Celal Bayar University Journal of Science
Volume 13, Issue 4, p 901-906

Conversion of Diesel Vehicles to Electric Vehicles and Controlled by PID Controller

Onur Özdal Mengi

Giresun University, Engineering Faculty, Energy Systems Engineering Department, Giresun, Turkey,
+904543104119, onur.ozdal.mengi@giresun.edu.tr

Received: 14 September 2017
Accepted: 21 November 2017
DOI: 10.18466/cbayarfbe.338211

Abstract

Internal combustion engine vehicles are the most produced and sold vehicles on the market. In recent years, interest in electric vehicles has begun to increase, especially due to the environmental problems. In the near future, it is estimated that gasoline and diesel vehicles will be completely electric vehicles. For this reason, many studies have been conducted on electric vehicles. Particularly the change of the engine parts, the turning of the internal combustion part to the electric motor, and the design of these motors has become an important parameter. In order to improve the performances of electric vehicles, the batteries of electric motors have been improved. In this study, a simulation was carried out to conversion 1.3 JTD and 1.3 Multijet motors to electric vehicles and the performances of these forms are evaluated by comparing the motor power, torque, and speed of the two vehicles. It was tried to predict what kind of changes will be achieved by conversion these two cars into electrical forms. PID controllers were used for inspecting components. In the study including detailed calculations, the program named AVL Cruise was used. The findings have shown that the quality of the new electric vehicle equipment used instead of the internal combustion engine can also affect results. The graphs from electric vehicles were explained and compared in detail. It was observed that there may be significant differences in the efficiency of the vehicles as a result of the conversion of the internal combustion engine to the electric motor. This made the biggest difference between the two vehicles. Since there is no data related to the sale prices of vehicles in the case of the conversion internal combustion vehicles to electric vehicles, comparisons were performed only on equipment. The latest price information of the vehicles has not been discussed.

Keywords—AVL Cruise, diesel vehicle, environment, electrical vehicle, PID controller

1. Introduction

The first Electric Vehicle (EV) in Turkey was ordered by Aldülhamit Han to the company named as Messrs Immisch & Co, and it was specially designed for Aldülhamit Han by two engineers. On the front of it, two close small wheels were used instead of a single large one and get patented by the company. The vehicle had a motor at 20 A, 48V, and 1 horsepower [1].

Despite the interest on EV's between 1920 and 1960 had been reduced [2, 3] it was understood that Internal Combustion Engines (ICE) caused air pollution by releasing the exhaust gases to the atmosphere, and thus people began to produce the EV's again to prevent air pollution [3, 4].

When it is considered that the maximum efficiency is 35% in ICE vehicles, the energy loss occurs in the compression of the fuel and the friction of the pistones, and some of it spread as a heat to the environment [5]. However, the electric vehicles provide up to 80% energy savings due to the high efficiency of their electric engines [6]. In terms of performance and comfort, electric vehicles can easily compete with ICE vehicles [7].

A lot of parameters are used in the conversions of electric vehicles, and in some cases the differantial is lifted and four Parmanent Magnet Synchronous Motor (PMSM) wheels to each wheel are placed, and the effect of the system on current is analysed at the beginning of the vehicles torque [8]. The efficiency, power and speed of the engine were analysed and compared with New European Driving Cycle (NEDC) and China Typical Urban Cycle by determining all of the motor drive parameters and battery power of the all-electric vehicles [9]. By comparing Japan 08 Driving Cycle and NEDC cycles, the motor efficiency, engine power, speed, and fuel efficiency of the electric vehicle were calculated and compared in both hibrid electric vehicle and the all-electric vehicle [10]. The engine speeds, torques, and powers are compared by performing the simulation of ICE vehicle and hibrid electric vehicles with supercapacitors connected to the electric motor [11].

In the study, 1.3 JTD and 1.3 Multijet ICE vehicle models were converted to the all-electric vehicle, the simulations of these models were performed, and the speeds, mechanical powers, and torques of the electric vehicles after the conversion were compared. 1.3 JTD and 1.3 Multijet electric vehicles had the electrical power with the values in current-voltage curve, and when these vehicles were analysed in the NEDC cycle, the electric power and efficiency of the electric motor and the electric power and power loss of the battery were investigated. PID controllers were used to the regulation and control of all these systems. The simulation was carried out with the AVL Cruise program.

2. Materials and Methods

The ICE vehicles were converted to the all-electric vehicles by modifying on 1.3 JTD and 1.3 Multijet models found in the AVL Cruise. The basic structure of an electric car model is shown in Figure 1. The reason for choosing these two models was that these models have not been converted to electric vehicles yet.

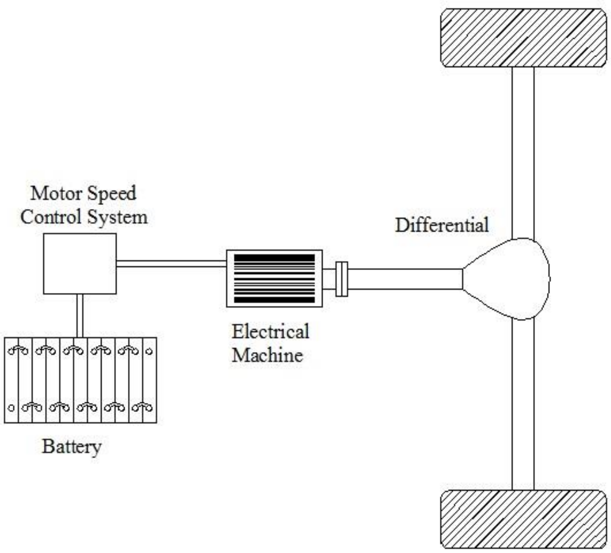

Figure 1. The electric vehicle model

The mathematical equations belonging to the vehicles were given between Equation (1) and Equation (12). In these formulas, important values such as powers, efficiency and torque that would be obtanied from the motors were calculated.

The engine power (P) was calculated by using Equation (1):

$$P = T * \frac{2 * \pi * n}{60} \tag{1}$$

Here, T is tork and n is speed.

The electric power was calculated with Equation (2) as follows

$$P_{elk} = V * I \tag{2}$$

Here, V is voltage and I is current.

The efficiency was

$$\eta = \frac{effective\ power}{total\ power} = \frac{P_{eff}}{P_{sum}} \tag{3}$$

The power loss was calculated as

$$P_{loss} = P_{sum} - P_{eff} \tag{4}$$

A real tork of power transfer was calculated as:

$$M_{EM;dt} = M_{EM} - \Theta_{EM,nom}\ddot{\varphi}_{EM,out} \tag{5}$$

The following calculation was used for asynchronous machines:

$$M_{EM}(T_{EM}) = (1 + \beta_{EM,REm}(T_{EM} - T_{EM,L}))M_{EM}(T_{EM,L}) \tag{6}$$

(Power transfer was off)

$$M_{EM} = M_{EM,drag}\ (\dot{\varphi}_{EM} / \dot{\varphi}_{EM,max})^2 \tag{7}$$

Iron losses must be taken into consideration for asynchronous machines. Power transfer was (if k>0);

$$M_{EM} = kM_{EM,max,mot} \tag{8}$$

Otherwise, $M_{EM} = (-k)M_{EM,max,gen}$

The electric power:

$$P_{EM,el} = P_{EM,mec} + P_{EM,loss} \tag{9}$$

$P_{EM,loss}$ consist of the iron loss, the cupper loss and the loss according to the friction. It turns completely into heat. Power transfer is

$$P_{EM,mech} = \dot{\varphi}_{EM} M_{EM} \tag{10}$$

The maximum torque was defined using the following power loss:

$$R_{th} = 1/\propto_{EM;th} \tag{11}$$

$$I_{EM} = P_{EM,el} / U_{EM,net} \tag{12}$$

Here, the characteristic maps and curves (M_{EM}) are shown as inertia moment ($\Theta_{EM;nom}$), drag torque ($M_{EM,drag}$), magnet induction temperature coefficient ($\beta_{EM,REm}$), maximum torque-motor ($M_{EM,max,mot}$), maximum torque-generator ($M_{EM,max,gen}$), power loss ($P_{EM,loss}$), maximum angular speed ($\dot{\varphi}_{EM,max}$), actual electric power ($P_{EM,el}$), net voltage ($U_{EM,net}$), current (I_{EM}), temperature (T_{EM}), layout temperature ($T_{EM,L}$), specific heat transition $\square_{EM;th}$, torque M_{EM} (T_{EM}) abd loss of power R_{th} [12].

3. Simulations

The vehicles with 1.3 JTD and 1.3 Multijet motors were converted to the electric vehicles, and the simulations were performed. The performances of these two vehicles were investigated by using the same type of electric motor and battery. System has an inverter in eDrive block. The gear changes according to the number of speed.

3.1 1.3 JTD EV

The converted form of the vehicle with 1.3 JTD motor to electric vehicle is shown in Figure 2.

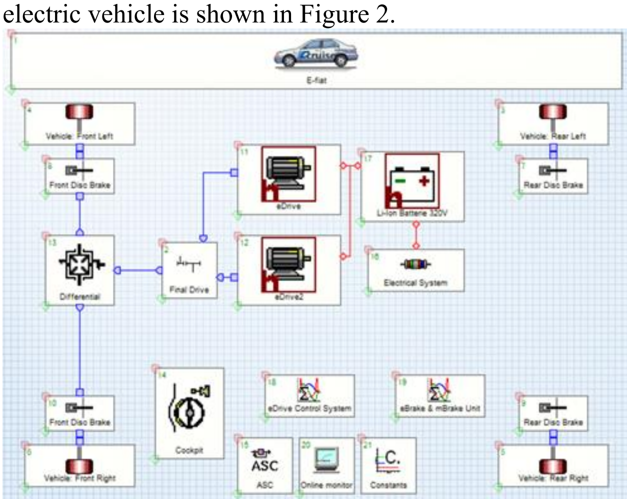

Figure 2. 1.3 JTD electric vehicle model

Lithium ion type battery was used in the model. The voltage had a minumum value of 220 V and maximum of 420 V. The electric motor used as an asynchronous motor had a voltage of 320 V, inertia moment of 1.0 $e^{-4}kgm^2$, and rotation speed of the electric machine varied between 500 rpm and 7500 rpm and accordingly the efficiency varied between 65 and 93%. When the load status of the vehicle is empty, half and full, the distance of the center of gravity was 930.5 mm and the gross weight was 1700 kg.

3.2 1.3 Multijet EV

The converted form of the vehicle with 1.3 Multijet motor to electric vehicle is shown Figure 3. Lithium ion type battery was used in the model. The voltage had a minumum value of 220 V and maximum of 420 V. The electric motor used as an asynchronous motor had a voltage of 320 V, inertia moment of 1.0 $e^{-4}kgm^2$, and rotation speed of the electric machine varied between 500 rpm and 7500 rpm and accordingly the efficiency varied between 65 and 93%. When the load status of the vehicle is empty, half and full, the distance of the center of gravity was 850 mm and the gross weight was 1520 kg.

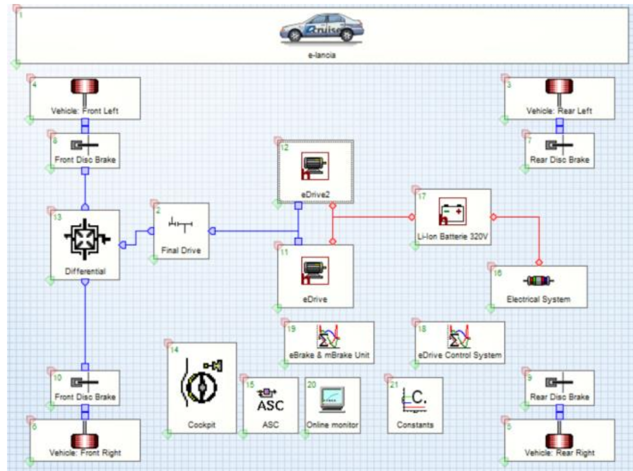

Figure 3. 1.3 Multijet electric vehicle model

3.3 PID Controller

PID controllers are the most widely used controllers in industry. They consist of proportioanal-integral-derivative components. By adjusting these coefficients, it is tried to reduce the error value to the lowest one. The proportional, integral and derivative coefficients are determined by taking into consideration such as the rise time, settlement time and maximum overshot of the system [13]. The basic equation of the controller output is:

$$U(s) = K_P + \frac{K_I}{s} + K_D.s\,E(s) \qquad (13)$$

Here, K_P, K_I, K_D are proportional, integral and derivative coefficients, respectively [14, 15]. The PID controller was used to set and control the motor parameters. PID controller parameters were found by try and test. It controls the car speed. Proportional parameter is 10 and integral parameter is 0.0001.

4. Results

When analysed the performance graph in Figure 4 of 1.3 JTD model after the conversion to the electric vehicle, after the vehicle started, the electric motor reached the highest torque at 0,083 s.

This value then remained stable for a while and decrased. The torque was read as 240 Nm from the graph. When the torque of the electric motor was the highest, the speed of the motor increased from 2560.18 1/min to 2999.57 1/min and the mechanical power increased from 64.34 kW to 75.39 kW. When the maximum speed of the motor was 3806,31 1/min, the power of the motor was 75.29 kW.

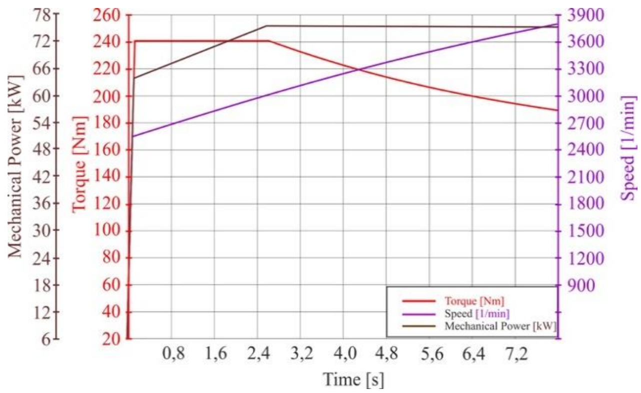

Figure 4. The torque, power, and speed of the electric motor of the 1.3 JTD electric vehicle over time

The torque and the motor speed respectively were selected values between 15.61 Nm<T<240 Nm and 2526.61 1/min<n<3806.31 1/min. When these values were placed in the Equation (1), the following result was obtained:

$P=228.085*((2*\pi*3153.36)/60)= 72.32$ kW
Here, the torque and the rotation speed were read as 228.09 Nm and 3153.36 1/min, respectively.

According to the NEDC, when the 1.3 JTD electric vehicle was tested, the speed of the vehicle engine appeared as Figure 5. In this cycle, the speed, acceleration, and speed in travelling at constant speed of the vehicle were seen. It was observed that as the speed of the vehicle increased, the mechanical strenght increased, and the power decreased as the vehicle slowed down.

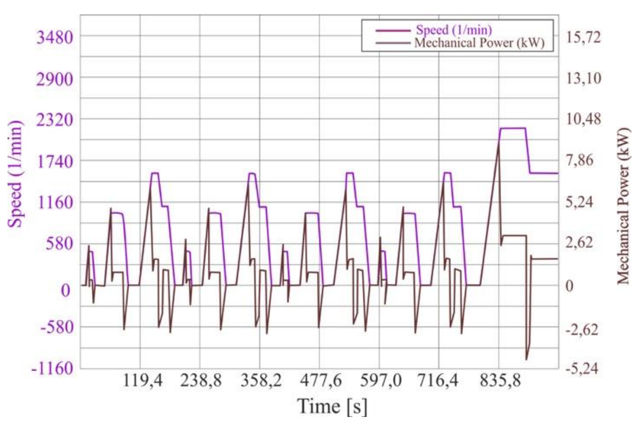

Figure 5. The speed and mechanical strenght of the 1.3 JTD electric vehicle engine in the NEDC cycle

The variations of current and voltage with time belonging to the same vehicle are shown in Figure 6.

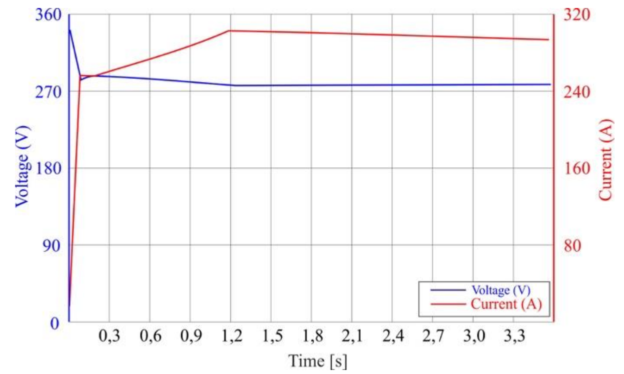

Figure 6. The current and voltage of the 1.3 JTD electric vehicle engine

In Figure 7, the electrical power and efficiency of the vehicle were compared. As in the ICE vehicles, the efficiency was very high in electric vehicles due to the some of the power obtained did not turn into heat and there was no great difference between electrical power and mechanical power. The efficiency of the vehicle was 85% and the electrical power was 19.73 kW. The remaining power loss of 15% has shown that electric vehicles are quite good compared to the efficiency of the vehicles with internal combustion motor.

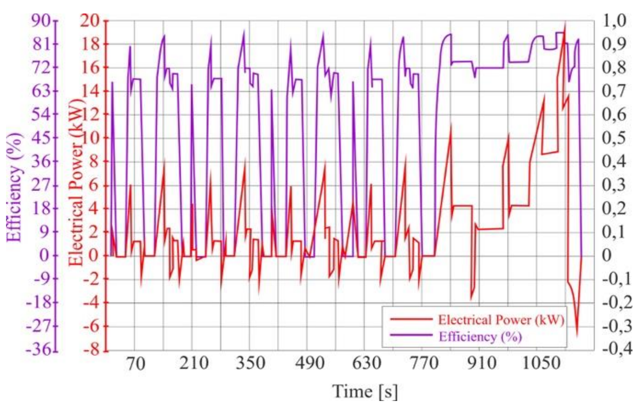

Figure 7. The electrical power and efficiency of the 1.3 JTD electric vehicle engine in the NEDC cycle

The voltage and current values were between 276.17<V<345.07 and 15.82<I<303, respectively. When the values in these ranges were substituted in Equation (2), the following result was obtained;

$P_{elk}=345.05$ V*15.83 A=5.46 kW
P_{sum} was between 5.46 kW and 83.76 kW and P_{loss} was between 1.33 kW and 8.51 kW. The values were placed in Equation (4), the following result was obtanied;

$P_{eff}=5.46$ kW-1.33 kW=4.13 kW
These values were substituted in Equation (3) the following result was obtained;

$\eta=P_{eff}/P_{sum}$ =4.13 kW/5.46 kW=%75.6
The graph of the current voltage values of the electric motor is as follows.

The electrical power and power loss of the battery of the electric vehicle are shown in Figure 8. Since the electric motors will use the power in the battery, the electrical power is taken as negative and the losses are taken as positive. Also, the portions where the electrical power is positive are the moments when the vehicle stops.

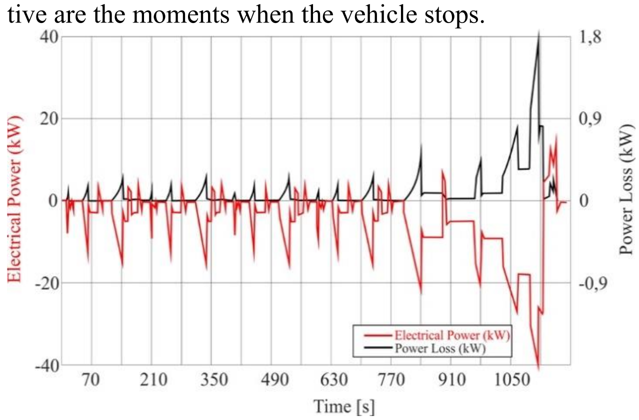

Figure 8. The electrical power and power loss of the battery of the 1.3 JTD electric vehicle over time in NEDC cycle

When investigated the performance graph after the conversion of 1.3 Multijet model to the electric vehicle, after the vehicle started, the electric motor reached the highest torque at 0.083 s in Figure 9.

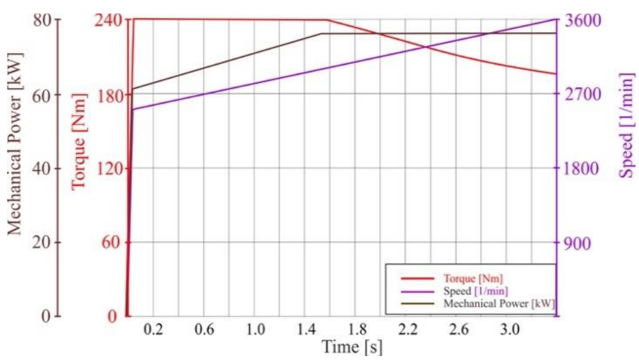

Figure 9. The torque, power and speed over time of the electic motors of the 1.3 Multijet electric vehicle model

This value then remained stable for a while and decrased. The torque was read as 240 Nm from the graph. When the torque of the electric motor was the highest, the speed of the motor increased from 2393.38 1/min to 2992.13 1/min and the mechanical power increased from 60,15 kW to 75.2 kW. When the maximum speed of the motor was 3550.34 1/min, the power of the motor was 75.16 kW.

The torque and the motor speed respectively were selected values between 16.7 Nm<T<240 Nm and 2361.77 1/min<n<3550.34 1/min. When these values were placed in the Equation (1), the following result was obtained:

P=232.04*((2*π*3100.75)/60)= 75.35 kW

According to the NEDC, when the 1.3 Multijet electric vehicle was tested, the speed of the vehicle engine appeared as Figure 10. In this cycle, the speed, acceleration, and speed in travelling at constant speed of the vehicle were seen. It was observed that as the speed of the vehicle increased, the mechanical strenght increased, and the power decreased as the vehicle slowed down.

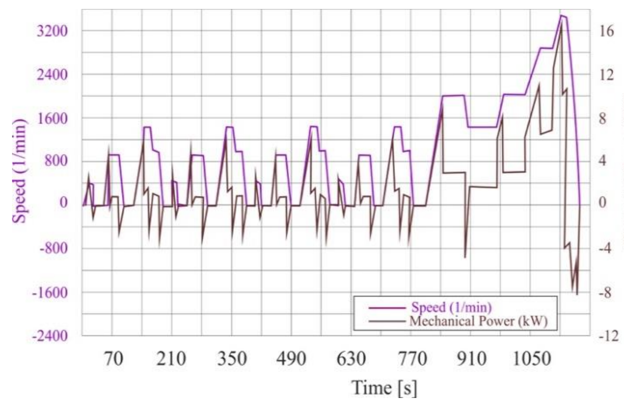

Figure 10. The speed and mechanical strenght of the 1.3 Multijet electric vehicle engine in the NEDC cycle

When evaluated the electrical power and efficiency data related to the operating performance of the vehicle, the efficiency was very high because of few losses would obtained from the power. Furthermore, when evaluated the mechanical power and the electrical power in Figure 11, there was no significant difference between them.

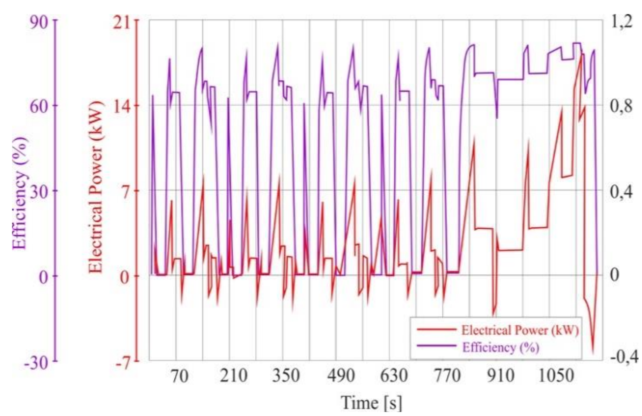

Figure 11. The electrical power and efficiency of the 1.3 Multijet electric vehicle engine in the NEDC cycle

The voltage and current values were between 274.18<V<343.61 and 15.72<I<305.92, respectively. When the values were placed in Equation (2), the following result was obtained;

P_{elk}=277.86 V*293.65 A=81.59 kW

P_{sum} was between 5.4 kW and 83.7 kW and P_{loss} was between 1.27 kW and 8.54 kW. The values were placed in Equation (4), the following result was obtanied;

P_{eff}=82.73-7.56=75.17 kW

When these values were substituted in Equation (3) the efficiency was calculated as

$\eta = P_{eff}/P_{sum}$=75.17 kW/82.73 kW=90,8%

The graph of the current voltage values of the electric motor is as follows. The electric power of the electric motor was solved as given in Equation (2).

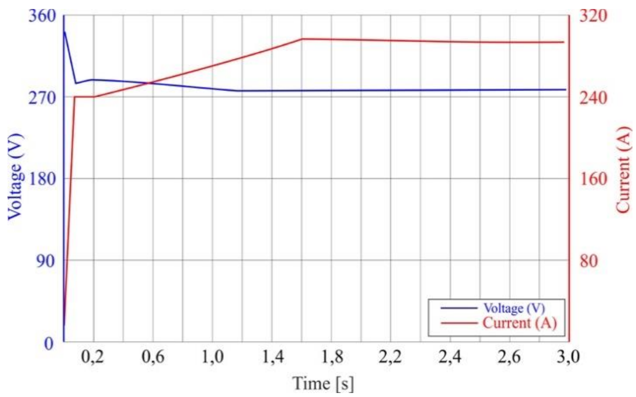

Figure 12. 1.3 The current and voltage of Multijet electric vehicle motor

The electrical power and power loss of the battery of the electric vehicle are shown in Figure 13. The electrical power of 19.57 kW obtained with the efficiency of 87% and the remaining power loss of 13% makes this vehicle more useful than the 1.3 JTD electric vehicle.

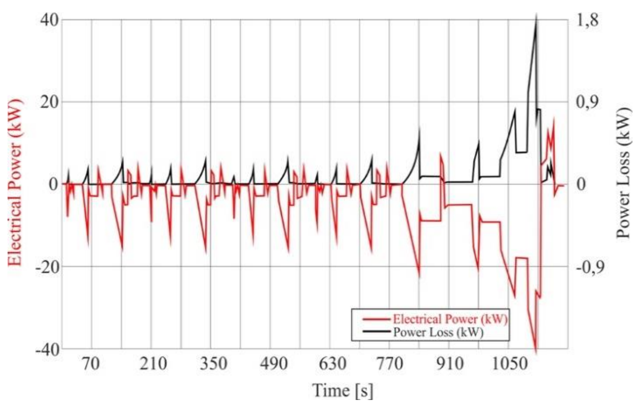

Figure 13. The electrical power and power loss of the battery of the 1.3 Multijet electric vehicle over time in NEDC cycle

5. Discussion

After the simulation of 1.3 JTD and 1.3 Multijet EVs, the highest torque values were the same because of the same electric motor were used for both vehicles, but the speed of the 1.3 Multijet EV model were higher than that of the other in terms of motor power. Therefore, when considered the power of the vehicles, the power of 1.3 Multijet EV was more increased than that of 1.3 JTD EV. When the EV models were simulated in the NEDC cycle, the data obtained from the current-voltage curve were used to find the electric power, and the mechanical power data was similar for both vehicles. When the efficiency of both vehicles was compared, the efficiency of 1.3 Multijet EV was 90.8% while the efficiency of 1.3 JTD EV was 75.6%. The results were obtained by using specific parameters related to the vehicles. As the vehicles will evolve or more parameters are controlled, the results may change. Furthermore, the costs of the vehicles have not evaluated in the present study.

References

1. Wakefield, E.H., "History of the electric automobile, The Society of Automobile Engineers, Warrandale, 1994.
2. Nor, J.K., Art of charging electric vehicle batteries. WESCON/93. Conf. Rec., San Francisco, CA, 1993.
3. Dhameja, S., Electric vehicle battery systems; Press: Newnes Press Boston, 2002.
4. Leitman, S. and Brant, B., Build your own electric vehicle, Press: McGraw-Hill Companies, USA, 2008.
5. Larminie, J; Lowry, J., "Electric vehicle tecnology explained", Press: John Wiley and Sons, England, 2003.
6. Chau, K.T; Wong, Y.S, Overview of power management in hybrid electric vehicles, *Energy Conversion and Management*. 2002;43(15), 1953-1968.
7. Çınar, M.A; Gündoğan, Ç; Kuyumcu, F.E., Elektrik tahrikli taşıtlar için çekiş kontrol sistemi simülasyonu. ELECO'2004 Elektrik Elektronik Bilgisayar Mühendisliği Sempozyumu, Bursa, Türkiye, 8-12 Aralık 2004.
8. Jin, L.Q; Cai, W.B., Study on fuzzy control for starting torque of vehicle with motorized wheels, IEEE 7th International Power Electronics and Motion Control Conference – ECCE, Harbin, China, 2-5 Haziran 2012.
9. Meilan, Z; Liping, Z; Yu, Z; Zhaoming, G; Rongjie, P., Pure electric vehicle power-train parameters matching based on vehicle performance, *International Journal of Control and Automation*. 2015; 8(9), 53-62.
10. Bambang, W; Widodo, B.S; Arifin, N.A., Analysis of range extender electric vehicle performance using vehicle simulator, Energy Procedia, 2015; 68, 409 – 418.
11. Yajuan, Y.; Han, Z.; Hao, J., Drive train design and modeling of a parallel diesel hybrid electric bus based on avl/cruise, *World Electric Vehicle Journal,* 2010, 4, 75-81.
12. AVL list GmbH. AVL Cruise theory manual; Document no. 04.0108.2009, Austria, 2009.
13. Kuo, B., Otomatik kontrol sistemleri; Press: Literatür, Türkiye, 1999.
14. Dorf, R., Modern control systems; Press: Pearson, USA, 2014.
15. Palm, W., System dynamics; Press: McGraw Hill Int., USA, 2014.