INVESTIGATION OF CHARGING AND DISCHARGING CHARACTERISTICS OF DIFFERENT TYPE BATTERIES USING TRAMBUS ACCELERATOR PEDAL DATA ON HYBRID ELECTRIC VEHICLE MODEL

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ABSTRACT

In this study, component-based modeling of a hybrid vehicle was performed. In order to model different battery types, a battery model has been created and then different types of batteries are modeled with different parameters. As a result, the charge and discharge characteristics of different battery types were analyzed on a hybrid vehicle model. In this analysis, two different driving scenarios are designed with equal starting conditions. These driving scenarios were carried out by analyzing the black box of the Trambus in Malatya and the charge discharge characteristics of the batteries were examined separately in these scenarios. The results are presented comparatively.

Keywords: Batteries, hybrid electric vehicles, charging and discharging, traction system, trambus.

1. INTRODUCTION

Today, the decrease of fossil fuels and the increasing environmental awareness by environmental organizations have increased the importance of renewable energy resources. Researchers have accelerated their work on renewable energy sources [1]. The transition from the internal combustion engine technology in the automotive industry to the electric vehicle technology constitutes a great risk for companies producing vehicles [2]. In addition, the fact that states do not fully support the vehicles operating with renewable energies, independent of fossil fuels, reduces the inclination towards these instruments by the consumption society [3]. Vehicle manufacturers face the dilemma in the face of these negativities [4].

Despite the above mentioned problems, companies that produce renewable energy vehicles should be careful about batteries. The right choice of batteries' cost, safety and energy storage capacity is a critical parameter for vehicle production. For manufacturers working on the hybrid electric vehicle concept, the right battery selection is of greater importance. In today's electric vehicle technologies, three types of battery chemistry are the main candidates for automotive applications. These b; Pb-acid, nickel metal hydride and lithium based batteries. Lead acid batteries contain six sequential cells and are used in automobiles. In such batteries, the anode of each cell

is made of lead. The cathode part is also made of leaddioxide on a metal plate. The cathode and the anode were immersed in the solution of sulfuric acid, which served as an electrolyte. Pb-acid batteries are widely used by manufacturers for these systems as they are used in systems such as lighting, starter and ignition because of their low cost. It is widely used in vehicles such as golf carts and wheelchairs.
Nickel Metal Hydride batteries are one of the most used battery types for electric vehicles and are used by many electric vehicle companies. For example, nickel metal hydride batteries were used in electric vehicles such as General Motors EV1. [5].
In recent years, various Li-ion battery technologies have been studied and developed for use in electric vehicles and hybrid electric vehicles. Among them, lithium iron phosphate (LiFePO4) batteries have an important role in the electric vehicle sector. Batteries of this type are less affected by cold, give full current at high temperatures, they charge very fast with high current. Lithium iron phosphate is used in projects requiring high power and its nominal voltage is 3.3 volts. Lithium iron phosphate batteries have a slower capacity loss compared to lithium ion batteries and have a long shelf life. LiFePO4 batteries are gaining popularity among auto manufacturers and R & D communities because they can protect their nominal voltage in the range of 10% to 90% SOC [6-8].

Table 1 presents the parameters of these three types of batteries mentioned above. As it is seen, with its high energy density, long working life and high safety, Lithium iron phosphate is the battery type that is most suitable for use in electric vehicles [9-10].

Table 1. Technical Specifications of Cells Used in Electric Vehicles by 21st Century

Spesification / Battery Types	Pb-Acit	Nickel Metal Hydride	Lithium Ion
Rated Voltage (V)	12	3.2	3.6 – 3.7
Charge Limit (V)	16	3.7	3.7
Cycle Life (cycles)	2000	1500	3000
Operating Temperature (T)	60	100	80
Safe	low	middle	good
Energy Intensity (Wh/kg)	40	70	150

Battery types have different voltage and current levels. For this reason, the battery packs enable it to operate in different value ranges. In this study, a hybrid electric vehicle has been modeled and two different scenarios have been applied to the gas pedal signals on different days and hours taken from the black box of Trambus vehicles operating in Malatya. This data obtained with the permission of Motaş Inc. was applied for the hybrid vehicle and at the different times of the day, a real driving scenario of the hybrid vehicle was generated. In our previous studies, different driving scenarios and four different chemistry batteries have been studied and their data has been presented [12-13]. In this study, more realistic data have been obtained with the accelerator signals received while driving on an electric vehicle and during this application a parameter was needed to define the passage of the vehicle from the internal combustion engine to the electric motor. For this reason, hybrid mode is defined. Charge and discharge characteristics of four different types of batteries are examined on this model.

2. MATERIALS AND METHODS

2.1 Hybrid Vehicle Model

Almost all of the hybrid engines used today are formed by the addition of an internal combustion gasoline engine as well as the battery, electric motor and generator. This technology is 40-50% more efficient than gasoline engines. Because the hybrid motor technology is a smarter system and the engine determines five different modes of operation. Hybrid electric vehicles are wired and wireless. The hybrid electric vehicle model includes a diesel engine, electric motor and battery pack. Batteries are used according to diesel fuel and driving performance while driving. The batteries are charged by the user and charged for the next drive [11].
In the second model, there is no need for any cables to charge the batteries. The diesel engine in the hybrid vehicle allows the batteries to be charged by running the generator. In this study, the second model of electric vehicle is selected as simulation subject when it is studied to examine the characteristics of the battery at the time of driving.

2.2 Battery Model

The battery model is shown in Figure 1. Charge and discharge equations are presented in Equations 1 and 2.

In the equations;

- EBatt is nonlinear voltage, in V.
- E0 is constant voltage, in V.
- Exp(s) is exponential zone dynamics, in V.
- Sel(s) represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.
- K is polarization constant, in Ah^{-1}.
- i* is low frequency current dynamics, in A.
- i is battery current, in A.

- It is extracted capacity, in Ah.
- Q is maximum battery capacity, in Ah.
- A is exponential voltage, in V.
- B is exponential capacity, in Ah^{-1}.

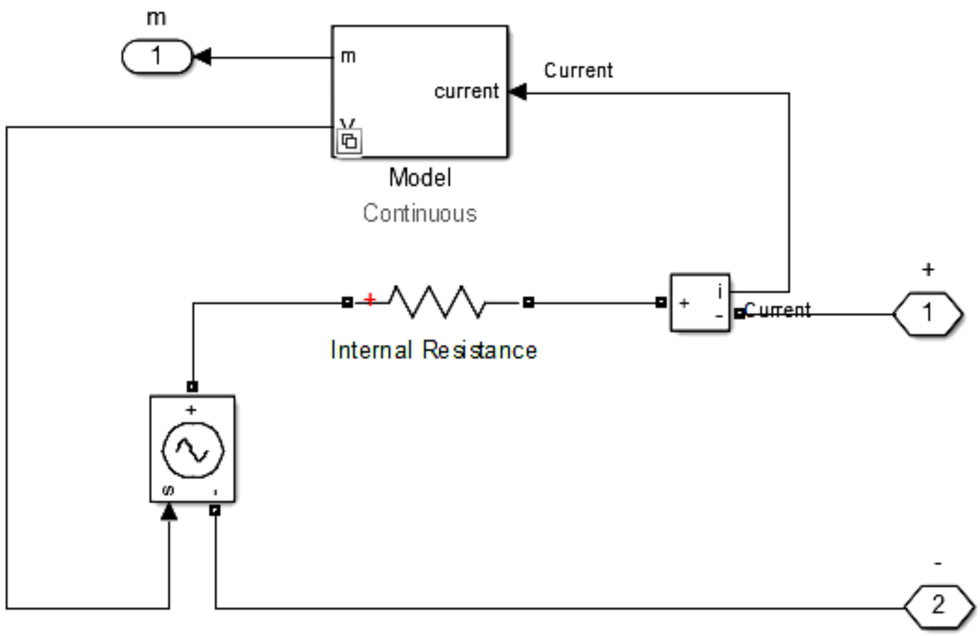


Figure 1. Battery Model

$$E_{Discharge}=E_0 - K\frac{Q}{Q-t}i^* - K\frac{Q}{Q-t}it + Ae^{-\beta it} \quad (1)$$

$$E_{Charge}= E_0 - K\frac{Q}{0.1Q+t}i^* - K\frac{Q}{Q-t}it + Ae^{-\beta it} \quad (2)$$

The charge-discharge characteristics of a lithium battery are obtained from the detailed model shown in Figure 2.

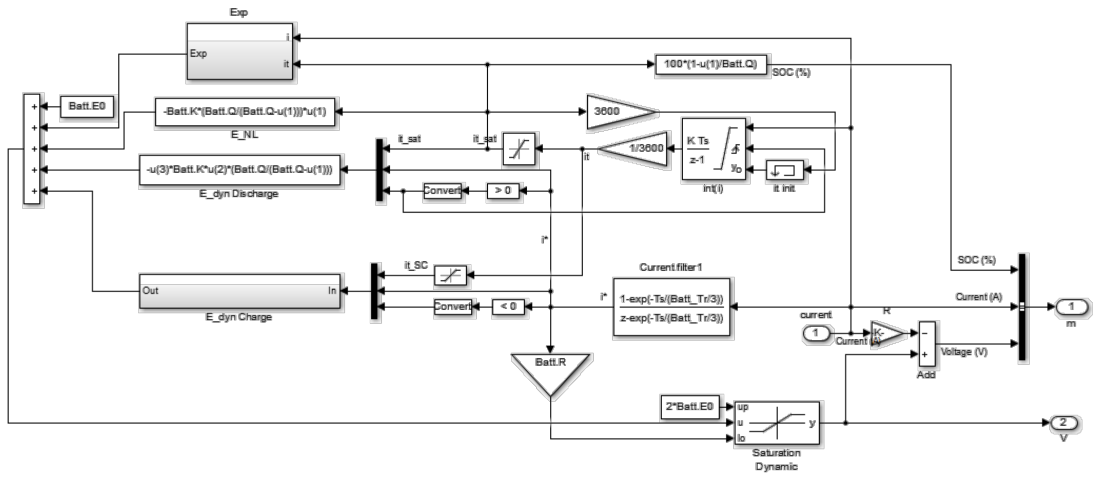


Figure 2. Detailed Battery Model

3. SIMULATION

Simulation was prepared in SIMULINK under MATLAB® 2015a. The ideal sampling frequency of the simulation is 1 kHz. The solvent was used as ode23tb. An overview of the Hybrid Electric Vehicle simulation is shown in Figure 3. In addition, the following assumptions are made for the simulation.

- Switches and contacts are ideal.
- The batteries are completely healthy.

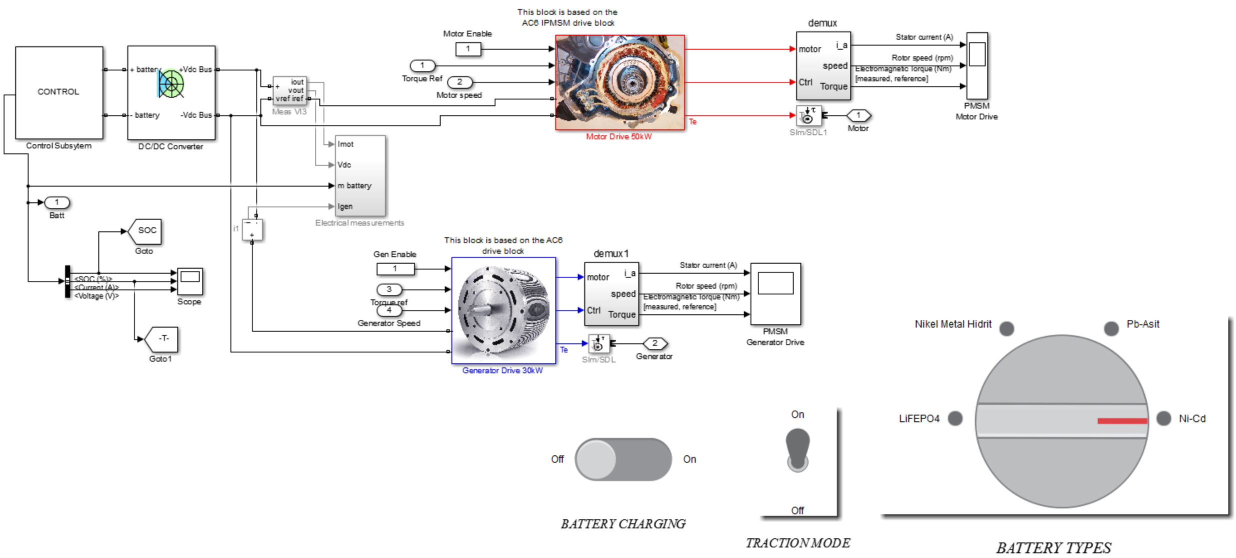


Figure 3. Hybrid Electric Vehicle Model

A hybrid electric vehicle model was taken from Mathworks and LiFePO4, Nickel-metal-hydride, Lead-Acid and Nickel Cadmium type battery groups were installed. Four battery packs were created from different types of batteries with 14 kWh of power. The initial State of Charge (SOC) values of all battery packs on the designed hybrid electric vehicle model are determined as 50%. In addition, the importance of each battery group to be equal power. However, due to the difference in the nominal voltage of the batteries, the battery packs are composed of a different number of batteries and have different total voltage values. In addition, the gas pedal data from the Trambus vehicles were taken from the most crowded and most secluded times of the day.

Table 2. Four Different Types of Battery Parameters

Spesifications	LiFEPO4	Nickel Metal Hydride	Pb-Acit	Nickel Cadmium
Rated Voltage (V)	3.2	3.2	2	1.25
Full Charging Voltage (V)	3.5	3.7	2.5	1.5
Current Capacity (Ah)	3	1.5	2.3	2.05
Internal Resistance (R)	1.3	1.6	1.05	1.2

The first driving scenario obtained from Trambus vehicles was taken from 02.00 to 04.00 in the same manner as in Figure 4, and the hybrid electric vehicle was considered as a gas pedal signal. One minute sample signal was generated from the received data and this signal was presented in Figure 5.

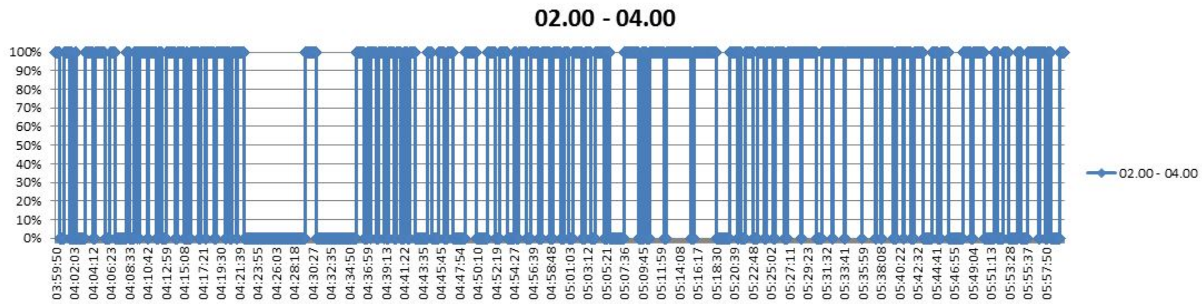


Figure 4. Acceleration rate for the first driving scenario

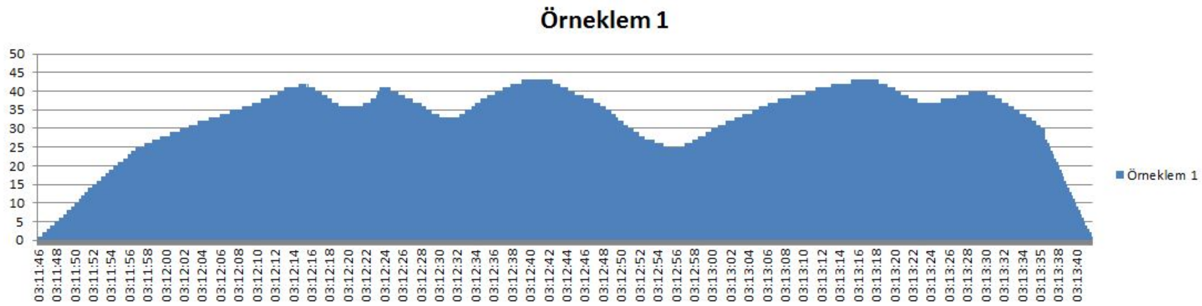


Figure 5. Sampling accelerator pedal applied to the hybrid vehicle for the first driving scenario

The data in the second driving scenario was obtained when the passengers were most crowded. These data are taken from 11.00 to 13.00 and are presented in Figure 6. Again a two-hour data record was made and then a one-minute sample signal which could be integrated into the hybrid vehicle simulation was generated and presented in Figure 7.

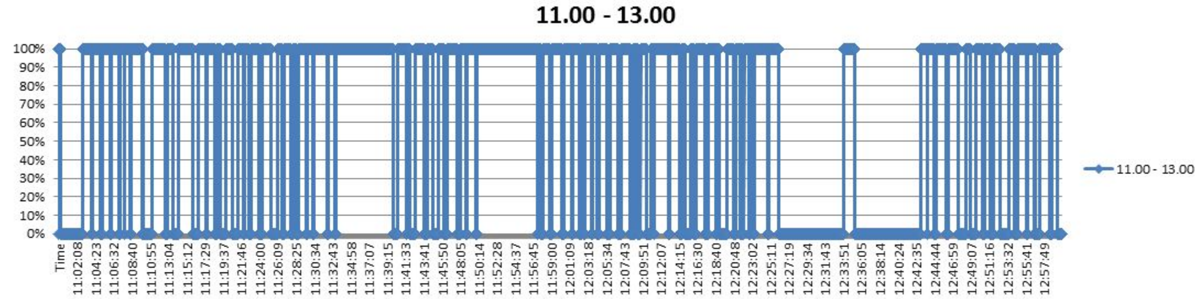
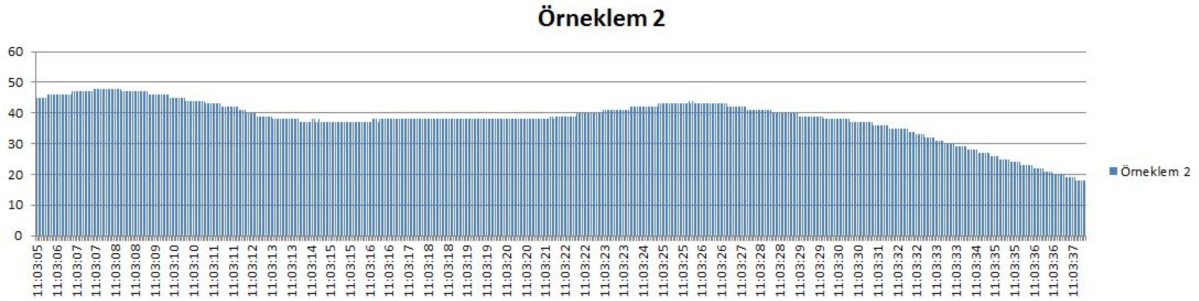


Figure 6. Acceleration rate for the second driving scenario



Şekil 7. Sampling accelerator pedal applied to the hybrid vehicle for the second driving scenario

When the sampling signals from the Trambus vehicles for driving scenarios first and second are applied on a hybrid electric vehicle model, the signals as shown in Figures 8 and 9 have occurred.

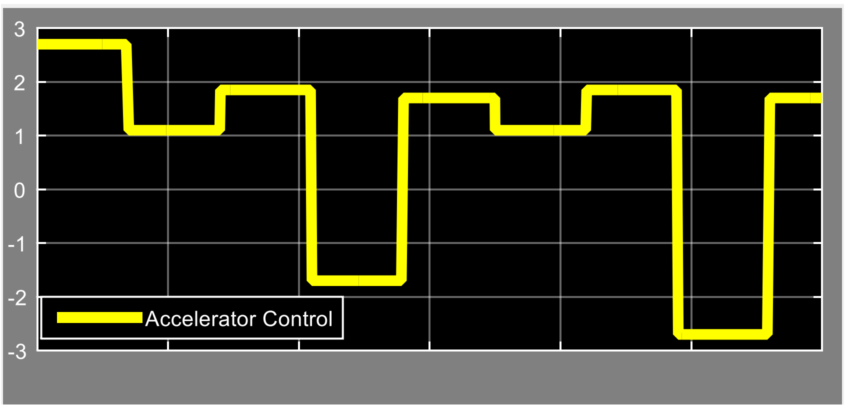


Figure 8. Hybrid electric car accelerator pedal signal for the first driving scenario

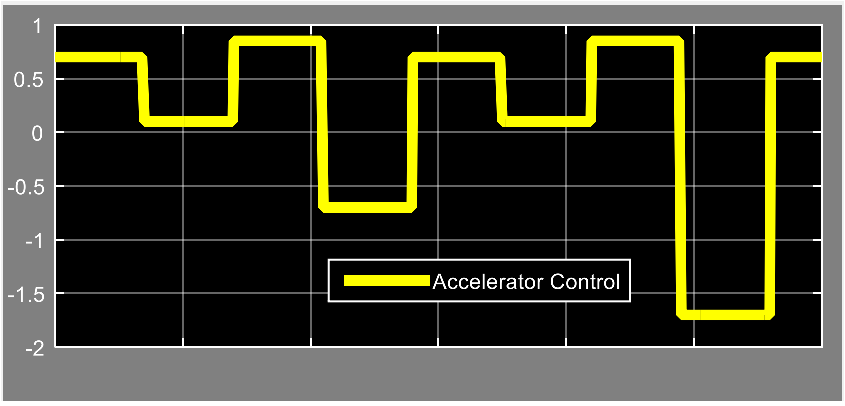


Figure 9. Hybrid electric car accelerator pedal signal for the second driving scenario

The accelerator signals, which move from negative to positive and from positive to negative, are also effective on hybrid mode change with accelerator signals indicating sudden drop in value and rise. While the accelerator pedal signals are positive, energy flows from the batteries to the electric motor. If the accelerator pedal signals are negative, the motor is powered by the engine and energy is flowing from the motor to the batteries. In this way, a detailed review of the charge and discharge graphs of the batteries and the more clear comments between the batteries has been made possible.

4. RESULTS AND DISCUSSION

In order to examine the charge and discharge characteristics of the batteries, the hybrid mode must change on the system. When hybrid mode is activated, discharge of batteries starts. When the hybrid mode switches to passive mode, it is ensured that the batteries are charged by running the generator on the system. As a result of the implementation of the first scenario on the simulation, hybrid mode change was achieved at five points. In this way, the five-time charging-discharge or discharge-to-charge characteristics of the battery packs were investigated.

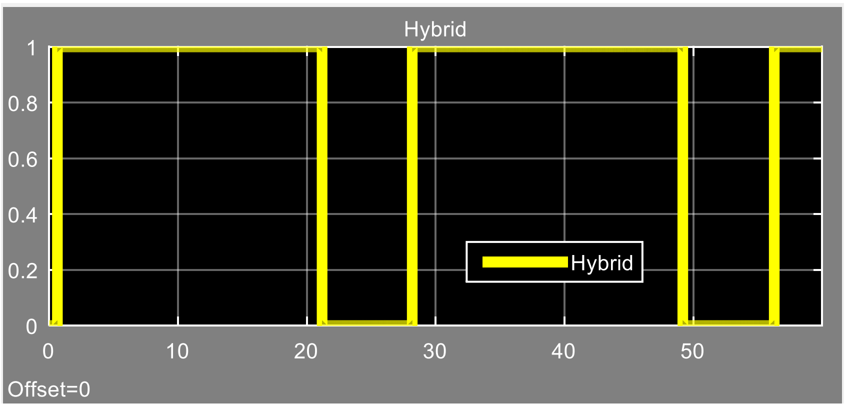


Figure 10. Hybrid mode change for the first driving scenario

In the second scenario, hybrid mode change was observed seven times. Transitions from charge in the first scenario were softer. In the second scenario, the reactions in harder transitions were analyzed.
In order to compare the performance of the battery packs with respect to each other, the occupancy rates at the minimum and maximum points of charge and discharge (SOC) are selected as parameters.

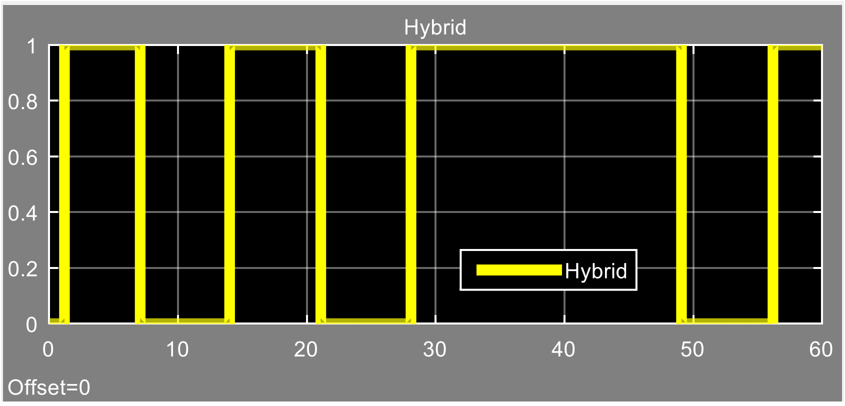


Figure 11. Hybrid mode change for the second driving scenario

4.1 First Driving Scenario

In the first scenario, when the charge-discharge characteristic analysis of LiFEPO4, Nickel-Metal-hydrid, Lead-Acid and Nickel-Cadmium batteries are examined, it is observed that the energies of the battery packs are reduced to minimum and recovered by charging at the fifty second of the simulation. During these transitions and energy changes, the LiFePO4 battery was observed as the least energy loss battery. It is observed that Lead Acid batteries have the most energy loss. These changes are presented in Figures 12, 13, 14 and 15.

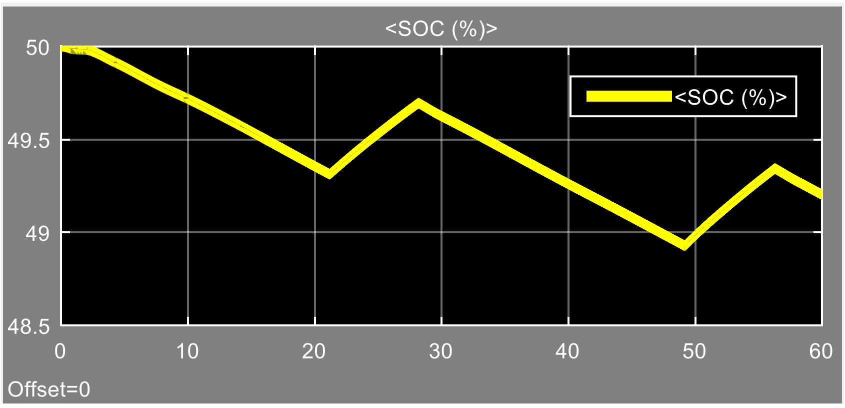


Figure 12. LiFePO4 battery charge and discharge characteristic

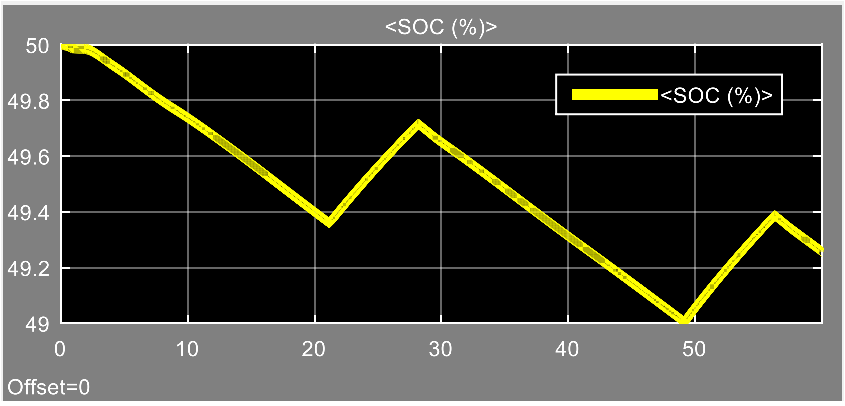


Figure 13.Nickel Metal Hydride battery charge and discharge characteristic

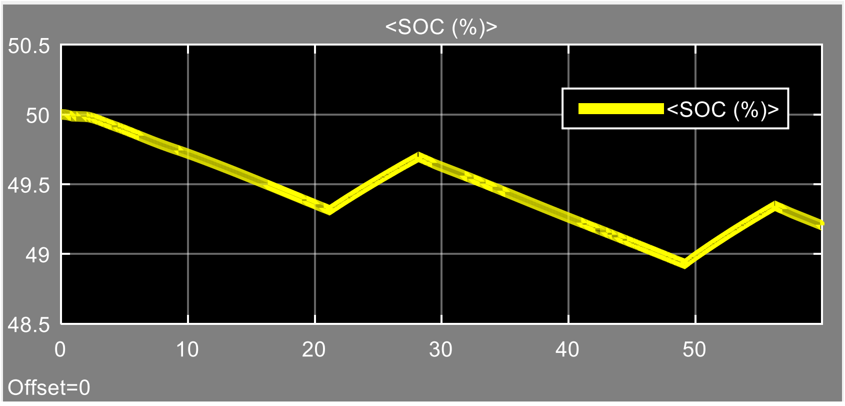


Figure 14. Pb-Acit battery charge and discharge characteristic

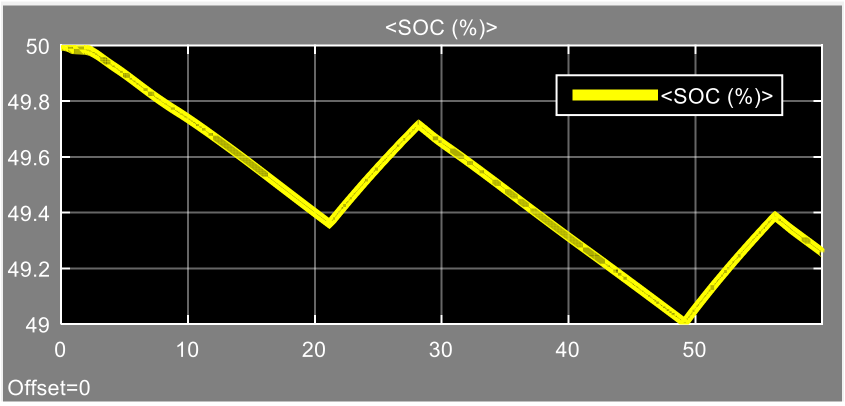


Figure 15. Nickel Cadmium battery charge and discharge characteristic

4.2 Second Driving Scenario

In the second scenario, when the charge-discharge characteristic analysis of LiFEPO4, Nickel-Metal-hydrid, Lead-Acid and Nickel-Cadmium batteries are examined, it is observed that the energy of the battery packs are reduced to minimum and recovered by charging in forty-ninety seconds of the simulation. During these transitions and energy changes, the LiFePO4 battery was observed as the least energy loss battery. It is observed that Lead Acid batteries have the most energy loss. These changes are presented in Figures 16, 17, 18 and 19.

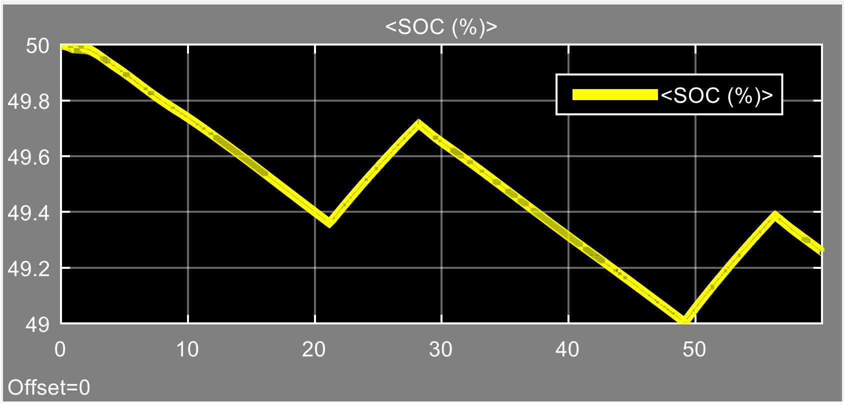


Figure 16. LiFePO4 battery charge and discharge characteristic

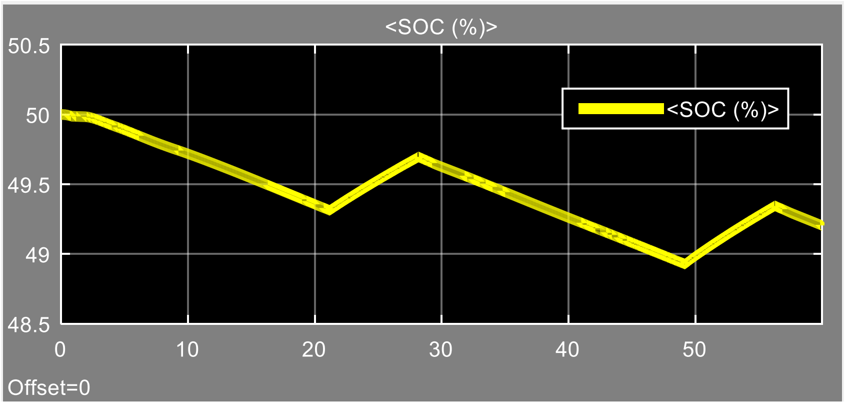


Figure 17.Nickel Metal Hydride battery charge and discharge characteristic

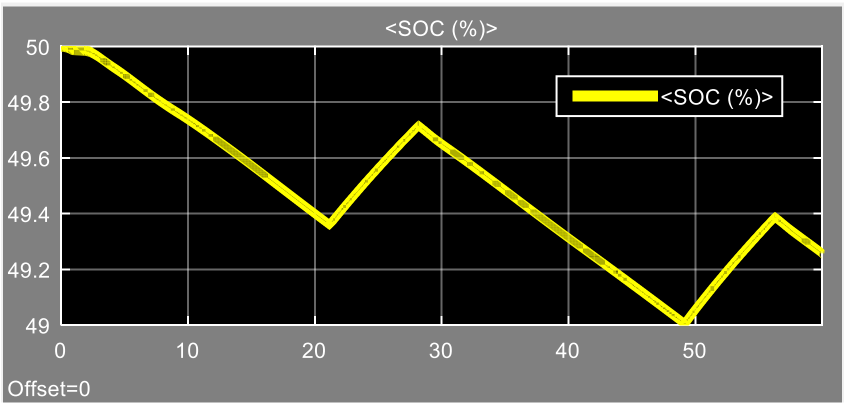


Figure 18. Pb-Acit battery charge and discharge characteristic

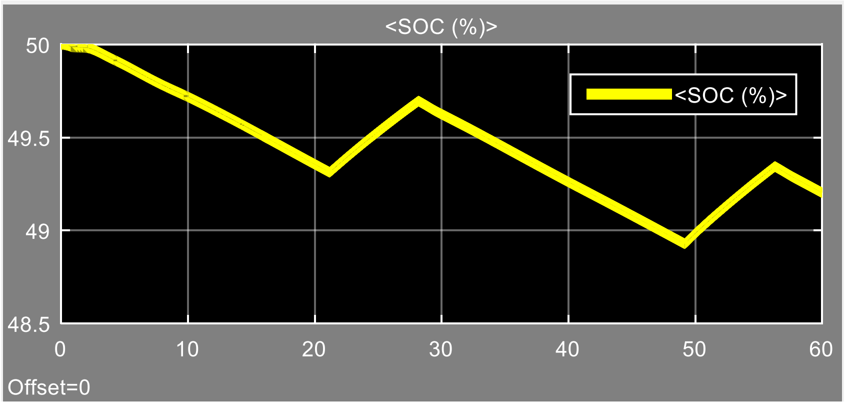


Figure 19. Nickel Cadmium battery charge and discharge characteristic

5. CONCLUSIONS

In this study, the problem of the selection of battery chemistry used in hybrid vehicles is discussed. The charge-discharge characteristics of the battery packs with four different chemistry models modeled in this scope were examined on two different scenarios on a hybrid vehicle model. The results were examined in terms of SOC parameters. The results obtained in the first driving scenario and the second driving scenario are presented in Table 3 and Table 4.

Table 3. SOC status of the batteries at the end of the first driving scenario

Batarya / Zaman	LiFEPO4 (SOC)	Metal Nikel Hidrit (SOC)	Kurşun Asit (SOC)	Nikel Kadminyum (SOC)
Başlangıç	%50	%50	%50	%50
T=21	%49.4	%49.45	%49.35	%49.4
T=28	%49.3	%49.6	%49.7	%49.55
T=50	%49	%48.95	%49	%48.9
T=55	%49.25	%49.2	%49.15	%49.2

Table 4. SOC status of the batteries at the end of the second driving scenario

Batarya / Zaman	LiFEPO4 (SOC)	Metal Nikel Hidrit (SOC)	Kurşun Asit (SOC)	Nikel Kadminyum (SOC)
Başlangıç	%50	%50	%50	%50
T=21	%49.5	%49.5	%49.55	%49.55
T=28	%49.7	%49.6	%49.8	%49.8
T=50	%49.2	%49.1	%49.4	%49.1
T=55	%49.5	%49.4	%49.2	%49.25

Accordingly, in both scenarios, LiFEPO4 was observed as a battery pack with the highest occupancy rate at the end of the simulation. Lead Acid was the lowest battery pack. In this study where the design constraints of the vehicles are not taken into consideration, it is observed that LiFEPO4 batteries exhibit the highest performance when considered as a SOC performance parameter for a hybrid electric vehicle.

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