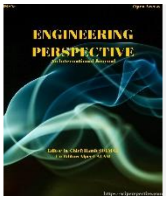
Engineering Perspective 1 (2): 52-62, 2021



e-ISSN: 2757-9077

ENGINEERING PERSPECTIVE

https://sciperspective.com/

Research Paper

Modeling of an Electric Bus Using MATLAB/Simulink and Determining Cost Saving for a Realistic City Bus Line Driving Cycle

Oğuzhan Karakaş[1*], Umut Buğra Şeker[1], Hamit Solmaz[1]

[1] *Automotive Engineering Department, Faculty of Technology, Gazi University, Ankara, 06500, Turkey*

ABSTRACT

Since the discovery of the internal combustion engine in the 19th century, petroleum and its derivatives are used in most of the vehicles which is using for transportation on the Earth. The environmental pollution caused by petroleum, the largest energy source used worldwide for over 100 years, the danger of depletion of the reserves and the increase in the price of the barrels have encouraged scientists to develop cleaner and more efficient clean energy sources. Electric vehicles, according to conventional vehicles with internal combustion engine; has advantages such as noiselessness, high efficiency, low fuel consumption and low maintenance costs. In this paper, city buses, which are frequently used worldwide and in our country, have been handled to find out what advantages will be provided when the electric motor is switched to use, to calculate what the costs will be and to show how this change can be applied were carried out. Considering the concepts such as emission, fuel-maintenance costs and noise pollution caused by the use of city buses, a 12-meter bus is modeled in MATLAB/Simulink environment for full electrical urban use. The “HV SUMO HD HV3500” model of TM4 was chosen as the electric motor for the modeled vehicle. For the simulation process, driving cycle has generated in 541 Eryaman-Kızılay line which is one of the urban bus lines and simulations were applied on this cycle. As a result of the simulations performed, total range, remaining range and energy consumptions were examined and comparisons were made for the different weights of the bus. The effects of regenerative braking on battery status were investigated. Simulations were repeated by changing the resistance values and the effects on battery usage and range were investigated.

Keywords: electric engine, modelling of an electric vehicle, simulation, Matlab/Simulink, NEDC, electric vehicle, electrical bus

History
Received: 16.04.2021
Accepted: 24.06.2021

http://dx.doi.org/10.29228/eng.pers.51422

Author Contacts
**Corresponding Author*
e-mail addresses : oguzkarakas08@gmail.com, sekerumutbugra@gmail.com, hsolmaz@gazi.edu.tr
Orcid numbers : 0000-0001-9028-1579, 0000-0001-5020-5061, 0000-0003-0689-6824

1. Introduction

Electric vehicles have advantages compared to conventional vehicles with internal combustion engine; such as silence, high efficiency, low fuel consumption and low maintenance costs [1,2,3].

In this study, city buses that are frequently used in our country are discussed. It was made to learn how to gain advantage in the use of electric motors in buses, to calculate what the costs would be, and to examine how applicable this change would be. Considering the concepts such as emissions, fuel-maintenance costs and noise pollution caused by the use of city buses, a 12-meter fully electrical bus for urban use was modeled in MATLAB / Simulink.

Many researchers have been studied on electric vehicle modeling to examine motor choices and the advantages of electric vehicles. S. Çağlar Başlamış, Bayramcan İnce, Mertcan Koçak, Hasan H. Saygılı (2016) studied the fuel consumption and saving methods of a hybrid electric city bus by using Istanbul and Konya driving cycles. In their study, they modeled the system algorithm according to the torque demand of the engine by using two different strategies, which they called the limited thermostat strategy and the maximum battery charge strategy [23]. Vyas Singh Chauhan (2017) modeled 10 different electric, hybrid electric and fuel cell vehicles on Matlab / Simulink in order to observe the data of vehicles known in the market under different driving conditions and analyzed these vehicles for 7 different driving cycles [16]. X. D. Xue, K. W. E. Cheng, N. C. Cheung (2008) aimed to find the most suitable engine for electric vehicles in their thesis study. They made comparisons between electric motors on criteria such as efficiency, weight, cost, cooling, maximum speed and fault tolerance. As a result of these comparisons, they determined the "Permanent Magnet Synchronous Motor" as the most efficient motor [9]. Ekrem Başer

(2016) made a comparison of asynchronous motor and permanent magnet synchronous motor in urban use in his master's thesis. Başer, who modeled both engines on Matlab/Simulink in his study, examined which engine was more efficient under equal speed conditions. Comparison of motors was made on efficiency, cost, performance and energy consumption parameters [11].

According to the data obtained from the EGO organization to which Ankara city buses are affiliated; In January 2018, a total of 8454114 km was traveled and 5506700 liters of natural gas and 768520 liters of diesel were used in the same month. In the same month, a total of 17611336 people used EGO's inner city bus lines. This number of passengers is just one of the proofs showing the place of city buses in our lives.

In January 2018, 1 liter of diesel was sold for 1,36 USD and 1 m3 of CNG for 0,89 USD. Based on these data, January EGO buses used a total of 1.054.013,61 USD of fuel. During January, 34739 vehicles were put into service, on average, 1121 vehicles served the public on the streets of Ankara on a daily basis [4].

In order to provide real driving conditions in modeling, a test drive cycle has been created on the line 541 of the EGO organization Eryaman-Kızılay of Ankara Metropolitan Municipality.

In this study; Electric motor, drivetrain and bus body data from various companies were used. A transfer function has been created for the powertrain of the electric vehicle. By this way, the angular velocity of the electric motor that drives the vehicle has been calculated. As a result of this calculation, an electric motor model was created by using angular velocity.

A model was created for the resistance forces affecting the vehicle in dynamic driving conditions and added to the main model. By creating a battery and energy consumption model, measurements such as the amount of energy consumed by the vehicle during the driving cycle, battery capacity and remaining range data were obtained. In addition, a brake model was added to the Simulink model, allowing the energy gained by regenerative braking to be used in battery charging.

The "SUMO HD HV3500" model of DANA TM4 company was chosen as the electrical motor for the modeled bus. The selected electrical motor can produce maximum 3500 Nm of torque and 350 kW of power. For the Drivetrain, ZF Company's "Rear Axle System AV 133" model was selected. While choosing the reference vehicle information, the buses currently produced by Mercedes-Benz, Güleryüz and BMC companies were used.

1.1 Electrical Vehicles

Electric vehicles contain a main power source and auxiliary power sources, motor inverter and electric motor. The motor inverter is responsible for the parameters such as the conversion and control of the electrical energy stored in the batteries of full electric vehicles. The motor inverter provides this control according to the accelerator pedal position, and provides adjustment of the power to the electric motor. Although it varies according to the motor and inverter used in vehicle, some motor inverters can convert the DC taken from the battery to AC [5,6].

The electrical motors provides the main power that necessary to drive from the batteries; In addition to this, auxiliary power supplies are used for sudden acceleration and loads. These auxiliary sources are super capacitors and secondary batteries. Their purpose is to power the electric motor under peak operating conditions for short periods [7]. The fully electrical vehicle scheme is shown in Figure 1.

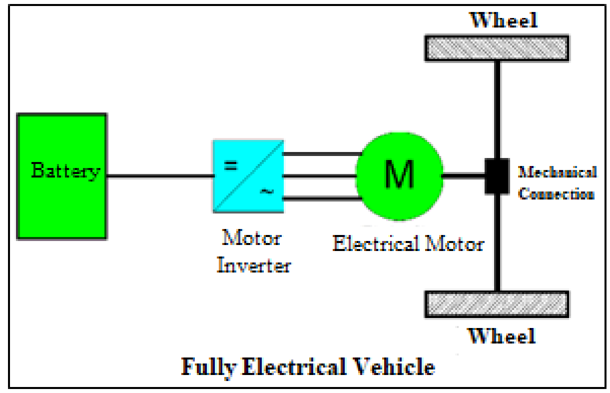


Figure 1. Fully Electrical Vehicle

Fully electrical vehicles are more efficient than conventional internal combustion engine vehicles. In a vehicle with an electric motor and battery, %46 of the energy taken from the plug is converted into usable work. On the other hand, only 18-25% of the energy that a conventional internal combustion engine generates from fuel is used [8].

2. Material-Method

2.1 Electric motor model

In order to meet the required values, the electric motor "SUMO HD HV3500" from DANA TM4 was selected for the modelled vehicle [9,10]. This motor is designed for heavy duty vehicles and 6 - 18 meters buses [11]. The features of the electric motor are given in Table 1 and Figure 2.

Table 1. Features of The Electric Motor [12]

Features	SUMO HD HV3500
Used Inverter	TM4 Reflex CO300-HV
Maximum Power (kW)	350
Continuous Power (kW)	260
RPM Range (rpm)	0 – 3400
Peak Torque (Nm)	3500
Continuous Torque (Nm)	1830
Number of Phase	9
Mass (kg)	340+36

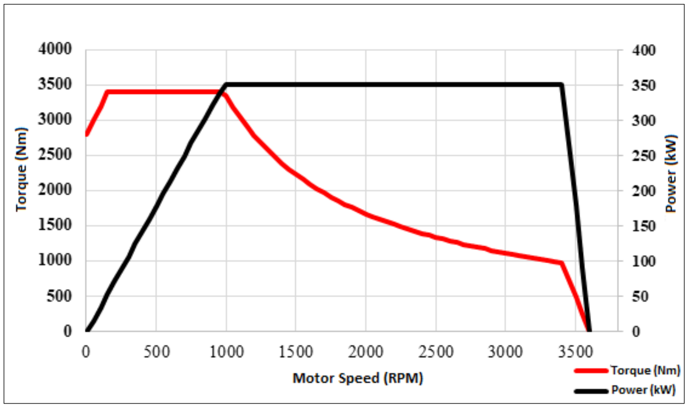


Figure 2. Electric Motor Performance Curve [4]

Simulink model of the electric motor is shown in Figure 3. In this model, the revolution of the electric motor is applied, the maximum torque value produced by the motor at that revolution is calculated. The torque value calculated here will be included in the dynamic model with the accelerator pedal control. Since the efficiency map of the electric motor could not be reached, the electric motors in the market were examined and 90% efficiency value was used.

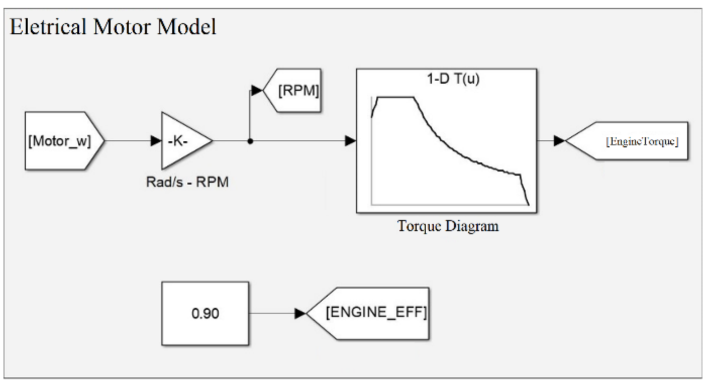


Figure 3. Electric Motor Simulink Model

2.2 Model of total resistance torque affecting the vehicle

Vehicles are exposed to some resistance forces while in motion, and these resistances must be overcome by engine power. While the reduction of these resistances causes a decrease in fuel consumption in vehicles with conventional internal combustion engines, decreasing the resistances causes energy savings in electric motor vehicles and increases the range. For this reason, it is very important to reduce resistances in electrical vehicles.

There are four different resistance forces acting on the vehicle. These are called aerodynamic resistance, rolling resistance, hill resistance and acceleration resistance. Real working conditions are created by applying these resistances that the vehicle is exposed to while driving. These resistances are shown in Figure 4.

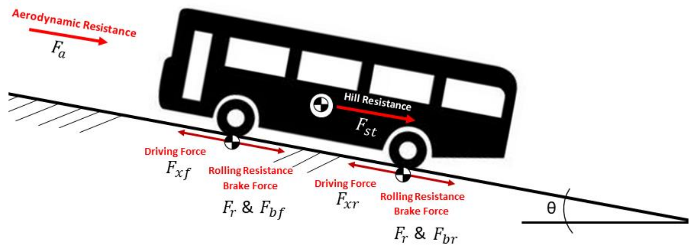


Figure 4. Resistance Forces Acting on Vehicle

2.2.1 Aerodynamic Resistance

The aerodynamic resistance force is calculated by the following equation [13].

$$F_a = 0.5\rho C_d A_f (V + V_0)^2 \tag{1}$$

In the last equation;

- C_d: Aerodynamic drag coefficient,
- A_f: Front projection area of the vehicle, m^2
- V: Vehicle speed, m/s
- V_0 : Wind speed opposite to the direction of movement, m/s
- ρ : Air density, $\frac{kg}{m^3}$

Aerodynamic drag force model is given in Figure 5.

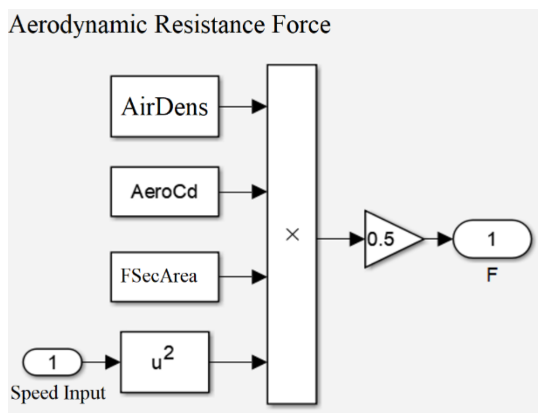


Figure 5. Aerodynamic Resistance Force Model

2.2.2 Rolling resistance

Rolling resistance is affected by parameters such as vehicle mass, tire type, tire air pressure and road conditions.

Rolling resistance force:

$$F_r = mgf_{ro} \tag{2}$$

is calculated by this equation. In this equation, "f_{ro}" refers to the rolling resistance coefficient [13]. Rolling resistance coefficients for different road conditions are given in Table 2. The rolling resistance force model is given in Figure 6.

Table 2. Rolling resistance coefficients for different road conditions [13]

Road Conditions	f_{ro}
Smooth asphalt, concrete	0.013
Small stone road	0.015
Cobblestone road	0.015
Macadamized road	0.02
Muddy road	0.05
Loose soil, sand	0.1…0.35

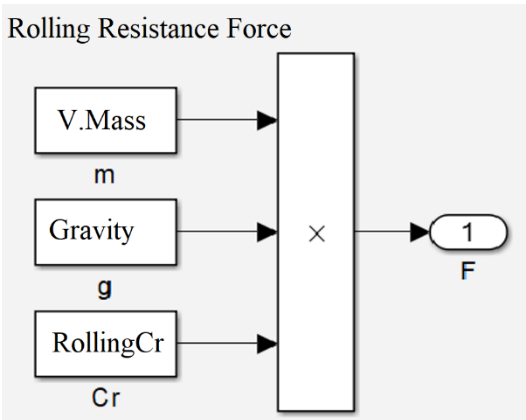


Figure 6. Rolling Resistance Force Model

2.2.3 Acceleration resistance

According to Newton's 2nd law of motion, during the acceleration and deceleration of an object, an inertial force occurs in the opposite direction to this motion. This force encountered during positive and negative acceleration of the vehicle is called the acceleration resistance. This resistance;

$$F_i = ma \quad (3)$$

is calculated by this equality [13]. Acceleration Resistance Force Model is given in Figure 7.

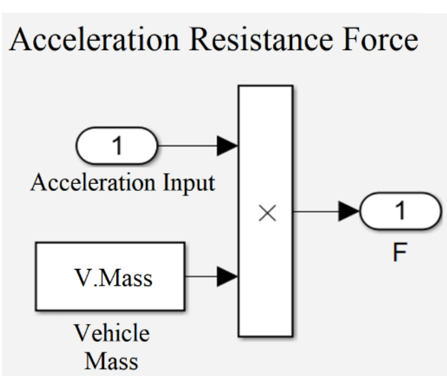


Figure 7. Acceleration Resistance Force Model

2.2.4 Gradient resistance

Gradient resistance is a resistance force that occurs due to the component of the Mass force during the movement of the vehicle on an inclined road and is opposite to the direction of movement of the vehicle. This resistance directly affects the mass of the vehicle and the slope of the hill. Gradient resistance;

$$F_{st} = mg \sin \alpha \quad (4)$$

is calculated by the equation 3. With “α”, the slope of the road is expressed in angle [13].

The model assumes that the vehicle is traveling on a straight road and has no hill resistance effect**.**

2.2.5 Total Resistance Force:

Total resistance force is the sum of aerodynamic, rolling, hill and acceleration resistances.

$$F_{Load} = F_i + F_{st} + F_r + F_a \quad (5)$$

is calculated by this equality. Torque force in the powertrain due to vehicle resistance forces,

$$T_{Load} = F_{Load} \times r_w \quad (6)$$

It is aimed to obtain more realistic data on modeling. Resistors acting on the vehicle are applied to the model as in Figure 8.

The total torque generated by multiplying the total resistance forces acting on the vehicle by the wheel radius and the total brake torque applied to the system by the brake model constitute the total resistance torque.

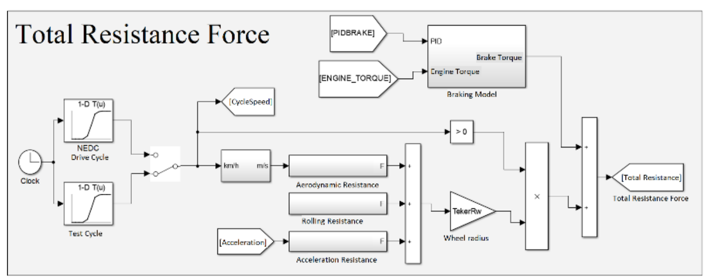


Figure 8. Total Resistance Force Model

A "Compare to Zero" block has been added to the model in order to prevent the application of a formula-induced torque to the powertrain while the vehicle is at a standstill. In this way, when the cycle speed is zero, the resistance forces affecting the vehicle are zeroed. After the total resistance torque affecting the vehicle is calculated, the power transmission system is used in the transfer function [14].

With the help of the "Manual Switch" added to the model, it is possible to choose between the two drive cycle in the model. In this way, the vehicle model can be controlled with a standard drive cycle or the model can be run by selecting the test drive cycle.

2.3. Speed control model (PID Controller)

Driving cycles are used as references in the simulation process and the model must be able to follow these cycles. For this reason, it is necessary to create a speed control model that can follow the reference. A PID controller is used for speed control in the model. The block that matches the speed values with the values coming from the driving cycle ensures that the output values and the torque value of the electric motor are formed. For this process, the output values of the PID controller are limited between "1" and "-1" values. For pedal control, "0-1" range is selected as accelerator pedal, "0 - (-1)" range is selected as brake pedal. In this way, it helped the braking model to control the brakes [15].

The Ziegler-Nichols method was used to find the PID controller parameters. According to this method, P (proportional value) value was increased, I (integral value) and D (derivative value) values were accepted as 0. After that, the parameters were adjusted with the "PID Tuner" in the PID controller block. Thus, the tracking process is provided with the lowest error and oscillation. Speed control model is shown in Figure 9.

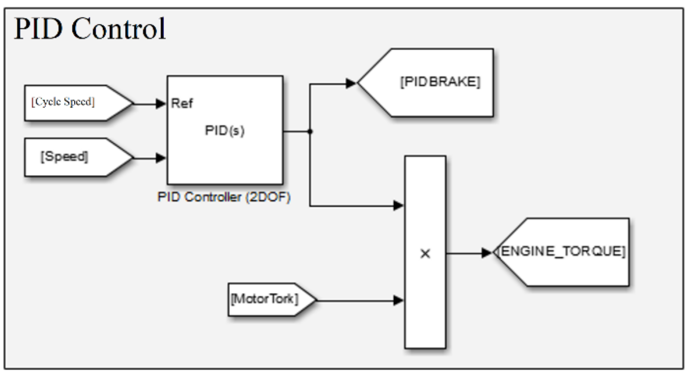


Figure 9. PID Control Model

2.4. Powertrain system model

The power transmission system transmits the motion energy obtained from the engine to the wheels [16]. "Rear Axle System AV 133" axle and differential system of ZF company was taken as a reference to be used in the designed bus and the differential reduction ratio was obtained from here. Figure 10 shows a schematic of a direct drive electrical vehicle.

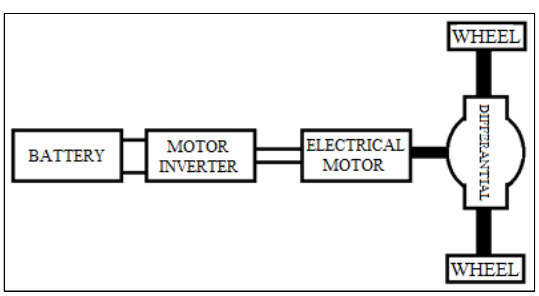


Figure 10. Schematic Of A Direct Drive Electrical Vehicle

In order to create the transfer function, some mathematical calculations must be done first. The moment of inertia occurs in the components that make the rotational motion due to their mass. It is known that the net torque value at the motor output is equal to the product of the total moment of inertia times the angular acceleration. As a result of this transfer function, it is desired to reach the speed information of the vehicle. For this reason, the net torque value at the output of the motor should be calculated first, then this torque value should be divided by the total inertia forces and the angular acceleration of the motor should be calculated. By integrating the angular acceleration value, the angular velocity of the motor is calculated. The angular velocity of the motor is the angular velocity at the differential input. It must therefore be divided by the differential reduction ratio. Thus, the speed at the differential output is calculated. The vehicle speed is calculated by multiplying this value by the wheel radius.

The mathematical operations of the power transfer transfer function used in the modeling process are performed as follows:

$$M_{net} = M_{motor} \times \eta_{motor} \quad (7)$$

$$M_{net} = \dot{w} \times I \quad (8)$$

$$M_{d_{in}} = M_{net} \quad (9)$$

$$M_{d_{out}} = M_{d_{in}} \times i_{diff} \times \eta_{diff} \quad (10)$$

$$M_{axle} = M_{d_{out}} - 2 \times I_{axle} \times \dot{w}_{axle} \quad (11)$$

$$M_{d_{out}} = M_{axle} + 2 \times I_{axle} \times \dot{w}_{axle} \quad (12)$$

$$M_{wheel} = M_{axle} - 6 \times I_{wheel} \times \dot{w}_{wheel} \quad (13)$$

$$M_{axle} = M_{wheel} + 6 \times I_{wheel} \times \dot{w}_{wheel} \quad (14)$$

The net torque will be calculated with the engine torque and the resistance torque generated in the wheels.

$$M_{net} = M_{d_{in}} \quad (15)$$

$$M_{net} = \frac{M_{d_{out}}}{i_{diff} \times \eta_{diff}} \quad (16)$$

$$M_{net} = \frac{M_{axle} + 2 \times I_{axle} \times \dot{w}_{axle}}{i_{diff} \times \eta_{diff}} \quad (17)$$

$$M_{net} = \frac{M_{wheel} + 6 \times I_{wheel} \times \dot{w}_{wheel} + 2 \times I_{axle} \times \dot{w}_{axle}}{i_{diff} \times \eta_{diff}} \quad (18)$$

$$M_{wheel} = M_{Load} \ , \quad \dot{w}_{axle} = \dot{w}_{wheel} = \frac{\dot{w}_{motor}}{i_{diff}} \quad (19)$$

is known. By arranginge these equations;

$$M_{net} - \left(\frac{M_{Load}}{i_{diff} \times \eta_{diff}}\right) = \frac{6 \times I_{wheel} + 2 \times I_{axle}}{i_{diff} \times \eta_{diff}} \times \frac{\dot{w}_{motor}}{i_{diff}} \quad (20)$$

$$M_{net} - \left(\frac{M_{Load}}{i_{diff} \times \eta_{diff}}\right) = \frac{6 \times I_{wheel} + 2 \times I_{axle}}{i^2{}_{diff} \times \eta_{diff}} \times \dot{w}_{motor} \tag{21}$$

$$\dot{w}_{motor} = \frac{M_{net} - \frac{M_{Load}}{i_{diff} \times \eta_{diff}}}{\frac{6 \times I_{wheel} + 2 \times I_{axle}}{i^2{}_{diff} \times \eta_{diff}}} \tag{22}$$

By integrating the last equation;

$$w_{motor} = \int \left(\frac{M_{net} - \frac{M_{Load}}{i_{diff} \times \eta_{diff}}}{\frac{6 \times I_{wheel} + 2 \times I_{axle}}{i^2{}_{diff} \times \eta_{diff}}} \right) dt \tag{23}$$

the angular velocity of the motor is calculated [17]. Figure 11 is shown the Simulink powertrain model.

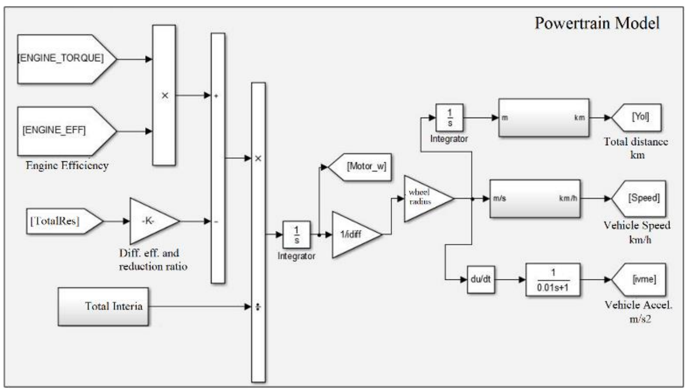


Figure 11. Powertrain Model

2.5. Regenerative brake model

The designed bus is required to recover energy by regenerative braking. For this reason, a regenerative braking system has been modeled and regenerative brake recovery has been assumed to be 30%. In the modeling process, the motor torque values formed by the values in the range of 1 - (-1) coming from the output of the PID controller were put into an 'if' loop and regenerative braking was provided with the values occurring in the 0 - (-1) range [18,19]. Brake model is shown in Figure 12.

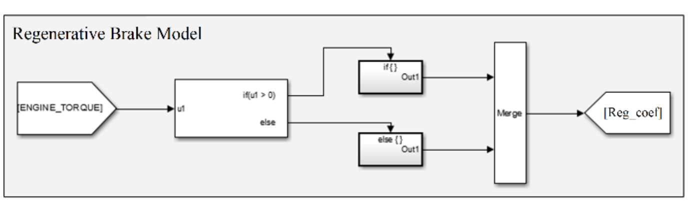


Figure 12. Regenerative Brake Model

2.6. Energy Consumption Model

The "SOC" method was used for the energy consumption model [20]. By using "SOC", the method of learning the current state of charge of the battery, the percentage of the battery consumed by the vehicle throughout the cycle was printed out and recorded. With this output, it is aimed to calculate the maximum range that the battery can achieve with 100% charge, and the capacity of the battery consumed per 100 km.

In the model, the efficiency and torque of the electrical motor are taken as input, so it is determined whether the electric motor operates in the drive mode or regenerative mode. Afterwards, the instantaneous power of the electrical motor was calculated by dividing the motor torque by the efficiency If the electric motor is operating in regenerative mode, the battery is charged by gaining 30% from the kinetic energy of the vehicle.

The energy consumed by high and low voltage accessories is considered constant in all cases. The efficiency of the converter is taken into calculation when calculating the power amount of low voltage accessories. The total power consumed by the electric motor, low and high voltage accessories has been calculated. Then this value is integrated and the total amount of energy consumed by the vehicle during one cycle is calculated. The energy consumption model is shown in Figure 13.

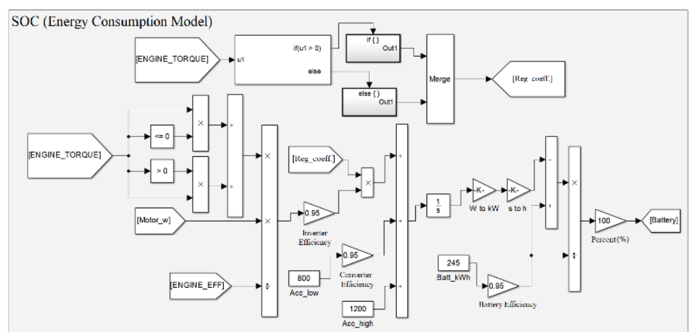


Figure 13. “State of Charge” Energy Consumption Model

2.7. Test drive cycle

A realistic driving cycle has been created and included in the vehicle model so that the vehicle modeled in Matlab / Simulink can be modeled in a more realistic way and compared with the buses available on the market. This test drive cycle was created on Eryaman-Kızılay 541 line of EGO organization affiliated to Ankara Metropolitan Municipality. An application specially made for this study is used to create a cycle. Vehicle speed information is received via GPS and recorded over time. The data taken from the application has been arranged and transferred to the model. Test driving cycle is shown in Figure 14 and its features are shown in Table 3.

Table 3. Test Drive Cycle Features

Time (s)	3190
Distance (km)	31.16
Maximum Speed (km/h)	87
Average Speed (km/h)	36
Conversion Sensitivity (m)	7

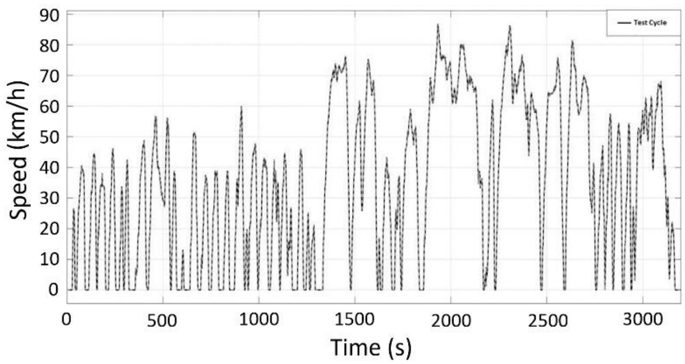


Figure 14. Test Drive Cycle

2.8. Simulation result model

Figure 15 is shown the output from the electricity consumption model and the remaining range, total range, battery capacity consumed per 100 km, the data obtained from the torque output of the engine and the result model where the engine power is calculated [21].

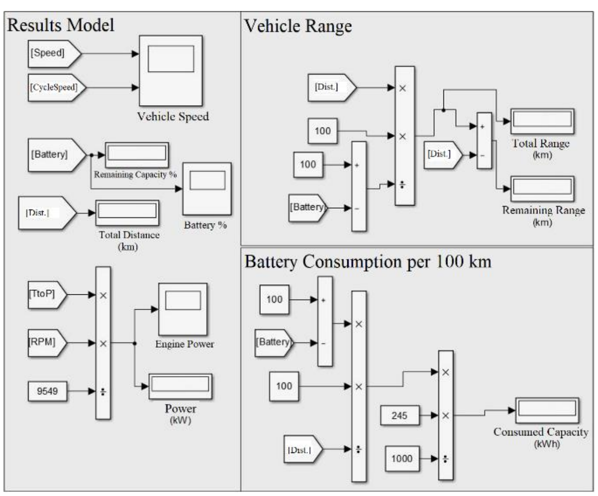


Figure 15. Simulation Result Model

3. Simulation results

After modeling, values such as energy consumption in the test drive cycle, remaining range, battery capacity consumed per 100 km were obtained according to vehicle parameters. According to this drive cycle, benefits from regenerative breaking, fuel costs, effects of vehicle resistance force parameters on battery-range were examined for different vehicle status' which are simulated empty, half-full and full.

Results graphics of the electric bus model have been obtained. These graphics were created by following the test drive cycle. Figure 16 is shown the graph of the test driving cycle versus vehicle speed.

According to the simulation results including test driving cycles, vehicle speed follows the cycle speed. Thus, it is concluded that the energy consumption values obtained from the simulation applied are correct. In Figures 17 and 18, electric motor torque and speed can be seen in the test drive cycle.

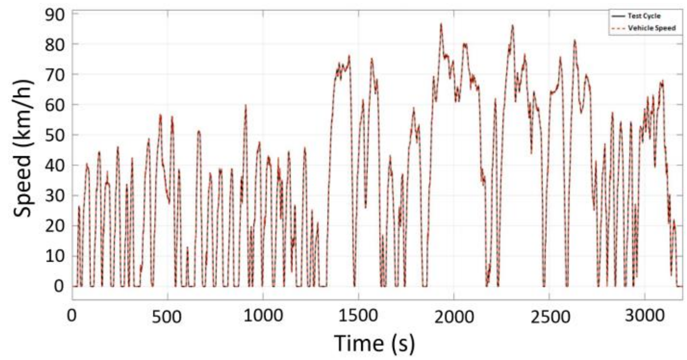


Figure 16. Driving Cycle and Vehicle Speed

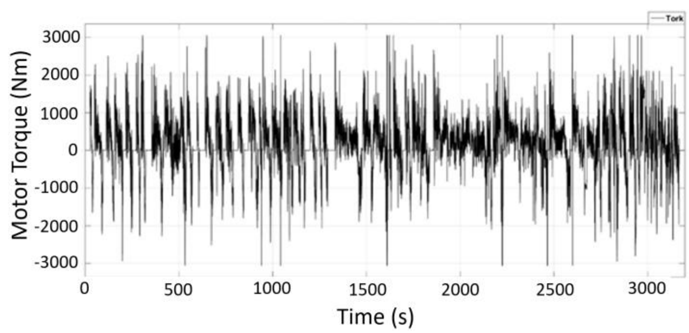


Figure 17. Electric Motor Torque Graph

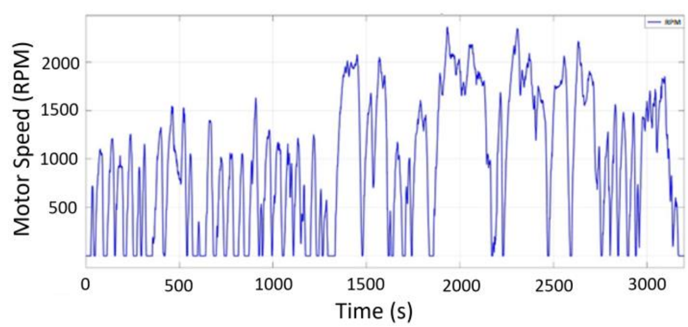


Figure 18. Electric Motor Revolution Graph

The acceleration and velocity graphs of the vehicle during the test driving cycle are shown in Figures 19 and 20. The acceleration of the modeled vehicle increases to 2.7 m / s2 in the case of acceleration and up to -6.8 m / s2 in the case of deceleration.

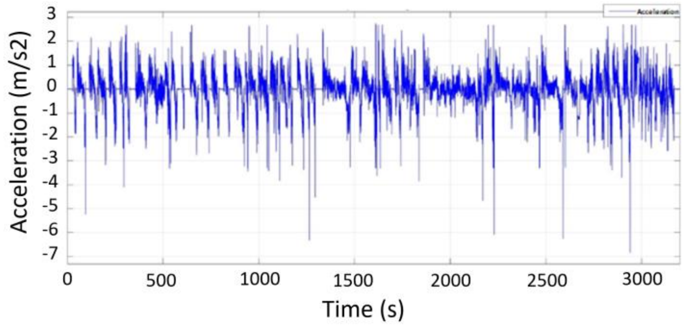


Figure 19. Vehicle Acceleration Graph

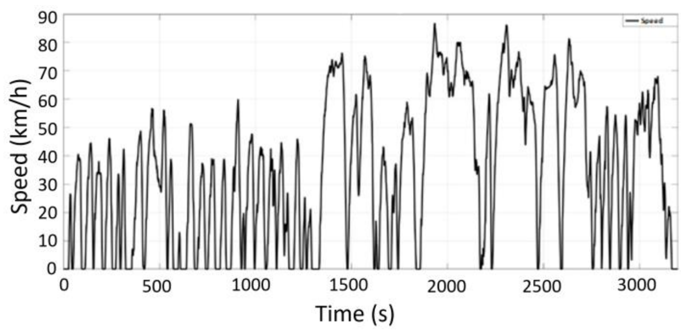
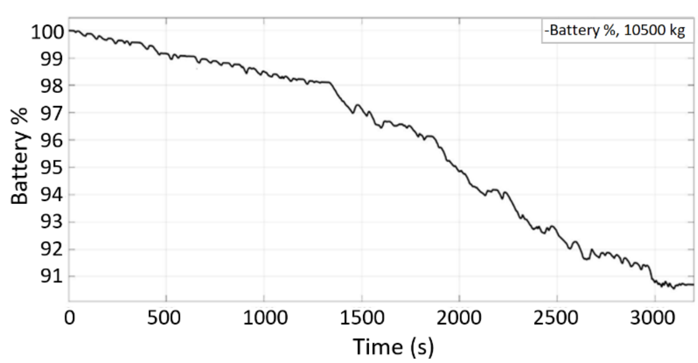


Figure 20. Vehicle Speed Graph

In the Simulink model, the vehicle mass has been changed according to the status of the vehicle being empty, half-full, full; and for these values remaining battery conditions, total distance, remaining range, 100 km-spent battery-capacity are shown in Table 4. The results obtained are shown in the graph in Figure 21. A more realistic energy consumption model was created by including low and high voltage accessories in the vehicle model, and energy consumption was uphold even when the vehicle was on steady state.

Table 4. Battery Consumption by Vehicle Mass

Vehicle Mass (kg)	10500	14000	17000
Total Distance (km)	335.2	226.6	114.6
Remaining Distance (km)	304	195.4	83.42
Battery Capacity Spent per 100 Km (kWh)	73.09	108.1	213.8
Battery Charge Status (%)	90.7	86.25	72.8



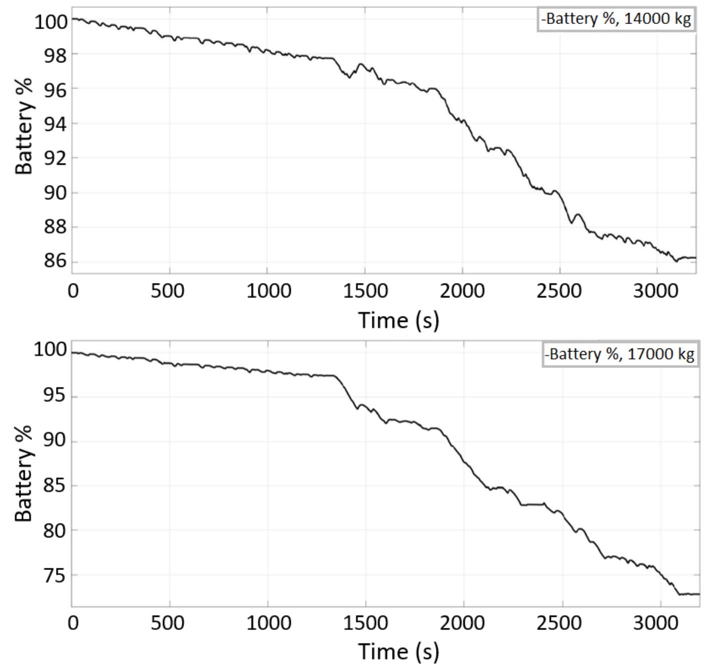


Figure 21. Battery Consumption Graph

The simulation was repeated for each mass on the Test Driving Cycle and the battery consumption results were obtained. According to this situation, it was observed that %9.3 battery capacity was consumed for 10500 kg vehicle mass, %13.75 battery capacity for 14000 kg vehicle mass, %27.2 battery capacity for 17000 kg vehicle mass during the 31.16 km driving cycle. Inner city buses vehicle mass varies continuously depending on the number of passengers. For this reason, based on half-full and full vehicle; When the vehicle is half full, an average of 7 full trips will be on the line, and when it is fully loaded, an average of 4 full trips will be able to go back and forth

3.1. Investigation of regenerative braking gain effect

Without changing the parameters on the model; Tests have been carried out for 10500, 14000 and 17000 kg vehicle conditions with the aim of observing the battery charge status and total range change while the regenerative braking system is activated and deactivated. The results according to these tests are shown in Table 5, Figure 22 and Figure 23.

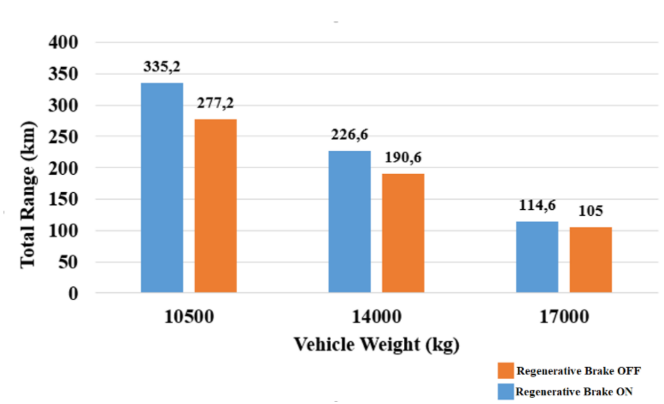


Figure 22. Effect of Regenerative Braking Gain on Total Range

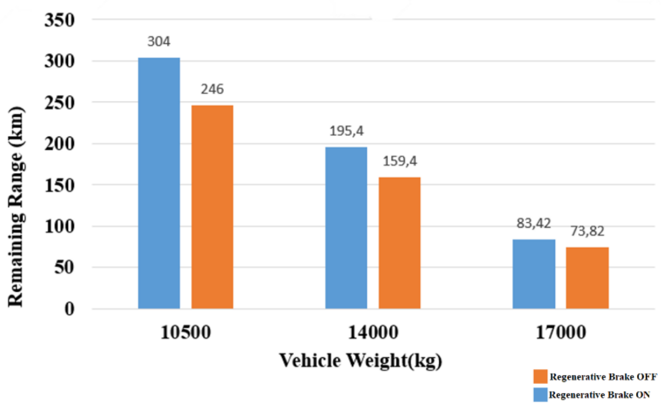


Figure 23. Effect of Regenerative Braking Gain on Remaining Range

Table 5. Regenerative Braking On/Off Results

Vehicle Mass (kg)	10500	14000	17000
Total Distance (km) (Regenerative Brake ON)	335.2	226.6	114.6
Total Distance (km) (Regenerative Brake OFF)	277.2	190.6	105
Remaining Distance (km) (Regenerative Brake ON)	304	195.4	83.42
Remaining Distance (km) (Regenerative Brake OFF)	246	159.4	73.82
Battery Capacity Spent per 100 Km (kWh) (Regenerative Brake ON)	73.09	108.1	213.8
Battery Capacity Spent per 100 Km (kWh) (Regenerative Brake OFF)	88.39	128.6	233.4
Battery Charge Status (%)(Regenerative Brake ON)	90.7	86.25	72.8
Battery Charge Status (%)(Regenerative Brake OFF)	88.76	83.65	70.31

Regenerative braking gain increased by 58 km for 10500 kg vehicle mass, 36 km for 14000 kg vehicle mass and 9.6 km for 17000 kg vehicle mass in total range. According to these results, it has been observed that there is a significant increase in the total range that can be traveled when regenerative braking gain is open.

3.2. The Effect of vehicle resistance parameters on range and battery consumption

The effect of vehicle resistance parameters on the modeled vehicle is examined in this section. Aerodynamic drag coefficient and rolling resistance coefficient were changed on the model and the simulation was repeated. As a result of the simulation, the effects of these two resistance parameters on the total range, remaining range, battery capacity and battery capacity spent per 100 km were examined. The results are shown in Tables 6 and 7.

Table 6. Effects of Aerodynamic Resistance

Aerodynamic Resistance Coefficient	0.6	0.65	0.7
Total Distance (km)	346.7	335.2	331.1
Remaining Distance (km)	315.6	304	300
Battery Capacity Spent per 100 Km (kWh)	70.66	73.09	73.99
Battery Charge Status (%)	91.01	90.7	90.59

Table 7. Rolling Resistance Effects

Rolling Resistance Coefficient (fro)	0.01	0.015	0.02
Total Distance (km)	450.9	335.2	263.5
Remaining Distance (km)	419.7	304	232.4
Battery Capacity Spent per 100 Km (kWh)	54.34	73.09	92.96
Battery Charge Status (%)	93.09	90.7	88.18

As a result of the tests, the effects of the change in aerodynamic and rolling resistance coefficients on the modeled vehicle were examined. As a result, the effect of rolling resistance was %34.5 on ranges, while the effect of aerodynamic resistance was %3.43.

When the aerodynamic resistance coefficient, taken as 0.65, was changed to 0.6, the total range increased from 335.2 km to 346.7 km, and the battery usage decreased by %0.31. When the resistance value is taken as 0.70, the total range has decreased from 335.2 km to 331.1 km, and the battery usage has increased by %0.21. As can be seen from the values, the effect of aerodynamic resistance on the vehicle is very small. It did not have a significant effect on the capacity spent per 100 km.

When the rolling resistance coefficient, which was taken as 0.015, was changed to 0.010, the total range increased from 335.2 km to 450.9 km, and the battery usage decreased by %2.39. When the resistance value is taken as 0.020, the total range decreased from 335.2 km to 263.5 km, and battery usage increased by 2.52 percent. The spent capacity at 100 km decreased by 18.75 kWh for the resistance coefficient of 0.01, and increased by 19.87 kWh when the coefficient was made 0.02.

The values were obtained by changing the aerodynamic resistance and rolling resistance coefficients on the model. According to these, while the effect of aerodynamic resistance on the total and remaining range, battery capacity and battery capacity consumed per 100 km was minor, but rolling resistance majorly changed the values.

3.3. Fuel consumption vs emission comparison

Fuel consumption, fuel economy and accordingly emission status of the modeled city bus compared to its equivalents with an internal combustion engine will be examined under this title. Table 8 shows the fuel consumption of the modeled vehicle and the vehicle with ICE, the fuel liter price and the amount spent for the fuel consumed per 100 km.

Table 8. Fuel Consumption Values

	Modeled Bus	Diesel Bus	CNG Bus
Fuel consumption (100 km)	73.09 kWh	31 L	32 m^3
Fuel Unit Price	0,12 USD/kWh	1,51 USD/L	0,89 USD/m^3
Fuel Cost (for 100 km)	9,06 USD	46,81 USD	28,64 USD

According to the values given in the table, based on today's fuel unit prices for 100 km fuel consumption, the fuel cost of the modeled electrical bus; It is 37.74 USD more economical than a diesel bus and 19.57 USD more than a CNG bus. According to this information, it can be said that the electric bus is a better choice in terms of fuel costs.

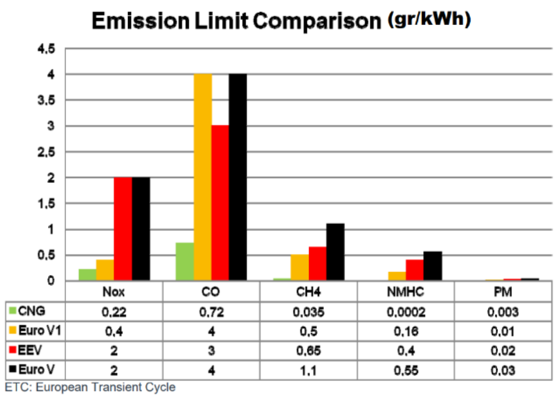


Figure 22. Emission Values [22]

In Figure 22, CNG, EuroV1, EEV and Euro V; Emission values are seen in terms of Nox, CO, CH4, NMHC, and PM. Electric energy used as fuel in vehicles has no emission value. This makes fully electrical vehicles one of the most environmentally friendly vehicles.

4. Conclusions

In order to provide the real driving conditions for the electrical vehicle modeled in MATLAB/Simulink, a test drive cycle was created on the line 541 of the EGO organization of Ankara Metropolitan Municipality.

• When the electrical vehicle modeled in MATLAB/Simulink was simulated with reference to the test driving cycle, it was seen that it consumed 73.09 kWh of energy per 100 kilometers and offered a range of 335.2 kilometers with a fully charged battery.

• The fuel consumption and cost of the modeled electric bus compared to similar buses using Diesel and CNG fuel in the market were compared. Accordingly, a fuel cost of 37.74 USD in a diesel bus and 19.57 USD in a CNG bus is saved.

• It has been observed that the electric bus provides a great advantage in exhaust emissions and noise emissions compared to the buses using Diesel and CNG fuel. When reviewed only as a vehicle, the noise emission is greatly reduced, while the exhaust emission is zeroed.

• Parameters such as aerodynamic drag coefficient, rolling resistance coefficient, regenerative braking gain and vehicle mass were changed on the modeled vehicle and as a result, the change of values such as range, energy consumption was examined.

• The regenerative braking gain in the electric vehicle model has increased by 58 km for 10500 kg vehicle mass, 36 km for 14000 kg vehicle mass and 9.6 km for 17000 kg vehicle mass in the total range. Based on these results, it is seen that regenerative braking is of great importance for the vehicle.

• The mass parameter was changed to be empty, half-full and full weight on the modeled vehicle. Accordingly, it was observed that %9.3 battery capacity was consumed for 10500 kg vehicle mass, %13.75 battery capacity for 14000 kg vehicle mass, %27.2 battery capacity for 17000 kg vehicle mass during the 31.16 km driving cycle. Based on half-full and full vehicle; When the vehicle is half full, it will be able to make an average of 7 full trips on the line, and an average of 4 full trips when fully loaded.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

CRediT Author Statement

Oğuzhan Karakaş: Methodology, article editing, Writing original draft and revision; **Umut Buğra Şeker:** Methodology, article editing, Writing original draft and revision; **Hamit Solmaz:** Supervision

References

1. Kocakulak, T., & Solmaz, H. (2020). "Hcci Menzil Arttirici Motor Kullanilan Seri Hibrit Bir Aracin Modellenmesi", Gazi Üniversitesi Fen Bilimleri Dergisi Part C: Tasarım ve Teknoloji, 8(2), 279-292.
2. Kerem, A., "Elektrikli Araç Teknolojisinin Gelişimi ve Gelecek Beklentileri", Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 5(1), 1-2 2014.
3. Emadi, A., Ehsani, M., Miller, J. M., 2004. "Vehicular Electric Power Systems Land, Air, And Space Vehicles", Marcel Dekker, New York.
4. Internet. "https://www.ego.gov.tr/tr/sayfa/61/istatistikler" [Online].
5. Chan, C. C., Wong, Y. S., 2004. "Electric Vehicles Charge Forward, Ieee Power Energy Mag"., Vol.2, No.6, Pp.24-33.
6. School Of Public And Environmental Affairs At Indiana University, "Plugin Electric Vehicles: A Practical Plan For Progress", Indiana, 2011
7. Solmaz H., & Kocakulak T., "Determination of Lithium Ion Battery Characteristics for Hybrid Vehicle Models." International Journal of Automotive Science and Technology, 4(4), 264-271.
8. Ünlü N., Karahan Ş., Tür O., Uçarol H., Özsu E., Yazar A., Turhan L., Akgün F., Tırıs M., "Elektrikli Araçlar", TÜBİTAK – Marmara Araştırma Merkezi Enerji Sistemleri ve Çevre Araştırma Enstitüsü, Kocaeli, 6-10 (2003).
9. Xue, X. D., Cheng, K. W. E. And Cheung, N. C., "Selection Of Electric Motor Drives For Electric Vehicles", Australasian Universities Power Engineering Conference, Hong Kong, 170-175 2008.
10. Hurst, D.veWheelock, C, "Battery Electric And Plug-İn Hybrid Electric

Vehicles: Oem Strategies, Demand Drivers, Technology Issues, Key Industry Players, And Global Market Forecasts", Pike Research, New York, 2010.
11. Başer E.,"Elektrikli Araçlarda Yol Koşullarına Uygun Motor Seçimi Algoritması Geliştirme", Düzce Üniversitesi Fen Bilimleri Enstitüsü, Düzce, 2016.
12. Internet."https://www.tm4.com/products/direct-driveelectricpowertrain/sumo-hd" [Online].
13. S. Çetinkaya, Taşıt Mekaniği Geliştirilmiş 8. Basım, 2017
14. Fan B. S., "Modeling and Simulation of A Hybrid Electric Vehicle Using MATLAB/ Simulink and ADAMS", University of Waterloo, Mechanical Engineering thesis, Canada 2007.
15. Gökçe, C., "Modeling And Simulation Of A Series Parallel Hybrid Electrical Vehicle", Master Thesis, İstanbul Technical University Institute Of Science And Technology, Istanbul (2005).
16. Chauhan V. S., "Simulation of Electric Vehicle Including Different Power Train Components", Master Thesis, Czech Technıcal Unıversıty, Prague, 2017.
17. Kiyakli, A. O., & Solmaz, H. (2018). "Modeling of an electric vehicle with MATLAB/Simulink". International journal of automotive science and technology, 2(4), 9-15.
18. Yurdaer, E., & Kocakulak, T. (2021). "Comparison of Energy Consumption of Different Electric Vehicle Power Systems Using Fuzzy Logic-Based Regenerative Braking.", Eng. Perspect, 1(1), 11-21.
19. Şahin Y., Güneş U., Umman F., Ceceloğlu A. C., Güner H. E., Ertunç H. M., "Bulanık Mantık Kontrollü Rejeneratif Frenleme Sistemi Regenerative Braking System using Fuzzy Logic Controller", Kocaeli Üniversitesi Mekatronik Mühendisliği, 2015
20. Mastanamma Y., Bharathi M. A., "Electric Vheicle Mathematical Modelling an Simulation Using MATLAB-Simulink", Journal of Electrical and Electronics Engineering, 47-53 (2017)
21. Park C., Kwon M., Jeong N., Lee S., Suh M., Kim H., Hwang S., "Development of Electric Vehicle Simulator for Performance Analysis", Universal Journal of Mechanical Engineering 2 (7), 231-239 2014.
22. Internet."https://www.grazerea.at/cms/upload/gashigh/staimer_man_cng_buses.pdf" [Online].
23. Çağlar S., İnce B., Koçak M., Saygılı H. H., "Hibrit-Elektrikli Şehir İçi Otobüslerde Yakıt Ekonomisinin İyileştirilmesine Yönelik Enerji Yönetim Sistemi Algoritmalarının Tasarımı", 8. Otomotiv Teknolojileri Kongresi, OTEKON, 2016