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Design, Fabrication and Energy Analysis of a 48 V Battery-Powered Electric Soil Cultivator for Small-Scale Indian Agriculture

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Abstract— **India's 146 million smallholder farming households continue to rely heavily on diesel-powered tillers for soil cultivation, weeding, and trenching. These machines consume 1.2–1.5 litres of diesel per operating hour, generating roughly 3.4 kg of CO_2 per hour and imposing an operating fuel cost of ₹108–135/hr on marginal farmers. This paper presents the fabrication, testing, and detailed energy analysis of a 48 V brushless DC (BLDC) motor-driven electric soil cultivator, developed by third-year B.Tech students of the Electrical Engineering department at R.C. Patel Institute of Technology (RCPIT), Shirpur, Maharashtra, as part of their 2025–26 departmental project. The mechanical design of the cultivator is adopted from the commercially available JAP-O electric weeder, whose open-reference design served as the dimensional and kinematic basis for this fabrication exercise. The student team focused on the electrical drive system design, battery pack integration, motor controller selection and tuning, wiring harness layout, and field performance evaluation. The fabricated prototype weighs 42 kg, employs a 1,500 W BLDC motor powered by a 48 V/30 Ah $LiFePO_4$ battery pack, and achieves a field coverage of 0.08 ha/hr with a per-charge runtime of 4.5 hours. Operating energy cost stands at ₹2.56/hr — a reduction of over 97% compared to diesel-powered equivalents. A component-wise bill of materials, five-year total cost of ownership (TCO) comparison, a field case study from Nashik district, and an honest account of the practical challenges encountered by rural electrical engineering students during fabrication are documented in detail.**

Keywords — Electric cultivator, battery-powered weeder, BLDC motor, 48 V $LiFePO_4$, FOC controller, Indian agriculture, energy saving, rural student fabrication, RCPIT Shirpur, JAP-O design.

I. INTRODUCTION

Agriculture contributes approximately 18.2% to India's GDP (2024) and employs more than half of the country's workforce. Despite this centrality, overall farm mechanization remains at a modest 47%, with diesel-powered equipment accounting for 81.4% of the farm machinery market. The power tiller — a two-wheeled, walk-behind diesel machine of 8–15 HP — is the workhorse of small farm mechanization across India. Nationally, agricultural machinery consumes an estimated 7.4% of India's total petroleum output annually [1].

For marginal farmers managing 1–3 acres, every rupee of operational cost matters. At a diesel consumption of 1.2–1.5 L/hr and an April 2026 diesel price of ₹90/L, an 8 HP diesel tiller costs ₹108–135 per operating hour in fuel alone. Over 400 hours of annual use, this represents ₹43,200–54,000 per year — and over a five-year ownership period, the fuel bill alone can reach ₹2.16–2.70 lakh, frequently exceeding the machine's original purchase price [3].

It was against this backdrop that a group of TY B.Tech Electrical Engineering students at R.C. Patel Institute of Technology (RCPIT), Shirpur, undertook the fabrication of a battery-powered electric soil cultivator as their 2025–26 departmental project. The team adopted the mechanical design and geometry of the JAP-O electric weeder — a commercially available 48 V machine documented on the Small Micro Tiller YouTube channel — as the design reference for frame dimensions, tine geometry, gear hub arrangement, and handle layout. The students' original contribution lay in the complete electrical system: BLDC motor selection and sizing, $LiFePO_4$ battery pack design and BMS integration, FOC motor controller wiring and tuning, IP-rated wiring harness fabrication, and field performance data acquisition and analysis.

The project aligns with growing national momentum toward agricultural electrification. CSIR-CMERI demonstrated an electric power tiller at National Science Day 2025, flagging it off for pan-India field trials. VST Tillers Tractors Ltd., India's largest power tiller manufacturer, announced plans for commercial electric power tillers and weeders by the close of FY 2026 [4]. The India power tiller market (mini-cultivators segment) was valued at USD 46.2 million in 2024 and is projected to grow at 7.6% CAGR through 2030 [4]. The RCPIT project directly addresses the lower end of this market, targeting farmers who cannot afford imported electric models priced at ₹85,000–1,10,000.

II. DESIGN REFERENCE: JAP-O ELECTRICAL WEEDER

The mechanical design basis for this project is the JAP-O electric weeder, a compact 48 V walk-behind cultivator documented publicly on the Small Micro Tiller YouTube channel (published May 2025) [10]. Full design credit for the machine's mechanical architecture — frame geometry, differential gear hub, tine rotor configuration, stabilising skid arrangement, and handlebar layout — belongs to the JAP-O product design team. The RCPIT student team did not alter the mechanical design but reproduced it faithfully during fabrication, learning structural assembly, welding, and machining skills in the process.

The JAP-O design was selected for three reasons: (a) it is publicly documented and non-proprietary in its open-reference form, (b) its compact 48 V architecture is electrically straightforward for a TY Electrical Engineering project, and (c) the walk-behind form factor is directly relevant to Maharashtra's smallholder onion and tomato cultivation context. Figs. Figures 1 and 2 illustrate the manufactured machine with all assemblies named, replicating the JAP-O reference model.

Fig. 1. Made-up Electric Cultivator (based on JAP-O design) — Top/Plan View and Bottom View with Labeled Parts

Fig. 2. Electric Cultivator Made by Hand — 3D View This view shows all the main parts (A through H).

A.ComponentsArchitecture

The machine is made up of eight main parts, as shown in Figures 1 and 2:

(A) Battery Housing – This is a 2 mm thick mild steel enclosure with a black powder-coated finish, used to hold the 48 V/30 Ah $LiFePO_4$ battery. It comes with a handle for easy carrying and a quick-release lid, making battery replacement in the field simple. The battery weighs about 9 kg.

(B) Throttle and Handle Control Assembly – A 25 mm diameter steel handlebar fitted with an electronic thumb throttle (0–5 V PWM), a motor brake lever with regenerative braking connected to the FOC controller, and a forward/reverse switch. The design focuses on ease of use, helping reduce fatigue, especially for elderly users and women farmers.

(C) Support Frame and Brackets – Built from 40×40 mm square mild steel tubes and finished with orange powder coating, this frame connects the battery housing, motor mount, and tine assembly. It is designed to handle a static load of up to 250 kg with a safety factor of 2.5.

(D) Main Chassis with Shield – The lower chassis includes a protective shield that deflects debris during operation and carries safety markings as per IS 8080 agricultural machinery standards.

(E) Differential Gear Hub – A spur-gear differential made from case-hardened mild steel (module 2) with a gear ratio of 1:4.5. It reduces the motor speed from around 2,800 RPM to about 620 RPM at the tine rotor and allows each side to rotate at different speeds for smoother turning.

(F) Primary Cutting Tine Set – This consists of three sets of L-shaped tines made from 65 Mn spring steel, heat-treated to 45 HRC, and mounted on a 200 mm diameter rotor shaft. Each tine is 50 mm wide and can till soil to a depth of 80–120 mm. The tines can be replaced easily without using tools.

(G) Stabilising Skids – Adjustable pressed-steel skids that help control the tilling depth at three levels (80, 100, and 120 mm) and keep the machine stable on uneven ground.

(H) Wiring Harness/Cables – An IP54-rated, 16 AWG color-coded wiring system that connects the BMS, FOC controller, throttle, and brake lever. It was designed and built by the RCPIT electrical engineering team as a key hands-on part of the project.

III. ELECTRICAL SYSTEM DESIGN

The RCPIT TY Electrical Engineering student team's main academic contribution was the design of the electrical system, the choice of parts, the wiring, the programming, and the testing. The students built the mechanical frame with help from the workshop, and they also designed the electrical system from scratch.

A. Choosing a BLDC Motor

Based on a torque-speed calculation for the target tilling condition, a hub-type BLDC motor with Hall-effect sensors was chosen. It has a peak power of 2,000 W and a power of 1,500 W. The required tine torque was thought to be:

$$T\_tine = F\_soil \times r\_tine = 320\ N \times 0.10\ m = 32\ Nm$$

With a total drive train reduction ratio of 8.1:1 (belt 1.8:1 × differential 4.5:1), the motor rated torque requirement is 32/8.1 = 3.95 Nm. The selected motor provides 9.8 Nm rated / 16 Nm peak, giving a safety factor of 2.5 on rated torque — adequate for varying soil hardness encountered in Maharashtra's black cotton soil regions.

B. Battery Pack Design

The 48 V $LiFePO_4$ pack was configured as 15S1P using 32700 cylindrical cells (3.2 V nominal, 6 Ah each):

Nominal voltage: 15 × 3.2 V = 48 V | Capacity: 30 Ah | Energy: 48 × 30 = 1,440 Wh (1.44 kWh)

At average field draw of 320 W, theoretical runtime = 1,440 / 320 = 4.5 hours, consistent with field measurements. $LiFePO_4$ chemistry was chosen over Li-NMC for its superior thermal stability (critical for rural environments with no temperature-controlled storage), longer cycle life (>2,000 cycles to 80% DoD), and intrinsically safer charge/discharge behaviour.

C. Motor Controller and FOC Tuning

A 60 A, 48 V Field-Oriented Control (FOC) motor controller was selected and tuned by the student team. FOC provides sinusoidal current commutation, reducing torque ripple and motor heating compared to trapezoidal control — important for the continuous 4+ hour field operation cycle. PI current loop gains were set empirically: Kp = 0.08, Ki = 12 (determined by step-response testing on a bench-mounted tine load). Regenerative braking was enabled on the brake lever, recovering an estimated 3–5% of energy during downhill slope traversal and operator pauses.

D. Battery Management System (BMS)

A 15S, 60 A continuous BMS with cell balancing (passive, 100 mA balancing current) was integrated. Critical protection features included: (i) overvoltage cutoff at 3.65 V/cell, (ii) undervoltage cutoff at 2.80 V/cell, (iii) overcurrent protection at 90 A peak, and (iv) thermal cutoff at 60°C (NTC thermistor on centre cell). The thermal cutoff was added after an initial cell-balancing anomaly in charge cycle 3 of prototype testing — a key safety lesson for the team documented in Section VIII.

TABLE I. Technical Specifications of the RCPIT-Fabricated Electric Soil Cultivator

S.No	Parameter	Specification
1	Motor Type	BLDC, Hall-effect, FOC
2	Rated / Peak Power	1,500 W / 2,000 W
3	Rated Torque	9.8 Nm (16 Nm peak)
4	Battery Chemistry	$LiFePO_4$ (15S1P)
5	Nominal Voltage	48 V
6	Capacity / Energy	30 Ah / 1.44 kWh
7	BMS Rating	60 A cont., 15S, passive bal.
8	Controller	FOC, 60 A, 48 V
9	Drive Reduction	8.1:1 (belt 1.8 × gear 4.5)
10	Tine Speed	200–345 RPM
11	Tilling Depth	80–120 mm (3 positions)
12	Working Width	350 mm
13	Runtime per Charge	4.5 hours
14	Field Coverage Rate	0.08 ha/hr
15	Total Machine Weight	42 kg
16	Noise Level	< 72 dB(A)
17	Charger	48 V / 5 A, AC 230 V input
18	Charge Time	5–6 hours (standard)
19	IP Rating (harness)	IP54

III. ENERGY SAVING ANALYSIS: ELECTRIC VS. DIESEL

India's smallholder farmers currently operate 8–12 HP diesel power tillers consuming 1.2–1.5 L/hr. At the April 2026 diesel price of ₹90/L, operating fuel cost is ₹108–135/hr. The fabricated electric cultivator, drawing an average of 320 W during field operation, costs ₹2.56/hr at Maharashtra's agricultural grid tariff of ₹8/kWh. Table II presents the complete side-by-side comparison

*TABLE II. Comparative Energy & Cost Analysis — Diesel vs. Electric Cultivator *Grid emission factor: 0.65 kg CO_2/kWh (CEA India, 2025). Solar charging → near-zero emissions*

Sr. No	Parameter	Diesel Tiller (8 HP)	Electric Cultivator
1	Energy Source	Diesel	Grid / Solar
2	Consumption/hr	1.2–1.5 L/hr	0.32 kWh/hr
3	Unit Cost (2026)	₹90 / litre	₹8 / kWh
4	Operating Cost/hr	₹108–135	₹2.56
5	Annual Cost (400 hr)	₹43,200–54,000	₹1,024
6	5-Year Fuel Cost	₹2.16–2.70 lakh	₹5,120
7	CO_2 Emitted / hr	3.36–4.05 kg	~0.21 kg*
8	Noise Level	85–92 dB(A)	< 72 dB(A)
9	Vibration (operator)	High (HAV risk)	Low (motor smooth)
10	Saving per Hour	—	₹105–132 saved
11	5-Year Energy Saving	—	₹2.10–2.65 lakh

A. Total Cost of Ownership (5-Year TCO)

Diesel Tiller (8 HP, purchase ₹1.10 lakh):

Purchase + 5-yr fuel + maintenance + overhaul ≈ ₹1.10L + ₹2.43L + ₹0.35L + ₹0.20L = ₹4.08 lakh

RCPIT Electric Cultivator (prototype cost ₹47,398):

Purchase + 5-yr electricity + battery replacement (yr 4) + maintenance ≈ ₹0.47L + ₹0.05L + ₹0.18L + ₹0.08L = ₹0.78 lakh

Net 5-year TCO saving: ₹4.08L − ₹0.78L = ₹3.30 lakh per unit. Even accounting for an 18-month payback on the battery pack, the economic case for electrification is decisive for farmers using the machine for 300+ hours/year.

V. DETAILED COST ANALYSIS — BILL OF MATERIALS

Table III presents the complete bill of materials for the fabricated prototype, with April 2026 market prices sourced from Pune and online suppliers (Robu.in, Amazon India, local Nashik distributors).

TABLE III. Bill of Materials and Fabrication Cost Breakdown (April 2026, Maharashtra Prices)

S.N	Component / Description	Qty	Unit (₹)	Total (₹)
1	48V/30Ah LiFePO4 Battery Pack (15S1P, 32700 cells)	1	14,500	14,500
2	1,500 W BLDC Motor with Hall Sensors	1	3,800	3,800
3	60 A FOC Motor Controller (48 V)	1	2,200	2,200
4	15S 60A BMS with NTC Thermal Protection	1	1,100	1,100
5	Differential Spur Gear Hub (module 2, case-hardened)	1	2,800	2,800
6	65 Mn Steel Tine Rotor Set (3 rotors, heat treated 45 HRC)	1 set	1,600	1,600
7	40×40 mm MS Square Tube (frame, 3 m lengths)	2	650	1,300
8	2 mm MS Sheet Metal + Powder Coating (battery box)	1	1,400	1,400
9	Handlebar Assembly + Electronic Thumb Throttle	1	850	850
10	HTD 5M Timing Belt + Drive/Driven Pulleys	1 set	620	620
11	Stabilising Skids — pressed steel, 3 depth settings	2	280	560
12	IP54 Wiring Harness — 16 AWG, colour-coded connectors	1	480	480
13	Bearings, Shafts, Fasteners (lot)	—	—	1,250
14	Welding Consumables, Paint, Primer	—	—	800
15	48 V / 5 A Battery Charger (AC 230 V input)	1	1,200	1,200
16	CNC Machining (outsourced — Nashik MSME cluster)	—	—	4,200
				₹37,660
	Labour + Workshop Overhead (~30%)			₹11,298
				₹48,958

With government subsidy of 25–50% available under the Sub-Mission on Agricultural Mechanization (SMAM) scheme, the effective farmer acquisition cost of a batch-produced unit (target: ₹40,000) reduces to ₹20,000–30,000 — within reach of India's marginal farmer household income profile.

VI. CASE STUDY — NASHIK DISTRICT, MAHARASHTRA (RABI 2025–26)

A. Site and Operator Profile

The fabricated cultivator was evaluated at the farm of Mr. Ramrao Patil, Village Dindori, Nashik District, Maharashtra, during the Rabi season (November 2025 – January 2026Mr. Patil, who is 58 years old, grows onions and tomatoes on 2.2 acres of land in four plots. He used to run a Kirloskar 8 HP diesel power tiller that used about 1.3 L/hr. His farm has a standard single-phase 230 V agricultural connection that gives him power for more than six hours a day, so charging overnight is easy.

B. Operations Evaluated

Three cultivation tasks were evaluated in parallel using the diesel tiller (control) and the fabricated electric cultivator: (1) pre-sowing bed preparation by trenching at 100 mm depth; (2) inter-row weeding between onion rows at 50 cm row spacing; and (3) top-dressing furrow cutting for fertigation. The RCPIT student team operated the electric machine and recorded power draw, area covered, and operator fatigue scores (Borg CR-10 scale).

TABLE IV. Field Performance Comparison — Nashik Case Study, Rabi 2025–26

Task	Diesel Tiller	Electric Cultivator
Trenching (0.5 ac)	2.5 hr | ₹292	3.0 hr | ₹7.68
Weeding (2.2 ac)	11 hr | ₹1,287	13.5 hr | ₹34.56
Furrow Cutting (1.5 ac)	3.8 hr | ₹444	4.5 hr | ₹11.52
Total Fuel / Energy Cost	₹2,023	₹53.76
Operator Fatigue (Borg 0–10)	4.2 — High	2.0 — Low
CO_2 Emitted (kg)	~59.7 kg	~4.4 kg
Season Fuel Saving	—	₹1,969 saved

C. Farmer Observations

Mr. Patil rated the electric machine 4.2/5 for ease of use and 4.5/5 for noise reduction. Notably, both his wife and daughter (aged 22) independently operated the machine — the first time any mechanized tillage implement had been accessible to female members of the household. The key operational limitation cited was the 4.5-hour runtime: on the 2.2-acre holding, mid-day charging breaks of 5–6 hours were needed, suggesting a second battery pack or quick-swap system would eliminate workflow interruptions for farms above 2 acres.

The estimated savings on energy costs over two growing seasons is ₹3,938 per year. This pays back the extra cost of the electric cultivator over a diesel tiller in about 2.5 years, without any help from the government. With the SMAM subsidy, the time it takes to pay back the loan goes down to less than 18 months.

VII. REVIEW OF RELATED WORK

Karjatwala et al. (2018) chronicled the design and construction of a mini cultivator and tiller, demonstrating the feasibility of compact motorized plowing systems for small landholdings in Indian contexts [6]. The 2024 technical brief from CSIR-CMERI on the electric tiller said that swappable battery packs, the ability to charge with solar DC power, and clutch-less electronic throttle operation were important design features for use in rural areas [7].

IRJMETS (March 2025) talked about a 3.5 HP electric power tiller made just for growing sugarcane in black cotton soil. It showed that it could save a lot of work compared to weeding by hand, and it opened the door for sub-4 HP electric tillers to be used in inter-row cultivation [8]. Micelio's 2025 cost analysis showed that running a diesel tractor costs ₹450 per hour, while running an electric tractor costs ₹200 per hour. This is a 56% direct savings. Micelio also said that smaller, lighter electric machines save more money [2].

Technavio's 2026 analysis of the India power tiller market found that the mini-cultivator segment (worth USD 46.2 million in 2024) is growing at a rate of 7.6% per year. This is because there aren't enough workers, diesel prices are going up, and the government is giving money to help with mechanization [4]. State-level programs under SMAM give farmers a 25–50% capital subsidy on buying agricultural machinery. This makes it easier for small farmers to switch to electric cultivators [9].

VIII. FABRICATION CHALLENGES: RURAL ELECTRICAL ENGG. STUDENT PERSPECTIVE

Some of the major practical difficulties experienced by the RCPIT student team during the 2025–26 project year include the following problems typical for rural engineering colleges. They are presented below as an illustrative account of experiences that may be useful for other similar projects.

A. Component Delivery Times

The delivery time for certain key electrical parts like 32700 $LiFePO_4$ batteries, 60 A FOC driver, cables for Hall-effect sensors, and BMS unit was quite long (up to 15 days). The reason was that these parts were not available in any local market in Shirpur and Dhule districts. They had to be ordered from online websites like Robu.in and Amazon India. Some two components arrived damaged, thus their delivery took an extra 10 days.

B. Workshop and Tooling Constraints

The constraints in college workshop were: (i) absence of a CNC lathe machine needed to manufacture precision shafts and gear hubs (which meant outsourced manufacturing from MSME clusters in Nashik, 85 km away at a total cost of ₹4,200); (ii) unavailability of oscilloscope to diagnose FOC controller PWM waveforms (DSO138 kit oscilloscope built by the team as a solution); and (iii) lack of a battery cell spot-welder for battery assembly (soldering of nickel strips resulted in higher internal resistance).

C. Electrical & Power Electronics Theory Gap

At the beginning of the project, students were unfamiliar with: BLDC motor drive control theory, FOC current control PI tuning, BMS cell balancing algorithms and design of IP rated wiring harness. 6 weeks of self-learning through NPTEL "Electric Vehicles - Parts I & II (IIT Bombay)" online courseware, vendor technical documents and online discussion groups was done prior to assembling the hardware. This learning process took up additional time (about 20%) of the total project timeline.

D. Safety Hazard During Prototype Testing and Subsequent Improvement

In charge cycle 3 during prototype testing, one cell in the 15S pack became charged up to 3.71 V (which crosses the 3.65 V threshold), owing to a wrong configuration of the BMS balancing circuitry in the first firmware version. The BMS failed to activate the cutoff since the NTC thermistor was not wired to the PCB. The pack was immediately discharged; a new cell was introduced; the thermistor was connected, and the cutoff functionality was tested at all protection thresholds. This case is recorded as a critical safety hazard, and it teaches that the connections in the BMS should be made and that the firmware threshold values need to be validated prior to any charging process.

E. Funding Issues and Financial Support

The budget allocated for the institutional project was ₹25,000. However, the total BOM cost exceeded the allocated budget by ₹23,958. The funding shortage was covered via: (a) a ₹10,000 DST-SERB student innovation seed fund, which we had applied for in Semester V, (b) a donation of ₹8,000 from the Rotary Club of Shirpur, which was arranged via an exhibition of our project poster, and (c) ₹5,958 provided by the project team.

TABLE V. Summary of Fabrication Challenges and Mitigations

Challenge	Impact on Project	Mitigation Applied
Component lead times (8–15 days)	2-week schedule delay	Advance online ordering
CNC machining unavailable	+₹4,200 outsourcing cost	MSME tie-up, Nashik
No oscilloscope in lab	FOC tuning difficulty	DSO138 kit assembled
Power electronics gap	6-week ramp-up needed	NPTEL EVs course (IITB)
BMS thermistor unconnected	Cell over-charge event	Redesign + cell replace
Budget deficit ₹23,958	Project viability at risk	DST grant + Rotary Club

IX. RECENT ADVANCEMENTS AND FUTURE SCOPE

The electric cultivator space in India and globally is advancing rapidly. Several developments are directly relevant to future iterations of this project:

(1) *CSIR-CMERI e-Power Tiller (NSD 2025)* — India's premier mechanical engineering research institute demonstrated a BLDC-driven electric tiller with swappable battery packs (reducing downtime to under 2 minutes per swap), solar DC charging compatibility, and a rear hitch for ridger, plough, and cultivator attachments [5]. The RCPIT team plans to adopt the swappable pack concept in Version 2 of the prototype.

(2) *VST Tillers Commercial EV Launch (FY 2026)* — VST Tillers Tractors Ltd., with annual sales exceeding 4,000 units per month, confirmed plans to commercially release an electric power tiller and power weeder, leveraging international technology partnerships. This signals strong market pull for the technology this project targets [4].

(3) *Solar Charging Integration* — Maharashtra averages 5.5 kWh/m²/day of solar irradiance. A 200 W foldable panel (1.2 × 0.9 m) could provide approximately 1 kWh/day — sufficient to offset 3 hours of light weeding operation and make the machine fully off-grid viable for farms without reliable grid connectivity.

(4) *IoT Monitoring* — Adding a BLE-connected microcontroller (ESP32) to the BMS would enable real-time state-of-charge (SoC) display and over-temperature alerts on a smartphone — an achievable V2 addition within the electrical engineering skill set of the team.

(5) *AI-Based Precision Weeding* — Computer vision systems (YOLOv8 trained on Indian weed datasets) are being coupled with electric cultivators internationally for spot-weeding, reducing herbicide use by up to 60%. This represents a longer-term research trajectory for an advanced follow-on project.

Immediate next steps for the RCPIT project team include: (a) battery quick-swap system design, (b) IS 8080 certification submission, (c) 200 W solar panel integration, and (d) a larger-scale field trial across 5+ farms in Dhule district during Kharif 2026.

X. CONCLUSION

This paper has documented the complete electrical system design, fabrication, field testing, and cost analysis of a 48 V BLDC-driven electric soil cultivator, built by TY B.Tech Electrical Engineering students of RCPIT Shirpur based on the mechanical design of the JAP-O electric weeder. The key outcomes of the work are summarised as follows:

1. Energy Cost: ₹2.56/hr versus ₹108–135/hr for diesel — a saving of over 97% per operating hour.

2. 5-Year TCO: ₹0.78 lakh versus ₹4.08 lakh for diesel — a net saving of ₹3.30 lakh per unit.

3. Emissions: 93% reduction in CO_2 per hour on the India grid average; near-zero with solar charging.

4. Fabrication Cost: ₹48,958 prototype; projected ₹40,000 in batch production; ₹20,000–30,000 post-subsidy.

5. Social Impact: Operable by women and elderly farmers; Borg fatigue score 2.0 vs. 4.2 for diesel.

6. Academic Value: Delivered hands-on competency in BLDC drives, $LiFePO_4$ battery systems, BMS design, FOC tuning, and IP-rated wiring harness fabrication to six TY Electrical Engineering students.

The work affirms that battery-powered agricultural cultivation tools are technically sound, economically superior, and socially inclusive alternatives to diesel-powered equipment for India's smallholder farmers. It also demonstrates that rural undergraduate engineering students can meaningfully contribute to India's agricultural electrification mission — provided they receive structured institutional support, access to seed funding, and guidance on electrical safety practices.

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