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Original Research

Drive System Planning for a Two-Wheeled Electric Vehicle Using a BLDC Motor with a 130 Kg Load

Ahmad Andi Mustopha[1], Zuriman Anthony[2], Anggun Anugrah[2], Sepannur Bandri[2], Zulkarnaini[2]
[1] Bachelor of Electrical Engineering, Padang Institute of Technology, Indonesia
[2] Department of Electrical Engineering, Padang Institute of Technology, Indonesia

Corresponding Author:

Zuriman Anthony
Department of Electrical Engineering
Institut Teknologi Padang
Padang, West Sumatra, Indonesia

E-mail:
zuriman@itp.ac.id

ABSTRACT

The goal of this research is to develop an environmentally friendly, efficient, two-wheeled electric vehicle that can reduce carbon emissions. The Brushless DC (BLDC) motor was chosen as the main drive due to its high efficiency, minimal maintenance, and optimal performance for lightweight vehicles. A key challenge in this study was determining the appropriate motor power and torque to allow the vehicle to operate with a total load of 130 kg on both flat roads and inclines. The research method uses a quantitative approach, starting with an analysis of vehicle dynamics. The calculations include rolling resistance, aerodynamic drag, grade force, acceleration force, wheel torque, and wheel power. These calculations were then used to determine the suitable BLDC motor specifications. Testing was conducted both statically and dynamically on flat roads, inclines, and through endurance trials with a 130 kg load. The results show that a BM1418ZXF BLDC motor with 1000 Watts of power and a nominal torque of 3.5 Nm can optimally drive the vehicle with a total load of 130 kg. Although the research methodology included formulas for gear ratio analysis, the motor was selected based on direct power requirements without applying a transmission system calculation, which led to higher procurement costs. The vehicle dynamics analysis method has proven effective in designing the BLDC motor drive system. However, the study would be more complete if it included a transmission system analysis to improve cost efficiency and overall performance.

Keywords: BLDC motor, electric vehicle, drive system, energy efficiency, optimal torque, vehicle dynamics, electric motorcycle.

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1. Introduction

The development of transportation technology is now moving toward innovative solutions to address issues of pollution and carbon emissions, where conventional vehicles are among the main contributors. Electric vehicles have emerged as a promising alternative thanks to their far superior energy efficiency, reaching 85–90%

compared to fossil-fueled vehicles, which only achieve around 20–30%. Among the various types of electric vehicles, two-wheeled models have become a popular choice due to their compact design, low operating costs, and smaller battery power requirements [1], [2], [3].

In the development of two-wheeled electric vehicles, the selection of the drive motor is a crucial factor. Brushless DC (BLDC) motors are recognized as the ideal choice because they offer high efficiency, compact size, and minimal maintenance. Studies show that BLDC motors achieve superior efficiency (85–95%) compared to conventional DC motors (70–85%) and induction motors (80–90%) due to the absence of friction losses from brushes. The successful implementation of this motor greatly depends on proper capacity planning, as factors such as rolling resistance and air drag significantly affect the performance of the drive system [4], [5].

A major challenge in the development of two-wheeled electric vehicles is the design of an efficient drive system. Accurate motor specification is critical to achieving an optimal balance between torque, speed, and energy efficiency under real operating conditions. However, many previous studies have focused solely on direct motor sizing without incorporating gear ratio analysis. This limitation may result in oversized motors, increased procurement costs, and reduced system efficiency. Therefore, errors in estimating power and torque requirements can lead to inappropriate motor selection, ultimately degrading vehicle performance and wasting energy [6], [7].

To address this issue, this study aims to design an optimal drive system for a two-wheeled electric vehicle with a total load target of 130 kg, using a BLDC motor. The proposed solution involves a quantitative approach starting with a systematic analysis of vehicle dynamics. Through this method, the total resistive forces including rolling resistance, air drag, and acceleration will be accurately calculated to determine the actual power and torque requirements. The results of these calculations will then serve as the basis for selecting the most efficient and suitable BLDC motor specifications, thereby creating a reliable drive system that achieves a balance between performance and energy efficiency [2], [7], [8].

2. Research method

This research employs a quantitative method to design and validate an optimal drive system for a two-wheeled electric vehicle. The methodology begins with a theoretical analysis of vehicle dynamics to determine the required power and torque, followed by the selection of an appropriate BLDC motor. The process concludes with a series of systematic tests to validate the system's performance and efficiency under real-world conditions. The initial phase involved designing the vehicle's frame and overall structure using SolidWorks software to ensure all components could be integrated effectively.

2.1. Vehicle Design and Components

2.2.1 Vehicle Design

The conceptual design and dimensions of the electric vehicle are illustrated in the figures below.

Figure 1. Conceptual design of the electric vehicle.

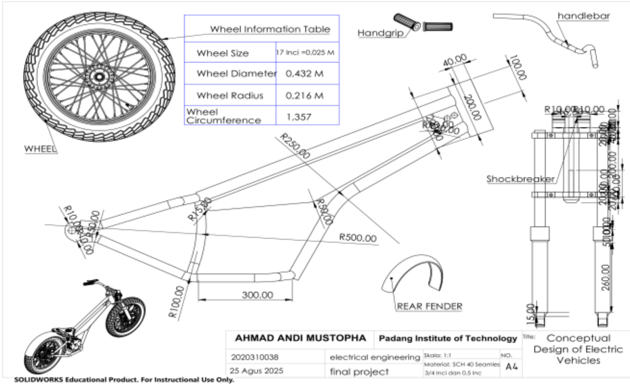

Figure 2. Detailed dimensions of the electric vehicle frame and components.

2.2.2 System Components

The drive system was constructed using several key hardware components, selected to meet the calculated performance requirements for a total vehicle load of 130 kg. The primary components are detailed in the table below.

Table 1. Components of an electric vehicle drive system

Components	Specifications
BLDC motor	Type: BM1418ZXF, Power: 1000 W, Voltage: 48V,
Battery	Lithium-ion 48V, Capacity: 30Ah
Controller	Compatible with 48V 1000W, 3-phase, supports Hall sensors
Throttle	3 cables: 5V (red), GND (black), signal (green)
switch ON/OFF	Manual, DC 48V
Arduino (optional)	Used for reading hall sensors and throttles

The system is powered by a 48V 30Ah lithium-ion battery pack and controlled by a Votol EM50 driver, which is capable of managing the motor's performance through sine wave control for higher efficiency.

2.2. Motor Selection Procedure

The selection of the motor was not arbitrary but based on a systematic procedure involving detailed calculations of the vehicle's dynamic forces.

2.2.1 Analysis of Vehicle Dynamics

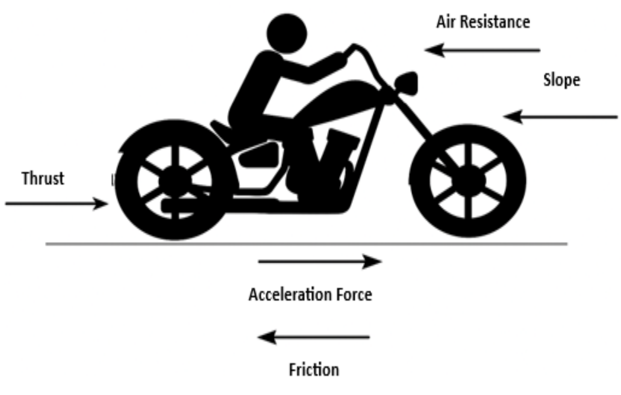

Figure 3. Resistance forces on vehicles

To determine the specifications of a BLDC motor for a two-wheeled electric vehicle with a total load of 130 kg (including the vehicle and rider), several calculation steps and technical considerations are required.

These include analyzing the vehicle's requirements (vehicle dynamics). First, the total resistive forces acting on the vehicle were calculated. This is the sum of rolling resistance (Frr), aerodynamic drag (Fudara), and acceleration force (Fpercepatan). The published formulas used are as follows [9]:

1. Rolling Resistance Force **(F_{rr})**

Rolling Resistance (often referred to as Rolling Resistance), which is the force that opposes movement when an object (such as a wheel or ball) rolls on a surface.

$$F_{rr} = C_{rr} \cdot m \cdot g \quad (1)$$

Where, C_{rr} is the rolling resistance coefficient, m is the total mass (130 kg), and g is gravity.

2. Aerodynamic Drag Force (Fair or Fdrag)

air resistance, often referred to as drag, is the force that opposes the movement of a solid object when it moves through a fluid (in this case, air). This force becomes very significant, especially at high speeds

$$F_{\text{Aero}} = \frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot v^2 \quad (2)$$

Where, ρ is air density, C_d is the drag coefficient, A is the frontal area, and v is velocity.

3. Grade Resistance Force (Hill Climbing Force)

In other words, hill-start assist is the minimum force that the engine must exert to prevent the vehicle from rolling backward on an incline.

$$F_{gxT} = m \cdot g \cdot \sin(\theta) \quad (3)$$

Where, m is the mass of the vehicle and rider, g is the gravitational acceleration and is θ slope angle of the road

4. Acceleration Force ($F_{\text{Acceleration}}$)

The basic principle is that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

$$F_{\text{Acceleration}} = m \cdot a \quad (4)$$

The acceleration value (a) can be determined by

$$a = \frac{\Delta v}{\Delta t} \quad (5)$$

Where, m is the total mass and a is the desired acceleration

5. Total force on the vehicle

is the sum of all forces that must be overcome and generated by a vehicle in order to move as desired. Simply put, this is the total thrust or tractive force that must be exerted by the engine and the vehicle's drive system.

$$F_{total} = F_{rr} + F_{\text{Aero}} + F_{gxT}(if\ there) + F_{\text{Acceleration}} \quad (6)$$

2.2.2 Calculation of Required Performance

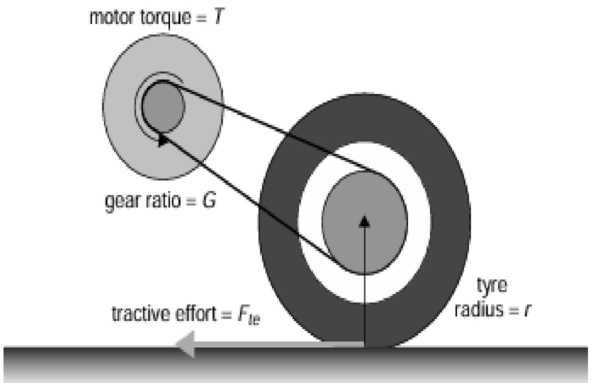

Figure 4. Simple setup for connecting the motor to the drive wheel

Using the total force (Ftotal), the minimum required performance at the wheel and motor was determined. The key formulas used are [9]:

1. Wheel torque

Wheel torque is the rotational force or twisting moment required on the wheel axle to generate forward thrust. Simply put, it is the “turning force” that must be applied to the wheels in order to propel the vehicle forward.

$$T_{wheel} = F_t \cdot r \quad (7)$$

Where, r is the wheel radius

2. Wheel power

Wheel power is the rate at which energy is transmitted by the wheels to move the vehicle. Simply put, power is a measure of how fast the engine can do work to propel the vehicle forward.

$$P_{wheel} = F_t \cdot v \quad (8)$$

Where, v is the vehicle's velocity

3. Wheel rpm

wheel rotation speed in RPM (Revolutions Per Minute), based on the vehicle's linear speed. This refers to how many times the wheel rotates in one minute, determined by the vehicle's forward (linear) speed. The faster the vehicle moves, the more rotations the wheel makes per minute. It is calculated by dividing the vehicle's linear speed by the wheel circumference and then converting it into RPM.

$$N_{wheel} = \frac{v \cdot 60}{2\pi \cdot r} \quad (9)$$

4. Gear ratio

Gear ratio, which is the ratio between the rotational speed of the engine (motor) and the rotational speed of the wheels. This ratio is a key value in a vehicle's transmission system that serves to convert torque and speed from the engine to suit driving needs. Simply put, this ratio tells us how many times the engine must rotate to make the wheels rotate once.

$$Gear\ Ratio = \frac{N_{motor}}{Nwheel} \quad (10)$$

where the gear ratio is the ratio of motor speed to wheel speed.

5. Motor torque

To calculate the torque that must be produced by an engine or electric motor to provide the torque required at the wheels after passing through the transmission system. Basically, we work backwards from the wheels to the engine. If the transmission acts as a torque multiplier, then to find the original torque of the engine, we must divide the multiplied torque (at the wheels) by the multiplication factor (gear ratio).

$$T_{motor} = \frac{T_{wheel}}{Gear\ Ratio} \quad (11)$$

6. Motor current

To determine the current value in the motor (I)

$$I = \frac{P}{V \times \eta} \quad (12)$$

7. Efficiency

Efficiency is the ratio between output energy and input energy, describing how effectively a system works. It serves to evaluate motor performance, identify energy losses, and compare the quality of different systems.

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \quad (13)$$

where, η (Efficiency (%)) indicates how well a system converts input energy into output, P_{out} (Output power) which is the mechanical power that is actually useful at the wheel or load, and P_{in} (Input power) which is the electrical power supplied to the motor from the battery.

This calculation resulted in a required power of 963.82 W and a motor torque of 2.71 Nm. These results were then compared with the manufacturer's specifications to select the BM1418ZXF BLDC motor, which perfectly matched the requirements with a power of 1000 W and 3.5 Nm**.**

2.3. System Testing and Data Collection

To validate the theoretical design, the integrated system was subjected to a series of tests. Data was collected through direct measurements using a tachometer, a clamp meter, and GPS-based speedometer applications for accuracy. The testing protocol is summarized below.

Table 2. Testing the performance of the motor and drive system

Types of Testing	Implementation Steps	Measured Parameters
Static Testing (Without Load)	1) Connect the BLDC motor to the controller and battery. 2) Turn on the system without mechanical load. 3) Record the current, voltage, and RPM.	- Voltage (V) - No-load current (A) - Motor speed (RPM)
Dynamic Testing – Flat Road	1) Install a total load of 130 kg. 2) Drive the vehicle on a flat road. 3) Record data at constant speed and during acceleration.	- Voltage (V) - Current (A) - Speed (km/h) - Wheel torque (Nm) - Output power (W) - Efficiency (%)
Dynamic Testing – Inclines	1) Prepare an incline track with a specific slope. 2) Run the vehicle with a total load of 130 kg. 3) Record the motor performance.	- Voltage (V) - Current (A) - Speed (km/h) - Torque (Nm) - Efficiency (%)
Endurance Testing	1) Charge the battery fully. 2) Drive the vehicle until the battery is depleted. 3) Record the distance traveled, travel time, and final battery voltage.	- Initial and final voltage (V) - Average current (A) - Distance traveled (km) - Travel time (minutes)

2.4. System Diagrams and Research Flow

The electrical connections and overall system architecture are depicted in the wiring and block diagrams below. The entire research process followed a structured flowchart, beginning with literature review and problem identification, moving through design and calculation, and culminating in testing, analysis, and conclusion.

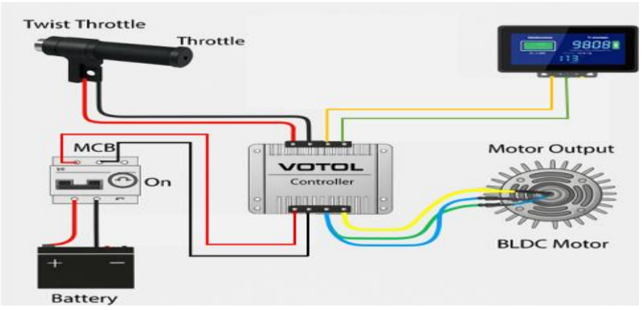

Figure 5. Wiring diagram showing the electrical connections of the drive system

3. Results and discussion

3.1 Results

This section presents the findings from the analysis and testing of the electric vehicle's drive system.

Motor Specification Analysis

The required specifications for the motor were determined through vehicle dynamics calculations. These calculations were then compared with the manufacturer's specifications for the selected BLDC motor (BM1418ZXF). The comparison is detailed in the table below.

Table 3. Comparison of BLDC motor specifications based on calculations and manufacturer BLDC motors

Parameter	Nameplate Value (Manufacturer)	Calculation Result	Difference
Power	1000 W	963,82 W	3.62%
Motor Current	26 A	26,7 A	2.69%
Operating Voltage	48 V	48 V	0%

Parameter	Nameplate Value (Manufacturer)	Calculation Result	Difference
No-load Speed	3400 RPM	3400 RPM	0%
Nominal Torque	3,5 Nm	2.71 Nm	22.57%

The results confirm that the specifications of the selected BLDC motor, BM1418ZXF, are highly suitable for the calculated requirements of the vehicle.

Drive System Testing

The drive system has undergone several tests to validate its performance under various conditions: static (without passenger load), dynamic on flat roads with a load of 130 kg, dynamic on inclines with a load of 130

1. Static Testing (Without Passenger Load)

In the static test, the motor was operated without any load to measure its basic electrical and mechanical characteristics.

Table 4. static test results (without passenger load)

Type of Test	Measured Parameter	Measurement Results		
		Speed 1	Speed 2	Speed 3
Static Test (Without Passenger Load)	Voltage (V)	29,80	36,73	40,63
	No-load Current (A)	1,8	2.97	16,73
	Motor Speed (RPM)	387	578.3	735.1

The relationship between voltage, current, and RPM from the static test is visualized in the following graphs.

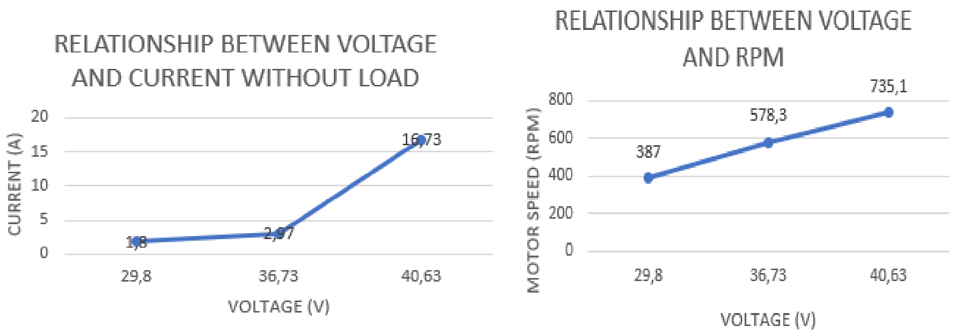

Figure 6. Relationship between voltage and current without load (left) and relationship between voltage and RPM (right).

2. Dynamic Testing on Flat Road (130 kg Load)

This test measured the vehicle's performance on a flat surface with a total load of 130 kg.

Table 5. Dynamic test results (flat road) with a load of 130 kg

Type of Test	Measured Parameter	Measurement Results		
		Speed 1	Speed 2	Speed 3
Dynamic Test (Flat Road) Load 130 kg	Voltage (V)	27,17	32,20	38,80
	Current (A)	9,67	13,50	17,43
	Speed (km/h)	11	16	21
	Wheel Torque (Nm)	4,79	5,54	6,56
	Output Power (W)	67,88	114,03	177,21
	Efficiency (%)	25,84%	26,23%	26,20%

The data illustrates how the system's electrical demand and mechanical output change with speed.

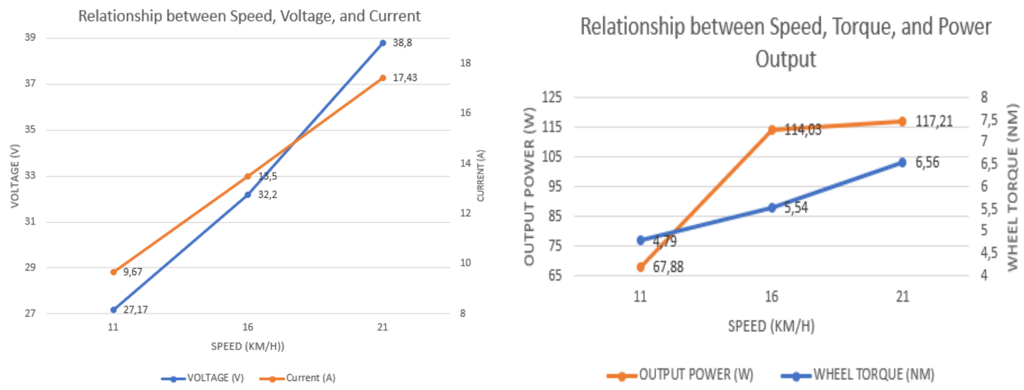

Figure 7. Relationship between speed, voltage, and current (left) and relationship between speed, torque, and power output (right).

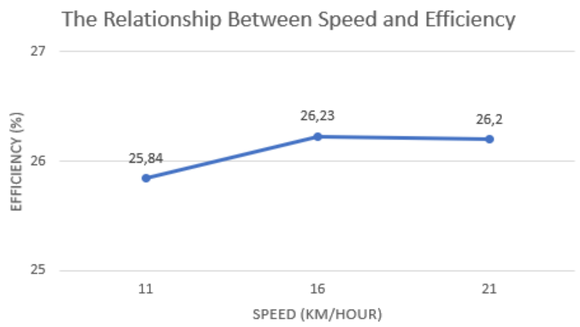

Figure 8. Graph of the Relationship between Speed and Efficiency

3. Dynamic Testing on 10° Incline (130 kg Load)

This test evaluated the system's ability to handle a significant load on a 10° incline.

Table 6. Dynamic test results (10° incline) with a load of 130 kg

Type of Test	Measured Parameter	Measurement Results		
		Speed 1	Speed 2	Speed 3
Dynamic Test (10° incline) Load 130 kg	Voltage (V)	48	48	48
	Current (A)	17,67	22,57	27,53
	Speed (km/h)	9	10	17
	Torque (Nm)	52,31	52,42	53,46
	Output Power (W)	605,78	674,49	1169,21
	Efficiency (%)	71,42%	62,26%	88,48%

The graphs below show the system's performance under heavy load during the hill-climb test.

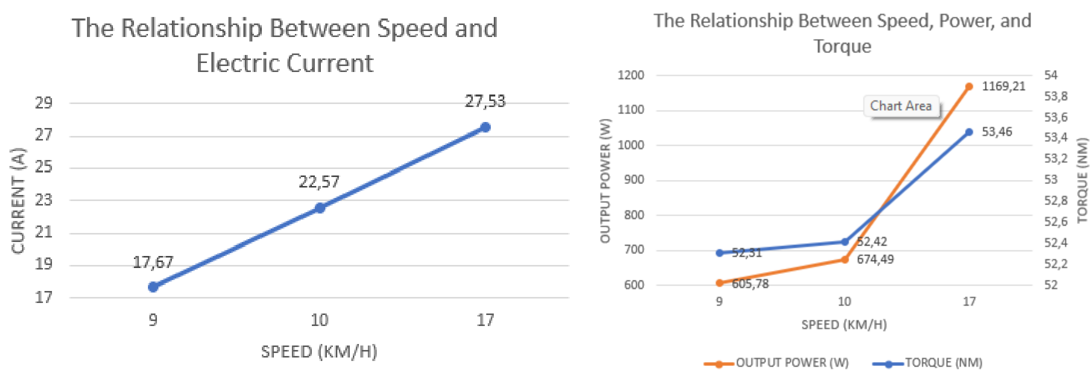

Figure 9. Relationship between speed and electric current (left) and relationship between speed, power, and torque (right)

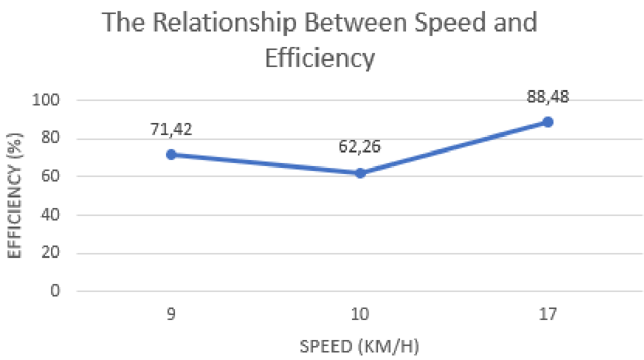

Figure 10. Graph of the Relationship between Speed and Efficiency

4. Endurance Testing

The endurance test was conducted to assess energy consumption over a fixed distance.

Table 7. Results of endurance testing with a load of 130 kg

Type of Test	Measured Parameter	Measurement Results		
		Speed 1	Speed 2	Speed 3
Endurance Test (with 130 kg load)	Initial Voltage (V)	48	48	48
	Final Voltage (V)	27,17	32,20	38,80
	Average Current (A)	9,71	13,01	20,56
	Travel Distance (km)	14	14	14
	Travel Time (minutes)	38,25	38,25	38,25

The electrical parameters from the endurance test are compared in the chart below.

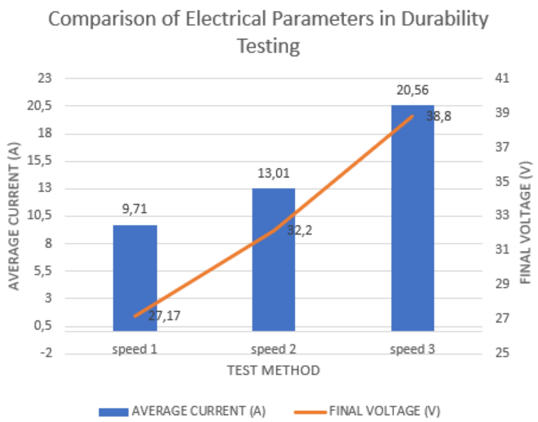

Figure 11. Comparison graph of electrical parameters in endurance testing

3.2 Discussion

The results of this study have several implications for practical electric vehicle (EV) design, particularly in terms of control strategies and drivetrain optimization.

Adaptive Control Strategies

The sharp contrast in efficiency between flat-road operation (~26%) and incline operation (~88%) highlights the importance of adaptive control. On flat terrain, the motor operates far below its nominal capacity, which explains the low efficiency. This suggests that an "eco-mode" could be implemented, where the controller adjusts voltage and current delivery to push the motor closer to its optimal efficiency range during light-load conditions. Conversely, a "hill-mode" could be introduced to provide higher torque output during climbing, ensuring both performance and efficiency are maintained. Such load-adaptive strategies would extend battery life and increase the effective range of the vehicle.

Gear Ratio Optimization

The study currently uses a direct drive approach without transmission considerations. However, the observed efficiency variation indicates that optimizing gear ratios could play a key role in flattening efficiency differences between driving conditions. A properly chosen gear ratio or even a two-stage transmission could allow the motor to consistently operate within its most efficient torque-speed band, particularly during low-speed cruising on flat terrain where efficiency losses are significant. This points toward integrated drivetrain optimization as a promising next step for reducing procurement costs and improving real-world performance.

Motor Efficiency Characteristics

The efficiency variation aligns with the known characteristics of BLDC motors, where peak efficiency is typically achieved under higher load and torque conditions, while low-load operation often results in higher electrical losses due to iron losses, switching losses, and idle current draw. The results confirm that system-level design must account not just for peak motor specifications but also for the operating conditions under which the motor spends most of its duty cycle.

Future Research Directions

Future work should extend beyond simulation and controlled track testing. Real-road testing under mixed driving conditions (stop-and-go traffic, variable inclines, and sustained cruising) will be essential for validating the effectiveness of adaptive control strategies and efficiency predictions. In addition, integrated design approaches that simultaneously optimize motor selection, controller strategies, and gear ratio(s) should be pursued. Multi-objective optimization methods, possibly supported by AI-based algorithms, could be employed to balance cost, efficiency, and performance.

4. Conclusions

This study successfully designed and validated a two-wheeled electric vehicle drive system using a BLDC motor based on vehicle dynamics analysis. The calculated requirements of 963.82 W power and 2.71 Nm torque closely matched the specifications of the selected BM1418ZXF motor (1000 W, 3.5 Nm), ensuring reliable operation for a total load of 130 kg. Experimental tests confirmed that the vehicle achieved a top speed of 21 km/h, with efficiency varying significantly depending on operating conditions. On flat roads, the system showed relatively low efficiency of around 26%, while on a 10° incline the efficiency increased sharply to nearly 88%, reflecting the strong influence of load on BLDC motor performance. These findings emphasize the importance of adaptive control strategies, such as eco-mode for light-load operation and hill-mode for climbing, as well as the potential benefits of gear ratio optimization to keep the motor operating near its peak efficiency. Future research should focus on real-road testing under diverse traffic conditions and integrated optimization of motor, controller, and gear ratios to enhance efficiency, extend driving range, and reduce procurement costs.

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