



Fabrication of an Extended Electric Bike

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ABSTRACT

Background: The fabrication of an Extended Electric Bike (EEB) has been developed as a practical solution for low-income communities. It aims to reduce pollution and ensure compliance with government regulations. Surveys were conducted to gather feedback on electric and hybrid bikes, which supported the design process.

Objective: The objective of EEB is to create a user-friendly hybrid bike that utilizes both fossil fuel (petrol) and batteries, providing a sustainable and convenient mode of transportation.

Methodology: The system was configured to utilize a petrol-powered alternator for charging onboard batteries, which subsequently supplied power to a brushless direct current (BLDC) motor for propulsion. Before the operation, the batteries were fully charged to ensure continuous performance. During operation, the alternator recharged the batteries, thereby extending usage time without the need for external charging. In cases of battery depletion, the petrol engine served as a backup power source. An Arduino microcontroller was employed to regulate system functions, including real-time monitoring of battery status and automatic switching between petrol and battery power.

Results: The fabricated design successfully integrated petrol and battery power. The alternator-based charging system eliminated the need for external charging, while the Arduino-controlled unit ensured efficient power management and enabled Internet of Things (IoT) functionality.

Conclusion: The EEB design effectively addressed transportation challenges by offering a dual-power system that reduces pollution, supports low-income communities, and enhances user convenience through smart control features.

INTRODUCTION

In many developing countries, energy resources are limited, and environmental protection is often not given priority (Zahedi *et al.* 2025). Internal combustion (IC) motorcycles are a major source of pollution, releasing carbon dioxide, carbon monoxide, sulfur oxides, nitrogen oxides, and lead (Sugiarto *et al.* 2025). These emissions create serious environmental problems. Electric motorcycles provide an alternative by supplying power directly to the motor rather than relying on fuel combustion. Unlike IC engines, they do

not consume fuel or produce exhaust when idling. However, electric motorcycles also have limitations. Under heavy load, the battery drains more quickly, which reduces speed and can eventually stop the bike. In addition, the absence of portable charging systems makes them less practical, and without such systems, their use becomes restricted. The concept of an extended electric bike has the potential to address these issues by improving performance, reliability, and efficiency. At the global level, electric vehicles are gaining attention because of both economic and environmental concerns. Rising oil demand, increasing fuel



prices, and the effects of climate change have accelerated this shift. The transport sector is one of the largest contributors of greenhouse gases, including CO₂ and CH₄. In recent years, environmental awareness and the search for cleaner energy alternatives have grown to a stage where they cannot be ignored. As a result, electric power in transportation is expanding, reflecting the global move toward sustainable and pollution-free mobility. In Pakistan, the demand for fuel-efficient and environmentally friendly motorcycles is particularly high because a large part of the population lives in urban areas. Vehicles that combine conventional engines with electric motors can reduce fuel use and emissions. Fossil fuel, mainly petrol, is still widely used, but the country is not entirely dependent on it. New technologies such as regenerative braking, where the electric motor on the wheel reduces vehicle speed while recharging the battery, further lower the power demand (Sheu 2020; Nosratzadehi *et al.* 2025).

Although electric vehicles are more efficient than IC engine motorcycles, their higher cost and lower speed have limited their adoption. Increasing production can make them more affordable and attractive to users. A recent advancement is the extended electric bike, which has strong potential to expand its access to sustainable and pollution-free mobility. The addition of Internet of Things (IoT) features enhances this design by allowing real-time monitoring, GPS tracking, route information, emission detection, and advanced security systems. These advantages demonstrate the promise of IoT-based extended electric bikes in addressing transportation challenges (Hadayat *et al.* 2025).

MATERIALS AND METHODS

The extended model of the electric bike is designed to operate on the principle of dual-drive functionality, utilizing two independent power sources. The motor receives energy first from a battery and subsequently from an alternator.

Battery source

The motor is powered by a 20Ah battery operating at 48V. Dry-cell batteries manufactured by YUASA were employed for this purpose. The battery consists of eight individual 12V cells connected in series as four sets of two cells. This configuration enables the system to deliver 48V and 20A under full operating conditions. The battery supplies power to the motor, thereby propelling the vehicle.

Charging methods

Two distinct charging methods were adopted. The first is the plug-in charging method, utilizing electricity from the grid, which is readily available. Charging requires 4–5 hours and consumes approximately 1.5 units of electricity to reach full capacity. When fully charged, the vehicle can travel approximately 60 kilometers at maximum speed while

carrying loads up to 250 kg. The maximum speed achieved under these conditions is 60 km/h. Upon ignition, the controller evaluates the charge status and displays the remaining power. If the charge level falls below 15%, the controller automatically initiates engine ignition. The second method is alternator-based charging. In this configuration, the alternator derives mechanical power from the engine once it is activated. The alternator supplies power to both the engine and the battery while simultaneously recharging the latter.

A boost converter was integrated to maximize charging efficiency by amplifying the current and filtering harmonic distortions. The dynamo, coupled with the motor, enables charging during motion. Four LED indicators reflect charging status, with each light representing 25% capacity. Once the battery reaches full capacity, the engine disengages automatically, and the battery assumes exclusive operation of the motor. The tachometer is monitored by the controller to assess vehicle speed, enabling real-time adjustment of motor revolutions per minute. A GPS module was incorporated to provide continuous location tracking, enhancing safety and security (Fig. 1).

Construction methodology of the extended electric bike

The fabrication methodology of EEB is presented in Fig. 1. The dual-drive bicycle is powered by a 48V, 20Ah battery assembled from eight series-connected 12V cells. Charging can be achieved through plug-in connection, requiring 4–5 hours, or via the alternator powered by the vehicle's engine. The alternator provides direct energy to the motor while recharging the battery. A boost converter enhances efficiency by regulating voltage and eliminating harmonics. Once the battery attains full charge, the system automatically transitions to battery-only operation. The controller regulates motor speed according to variations in voltage and current, while the GPS module provides continuous location tracking for improved safety.

Component analysis

During construction, an integrated electrical framework was established to facilitate the reliable performance of the EEB. When the system is activated, the electric mode becomes operational. The electrical configuration comprises several core components:

BLDC hub motor: A 1000W, 48V hub motor was employed. Hub motors have become increasingly popular for lightweight electric vehicles, including e-bikes and scooters, due to their efficiency and compact design (Siddique *et al.* 2020). Load-bearing capacity and resistance forces were considered during motor selection.

Controller for BLDC hub motor: A 1000W, 48V speed controller was utilized to regulate the hub motor. Brushless DC motors offer advantages over brushed motors due to electronic commutation, which allows efficient current

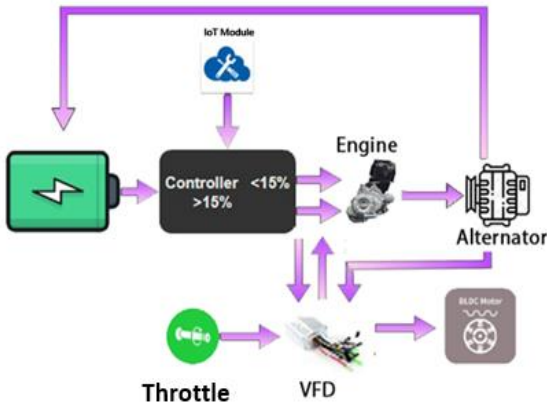


Fig. 1: Methodology of the system

Table 1: Specifications of BLDC Hub motor

Specifications	Ratings
Power	1000 W
Torque	18 Nm
Peak torque	83 Nm
Voltage Operation	48 V
Current	23 A
Limiting current	38 A
RPM	510

Table 2: Specifications of Controller

Specifications	Rating
Voltage	48 V
Power	1000 W
Phase Angle	120/60°
Limiting current	38 A

Table 1 Specifications of a dry battery

Specifications	Rating
Voltage	48 V
Maximum current	20 A
Charging time	3 h
Weight	17.6 kg
Dimension	5.95×2.56×3.7 inches

switching. The controller enables starting, stopping, reversing, and precise regulation of torque and speed. Specifications of the controller are provided in Table 1–2.

Dry battery: A 12V, 9Ah sealed dry battery with high energy density and leak-proof design was adopted. Such batteries are widely used in UPS, CCTV, and fire monitoring systems. In EEB, a combination of these units was arranged to provide 48V/20Ah, with a discharge capacity of 20A per hour. The batteries were positioned beneath the seat to conserve space and maintain balance, thereby supporting eco-friendly operation.

Charger (AC to DC): The charger employs a front-end AC-DC converter, allowing connection to a residential AC supply (Hazarathaiyah *et al.* 2019). This ensures accessibility for routine charging. Specifications are shown in Table 3.

Alternator: An alternator powered by fuel was integrated into the system. This component supplies energy when the battery charge is insufficient, ensuring uninterrupted operation. Placement of the alternator was in the carburetor position of the base motorcycle, making it a critical feature of the extended system.

Boost converter: The boost converter stabilizes voltage, filters harmonics, and improves energy transfer efficiency, ensuring continuous battery charging during engine operation.

Self-start motor: A self-starting mechanism was implemented to enable ignition without external assistance. Once combustion is initiated, inertia sustains engine cycles without requiring repeated starter use.

GPS module: The GPS module, integrated as part of the IoT-based security system, provides anti-theft protection, remote locking, and real-time location monitoring. The module disables the motor within 10 sec if unauthorized movement occurs. Additional features include monitoring of charging status and battery condition.

Bike frame: The Honda Pridor was selected as the structural base. This motorcycle is equipped with an overhead cam four-stroke engine, refined suspension, improved aerodynamics, and a durable frame. Its robust design made it suitable for integration with the extended electric system.

Mechanical design and modeling

Positioning of electrical and mechanical components presented a key challenge, as integration was required without compromising aesthetic appearance. Careful design and adjustments were implemented to arrange components in a manner that maintained both structural appeal and functional efficiency.

Speed parameters controller

Nominal power=35 kg
 Nominal voltages=48 V
 Nominal current=30 A
 Efficiency = 90%
 Protection voltage=60 V

Torque calculations

Weight of the bike=80 kg
 One person's average weight=70 kg
 Batteries weight=20 kg
 Alternator weight=5 kg
 Total weight= $m \times g$(1)
 Total weight=175×9.81
 Total weight=1715 Newtons

Force required to displace the body

Rolling friction between rubber and coal tar=0.05

$F = \mu \times \text{Total weight acting downward} \dots\dots\dots(2)$
 $F = 0.05 \times 1715$
 $F = 85.75$
 Wheel diameter = 45.75 cm
 Wheel radius = 22.875 cm
 $\text{Torque} = r \times F \dots\dots\dots(3)$
 $\text{Torque} = 0.227 \times 85.75 \text{ cm}$
 $\text{Torque} = 19.4 \text{ Nm}$
 On one wheel, it will be = 9.73 Nm

$TW = 20 + 15.3 + 12.8 = 48.19 \text{ Nm}$

Motor calculations

Power of motor = torque \times speed... (9)
 $P = 48.19 \times 16.6$
 $P = 800 \text{ W}$
 Motor selected = 1000 W
 Factor of safety = 0.25
 Battery calculations
 Battery = 48 V
 Battery ampere per hour = 20 Ah
 Total power = 1000 W
 Battery back-up
 $\text{Battery time} = (V \times I) / 1000 \dots\dots\dots(10)$
 $\text{Battery time} = (48 \times 20) / 1000$
 Battery time = 1 hour (at full speed at full load)
 Charging calculations
 $\text{Power of adopter} = V \times I \dots\dots\dots(11)$
 $\text{Power of adopter} = 48 \times 7$
 $\text{Power of adopter} = 336 \text{ W}$
 $\text{Time to charge} = 1000 / 336$
 $\text{Time to charge} = 3 \text{ h}$

Wind load estimation

The maximum velocity of the design
 $V(\text{max}) = 70 \text{ km/h}$
 $V(\text{max}) = 19.66 \text{ m/s}$
 $\text{Wind pressure} = \text{constant} \times \text{wind density} \times V(\text{max})^2 \dots\dots\dots(4)$
 $\text{Wind Pressure} = 0.5 \times 1.2 \times 361$
 $\text{Wind Pressure} = 216.6 \text{ N/m}^2$
 Total drag force
 $\text{Total Drag Force acting on the structure} = 19.79 \text{ N}$
 $\text{Torque load to resist the wind load} = 225 \times 19.79 / 4$
 $\text{Torque load to resist the wind load} = 1113.18 \text{ N-mm}$
 Considering the Frictional load and Inertial load 10% each
 $\text{Total torque} = \text{derive torque} + \text{wind load torque} + \text{frictional torque} + \text{inertial torque} \dots\dots\dots(5)$
 $M(t) = 19.4 + 1.1 + (0.1 \times 19.74) + (0.1 \times 19.74)$
 $M(t) = 24.38 \text{ Nm}$
 Total tractive effort method for calculating torque
 $\text{Gross vehicle weight} = m \times g \dots\dots\dots(6)$
 $\text{Gross vehicle weight} = 105 \times 9.81$
 $\text{Gross vehicle weight} = 1030 \text{ N}$
 The weight on each vehicle is derived
 $W = 1030 / 2$
 $W = 515 \text{ N}$
 Radius of wheel = 22.83 cm
 Desired top speed = 20 km/h
 $\text{Desired to speed} = 5.5 \text{ ms}^{-1}$
 Desired acceleration time = 40 sec
 Working surface = Coal tar

Charging at the alternator

$\text{Power for charging} = P \times I \dots\dots\dots(12)$
 $\text{Power for charging} = 48 \times 1.1$
 $\text{Power} = 528 \text{ W}$
 $\text{Time} = 1000 / 528$
 $\text{Time} = 1.8 \text{ hour}$
 $\text{Efficiency} = 800 / 1000 = 80\%$
 Alternator calculation
 $\text{Total power} = 1000 \text{ W} + 528 \text{ W}$
 $\text{Total power} = 1528 \text{ W}$
 $\text{Alternator voltage} = 24 \text{ V}$
 $\text{Alternator ampere} = 90 \text{ at full speed}$
 $\text{At optimum speed} = 65 \text{ A}$

Acceleration force

Acceleration Force (FA) is the force necessary to accelerate from a stop to maximum speed in the desired time. The vehicle will perform as designed regarding tractive effort and acceleration; it must calculate the required wheel torque (TW) based on the tractive effort.
 $\text{FA} = (\text{Gross weight vehicle} \times V_{\text{max}}) / (g \times \text{Time required}) \dots\dots\dots(7)$
 $\text{FA} = ((1715 \times 5.5)) / ((9.81 \times 40))$
 $\text{FA} = 24.06 \text{ W}$
 Wheel motor torque
 $\text{TW} = \text{Resistive torque} + \text{Accelerating torque} + \text{wind torque} \dots\dots\dots(8)$

Bike mileage

Mileage at petrol = 45 km (in 1 L of petrol and 20% charge of batteries)
 In that 20%, the bike can run 18 km
 $\text{Total gross mileage at petrol and battery charge} = 60 \text{ km (battery) and } 63 \text{ km (petrol)}$
 $\text{Total mileage} = 60 + 63 = 123 \text{ km}$

Security through IoT-based GPS tracking

GPS tracking devices are employed to monitor and record the location of an object, most commonly when installed in automobiles as part of vehicle tracking systems. Although it shares certain similarities with car navigation systems, the two technologies serve distinct purposes. Navigation systems primarily display the driver's current location on a digital

map and provide route guidance to a selected destination, whereas GPS trackers focus on recording a vehicle’s position and travel history. The tracking device transmits collected GPS data wirelessly to an external platform such as a computer, smartphone, or tablet. A typical GPS module provides live tracking, playback of completed rides, mileage summaries, and other trip-related details. Additional features often include remote locking capability, information regarding route start and end times, duration of travel, and maximum speed achieved. Notifications on speed limit violations and engine ON/OFF status can also be transmitted via SMS. The associated application displays all these parameters in a user-friendly format. Functionally, GPS trackers rely on satellites to determine precise location. By employing trilateration with signals from three or more Global Navigation Satellite System (GNSS) satellites, the device calculates latitude, longitude, elevation, and time. Power for these trackers is generally supplied through the onboard diagnostics (OBD) connector, cigarette lighter port, accessory socket, or an internal rechargeable battery. The data collected were subsequently transmitted to specialized software, where they were aggregated, stored, and analyzed for interpretation and further application.

SIMULATION AND RESULTS

A voltmeter was used to measure values in a hardware simulator, which was then simulated using MATLAB R2021b and the TRINAMIC trainer. A boost converter and a BLDC hub motor were both tested in this setup. The input and output voltages of the boost converter were measured with a voltmeter in order to test its operation and to measure voltage regulation. Some of the operational parameters of the BLDC hub motor were measured during simulation, such as speed, current, input power, torque, output power, and efficiency. These were measured with the help of the voltmeter, TRINAMIC trainer, and other necessary equipment. The general aim of the simulation was to examine the dynamic operation of the BLDC hub motor, focusing on speed variation, directional control, current variation over time, and the maximum achievable speed under load (Table 4–9).

BLDC Hub Motor Simulation

The BLDC hub motor was simulated in various stages. The speed torque relationship, as shown in Fig. 2–6, was examined in the first stage. The second stage included applying changing torque values to the motor and measuring the obtained speeds. The information gathered was utilized in determining the relationship between motor speed and torque output, as seen in Fig. 7. The simulation was able to replicate varying operating conditions by altering torque values in various ranges.

The third phase examined the interaction between torque and current consumption. Varying torque loads were

Table 2: Specification of AC to DC charger

Specifications	Rating
AC voltage	220 volts
DC voltages	55 volts
Maximum current	20 Amperes

Table 3: Specification of the alternator

Specifications	Rating
Voltage	24 V
Current	90 A

Table 4: Specification of the boost converter

Specifications	Rating
Power	1000 W
Torque	18 Nm
Peak Torque	83 Nm
Voltage	48 V
Current	23 A
Limiting current	38 A

Table 5: Self-start motor specification

Specifications	Rating
Voltage	12 V
Current	5 A

Table 6: Specification of the GPS module

Specification	Rating
Operating voltage	12 V
Current	1 mA
GPS positioning precision	10 m
Temperature	-20°C to 70°C
RH	20–80%
Dimensions	6.7 cm*3.88cm*1.15cm
Weight	0.125 kg

Table 9: Overall comparison of three bikes

Design parameters	Extended electric bike	Electric bike	IC engine bike
Maximum speed	60 km/h	60-65 km/h	100 km/h
Lifetime of battery	5-7 years	5-7 years	N/A
Physical weight	105 kg	72 kg	96 kg
Energy used	Electrical energy or chemical energy of petrol to convert into mechanical energy	Electrical energy	The chemical energy of petrol + chemical gasoline energy to converted into mechanical energy
Manufacturing cost	Rs. 70,000	Rs. 95,000	Rs. 130,000
Time of charging	2.5 h	2.5 h	N/A
per km cost	Rs. 1.4	Rs. 0.5	Rs. 2.38
Noise during driving	60-100 dB	60-80 dB	80-100 dB
Maintenance cost	Slightly less	Low	Slightly high
Braking power	Good	Good	HIGH
Fuel required	YES	NO	YES
Efficiency	Best	Good	Best
Effects on environment	Slight	No	Yes
Emission of gases	Slight	No	Yes
The capacity to carry the load	High	Slightly high	Very High

imposed upon the motor, and current was measured. The linear correlation between current and torque, as shown in

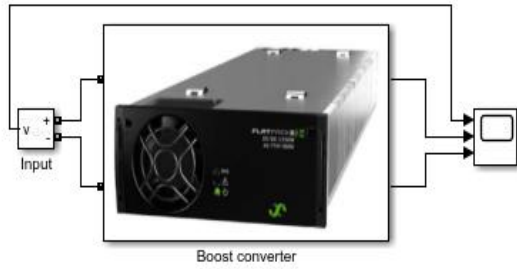


Fig. 2: Boost converter



Fig. 2: Fabricated Extended Electric Bike



Figure 3: Placement of part



Fig. 4: GPS-based IoT module

Fig. 8, sheds light on motor efficiency and control methods. A fourth test was then performed with the TRINAMIC trainer to test motor performance at full load. This trainer allowed precise measurement, in-depth simulations, and real-time feedback. Advanced control algorithms, accurate data measurement, and light-to-heavy loading flexibility enabled the system to produce realistic performance for motors. The velocity–load characteristic is presented in Fig.

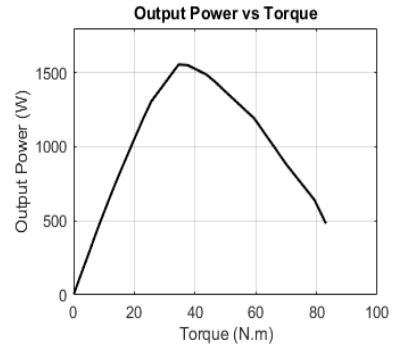


Fig. 6: Output vs torque

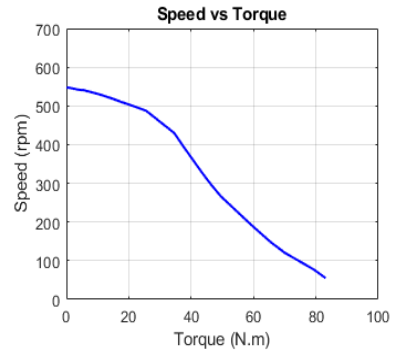


Fig. 1: Speed vs. torque

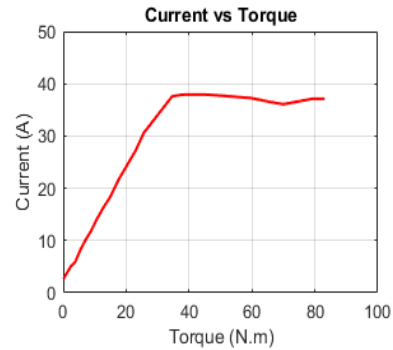


Fig. 8: Speed vs. current

9. In stage five, direction control of the BLDC hub motor was tested via the TRINAMIC trainer (Fig. 10).

Boost Converter Simulation

Sufficient supply for the BLDC hub motor and battery charging requirements. In the simulation, a graph was obtained showing output current and voltage versus input. The primary role of the boost converter in this system was to elevate the voltage from 24 V to 55 V, ensuring a voltage that demonstrated the converter’s efficiency across varying conditions. The converter exhibited stable performance when maintaining an output voltage of 48 V, a current

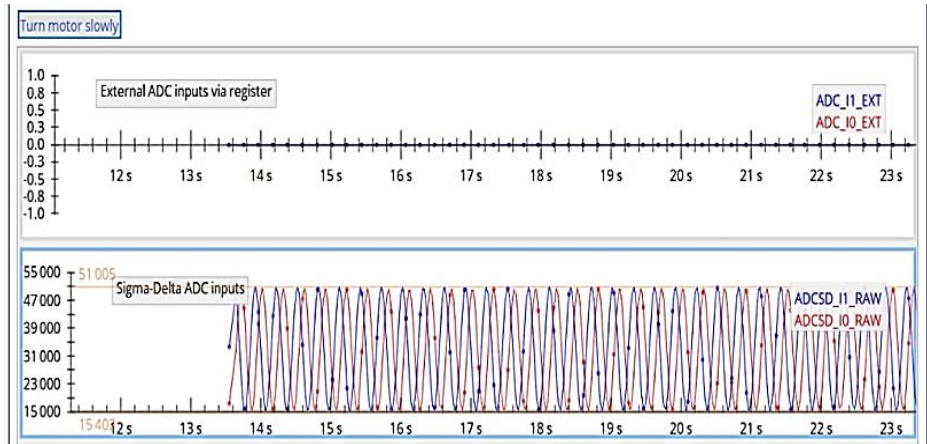


Fig. 5: Velocity simulation at full load

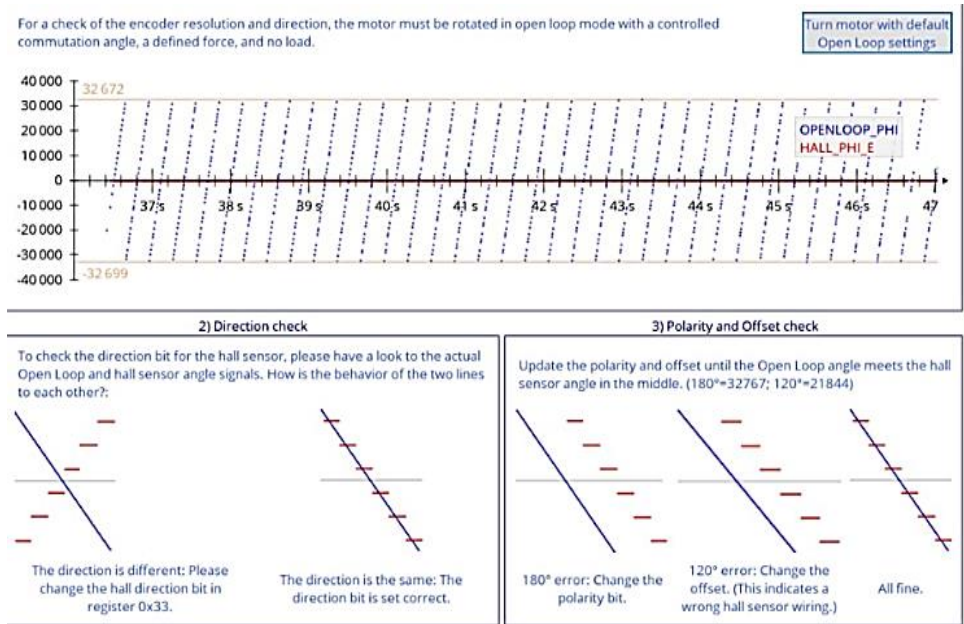


Fig. 6: Directional control of motor

adequate to power the motor load, and voltage stability under transient conditions. Fig. 11 presents the simulation of the boost converter.

Practical Results of IoT-Integrated GPS Module

Simulation results also highlighted the integration of the Burj Track application with the Internet of Things (IoT) and GPS systems. The module provided real-time monitoring of the vehicle’s location and performance. Features included mileage tracking, ride playback, and live updates on parameters such as fuel consumption, engine ON/OFF times, and total distance traveled. When connected to a mobile device, the system displayed comprehensive information regarding the vehicle’s operation. Fig. 12 and

13 illustrate simulation results of the Burj Track application under IoT control, demonstrating its potential to enhance both monitoring and security of the EEB system.

CONCLUSION

In an increasingly resource-constrained and polluted environment, technologies that optimize motor performance while reducing operational cost and environmental burden are needed for sustainable, low-cost, and pollution-free mobility. The integration of alternator-assisted battery charging and IoT-enabled GPS monitoring significantly improves the overall utility of the system. The primary objective of this work was to maximize efficiency at minimal cost, while the secondary objective was to alleviate

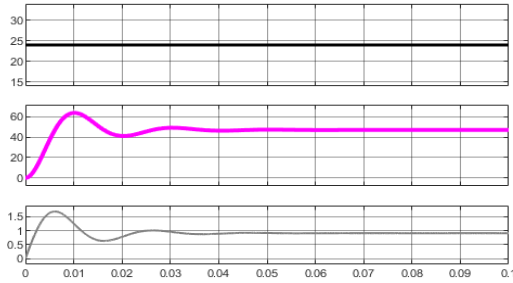


Fig.11: Boost Converter Simulation

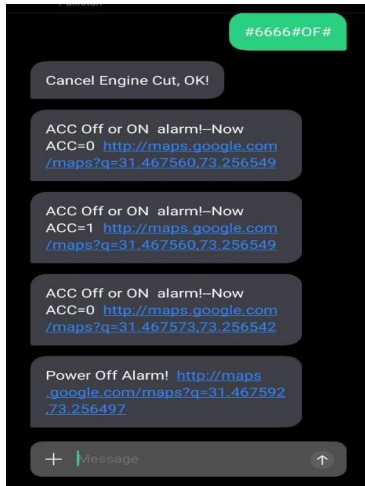


Fig. 12: Engine on/off message

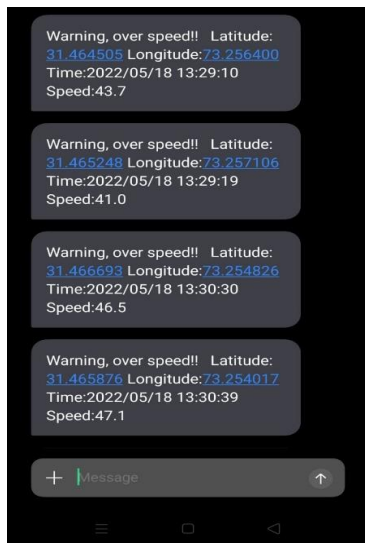


Fig. 7 Speed limit warning message

environmental strain. Battery units, designed for ease of replacement, ensure continuous energy availability, and gasoline provides a supplementary source of power when necessary. Furthermore, the IoT-enabled GPS enhances vehicle security and provides essential data for system

management. Overall, this approach combines affordability, sustainability, and operational safety, thereby contributing to both user convenience and environmental conservation.

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AUTHOR CONTRIBUTIONS

MS contributed to conceptualization, methodology design, data curation, and drafting of the manuscript. MAH performed the experimental setup, conducted performance analysis, and validated the results. MUK provided critical review, and technical guidance. MA, MA and ZA carried out simulations, data interpretation, and figure preparation.

CONFLICTS OF INTEREST

No conflict of interest among the authors to declare

DATA AVAILABILITY

Data will be made available on a fair request to the corresponding author

ETHICS APPROVAL

Not applicable to this paper.

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REFERENCES

- Hazarathaiha P, Reddy YAK, Reddy PVB, Sreenivasulu M (2019) Design and fabrication of a hybrid electric bike. *International Journal of Applied Engineering Research* 14: 930–935.
- Hidayat MN, Nugroho A, Munir AF, Putri RI (2025) Internet of things (IoT) based monitoring system for hybrid-powered E-bike charging station. *International Journal of Power Electronics and Drive Systems* 16: 243–250. <https://doi.org/10.11591/ijped.v16.i1.pp243-2>.
- Nithya Kumari R, Bari A, Achar GV, Kumar RA, Harshavardhan K (2018) Smart motorbike integration using IoT. *International Journal of New Technologies in Science and Engineering* 5: 235–240.
- Nostratzadeh H, Bhowmick D, Ríos Carmona AB, Thompson J, Thai T, Pearson L (2024) A scoping review of the design and characteristics of e-bike financial incentives. *Transport Reviews* 44: 149–171. <https://doi.org/10.1080/01441647.2024.2419884>.
- Sugiarto M, Herdiyatno YD, Prasetyo H, Karyanto Y, Sadili R, Hardianto D (2025) Air optimization on motorcycle intake manifold towards work performance and exhaust gas emissions. *Jurnal Teknologi Transportasi dan Logistik* 6: 85–94. <https://doi.org/10.52920/jttl.v6i1.420>.
- Zahedi R, Sadeghitabar E, Khazaei M, et al. (2025) Potentiometry of wind, solar and geothermal energy resources and their future perspectives in Iran. *Environment, Development and Sustainability* 27: 15311–15337. <https://doi.org/10.1007/s10668-024-04633-2>