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SIMULATION BASED STUDY OF ELECTRIC VEHICLE PARAMETERS

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ABSTRACT

As electric vehicle becomes a favorable alternative for sustainable and cleaner energy emission in transportation, modeling and simulation of electric vehicle has attracts increasing attentions to the researchers. Selecting appropriate parameters of electric vehicle and understanding their characteristics, are the preliminary step in modeling a good electric vehicle. This paper presents the study of vehicle parameters based on simulation of electric vehicle. Three different car segments are proposed for the simulation of three driving cycles. The simulations result demonstrates the significance of each segment parameters to the performance and fuel economy of electric vehicle. All works are performed in MATLAB/Simulink environment.

Keywords: electric vehicle, vehicle parameters, segmentation, simulation, MATLAB/Simulink.

INTRODUCTION

Nowadays, the trend of reducing energy consumption and environmental impact has led to the electrification of vehicle for future transportation. The serious issue of global warming, also known as the greenhouse effect, urban pollution, and the depletion of fossil fuels have increased the worldwide tensions. Although the Internal Combustion Engine (ICE) technology is being matured over the past 100 years, it will mainly rely on improving the fuel economy and reduce emissions [1]. Powered by battery, Electric Vehicles (EV) have been proposed by many as one of the above solution as they are highly efficient, silent, produce zero emission, and can be regulated by the power grid operator [1-7]. However, the main challenges to solve in EV are battery-related issues; the high initial cost, limited driving range, and long charging time of its battery [2, 8]. The battery must contain sufficient energy to drive certain range and provide enough power during accelerations.

In order to estimate and optimize the energy consumption of EV, we need to model an EV. It is important to have a good model of EV to prevent wrong conclusions [2]. In this study: (1) modeling of EV is presented and discussed, (2) three vehicles (with parameters correspond to their segment) and three driving cyles are selected in order to test the performance and fuel economy of the designed model. From the performed simulation, we decide: (1) the best vehicle segment for each driving cycle, and (2) propose suitable segmentation for EV. The best vehicle segment will be used next in the further research to find optimal design of EV which is not included in this paper.

In the following section, the selected vehicle parameters are specified into three car segments. Section 3 contains the description on EV modeling, and the simulation results of each vehicle are presented and compared in section 4. Finally, section 5 concludes the study.

VEHICLE PARAMETERS

Electric Vehicle design parameters in [9] could be classified into three: (1) vehicle parameters, (2) electric elements parameters, and (3) environment parameters. Vehicle parameters contain vehicle information such as drag coefficient, frontal area, tire specification, rolling resistance, brake and steering and mass. Electric elements include specifications of electric motor, battery pack, motor controller and battery charger, while environmental parameters include data in which the vehicle is to be driven; incline angle, wind speed and tire inflation factor. For this study, we only select four parameters: mass, wheel radius, frontal area and drag coefficient, to be implemented into three electric vehicles based-on three conventional car segments: (1) A-segment Ford Ka 2008, (2) C-segment Ford Focus 2007 and (3) F-segment BMW 7 Series 2002. The selected vehicle parameters are presented in Table-1. The rest parameters are assumed similar as follows; gravitational acceleration = 9.81 ms^{-2}, air density = 1.204 kgm^{-3}, rolling resistance coefficient = 0.014, road slope angle = 0, wind speed = 0.

Table-1. Selected vehicle parameters.

Parameters	Vehicle		
	EV1 (Ford Ka 2008)	EV2 (Ford Focus 2007)	EV3 (BMW 7 Series 2002)
Segment	A	C	F
Mass, M (kg)	940	1230	2150
Wheel rad, r_d (m)	0.18	0.20	0.23
Frontal area, A_f (m^2)	2.11	2.26	2.38
Drag coefficient, C_d	0.337	0.324	0.290

a) Modeling of EV

As there are many possibilities in electric vehicle architectures, automakers could choose from any different architectures exist [6], e.g., DC or AC machines, one to four electric machines, gearbox or no gearbox, high or low battery voltage, one or three phase charging. In term of powertrain, electric vehicle may include of a battery pack, an electric machine system, a transmission, vehicular devices, and control systems [1]. In this study, we develop the model of electric vehicle based on vehicle dynamics and physical principles of these components in MATLAB/Simulink workspace.

A. Simulation model of electric vehicle

Forward simulation model is selected to analyze several electric vehicles subject to segments. This simulation method utilizes the driver model which is unavailable in backward simulation; make it possible to discover the vehicle dynamics, considering both the vehicle's operating condition and the driver's intention. The model as shown in Figure-1 contains the driving cycle, driver model, motor model, transmission model, battery model and longitudinal vehicle dynamics model.

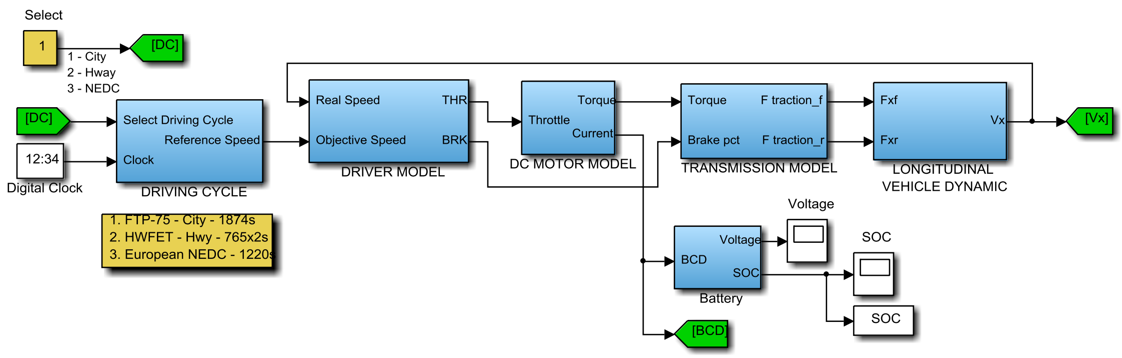

Figure-1. Simulation model of electric vehicle (forward).

B. Driving cycle

A driving cycle is a set of vehicle velocity values the electric vehicle is to achieve during the simulation [10]. For the purpose of fuel economy and vehicle performance testing, three driving cycles are selected: (1) FTP-75 to represent US urban driving, (2) HWFET to represent US highway driving, and (3) NEDC to represent European urban and extra urban driving.

C. Driver model

As the feature of forward simulation model, the driver model considers the objective speed and the present real speed to develop appropriate throttle and brake commands (usually through a PI controller) [11]. A feedback control loop of a vehicle speed is employed to ensure the precise reference speed tracking by the vehicle. The throttle command from the driver model is translated into torque provided by the electric motor and became input to the transmission model.

D. Motor model

The motor model developed is based on a dc motor with rigid rotor and shaft, and the friction torque is proportional to shaft angular velocity, using the following equations:

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}\left(K_t i - b\frac{d\theta}{dt}\right) \quad (1)$$

$$\frac{di}{dt} = \frac{1}{L}\left(-Ri + V - K_e\frac{d\theta}{dt}\right) \quad (2)$$

where $\frac{d\theta}{dt}$ is the angular velocity, $\frac{d^2\theta}{dt^2}$ is the angular acceleration, J is the moment of inertia, b is the motor viscous friction constant, K_t is the motor torque constant, and K_e is the electromotive force constant. The model outputs are the torque and current.

E. Transmission model

The transmission model translates torque from motor model and braking force from driver model into front and rear traction forces. These forces are the inputs to the longitudinal vehicle dynamic model. The braking force, F_b can be expressed as:

$$F_b = \frac{T_b}{r_d} \quad (3)$$

where T_b is the braking torque and r_d is the radius of wheel.

F. Battery model

This model contains a simple battery pack based on Toyota Prius battery. The current draw from the motor is simply subtracted from the total charge of the battery. The voltage output of the battery is then taken from a typical discharge graph plot. The state of charge (SOC) is obtained using the following equation:

$$SOC = \frac{C_{max} - C_{used}}{C_{max}} \quad (4)$$

where C_{used} is the battery's consumed capacity.

G. Longitudinal Vehicle Dynamic Model

It is necessary to identify each of the acting forces in a vehicle direction to determine its movement behavior. The dynamic equation of vehicle motion along the longitudinal direction is given in [12, 13] as follows:

$$M\frac{dV}{dt} = (F_{tf} + F_{tr}) - (F_{rf} + F_{rr} + F_{ad} + F_{hc}) \quad (5)$$

where M is the vehicle mass, $\frac{dV}{dt}$ is the linear acceleration of the vehicle along the longitudinal direction, F_{tf} and F_{tr} is the traction force of the front and rear tires, F_{rf} and F_{rr} is the rolling resistance force of the front and rear tires, F_{ad} is the aerodynamic drag force and F_{hc} is the hill climbing force.

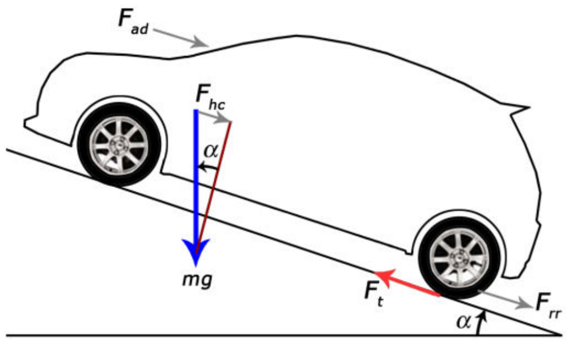

Figure-2. Forces acting on a vehicle moving uphill.

The tractive effort, F_t between the driven wheels and road surface produced by the motor torque to transmission, final drive to drive wheels. The resistance includes tire rolling resistance (F_{rr}), aerodynamic drag (F_{ad}), and uphill resistance (F_{hc}) [3, 12, 13] as shown in Figure-2.

The above resistance forces are described by the following equations:

$$F_{rr} = MgC_r \cos\alpha \quad (6)$$

$$F_{ad} = \frac{1}{2}\rho A_f C_d v^2 \quad (7)$$

$$F_{hc} = Mg\sin\alpha \quad (8)$$

where g is the gravitational acceleration, C_r is tire rolling resistance coefficient, α is the slope angle of the road, ρ is the air density, A_f is the vehicle frontal area, C_d is the aerodynamic drag coefficient, and v is the wind speed.

b) Simulation

Based on the forward simulation model of EV and the proposed parameters, the simulation is conducted in MATLAB/Simulink to testify the vehicle designed parameters for performance. The three sets of vehicle parameters from different car segments EV1, EV2, EV3 are tested within three driving cycles. The simulation results are shown in Figure-3.

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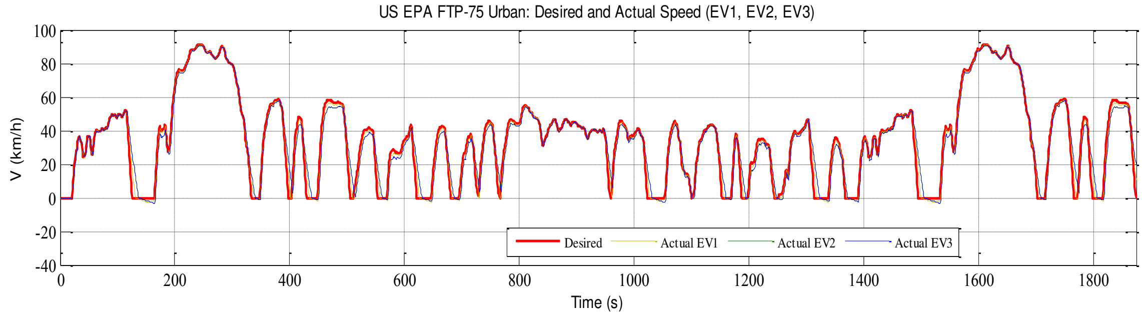
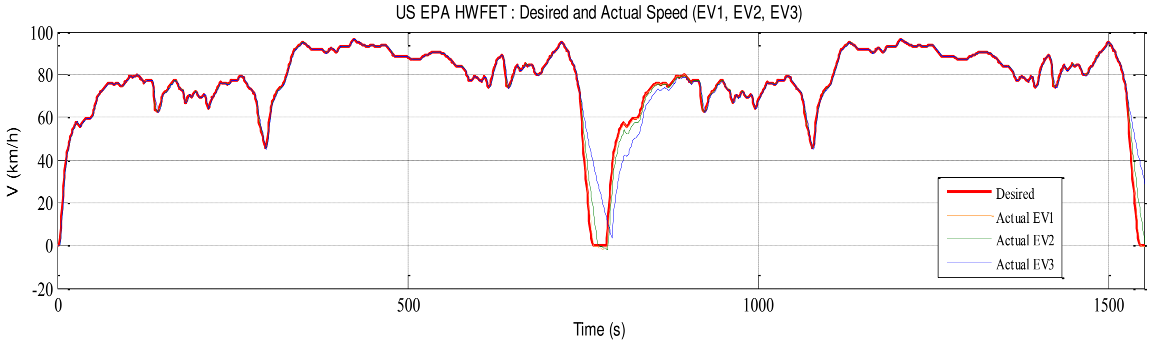


(a)



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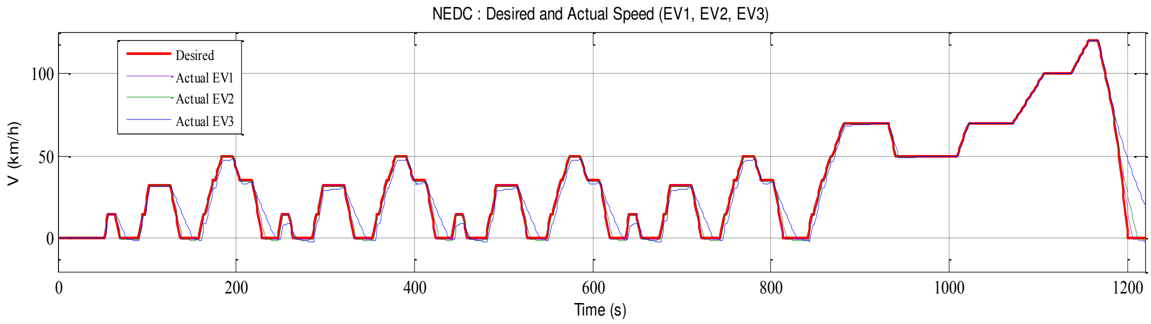

(c)

Figure-3. Simulation results of EV1, EV2 and EV3 in three drive cycle. (a) FTP-75, (b) HWFET, and (c) NEDC.

Figure-3 demonstrates the actual driving cycle superimposed on the desired driving cycle. Generally, the figures revealed the small error in all cycles, so it apparent that the controller did a good job in eliminates error. The error distributes obviously at points where the speed having a rapid increases or decreases (heavy fluctuations). Associating the variation of error between segments, the error increases as the segment increases respectively from EV1 to EV3. It is due to the increases in three parameters; mass, wheel radius and frontal area as the segment increases.

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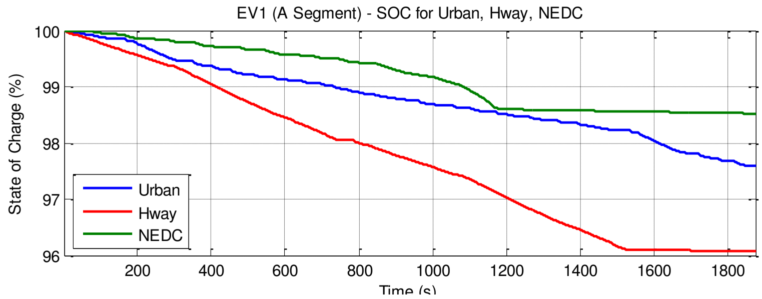
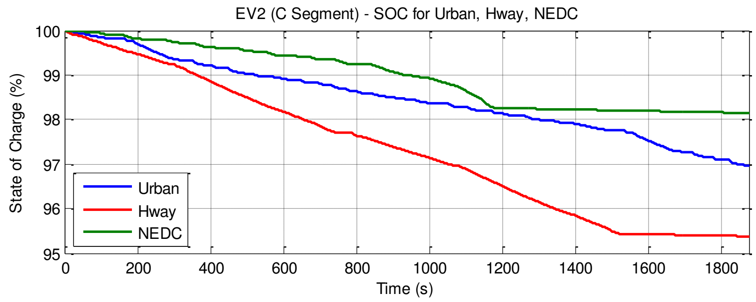


(a)



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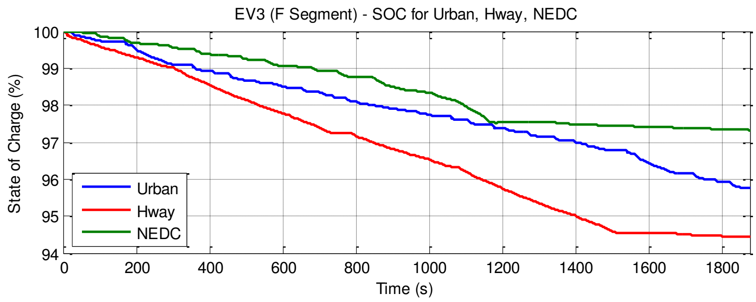

(c)

Figure-4. Simulation results of State of Charge (SOC) during FTP-75 Urban, HWFET Highway and NEDC. (a) EV1 (A-Segment), (b) EV2 (C-Segment), and (c) EV3 (F-Segment).

Battery SOC is the ratio of the residual capacity to the maximum capacity. Figure-4 illustrates the battery SOC over the run cycles. The figures show the same pattern for all segments of EV1, EV2 and EV3. Generally, the FTP-75 urban cycle shows how discharge varies greatly, because of the different stopping and starting. The HWFET highway cycle has a much smoother discharge profile. The NEDC cycle is a combination of repeated four times urban part (ECE) and an extra urban part (EUDC), is the most varies in discharge.

Comparing between driving cycles, the highest percentage of charge depleted is in HWFET cycle which fuel economy is the lowest. The second highest depleted charge is in FTP-75 and the lowest depleted charge is in NEDC which the greatest in fuel economy.

Between car segments, the most economic car is the EV1, the second is the EV2 and the EV3 goes third. It is expected that due to the increases in parameter of mass, wheel radius and frontal area; contribute to the decreases in fuel economy.

CONCLUSIONS

In this study, we provide the same battery capacity for different segment parameters of electric vehicle model. Conceptually, the study has proven that the model of electric vehicle must be light and small enough in order to accommodate for fuel economy. The smaller the car segments, the better the performances and energy consumptions. However, due to weight and space constraints, small electric vehicle with smaller battery capacity is highly recommended for urban commutation which could benefit from the regenerative braking mode. Higher segment car consuming bigger energy capacity should take on highway with a less fluctuation discharge profile to prolong the battery lifetime.

Conventional segmentation (i.e. by dimension) is quite inappropriate for electric vehicle; small EV might operate faster and longer range than big EV due to its traction battery. As such, the segmentation for electric vehicle should represent by its range and top speed.

Nevertheless, car segment is not the only factor in modeling an electric vehicle. Many factors should be considered as mentioned in Section 3, sometimes conflicting each other and always impose a trade-off conditions. In addition, motor control and energy management strategies are the two major factors having received an increasing attention among researchers nowadays.

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REFERENCES

[1] Chan, C.C. 2007. The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles. Proceedings of the IEEE. 95(4): p. 704-718.

[2] Schaltz, E. 2011. Electrical Vehicle Design and Modeling, in Electric Vehicles - Modelling and Simulations, S. Solyu, (Editor), In Tech.

[3] Larminie, J. and J. Lowry. 2003. Electric Vehicle Technology Explained. Chichester, UK: John Wiley and Sons, Ltd.

[4] [4] Khajepour, A., S. Fallah and A. Goodarzi. 2014. Electric and Hybrid Vehicles Technologies, Modeling and Control: A Mechatronic Approach., Chichester, UK: John Wiley and Sons Ltd.

[5] Husain, I. 2003. ELECTRIC and HYBRID VEHICLES Design Fundamentals., New York, USA: CRC Press.

[6] Chan, C.C., Bouscayrol, A. and Chen,K. 2010. Electric, Hybrid, and Fuel-Cell Vehicles: IEEE Transactions on Architectures and Modeling. Vehicular Technology. 59(2): pp. 589-598.

[7] Mohd, T.A.T., Hassan, M.K. and Aziz, W.M.K.A. 2014. Mathematical Modelling and Simulation of Electric Vehicle using Matlab-Simulink. In: International Conference on Automotive Innovation and Green Energy Vehicle (AiGEV2014), Pahang, Malaysia.

[8] Perujo, A., Grootveld, G.V. and Scholz, H. 2012. Present and Future Role of Battery Electrical Vehicles in Private and Public Urban Transport. In New Generation of Electric Vehicles.

[9] Reddy, G.N. 2012. A MATLAB-based tool for EV-design. In: 2012 International Conference on Education and e-Learning Innovations (ICEELI).

[10] McDonald, D. 2012. Electric Vehicle Drive Simulation with MATLAB/Simulink. In: Proceedings of the 2012 North-Central Section Conference. Ohio Northern University, United States.

[11] Markel, T., *et al*., 2002. ADVISOR: a systems analysis tool for advanced vehicle modeling. Journal of Power Sources. 110(2), pp. 255-266.

[12] Ehsani, M., Gao,Y. and Emadi, A. 2010. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles Fundamentals, Theory and Design. Second Edition, New York, USA: CRC Press.

[13] Ehsani, M., *et al.* 2005. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles Fundamentals, Theory and Design. Power Electronics and Applications Series, M. H. Rashid (Ed.), New York, USA: CRC Press.