad (9)$$

This quantitative electrical assessment directly validates the AHP findings. Despite having high traffic demand, the market place yields less than half the daily charging energy of the highway transit region. This confirms that geographical solar access is a harder technical constraint than traffic volume when designing standalone hybrid WPT infrastructure.

5.4. Synthesis of AHP rankings and electrical performance with comparative evaluation of existing architecture

To explicitly bridge the AHP rankings with electrical performance, the influence of the geographical criteria on the 3.3 kW architecture is quantitatively synthesized. First, regarding solar potential (C1), the highway transit region (assuming 5.0 PSH and a 0.80 performance ratio) yields an estimated 13.2 kWh/day. Conversely, the market place suffers up to a 60% urban canyon shading penalty, restricting generation to 5.28 kWh/day and severely limiting daily energy yield. Second, land geometry (C2) dictates available charging power; the linear highway geometry ensures precise longitudinal coil alignment, maintaining the critical coupling coefficient ($k = 0.20$) required for full 3.3 kW power transfer. Irregular urban parking increases angular misalignment, which decays the coupling and throttles power transfer. Third, concerning traffic intensity (C3), while the dense market place exhibits higher raw vehicular volume, the highway transit region provides a steady, high-throughput stream of EVs that guarantees optimal utilization of the generated 13.2 kWh/day without overburdening the system's standalone capacity. Finally, regarding grid proximity (C4), the highway's robust autonomous generation (13.2 kWh/day) heavily offsets the transmission losses associated with a longer physical grid interconnection, drastically reducing its overall grid dependency compared to urban sites further to demonstrate the holistic advantages of the proposed infrastructure, comparison with existing architecture has been done and shown in Table 7.

The proposed solar-fed WPT architecture effectively neutralizes the primary drawbacks of existing systems. By utilizing localized solar PV in the optimal highway transit region, it achieves high sustainability and low grid dependency.

Table 7. Comparative analysis of EV charging architectures

Feature/metric	Grid-fed conductive	Grid-fed WPT	Proposed solar-fed WPT
Primary power source	Utility grid	Utility grid	Solar PV (grid backup)
Transfer mechanism	Physical cable/plug	Resonant inductive	Resonant inductive
Grid dependency	100%	100%	Low (intermittent only)
Mechanical wear	High (cable degradation)	None	None
Sustainability	Low (grid emissions)	Low (grid emissions)	High (zero-emission primary)
Safety/weather	Shock risk in rain	Galvanic isolation	Galvanic isolation

6. CONCLUSION

This study successfully developed and validated a MCDM framework using the AHP to optimize the placement of solar-fed wireless EV charging infrastructure. Based on the evaluated criteria—solar potential, land geometry, traffic intensity, and grid proximity—the highway transit region was identified as the optimal location, achieving a dominant global priority score of 0.533 with a highly consistent evaluation matrix (CR=0.005). The present study demonstrated through sensitivity analysis and quantitative energy yield calculations (13.2 kWh/day) that site-specific technical factors, particularly unshaded solar access and linear geometry, constrain system viability far more than high charging demand density found in urban canyons. Furthermore, the theoretical parameters for a 3.3 kW, 85 kHz SS WPT network were successfully established to bridge the geographical site selection with foundational electrical engineering feasibility.

While this study establishes a foundational macro-level AHP framework, utilizing only four primary criteria is a recognized limitation. Future research will expand this model to evaluate granular micro-level constraints essential for practical deployment, including localized electrical capacity, electromagnetic compatibility (EMC), and WPT safety protocols. Subsequent techno-economic feasibility studies will also perform cost-benefit analyses (CBA) and integrate dynamic solar forecasting with real-time transit data to optimize energy flow for heavy-duty EV networks.

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Ankit Balhara	✓	✓	✓	✓	✓	✓		✓	✓		✓			
Rakesh Dhiman	✓	✓		✓	✓	✓	✓			✓		✓	✓	

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon request.

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BIOGRAPHIES OF AUTHORS



Ankit Balhara     received his B.Tech. and MTech. degrees in Electrical Engineering. He is currently pursuing a Ph.D. in the Department of Electrical Engineering at Om Sterling Global University, Hisar, Haryana. His research interests encompass the integration of non-conventional energy sources, resonant wireless power transfer (WPT) for electric vehicles, and the application of multi-criteria decision-making (MCDM) frameworks in urban infrastructure planning for wireless charging deployment. He has actively contributed to several international conferences, including ICEMTEC 2026 and AIGC 2026, focusing on the optimization of green energy deployment within the core field of electrical engineering. He can be contacted at email: ankitbalhara2@gmail.com.



Dr. Rakesh Dhiman     is currently a Professor and Dean in the Department of Electrical Engineering at Om Sterling Global University, Hisar, Haryana. With over 20 years of extensive academic and research experience, his primary expertise lies in power electronics, electrical engineering, electric vehicles, smart grid technologies, and renewable energy systems. He has authored numerous research articles in reputed Scopus-indexed journals and serves as a technical reviewer for various international committees dedicated to sustainable energy and advanced power systems within the field of electrical engineering. He can be contacted at email: drrakesh@osgu.ac.in.