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Analyzing The Impact Of Transmission Ratios And Wheel Radius On Electric Motorcycle Performance Through Simulation Modeling

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ABSTRACT

This research analyzes the impact of input parameters on the performance of electric motorcycles, utilizing a simulation model that comprises both a dynamic model and a battery model. The study focuses on investigating the effects of transmission ratio and wheel radius. Simulation results show that increasing the transmission ratio from 2.66 to 4.94 leads to an decrease in speed and distance traveled, while electricity consumption increases by 0.16%. Similarly, increasing the wheel radius from 0.1 m to 0.25 m results in a higher maximum speed and travel distance but with decreased battery voltage and increased engine power consumption. These results suggest that altering the transmission ratio and wheel radius can enhance the efficiency and dynamics of electric motorcycles. The research highlights the usefulness of utilizing MATLAB SIMULINK software and mathematical models in the field of electric motorcycles and their practical applications.

KEYWORDS

transmission ratio, wheel radius, electric motorbike model, distance, velocity

INTRODUCTION

As the world transitions towards an environmentally sustainable future [1] the transportation sector plays a vital role in driving this shift. The advent of electric motorcycles (EMs) represents a promising solution to reduce carbon emissions, improve air quality and promote a sustainable future. Enhancing the operational efficiency and performance of EM through the study and analysis of various factors is necessary to promote its widespread adoption around the world. Yunfei Zhang et al. focuses on developing a simulation model for PMSM electric vehicles using the Simulink software tool [2]. The study aims to provide insights into the design and optimization of PMSM electric vehicles for practical applications. The simulation model includes the vehicle dynamics, PMSM motor, battery, and power electronics control, and is developed based on motor control theory. The article provides a detailed description of the simulation model's development process and its validation through a series of experiments conducted under different driving conditions. The simulation results suggest that PMSM electric vehicles possess good acceleration performance and energy efficiency, and the model can accurately predict the dynamic behavior of the electric vehicle. The study also analyzes the effects of different parameters, such as motor and battery capacity, on the vehicle's performance. Overall, the research findings are significant for the development of more efficient and environmentally friendly electric vehicles. M. Khajavi and M. T. Ameli, published in the IEEE Transactions on Vehicular Technology in 2011, presents a study on the performance of an electric motorcycle using computer simulations [3]. The study aims to develop a comprehensive model of an electric motorcycle that includes the motor, battery, controller, and vehicle dynamics. The simulations are performed utilizing diverse operational circumstances, including varying driving speeds and road inclinations, and the outcomes are compared to empirical information. The simulations provide a better understanding of the electric motorcycle's performance under different conditions. The study also analyzes the impact of different parameters, such as regenerative braking and motor controller parameters, on the motorcycle's performance. The results suggest that computer simulations can be a valuable tool for designing and optimizing electric motorcycles, especially in the early stages of development. The authors propose that further research can be conducted to explore the use of simulations for other types of electric vehicles and to refine the model used in this study to enhance its accuracy and reliability. The article by author Pardis Khayyer presents a new configuration for hybrid vehicles using fuel cells [4]. The author uses multiple downsized fuel cell power sources instead of a single power source and storage device. This configuration brings advantages in productivity and reliability in urban driving conditions. The article presents a proposed power management system and simulation results for a double fuel cell configuration, showing the predicted response of power sources. Efficiency curves for fuel cells are introduced and used for efficiency analysis, with the goal of achieving higher efficiency in urban driving cycles. The new configuration allows fuel cells to be loaded in their efficient region, resulting in a more fuel-efficient vehicle. Efficiency simulations show that efficiency is improved by about 27.3% in standard urban driving cycles compared to traditional configurations. Overall, this research presents a promising method for improving the efficiency and reliability of hybrid fuel cell vehicles. In this article, Josefa Morales and her research team analyzed the configuration of several converters in the powertrain system of a hybrid electric vehicle [5]. The use of electrical components was employed in designing this setup. The C-CM model concluded that the appropriate selection of powertrain system cells and control units depends on the load and power of the vehicle. This model was tested in a vehicle case study, which included two different terrain scenarios: CITY and ECE. The findings indicated that the key variables of C-CM were primarily reliant on the state of charge of the cells and control units before assessing various operational situations. To summarize, all configurations resulted in identical energy consumption in the case of CITY II, contemplating the level of charge in the cells. However, in the case of ECE, C-UC/B consumed less energy than CB/UC and C-CM. The variations between configurations were negligible, and thus any configuration could be chosen. In addition, the researchers compared C-CM's autonomy to that of C-UC/B and CB/UC. The two driving cycles caused C-CM to have a poorer performance than the other configurations, as evidenced by the results. In the case of CITY, the autonomy difference between C-CM and CB/UC configurations was not significant. However, in the case of ECE, CB/UC had better performance than CB/UC in the same situation. Ravi Prakash, Mohammad Junaid Akhtar, R.K. Behera, and S.K. Parida introduces a basic design for a propulsion motor, using traditional methods and the RMxprt software [6]. The research indicates that the theoretical findings and simulation outcomes are in agreement, and as the slot width is amplified, the torque also rises. The authors utilized a genetic algorithm in order to enhance the performance of the conventional motor design. The results show improvements in efficiency and power of the motor. The article proposes further research and development on optimal parameters such as torque to weight ratio, efficiency, etc., to achieve higher performance propulsion motors in the future.

Based on some studies on simulating the performance of electric vehicles, we have found that most studies focus on batteries and motor control to enhance the efficiency of the vehicles. However, among the factors affecting the efficiency of the vehicles, transmission ratio and wheel radius are also very important. The goal of this study is thus to investigate the impact of transmission ratio and wheel radius on the performance of electric vehicles through a simulation model.

METHODOLOGY

Input parameters

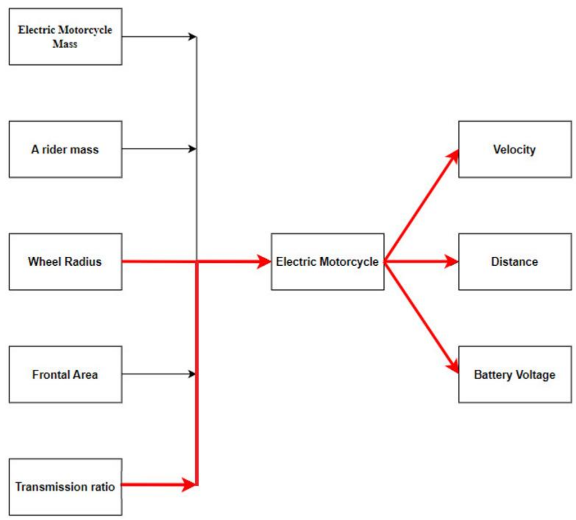


Figure 1. Flowchart showing the effective parameters of an Electric Vehicle

The electric motorcycle's performance is influenced by vehicle mass, rider mass, wheel radius, front bumper area, and gear ratio. This research aims to investigate the impact of modifying the gear ratio and wheel radius on the electric motorcycle's speed, distance traveled, and power consumption.

Electric motorbike model

In Figure 2, the diagram depicting the forces acting upon an electric motorcycle is displayed, which forms the foundation for simulating the motorcycle's dynamics.

The acceleration of an object, as per Newton's second law, can be expressed as:

$$F = m\frac{dv}{dt} = ma$$

Using Newton's Second Law, analyze the motion of an electric motorcycle that is described by:

$$F_{pf} - \left(F_{sf} + F_{wf} + F_{rf}\right) = M\frac{d^2x}{dt^2} = Ma \quad (1)$$

Where: F_{pf} the propulsion force; F_{sf} the opposition force from slope. $F_{sf} = MgC_s$, F_{wf} the opposition force from wind, $F_{wf} = \frac{1}{2} A_{fa}C_a\rho(v_w + v_{EM})^2$, F_{rf} the rolling resistance force $F_{rf} = gMC_{rr}\cos a$

Where:

A_{fa} : Frontage area (m^2)

C_a : The coefficient of aerodynamic drag

ρ : Air density, kg/m^3

v_w : Wind speed, km/h

v_{EM} : Electric motorcycle speed, km/h

g : Gravity force, m/s^2

C_{rr} : Rolling opposition coefficient

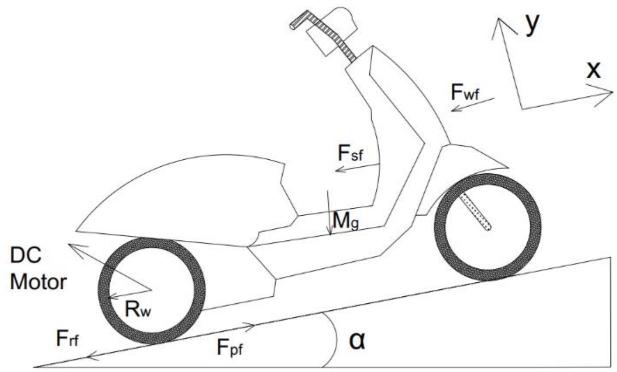


Figure 2. The distribution of acting forces

The DC motor shown in Figure 3 is used to power the electric scooter when it is in operation. The power source for the DC motor comes from the Li-ion battery, which generates the necessary thrust. The torque can be determined using the following equation:

$$T_p = F_{pf} R_w \tag{2}$$

Where: T_p propulsion torque, R_w wheel radius.

$$T_p = \gamma T_m \tag{3}$$

Where γ transmission ratio, T_m Torque of motor (Nm)

The torque can be calculated by combining equations (2) and (3) in the following way:

$$F_{pf}.R_w = \gamma T_m \tag{4}$$

Figure 3 shows the DC motor model in continuous-time.

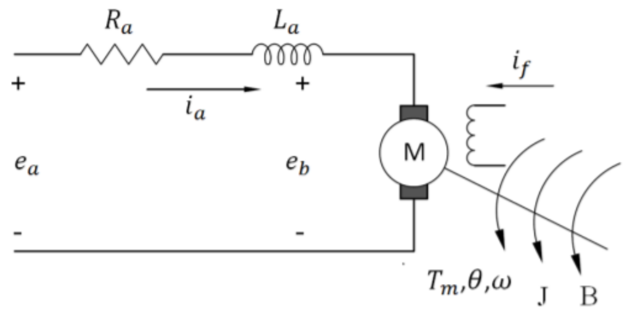


Figure 3. DC motor model

The relationship between time, voltage, and torque of the motor is shown in equations (5) and (6).

$$L_a \frac{di_a}{dt} + i_a R_a + E_c = K_a u \tag{5}$$

$$\int \frac{dw_m}{dt} + B_1 w_m = T_e - T_m \tag{6}$$

Where

L_a (Inductance of the motor) (H)

K_b (Electromotive constant)

K_a (Motor gain)

u (Input voltage) (V)

J (Motor moment of inertia) (N.m)

T_e (Torque generated)

E_c(EMF back side)

$B1$(Coefficient of friction of the electric motor)

T_m(The motor torque) (N.m).

R_a(Motor resistance)

t (Time) (s)

The DC motor has two variables, armature current as the electrical variable, and speed as the mechanical variable. The speed is proportional to the E_{mf} return (E_c), while the torque generated (T_e) is proportional to the armature current.

$$E_c = K_b w_m \tag{7}$$

$$T_c = K_b i_a \tag{8}$$

Equations (9) and (10) can be derived by combining equations (5) through (8), which represent illustrates the motor's electrical and mechanical characteristics.

$$L_a \frac{di_a}{dt} + i_a R_a + R_b w_m = K_a u \quad (9)$$

$$\int \frac{dw_m}{dt} + B_1 w_m + T_m = K_b i_a \quad (10)$$

The propulsive force can be obtained by combining equations (4) - (10) as shown below:

$$F_{pf} = \frac{1}{R_w}\left[\frac{K_b K_a}{R_a} u - \frac{K_b L_a di_a}{R_a dt} - \int \frac{dw_m}{dt} - \left(B_1 + \frac{K_a K_b}{R_m}\right) w_m\right]$$

Electric motorbike's performance model

The gross power is employed to aid cyclists and electric scooters in overcoming air resistance, inclines, and rolling friction

$$P_{total} = P_{air} + P_{slope} + P_{friction} \quad (11)$$

Here, P_{air} is the power needed to overcome air resistance. The following equation can be used to calculate this power:

$$P_{air} = \frac{A_{fa} C_a \rho (v_w + v_{EM})^2}{2} v_{EM} \quad (12)$$

The power necessary to surmount slope resistance (P_{slope}) can be calculated using the formula below:

$$P_{slope} = MgC_s v_{EM} \quad (13)$$

The power necessary to surmount rolling friction can be calculated using the formula below:

$$P_{friction} = gMC_{rr} \cos a v_{EM} \quad (14)$$

Battery model

The DC motor of the electric scooter is powered by a Li-Ion battery. During operation, the battery transfers power to the motor as it discharges. According to [25], the voltage of a discharging Li-Ion battery can be expressed as:

$$v_b = E_0 - \frac{KQ}{Q - i_{(t)}}(i) - R.i + Ae^{(-B.i(t))} - \frac{KQ}{Q - i_{(t)}} i^* \quad (15)$$

Where

E_{0}(Constant voltage of battery) (V)

K(Polarization Constant) (V/Ah)

Q(Battery capacity) (Ah)

R(Internal resistance)

i(Current) (A)

Table 1 of this research presents the simulation case studies carried out on the electric scooter using different wheel radius and transmission ratios.

Table 1. Wheel radius and transmission cases study

Speed	**Wheel radius (m)**	**Transmission ratio (γ)**
Case 1	0.1	3
Case 2	0.12	3.638
Case 3	0.15	3.954
Case 4	0.2	4.271
Case 5	0.25	4.587

RESULTS AND DISCUSSION

Matlab/Simulink can be utilized to evaluate the performance of electric motorcycles, based on the mathematical model.

The process of simulating an electric vehicle model involved using several modules, such as those in Figure 4.

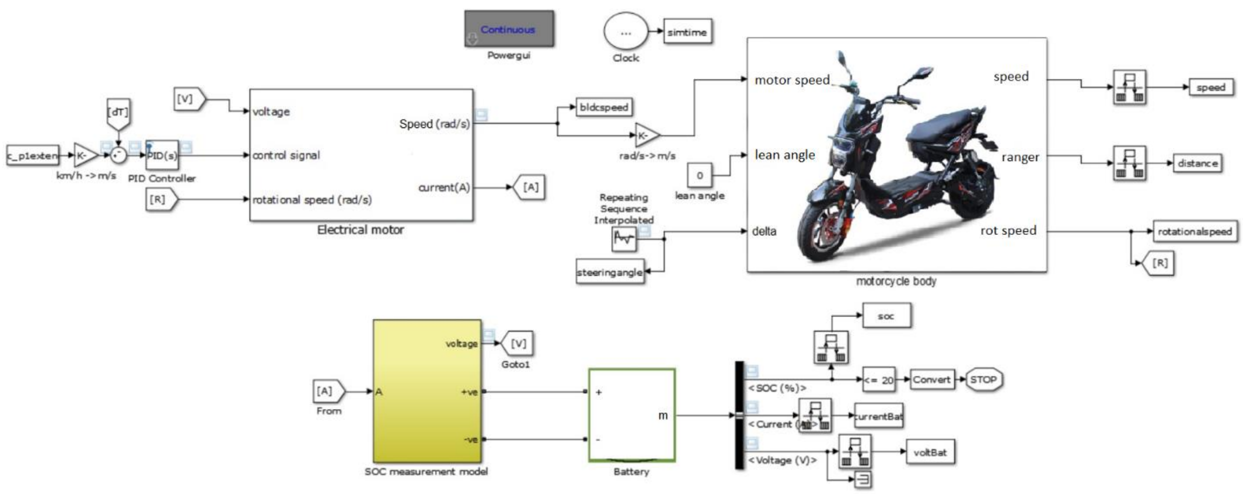
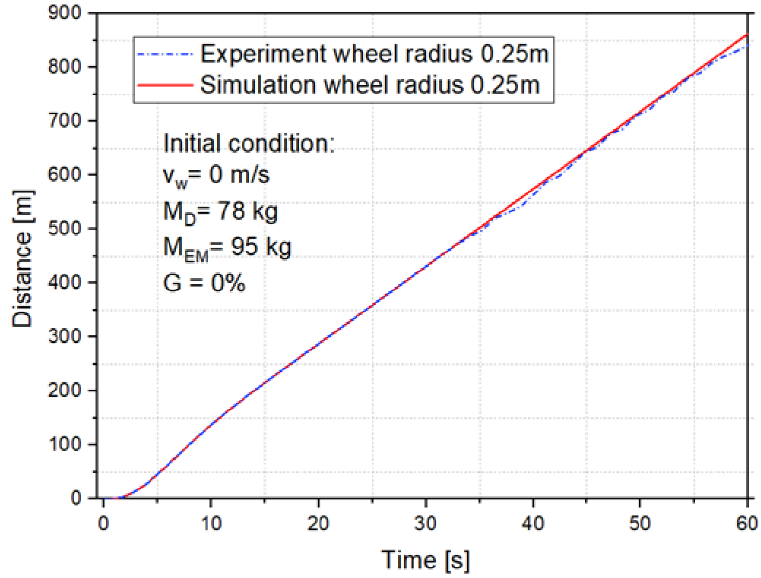


Figure 4. Simulation Electric vehicle model.

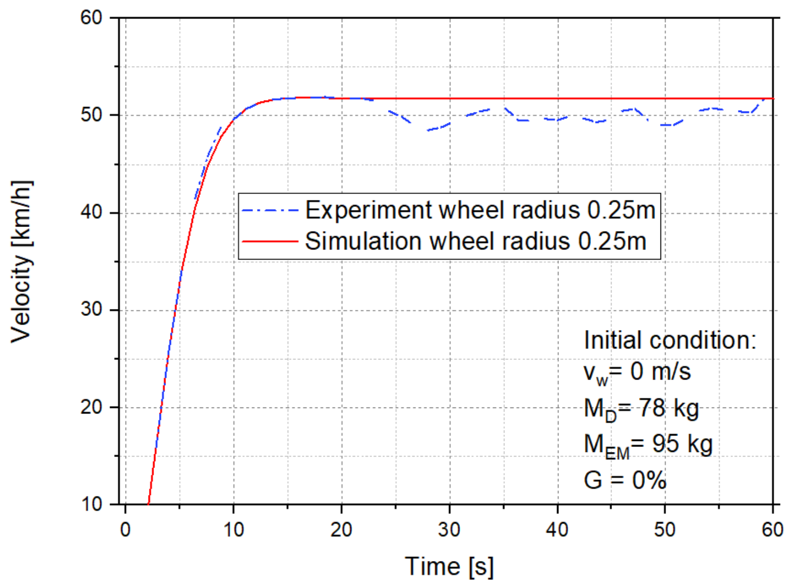
Table 2. The specification of the testing vehicle

The specifications of a vehicle	
Weight	95kg
Electric motor power	1400w
Traveled distance/ 1charge	100 km/ charge
Size (DxRxC)	1780 x 730 x 1109 mm
Max speed	40-55km/h
Driver's meter	LCD Led Backlit 4.5”
Wheel	10” / 10”

The simulation model was validated based on the experimental results.



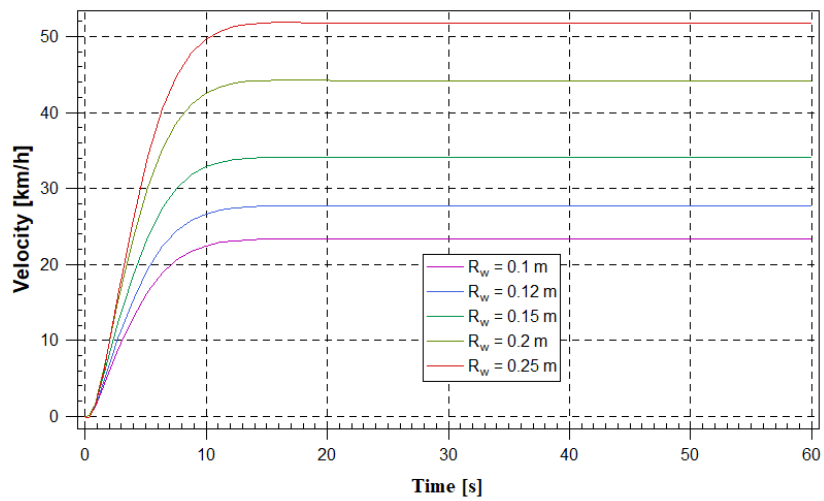
5a)



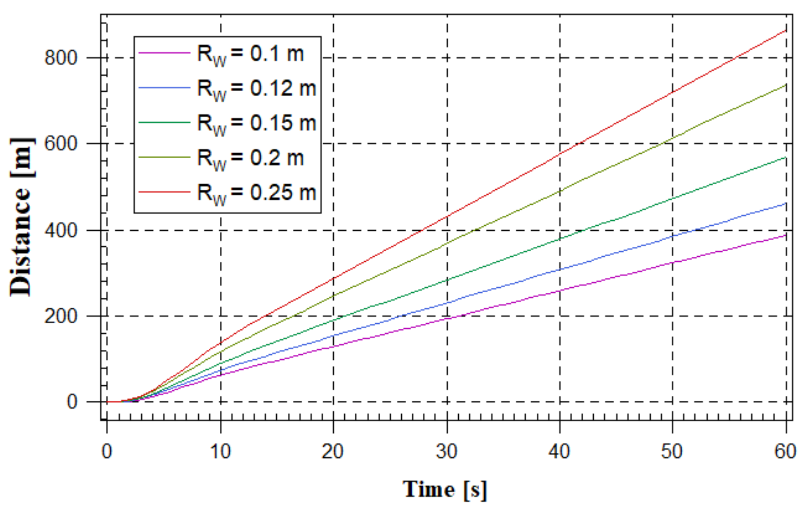
5b)

Figure 5a and 5b: Comparison of the simulation results and the experimental results in traveled distance and vehicle velocity

The experiment was conducted under specific conditions, which included a rider with a mass of 78 kg, an electric motorcycle with a weight of 95 kg, no wind speed, and a slope of 0%. The vehicle was able to run within 60 seconds, as evidenced by Figures 3a and 3b, which show the comparison of the simulation results and the experimental results in traveled distance and vehicle velocity. The results of the comparison between simulation and experiment show that the distance traveled by the vehicle is almost the same, while the biggest difference in speed is 4.3% at 28^{th} seconds. This difference between simulated and experimental values is completely acceptable because the experimental recorded values are average values. The comparison results between the simulations have demonstrated the reliability of the simulation model, which can be used for further studies.



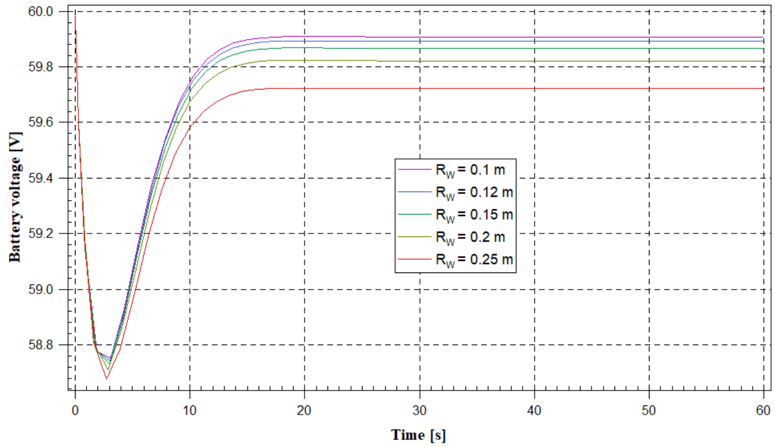
a)



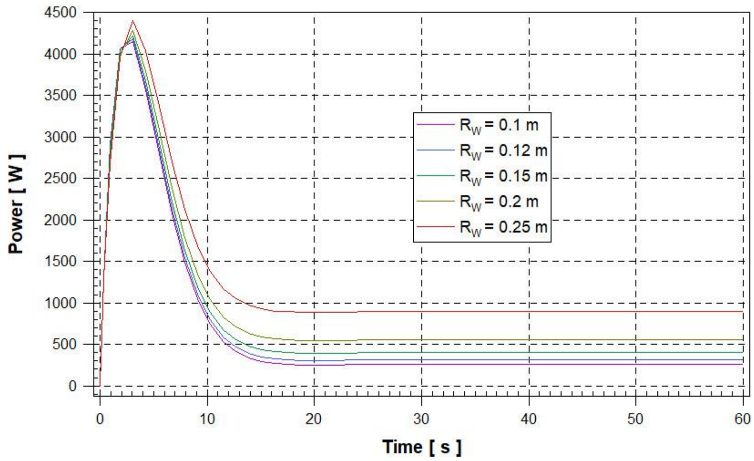
b)

Figures 6a and 6b. Illustrate the impact of wheel radius on velocity and distance traveled

As seen in Figures 6a and 6b, the vehicle speed and distance traveled can all be visualized as functions of wheel radius in the simulation results. By increasing the wheel radius from 0.1 to 0.25 m, the maximum speed increases from 23 to 52 km/h. This phenomenon is attributable to the increase in rotational inertia caused by the larger wheel radius. In turn, the increase in velocity results in a greater distance traveled, from 400 to 850 m after 60 seconds of simulation time.



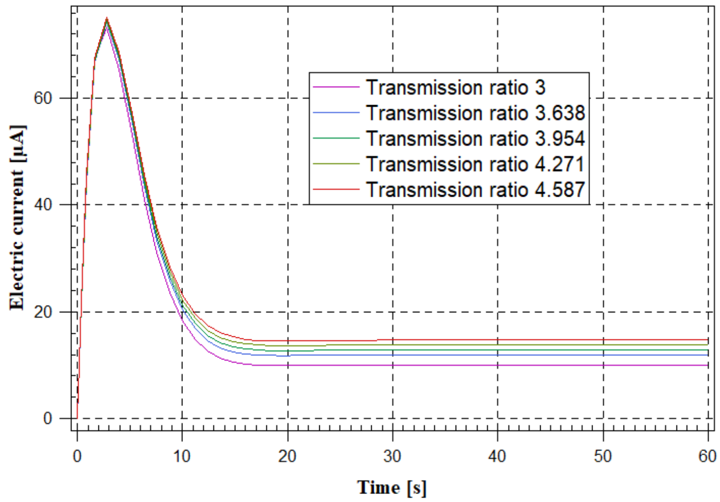
c)



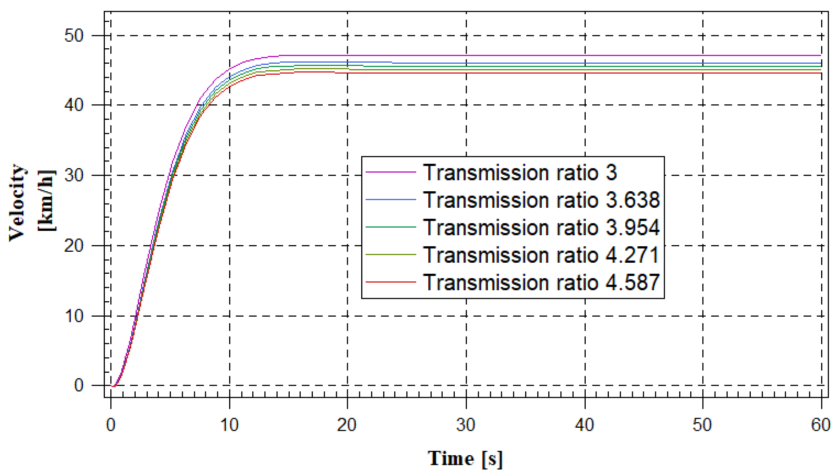
d)

Figure 6c and 6d. illustrate the impact of wheel radius on batery voltage and power

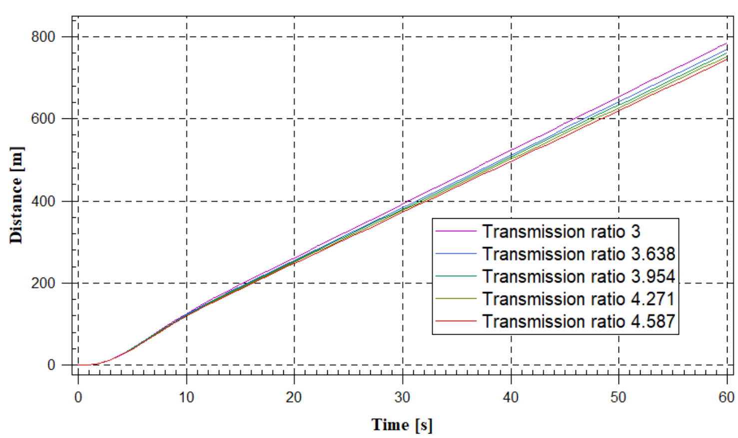
An increase in wheel radius resulted in a rise in the necessary propulsion torque, and higher velocity led to a greater load on the motor, resulting in greater energy requirements for the motor and consequently higher electricity consumption. This can be seen in the decrease in battery voltage (Figure 6c) and increase in engine power consumption (Figure 6d). By increasing the wheel radius from 0.1 to 0.25 m, the batery voltage decreases 0.34% while the power increases 133%.


Transmission ratio 3
Transmission ratio 3.638
Transmission ratio 3.954
Transmission ratio 4.271
Transmission ratio 4.587
Electric current [µA]
Time [s]
0
20
40
60
0
10
20
30
40
50
60

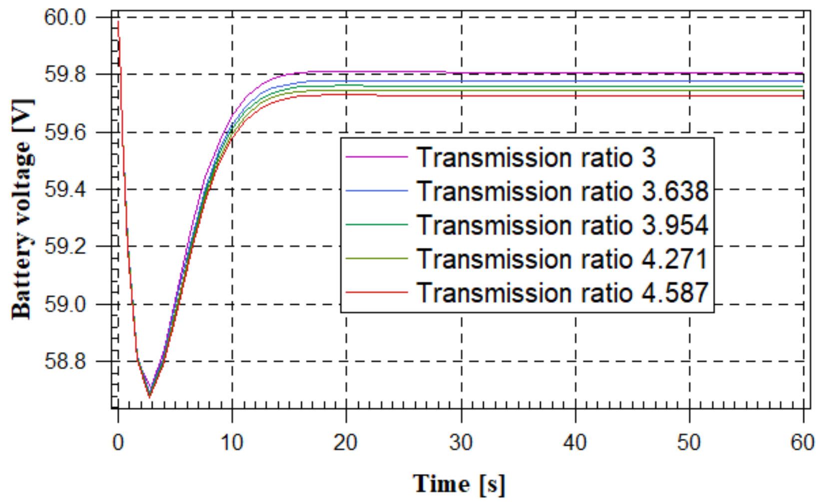
a)


Transmission ratio 3
Transmission ratio 3.638
Transmission ratio 3.954
Transmission ratio 4.271
Transmission ratio 4.587
Velocity
[km/h]
Time [s]
0
10
20
30
40
50
0
10
20
30
40
50
60

b)


Transmission ratio 3
Transmission ratio 3.638
Transmission ratio 3.954
Transmission ratio 4.271
Transmission ratio 4.587
Distance [m]
Time [s]
0
200
400
600
800
0
10
20
30
40
50
60

c)



d)

Figure 7. Effect of transmission ratio on output parameters

The results of the simulation for speed, distance covered, power used, and thrust torque in relation to the transmission ratio are depicted in Figure 7.

Figures 7a and 7b depict how changes in the transmission ratio affect speed and distance traveled. Increasing the transmission ratio causes a decrease in both speed and distance traveled. At a transmission ratio of 2.66, the highest speed and distance traveled are 70.7 km/h and 710.44 m, respectively, while at a transmission ratio of 4.94, they are 30.74 km/h and 303.12 m. The relationship between thrust and transmission ratio explains this pattern, as an increase in thrust leads to an increase in the electric motorcycle's speed. Figure 7c demonstrates the impact of the transmission ratio on power consumption. As the transmission ratio is raised from 2.66 to 4.94, power consumption increases by 0.16%. An increase in transmission ratio necessitates more thrust, which leads to a heavier load on the motor and an increased power demand.

CONCLUSION

The study demonstrates the high effectiveness of using Matlab and Simulink mathematical models and simulations for both research and practical applications. The manipulation of input parameters, such as wheel radius, allows for the optimization of dynamic performance and power consumption in electric motorcycles. Results show that increasing the wheel radius from 0.1 to 0.25 leads to a rise in maximum speed from 23 to 52 km/h and an increase in travel distance from 400 to 850 m after 60 seconds of simulation time, albeit with a higher power consumption. Similarly, an increase in the transmission ratio from 2.66 to 4.94 results in higher speed and distance traveled from 30.74 km/h to 70.7 km/h and from 303.12 m to 710.44 m, respectively, with a corresponding increase in power consumption by 0.16%.

In conclusion, the study suggests that modifying the transmission ratio and wheel radius using Matlab and Simulink models is a feasible approach for enhancing the dynamic performance and minimizing power consumption in electric motorcycles.

Acknowledgement

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