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Original Research Article

The Simulation of a Full Electric Vehicle Using the City Cycle

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Abstract

In this present study, the design and simulation of an electric vehicle again commonly being started to be used in twenty-first century have been carried out by Matlab program. A full-electric vehicle has been used as a model. In modeling, the dimensions of a vehicle suitable for use and the technical features of an electric motor used in today's electric vehicle technology have been utilized. In this model, a DC motor for the propulsion of the electric vehicle, a battery with sufficient quality as a source of energy and Urban Dinamometre Driving Schedule (UDDS) city cycle as a cycle has been used. According to this cycle, forces make the vehicle move and resistance forces preventing its movement have been calculated. Besides, a data file which describes the movement characteristic of the vehicle has been composed. This file brings also simultaneously the rates of power and torque which the vehicle needs. For the same cycle, torque, power and current changes of the electric motor used for the propulsion of the vehicle have been obtained depending upon time.

Key words: Electric vehicle, Matlab, simulation, vehicle design, UDDS

Nomenclatures

A	frontal area of the vehicle [m^2]
a	vehicle acceleration [m/s^2]
B	magnetic field strength [Wb/m^2]
C_d	aerodynamic resistance coefficient [-]
E	motor voltage constant [-]
E_b	back EMF [V]
E_s	supply voltage [V]
F	force [N]
F_{ad}	air resistance (drag) force [N]
F_{rr}	rolling resistance force [N]
F_{hc}	climbing resistance force [N]
F_{la}	linear acceleration force [N]
F_{wa}	transmission resistance force [N]
F_{te}	total tractive effort force [N]
G	gear ratio [-]
I	current [A]
K_m	motor constant [-]
I_i	moment of inertia of motor rotor [kgm^2]
m	Mass of vehicle (kg)
n_a	armature revolution number[min^{-1}]
P_{te}	total effort power [W]
R_a	impedance of armature [Ω]
r	wheel radius [m]
r_a	armature radius [m]
T	motor torque [Nm]
T_{max}	maximum motor torque [Nm]
V	vehicle speed [m/s]
v_a	speed of excitation winding [min^{-1}]
ω	angular speed [rad.s^{-1}]
ω_c	critical angular speed [rad.s^{-1}]
η	gear system efficiency [%]
μ_{rr}	rolling resistance coefficient [-]
ρ	air density [kg/m^3]
ψ	angle of road slope [°]
Φ	magnetic flux [Wb]doi:

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1. Introduction

The 40% of based petroleum fuels is used in transportation and transport [1]. Among all pollutants thrown into atmosphere; the 65% of carbon monoxide, the 55% of nitrous oxide, and the 55% of hydrocarbon result from the exhaust emissions of vehicles using gasoline and diesel fuels [2]. The damage to nature of fossil based fuels effects human healthy negatively [3-7] and also increasing prices of fuels compel today people to search the alternative fuel [8].

In 21st century, the vehicles that have high energy efficiency, environmentally friendly and also relatively low fuel consumption are preferred by humankind. The vehicles that can respond to this demand are vehicles operating with alternative fuels and electric, hybrid electric, fuel cell vehicles [9]. The range of the vehicle is short due to heavy and large volume batteries used in full electric vehicles. The other reason of this situation depends on their capacities which are limited, and their long charge duration [9]. This disadvantage of full electric vehicles has brought out the hybrid electric vehicle technology. Hybrid electric vehicles have composed of a power supply producing power with fuel or a storage element storing electric energy assisted by solar energy [10-11] and electric motor [12-14]. In the electric vehicle technology, the other type is the vehicle operating with the fuel cell. The application of the fuel cells to vehicles is at the final stage, and it is predicted that its usage will increase with its proliferation of the production basis, service network, and also the production and storage of the fuel [9, 15-17]. Electric motor acts as a generator and can charge the battery while braking in full electric and hybrid electric vehicles [18-19]. Thus, the kinetic energy which the vehicle lost because of pedaling is recovered [20-21]. The first stage of design and production consists of the design and simulation of electric vehicle. Simulation programs are used for this and ease the production by providing its made in short time without any system performance [9]. The energy that will be spent on performance provides savings from cost and time [22]. In many research [23-28] electric and hybrid vehicle simulations have been made by using various simulation programs. In this performed study, the characteristics of electric motor and vehicle movement are described by using the dimensions of a vehicle that is convenient to be used in real conditions.

2. Electric Vehicle Dynamic's Determination

When a vehicle moves, it is under the influence of forces propelling to move, and also vehicle resistance forces preventing to move. These forces are two types; which one is the propulsion force transmitted to wheels with the drivetrain and produced by the motor to the move, and the other is the force that resists to this move. As seen in Figure1, Resistance force preventing to vehicle's move consist of transmission resistance force, rolling resistance force, aerodynamic drag resistance force, hill climbing resistance force, and linear acceleration resistance force. The vehicle has to overcome the resistance forces to move.

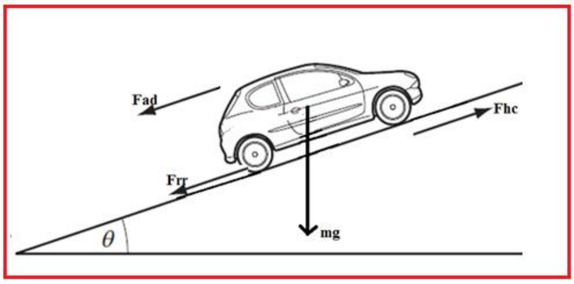

Figure1. Powers effecting to vehicle's move

An expression is required to describe the total propulsion force that is essential for vehicle to move. By summing the resistance forces for this equation;

$$F_{te} = F_{rr} + F_{ad} + F_{hc} + F_{la} + F_{wa} \quad (1)$$

the equation is obtained [29] In this equation; Rolling resistance force;

$$F_{rr} = \mu_{rr} mg \quad (2)$$

Aerodynamic drag resistance force;

$$F_{ad} = \frac{1}{2}\rho A C_d V^2 \quad (3)$$

Hill climbing resistance force;

$$F_{hc} = mgsin(\theta) \quad (4)$$

linear acceleration resistance force;

$$F_{la} = ma \quad (5)$$

and

$$F_{wa} = I_i \frac{G^2}{\eta . r^2} a \quad (6)$$

transmission resistance force is described. Where, I_i: the moment of inertia of the electric motor (kgm^2), G: Gear ratio, r: Wheel radius (m), η: Transmission efficiency (%), m: vehicle mass (kg), μ_{rr}: Rolling resistance coefficient, ρ: air intensity (kg/m^3), C_d: Aerodynamic resistance coefficient, V: vehicle speed (m/s), θ: slope angle, A: front surface of the vehicle area (m^2), a: vehicle acceleration (m/s^2).

A tractive effort is required to be composed in the propulsion wheels in order to move the vehicle as the total of the movement resistances that affect the vehicle [30]. The essential power statement for the vehicle to move is given with;

$$P_{te} = F_{te} V \quad (7)$$

Depending upon vehicle propulsion force, the electric motor torque is given with;

$$T_m = \frac{F_{te}\, r}{G\eta} \quad (8)$$

The statement of electric motor power depending on the electric motor torque is given with;

$$P_m = \frac{T_m\, n}{9549} \quad (9)$$

The wheel propulsion torque depending on the vehicle propulsion force

$$T_w = F_{te} r \quad (10)$$

can be written.

The angular velocity of electric motor depending upon vehicle radius, the expression

$$\omega = G \frac{V}{r} \text{ (rad/s)} \quad (11)$$

The maximum speed of vehicle calculated by considering maximum revolution of electric motor,

$$\omega = G \frac{V_{max}}{r} \text{ (rad/s)}, \; V_{max} = \omega \frac{r}{G} \quad (12)$$

is found by these expressions.

As using the given values of motor at Chart 2, the impedance is found from term of;

$$R_a = \frac{E_m}{I_{max}} \quad (13)$$

As using a revolution of motor, E_m motor voltage; E voltage constant is found from the term of,

$$E = \frac{n}{E_m} \quad (14)$$

The statement can be written. The changeable numeric value is indicated with $K_m\Phi$ depending upon the magnetic area wraps and number of pole pairs and other aspects of electric motor;

$$K_m\Phi = \frac{60.E}{2.\pi.n} \quad (15)$$

Statement is obtained. Numerical value of term $K_m\Phi$ is found. Then maximum moment of motor is calculated from the formulation;

$$T_{max} = K_m \Phi I_m \quad (16)$$

Depending upon electric motor torque, for electric current of the motor,

$$I_m = \frac{T_{max}}{K_m\, \Phi} \quad (17)$$

can be written.

3. Material and Methods

The features of vehicle and motor are required to be known so that simulation studies of the electric vehicle can be made. In adapting the electric motor with the vehicle movement characteristics, technical features that are given in Chart 1 are used for the vehicle. For electric motor, a modeling has been made in Matlab by considering technical features of DC series motor that has 72 kW power and 154 Nm maximum torque in given Chart 2, as well as expressions which describe DC motor characteristics.

Table 1: The technical features of electric modeled vehicle.

Vehicle		**Other parameters**
Length of the vehicle	4.6 m	G=6 ρ=1.25 kg/m^3
Vehicle width	1.85 m	μ_{rr}= 0.0048 g=9.81 m/s^2
Vehicle height	1.4 m	C_d=0.19 A=2.33 m^2
Total vehicle weight	1105 kg	
Wheel radius (r)	0.3 m	
Battery	Lithium-Ion	
Nominal Voltage	340 V	
Nominal Current	265 A	
Capacity	72 Ah	

Table 2: Technical values of electric motor

Electric Motor	DC
Rated Voltage, Current, Max Current	340 VDC, 265A, 1400A
Rated Power	72 kW
Rated speed	5600 min^{-1}
Excitation	Series

In the simulation studying, the model of the series hybrid electric vehicle given in Figure 2 has been taken as basis.

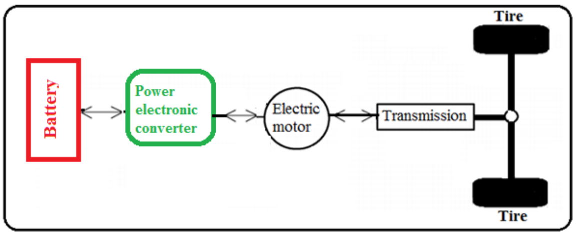

Figure 2. Electric vehicle model layout

In Figure 2, the schematic figure of electric vehicle model used in simulation studies and the elements composing the model are given. In the model, the electric motor propelling wheels and the battery system providing required energy to the motor has been used. The electronic control unit (ECU) that controls the energy management of battery also exists.

4. Results and Discussion

In the simulation of electric vehicle, UDDS city cycle has been used as the city cycle. In this cycle, the simulation duration is taken as 1369 seconds.

In UDDS speed-time cycle, the calculations have been made by taking into consideration of values that belongs to electric vehicle given in Table 1. At the end of these calculations, the graph of the acceleration and range of electric vehicle is drawled.

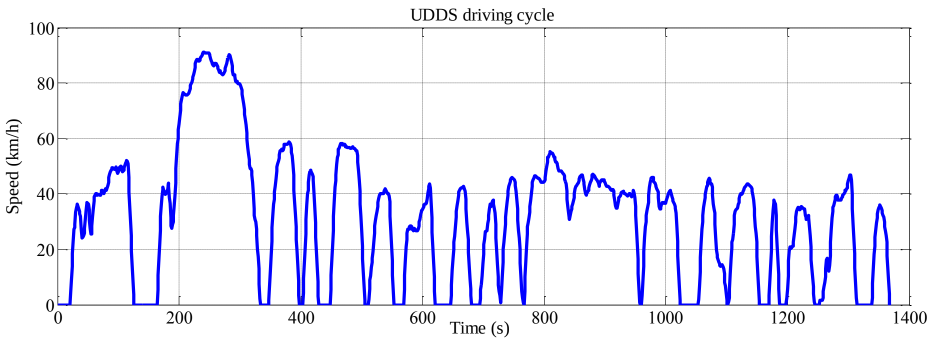

Figure 3. UDDS driving cycle

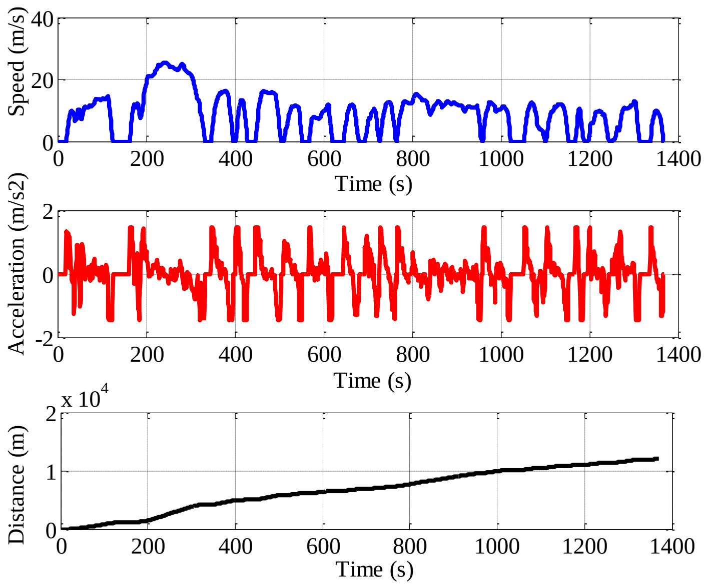

Figure 4.The graph of vehicle’s speed, momentum and range

The electric motor torque has been calculated by using Equation (8) and the interchange of the calculated motor torque graph has given in Figure 5. The obtained maximum torque during the cycle overlaps with the value of motor given in the chart. Besides, the motor torque increases during the stages of speed increasing of the vehicle, and the current that motor requires increases in positive value.

The power amount of electric motor needed for the propulsion of vehicle has been calculated by using Equation (9) during UDDS cycle and the graph of obtained power has given in Figure 6. Power values needed for the propulsion of vehicle during cycle varies depending on the time. Negative values in the graph based on the power which is not needed during the vehicle decelerates. Regenerative energy is produced. This energy is used to charge the battery. However, amount of this energy is not mentioned in this study. It is considered that the battery completely supplies the amount of energy required for the vehicle's movement with this charge energy support. References with number [18-22] are in the manner to support this consideration when the vehicle speed reaches the maximum values, the electric motor power reaches an also maximum value that is 72 kW at the same time. This situation has been seen in Figure 6.

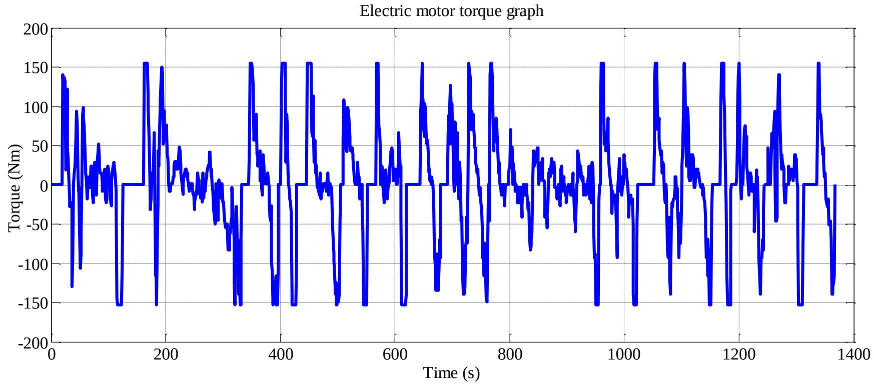

Figure 5. Electric motor torque

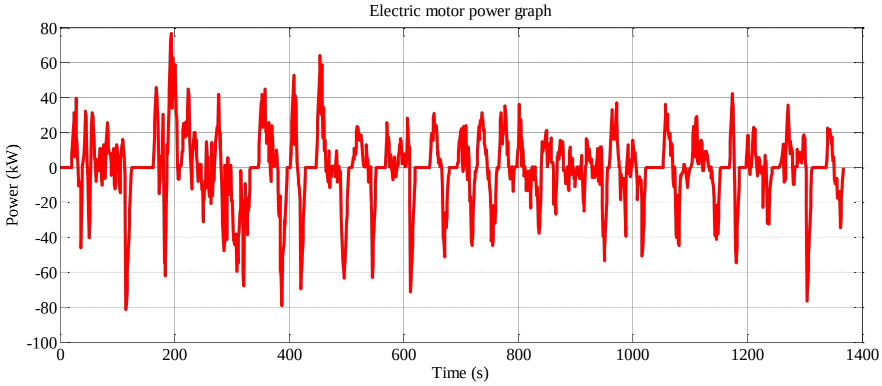

Figure 6.Electric motor power

Using the Equation (17), the current change of electric motor is calculated through the cycle. The working current of electric motor is 265 A value that is stated in Table 2.

After the simulation, the current values of electric motor indicate similarities with the catalog values. The current graph of electric motor depending upon time is seen in Figure 7. The values seen in graph adjust to the values of the power-time graph that the vehicle needs instantaneous. Electric motor currents increase during the increase of vehicle's torque requirement whereas they produce regenerative energy by having negative values at stages when the vehicle slows down.

Considering the Equation (10), the torque values that the vehicle need have been calculated in UDDS cycle. As seen in Figure 8, the torque for the propulsion of the vehicle is calculated as 905 Nm.

Based on the Equation (7), the propulsion power of the vehicle is calculated by depending upon time. The power values that are required for the propulsion of the vehicle are given in Figure 9. The power values produced by electric motor must be equal to power value required for propelling the vehicle since only the electric motor used in electric vehicle as a propulsion mechanism. This harmony is seen when Figure 9 and 6 is analyzed together. In this present study, an evaluation has been made by comparing obtained data with the studies in the literature. In some studies carried out by [31-36], a simulation has been made by using various standard city cycles. The obtained data resulting from the simulation accord with obtained results in their studies.

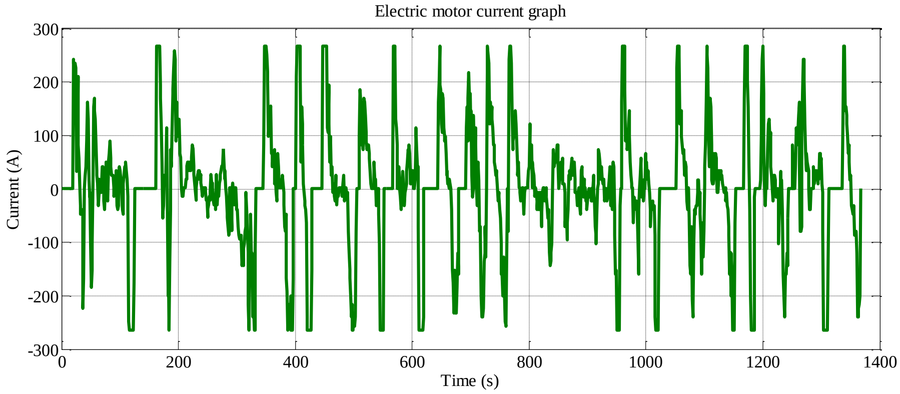

Figure 7.Electric motor current

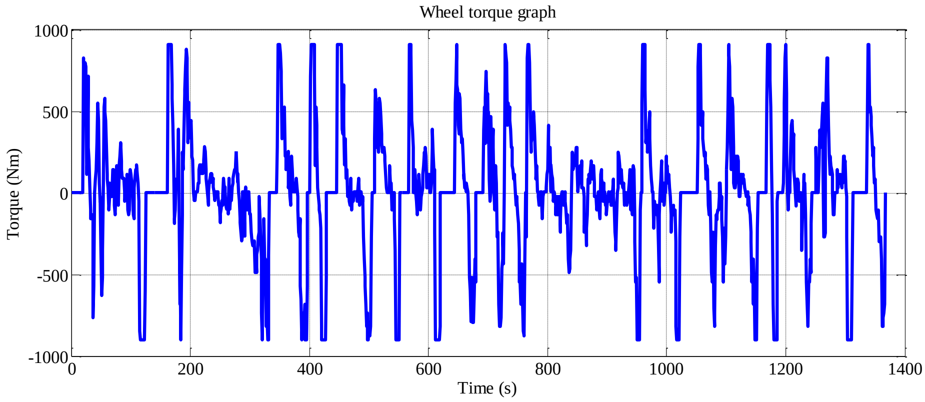

Figure 8.Vehicle's driving torque

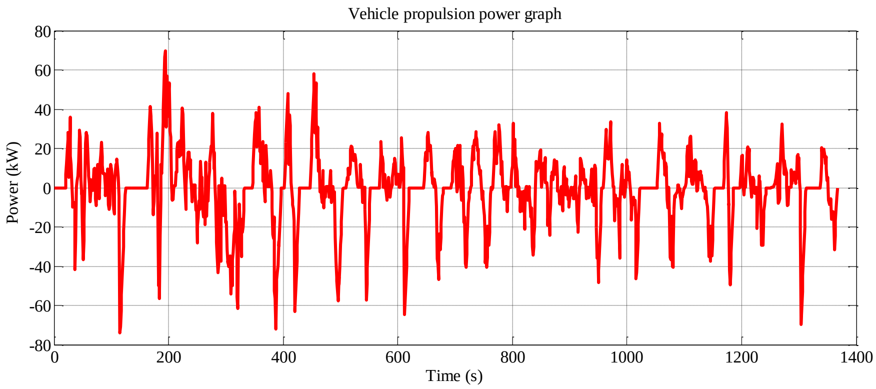

Figure 9.The drive power of the vehicle

5. Conclusion

In this study; a model has been composed by using the vehicle features and an electric motor for an electric vehicle simulation. This model has been solved using Matlab programming language. In the program, the catalog values of a sample DC motor has been benefitted and the technical features of a vehicle that is suitable for real condition have been based on. With this developed program, the simulation of an electric vehicle for the city cycles before production can be made. Besides, the harmony of electric motor characteristics and the characteristics of the vehicle movement can be evaluated together. The obtained motor characteristics through the cycle present also the required information which is able to identify battery characteristics. It is thought that the simulation model of this electric vehicle and the program would contribute for the designers who would make a new vehicle design in future.

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