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Design and Development of Scootico: A Compact Single-Seater Electric Scooter for Urban Mobility

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Abstract—**This paper delves into the conception, design, and development of an eco-friendly electric scooter tailored to meet the growing demands for sustainable urban transportation. By emphasizing portability, efficiency, and sustainability, this scooter incorporates advanced features such as a hub motor for high efficiency, sealed lead-acid batteries for affordability and dynamic riding comfort. The engineering challenges faced during development, including power consumption optimization, thermal management, and cost efficiency, were meticulously addressed through innovative solutions to ensure reliability and practicality.**

Further, the project envisions future enhancements such as solar auxiliary charging to improve energy autonomy and a foldable design to increase portability. Inspired by the mobility constraints observed during the COVID-19 pandemic, this scooter presents an ideal solution for short-distance travel, especially in regions where public transport options are scarce. It not only provides a practical means of transportation but also contributes significantly to reducing carbon emissions and promoting sustainable living.

Keywords—Electric Scooter, Hub Motor, Sealed Lead-Acid Battery, Thermal Management, Eco- Friendly Transportation

I. INTRODUCTION

The increasing urban population and the associated rise in vehicular traffic have resulted in severe congestion and problems across cities worldwide. Conventional transportation systems struggle to cope with these challenges, leading to a growing demand for innovative and sustainable solutions. Electric vehicles (EVs) have emerged as a promising alternative due to their low carbon footprint and operational efficiency. Among EVs, electric scooters stand out as an affordable and practical choice for personal transportation, particularly for short-distance travel. This study focuses on the development of an eco-friendly and portable electric scooter, emphasizing features such as energy efficiency, reliability, and cost-effectiveness. The project was conceptualized during the COVID-19 pandemic, a period that underscored the necessity for individual mobility solutions as public transportation systems faced severe disruptions. By catering to the need for safe and independent travel, the electric scooter also aligns with global sustainability objectives, addressing both environmental and practical concerns.

Through a combination of robust engineering design and strategic component selection, the scooter leverages a hub motor, controller and sealed lead-acid batteries. This paper details the technical specifications, challenges encountered, and future potential of the scooter, positioning it as an innovative solution to modern urban mobility needs.

II. EASE OF USE

A. System Development

The main components of the scooter are as follows:

1. Motor
2. Motor Controller
3. Battery
4. Battery Charger

Fig.1 shows a block diagram that represents a system involving a Battery, a DC to DC Converter, a Brushless DC Motor, a Controller and a Load.

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- Battery:
  The primary source of energy for the system. It provides DC power to the entire circuit.

- BLDC Motor:
  The main component responsible for converting electrical energy into mechanical energy. Used to drive the load efficiently. BLDC motors are preferred due to their high efficiency, low maintenance, and long lifespan.[1]

- Controller:
  Acts as the brain of the system. Controls the speed, torque, and direction of the BLDC motor by adjusting voltage and current based on feedback. May also protect the system from faults like overcurrent or undervoltage.

- Load:
  Represents the device or machinery powered by the BLDC motor, such as a fan, pump, or electric vehicle drivetrain. The motor's mechanical energy is transferred to perform the desired operation.

Process Flow:

The Battery supplies energy to the DC-DC Converter, which adjusts the voltage and sends it to the BLDC Motor. The Controller manages the motor's performance by taking feedback from the system and ensuring proper motor operation. Finally, the mechanical energy from the motor is transferred to the Load for practical use.

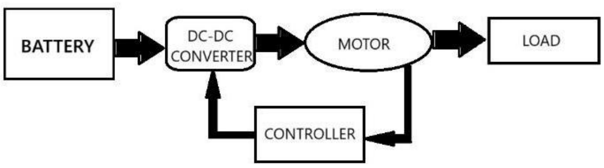

Fig1. Block Diagram

B. Motor Controller

The 48V 250W Field-Oriented Control (FOC) controller [5] is a high-efficiency motor controller designed for driving Brushless DC (BLDC) motors in electric scooters and similar light electric vehicles. Utilizing FOC technology, this controller ensures smoother acceleration, precise torque control, and reduced power loss, enhancing overall performance. It operates with a 48V power supply and delivers 250W output, with a current limit of approximately 30A, protecting the motor from excessive load. The sine wave output minimizes noise and vibrations, resulting in a comfortable and efficient ride experience. Designed for durability, the controller features a waterproof casing, making it suitable for various environmental conditions. It also incorporates under-voltage protection (38V–48V) to safeguard the battery from deep discharge, extending its lifespan. Advanced safety mechanisms, including overcurrent and short-circuit protection, further enhance reliability. Additionally, the controller supports smooth throttle response and efficient motor synchronization, optimizing energy conversion and improving ride quality.

C. Motor

A 250-watt BLDC (Brushless DC) motor is a type of electric motor that uses direct current and relies on electronic commutation instead of physical brushes to switch the current in the motor’s windings. This design makes it more efficient and durable compared to brushed DC motors, as it eliminates the wear and tear caused by brushes. A 250-watt BLDC motor delivers a moderate power output, typically suitable for applications such as small electric vehicles (e-bikes, scooters), robotics, fans, and other consumer devices.

The 250-watt rating indicates the motor’s ability to convert electrical energy into mechanical energy, offering up to 250 watts of continuous power under normal conditions. The motor operates efficiently due to an electronic controller that regulates the timing and current flow to the motor coils, allowing for precise control over speed, torque, and direction. This results in smooth operation, making BLDC motors ideal for applications that require accurate performance and high reliability. Additionally, their high efficiency reduces energy loss and heat buildup, which helps extend the motor’s lifespan and improve overall performance.

BLDC motors are particularly favoured for their compact size, low maintenance needs, and quiet operation, which make them suitable for environments where long-term reliability and minimal upkeep are essential. The 250-watt motor rating is typically chosen for small-scale applications where moderate power, space efficiency, and quiet operation are necessary.

D. Battery

A 48V, 27Ah Sealed Lead Acid Battery [6] can be arranged as four 12V, 27Ah batteries connected in series to achieve the desired 48V system. In this configuration, the voltages of each 12V battery add up to provide a total of 48V (12V + 12V + 12V + 12V), while the capacity remains 27Ah since the amp-hour rating does not change in a series connection. Proper balancing of the batteries and careful wiring are done to ensure safe and efficient operation of the system. Fig.2 shows the type of battery used in Scootico

Fig 2. Battery

E. Battery Charger

The Scootico electric scooter utilizes a 48V lead-acid battery pack, requiring a dedicated charger for efficient energy replenishment. Operating with a 230V AC input, the charger delivers a regulated 54.6V DC output, ensuring optimal battery performance and lifespan. It follows a Constant Current - Constant Voltage (CC-CV) charging method, where the initial phase provides a steady current (3A) for rapid charging, followed by a constant voltage phase to prevent overcharging.

To enhance reliability, the charger incorporates protective features against overvoltage, overcurrent, short circuits, and reverse polarity. Additionally, an LED indicator provides real- time charge status updates. Designed for portability and ease of use, it enables convenient charging at home or public stations, making it a practical solution for urban mobility.

III. CALCULATIONS

T_{tf} (Total tractive force) = $F_{rr}+F_{hc}+F_{ad}+F_a$ [5]

F_{rr} - Rolling resistance force

F_{hc} - Hill climbing force

F_{ad} - Aerodynamic drag force

F_a - Acceleration force

1) Force due to Rolling Resistance (F_{rr})

$F_{rr} = \mu\ m\ g\ \cos\alpha$

- μ - Coefficient of rolling resistance = 0.017(asphalt road)
- m - Mass of vehicle = 100 kg
- g - Acceleration due to gravity = 9.81 m/s2
- α is the grade angle, for normal surface taken as 2 degrees

Therefore, F_{rr} = 16.66 N (1)

2) Force due to Hill climbing (F_hc)

$F_{hc} = m\ g\ \sin\alpha$

Therefore, F_{hc} = 34.23N (2)

3)Force due to Acceleration (F_a)

$F_a = ma$

m = 100kg

$a = \frac{v}{t}$

Taking v = Velocity = 25kmph

t = 25sec

Therefore,

F_a = 27.77N (3)

Aerodynamic drag is negligible at 25 km/h due to minimal frontal area, allowing air to pass easily; thus, it's ignored in calculations.

$T_{tf} = F_{rr}+F_{hc}+F_{ad}+F_a = 78.66N$

Total power required = T_{tf}×Velocity

= 78.66×6.94 = 545W (4)

Torque = Force × Radius of wheel × Resistance factor

Radius of wheel = 0.3048m

Therefore,

Torque = 78.66 × 0.3048 × 1.1 = 26.37Nm (5)

Battery

We got Wattage(W) = 550w

Taking Voltage(V) = 48V and Range = 30km

Battery Capacity =

Range(km) × Power(W) / Speed(km/hr)

$= 30 \text{ x } \frac{550}{25} = 660$ Whr

Taking 80% efficiency,

Whr = 1.2 × 660 = 792Whr

Current(Ah) $= \frac{Whr}{V} = \frac{792}{48}$ = 16.5Ah (6)

Battery Charger

Assuming charging time of 5hr

$W = \frac{550}{5} = 110W$

$I = \frac{110}{48} = 2.29A$ which is approximated to 3A

So charger is 48v 3A charger (7)

To drive a 250W, 48V motor with a 48V and 27Ah battery, here's how we can calculate the required battery specifications:

1. Battery Voltage and Motor Compatibility
   - Motor Power: 250W
   - Motor Voltage: 48 V
   - Required Battery Voltage : 48V

The voltage of the battery should match the motor's voltage, so that 48V is the correct voltage for the battery.

2. Required Battery Capacity (Ah)

To calculate the battery capacity (Ah) required for a desired runtime, use the formula:

Battery Capacity (Ah)
=Runtime (hours) × Motor Current (A)

Assume a runtime of 5 hours, the capacity required would be:

Battery Capacity =5 x 5.21 =26.05 Ah (8)

So, a 27Ah battery would be ideal for 5 hours of operation.

3. Energy Calculation

The total energy stored in the battery is:

Energy(Wh) $= Voltage\ (V)\ x\ Capacity(Ah)$

$= 48\ x\ 27$ =1296 Wh (9)

4. Range Estimation

To estimate the range of your system at a full charge, assuming no load, ideal conditions, and a constant speed of 25 km/h:

- Battery runtime at full load: 5.2 hours.
- Range(km): Speed (km/h) × Runtime (h)
  = 25 ×5.2 =130 km (10)

However, considering real-world inefficiencies, the range is typically reduced by 30–50%. So, the real- world range could be around 60–80 km.

5. Final Battery Specification
   - Voltage: 48V
   - Capacity: 27Ah
   - Estimated Range: 30-40 km (real-world conditions).

Therefore, to run a 250W, 48V motor, a 48V, 27Ah Battery is suitable, providing 5.2 hours of runtime with real-world range of 30-40 km

IV. DESIGN CONCEPT

The 3D design concept of the electric scooter is focused on a simple, minimalistic, and functional approach, ensuring practicality and style. The frame is crafted from galvanized polymer pipes, offering a lightweight yet durable structure that resists corrosion and provides long-term reliability. The design integrates the 48V, 27Ah battery and motor within the frame, maintaining a clean and functional appearance.

Key features include a spacious deck for comfortable riding and a compact digital display for monitoring speed and battery status. This minimalist yet robust design makes the scooter an ideal solution for efficient and eco-friendly urban transportation. Fig. 3 and Fig. 4 shows the 3D Animated Model of Scootico

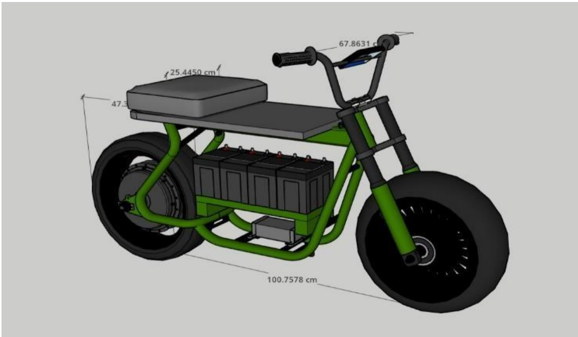

Fig 3. 3D Model (Dimensions)

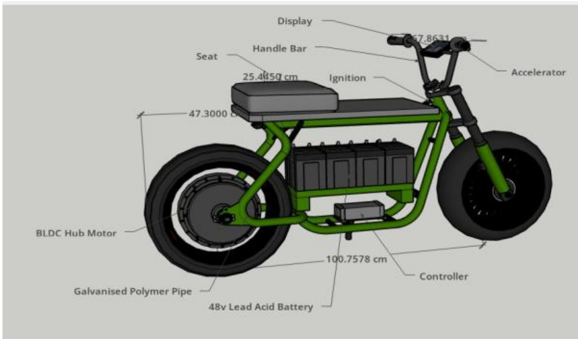

Fig 4. 3D Model (Components)

V. INTERNAL CIRCUIT DIAGRAM

The Internal Circuit Diagram [9] shows how all the components in the system are connected. It includes the 48V, 27Ah battery, made up of four 12V lead-acid batteries in series. The BLDC motor is powered by the battery and controlled by the motor controller, which manages the motor's speed and direction. The diagram also features a charging socket for recharging the battery, as well as a switch to turn the system on and off. Fuses are included for protection against overcurrent and short circuits. Additionally, the throttle is used to control the motor's speed, while the brake is connected for safety, allowing the user to stop the motor when needed. This diagram helps visualize how all components work together for safe and efficient operation. Fig. 5 shows the Internal Circuit Diagram of Scootico.

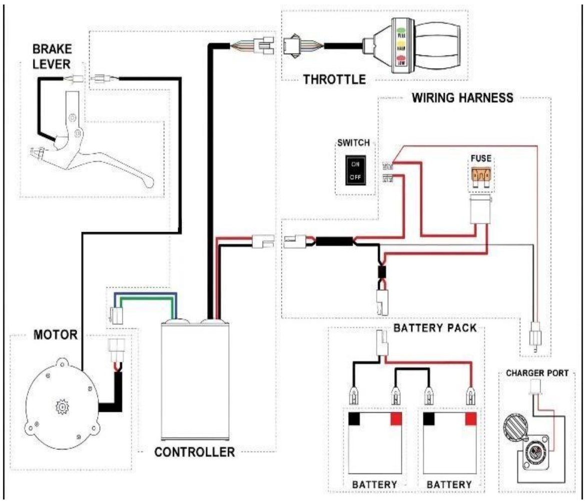

Fig 5. Internal Circuit Diagram

VI. APPLICATION INTEGRATION

The Scootico app offers a convenient and efficient solution for scooter rentals, designed with user experience in mind. Whether you're looking for a quick ride, a regular rental, or a scooter for delivery purposes, Scootico provides an easy-to-use platform that allows users to book scooters in real-time, check scooter availability, and access optimized routes. With features like real-time battery monitoring, secure payment options, and a user-friendly interface, Scootico makes it simple to enjoy hassle-free rides while keeping track of your trips and expenses. It's the ideal app for anyone seeking reliable and sustainable transportation.

The major features of the Scootico app are :

i. User-Friendly Interface: Simple, intuitive design for easy navigation.
ii. Real-Time Scooter Availability: Shows nearby available scooters for quick access
iii. Ride Booking: Allows users to reserve and book scooters instantly.
iv. Route Mapping: Provides optimized routes for efficient and safe travel.
v. Scootico App Payment Integration: Secure payment options, including credit/debit cards and e-wallets.
vi. Ride History: Tracks past rides and expenses for user reference.
vii. Battery Monitoring: Displays real-time battery status for each scooter.

Fig. 6 and Fig. 7 shows the Main interface of Scootico-App

Fig 6. App Interface

First page interface description:

- Service Options:
  - Hourly Rentals: For short trips.
  - Monthly Rentals: For regular use.
  - Delivery Rentals: For delivery needs.
- Clear Design: Easy-to-read icons and brief descriptions.
- Quick Booking: Simple selection and booking process.
- Interactive Elements: Engaging visuals and buttons for a smooth experience.

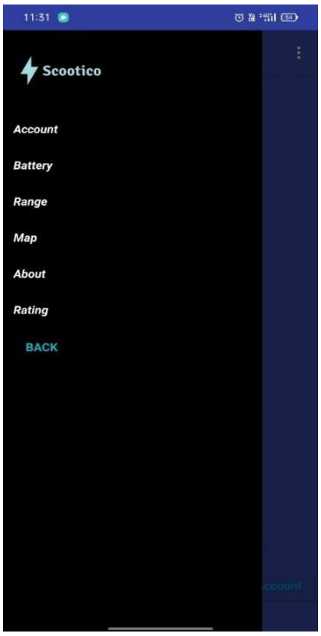

Fig 7. Side Panel of Scootico App

The description of the side panel features in the Scootico App:

- Account: Access personal details, payment methods, and booking history.
- Battery: View the current battery level of the selected scooter. Range: Check the estimated range the scooter can cover based on battery life.
- Map: View nearby available scooters and your current location.
- About: Learn more about the Scootico service and mission.
- Rating: Rate your ride and provide feedback on your experience

The GPS tracking system is centred around the Arduino Uno microcontroller, integrated with a Neo-6M GPS module, SIM800L GSM module, BSNL 2G SIM card, and dedicated external antennas to boost signal reliability and communication efficiency. The Arduino coordinates the flow of data between the GPS and GSM modules, processes positional information, and manages SMS dispatch.

The Neo-6M module acquires satellite signals to determine accurate geographic coordinates and communicates this data through UART to the Arduino. Meanwhile, the SIM800L GSM module, powered separately by a 3.7V lithium battery to meet its high current needs, transmits the location details via SMS over the BSNL 2G network. External antennas further strengthen signal reception for both GPS and GSM modules. The circuit connects the GPS module's TX and RX to Arduino pins 4 and 3, while the GSM module interfaces through pins 7 and 2. The Arduino receives power through USB or an external adapter.

During operation, the system first initializes the GPS and GSM units, retrieves live coordinates from the Neo-6M, processes the data using the Arduino, and sends the location as a clickable Google Maps link via the SIM800L. This design is suited for various applications including vehicle tracking, personal safety, logistics monitoring, and emergency response.

Key benefits of this system are its cost-effectiveness, dependable communication through external antennas, and easy scalability for future IoT integrations.

Fig. 8 shows the detailed GPS Circuit diagram of Scootico

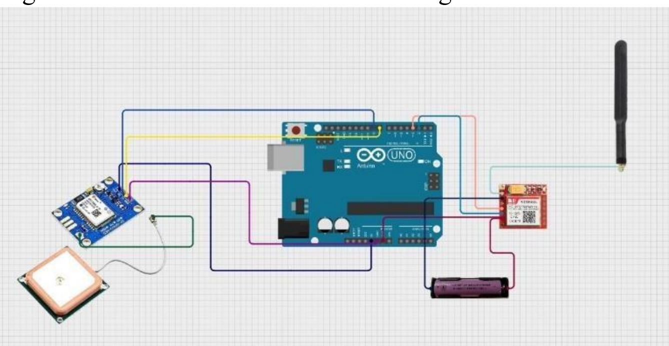

Fig 8. GPS Circuit

VII. RESULTS AND DISCUSSIONS

The Scootico single seater electric scooter successfully achieves its objectives of providing an efficient, eco-friendly, and cost-effective urban mobility solution. The system incorporates a 48V,27Ah Sealed Lead-Acid Battery powering a 250W BLDC motor, ensuring high efficiency, low maintenance, and a real-world range of 60-80 km per charge. The Field-Oriented Control (FOC)motor controller ensures smooth acceleration, precise torque control, and reduced power loss, optimizing both performance and energy consumption.

The structural design of the scooter prioritizes durability and portability, with a galvanized polymer pipe frame offering a lightweight yet sturdy build. This material choice ensures high corrosion resistance, longevity, and stability, making it well-suited for extended urban use. The internal circuit design, including overcurrent protection, under-voltage safeguards, enhances safety and reliability.

In addition to its engineering advancements, Scootico integrates digital connectivity through a dedicated mobile application. The Scootico app provides real-time battery monitoring GPS-based scooter tracking ride booking options, and secure payment methods, ensuring a seamless user experience. The app's ride history tracking and optimized route suggestions further enhance the convenience of using Scootico as a daily commuting solution. Fig. 9 shows the End Model of Scootico

Fig 9. Scootico

VIII. TEST DRIVE VALIDATION

The Scootico electric scooter underwent comprehensive testing to evaluate its range, speed, and operational efficiency under real-world conditions. It achieved a maximum speed of 25 km/h, with a per-charge range of approximately 20–25 km, influenced by terrain, rider weight, and riding behaviour. The integrated BLDC motor maintained stable torque output with minimal thermal rise during extended operation, while the 48V lead-acid battery delivered sufficient power despite slight efficiency drops under high-load conditions. To maintain affordability, the design excluded suspension, resulting in smooth performance on even surfaces but noticeable vibrations over rough terrain. The braking system functioned reliably, though further enhancements in response time are recommended to improve safety.

Overall, Scootico demonstrated practicality for urban mobility, with future enhancements in battery efficiency, braking responsiveness, and ride comfort expected to elevate its performance for daily commuting.

IX. CONCLUSION

The Scootico electric scooter represents a breakthrough in sustainable micro-mobility, combining technological innovation with practical urban commuting solutions.

Designed to address challenges posed by traffic congestion, environmental pollution, and limitations in public transportation, the scooter offers a reliable and independent means of travel, particularly in high- density urban areas. By overcoming key engineering challenges such as thermal management, power efficiency, and structural integrity, Scootico provides a safe, efficient, and user-friendly commuting alternative. The incorporation of highly efficient BLDC motor, and a well-optimized powertrain ensures maximum performance while keeping energy consumption minimal.

Furthermore, the potential for future enhancements, including solar-assisted charging, a foldable frame for greater portability, and extended battery life, highlights Scootico's scalability and adaptability to evolving urban transportation needs. The integration of smart app features strengthens its market potential as an innovative rental-based mobility service, catering to diverse user needs such as hourly rentals, monthly subscriptions, and delivery-based commuting.

Ultimately, Scootico serves as a model for next-generation sustainable transportation, promoting carbon footprint reduction, energy conservation, and user convenience. With continued advancements, it has the potential to reshape personal mobility and contribute significantly to the vision of clean and green urban transport systems.

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