**Modeling and Simulation of Electric Vehicles: An Approach Using MATLAB**

***Tevfik ATAMAN1,[[1]](#footnote-1)\*[C:\Users\Abdullah\AppData\Local\Microsoft\Windows\INetCache\Content.Word\ORCID-iD_icon-16x16.gif](https://orcid.org/my-orcid?orcid=0000-0003-1346-5651)***

*1 Vocational School, Machine and Metal Technologies, Çankırı Karatekin University, Çankırı, Türkiye*

|  |
| --- |
| **Abstract**  Electric vehicles (EVs) are becoming progressively pivotal in the automotive sector owing to environmental issues and the necessity to diminish reliance on fossil fuels. This research centers on the modeling and simulation of an electric vehicle system with MATLAB/Simulink. The essential elements of electric vehicles, such as the battery, electric motor, power converter, and vehicle dynamics, are examined and modeled comprehensively. Lithium-ion batteries were selected for the battery module during the modeling process, focusing on charge-discharge characteristics and energy density. A permanent magnet synchronous motor (PMSM) was chosen as the electric motor, and its torque-speed relationship was dynamically modeled. Vector control algorithms were employed for motor control in the power converter. The vehicle dynamics model was developed to incorporate external elements such aerodynamic drag, rolling resistance, and gradient forces on the vehicle. The simulation findings offered a comprehensive examination of performance metrics including acceleration, energy consumption, and battery longevity of the electric car. The adaptable architecture of MATLAB/Simulink facilitated the seamless incorporation of various driving scenarios and battery capacity into the model. This project seeks to enhance the advancement of sustainable transportation systems by providing an efficient simulation environment for evaluating the performance of electric vehicles. |
| Keywords: Electric vehicle, Energy consumption, Vehicle modelling. |

1. **Introduction**

The increase in the world population and the growth of the industrial branches continue to increase the need for production and increase the energy requirement. Today, most of the electricity needs are met by fossil fuels. After electricity generation, the oldest of fossil fuels is the transport and transportation sector, with the highest energy use growth rate [1].Internal combustion engines operating with petroleum derivative fuels can operate around 40% efficiency today, despite the development of engine technologies. Most of the energy released by the burning of the fuel is expelled as heat. One of the alternatives recommended for cleaner and more efficient road vehicles is the use of hydrogen as fuel. Since only water vapor is released as a result of its combustion, hydrogen-powered vehicles will be zero-emission vehicles. However, the lack of hydrogen in nature and the use of fossil fuels in its production, the low energy efficiency until the hydrogen is obtained from the source and transformed into the road traveled in the vehicle, and the high emissions in this general cycle are the biggest obstacles to fuel cell studies [2]. In hybrid electric vehicles, the battery is used as a buffer in power requirement regions where internal combustion engines operate with low efficiency and high emissions, increasing the average efficiency of the internal combustion engine throughout the driving Cycle [3].

Innovations brought by hybridization such as recovery of brake energy, stopping of internal combustion engines and power management allow more efficient use of energy in road vehicles and travel with lower emissions. Energy efficiency in the conversion of vehicles operating with various energy systems calculated by Toyota from energy source to motion energy is shown in Figure 1 [4].

metin, ekran görüntüsü, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu

**Figure 1.** Efficiency of vehicles operating with various energy sources from source to wheel.

As can be seen from Figure 1, the fuels with the highest efficiency in the transformations from the source of energy to the energy storage on the vehicle are petroleum derivative fuels. In hybrid electric and fuel cell vehicles, the efficiency on the vehicle is higher and therefore the total efficiency of these vehicles is higher than the vehicles operating with petroleum-based fuels. The increased need for electrical energy in vehicles for higher HEV efficiency, low emission high fuel economy, driving comfort and cruise safety has made hybrid electric vehicles an important need today [5].

1. **Materials and Methods**

Hybrid electric vehicles provide a reduction in fuel consumption and exhaust gas emissions compared to conventional vehicles with the advantages they provide such as engine downsizing, engine stopping while driving, recovery of brake energy and energy management. The biggest problem encountered after determining the power components and their relationship with each other in hybrid electric vehicles is that this complex system can be controlled in the best way. To develop HEV control algorithms, first of all, the mathematical model of the designed system must be established in accordance with the calculations to be made. In order to make distribution calculations between power systems in HEV systems, longitudinal vehicle dynamics models should be established. This project aims to mimic a hybrid vehicle using the Matlab Simulink module. The study identified motor power, motor torque, and design parameters (projected area and drag coefficient) as input variables.

**Vehicle Dynamics**

In the first step, the parameters shown in Table 1 were used to model vehicle dynamics. This table also includes abbreviations for total vehicle load modeling. With the help of these parameters, it is possible to calculate the load forces applied to the vehicle. Also, the results to be obtained with changes in these parameters will be evaluated [6].

**Table 1.** Vehicle body parameters.

|  |  |  |  |
| --- | --- | --- | --- |
| Abbreviation | Definition | Value | Unit |
| M | Mass | 1250 | Kg |
| g | Gravity | 9.81 | m/s2 |
| Α | Slope of road | - | ˚ |
| Ρ | Air density | 1.225 | kg/m3 |
| A | Vehicle frontal area | 1.7 | m2 |
| Cd | Drag coefficient | 0.3 | - |
| Cf | Friction coefficient | 0.02 | - |
| V | Vehicle speed | - | m/s |

* 1. **Vehicle Model**

HEVs can generally be classified into parallel HEVs and series HEVs based on their powertrain design. Parallel hybrid electric vehicles (HEVs) can be concurrently powered by an internal combustion engine (ICE) and an electric motor (EM). In a series hybrid electric vehicle (HEV), the propulsion system is exclusively driven by the electric motor (EM), which derives its energy from the onboard battery unit, charged by the vehicle's engine.

**ekran görüntüsü, diyagram, simge, sembol, tasarım içeren bir resim

Açıklama otomatik olarak oluşturuldu**

**Figure 2.** Configuration of the hybrid powertrain.

The powertrain design of the examined vehicle, featuring a single-shaft parallel hybrid layout, is seen in Fig. 2, which is often employed in numerous hybrid models. The automated machine transmission (AMT) is essential for optimizing the operational parameters of internal combustion engines (ICE) and electric motors (EM) to function within their respective high-efficiency ranges. The EM might function as a generator while recharging the battery. The clutch may be utilized to alter the operational modes of the powertrain, including EV mode, engine-drive mode, hybrid drive mode, and regenerative-brake model [6].

In this model, the speed profile that the driver must follow is given to the driver modeled with PI (proportional-integral), the driver model tries to reduce the error between the actual speed and the determined speed profiles by generating throttle, brake and clutch signals according to the actual vehicle speed. For any given cycle, the road forces corresponding to the vehicle speed are calculated, the loads on the wheels and the speed values are calculated backwards through the transmission organs, and the torque values that the motors must give with the rotation speeds are determined. All vehicle models created were prepared in MATLAB/Simulink environment (Figure 3).

**diyagram, teknik çizim, plan, şematik içeren bir resim

Açıklama otomatik olarak oluşturuldu**

**Figure 3.** MATLAB/Simulink vehicle model.

Travel loads affecting the vehicle are calculated. These travel loads consist of wind resistance, rolling resistance in the wheels, braking and acceleration resistances and slope resistance. Travel resistances affecting the vehicle are given in Figure 4.

**diyagram, taslak, çizgi, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu**

**Figure 4.** Forces acting on the vehicle.

* 1. **Rolling Resistance**

While the vehicle is in motion, rolling resistance acts on the wheels slightly in front of the wheel-road contact plane due to its elastic structure. A standard formulation was used to calculate the rolling resistance in the studies [6].

Rolling resistance arises from the tire's deflection during rotation on the road, resulting in a larger distribution of normal pressure in the leading half of the contact interface compared to the trailing half. Consequently, the horizontal corresponding force is generated at the interface between the tire and the road, referred to as rolling resistance. Rolling resistance is influenced by various characteristics, notably tire shoulder temperature, ambient temperature, tire diameter, road conditions, tire inflation pressure, and tire type. Numerous empirical relationships are established for the rolling resistance coefficient as a function of velocity for different tire types and road conditions. The rolling resistance of each wheel can be computed using the following formulae:

(1)

* 1. **Grade Resistance**

Simple trigonometric calculations are used in the calculation of the grade resistance affecting the vehicle. This calculation is shown in equation 2.

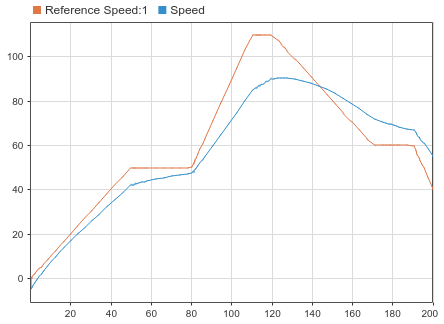
(2)

1. **Results and Discussion**

The vehicle dynamics model was developed, and a Simulink model was created in the preceding section. The simulation results are derived by delineating several scenarios. The schematic diagram of the Simulink blocks, which includes the vehicle model, front wheels, rear wheels, and traction force, is depicted in the preceding drawings. The velocity of each wheel and the vehicle's overall velocity are computed at each time step during the simulation. The velocity determined by each block is input into the slip computation block to derive the slip corresponding to each wheel. These blocks compute the slip amount for each wheel using the equations, and these values are subsequently utilized by the traction force block to determine the longitudinal effective force, which is the force generated at the tire-road interface at the contact point that propels the vehicle forward. The orientation of this force alters during brake application, countering the vehicle's motion.

Owing to the dynamics of the brake model described, the velocity of the vehicle and each wheel reaches zero simultaneously. To assess the model's performance in scenarios where the vehicle comes to a halt and subsequently resumes movement, a test was conducted by simulating the conditions defined by the throttle opening position and brake pedal engagement.

Changes in vehicle speed were observed by entering different Cd and different Cf values. The relationship of these changes with other parameters and the changes of the change were evaluated.

****

**Figure 5.** Cd = 0.75 situation.

**çizgi, öykü gelişim çizgisi; kumpas; grafiğini çıkarma, diyagram, metin içeren bir resim

Açıklama otomatik olarak oluşturuldu**

**Figure 6.** Cf = 0.04 situation.

1. **Conclusion**

This project aims to model a hybrid vehicle using the Matlab/Simulink module. In the analysis, rolling resistance, traction force, grade resistance, and design characteristics (frontal area and drag coefficient) were identified as input values. The study aims to determine the fuel consumption, specific fuel consumption, vehicle speed, and aerodynamic resistance parameters of a hybrid vehicle.

These inferences can be made by looking at real-time speed values compared to the reference speed. By looking at the changes in Cd and Cf values, optimization should be made to approach the reference speed values.

**References**

1. Guzzella L. and Sciarretta A., 2007, Vehicle Propulsion Systems:Introduction to Modeling and Optimization, Springer Science & Business Media, Berlin.
2. Boyalı A. and Güvenç L., 2010, *Hibrid Elektrikli Araçların Modellenmesi ve Kural Tabanlı Kontrolü*, İTU Engineering Magazine, Istanbul, 83-94.
3. Toyota Motor Corporation, *Toyota’s Global Strategy Report,* 2003*.*
4. Pacejka, H. B., 2002, *Tyre and Vehicle Dynamics*, Butterworth – Heinemann, U.K.
5. Internet, 2005, *United States Environmental Protection Agency, National Air Toxics Assessment*, http://www.epa.gov.
6. Ehsani, M., 2004, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicle Fundamentals Theory and Design*, CRC Press , 102-108.

1. \* Corresponding author. *e-mail address: tevfikataman@karatekin.edu.tr* [↑](#footnote-ref-1)