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NEW-GENERATION AUTONOMOUS BATTERY-FREE ELECTRIC VEHICLE

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Abstract—Dynamic Wireless Power Transfer (DWPT) is proposed as a pathway toward eliminating onboard batteries in electric vehicles (EVs), thereby addressing the weight, cost, and end-of-life disposal challenges associated with conventional lithium-ion packs. A prototype EV system is presented that operates with zero onboard energy storage, receiving power continuously from 18 road-embedded transmitter coils operating at 120 kHz through a fixed 5 mm air gap. Three relay switches, sequenced by a hardware timer circuit, activate coil zones autonomously without the need for a programmable controller. A hybrid supply combining solar photovoltaic energy with a 12 V AC-DC adapter powers the transmitter infrastructure, while a separate 5 V adapter maintains the isolated control plane. Experimental validation confirms continuous battery-free vehicle motion, reliable autonomous coil sequencing, and seamless hybrid supply switchover across all test conditions.

Index Terms—Dynamic Wireless Power Transfer; Battery-Free Electric Vehicle; Inductive Coupling; Timer-Controlled Relay Sequencing; Hybrid Solar-AC Supply; 120 kHz Resonant Transfer; Autonomous Coil Activation.

I. INTRODUCTION

ELECTRIC vehicles (EVs) are broadly recognised as an effective near-term strategy for reducing transport-sector carbon emissions. However, the onboard battery system that defines every commercially deployed EV introduces a compounding set of engineering and environmental constraints. Battery packs represent 30–40% of total vehicle weight and up to 40% of purchase price [1]. Capacity degradation of 20–30% is typical after 1,000–1,500 charge cycles [2]. Critically, the global EV fleet — reported at over 58 million vehicles by end-2024 with 17 million new sales in that year alone [3] — implies a large-scale battery disposal burden within the current decade, for which adequate recycling infrastructure does not yet exist.

Dynamic Wireless Power Transfer (DWPT) via electromagnetic inductive coupling offers an alternative paradigm: energy is delivered to the vehicle in real time from coils embedded in the road surface, removing the dependency on onboard stored energy entirely. Resonant coupling at high frequency enables efficient power transfer across a small, fixed air gap with no physical contact between the vehicle and the infrastructure [4], [5].Prior DWPT deployments — including the KAIST On-Line Electric Vehicle (OLEV) system [6] and the Electreon dynamic charging road [7] — have demonstrated wireless charging in motion, but retain onboard batteries as energy buffers. The present work advances beyond these architectures by eliminating onboard energy storage entirely, achieving a genuinely battery-free operational configuration. Autonomous coil-zone sequencing is accomplished through a hardware timer circuit driving three relay switches, removing the need for any programmable microcontroller in the road infrastructure and improving system determinism. A hybrid supply combining solar photovoltaic (PV) energy with a grid-connected AC-DC adapter powers the transmitter coils, with a separate, electrically isolated 5 V adapter supplying the control plane.

II. SIGNIFICANCE OF BATTERY-FREE ARCHITECTURE

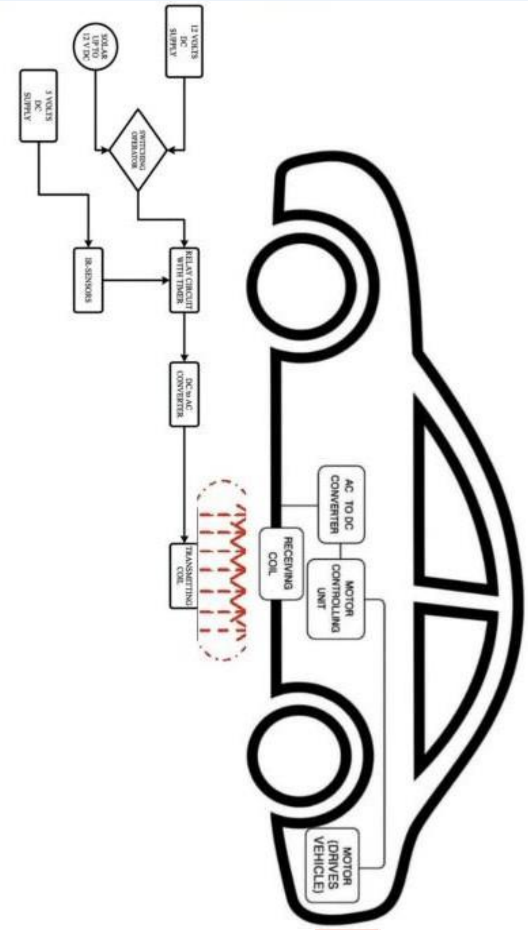
The environmental impact of large-format lithium-ion battery packs extends across the full lifecycle. Extraction of lithium, cobalt, nickel, and manganese involves processes that carry documented risks of soil and water contamination [2]. Manufacturing a single EV battery pack produces approximately 40–80 kg CO_2-equivalent per kWh of capacity [8]. At end of life, the hazardous materials present within the pack — including electrolyte solvents and heavy-metal cathode materials — require careful handling that is not yet consistently available at the scale demanded by the expanding global fleet [3].

A vehicle architecture that requires no onboard battery eliminates these burdens at the design level: no mining impact attributable to that vehicle, no pack replacement after a few years of service, and no end-of-life disposal event. From the operator perspective, battery-free operation also removes charging downtime — a significant economic factor for high-utilisation fleet vehicles such as automated guided vehicles (AGVs), campus shuttles, and airport ground support equipment operating on fixed routes.

III. LITERATURE REVIEW

Wireless power transfer via inductive coupling for EV applications was systematically characterised by Li and Mi [4], who established that loosely coupled resonant systems can achieve efficiencies exceeding 85% across air gaps representative of vehicle ground clearance. The mutual inductance relationship $V_2 = M(dI_1/dt)$ and the role of series resonant compensation were central to their analysis.

Mi et al. [5] extended this framework to dynamic scenarios, examining segmented transmitter arrays with independent switching and developing optimisation criteria for minimising electromagnetic field (EMF) exposure and energy loss during transit. Zhang et al. [9] provided empirical characterisation of segmented arrays under dynamic conditions, identifying that coil-zone transition intervals must remain below 50 ms to prevent supply interruption at the receiver. This finding is directly relevant to the relay switching timing adopted in the presented prototype.



The KAIST OLEV system [6] demonstrated DWPT in commercial transit service, transferring 100 kW at 20 kHz with 85% peak efficiency and a 17 cm air gap to a public bus in Gumi City. The vehicles, however, retain reduced-capacity onboard batteries. Electreon's road deployments [7] in Europe and the United States have demonstrated higher power levels (>300 kW peak) but similarly retain onboard energy storage, with one reported trial reducing pack size from 400 kWh to 42 kWh. Budhia et al. [10] analysed circular pad geometries for lumped inductive transfer and provided optimised coil design criteria that informed the planar spiral geometry adopted in the transmitter and receiver coil fabrication.

The presented system addresses the gap in literature by combining zero onboard energy storage, hardware-only timer-based autonomous coil sequencing, and solar-hybrid road-side supply in a single validated hardware prototype.

IV. SYSTEM ARCHITECTURE AND DESIGN

A. Theoretical Basis

Energy transfer between coil pairs is governed by Faraday's law of electromagnetic induction. The voltage induced in the receiver coil is described by:determinism. The timer circuit and relay drivers are powered by an isolated 5 V AC-DC adapter, maintaining electrical separation between the control plane and the 12 V transmitter power bus.

D. Vehicle-Side Receiver and Drivetrain

Three receiver coils, geometrically matched to the transmitter coil array, are mounted on the vehicle undercarriage at a fixed 5 mm separation from the track surface. The high-frequency AC induced in each receiver coil is converted to DC by a bridge rectifier. The combined rectified output drives the vehicle's DC motor through a motor driver module with no intermediate energy storage device in the power path. The system is operationally battery-free: at no point during vehicle motion is energy stored onboard.

$$V_2 = M \times (dI_1/dt) \quad (1)$$

where V_2 is the induced receiver voltage, M is the mutual inductance between the transmitter–receiver coil pair, and dI_1/dt is the rate of change of transmitter current. Operation at 120 kHz maximises dI_1/dt for a given coil geometry, increasing induced voltage across the fixed 5 mm air gap. Both transmitter and receiver coil banks are resonance-tuned via series capacitors selected to satisfy:

$$f_0 = 1 / (2\pi\sqrt{LC}) \quad (2)$$

targeting a common resonant frequency of 120 kHz on both transmitand receive sides.B. Transmitter Infrastructure Eighteen copper transmitter coils are embedded at regular intervals beneath the prototype track surface, wound in a planar spiral configuration from enamelled copper wire. The coils are organised into three sequential zones of six coils each. Each zone is connected to the 12 V transmitter power bus through a dedicated relay switch. In the default state, all relays are open, and no coil zone dissipates standby power.

C. Timer-Based Autonomous Sequencing

Autonomous coil-zone activation is achieved through a hardware timer circuit that drives the three relay switches at intervals calibrated to match the vehicle's transit time across each coil zone. As the vehicle advances, the timer progressively opens the prior relay and closes the subsequent one, ensuring that only the zone directly beneath the vehicle is energised at any instant. This approach eliminates the programmable microcontroller from the road infrastructure, reducing potential software failure modes and improving long-term operational

Fig. 1. Complete system block diagram: hybrid solar/12 V transmitter supply, three timer-sequenced relay switches, 18-coil TX array (3 zones), vehicle-mounted 3-coil RX array, bridge rectification, and DC motor drive.

E. Hybrid Solar-AC Power Supply

The 12 V transmitter bus is fed by a solar photovoltaic panel as the primary energy source. An OR-diode configuration between the solar panel output and a 12 V AC-DC grid adapter ensures automatic selection of whichever source presents the higher terminal voltage. Under sufficient solar irradiance, the transmitter coils are powered entirely from the renewable source with no grid consumption. The 5 V control supply operates independently from the grid adapter at all times.

V. HARDWARE IMPLEMENTATION

Table I enumerates the prototype hardware. The prototype track is constructed from MDF board with transmitter coils embedded in routed channels at 5 mm depth. The vehicle chassis is fabricated from lightweight acrylic sheet, with the three receiver coils and motor driver module mounted at the base. The timer circuit and relay board are housed in a dedicated control enclosure.

TABLE I

Hardware Bill of Materials

Fig. 2 — Hardware Prototype

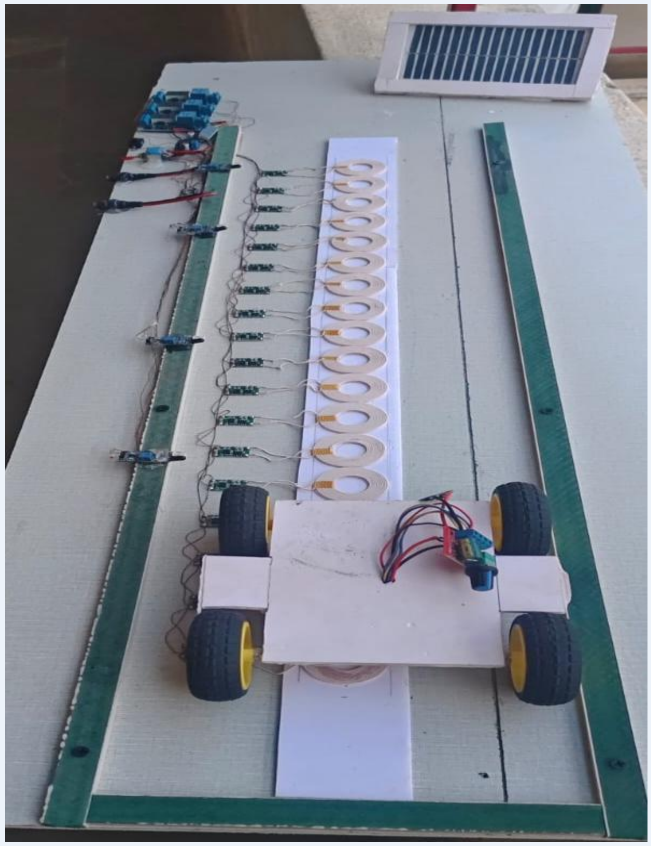


Fig. 2. (a) Prototype track with 18 embedded TX coils and relay control enclosure. (b) Vehicle chassis with 3 RX coils, bridge rectifiers, and DC drive motor. Air gap fixed at 5 mm.

VI. RESULTS AND DISCUSSION

Experimental evaluation was conducted across three test categories: static power transfer characterisation at fixed air gap, dynamic vehicle transit with autonomous coil sequencing, and hybrid supply performance under simulated irradiance variation. Table II presents the key measured outcomes.

Table I. Complete hardware bill of materials.

S.N	Component	Specification and Role
1	TX Copper Coils ×18	Planar spiral; 120 kHz resonant; embedded in track surface
2	RX Copper Coils ×3	Planar spiral; 120 kHz resonant; vehicle-mounted; 5 mm gap
3	Timer Circuit	Hardware sequencer — drives relay bank without MCU
4	Relay Switches ×3	12 V coil; one per TX coil zone; normally open
5	Bridge Rectifiers ×3	Converts 120 kHz AC from RX coils to DC
6	Motor Driver Module	Regulates DC from rectifiers to drive motor
7	DC Drive Motor	Rear-axle vehicle propulsion
8	Solar Panel	Primary source for 12 V TX bus (renewable)
9	AC-DC Adapter (12 V)	Grid backup for TX bus via OR-diode auto-switchover
10	AC-DC Adapter (5 V)	Isolated supply for timer circuit and relay control plane

TABLE II

Experimental Results Summary

Parameter	Result	Observation
Operating frequency	120 kHz	Series LC resonance confirmed on TX and RX
TX–RX air gap	5 mm (fixed)	Stable transfer across full track
TX coil array	18 coils	3 zones × 6 coils; one zone active per instant
RX coil array	3 coils	Parallel output to rectifier stage
Relay switches	3	One per TX zone; timer-driven

Table II. Experimental results across all test scenarios.

Parameter	Result	Observation
Autonomous sequencing	Confirmed	Hardware timer; no MCU required
Battery-free vehicle motion	Continuous	Zero onboard storage throughout
Solar-only operation	Confirmed	TX bus sustained under test irradiance
Hybrid supply switchover	Seamless	No motor speed variation observed
12 V/5 V isolation	Verified	Control plane electrically independent

A. Battery-Free Operation

Battery-free vehicle motion was confirmed across the full prototype track length in all test runs. Energy transferred from the active TX coil zone through the RX array and bridge rectifiers to the DC motor with no intermediate storage element in the power path. Motor operation was stable throughout, with no evidence of stall or speed reduction attributable to power delivery gaps.

B. Timer-Based Coil Sequencing

The timer circuit drove the three-relay sequencer reliably across all dynamic vehicle transit runs. Zone-to-zone handover transitions were completed without observable variation in motor speed, confirming that the timer period was well-matched to the vehicle's transit time over each six-coil zone. The hardware-only approach to sequencing produced deterministic switching behaviour that is inherently free from the software fault modes present in microcontroller-based implementations.

C. Hybrid Supply Performance

Under full test irradiance, the solar panel provided sufficient power to sustain vehicle motion at all tested speeds with no draw from the AC-DC adapter. Simulated cloud cover (manual panel shading) triggered automatic transition to the grid adapter via the OR-diode configuration. No change in motor speed was recorded during the transition event. When irradiance was restored, the solar panel resumed supplying the TX bus without interruption. The 5 V control supply remained stable and electrically isolated throughout all test conditions.

D. Comparison with Prior Art

KAIST OLEV buses [6] achieved 85% peak WPT efficiency and reduced battery size by approximately two-thirds, but retained onboard batteries. Electreon deployments [7] reduced pack size by up to 90% in trial configurations, yet onboard storage was still present. The system presented here achieves zero onboard energy storage — a distinction not reported in any prior vehicle-scale DWPT deployment. The use of a hardware timer for coil sequencing, rather than V2I communication or RFID-based vehicle detection, further simplifies the road-side infrastructure and reduces the control system cost substantially compared with existing deployments.

VII. ADVANTAGES OF THE PROPOSED SYSTEM

- **Zero Onboard Battery — Zero Battery Waste:** The absence of onboard energy storage eliminates lithium mining impact, pack degradation, replacement cost, and end-of-life disposal burden for the vehicle over its entire service life. This constitutes the primary differentiator from every existing DWPT deployment reported in the literature.
- **No Charging Downtime:** Continuous energy delivery during vehicle motion removes the operational pause required by plug-in or battery-swap charging. For fixed-route fleet vehicles, this enables full utilisation during service hours.
- **Deterministic Hardware-Only Control:** Timer-circuit-based relay sequencing removes the programmable controller and associated firmware from the road infrastructure, eliminating software failure modes and simplifying long-term maintenance.
- **Reduced Vehicle Weight and Cost:** Elimination of the battery pack reduces vehicle mass by an estimated 30–40% and removes the component that represents up to 40% of conventional EV purchase price [1].
- **Direct Renewable Energy Integration:** Solar PV energy is delivered to the vehicle powertrain at the point of use, rather than being mediated through the broader grid. Under adequate irradiance, grid consumption is zero.
- **Absence of Performance Degradation:** With no onboard energy storage subject to electrochemical ageing, vehicle performance is not expected to diminish over the operational lifetime.
- **Scalable Coil Architecture:** Additional coil zones are accommodated by adding relay switch stages to the timer sequence without modification to the vehicle or the fundamental system architecture.
- **Addresses Emerging Battery Disposal Crisis:** The global EV fleet growth trajectory implies tens of millions of end-of-life battery packs within this decade [3]. A vehicle requiring no battery is inherently exempt from this disposal burden.

VIII. CHALLENGES AND FUTURE WORK

A. Off-Track Operation

In the absence of onboard energy storage, vehicle motion ceases immediately upon leaving the DWPT-equipped track. For the targeted application class — closed-loop, fixed-route systems — this constraint is consistent with operational requirements. For broader deployment, the integration of a supercapacitor buffer (as distinct from a conventional battery, given the supercapacitor's negligible mass and effectively unlimited cycle life) could provide brief off-track capability without reintroducing battery disposal concerns.

B. Variable Vehicle Speed

The fixed-period timer assumes approximately constant vehicle speed. Speed variation may cause premature or delayed zone transitions. A velocity-adaptive timer, incorporating a simple tachometer input to modulate the switching period in real time, represents a natural extension of the current architecture.

C. Coil Alignment Tolerance

The 5 mm fixed air gap and lateral alignment sensitivity impose constraints on track guidance. Transitioning to DD or DDQ coil geometries, as characterised in [10], would substantially improve lateral misalignment tolerance. Ferrite shielding on the transmitter coils would further concentrate flux toward the receiver and reduce lateral leakage.

D. Power Level Scaling

Scaling to full-size EV power requirements necessitates higher-power coil fabrication, SiC-based inverter switching for the transmitterdrive stage, and resonant compensation topologies such as LCC or SS networks to maintain efficiency at higher power and extended air gap [5], [9].

IX. APPLICATIONS

- **University, Hospital, and Industrial Campuses:** Fixed-route battery-free shuttle services where predictable paths, low speeds, and institutional infrastructure ownership simplify coil installation.
- **Airport Ground Support Equipment:** Baggage handling vehicles and passenger transport buggies on defined tarmac corridors with controlled operating environments.
- **Industrial Automated Guided Vehicles:** Factory-floor AGVs on fixed guidance paths where continuous operation without charging pauses improves throughput and reduces downtime.
- **Smart Highway Freight Corridors:** Electrified highway lanes enabling long-haul EV freight with substantially reduced onboard battery capacity requirements.
- **Last-Mile Urban Delivery:** Lightweight electric delivery vehicles and passenger rickshaws on defined urban circuits, particularly relevant to Indian Tier-2 and Tier-3 city contexts.

X. ALIGNMENT WITH SUSTAINABLE DEVELOPMENT GOALS

The proposed system contributes directly to four United Nations Sustainable Development Goals. SDG 7 (Affordable and Clean Energy): solar PV energy is delivered to the vehicle powertrain at the point of use. SDG 9 (Industry, Innovation and Infrastructure): passive road surfaces function as active energy delivery infrastructure. SDG 11 (Sustainable Cities and Communities): elimination of battery packs reduces vehicle mass, urban noise, and the downstream environmental burden of battery production and disposal. SDG 13 (Climate Action): the combination of solar road power and zero onboard battery manufacturing reduces both operational and embodied carbon across the full vehicle lifecycle.

XI. CONCLUSION

A prototype electric vehicle system has been designed, implemented, and experimentally validated that operates with zero onboard energy storage, receiving power entirely through dynamic inductive wireless transfer from 18 road-embedded transmitter coils operating at 120 kHz across a 5 mm air gap. Three receiver coils on the vehicle undercarriage feed bridge rectifiers that supply the drive motor directly. Autonomous coil-zone sequencing is achieved by a hardware timer circuit driving three relay switches without the involvement of any programmable controller in the road infrastructure. A solar PV panel supplies the 12 V transmitter bus as the primary energy source, with automatic OR-diode switchover to a grid AC-DC adapter, while a separate 5 V adapter maintains the isolated control plane. Experimental results confirm continuous battery-free vehicle motion, reliable timer-driven coil sequencing, stable hybrid supply operation, and clean electrical isolation between the power and control planes.

The primary contribution of this work is the demonstration that battery-free operation of a dynamic WPT vehicle is experimentally feasible at the prototype scale, and that hardware timer-based coil sequencing provides a deterministic, low-complexity alternative to microcontroller-based or V2I-dependent approaches. As the global EV fleet continues to expand, the battery disposal challenge will intensify; vehicle architectures that eliminate onboard batteries at the design level represent a structurally distinct response to that challenge.

Future work will address variable-speed timer adaptation, DD coil geometry for improved lateral misalignment tolerance, scaling to higher transmitter power levels using SiC switching, and formal electromagnetic field compliance characterisation against ICNIRP reference levels.

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