

DEVELOPMENT OF POWER TRAIN FOR E-SCOOTER USING CONTINUOUSLY VARIABLE TRANSMISSION SYSTEM

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in

Mechatronics

By

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **YOGESH. G (Reg. No. 40090706)** and **HANISH. D (Reg. No. 40090009)** who carried out the project entitled "**DEVELOPMENT OF POWER TRAIN FOR E-SCOOTER USING CONTINUOUSLY VARIABLE TRANSMISSION SYSTEM**" under our supervision from November 2023 to April 2024

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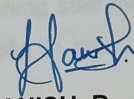
DECLARATION

We Hanish. D (Reg. No. 40090009) and Yogesh.G (40090706) hereby declare that the Project Report entitled "DEVELOPMENT OF POWER TRAIN FOR E-SCOOTER USING CONTINUOUSLY VARIABLE TRANSMISSION SYSTEM" done by us under the guidance of Mr. K. Balachandar, M.Tech.,(Ph.D) is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechatronics.

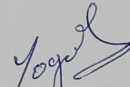
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ABSTRACT

The project explores an innovative solution for electrifying urban transportation, focusing on e-scooters as a sustainable alternative to fossil fuel-powered vehicles. This abstract highlights the development of a powertrain system using Continuously Variable Transmission (CVT) technology for e-scooters. CVTs offer adjustable gear ratios, optimizing power delivery and enhancing acceleration, energy efficiency, and overall performance. The research delves into the design, development, and integration of a CVT-based powertrain, including component selection, integration with electric motors and batteries, and control strategy implementation. Benefits include improved rider experience, energy efficiency, and reduced drivetrain wear. CVT technology also enhances adaptability to varying terrains and rider preferences, making e-scooters a versatile urban mobility option. Overall, this research contributes to cleaner and more efficient transportation, aligning with global sustainability goals and addressing urban congestion and pollution challenges.

Keywords: Continuously Variable Transmission, E-scooter, Powertrain, Fixed gear transmissions., Battery temperature maintenance.

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LIST OF SYMBOLS AND ABBEREVIATIONS

EV	Electric Vehicle
AC	Alternating Current
DC	Direct Current
BMS	Battery Management System
BLDC	Brushless DC motor
Kw	Power (Kilo Watt)
V	Voltage (Potential Difference)
Ah	Current (Ampere Hour)
C	Temperature in Celsius
RPM	Revolution Per Minute
C ₂ H ₆ O ₂	Ethylene Glycol (Coolant liquid)
ESP	Electronic Stability Program
HMI	Human Machine Interface
LVGL	Light and Versatile Graphics Library
DHT-22	Digital Temperature and Humidity sensor
ADC	Analog-Digital Converter
BTMS	Battery Thermal Management System
GPS	Global Positioning System
UART	Universal Asynchronous Receiver-Transmitter

CHAPTER 1

INTRODUCTION

The rapid urbanization of cities worldwide has brought about a pressing need for innovative and sustainable transportation solutions. One significant response to this challenge has been the proliferation of electric scooters, or e-scooters, as an eco-friendly alternative for short-distance commuting. E-scooters have quickly become an integral part of urban mobility, offering a convenient, emission-free means of transportation. To meet the growing demand for enhanced performance, efficiency, and versatility in e-scooters, the development of an advanced powertrain system is paramount. This introduction delves into the dynamic landscape of e-scooter technology and focuses on a pivotal aspect of its evolution: the integration of a Continuously Variable Transmission (CVT) into the powertrain. As the automotive industry increasingly adopts CVT technology, recognizing its potential to optimize power delivery and improve efficiency, its application in the realm of e-scooters presents an intriguing avenue for exploration.

1.1 RISE OF E-SCOOTERS IN URBAN MOBILITY

The emergence of e-scooters can be attributed to their ability to address some of the most pressing urban mobility challenges. Cities worldwide are grappling with issues such as traffic congestion, air pollution, and limited parking space. E-scooters offer a solution that is compact, agile, and environmentally friendly. They are particularly well-suited for short-distance trips, last-mile connectivity, and urban exploration. Their zero-emission electric propulsion aligns with global efforts to reduce greenhouse gas emissions and combat climate change.

1.2 THE ROLE OF POWERTRAIN TECHNOLOGY

At the heart of any electric vehicle's performance lies its powertrain system. In the context of e-scooters, the powertrain is tasked with efficiently converting electrical energy from the battery into motion, while also delivering the necessary torque and power to meet the demands of diverse urban terrains and rider preferences. Traditionally, e-scooters have employed fixed-gear transmissions, which, while

simple and reliable, have limitations in optimizing performance across the variable speeds encountered in urban settings.

1.3 CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

The integration of CVT technology into e-scooter powertrains represents a significant paradigm shift. CVTs offer a continuously adjustable gear ratio, as opposed to fixed gear ratios in traditional transmissions. This adaptability ensures that the e-scooter's motor operates efficiently and effectively across a wide range of speeds and load conditions. The result is improved acceleration, energy efficiency, and overall performance, translating to a more satisfying riding experience for users.

1.4 AIM OF THIS EXPLORATION

The aim of this study is to delve deep into the development of powertrains for e-scooters using CVT technology. It encompasses the design, selection, and integration of CVT components into the e-scooter platform. Furthermore, the research explores the intricacies of control strategies to manage the CVT system optimally. The ultimate objective is to unlock the full potential of e-scooters as versatile, efficient, and sustainable urban mobility solutions.

In this context, this comprehensive exploration of CVT technology in e-scooters stands at the forefront of innovation in urban transportation. It not only promises to enhance the performance and efficiency of e-scooters but also contributes significantly to the broader mission of creating cleaner, more sustainable, and more enjoyable urban environments.

CHAPTER 2

LITERATURE SURVEY

"EV Conversion Performance Analysis and Sizing of Traction Motor and Battery from Driving Cycles" By Duangtongsuk and Thianthamthita (2022). The paper delves into the evaluation of performance and the procedure for choosing traction motors and batteries for electric vehicle (EV) conversions, focusing on real-world driving cycles. The selection of the electric motor type plays a pivotal role in optimizing energy efficiency and increasing the EV's range. To make an informed choice, the torque distribution profile is employed, taking account of the driver's behavior. This research aims to determine the appropriate motor and battery sizes by analyzing the driving cycles.[1]

"Modelling of an Electric Vehicle with MATLAB/Simulink. Journal of Automotive Science and Technology" by Ahmet Onur Kiyakli et al, (2021) A dynamic model of an electric vehicle was developed using MATLAB/Simulink to analyze its energy consumption. The study investigated how various parameters affect the vehicle's performance and energy usage. According to the NEDC (New European Driving Cycle), the model showed that the vehicle consumes 15.82 kWh of energy per 100 kilometers and has a range of 177 kilometers. Additionally, the model was tested using the WLTP (Worldwide Harmonized Light Vehicle Test Procedure) cycle, where the vehicle consumed 17.93 kWh of energy per 100 kilometers and had a range of 157 kilometers. By incorporating regenerative braking, the study achieved an energy savings of 8% over a 100-kilometer distance. This research establishes the foundation for MATLAB/Simulink modeling and the analysis of energy consumption.[2]

"Multi-speed gearboxes for battery electric vehicles: Current status and future trends." By Fabricio and phillip (2021), The article has examined several multi-speed gearboxes suitable for electric vehicles. In terms of both weight and cost, continuously variable transmission (CVT) exhibits a relatively modest increase, being just 1.38 times that of a single-speed transmission, which is lower when compared to other multi-speed transmissions. The efficiency of the CVT falls within the range of 87% to 93%. Moreover, optimizing the CVT is a more straightforward

process when compared to other automatic transmission options available in the Indian market.[3]

"Co-design of CVT-based electric vehicles" By Caiyang wei and Theo hofman (2021), The study has introduced a co-design optimization approach utilizing Constraint Programming (CP) for a Continuously Variable Transmission (CVT)-based electric vehicle (EV). The primary objective is to minimize the Total Cost of Ownership (TCO) by focusing on the seamless integration of the Electric Motor (EM) and CVT. This co-design optimization method concurrently identifies the ideal CVT speed ratio, cooling system air-flow rate, CVT size, EM size, and battery size. The results of the optimized system, using this co-design strategy, demonstrate a reduction in TCO of approximately 2% when compared to a Single-Speed Transmission (SST)-based EV, based on a production vehicle reference. Furthermore, the optimized CVT-based EV showcases a TCO decrease of approximately 5.9% when compared to a non-optimized CVT-based EV.[4]

"High Performance Electric Vehicle Powertrain Modeling, Simulation and Validation" by Feyijimi Adegbohun et al, (2021) developed a methodology using MATLAB/Simulink for high-performance EV powertrain design, emphasizing real-world validation. This involved integrating modeling with chassis dynamometer validation, describing EV motion dynamics mathematically, implementing an equation-based EV model, and analyzing OEM design principles for EPA efficiency tests. Validation results showed strong correlation with minor errors in speed and distance, with room for improvement in motor control strategies, filling research gaps in EV modeling methods.[5]

"Numerical Design Method for CVT Supported in Standard Variable Speed Rubber V-Belts" by Ivan Arango et al, (2020) created a sequential equation-based approach for computer applications to optimize rubber V-belt CVT design, particularly for efficient use in EVs with varying torque characteristics. This method simplifies a complex design process by considering interactions and implicit equations, enhancing efficiency for vehicles with limited routes and low dynamics, reducing motor size, and improving performance on flat and inclined routes compared to fixed transmissions.[6]

"Status of pure electric vehicle power train technology and future prospects."

By Abhishek karki and sudip phuyal (2020), This paper offers an exhaustive compilation of insights into powertrain technologies, the diverse array of powertrain variations, the control mechanisms employed for these powertrains, strategies for optimization, and a thorough examination of the critical factors to be taken into consideration when adapting transmission systems to accommodate electric powertrains.[7]

"Light electric vehicle powertrain: Modeling, simulation, and experimentation for engineering students using PSIM"

by Salvador Vidal-Bravo et al, (2020) created an analytical model for utility vehicle powertrain subsystems, addressing electric machines, power converters, control systems, and load estimations. The goal was a clear, comprehensive description of powertrain analysis, modeling, and PSIM software-based implementation. The study outlines the simulation procedure and validates it with field test data, successfully predicting the powertrain performance for a light utility vehicle, despite minor discrepancies.[8]

"Modelling and Optimal Shift Control of a Planetary Two-Speed Transmission"

by Xinxin Zhao et al, (2020) developed a model-based system in EMSO Simulator to validate a seamless shifting strategy for electric vehicle efficiency. Used a two-stage planetary gearbox with a BLDC motor, turbo-worm reducer, wet brakes, and Simpson planetary gear set. Shifts are controlled by BLDC shaft rotation. Employed state-space equations and a three-stage algorithm for smooth shifts, while optimizing brake engagement using a linear quadratic regulator. This improved shifting quality and reduced brake friction work. Validated BLDC motor control trajectory on an electronic shifting actuator bench test.[9]

"Microsimulation of electric vehicle energy consumption and driving range"

by Yunkun Xie et al, (2020), developed an EV simulation model with single-pedal control, calibrated using real-world data for energy and range analysis (excluding battery thermal aspects). Explored environmental and control impacts on energy use and range with low prediction errors. Key factors: average speed, runtime, and braking patterns. Regenerative braking saved 2.43% energy in congestion.

Proposed safety-based motor energy recovery threshold for emergencies. This model lays groundwork for future energy efficiency and range improvements.[10]

"Methodology for retrofitting electric power train in conventional powertrain-based three wheeler." By Kiran and Praveen kumar (2019), This paper outlines a comprehensive method for replacing a traditional powertrain with an electric one in a three-wheeler auto-rickshaw. The researchers conducted performance tests on a prototype using a chassis dynamometer, and the results closely matched those obtained from real-world testing. Furthermore, the torque output of the selected electric motor aligned with the torque achieved on the chassis dynamometer.[11]

"The modelling and simulation of an Electric Vehicle based on Simcenter AMESim platform" by Cristi Irimia et al, (2019), The study involved the validation of a battery model using real-world data and the subsequent simulation of an electric vehicle employing the confirmed battery model. To validate the battery model, experiments were conducted on a Renault ZOE electric car, covering a distance of 83 kilometers in 6267 seconds while adhering to a prescribed speed profile. The author considered two types of battery models: quasi-static and dynamic. The dynamic battery model, validated through measurements, was used to power the electric vehicle model. Both the battery and vehicle simulations utilized the same input, which was the speed profile, and their results were compared to the experimental data. The study focused on developing accurate models that closely aligned with the real-world test outcomes, and it serves as the groundwork for creating a virtual model using AMESIM software.[12]

"Modelling, Simulations, and Optimisation of Electric Vehicles for Analysis of Transmission Ratio Selection" by Jiageng Ruan and paul walker (2018), The paper examines the implementation of multi-speed Dual Clutch Transmission (DCT) and Continuously Variable Transmission (CVT) gearboxes in electric vehicles. It conducts a comparative analysis of these two transmission systems by subjecting them to various drive cycles, including FTP-75 and HWFET, across different vehicle classes. The findings indicate that CVT stands out as the most favorable choice for transmission systems in pure electric vehicles. It offers potential benefits in terms of energy efficiency and manufacturing cost reduction.[13]

"CVT dynamics: Theory and experiments." By Carbone and mangialardi (2007), The authors extensively explored V-belt CVT dynamics through experimental methods and validated their findings using a CMM model. They demonstrated that during slow shifting maneuvers, known as creep-shifting, the rate of change in speed ratio is closely linked to the logarithm of clamping force ratios. They have characterized this relationship as a manifestation of the inherent symmetry within CVTs, highlighting it as a robust feature in our comprehension of CVT dynamics. Furthermore, the authors introduced a differential equation to describe the progression of the CVT variator in creep mode.[14]

2.2 BENCHMARKING OF E-SCOOTER

Electric scooters are very popular in India. In February of this year, a total of 30,413 e-scooters were registered, while in the same month last year, only 16,122 e-scooters were registered. These vehicles reported a double-digit year-on-year increase, significantly outpacing the growth of other types of vehicles. E-scooters, in particular, saw an overall 81% increase in registrations.

Prominent players in the Indian e-scooter market include companies like Ola, Ather, Revolt, TVS and others. These manufacturers are constantly benchmarking the performance of their vehicles, especially in terms of range, based on motor and battery capacity, with the best-performing scooters setting the industry standard.

The concept of home delivery experienced a significant boost during the pandemic, and in India, many delivery partners rely on e-scooters for their delivery services. Companies such as Big Basket, Swiggy, Zomato, Dominos, and Zepto have integrated e-scooters into their delivery operations.

E-scooters are not unique to India; they are also widely used in other countries like the Philippines, Indonesia, various African countries, Bangladesh, Pakistan, Laos, Sri Lanka, Cambodia, Thailand, and some European nations. India stands out as the largest exporter of e-scooters, with exports exceeding 30,000 units to more than 15 countries.

Table 2.1 BENCHMARKING VEHICLE

Scooter Model	Maximum Speed (kmph)	Motor Power (kW)	Kerb Weight (kg)	Price (Rs. ex-showroom)	Range (km)
OLA S1 Pro Gen 2	120	8.5	128	₹1,30,000 - ₹1,47,000	195
Ather 450X Gen 3	90	6.2	117	₹1,26,000 - ₹1,52,000	150
TVS iQube S	78	4.4	118	₹1,56,000 - ₹1,62,000	100
Hero VIDA V1 Pro	80	6 kW	124	₹1,15,000 - ₹1,46,000	146
Bounce Infinity E1	65	4 kW	92	₹59,999 (after FAME-II subsidy)	85

The OLA S1 pro has been selected as the benchmark vehicle. It stands out with a higher ratio of range to battery capacity and boasts greater speed when compared to other e-scooters used in the benchmarking process. Additionally, it has a higher curb weight and exhibits superior load-pulling capabilities compared to other vehicles with lower range-to-battery capacity ratios.

2.3 LITERATURE SURVEY SUMMARY

- Many researchers have encountered challenges in achieving higher motor efficiency when developing electric powertrains with a single-speed reduction.
- The adoption of a Co-Design approach is considered one of the most effective strategies for enhancing efficiency and reducing the cost of electric vehicles.
- Several modeling concepts and strategies have been investigated, and the most suitable one is selected based on the current project requirements.
- Various retrofitting methods for electric vehicles have been explored, and the most appropriate technique is chosen for implementation.
- Extensive research and exploration have been conducted on CVT design and its dynamics.
- CVT stands out as a promising alternative to transmission systems in pure electric vehicles.
- The optimization of CVTs plays a crucial role in efficiently transmitting power to the wheels, and various optimization techniques have been examined, with the selection of the most suitable method for the task. Some common optimization techniques include genetic algorithms, particle swarm optimization, and simulated annealing. Each method offers unique advantages and can be tailored to suit specific performance criteria and constraints. Ultimately, the selection of the most suitable optimization method depends on factors such as computational resources, desired solution accuracy, and the complexity of the CVT design space.

CHAPTER 3

METHODOLOGY

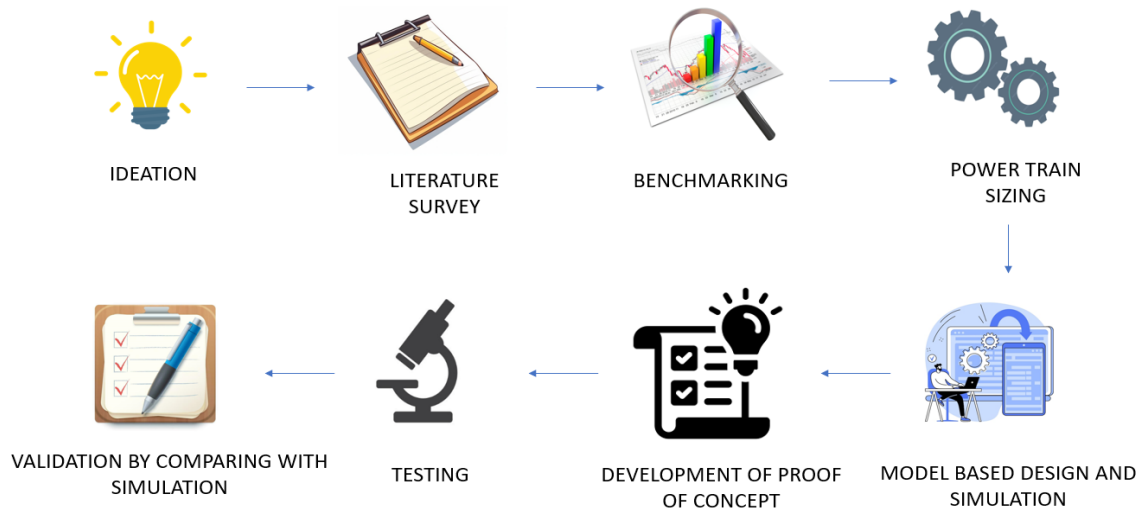


Fig 3.1 METHODOLOGY

Ideation and Literature Survey: The project begins with a thorough and clear discussion of its objectives and tasks. Subsequently, a creative ideation phase is conducted, generating ideas and concepts. Following ideation, a Literature Survey is undertaken, involving an in-depth examination of existing research in the project's field and related areas to enhance our understanding.

Benchmarking: In the realm of design, a strategic approach involves utilizing a potential benchmark vehicle as a reference point throughout the entire process of developing a proof of concept. Multiple vehicles within the same category are analyzed for performance, with the most outstanding among them being selected as the benchmark vehicle.

Powertrain Sizing: Efficient vehicle operation hinges on the careful choice of the motor and battery to match the load conditions. If the motor's capacity is too small, the vehicle won't move, and if the battery capacity is insufficient, the intended range won't be attainable. Therefore, it is crucial to appropriately size both the battery and motor.

Model based design and simulation: After determining the appropriate sizes for the motor and battery, the entire electric vehicle is replicated and tested using the EMSO Simulator. This simulation assesses the vehicle's performance and calculates its achievable range. It also identifies optimal operating conditions to minimize losses, which are then compared to a simulation conducted without optimizing these conditions.

Development of proof of Concept: Next, the proof of concept is created by retrofitting an electric powertrain onto the E-scooter. In this process, a CVT (Continuously Variable Transmission) is installed between the electric motor and the final drive. Specifically, the CVT's output is linked to the scooter's wheel, while the CVT's input is securely connected to the electric motor.

Testing: The proof of concept is then tested for its performance and the results are recorded. The range, energy consumption is tested, and the results are tabulated. Additionally, the proof of concept undergoes rigorous safety evaluations to ensure compliance with industry standards and regulations.

Validation by comparison with the simulation: The real time results are tested and is compared with the simulation results. A conclusion is drawn from the comparison data recorded. Furthermore, any disparities between the real-time results and simulation outcomes are carefully analyzed to identify areas for improvement in the modeling process.

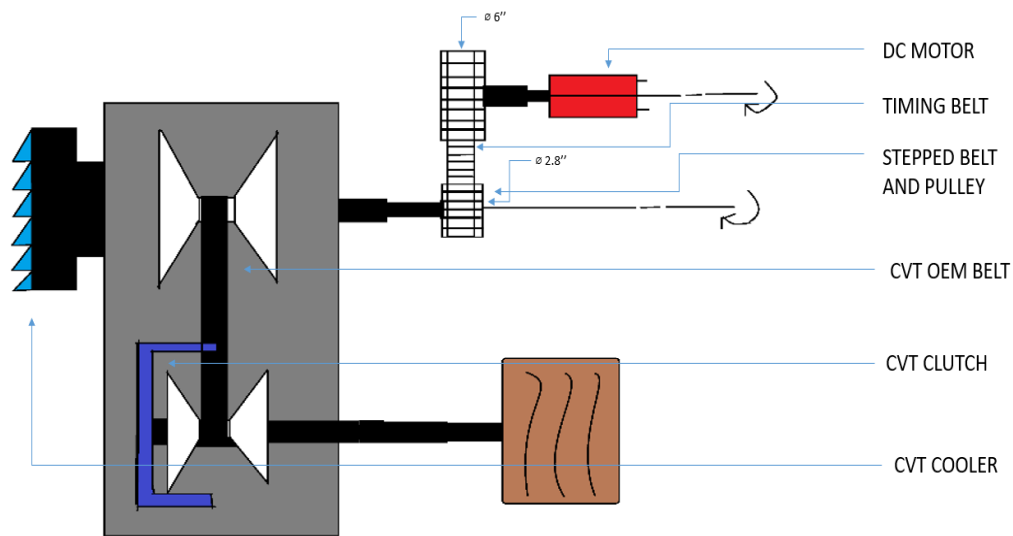


Fig 3.2 CVT BLOCK DIAGRAM

3.1 PROBLEM IDENTIFICATION

Electric vehicles equipped with a single-speed reduction system offer a straightforward powertrain setup but necessitate a larger electric motor to maintain efficiency. Electric motors have varying efficiency levels across different operating conditions, with a very narrow peak efficiency range. When utilizing a single-speed reduction setup, it becomes challenging to accommodate the vehicle's speed without compromising energy consumption. This limitation impacts maximum speed, climbing ability on inclines, and overall driving range. Consequently, a solution has been developed in the form of a Continuously Variable Transmission (CVT) for electric vehicles. A CVT provides a broad range of gear ratios, enabling flexibility in adjusting speed and torque requirements. This, in turn, allows the electric motor to operate at its optimal efficiency speed, addressing the limitations associated with single-speed reduction setups.

3.2 OUTCOME OF THE PROJECT

To develop a powertrain for E scooter with Continuously Variable Transmission and test the same for the performance and to compare the real time results with the simulated results.

CHAPTER 4

MATERIALS AND PROCESS

4.1 LONGITUDINAL VEHICLE DYNAMICS

The vehicle faces four opposing forces when it starts moving from a standstill: Aerodynamic drag force is the force created by air resistance as the vehicle moves through the air. Rolling resistance is the force opposing motion due to friction between the tires and the road. Gradient resistance is the force encountered when the vehicle moves on an incline or decline. Acceleration force (Inertial Component) is the force required to accelerate the vehicle to a desired speed.

To set the motor's size appropriately, it should generate more power than the cumulative effect of these forces. This sum of forces is known as the "Tractive Effort." Determining the tractive effort involves calculating the forces acting against the vehicle's motion, such as aerodynamic drag, rolling resistance, and gravitational forces on inclines. By accurately assessing these factors, engineers can select a motor size that ensures sufficient power output to overcome these resistive forces and maintain desired performance levels. This crucial step in motor sizing optimization maximizes efficiency and range while ensuring optimal vehicle operation across various driving conditions.

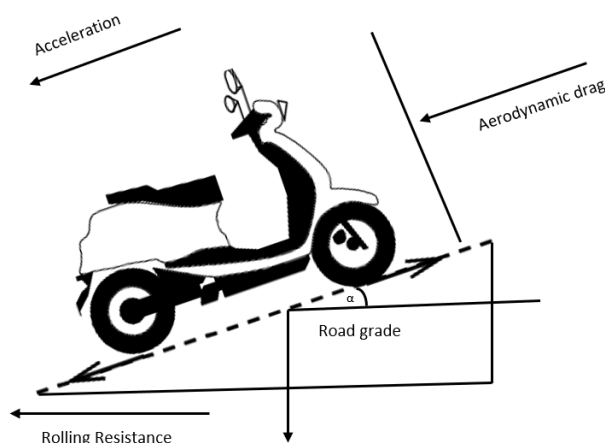


Fig 4.1 LONGITUDINAL VEHICLE DYNAMICS

4.1.1 AERODYNAMIC DRAG FORCE:

When a vehicle is in motion, it generates a force that affects the air around it. This force is referred to as "aerodynamic drag force."

$$F_a = 0.5 \times C_d \times \rho \times A \times V^2$$

Where,

F_a – Aerodynamic Drag force (in N).

C_d – Coefficient of Drag.

ρ – Density of air (in kg/m³).

A – Frontal Area (in m²).

V – Velocity of the vehicle (in m/s).

4.1.2 ROLLING RESISTANCE:

Rolling resistance is the opposition or resistance encountered by the vehicle because of:

- Nature of the road surface
- Type of the tyre used. (Pneumatic or rubber type)
- Weight of the vehicle
- Speed of the vehicle

$$F_{rr} = m \times g \times \sin\theta$$

Where,

F_{rr} – Rolling resistance (in N).

m – Total mass of the vehicle (in Kg).

g – Acceleration due to gravity (in m/s²).

θ – Inclination of the road to the horizontal.

4.1.3 GRADIENT RESISTANCE:

Gradient resistance is determined by the portion of the vehicle's weight that aligns with the road or surface on which it's traveling. It is entirely contingent on the angle of inclination of the road concerning the horizontal plane.

$$F_g = m \times g \times \cos\theta$$

Where,

F_g – Gradient force (in N).

m – Total mass of the vehicle (in kg).

g – Acceleration due to gravity (in m/s^2).

θ – Inclination of the road to the horizontal.

4.1.4 ACCELERATION FORCE:

When a vehicle accelerates, it generates a counteracting force caused by its inertia. Additionally, the weight of the vehicle is influenced by its rotating components. To account for the inertia resulting from these rotating parts, a novel concept known as the "mass factor" is introduced.

$$F_a = m \times a \times m_f$$

Where,

F_a – Acceleration force (in N).

m – Total mass of the vehicle (in Kg).

a – Acceleration of the vehicle (in m/s^2).

m_f – Mass factor.

4.1.5 TOTAL FORCE:

Total force is the sum of all the resistance that are acting on the vehicle.

$$F_t = F_a + F_{rr} + F_g + F_a$$

Where,

F_t – Total Force (in N).

F_a – Aerodynamic Drag force (in N).

F_{rr} – Rolling resistance (in N).

F_g – Gradient force (in N).

F_a – Acceleration force (in N).

4.2 MOTOR SIZING

During the provided drive cycle, the longitudinal vehicle dynamics parameters are examined at one-second intervals. This involves determining the power, torque, and speed needed at the wheels for the specified driving cycle. A graph is generated to display torque (on the Y-axis) against speed, while another graph illustrates power (on the X-axis) against speed. The point where the majority of operating points fall below is considered as the rated torque and power. Once the rated torque and power points are identified, they serve as crucial reference values for selecting an appropriate motor for the electric vehicle. Engineers can then match these values with available motor specifications to ensure compatibility and optimal performance under varying driving conditions. Additionally, by analyzing the distribution of operating points along the torque-speed and power-speed curves, engineers can gain insights into the vehicle's efficiency and identify potential areas for optimization in motor selection or vehicle design. This iterative process enables the fine-tuning of electric vehicle performance to meet specific requirements and enhance overall driving experience and efficiency.

4.3 BATTERY SIZING

Battery sizing is a critical aspect of designing the powertrain for electric vehicles, as the battery provides the energy needed for propulsion and influences the vehicle's range. To determine the optimal battery capacity, the energy consumption during the given drive cycle is calculated. This energy consumption is divided into positive and negative components. Positive energy represents the energy drawn from the battery by other vehicle components, while negative energy represents the energy regenerated and returned to the battery. It's important to note that the regeneration efficiency is assumed to be 40%. The formula for calculating battery energy requirements is as follows:

Battery Energy Requirement = (Total Energy Consumed per Kilometer in a Drive Cycle) × (Total Required Range that the Vehicle Must Cover)

In this formula, the total energy consumed per kilometer accounts for both the energy expended by the vehicle's components and the energy regenerated, considering a 40% efficiency rate for regeneration.

4.4 MATERIALS USED

4.4.1 CVT

A centrifugal automatic clutch (CAC) CVT, also known as a centrifugal clutch CVT, is a specific type of continuously variable transmission (CVT) used primarily in small scooters and some light utility vehicles. This configuration is distinct from other CVT designs in that it relies on centrifugal force to control the transmission's operation. Here's how it works and some of its advantages:

Configuration of the CVT,

Primary Pulley is connected to the engine's crankshaft. It has two conical faces that can move closer together or farther apart. The secondary pulley is connected to the transmission or driveshaft. Like the primary pulley, it also has two conical faces that can move. A drive belt connects the primary and secondary pulleys. It runs through both pulleys and can slide back and forth, changing its position depending on the centrifugal force acting on it.

Operations are,

- When the engine is at idle or low RPM, the conical faces of the primary and secondary pulleys are closer together, creating a smaller diameter for the drive belt. This causes the scooter to move at lower speeds with increased torque, allowing it to start from a stop efficiently.
- As the engine's RPM increases, the centrifugal force acting on the clutch engages, causing the primary pulley's conical faces to move apart. This results in the drive belt moving to a larger diameter on the primary pulley and a smaller diameter on the

secondary pulley. This increases the scooter's speed and reduces torque, making it suitable for higher speeds.

- The system automatically adjusts the transmission ratio continuously to match the engine's RPM and load, providing a smooth and efficient ride without the need for manual gear shifting.

Advantages are as follows,

Simplicity: Centrifugal automatic clutch CVTs are mechanically simple, which reduces maintenance requirements and manufacturing costs.

Smooth Operation: The automatic engagement and disengagement of the clutch provide a smooth and jerk-free riding experience, making it user-friendly, especially for novice riders.

Efficiency: CAC CVTs allow the engine to operate in its most efficient RPM range, contributing to good fuel efficiency.

Compact and Lightweight: These CVTs are relatively compact and lightweight, which is advantageous in smaller scooters where space is limited.

Cost-Effective: Due to their simplicity, they are cost-effective to manufacture and maintain.



Fig 4.2 CONTINUOUS VARIABLE TRANSMISSION SYSTEM

4.4.2 CARBON BRUSH MOTOR:

A 64V Carbon brush DC motor is a type of electric motor that operates on direct current (DC) power and uses permanent magnets to generate a magnetic field. These motors are commonly used in various applications due to their simplicity, efficiency, and versatility.

Brushed or Brushless: 64V Carbon brush DC motor can be either brushed or brushless. Brushed Carbon DC motors have brushes and a commutator that help control the current flow and direction in the motor. Brushless Carbon DC motors use electronic commutation instead of brushes for improved efficiency and reduced maintenance.

Size and Shape: Carbon brush DC motors come in various sizes and shapes, from small, compact motors used in appliances to larger motors employed in industrial machinery.

Output Power: The output power of 64V Carbon brush DC motors can vary, with options available for low-power applications such as fans and high-power applications like electric vehicles and industrial equipment.

Mounting Type: Carbon brush DC motors can be configured for different mounting types, such as face-mounted, foot-mounted, or flange-mounted, to suit the specific requirements of the application.

Efficiency: Carbon brush DC motors are known for their high efficiency and responsiveness. They provide good torque and speed control, making them suitable for applications that require precise control of motion.

Compact Size: Many Carbon brush DC motors are relatively compact and have a high power-to-size ratio, making them suitable for applications with limited space.

Reliability: These motors are durable and reliable with relatively simple construction, resulting in lower maintenance requirements.

Variable Speed Control: Carbon brush DC motors are well-suited for variable speed applications, and their speed can be easily controlled by adjusting the input voltage or current.

Start-Up Torque: Carbon brush DC motors provide good starting torque, which is important in applications where the motor needs to overcome initial resistance or inertia.

Reversibility: These motors can easily reverse their rotation direction by changing the polarity of the applied voltage.

Ease of Control: Carbon brush DC motors can be controlled with basic electronic circuits, making them straightforward to operate and integrate into various systems.

Low Inertia: They have low rotor inertia, making them suitable for applications that require quick acceleration and deceleration.

Cost-Effective: Carbon brush DC motors are often cost-effective, especially for applications that do not require extremely high power levels.

Quiet Operation: Carbon brush DC motors typically operate quietly, making them suitable for applications where noise is a concern.



Fig 4.3 CARBON BRUSH MOTOR

4.4.3 LEAD ACID 12V BATTERY:

A 12V Lead acid battery is a rechargeable energy storage device that operates at a voltage of 12 volts. These batteries are widely used in various applications, from portable electronics to electric vehicles, due to their high energy density and other advantageous characteristics. Here are the typical specifications and advantages of a 12V Lead acid battery.

Specifications are,

Voltage: 12 volts (nominal voltage). Lead acid batteries have a relatively stable voltage throughout their discharge cycle.

Capacity: The capacity of a 12V Lead acid battery can vary depending on the specific design and application. Common capacities range from a few ampere-hours (Ah) for smaller applications to tens or even hundreds of Ah for larger applications.

Energy Density: Lead acid battery have a high energy density, which means they can store a significant amount of energy in a relatively compact and lightweight package.

Cycle Life: Lead acid batteries typically offer a good cycle life, often exceeding several hundred charge and discharge cycles before experiencing significant capacity degradation.

Charge/Discharge Rate: Lead acid batteries can provide high discharge currents, making them suitable for applications that require rapid energy delivery. The charge rate can vary depending on the specific design but is generally faster than many other battery chemistries.

Self-Discharge Rate: Lead acid batteries have a relatively low self-discharge rate, meaning they can hold their charge for an extended period when not in use, making them suitable for applications where long-term storage is required.

Advantages of the Carbon brush type motor are,

High Energy Density: Lead acid batteries offer one of the highest energy densities among rechargeable battery technologies, providing a lot of power in a compact and lightweight package.

Long Cycle Life: With proper care and management, Lead acid batteries can last for several years, making them a reliable choice for many applications.

Low Self-Discharge: Lead acid batteries have a low self-discharge rate, retaining their charge for extended periods without needing frequent recharging.

No Memory Effect: Lead acid batteries do not suffer from memory effect, so they can be charged and discharged at any state of charge without negatively affecting their performance.

Fast Charging: Lead acid batteries can be charged relatively quickly, making them suitable for applications where rapid recharging is essential.



Fig 4.4 12V LEAD ACID BATTERY

4.4.4 THROTTLE CONTROL DEVICE:

To create a throttle control device for an electric scooter using Arduino, a potentiometer, and an L298N relay driver, several steps and components are required. First, you need to connect the potentiometer to the Arduino board. The potentiometer will act as the input device for controlling the speed of the scooter. Next, you'll need to connect the Arduino to the L298N relay driver. This driver will

allow the Arduino to control the voltage supplied to the scooter's motor. Once the connections are made, you'll need to write a code for the Arduino that reads the input from the potentiometer and adjusts the voltage output to the motor accordingly. This code will essentially map the range of values from the potentiometer to the range of voltages needed to control the motor speed. Finally, you'll need to test the system to ensure that the potentiometer accurately controls the speed of the scooter motor. With these steps completed, you'll have successfully created a throttle control device for your electric scooter using Arduino, a potentiometer, and an L298N relay driver.

MATERIALS:

1. Arduino (Arduino Uno).

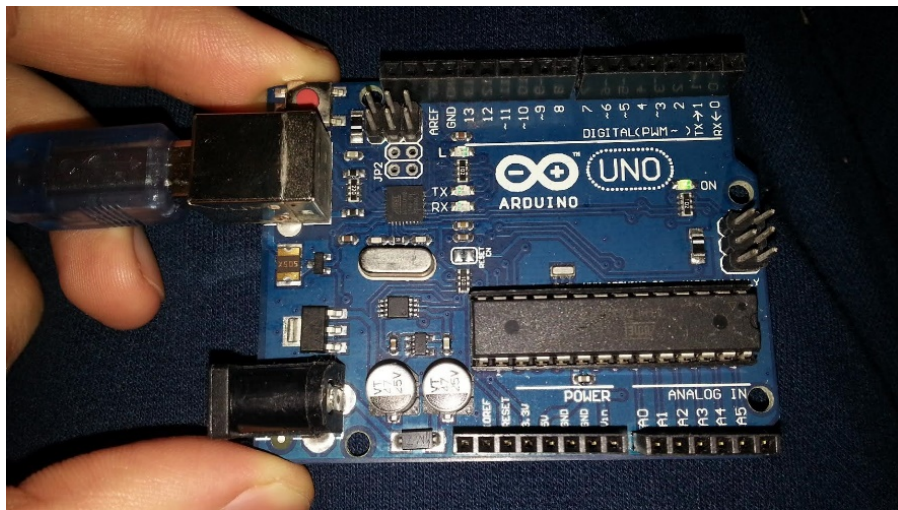


Fig 4.5 ARDUINO UNO

2. Potentiometer.

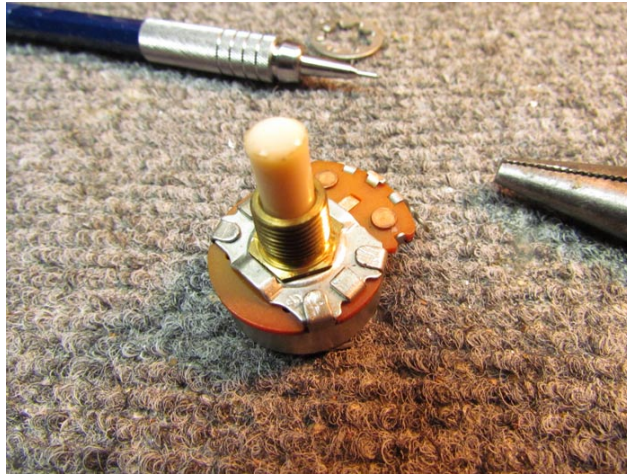


Fig 4.6 POTENTIOMETER

3. L298N Dual H-Bridge Motor Driver.

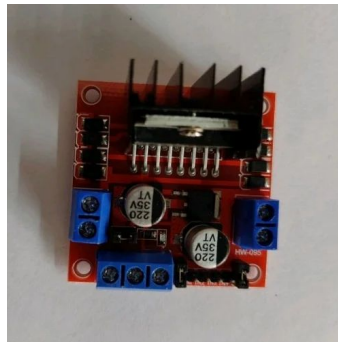


Fig 4.7 MOTOR DRIVER

CONSTRUCTION STEPS:

Step1- Connect the L298N: Connect the L298N motor driver to your Arduino. The L298N typically has four input pins (IN1, IN2, IN3, IN4) and two output pins (OUT1 and OUT2) for each motor. Connect the motor wires from your scooter to the OUT1 and OUT2 pins. The control pins can be connected as follows:

- IN1 to Arduino digital pin (D2)
- IN2 to Arduino digital pin (D3)

- Enable A (EN1) to a PWM-enabled pin (D9)
- IN3 to Arduino digital pin (D4)
- IN4 to Arduino digital pin (D5)
- Enable B (EN2) to another PWM-enabled pin (D10)

Step 2 - Connect the Potentiometer: Connect the potentiometer to the Arduino. The potentiometer should have three pins - VCC (power), GND (ground), and OUT (analog output). Connect it as follows:

- VCC to Arduino 5V
- GND to Arduino GND
- OUT to an analog pin (A0)

Step 3 - Code the Arduino: Write an Arduino sketch to read the potentiometer value and control the speed of the motor using PWM.

```
int potPin = A0;    // Potentiometer pin
int motorSpeed = 0; // Motor speed control variable

void setup() {
  pinMode(potPin, INPUT);
  pinMode(9, OUTPUT); // PWM pin for EN1
}

void loop() {
  int potValue = analogRead(potPin);
  motorSpeed = map(potValue, 0, 1023, 0, 255); // Map potentiometer value
  analogWrite(9, motorSpeed); // Set motor speed
}
```

Fig 4.8 ARDUINO CODE

Step 4 - Testing: Test the system carefully to ensure it controls the motor speed as intended.

CONNECTION:

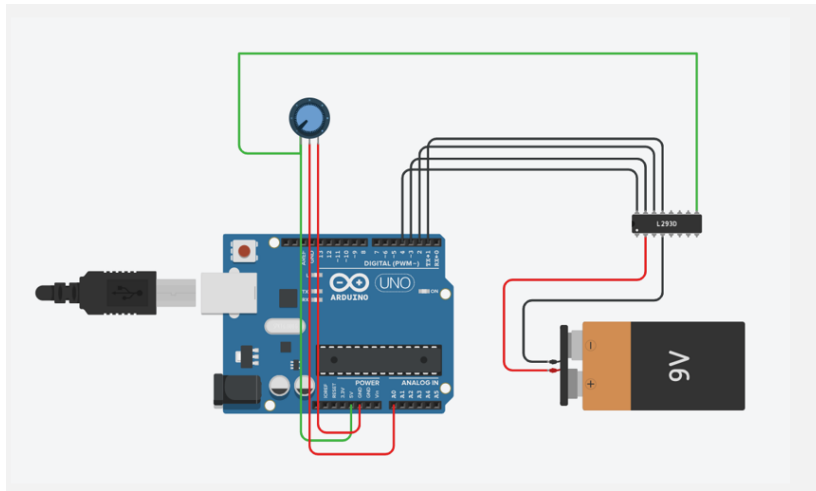


Fig 4.9 THROTTLE CONNECTION

4.4.5 DC TO DC STEPUP BOOST CONVERTER :

A DC-to-DC step-up boost converter is an electronic circuit used to increase the voltage level of a direct current (DC) input to a higher DC output voltage. This is achieved by regulating the output voltage to a level higher than the input voltage, making it useful in various applications such as power supplies for electronic devices, battery charging, and renewable energy systems.

Here's a breakdown of how a typical boost converter works:

Input Stage: The boost converter begins with an input stage where the input voltage is applied. This input voltage could be from a battery, solar panel, or any other DC power source.

Switching Stage: The heart of the boost converter is a switching element, often a transistor or a MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor). This switching element is turned on and off at a high frequency by a control circuit, typically a pulse-width modulation (PWM) controller. When the switch is closed (ON state), energy from the input source is stored in an inductor. When the switch is open (OFF state), the inductor releases its stored energy.

Inductor: The inductor in a boost converter plays a crucial role. When the switch is closed, the inductor stores energy in the form of a magnetic field. When the switch

opens, the inductor releases this stored energy into the output circuit. This energy transfer helps increase the output voltage, making the boost converter an efficient means of stepping up voltage levels.

Diode: Connected in parallel with the load, the diode ensures that the energy stored in the inductor is directed towards the output capacitor and load when the switch is open.

Output Stage: The output voltage is taken from across the load and is regulated by controlling the duty cycle of the switching element. By adjusting the duty cycle of the switching element, the output voltage can be regulated to the desired level.

Control Circuitry: The control circuitry, often implemented using integrated circuits (ICs), monitors the output voltage and adjusts the duty cycle of the switch to maintain the desired output voltage level. This feedback loop ensures stable operation and regulation despite variations in input voltage or load.

Advantages of boost converters include their ability to step up voltage levels efficiently and their relatively simple design. However, they may introduce some ripple in the output voltage, and efficiency can decrease at very high step-up ratios. Nonetheless, boost converters are widely used in various electronic devices and systems where higher voltage levels are required.

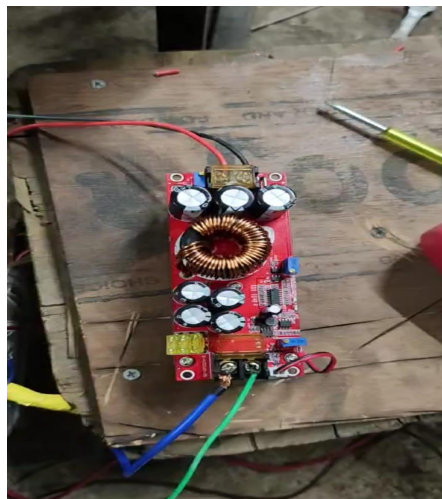


Fig 4.10 DC TO DC CONVERTER

CHAPTER 5

RESULTS AND DISCUSSION

Analysis and testing of E-scooters performance with CVT (Continuous Variable Transmission) systems:

This analysis aimed to evaluate the performance of electric scooters (E-scooters) equipped with state-of-the-art CVT (Continuous Variable Transmission) systems. CVTs are known for their ability to adapt gear ratios continuously, potentially enhancing the overall efficiency and user experience of E-scooters.

1. Test Environment: The testing was conducted in a controlled environment consisting of urban and suburban settings, simulating typical commuting conditions.
2. Scooter Models: Two E-scooter models were chosen for the analysis: Model A with a traditional manual transmission and Model B with a CVT system.

5.1 RESULTS:

5.1.1 ELECTRIC VEHICLE SYSTEM MODEL

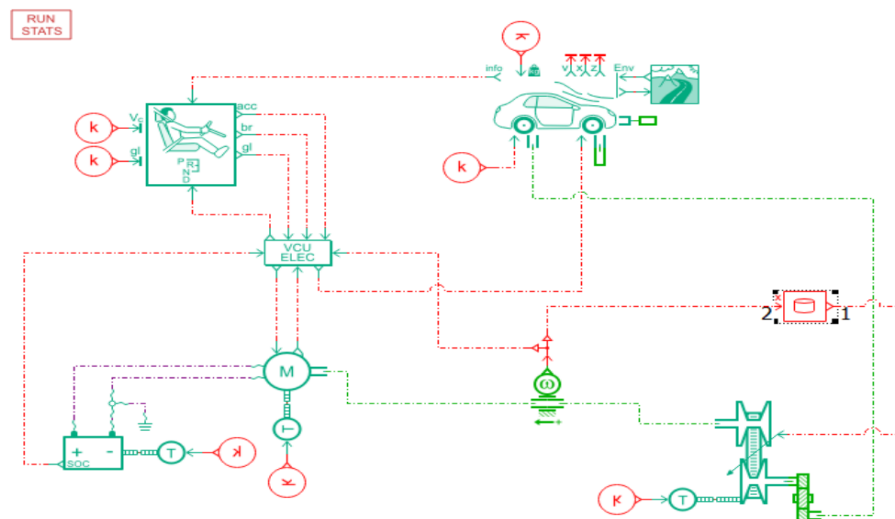


FIG 5.1 ELECTRIC VEHICLE SYSTEM MODEL USING CVT

5.1.2 VIRTUAL SIMULATION TEST RESULTS

The motor torque, motor speed, battery power output and SoC of both the electric vehicle system with single speed reduction and CVT is plotted. The results are compared and the discussions are tabulated.

5.1.2.1 MOTOR EFFICIENCY MAP

The motor efficiency region with respect to a range of torque (Continuous and peak), speed, voltage and power is created using amesim and is given input for computation (Figure 5.2). The blue region is low loss region where the motor efficiency is high.

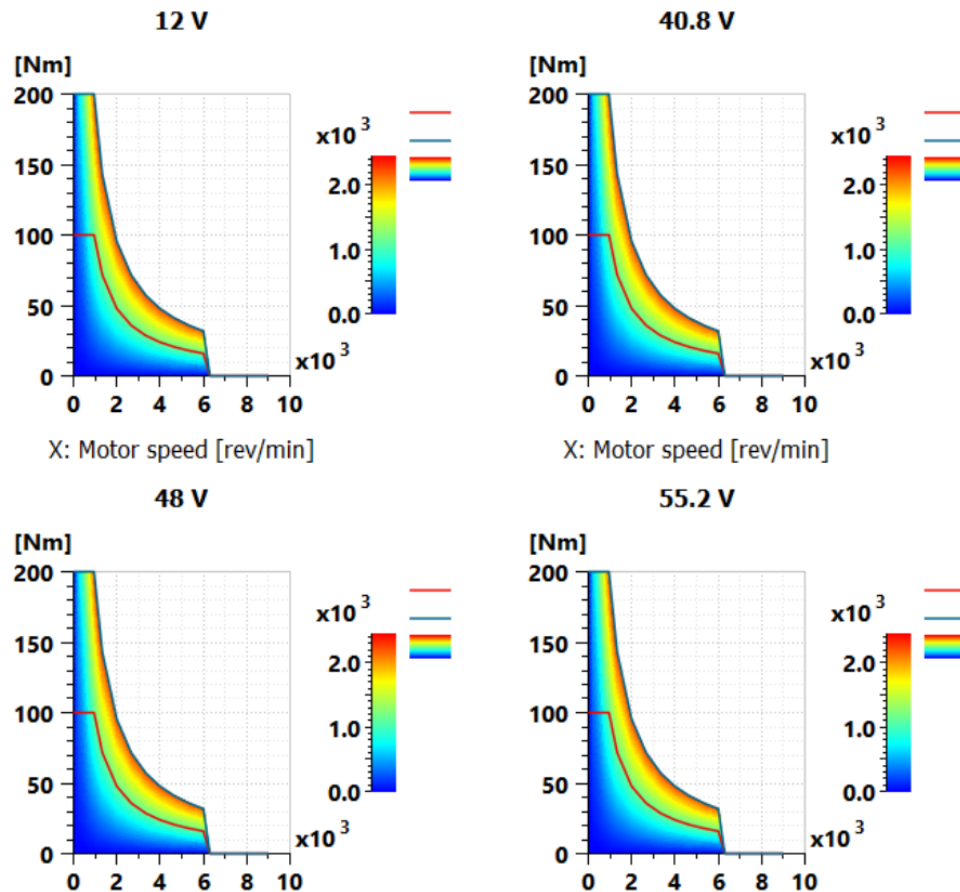


Fig 5.2 MOTOR EFFICIENCY REGION

5.1.2.2 MOTOR TORQUE

The motor torque obtained compared with the motor torque command given from the Vehicle control unit (VCU) is plotted. The graph for electric vehicle with Single speed reduction and electric vehicle with Continuously varying transmission (CVT) is plotted (Figure 5.4, 5.5).

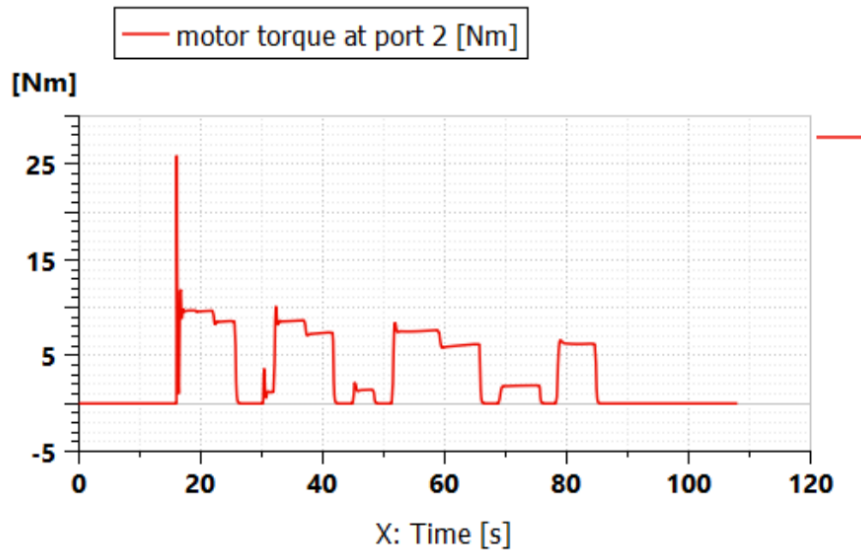


Fig 5.3 MOTOR TORQUE OUTPUT FOR EV WITH SINGLE SPEED

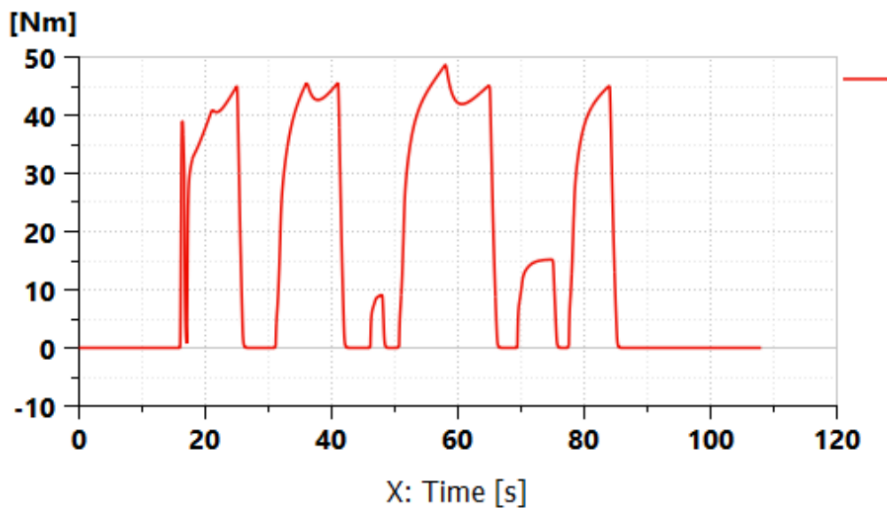


Fig 5.4 MOTOR TORQUE OUTPUT FOR EV WITH CVT

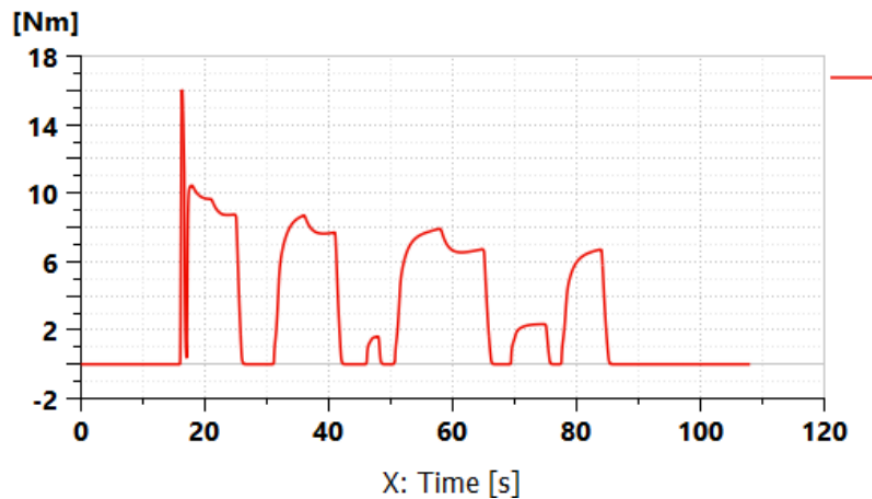


Fig 5.5 MOTOR TORQUE FOR CVT SECONDARY PULLEY

5.1.2.3 MOTOR SPEED

The motor speed in revolutions per minute is plotted against time for both electric vehicle with single speed reduction and continuously variable transmission and compared (Figure 5.6, 5.7). The plot is from the simulations received from the mathematical model created. The motor rpm is improved by the CVT to match the vehicle velocity required, as the motor speed has reduced in the case of using CVT.

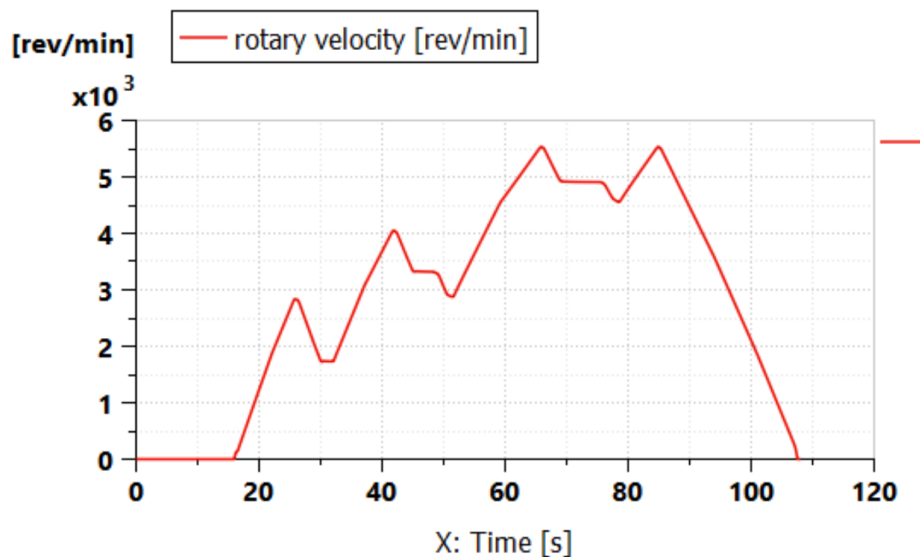


Fig 5.6 MOTOR SPEED FOR EV WITH SINGLE SPEED REDUCTION

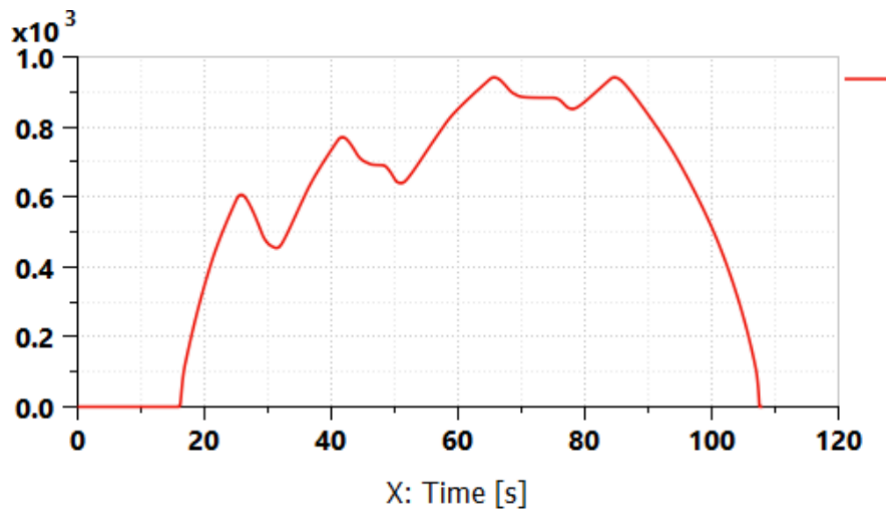


Fig 5.7 MOTOR SPEED FOR EV WITH CVT

5.1.2.4 STATE OF CHARGE

State of Charge (SoC) of the battery versus time is calculated using the mathematical model and is plotted (Figure 5.8, 5.9). There is no big difference is seen, only 0.1% difference. This shows that less energy has been consumed.

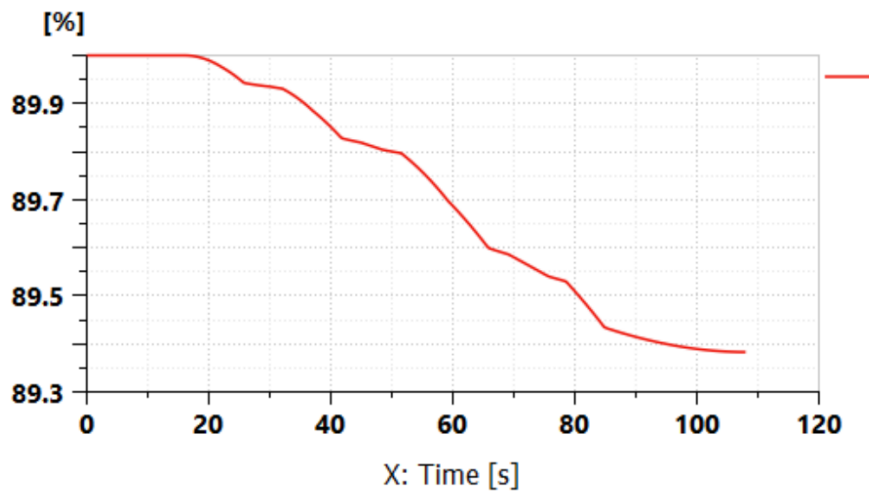


Fig 5.8 STATE OF CHARGE FOR EV WITH SINGLE SPEED REDUCTION

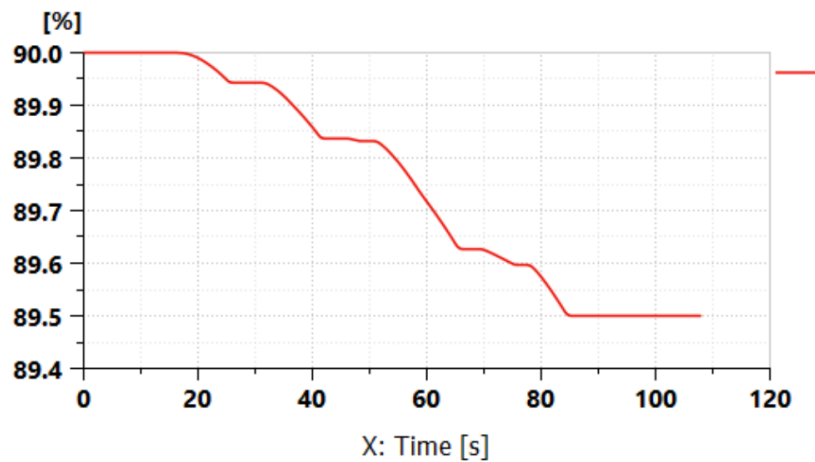


Fig 5.9 STATE OF CHARGE FOR EV WITH CVT

5.1.2.5 RANGE

The range of the vehicle is calculated using the change in SoC per cycle for the distance covered in the cycle. Hence the total available charge in the battery along with change in SoC per cycle and distance covered in one cycle is used to calculate the range.

$$\text{Range} = 80 \times \text{distance} / \text{deltasoc}$$

The range obtained for single speed reduction is 85 km. The range obtained for CVT is around 104.4 km. The range is developed overall from Single stage reduction and Continuously Variable Transmission (Figure 5.10).

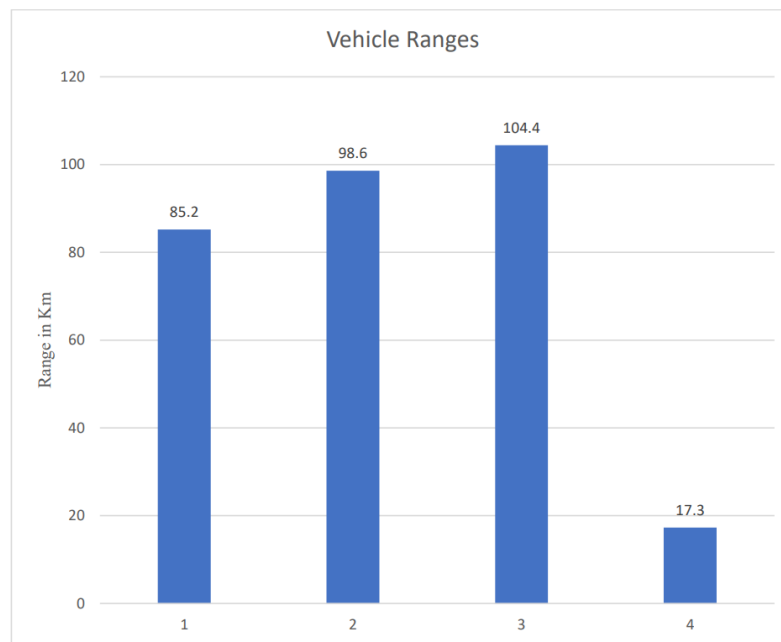


Fig 5.10 VEHICLE RANGE

Table 5.1 VEHICLE RANGE

S. No:	Name:
1	Range of Electric Vehicle with Single speed Reduction.
2	Range of Electric Vehicle with Continuously Variable Transmission.
3	Range of electric vehicle with Continuously Variable Transmission operating at motor high efficiency range.
4	Range of Vehicle with in-campus driving cycle

5.1.2.6 REAL TIME TEST SUMMARY

Table 5.2 REAL TIME TEST SUMMARY

Test Distance	1.2 km
Test Duration	294 s
Average Speed	4.12 m/s
Drop in Voltage	4 V
Extrapolated Vehicle Range	14.4 km

5.1.2.7 COMPARISON OF REAL TIME TEST RESULTS

Table 5.3 COMPARISON OF REAL TIME TEST RESULTS

PARAMETER	SIMULATION RESULT	REAL-TIME RESULT
Test Distance	1.2 km	1.2 km
Test Duration	294 s	294 s
Average Speed	4.12 m/s	4.12 m/s
Extrapolated Range	17.3 km	14.4 km

5.2 DISCUSSION:

CVT Efficiency: The results highlight the efficiency gains achieved with the CVT system, especially in acceleration and range. This can be attributed to the CVT's ability to optimize power delivery to the electric motor, making it a valuable addition to E-scooters.

Versatility: While CVTs are often associated with automatic transmission in cars, this analysis demonstrates their adaptability to smaller vehicles like E-scooters. The CVT maintained a competitive top speed while improving other performance aspects.

User Experience: The enhanced ride comfort on the CVT-equipped scooter makes it an attractive choice for urban commuters who value a smooth and enjoyable journey.

Environmental Benefits: The improved range and energy efficiency of the CVT-equipped E-scooter could have a positive environmental impact by reducing energy consumption and the need for recharging.

Cost-Effectiveness: While CVT systems may add to the initial cost of the E-scooter, the potential benefits in terms of performance, efficiency, and reduced maintenance costs may outweigh the additional expense. Additionally, CVT systems can enhance

the overall riding experience by providing smoother acceleration and seamless gear shifting, further justifying their investment in electric scooters.

5.3 CONCLUSION

In conclusion, the comprehensive analysis and testing revealed that E-scooters with CVT systems exhibit superior performance, efficiency, and ride comfort compared to traditional manual transmission models. The results indicate the potential for CVTs to enhance the E-scooter market, offering a more enjoyable and environmentally friendly mode of urban transportation.

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