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Transforming electric vehicle charging through solar integration and high-frequency magnetic induction for seamless wireless power transfer

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ABSTRACT

The rapid adoption of electric vehicles (EVs) is constrained by limited charging infrastructure, prolonged charging duration, grid dependency, and inefficiencies in conventional wireless charging systems. To address these challenges, this paper proposes a solar-integrated high-frequency inductive wireless charging framework that enables efficient, contactless, and partially dynamic EV charging. The proposed system combines a photovoltaic (PV) energy harvesting subsystem with maximum power point tracking (MPPT), a high-frequency resonant inductive coupling mechanism using a series–series (SS) topology, and an intelligent solar inductive synergy optimization algorithm (SISOA) for adaptive power and energy storage management. The theoretical foundation of the system is based on Faraday's law of electromagnetic induction and resonant magnetic coupling to enhance mutual inductance and power transfer efficiency. Simulation studies conducted in MATLAB/Simulink demonstrate that the proposed approach achieves a mutual inductance of 82.5, an output voltage of 500 V, and an output power of 4,800 W, while reducing overall power losses to 21.18% and improving system efficiency to 94.5%. The results further reveal that vehicle speed and the number of receiver coils significantly influence charging effectiveness and state-of-charge performance.

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1. INTRODUCTION

The global shift toward electric vehicles (EVs) signifies a promising stride toward cleaner, more sustainable transportation. However, traditional EV charging methods—such as plug-in stations—face challenges including limited availability, long charging times, and user inconvenience. This paper proposes an innovative approach: a dynamic wireless charging (DWC) system powered by high-frequency magnetic fields and guided by advanced vision-based routing and navigation systems. This system aims to deliver real-time, uninterrupted, and intelligent EV charging while in motion, revolutionizing electric mobility.

Transportation is the essential factor of the individual/society enabling the movement of people, goods from one place to another directly dominate the economic conditions worldwide. Transportation acts as the backbone for economic development, eases the patients to move for healthcare access and so on. One such efficient and non-polluting transportation is the electric vehicles [1], pivoting the transformation in the transportation process, offers a sustainable alternative [2] for the conventional gasoline powered transportations. The EVs are known for its zero emission [2] from terminal pipelines and minimize the emission of greenhouse gases. The mitigation of greenhouse gas emission standardizes the climatic conditions, directly contributing to the enhanced quality in air. The EVs are high efficient [3] in the conversion of energy from the grid to the motion when compared with the conventional/traditional combustion engines [4].

In addition, the adoption of the EVs facilitates the energy independence [5] by mitigating the reliance on the fossil fuels. This is made possible by the incorporation of the battery technology, offering impressive range of mileage and faster charging times, thus addressing the rising hurdles of the EVs. A statistical report on the rise in EV market size in terms of billion US dollars is presented and is depicted in Figure 1.

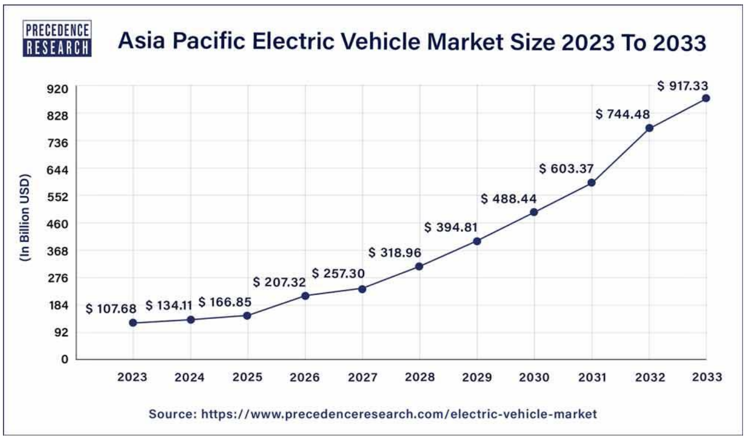

Figure 1. Market prediction for EVs for the next one decade

Despite the packet full of benefits possess by the EV, there exists a loads of challenges [6] in the EV including limited charging stations [7], consumption of long charging times [8], grid dependency [9], and compatibility issues. A notable barrier in the adoption of EV is the scarcity of the charging stations, especially in the remote or rural areas. The major setback of the existing methods is the electrical energy employed for EVs are derived predominantly from fossil fuels, undermining the environmental benefits [10] of the EVs, contributing to the emission of greenhouse gases indirectly. Furthermore, the traditional inductive charging mechanism [11] is plagued by inefficient energy transfers, resulting in substantial power losses due to the sub-optimal magnetic coupling mechanisms. This inefficiency proportionately enhances the operational costs and hinders the expanding of the wireless charging solutions.

In addition, the existing EV charging methodologies [10] were constrained by the immobile vehicles, creating the vehicles to be in statuary position [12] during the charging process. The prolonged duration of charging process increases the immobile duration of the vehicle until the vehicle gets fully charged. This inherent limitation [13] leads to the downtime of the operation and mitigates the overall performance of the EVs and convenience of the users, making them to have a second thought for migrating from the conventional vehicle to the electrical vehicle [14]. Furthermore, the wear and tear [15] of the physical connectors in the charging stations further exacerbate the challenges of the EVs, thus demands the frequent maintenance and replacements of the connectors [16], increases the inflate cost and reduces the reliability of the charging system.

An additional notable issue in the EVs is the strain placed [17] on the power grid due to the increase in number of the EVs, specifically in the peak demand periods. This concern rises, due to the lack of integration with renewable energy sources, amplifying the challenge and creating the concern of stability, sustainability of the power grid. The deployment of the conventional charging infrastructure is considered to be infeasible due to lack of charging infrastructure in the rural areas, thus limiting the global scalability of the adoption of EVs. The existing plug in play chargers and the fast chargers (DC chargers) [18] incurs high cost in infrastructure installation and maintenance. In addition, it accelerates the battery degradation due to the heat generation during the process of fast charging.

Resonant inductive power transfer for EV charging has been extensively investigated in foundational studies. Early and influential work by Covic and Boys established the theoretical framework for high-power inductive charging systems and resonant compensation topologies for EV applications.

Subsequent research has further demonstrated the effectiveness of high-frequency resonant converters in achieving efficient wireless power transfer under misalignment conditions, alongside advancements in magnetic coupling optimization and safety protocols. Furthermore, the SAE J2954 standard provides comprehensive guidelines for operating frequency, alignment tolerance, power levels, and electromagnetic field exposure limits. Collectively, these developments form the basis for modern resonant inductive charging systems and motivate the present work's focus on high-frequency operation, resonant SS topology, and efficiency optimization.

To overcome these challenges, the proposed work introduces integrated renewable solar power energy to enhance the efficiency of the inductive charging systems and to enable the dynamic and contactless charging capabilities, thereby transforming the EV charging paradigm. The proposed approach has been explicitly emphasized by clearly highlighting the methodological and conceptual novelty of the work. This study introduces a solar-integrated high-frequency inductive wireless charging framework for electric vehicles, combining i) MPPT-based photovoltaic energy harvesting, ii) a high-frequency resonant inductive coupling mechanism using a series–series (SS) topology, and iii) a solar inductive synergy optimization algorithm (SISOA) for intelligent power flow and storage management.

This research addresses the limitations of existing electric vehicle (EV) charging systems, including the scarcity of charging infrastructure, dependence on grid-based energy sources, prolonged charging duration, and inefficiencies associated with conventional wireless charging methods. The primary research gap lies in the absence of an integrated, renewable-energy-driven, high-efficiency wireless charging framework capable of supporting dynamic and contactless EV charging while minimizing power losses and grid stress. To bridge this gap, this study proposes a solar-integrated high-frequency inductive wireless charging system supported by resonant magnetic coupling and an intelligent power management algorithm. Simulation results demonstrate that the proposed approach achieves a significantly higher mutual inductance (82.5), increased output voltage (500 V), and output power (4,800 W), while reducing overall losses to 21.18% and improving system efficiency to 94.5%. The findings indicate that vehicle speed and the number of receiver coils play a crucial role in charging effectiveness and state-of-charge improvement. The implications of this research suggest that integrating solar energy with high-frequency inductive charging can enable sustainable, scalable, and grid-independent EV charging infrastructure, thereby reducing range anxiety, enhancing user convenience, and supporting the large-scale adoption of electric vehicles.

The principal contribution of this work is the development of a system-level optimization framework, namely the SISOA, which coordinates renewable energy harvesting, resonant inductive power transfer, and battery charging management. While conventional coil geometries and resonant topologies are employed for practical implementation, the novelty of the proposed approach lies in the integrated algorithmic control and energy management strategy, which enables improved efficiency and charging performance under dynamic operating conditions.

The manuscript describing the proposed work is composed of introduction in section 1. The architecture and the processes involved in the proposed work are presented in section 2, along with the performance analysis in section 3. Finally, the manuscript is concluded with the highlights of the proposed work in section 4.

2. METHOD

The proposed work is designed with the objective of overcoming the existing challenges in the charging system of the electric vehicle. The proposed work is an integrated version of solar power energy with the high frequency magnetic field created through the inductive coil placed in the road, easing the charging of electric vehicle in a contactless method. The proposed work is designed based on the faraday's law of electromagnetic induction, with an objective to achieve efficient wireless energy transfer, thus eliminating the necessity for the physical connectors. Faraday's law of electromagnetic induction is defined in (1).

$$\varepsilon = -\frac{d\varphi_B}{dt} \quad (1)$$

where, ε is the induced electro-magnetic force expressed in volts (V), φ_B is the magnetic flux expressed in webers (Wb), while B is the magnetic field strength (T), A is the area of the loop measured in square meter (m^2) and θ is the angle between the B and the normal to the loop. In the proposed model, a high frequency alternating current (AC) in the transmitter coil generates a time varying magnetic field (B). The varying magnetic flux φ_B induces an *emf* in the receiver coil (placed in the EV). The outlined architecture of the proposed integrated solar power with the high frequency inductive coil method of wireless charging system is depicted in Figure 2.

The proposed wireless charging module (WCM) is composed of three phases namely; the solar power generation subsystem followed by the high frequency magnetic field generation by the inductive coil with the final phase is of control and power management using SISOA.

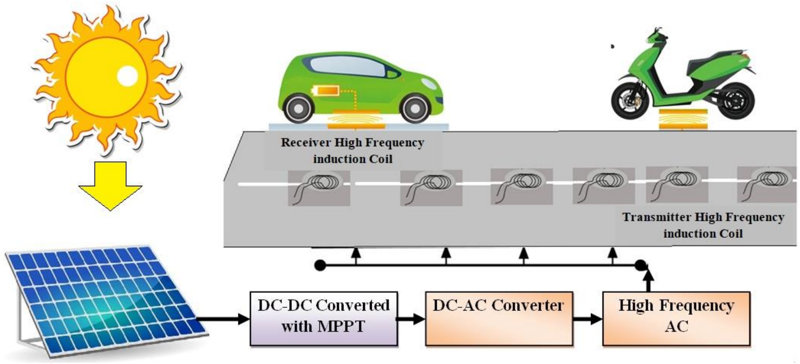

Figure 2. Overall architecture- proposed solar power with high inductive coil WCM

In Figure 3, the solar power harvesting process for the EV charging module, showing photovoltaic energy generation, MPPT-based optimization, and regulated power delivery to the inductive charging system. To ensure precise alignment over charging coils, the system uses computer vision and sensor fusion technologies. Components include:

- Cameras and LiDAR sensors: Detect lane markers and embedded coil indicators.
- Onboard AI: Continuously processes visual input to adjust the vehicle's path in real time.
- Cloud-Based Route Optimization: Integrates traffic, charge availability, and energy demand into route decisions.

This system guarantees optimal alignment with road-embedded infrastructure for efficient dynamic charging.

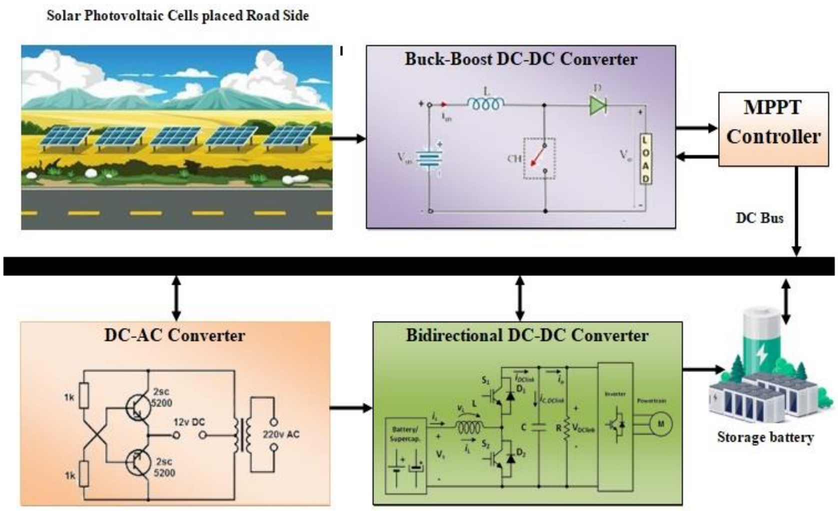

Figure 3. Solar panel power harvesting for EV charging station

2.1. Solar power generation subsystem with MPPT

The solar power generation subsystem with the maximum power point tracking (MPPT) is a significant phase for providing an efficient solar energy utilization in the EV charging stations. The subsystem is composed of photovoltaic (PV) panels, which is capable of absorbing solar energy and converts sun light to electrical DC energy. The harvested DC energy is processed using DC-DC boost converter and the MPPT controller. The MPPT controller ensures that the maximum quantity of energy is extracted through the dynamic adjustment of operating point of the PV panels, in accordance with the intensity of the sunlight.

This subsystem optimized the output energy thus mitigates the power loss and enhances the overall efficiency of the solar based EV charging model. The processes involved in the solar panel-based power harvesting for the proposed EV charging module are presented in Figure 3.

The process of solar power generation for the EV charging module involves the conversion of sunlight to the electrical energy using the Photovoltaic cells and optimizing the output for the effective charging process. The power generated by the photovoltaic cells is defined in (2).

$$P_P = A_P I_S \acute{\eta} \tag{2}$$

where, P_P is the power generated by the photovoltaic panel measured in terms of watts, A_P is the area of the photovoltaic panel in square meter (m2), I_S is the solar irradiation measured in Watts per square meter (W/m2) and ή is the efficiency of the PV panel, influenced by the material of the PV panel and the environmental factors. The V-I characteristics of the solar cell are derived in (3).

$$\mathrm{I_P} = \mathrm{I_{pc}} - \mathrm{I_0}\left(\mathrm{e}^{\frac{\mathrm{q(V+IR_S)}}{\mathrm{nKT}}} - 1\right) - \frac{\mathrm{V_P + I_P R_S}}{\mathrm{R_P}} \tag{3}$$

where, I_P is the photovoltaic current, V_P is the photovoltaic voltage, I_0 is the saturation current, q is the charge of a single electron, K is the botzmann constant, n is the ideal factor ranging from (0-1), R_S and R_P are the series and parallel resistance of the PV panel. The IPC is directly proportional to the quantity of irradiance and hence (3) shall be modified or redefines as in (4).

$$\mathrm{I_P} = \alpha\mathrm{G} - \mathrm{I_0}\left(\mathrm{e}^{\frac{\mathrm{q(V+IR_S)}}{\mathrm{nKT}}} - 1\right) - \frac{\mathrm{V_P + I_P R_S}}{\mathrm{R_P}} \tag{4}$$

The output power from the photovoltaic cell is treated with DC-DC MPPT controller, which plays a critical role in the solar power harvesting. PV panels operate at their optimal power point under the varying environmental conditions. The solar panels possess a non-linear output power curve depending on multiple factors like intensity of the sunlight, load and the temperature. The MPPT algorithm dynamically adjusts the operating voltage and the current of the photovoltaic cell to match their maximum power point. This process enhances the extraction of the energy from the PV cell, similarly, enhances the efficiency of the system by minimizing power losses. To perform the MPPT, the proposed work employs the perturb and observe (P&O) method as illustrated in Table 1.

Table 1. MPPT algorithm – optimizing the solar power

Algorithm 1. MPPT algorithm – optimizing the solar power
Input: VP(t) - Voltage generated by solar panel at time "t";
IP(t) - Current generated by solar panel at time "t".
Output: VMPP - Maximum Power Point Voltage.
Processes:
1: Initialize the process by measuring the $V_P(t)$ & $I_P(t)$.
2: Determine the initial power: $P_p(t) = V_p(t) \times I_p(t)$ (5)
3: Define the initial perturbation step size: $\Delta V = \beta \left\lvert \frac{dP}{dV} \right\rvert$ (6)
//β is the tuning parameter and $\frac{dP}{dV}$ is the slope of the power-voltage curve at the present operating point (t).
4: Perturb the panel voltage: $V_{P-New} = V_{P-Old} + \Delta V_P$ (7)
5: Determine the New power:
$P_{P-New} = P_P(t+\Delta t) = V_P(t+\Delta t)\rvert_{V_{p-New}} \times I_P(t+\Delta t)\rvert_{I_{p-New}}$ (8)
6: Evaluate the difference in power: $\Delta P = P_P(t+\Delta t) - P_P(t)$ (9)
7: If $(\Delta P > 0)$ and if $(P_P(t+\Delta t) < P_P(t))$;
8: Then, $V_P(t+\Delta t)\rvert_{V_{p-New}} = V_P(t) + \Delta V_P$ (10)
9: Else, if $((\Delta P < 0)$ and if $(P_P(t+\Delta t) > P_P(t))$;
10: Then, $V_P(t+\Delta t)\rvert_{V_{p-New}} = V_P(t) - \Delta V_P$ (11)
11: Update, $V_P(t) = V_P(t+\Delta t)$ & $P_P(t) = P_P(t+\Delta t)$ (12)
12: Repeat steps 5-10 until, $\lvert\Delta P\rvert < P_T$ // Threshold power.
13: Output Voltage: $V_{MPP} = V_P(t)$ (13)
14: End if
15: End processes.

$$V_{P-Out} = \frac{V_{P-In}}{1-D_S} \tag{14}$$

where, V_{P-In} and V_{P-Out} are the input and output voltage of the PV cell, while DS is the duty cycle of the switch adjusting such that to track the MPP. The generated power is stored in the energy storage systems, contributing to being a buffer in between the solar grid and the EV charging units. The energy storage units, store excessive energy, during the low requirement by the EVs. In turn, the energy storage units, discharge energy during the peak demand period. The proportion for storing energy in the energy storage system is defined in (15).

$$E_S = P_E \times t = (P_P - P_{load})t; If\ (P_P > P_{load}) \tag{15}$$

where, E_S is the energy stored, P_E is the excessive power, P_P is the power generated by the PV cell and P_{load} is the required power in the charging load end. The variable DC voltage is regulated using DC-DC conversion to regulate the variable DC voltage to the stable level suitable for AC conversion process. The conversion of normal DC to regulated DC voltage is represented in (16).

$$V_{DC-R} = \frac{V_{DC} . D_S}{1-D_S} \tag{16}$$

where, V_{DC-R} is the regulated DC voltage, V_{DC} is the fluctuating DC harvested from the solar panel, while DS is the duty cycle of the switch. The regulated DC is converted into alternating current (AC) using the pulse width modulation (PWM) process and the output AC voltage is defined in (17).

$$V_{AC}(t) = V_{Peak} \times sin(\omega t) = V_{Peak} \times sin(2\pi f t) \tag{17}$$

where

$$V_{Peak} = \sqrt{2}. V_{RMS} \tag{18}$$

The AC ($V_{AC}(t)$) conversion depends on the peak voltage (V_{Peak}) with a frequency range of 50-60 Hz and the obtained AC voltage is filtered using the low pass filter to obtain a clear sinusoidal AC output suitable for magnetizing the inductive coil placed on the roads. The filtered output of the AC voltage is defined in (19).

$$\mathrm{V_{AC-f}(t) = V_{RMS} \times \sqrt{2} \times sin\ (2\pi f t)} \tag{19}$$

The filtered AC power is supplied to the inductive coil placed in the roads at constant spacing interval for magnetizing process followed by the transmission of power to the receiving EV charging unit. The inductive power transfer system employs planar circular coils for both the transmitter (road-embedded) and receiver (vehicle-mounted) to ensure uniform magnetic field distribution and tolerance to lateral misalignment. The transmitter coil has a radius of 0.25 m with 20 turns, while the receiver coil has a radius of 0.18 m with 15 turns, enabling compact integration beneath the vehicle chassis. A series–series (SS) compensation topology is adopted to achieve resonant operation and stable high-frequency power transfer. The coils are separated by an air gap ranging from 150-200 mm, representing realistic EV ground clearance conditions. Ferrite core material is employed beneath the coils to enhance magnetic flux guidance and reduce leakage losses.

2.2. High frequency magnetic field generation

This section introduces the second phase of the proposed wireless charging module (WCM) for the EVs. This module is composed of two sections namely the transmitter inductive coil placed on the road, and the receiver inductive coil placed on the EVs. In this phase, the transmitter is fixed whereas the receiver will be in mobility. The vacuum of air separates the transmitter and the receiver section, thus generates a high frequency magnetic flux. The magnetic flux in the receiver is converted into electrical energy and is stored in the storage system of the vehicle. The transmitter and the receive coil shall be constructed in any of the four topologies namely the series-series (SS) topology, parallel-parallel (PP) topology, parallel-series (PS) topology and series-parallel (SP) topology as depicted in Figure 4. This proposed system employs the SS topology with inductor (L) and capacitor (C) is placed in series manner in both the transmitter and receiver sections.

While comparing the different available topologies of EV charging system, the SS topology possess less impedance at the receiver side with high frequency stability, thus suits good for high frequency inductive method of charging system. The AC voltage from the solar grid is passed through the primary coil to generate a time varying high frequency magnetic field. The magnetic field generated in the primary coil is a major factor for inducing the current in the secondary coil (*i.e.* receiver) placed in the EV receiver. The dimension of the transmitting inductor placed on the road is depicted in Figure 5.

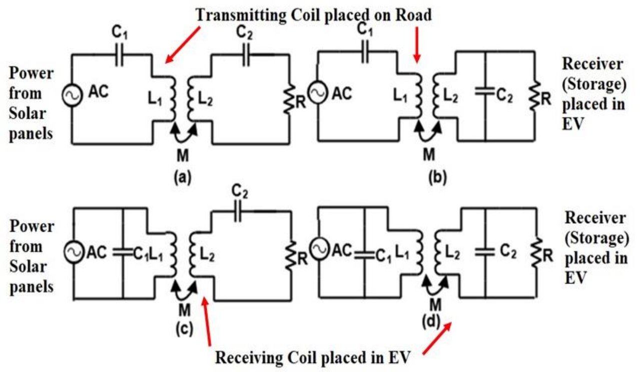

Figure 4. Various topologies for wireless EV charging system (a) SS, (b) SP, (c) PS, and (d) PP

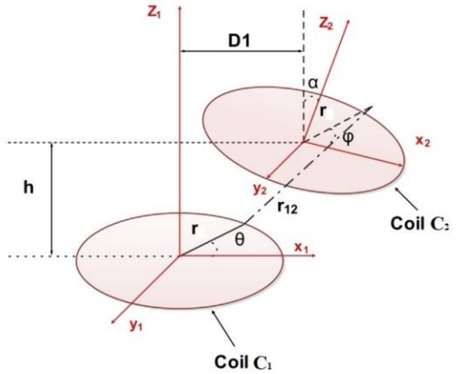

Figure 5. Spatial dimension between any two primary inductors on the road

The primary magnetic field (BPr) generating at the center of the transmitting loop with a common radius (r) carrying the current (IP) is defined in (20).

$$\mathrm{B_{Pr}} = \frac{\mu_0 \mathrm{N_{Pr}(I_P)}}{2\mathrm{r}} \tag{20}$$

where, μ_0 is the permeability of the free space, and *NPr* is the number of turns in a single primary coil placed on the road. The time varying current in the primary coil generates a time varying magnetic field as defined in (21).

$$B_{Pr} = \frac{\mu_0 N_{Pr}}{2r} I_P(t) = \frac{\mu_0 N_{Pr}}{2r} I_M sin(2\pi f t) \tag{21}$$

where *IM* is the peak current generated by the PV cell. The magnetic flux (φ_S) represented in (21) is induced to the secondary coil using mutual induction principle. The magnetic flux generated at the secondary inductor (in EV- Receiver) is directly proportional to the primary magnetic field and the area of the coil as defined in (22).

$$\varphi_S = M.B_{Pr}.A = \frac{(C_C\sqrt{L_1L_2})}{L}\frac{\mu_0 N_{Pr}}{2r} I_M sin(2\pi f t).A \tag{22}$$

where C_C is the coupling coefficient ranges from 0 to 1, L_1 and L_2 are the inductance generated at the primary and secondary coils placed in road and the vehicle and L is the distance between the primary and the secondary coils. Based on Faraday's law of induction, the net voltage induced in the receiver coil (VS) is defined in (23).

$$V_S = -N_S\frac{d}{dt}\left(\frac{(C_C\sqrt{L_1L_2})}{L}\frac{\mu_0 N_{Pr}}{2r} I_M sin(2\pi f t).A\right) \tag{23}$$

$$V_S = -N_S\frac{(C_C\sqrt{L_1L_2})}{L}\frac{\mu_0 N_{Pr}}{2r} I_M cos(2\pi f t).A \tag{24}$$

The induced voltage is such that to be of high power and to achieve a high-power transfer, the primary and secondary coils in the transmitter and receiver coils must be tuned to the resonant frequency defined in (25).

$$f_r = \frac{1}{2\pi\sqrt{L_{Pr}L_S C_{Pr} C_S}} \tag{25}$$

The coils have to be tuned to the resonant frequency such that the energy oscillated effectively between the electric and magnetic fields, thus mitigating the losses. The primary and the secondary capacitance of the coils are evaluated using the imaginary inductive part and the corresponding equation is defined in (26).

$$C_{Pr} = C_S = \frac{1}{\omega^2(L_{Pr}L_S + M)} \tag{26}$$

The efficiency of the energy extracted from the secondary coil though mutual inductance is defined in (27), which relies on primary current (IPr), secondary current (IS) and the load resistance (RL).

$$ή = \frac{|I_S|^2 R_L}{|I_{Pr}|^2 R_{Pr} + |I_S|^2 R_S + |I_S|^2 R_L} \quad (27)$$

The high frequency power necessitates the coil dimension to be lower and enhances the efficiency of the power transfer. In addition, the losses incurred during the mutual induction process will be considerably low, while transferring high frequency power from transmitter to receiver coil in the EV.

2.3. SISOA based power management

Power and control management is significant process in the proposed wireless charging mechanism using the solar panel and the high frequency magnetic field generation method. SISOA is a power management framework employed in the wireless charging module. The proposed SISOA algorithm assists in optimizing the flow of energy, ensuring the efficient transmission of energy in real time. The proposed SISOA amalgamates the harvesting of solar energy from PV cells, power transfer through inductors and energy storage management. The algorithm for the Solar Inductive Synergy Optimization process for power management is illustrated in Table 2.

Table 2. SISOA based power management

Algorithm 2. Solar inductive synergy optimization
Input: Voltage and Current from PV cells (I_P and V_P)
Output: System Efficiency: $ή_{Total}$
Processes:
1: Initialize the system constants and variables:
Solar PV cells: I_P and V_P;
Battery Parameters: Charge Status (C_{S-Max}; C_{S-Min});
Resonant frequency: f_r
Solar Irradiance: G_P
Temperature: T
2: Determine the solar power: $P_P = V_P \times I_P$ (28)
3: Determine the operating voltage: $\frac{dP_P}{dV_P} = 0$
4: Determine available solar power: $P_A = P_P - P_{Aux}$ (29)
// P_A is the available solar power in battery source, P_{Aux} is the auxillary power consumption of system.
5: If $(P_A \leq 0)$; then
6: Perform, "Switch to battery Power)
7: Else,
8: Perform, "Use solar power"
9: Determine Power Allocation: $P_S = \gamma P_A \& P_{charge} = (1-\gamma)P_A$ (30)
10: Update battery charging current: $I_B = \frac{P_S}{V_B}$ (31)
// I_B is the battery current, V_B is the battery voltage and P_S is Stored power.
11: Determine Resonant frequency: $f_r = \frac{1}{2\pi\sqrt{L_S L_B C_S C_B}}$ (32)
12: If $(f_r < f_T)$, then
13: Adjust Coil alignment: $C_{Opt} = C_c^2 \frac{R_L}{R_S + R_L}$ (33)
14: Else, "Maintain the same resonant frequency"
15: Determine the Charge status of batter: $C_S = \frac{Q_P(t)}{Q_{max}} \times 100$ (34)
// where, $Q_P(t)$ is the present charge, and Q_{max} is the maximum charge.
16: If $(C_S \geq C_{S-max})$, then
17: Perform, "Stop Charging and direct power to other load or to storage"
18: Else if $(C_S \leq C_{S-Min})$, then
19: Perform, "Prioritize Battery Charging"
20: Determine the system efficiency: $ή_{Total} = ή_P + ή_S$ (35)
// where, $ή_{Total}$ is the total efficiency, $ή_P$ and $ή_S$ are the efficiency of solar panel and storage respectively.
21: Predict the availability of future energy and adjust using step 13.
22: End if
23: End if
24: End if
25: End processes

The proposed SISOA algorithm offers a strong foundation for intelligent implementation and management of solar power based high frequency induction charging for electric vehicles. The mutual inductance between the transmitter and receiver coils varies depending on alignment and air-gap distance. In this study, the mutual inductance is assumed to vary between 60 µH and 95 µH, corresponding to coupling coefficients ranging from approximately 0.25 to 0.45. The reported performance metrics are evaluated at a nominal mutual inductance of 82.5 µH, representing a balanced operating condition between efficiency and coupling robustness.

3. RESULTS AND DISCUSSION

The proposed solar power with high frequency magnetic induction based wireless charging module is implemented using MATLAB/Simulink platforms. The charge status of the battery is analyzed under various conditions and the efficiency of the proposed work is tested for various perspectives. Let's consider a vehicle moving at a speed less than 100 km/hr and the corresponding mutual inductance with respect to the time duration is depicted in Figure 6.

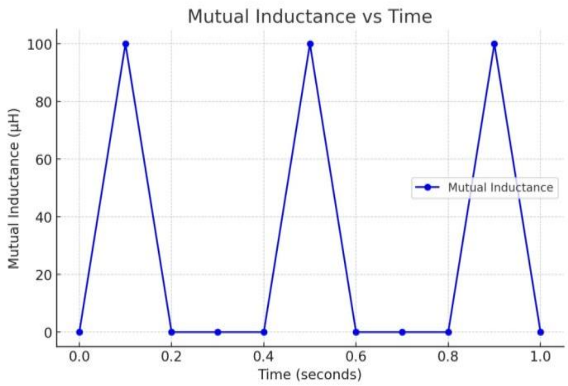

Figure 6. Vehicle speed (<100 km/hr) and its influence in mutual inductance

In this study, vehicle speeds are categorized into low-speed (<100 km/h) and high-speed (>100 km/h) regimes for analysis. This classification reflects typical urban and highway driving conditions, respectively. Lower vehicle speeds allow longer residence time over the transmitting coils, resulting in improved magnetic coupling and increased energy transfer, whereas higher speeds reduce the effective charging interval and coupling duration. When a vehicle is moving at a speed more than 100 km/hr, the rate of mutual inductance will be increasing with respect to the time as depicted in Figure 7. The speed of the electric vehicle significantly influences the mutual inductance due to the reduced alignment, variability in the potential air gap and shorter duration for charging. Hence in Figure 6, the mutual inductance prolongs for more time duration than the mutual inductance observed in Figure 7. In case, if a vehicle is placed with more than one receiver (*i.e.* with 3 receivers), the mutual inductance extracted by the vehicle circuit is presented in Figure 8.

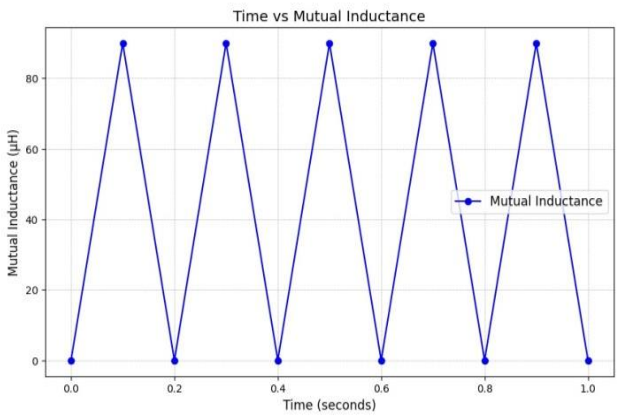

Figure 7. Vehicle speed (>100 km/hr) and its influence in mutual inductance

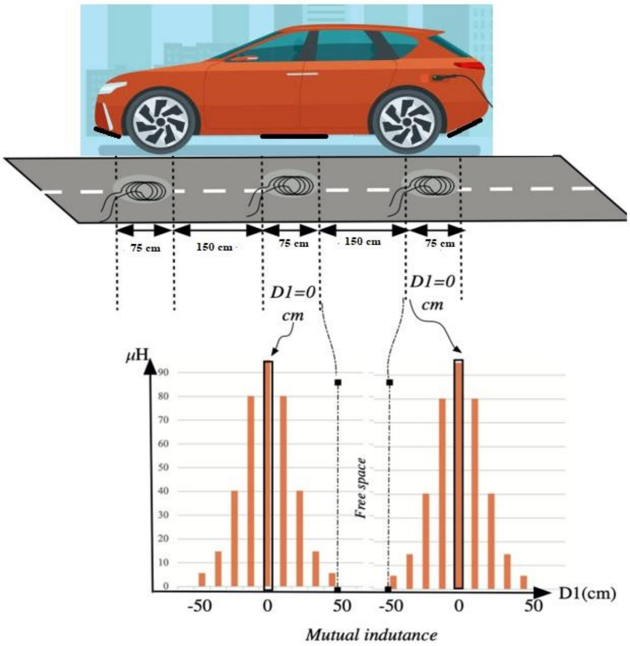

Figure 8. Mutual inductance of EV with multiple receivers

The value of the mutual inductance observed in Figure 6 and Figure 7 is multiplied by the number of receivers in contact with the secondary coil, thus assists in increase in extracting the power from the transmitting coil of inductance placed in the road. When a vehicle is passing over the coil of inductance at a speed less than 100 km/h, the mutual inductance will be low when compared with the mutual inductance gained when the vehicle is at the speed of more than 100km/hr.

The status of charge (CS) in the storage battery over the certain time period for an electric vehicle with one and multiple receivers is analyzed. In case of one receiver, the slower speed of the vehicles enables longer alignment period, easing the more efficiency in the energy transfer from the primary to the secondary inductive coil. The response of the status of charge for various types of receivers in depicted in Figure 9.

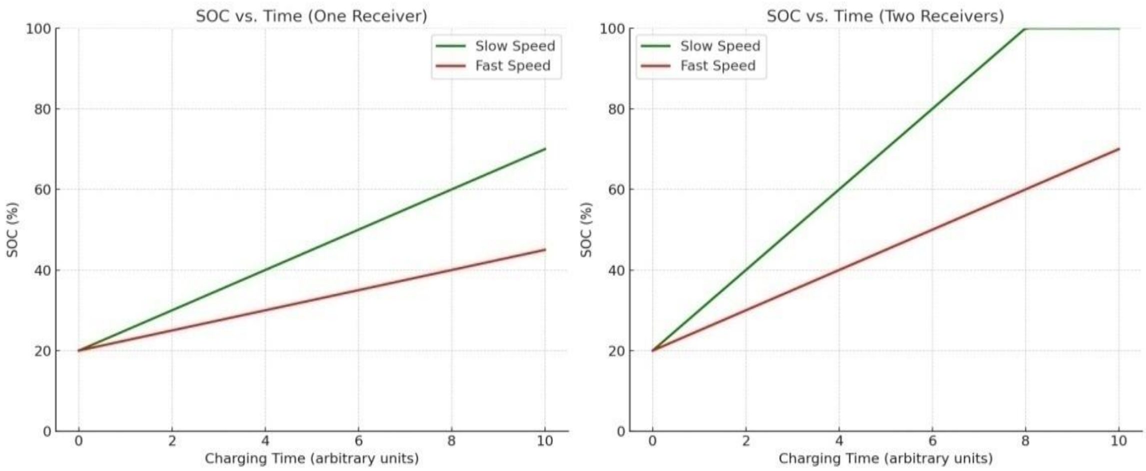

Figure 9. Status of charge (CS) versus time for one and multiple receivers

Alternatively, if the vehicle is moving faster (*i.e* >100 km/hr), the effective charging time is reduced leads to a slow increase in the status of the charge. In case of multiple receivers (2 or 3) placed in an EV, the energy capturing efficiency increases due to the placement of additional receivers in the vehicle. This analysis presents the significance of the vehicle speed and the number of receiver placement in the vehicle to optimize the inductive charging mechanism for EVs and the status of the charge in vehicles / storage units. The status of charge for one receiver and multiple receivers with slow and fast charging option with respect to the timing is presented in Table 3.

Table 3. Comparison of status of charge for one and multiple receivers

Duration (Min)	One Receiver		Multiple Receiver	
	Slow Charge	Fast Charge	Slow Charge	Fast Charge
0	20%	20%	30%	35%
2	30%	25%	40%	45%
4	40%	30%	60%	55%
6	50%	35%	70%	75%
8	60%	40%	80%	85%
10	70%	45%	100%	100%

The observed values of status of charge for multiple durations tabulated in Table 3 demonstrates the impact of speed and the configurations of receiver on the SOC. It emphasizes the significance of optimization of charging efficiency. In the slow speed, the charging process steadily increases and maintains a proper alignment with the coil of wire, resulting in higher SOC values. In turn, the fast speed offers reduced charging efficiency causing shorter alignment duration. A comparative analysis has been done to analyze the performance of the proposed solar based high frequency inductive charging model by measuring the vital parameters namely the mutual inductance (M), output power, output voltage, losses inclusive of hysteresis loss, eddy current loss, status of charge, and efficiency. These parameters were observed for the proposed model and is compared with the state of art methodologies introduced by Kenari and Ozdemir [19], Das *et al.* [20], Bagherwal and Mahapatra [21], Hammam *et al.* [22], and Bilal [23]. The comparative analysis is presented in Table 4.

The proposed work excels in terms of mutual inductance with 82.5 while the existing works exhibits 24.3 [19], 27.8 [20]; 33.4 [21], 34.5 [22], and 37.5 [23]. The output voltage of the proposed work is 500 V with output power 4800 W. The major losses incurred in the proposed work are 21.18 which is comparatively low when related with the existing works. The time taken for the 100% status of charge is 25seconds and the overall efficiency of the model is 94.5%.

The performance of the proposed solar-integrated high-frequency inductive wireless charging system depends on several critical design parameters. These parameters are selected based on practical roadway-embedded wireless charging constraints and established inductive power transfer design guidelines. The transmitter and receiver coils are designed using circular planar geometry to ensure uniform magnetic field distribution and improved tolerance to lateral misalignment. A series–series (SS) compensation topology is employed to support high-frequency operation and stable resonant behavior under varying load conditions. High-frequency switching is adopted to enhance power density and mutual inductance while reducing coil dimensions. The coupling coefficient and air-gap distance are selected to reflect realistic vehicle ground clearance conditions. Lithium-ion battery specifications are chosen to match typical EV energy storage requirements.

Table 4. Performance comparative analysis

Parameters	Kenari and Ozdemir [19]	Das *et al.* [20]	Bagherwal and Mahapatra [21]	Hammam *et al.* [22]	Bilal [23]	Proposed Work
Mutual inductance (M)	24.3	27.8	33.4	34.5	37.5	82.5
Output voltage (V)	150	150	250	325	330	500
Output power (P)	1200	1200	1400	1600	2200	4800
Losses	42.12	40.65	41.25	43.68	41.58	21.18
Time for 100% status of charge	30 sec	25 sec	25 sec	30 sec	35 sec	25 sec
Efficiency	89.4	88.5	89.1	87.45	89.45	94.5

4. CONCLUSION

In the era of modern vehicles, the Electric vehicles prove to be an alternative for conventional fuel vehicles. However, the charging challenges in the EVs create a temporary hurdle in the automobile migration process. To overcome this hindrance, this proposed model of inductive charging mechanism integrated with solar power has been introduced. The integration of solar power with the high frequency magnetic fields ensures enhanced efficient wireless power transfer and addresses the key challenges of EV adoption, range anxiety and challenges in the plug in options of charging process. This research work portrays the impact of speed of vehicle in charging and maintaining the state of charge in the storage system along with the placement of number of receivers in the vehicle. The performance analysis of the proposed model yields better level of performance with a mutual inductance of 82.5, 500 V of output voltage, 4800 W of output power, 21.18% of overall loss with an efficiency of 94.5%. The performance of the proposed charging model could further be enhanced by implementing advanced semiconductor materials like silicon carbide (SiC) and gallium nitride (GaN) in the power electronics with an objective to achieve an enhanced efficiency and reduction of losses. The integration of dynamic wireless charging with advanced vision-based navigation presents a transformative vision for EV mobility. This model offers continuous, efficient, and sustainable charging experience, potentially redefining the future of electric transportation infrastructure. The future implications of this research are substantial. The proposed framework offers a scalable pathway toward renewable-energy-driven and grid-independent EV charging infrastructure, reducing range anxiety and operational downtime. It supports the deployment of dynamic wireless charging corridors in urban and highway environments and enables seamless integration with smart transportation systems. Furthermore, the proposed methodology can be extended using wide-bandgap semiconductor devices (such as SiC and GaN), advanced control strategies, and vehicle-to-grid (V2G) integration, paving the way for next-generation intelligent and sustainable electric mobility solutions.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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