Wireless Charging of Electric Vehicles with CC–CV Control Using Power Balance Control

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***Abstract*—This paper develops the proposed design and evaluation methodology for a stationary inductive wireless charging system for an electric vehicle battery. It combines a Double-D (DD) transmitter/receiver coil arrangement, a high-frequency power conversion chain, Power Balance Control (PBC), and a battery-side Constant Current–Constant Voltage (CC–CV) charging regulator. During the CC phase, the controller tracks a current reference; after the battery reaches its manufacturer-defined voltage limit, the controller transitions to CV operation and allows charging current to taper. PBC coordinates the power demanded by the receiver with the power made available by the transmitter, helping limit power mismatch during coupling, load, and alignment changes. The supplied draft establishes the concept and literature background but does not provide validated hardware ratings or experimental results. Accordingly, this expanded version sets out the system architecture, design equations, component-selection criteria, control sequence, test plan, and reporting metrics. All numerical ratings must be selected for the actual battery and prototype before construction; no performance result is claimed here.**

***Index Terms*—Wireless power transfer, electric vehicle, inductive power transfer, Double-D coil, CC–CV charging, power balance control, Li-ion battery, battery management.**

I. INTRODUCTION

Electric vehicles require charging systems that are efficient, reliable, and convenient. Plug-in charging relies on exposed electrical connectors and requires the driver to connect and disconnect a cable. Inductive wireless power transfer (IPT) offers a contactless alternative: a primary coil produces an alternating magnetic field, and a nearby secondary coil receives energy through mutual inductance.

The power transferred by an IPT link depends on coil geometry, mutual inductance, coupling coefficient, air gap, alignment, compensation network, switching frequency, and load. Parking offset or a change in the battery load can therefore alter receiver voltage and transferred power. A regulated power-conversion stage and a suitable supervisory controller are required to keep battery charging within its permitted limits.
This work proposes a stationary DD-coil IPT charger with PBC for power coordination and CC–CV control at the battery interface. The focus is a controlled, low-voltage laboratory prototype that can be scaled only after electrical, thermal, electromagnetic-compatibility, and battery-safety validation.

II. PROJECT OBJECTIVES AND SCOPE

- Develop a contactless energy-transfer path using primary and secondary DD coils.
- Design a rectification and regulated DC output stage suitable for the selected battery.
- Implement CC charging followed by CV charging using battery voltage and current feedback.
- Use PBC to coordinate requested receiver power and available transmitter power.
- Evaluate output regulation, transfer efficiency, alignment sensitivity, temperature rise, and protection response.

Scope: Stationary charging with the vehicle at rest. Dynamic in-motion charging, grid-scale infrastructure, certified automotive integration, and production-level interoperability are outside the initial prototype scope.

III. SYSTEM ARCHITECTURE AND OPERATING PRINCIPLE

The proposed chain is: AC source → input protection and rectifier/DC link → high-frequency inverter → primary compensation network and DD transmitter coil → magnetic coupling across the air gap → DD receiver coil and compensation network → high-frequency rectifier → regulated DC–DC converter → battery/BMS (Fig. 1).

The inverter converts the DC-link voltage into high-frequency AC. The primary compensation network is selected with the coil parameters to obtain the required resonant behaviour. The alternating primary current creates a magnetic field; the receiver coil develops an induced voltage. The receiver compensation and rectifier convert the received energy into DC. A controllable DC–DC stage regulates the battery current and voltage.

PBC acts as a supervisory layer. It compares the power requested by the battery-side CC–CV regulator with the power estimated or measured at the receiver/transmitter. It adjusts the transmitter power command within safe current, voltage, temperature, and input-power limits. PBC does not replace the battery CC–CV regulator or the battery management system (BMS).

IV. PROPOSED METHODOLOGY

1. Define the battery and ratings. Identify chemistry, series-cell count, nominal voltage, maximum charge voltage, permitted charge current, temperature limits, and BMS interface from the battery manufacturer. These values determine every downstream rating.
2. Characterise the coils. Select DD coil dimensions and conductor construction; measure primary and secondary inductances, winding resistance, mutual inductance at nominal alignment, and coupling coefficient. Repeat measurements at the intended air gap and lateral/longitudinal offsets.
3. Select compensation. Evaluate a suitable compensation topology (for example, series-series as a starting candidate) using measured coil parameters. Calculate resonant components, then verify component voltage/current stress and resonance under load. The topology is a design choice, not a fixed value supplied by the original draft.
4. Design the power stages. Select the rectifier, DC-link capacitor, inverter switches, gate drivers, receiver rectifier, DC–DC converter, sensors, heat sinks, fuses, and emergency isolation. Rate each component above the maximum calculated electrical stress with appropriate engineering margin.
5. Implement the control. Measure battery voltage/current and relevant DC-link/receiver quantities. The CC–CV controller generates the required output-current or output-voltage command. PBC limits and coordinates the requested transmitted power. Add soft-start, current limiting, overvoltage, undervoltage, overtemperature, and loss-of-coupling shutdown logic.
6. Integrate and commission. Begin with a current-limited, low-voltage supply and a non-battery resistive/electronic load. Verify gate signals, dead time, sensor polarity, protection trips, and power-stage temperatures before connecting the approved battery/BMS.
7. Validate experimentally. Test nominal alignment, controlled misalignment, different air gaps, load steps, CC-to-CV transition, start/stop, and fault conditions. Record synchronized input/output voltage and current, battery temperature, coil temperature, and alignment.

V. CONTROL STRATEGY: CC–CV AND PBC

- CC phase: While battery voltage is below the prescribed transition threshold, the current controller tracks I* (the allowed constant-current reference). The reference must not exceed the battery manufacturer's permitted charge current or the BMS limit.
- Transition: When measured battery voltage reaches the configured charge-voltage threshold, the controller changes mode using hysteresis or a state machine to avoid rapid switching between modes.
- CV phase: The voltage controller holds the battery at the specified maximum charge voltage. Charging current naturally decreases as the battery approaches full charge. Termination is based on

the battery manufacturer's current threshold, timer, BMS command, or other approved criterion—not on an arbitrary generic value.

- PBC supervisory action: Calculate or estimate power demand Preq = $V_{bat} \times I_{bat}$. Compare it with measured receiver power P_{rx} and available transmitter power P_{tx}. A bounded power command is generated to reduce the mismatch while respecting maximum coil current, DC-link limits, and thermal constraints. If coupling falls sharply or a safety limit is exceeded, reduce power or shut down.

VI. TECHNICAL SPECIFICATIONS AND COMPONENT SELECTION

The source draft does not state a prototype power rating, operating frequency, coil dimensions, air gap, battery pack voltage, compensation values, or measured efficiency. These must not be represented as achieved specifications. Table I is a design-definition checklist; populate it from the selected battery, measured coils, and component datasheets before fabrication.

- Battery: Chemistry, series-cell count, nominal voltage, maximum charge voltage, allowed CC current, CV termination criterion, temperature range, BMS communication/protection requirements.
- Power level: Define target output power from the battery and laboratory supply limits. Determine input power and component ratings from expected conversion losses and measured coupling.
- Coils: DD geometry, outer dimensions, turns, conductor type, Lp, Ls, winding resistance, mutual inductance M, coupling coefficient k, air gap, and permitted alignment offset.
- Power electronics: Inverter topology and switch ratings; switching frequency; gate-driver supply and dead time; rectifier type; DC-link voltage/capacitance; DC–DC topology; sensor ranges and accuracy; fuse and isolation ratings.
- Control and protection: Controller platform, sampling rate, current/voltage feedback, power-command limits, soft-start, overcurrent, overvoltage, undervoltage, overtemperature, foreign-object/abnormal-loss detection where feasible, and emergency stop.
- Thermal and mechanical: Coil and semiconductor temperature limits, heat-sink design, enclosure, insulation, mechanical alignment guides, and safe separation from metallic objects.

VII. MATHEMATICAL MODELLING AND DESIGN EQUATIONS

- Transferred real power: Pout = V_{out} I_{out}. For DC quantities, use measured average voltage and current over the same time interval.
- Efficiency: $\eta = (P_{out} / P_{in}) \times 100\%$, where Pin is measured at the defined system input boundary. State clearly whether auxiliary controller/fan power is included.
- Mutual inductance: $M = k\sqrt{(L_p L_s)}$, where Lp and Ls are primary and secondary self-inductances and k is the coupling coefficient ($0 \le k \le 1$).
- Induced secondary voltage (sinusoidal steady-state approximation): $V_s \approx j\omega M I_p$, where $\omega = 2\pi f$, f is operating frequency, and Ip is primary-coil current. This is a simplified relation; compensation and load determine the complete circuit response.
- Series-resonant starting estimate: $f_0 = 1 / (2\pi\sqrt{(LC)})$. For a real compensated IPT link, calculate using the chosen topology and measured equivalent parameters, then verify experimentally.
- Battery-side power demand: Pbat = Vbat Ibat. Required transmitter power is higher than battery power because of losses; estimate it using measured stage efficiencies rather than assuming ideal conversion.
- Controller errors: CC controller error: eI = Iref − Ibat. CV controller error: eV = Vref − Vbat. A PI/PID regulator may be used, with output saturation and anti-windup. Controller gains must be tuned on the actual power stage.
- PBC power mismatch: eP = Preq − Prx (or a defined transmitter/receiver balance error). A bounded supervisory law adjusts the power command to reduce eP without overriding battery and hardware limits.

VIII. EXPERIMENTAL TEST PLAN AND PERFORMANCE METRICS

- Baseline: Measure input and output voltage/current at nominal alignment and a stable

resistive/electronic load. Calculate output power and end-to-end efficiency.

- Alignment test: Vary lateral and longitudinal offset in documented increments and repeat the measurements. Record coupling or received-power reduction and determine the practical alignment tolerance.
- Air-gap test: Repeat at the minimum, nominal, and maximum intended separation. Do not exceed insulation, touch-safety, or thermal limits.
- Load-step test: Apply defined load changes and record output-voltage/current deviation, settling time, overshoot, and PBC response.
- CC–CV test: With a battery pack approved for the prototype and its BMS connected, record current and voltage throughout charging. Confirm constant-current tracking, transition voltage, voltage regulation, current taper, and safe termination.
- Thermal and fault tests: Monitor coil, switch, rectifier, and converter temperatures. Verify overcurrent, overvoltage, overtemperature, loss-of-coupling, sensor-failure, and emergency-stop responses using safe simulated faults where practical.
- Report: Pin, Pout, η, CC current error, CV voltage error, transition point, ripple, transient response, temperature rise, alignment offset, air gap, and protection response. Include instrument accuracy and repeatability.

IX. RESULTS AND DISCUSSION – REPORTING FRAMEWORK

No measured prototype results are included in the supplied draft. Therefore, numerical efficiency, charging time, current ripple, alignment tolerance, and thermal performance cannot yet be claimed. Once testing is complete, present results in tables and plots against the test conditions.

Discuss whether PBC maintains stable power when coupling or load changes; whether the CC and CV loops meet battery limits; and which losses dominate. Separate measured values from simulation results and theoretical estimates. Include uncertainty, test duration, battery state of charge, and ambient temperature.

X. ADVANTAGES, LIMITATIONS AND SAFETY CONSIDERATIONS

- Potential advantages: Contactless operation; reduced connector wear; convenient parking-based charging; controlled battery charging; and a supervisory power-control layer intended to improve response to load/coupling variation.
- Limitations: Coil misalignment reduces coupling; compensation and high-frequency switching add complexity; switching and copper losses create heat; electromagnetic interference and foreign-object heating require attention; and cost, interoperability, and installation standards remain important barriers.
- Safety: Do not connect an unprotected cell or battery pack directly to the prototype. Use a compatible BMS, correctly rated fuses, isolation, current limiting, thermal monitoring, enclosure, and emergency shutdown. Verify the battery's charge profile from its manufacturer. Test power electronics initially with a current-limited supply and dummy load. A student prototype is not an automotive-certified charger.

XI. FUTURE SCOPE

Future work may include adaptive tuning for coil misalignment, improved foreign-object detection, communication between vehicle and charger, simultaneous power and data transfer, renewable-energy integration, multi-vehicle scheduling, and dynamic wireless charging. Any scale-up requires standards compliance, EMC testing, thermal validation, and independent safety assessment.

XII. CONCLUSION

The proposed system combines inductive wireless power transfer using DD coils with battery-side CC–CV charging and PBC-based power coordination. The methodology defines the design sequence from battery specification and coil characterization through converter design, controller implementation, protection, and experimental validation. The supplied draft supports the concept and identifies alignment, efficiency, power fluctuation, infrastructure cost, and system complexity as key concerns. Since no

prototype ratings or measured results were provided, the final technical values and performance claims must be completed only after design calculations and controlled testing.

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