

Design and Fabrication of a Low-Cost Electric Vehicle for Rural and Last-Mile Transportation

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ABSTRACT

The rising necessity for sustainable and economical mobility has emphasized the importance of developing low-cost electric vehicles, especially for rural transport and short-distance commuting. Traditional fuel-based vehicles are costly to run, require frequent servicing, and cause high levels of air pollution. This study is centered on creating and fabricating an affordable electric vehicle that overcomes these issues by presenting an eco-friendly, cost-saving, and practical option. The designed vehicle operates with a battery-driven electric motor, ensuring lower running expenses, minimal upkeep, and zero exhaust emissions. Focus is given to a simple structure, economic feasibility, and suitability for rural terrains with poor roads and limited charging facilities. The research explains component choice, integration, and fabrication techniques to achieve the best efficiency under limited resources. This work aims to deliver an inexpensive transport option that supports sustainable growth, enhances accessibility, and improves mobility in village regions.

With increasing competition in the automobile market, vehicles generally rely on petrol or diesel engines for movement. In recent times, e-bikes have gained attention due to their low maintenance and simple operation. Their main limitation, however, is the need for repeated charging from conventional electric supply. This paper introduces a charging mechanism within the e-bike itself. The motor receives energy from the battery, while the battery is recharged by a hub dynamo system [1]. The generated energy is stored back into the battery. Commercial e-bike batteries usually require 6–8 hours for charging using electric supply, but this arrangement aims to improve charging convenience and overall efficiency [2].

Keywords: BLDC motor, E-Cycle, Lithium-ion battery, Dynamo charging, DC Motor Drive System, Charging System

1. INTRODUCTION

Transportation plays a vital role in the socio-economic development of rural areas and in bridging the connectivity gap for last-mile mobility. However, conventional vehicles powered by internal combustion engines face challenges such as high fuel costs, dependency on fossil fuels, frequent maintenance requirements, and significant contribution to environmental pollution. These limitations make them less practical for rural communities where affordability, simplicity, and sustainability are crucial factors. The continuous rise in the consumption of natural resources such as petrol and diesel makes it essential to explore alternative energy sources like electric and solar vehicles. Compared to internal combustion engine

(ICE) vehicles, electric vehicles are simpler to manufacture, cheaper, and require less maintenance [3]. In recent years, electric vehicles (EVs) have emerged as a viable solution to address rising concerns of pollution, energy security, and operational cost. The Indian government has also emphasized the adoption of electric mobility through policies and roadmaps, encouraging the development of electric two-wheelers, three-wheelers, and small electric vehicles [4], [5]. Unlike conventional vehicles, electric vehicles operate with the help of rechargeable batteries and electric motors, ensuring zero emissions, reduced noise pollution, and lower running costs [6].

Electric bikes are comparatively easier to manufacture and more affordable than conventional vehicles, while also contributing to reduced pollution [7]. They are also eco-friendly, producing no emissions or noise, thereby helping to mitigate global warming. Electric vehicles can be charged using AC current and offer significantly lower cost per kilometer. Furthermore, the use of lithium-ion batteries enhances thermal and chemical stability [8]. More than 700 cities worldwide operate bicycle-sharing programs [9]. The benefits include flexible mobility, increased physical activity, and reduced emissions and fuel consumption. Their analysis combined assumptions regarding the travel modes replaced by shared bicycle journeys to estimate the overall reduction in vehicle kilometers traveled, showing a notable contribution to sustainable urban mobility.

2. LITERATURE REVIEW

K.J. Åström and R.E. Klein (2005) [10] analyzed bicycles from a control systems perspective. They presented models of varying complexity, from simple to advanced multimode simulations, that captured fundamental behaviors such as self-balancing and challenges in rear-wheel steering. They also shared experiences of using bicycles in control education and suggested engaging experiments for students. Additionally, bicycles were shown to play a role in clinical programs designed for children with disabilities. The German Naturalistic Cycling Study [11] investigated acceleration and speed patterns of conventional and electrically powered bicycles under real-world conditions. The study differentiated between e-bikes offering assistance up to 45 km/h (S-pedelecs) and 25 km/h models. Findings showed that while e-bikes assist riders in reaching their preferred speeds more easily, they do not necessarily increase the average cycling speed significantly. Nonetheless, the rising popularity of e-bikes, particularly among younger users, indicates a shift from being seen as “recovery vehicles” to fashionable mobility options. The authors suggested that this trend may influence two-wheeled transport and road safety in the medium to long term.

This research focuses on the design and fabrication of a low-cost electric vehicle specifically tailored for rural and last-mile transportation needs [12]. The proposed vehicle integrates simple design concepts, readily available components, and energy-efficient systems to achieve affordability and reliability. It aims to serve as an eco-friendly and economical alternative for short-distance commuting, local goods transport, and connectivity in semi-urban and rural zones where traditional vehicles are often impractical. By addressing cost-effectiveness, sustainability, and usability, the study highlights the potential of low-cost electric vehicles in improving accessibility and promoting green transportation solutions in developing regions.

The remainder of this paper is organized as follows. Section II explains the working principle of the proposed e-bicycle, while Section III describes the key components used in the design. Section IV discusses the construction details and electrical circuitry of the system. Section V highlights the results and key observations, followed by the final conclusions summarizing the paper outcomes and its future scope.

3. WORKING OF E-BICYCLE

The operation of an electric cycle is based on the conversion of electrical energy stored in batteries into mechanical motion for driving the wheels [13]. In a conventional bicycle, a dynamo connected to the wheel generates a small current for lighting purposes. The electric cycle functions in the reverse manner: instead of producing electricity, a battery supplies current to the motor [14]. The motor then rotates and provides the torque required to move the wheel, enabling motion with minimal or no pedaling effort.

The battery is the most critical component, as it stores the entire power needed to drive the vehicle [15]. Typical e-cycle batteries deliver 350–500 W of power, operating at 35–50 volts and 10 amps. Lightweight lithium-ion batteries are preferred due to their high energy density and reduced weight compared to traditional lead-acid or nickel-cadmium batteries [16].

Depending on terrain, such batteries provide a travel range of 10–40 miles per charge and a top speed of 10–20 mph, which complies with legal limits in most countries. The range can be extended through pedaling or freewheeling.

Electric motors in e-cycles are generally mounted in the hub of the front or rear wheel, or at the center near the pedal sprocket [17]. These hub motors are compact yet powerful, appearing bulkier than the hubs of conventional bicycles. The motor directly converts the battery's electrical energy into wheel rotation, offering efficient propulsion.

Thus, the e-cycle combines simplicity, efficiency, and eco-friendliness by integrating battery, motor, and control systems into a lightweight structure [18].

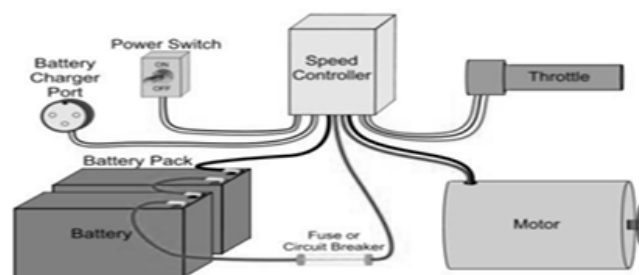


Fig.1. Block diagram of e-bike

In principle, any type of battery could be applied to an electric bicycle. However, in practical applications, the chosen battery must provide high energy storage while maintaining low weight, as excessive weight would waste significant power in simply transporting the battery. This limitation generally excludes heavy lead-acid batteries, such as those commonly used in automobiles, although they are still found in certain electric bicycles. The most widely adopted option today is lightweight lithium-ion batteries, which are also used in devices like laptops, mobile phones, and music players. These batteries are preferred for their efficiency and portability, despite being more costly than earlier rechargeable technologies such as nickel-cadmium (NiCad).

4. COMPONENTS OF E-BIKE

1. 24V 250W Brushed Motor Controller

The Brushless DC (BLDC) motor is selected as the prime mover due to its high efficiency, compact size, and low maintenance requirements. It offers a high power-to-weight ratio and ensures reliable torque output, which is suitable for rural terrain and last-mile connectivity. The motor is connected to the rear axle via a chain/belt drive system to transmit power efficiently.



Fig.2. 24V 250W Brushed Motor Controller

2. Lithium-Ion Battery 24v 13AH

Lithium-Ion (Li-Ion) battery technology, particularly the LiFePO₄ variant, is employed due to its long cycle life, low toxicity, and thermal stability [20]. The pack provides sufficient voltage and ampere-hour capacity to meet the low-cost vehicle's energy requirements while ensuring safety and durability.

It powers the BLDC motor and auxiliary systems.



Fig.3. Lithium-Ion Battery 24v 13AH

3. Rear Sprocket and Drive Chain

The drivetrain setup employs a single-speed freewheel sprocket with a roller chain to transfer torque from the motor to the wheel hub or axle. The freewheel mechanism is essential because it allows the motor to drive the cycle forward but prevents reverse motion, ensuring rider safety and enabling smooth coasting when moving downhill or across uneven surfaces.



Fig.4. Rear Sprocket and Drive Chain

4. Ignition/Key Switch Harness

A two-wire keyed ignition switch equipped with a pre-crimped connector, designed to control the low-voltage logic line of the traction controller. Its primary role is to enable or disable system operation, providing both functionality and safety.



Fig.4. Ignition/Key Switch Harness

5. Fasteners and Connector Set

The kit includes a selection of bolts, washers, and crimp-style two-pin housings with both male and female terminals, essential for assembling and wiring small electric vehicles. By using standardized hardware, the system ensures easier sourcing of parts and lowers costs, which is especially valuable in rural or community-level workshops where resources are limited. Standard fasteners and connectors also make field repairs more straightforward, as common hand tools are sufficient for most servicing needs.



Fig.5. Fasteners and Connector Set

6. Electronic brake levers with cut off

The electronic brake levers with cut-off are designed to enhance both safety and usability in light electric vehicles. Each lever integrates a small microswitch that communicates directly with the motor controller. When the lever is pulled, the switch instantly signals the controller to cut drive power. This ensures that motor torque is immediately disabled, preventing the motor from opposing braking action. Such a feature is particularly important on rural or uneven surfaces, where traction is limited and stopping distances must be minimized for safe handling.



Fig.6. Electronic brake levers with cut off

7. Motor mounting bracket

The motor mounting bracket is a key structural component that secures the traction motor to the chassis while allowing proper drivetrain alignment. Made from stamped steel, it features multiple slots and holes that provide flexibility in positioning the motor.



Fig.7. Motor mounting bracket

8. LED headlamp module

The LED headlamp module serves as an essential safety component, ensuring clear visibility for the rider during low-light conditions such as dusk, night, or foggy weather. It consists of a compact three-LED assembly that delivers bright and focused illumination, improving the rider's ability to see the road ahead and be noticed by others. Powered directly from the traction battery, the system efficiently utilizes electrical energy while maintaining low power consumption. Its lightweight and energy-saving design make it ideal for electric bicycles, enhancing both safety and performance without significantly affecting the vehicle's battery life or overall efficiency. It uses a three-LED assembly powered directly from the traction battery, providing bright illumination while consuming minimal power.



Fig.8. LED headlamp module

5. CONSTRUCTION AND CIRCUITRY

1. Vehicle Envelope

- Overall length: 2200–2400 mm (compact for narrow rural lanes)
- Overall width: 800–950 mm (single-lane passable)
- Overall height: 1250–1450 mm (with canopy optional)
- Wheelbase: 1400–1550 mm (stability + tight turning)
- Ground clearance: 160–200 mm (unpaved roads, speed breakers)
- Wheel/tire: 16–18 in equivalent (rugged, easy spares)
- Curb mass (w/o payload): 120–180 kg (depends on battery size)
- Payload: 120–200 kg (1–2 persons + light cargo)
- Powertrain targets:
 - Motor: BLDC hub/axial or mid-drive, 1.5–3.0 kW continuous (peak 3–5 kW)
 - Battery: LiFePO₄ 48–60 V, 30–60 Ah (energy 1.5–3.6 kWh)
 - Top speed (governed): 25–45 km/h (regional regulation compliant)
 - Typical range: 35–70 km per charge (duty-cycle dependent)

The geared DC motor is firmly bolted to the fabricated bracket on the chainstay, aligning the output sprocket with the wheel sprocket. A compact mount lowers part count and keeps the drivetrain accessible for roadside maintenance with basic tools.



Fig.9. Motor mounted on rear stay

The functioning of a lithium-ion battery is based on the movement of electrons between two electrodes, one acting as the anode (negative) and the other as the cathode (positive). Both electrodes are placed in an electrolyte, which allows ionic conduction. When the battery is discharging, electrons stored in the anode flow through an external circuit towards the cathode, creating electric current to supply power to the connected load. This transfer of charge maintains the potential difference between the electrodes and enables continuous current flow.



Fig.10. Prototyped battery and wiring mount

Central placement keeps mass inside the wheelbase, improving stability over rough tracks at low speeds. For the final build, replace tape with a vented metal or ABS enclosure and add fusing and strain relief for durability.

In the electric motorcycle, the direct current (DC) supplied by the battery is converted into a sinusoidal waveform using a transistorized DC-to-AC amplifier circuit. This switching arrangement regulates the flow of current towards the stator winding of the motor. A condenser connected in the system works as an energy storage device, releasing stored charge when extra power is required. The torque generated in the motor is transmitted through a sprocket fixed to the motor shaft.

Using a chain drive mechanism, this torque is further transferred to the rear sprocket wheel, which rotates the rear wheel of the motorcycle. Consequently, the vehicle moves forward using the electrical energy stored in the battery.

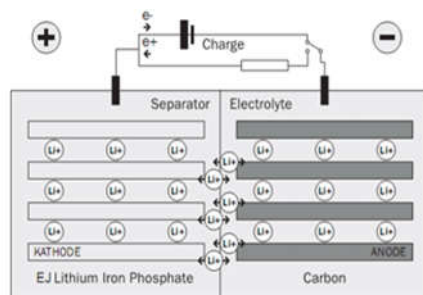


Fig.11. Working of lifepo4

6. RESULT AND DISCUSSIONS

The running cost of the e-bicycle has been calculated considering a payload of 120 kg (which includes both the rider and any carried load). Based on energy consumption and operating conditions, the cost per kilometer is approximately 12–15 paise, which is very low compared to petrol- or diesel-based vehicles.

The manufacturing cost of the e-bicycle is around ₹25,000. This cost is affordable for people from lower economic groups, especially when compared to commercially available e-bikes that are priced much higher, starting from ₹35,000 and going up to ₹1,80,000, depending on features and design.



Fig.12. E-Cycle

Another important aspect is the rigidity and safety of the frame, as the frame is the main structural component that supports the rider's weight and ensures stability during operation. To make sure the frame is safe and durable, its design has been theoretically verified using ANSYS software, a powerful simulation tool for stress analysis and structural testing. This ensures the e-bicycle can handle real-world loads and conditions without failure.

7. CONCLUSIONS

The development of a low-cost electric vehicle offers an affordable and sustainable mobility solution, particularly suited for rural and last-mile transportation needs. The design emphasizes simplicity, durability, and ease of maintenance, making the vehicle reliable even on unpaved roads and in areas with limited infrastructure. Incorporating a BLDC motor and a LiFePO₄ battery enhances efficiency, ensures reliability, and reduces running costs when compared to conventional fuel-powered vehicles.

By replacing fossil fuel usage, the fabricated vehicle helps to reduce pollution and supports cleaner modes of transportation. Its low manufacturing and operational costs make it a practical and viable alternative for rural populations, thereby improving accessibility and promoting local economic activities. With further scaling and the support of government incentives, such low-cost electric vehicles can play a vital role in advancing sustainable rural mobility and ensuring effective last-mile connectivity across India.

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