International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
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IJIEMR Transactions, online available on 10th Apr 2023. Link :http://www.ijiemr.org/downloads.php?vol=Volume-12&issue=Issue 04

10.48047/IJIEMR/V12/ISSUE 04/74

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Volume 12, ISSUE 04, Pages: 605-612

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E-Bike Dynamics Using Regenerative Braking in MATLAB

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Abstract

The use of light electric bikes is becoming more and more common as people become more concerned about pollution, traffic, and energy use. E-bikes have distinguished themselves among these vehicles as a practical, user-friendly solution with a compact design. These vehicles include electric motors and batteries for propulsion and come in a variety of shapes, from large models that resemble gasoline scooters to smaller ones with bicycle-like designs. With top speeds averaging about 30 km/h and weights ranging from 30 to 80 kg, they all share comparable technology despite their variances in appearance. In order to examine numerous electrical characteristics in the output as graphs, the lightweight and effective drivetrain of e-bikes has been studied using MATLAB Simulink. Electric vehicles (EVs), which are already widely used, are the most significant invention of this decade. The amount of energy in the EB's internal battery determines how far it can travel. The capacity of EBs to recover energy while braking is a crucial characteristic. Braking force is generated by the brushless DC motor under control, and this braking energy is captured and stored in an ultra-capacitor. Reusing this stored energy will boost the system's effectiveness and driving power and range. The development of new, energy-efficient batteries, such Li-ion, is the subject of continuous research in the field of batteries.

Keywords: Kinetic Energy Recovery Systems, State of Charge Estimation, Power Electronics and Machine Modelling, Battery Model.

Introduction

Regulations on CO2 and other pollutant emissions have been tightened as concerns about global warming and environmental pollution have grown. In this context, electric bikes (EBs) have as a zero-emission option, electric bikes have emerged as a potential alternative to conventional automobiles. Furthermore, because electricity is less expensive than gasoline or diesel, EBs are easier to recharge than traditional vehicles. Furthermore, EBs allow for energy recovery from regenerative braking, which further reduces energy expenditures and utilisation. Due to their short range, lengthy charging times, high cost of battery replacement, and other infrastructure-related restrictions, EBs are not yet widely used. The constrained EB range is one of these limitations that is particularly relevant to this study. Due to this restriction, drivers experience a problem known as "range anxiety," which is the worry that they will run out of fuel while driving. The problem of range anxiety, or the worry of running out of energy before arriving at the destination, is one that affects electric bikes (EBs). Increasing battery capacity and/or the quantity of charging stations can solve this problem. These options, though, can be pricey and may not increase drivers' trust in estimates of their remaining driving range. Since range estimators are primarily based on previous data, which results in estimating mistakes that cannot be entirely trusted by drivers, accuracy is a big challenge. To lessen range anxiety, it is therefore vital to improve range estimation. This study's main goal is to precisely calculate EV energy usage in order to improve range estimates and boost drivers' trust. The energy flow between the car and the grid is not taken into account in this study; instead, the emphasis is on the energy flow within the vehicle. An electric bike's (EB) typical energy consumption consists of three parts: the energy needed to move the vehicle forward at the wheels, the energy lost throughout the powertrain, and the energy required to power auxiliary devices. The overall amount of energy used by the EB is comprised of these three parts. As this can assist minimise "range anxiety" and boost driving range, electric bike (EB) makers are continuously looking for innovative approaches to improve the accuracy of energy consumption and range estimation. Drivers may be able to use their EV for longer on a single charge by giving them more assurance about the range of their car. Due to their lack of faith in the range of their EB, many drivers currently only use about 70% of the estimated remaining battery energy. To encourage a wider usage of EBs, increasing the accuracy of energy consumption and range estimation may be essential.

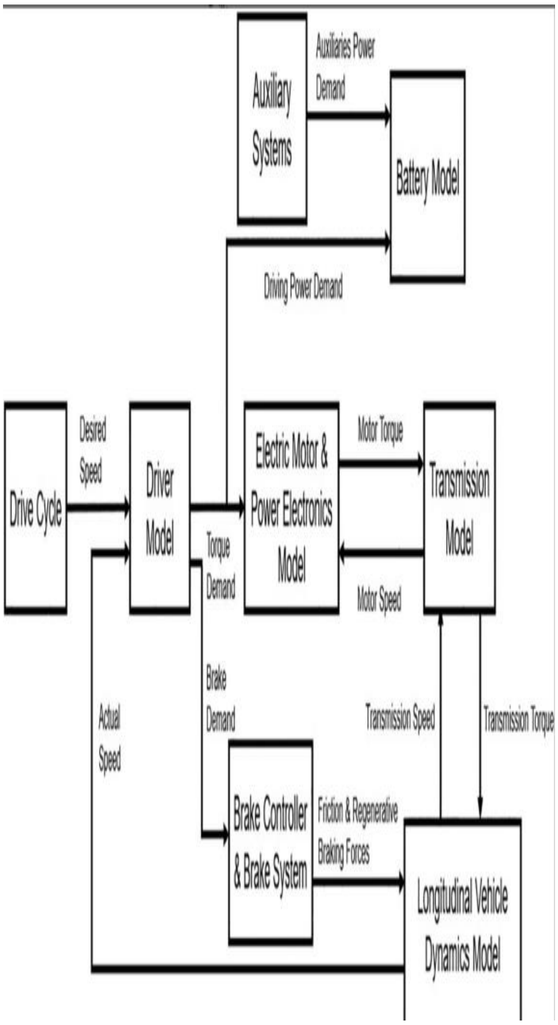


Fig. 1. Description

Bike Model

In particular, by simulating the powertrain system and longitudinal vehicle dynamics, this work aims to estimate the energy consumption of electric bikes (EBs). The model neglects lateral dynamics as it has a minimal impact on energy consumption. The model takes into account three main power flows: power from the battery pack to the wheels, power from the wheels to the battery pack during regenerative braking, and power from the battery pack to the 12V battery-operated auxiliary systems. The car model was created using MATLAB/Simulink and has a number of subsystems, one of which is the driving cycle subsystem. and controller for distributing braking force and torque between friction and regenerative brakes, an electric motor and inverter model that determines energy losses based on motor and inverter efficiency, a transmission model that takes energy losses into account while transmitting torque from the motor to the driving wheels, a driver model that controls the vehicle motion through accelerator and brake commands.

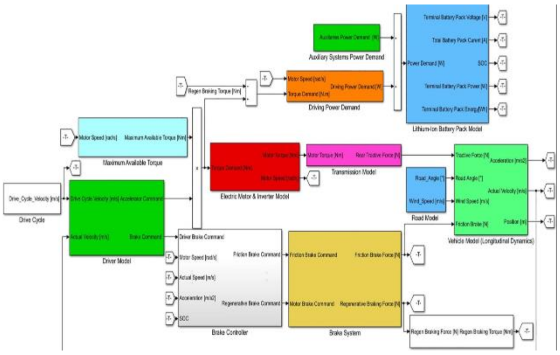


Fig.2. Description

Driver Model

The driver model aims to simulate a human driver's behaviours as accurately as possible, which is difficult because it contains arbitrary elements like the driver's emotions and physical health. This study employs a streamlined driver model that aims to reduce the error (V) between the desired and actual vehicle speeds during the drive cycle. In order to maintain the reference speed profile, the driver model generates commands for accelerating or braking based on the sign of V. In the event that V is positive, the driver model provides an acceleration command (DA), instructing the driver to depress the accelerator pedal to increase the speed of the car. The driver has two possibilities when the brake command (DB) is generated by the driver model if V is negative. They can either depress the brake pedal to use the friction brakes to slow down the car or they can depress the accelerator pedal just to use dynamic braking. The driver's braking technique will determine which of these two possibilities they choose. The driver controller and the accelerator and brake instructions are the two subsystems that make up the driver model that was presented in this study. Due to their widespread use and ease of installation, PID controllers are frequently employed in industry to construct the driver controller. Additionally, earlier research has shown that PI controllers are frequently used in driver modelling.

$$PI(S)=(P+I(1/S))$$

Regenerative Braking Strategy

Kinetic energy recovery system is another name for this type of regenerative braking. In electric automobiles, dynamic braking enables battery recharging while the car is moving. The maximum available braking force, XBMAX, must be ascertained in order to compute the required braking force needed to slow the vehicle. The usual load placed on the vehicle and the degree of tyre adhesion to the road surface both have an impact on this figure. In order to calculate the precise amount of braking force needed for the vehicle, it is crucial to consider these parameters.

$$X_{BMAX}=K(Z_f+Z_r)=K(M_{vehicle}.g)$$

In the suggested EB model, friction and regenerative brakes each provide a certain amount of braking power. The following formula can be used to determine the braking force:

Braking force = (μ * (Zf + Zr) * g) +: μ is the adhesion coefficient (regenerative braking force)

where between the tyres and the road, with typical values around 0.8 on dry or wet asphalt and concrete surfaces. Z_f and Zr are the normal loads on front and rear axles in Newtons (N), respectively.

M Vehicle is the vehicle mass in kilograms (kg).

g is the acceleration due to gravity in meters per second squared (m/s^2).

The braking force produced by the electric motor working as a generator to transform the kinetic energy of the vehicle into electrical energy that can be stored in the battery is known as regenerative braking. The electric motor's power output and the effectiveness of the energy conversion process determine the regenerative braking force. The amount of braking force applied by the wear and tear and regenerative brakes is determined by the road's conditions and the battery's level of charge. In general, lower speeds and higher states of charge are when friction braking is most effective, whereas higher speeds and lower stages of charge are when regenerative braking is most successful. The EV model's control system continuously modifies the amount of braking force applied by the vehicle's friction and regenerative brakes to maximise both their overall effectiveness and the vehicle's energy efficiency.

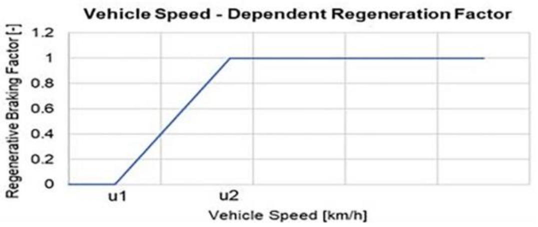


Fig.3.a.Graph

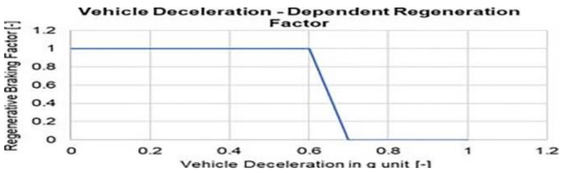


Fig.3.b.Graph

The suggested electric vehicle (EV) model uses a series brake system to achieve regenerative braking in order to overcome the aforementioned restrictions.

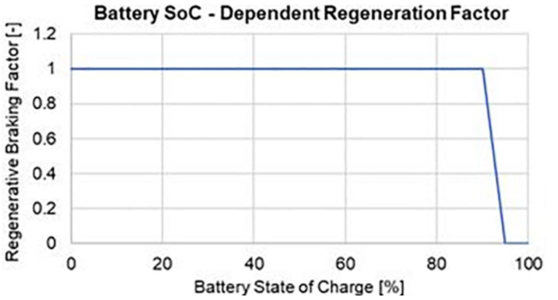


Fig.3.c.Graph

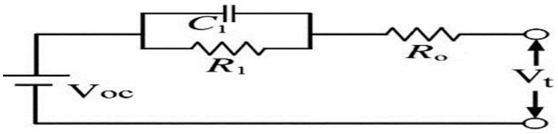
Power Electronics and Machine Model

The electric motor and power electronics subsystems of the recommended EV vehicle are the main emphasis of this section because of how much their effectiveness impacts total energy usage. Power electronics energy losses raise the amount of battery energy needed to power the electric motor and lower the amount of energy recovered during regenerative braking. Since the study does not take into account the energy loss between the grid and the EV battery, the onboard charger is not taken into account in this model. hus, in this study, only the inverter and converter are modelled. A 2D lookup table based on the Simulink-computed BMW i3 inverter efficiency map presented in Figure 2 is used to calculate the inverter's efficiency. Its efficiency is presumed to be 90%, which is the average efficiency of DC/DC converters, because there was no precise information regarding the converter technology used in the hero bike that was made accessible to the general public. The model must take into consideration the motor torque in Nm, motor speed in rpm, and motor efficiency in order to calculate the vehicle's energy consumption with accuracy. The electric machine model takes the torque requirement as an input and output torque from the motor, accounting for motor and inverter efficiencies. The driver model is used to calculate the torque demand (T Dem).

$$T_{Dem}=T_{Max}.D_{A}$$

Battery Model

The two main energy storage systems in e-bikes are a high voltage lithium-ion battery pack that powers the bike and a low voltage system. supplementary device battery powered by lead acid. In order to accurately calculate the high voltage battery pack's operating voltage and State of Charge (SoC), this section models the dynamic charging and discharging characteristics of the battery. Both batteries' efficiency when charging and discharging are taken into account because they have an impact on how much energy the electric car uses. It should be noted that the literature assumes that the Li-ion and Lead Acid battery packs have charging and discharging efficiencies of 95% and 80%, respectively.



$$V_t=V_{OC}-R_O.I_L-V_1$$

The current integration approach, commonly called as "Coulomb counting," is used in Equation to update the battery SoC at each time step. This method is highly helpful and accurate, even though it cannot be used in a practical application (due to measurement noise, etc.) in simulation environment. The most common method for determining a battery's state of charge (SoC) is Coulomb counting, a current integration technique involving Equation. This formula accounts for a number of variables, including the battery's starting state of charge (SoC0) in percentage (%), a single cell's capacity (C cell) in ampere-hours (Ah), and a single cell's current demand (I Cell, dem) in amperes. (A). This method is still helpful for precisely modelling and simulating battery behavior, even though it is not always appropriate in real-world applications because to things like measurement noise.

MATLAB Implementation

In comparison to the real result from testing, the simulation model depicts a higher vehicle energy consumption when auxiliary devices are used. This might be because the study overestimated the auxiliary load, which was less than During the NEDC test, 300W. Additionally, since the estimation is dependent on the power usage of commonly used auxiliary equipment, which may be different for the hero bike. The difference between simulation and experimental results for EPA cycles, on the other hand, is greatly reduced when auxiliary devices are included in the model, going from 10.6% to 1.1%, increasing the model's accuracy. This is due to the fact that several auxiliary devices, such air conditioning and lighting, are used throughout EPA cycles, and presuming that they are off causes major inaccuracies between simulation and experimental results.

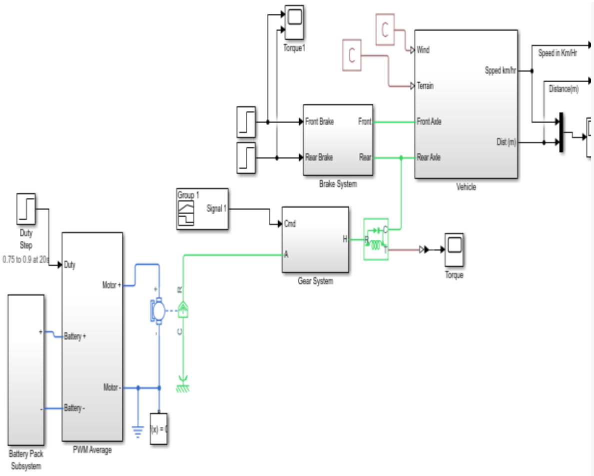
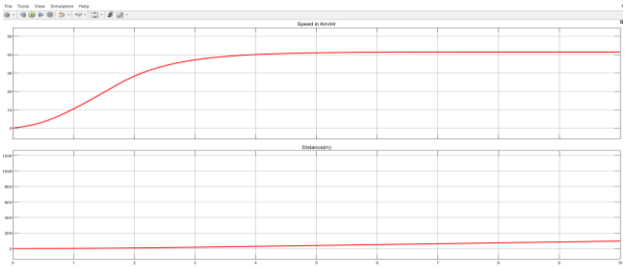
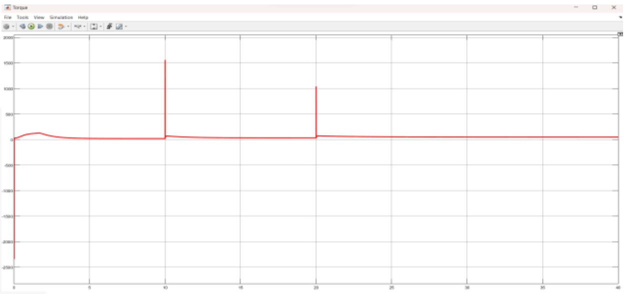


Fig.4.Matlab Diagram



Time period(S)

Fig.5.a. Results



Time period(S)

Fig.5.b. Gear Torque(N-m)

Prereqisites

For this project, we need to understand MATLAB from the ground up, as well as the various types of electrical drives that are sold today, their benefits and drawbacks, as well as information on electrical motors and gears.

Conclusion

The main goal of this study was to develop an accurate computer model that can calculate how much energy an electric car will need during a specific driving cycle. The BMW i3 was selected as a case study to show how well the model works. Using MATLAB/Simulink, a forward vehicle simulation model that incorporated the powertrain system and longitudinal vehicle dynamics was created. To ensure accuracy, the electric motor and inverter's accurate efficiency maps were used in the powertrain model. Thevenin equivalent circuit battery modelling was used to assess and simulate the entire powertrain system in this study, including the gearbox and battery. In longitudinal vehicle dynamics, the model also took into account the forces that oppose the motion of the vehicle. A regenerative braking strategy was presented to divide the braking torque requirement between the friction and regenerative brakes based on the behaviour of a real braking controller, and a driver model utilising a PI controller was constructed to regulate the vehicle's speed. The power consumption of the auxiliary devices was calculated using typical values taken from the literature to increase model accuracy. Using data that was made accessible to the public by BMW and other dependable sources from the literature, the model was validated. The originality of this study comes from the consideration of auxiliary device power usage, which has a big impact on energy consumption. The proposed model from this study could be used in the future as a basis for calculating the range of electric vehicles. The model should be improved by including more information on the state of the roads, such as traffic and weather, in order to accomplish this goal. Additionally, taking into account the battery's state-of-charge (SoC) and state-of-health can help the model's battery efficiency and energy usage. (SoH). The performance of the battery is significantly influenced by these variables. The accuracy of the model can further be increased by figuring out and incorporating the inertia of the vehicle's rotating parts, such as the wheels, brakes and rotor.

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