International Journal of Engineering & Technology, 7 (3.7) (2018) 134-137

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Modeling and Simulation of Series-parallel UMT PHEV Powertrain

M. Nur Haezah, W. H. Atiq, J. S. Norbakyah and A. R. Salisa

School of Ocean Engineering,
Universiti Malaysia Terengganu ,
21030 Kuala Nerus, Terengganu,
**Corresponding author E-mail:salisa@umt.edu.my*

Abstract

This paper presents a modeling and simulation of Universiti Malaysia Terengganu (UMT) plug-in hybrid electric vehicle (PHEV) powertrain. There are four main components of UMT PHEV are modeled, which are internal combustion engine, electric machine, battery and ultracapacitor. Firstly, the vehicle components are sized through a power flow analysis to meet the expected power and the energy requirements. Then, a mathematical model of each component is obtained and simulated in MATLAB/SIMULINK environment. As the results, all the simulation results seem that the pattern of graph and the range of value are in reasonable. It can be concluded that all main components models are correct.

Keywords: *Plug-in hybrid electric vehicle, Powertrain, Modeling, Simulation*

1. Introduction

Recently, more people realize about the pollution of the vehicles and rising fuel costs causing hybrid electric vehicles (HEVs) are much more popular. HEV also has advantage than conventional vehicle due to regenerative braking energy system that can recapture much of the car's kinetic energy and convert it into electricity, so that it can be used to recharge the car's batteries. Plug-in HEV (PHEV) have three main types of drivetrain configurations which are series, parallel and series-parallel powertrain. Usually, HEV is design with two electric machines (EMs) which are function as motor and generator separately and they are only use battery as their energy storage system (ESS) without using ultracapacitor [1-7], Pourabdollah et al., 2013., Lee et al., 1998. & Cheng et al., 2010).

This paper discusses about the mathematical model and simulation of Universiti Malaysia Terengganu (UMT) PHEV powertrain in MATLAB/SIMULINK environment. UMT PHEV considers a series-parallel powertrain which is the most efficient option at all times. The proposed UMT PHEV has only one EM which functions as either a motor or generator at a time and an ultracapacitor bank besides battery for ESS due to high power density, fast charging and discharging during capture the regenerative braking energy and fast acceleration.

2. UMT PHEV Powertrain Model Development

Fig 1 shows a schematic illustration of the proposed series-parallel UMT PHEV powertrain.

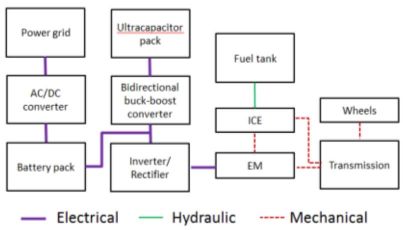

Fig 1. Schematic of illustration of series-parallel UMT PHEV powertrain.

To develop the UMT PHEV powertrain, the vehicle energy and power requirements are calculated based on the parameter, specifications and performance requirements. Table 1 lists the typical parameters, specifications and performance requirements of a vehicle of this type.

Table 1. UMT PHEV parameters, specifications and performancerequirements.

Parameters and specifications	
Vehicle configuration	Series-parallel
Vehicle class	Midsize
Vehicle mass	1360kg
Aerodynamic drag coefficient	0.26
Coefficient of rolling resistance	
Frontal area	0.01
Wheel radius	
Air density	2.57m²
Gravitational acceleration	0.282m
	1.2kg/m³
	9.81m/s²
Performance requirements	
Maximum speed	Over 80km/h
Electric vehicle (EV) range	54km

Based on the vehicle power requirements for steady state velocity, the main components of UMT PHEV powertrain were sized. The selected main components of UMT PHEV powertrain for steady state velocity, which are EM, internal combustion engine (ICE) and ESS based on each component specifications and requirements during the sizing process are list in Table 2.

Table 2. Main components of the UMT PHEV powertrain.

Component	Specifications
ICE	1.5 L, 57 kW @ 5000rpm
EM	50 kW AC induction motor
ESS	10 kWh, 28 Ah

There are four vehicle components of UMT PHEV are modeled, which are ICE, EM, battery and ultracapacitor.

2.1 Internal Combustion Engine (ICE)

Fig 2 shows the inputs and outputs of the ICE model in MATLAB/SIMULINK. The engine needs many data of lookup tables for carbon monoxide (CO), nitrogen oxide (NOx), and hydrocarbon (HC) and torque curve. The full data of lookup tables is based on Prius. Engine torque is calculated based on the engine power and speed.

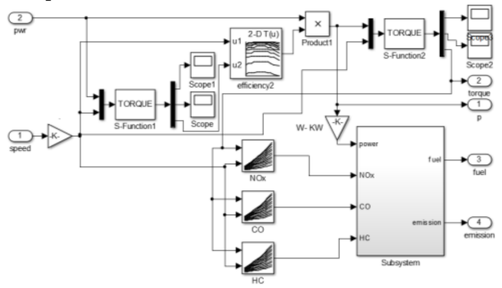

Fig 2. ICE model

2.2 Electric Machine (EM)

Fig 3 shows EM model that has two inputs, which are power supplied from ESS and velocity of the vehicle while produces two outputs which are the motor torque and speed in rad/s. The motor needs data of lookup tables for maximum torque curve and efficiency map. The motor torque is obtained as

$$torque = \frac{power}{speed} \tag{1}$$

An EM has two functions as either a motor or generator at a time. The switch block is used to differentiate the functions of the motor. When the switch block is show positive value, it means that power is supplied from battery while when it shows negative value, it means that power occurs during regenerative braking and is used to charge battery.

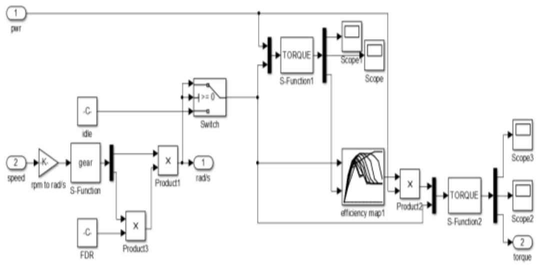

Fig 3. EM model

2.3 Battery

Fig 4 shows the inputs and outputs of the battery model. The battery needs many data of lookup tables for charging and discharging resistance and open circuit voltage. The full data of lookup tables is based on the Lithium Ion battery. State of charge (SOC) calculation, resistance and open circuit voltage are calculated in the sub-blocks. In the model, there are serially connected 25 Ah batteries. The output power of the battery can be calculated as

$$P_{out} = V_{oc} I_{out} - I_{out}^2 R \tag{2}$$

where R and V_{oc} are the internal resistance and the open circuit voltage of the battery, respectively. Solving the quadratic equation 2, the output current can be determined by

$$I_{out} = \frac{V_{oc} - \sqrt{V_{oc}^2 - 4RP_{out}}}{2R} \tag{3}$$

SOC can be determined by

$$SOC = SOC_0 - \frac{1}{C}\int_0^t \eta I d\tau \tag{4}$$

Where I is current, C is usable capacity and η is the efficiency of charging and discharging.

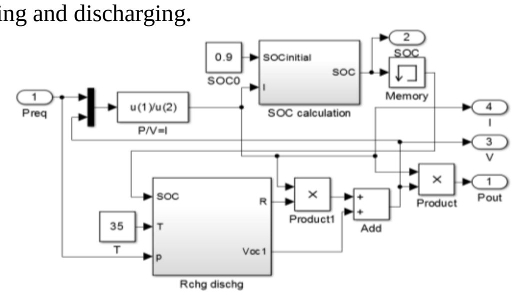

Fig 4. Battery model

2.4 Ultracapacitor

Fig 5 shows the inputs and outputs of the ultracapacitor model in MATLAB/SIMULINK. The capacity is a function of charge and discharge current and temperature. The capacity of ultracapacitor is defined as follows

$$C = I\frac{dt}{dv} \tag{4}$$

Equivalent resistance is also function of current and temperature. SOC is able to know the capability of ultracapacitor storing electricity. It is defined as

$$SOC = \frac{V - V_{min}}{V_{max} - V_{min}} \tag{5}$$

where V_{min} and V_{max} are the minimum and maximum voltage, respectively. The ultracapacitor needs many data of lookup tables for charging resistance, capacity and efficiency of the utracapacitor. The full data of lookup tables is based on the experimental data of Maxwell PC2500 supercapacitor from the U. S. National Renewable Energy Laboratory (NREL).

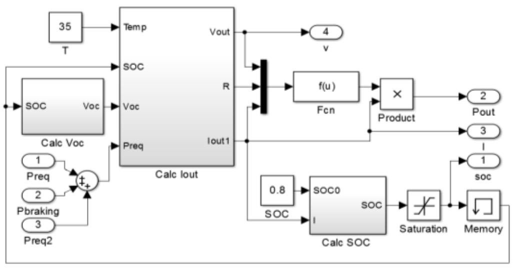

Fig 5. Ultracapacitor model

3. UMT PHEV Powertrain Simulation Results

The urban dynamometer driving shedule (UDDS) for city driving is used as driving cycle to simulate the UMT PHEV powertrain in MATLAB/SIMULINK environment. Fig 6 shows the UDDS drive cycle ends at 1369 seconds.

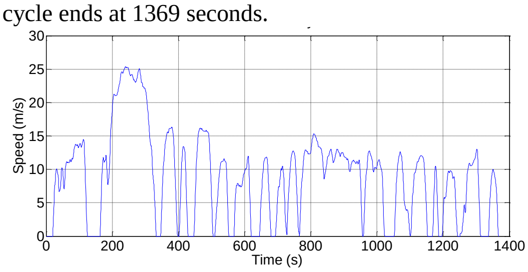

Fig 6. The UDDS drive cycle

Figs 7 – 15 show the simulated results of ESS power, ESS SOC, ESS current, EM torque, EM speed, EM power, wheel speed, wheel torque and vehicle speed.

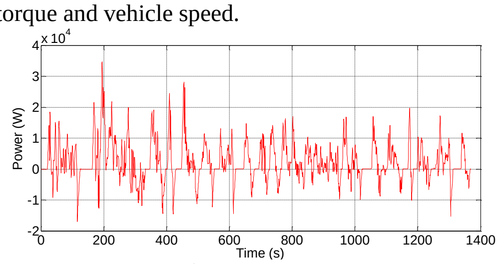

Fig 7. ESS power

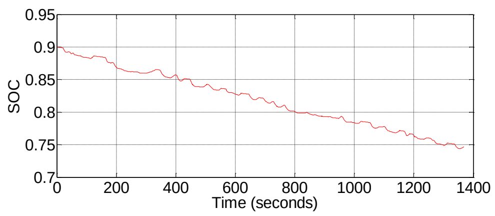

Fig 8. ESS SOC

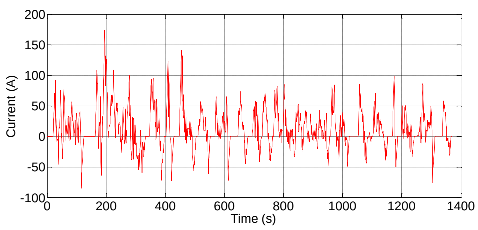

Fig 9. ESS current

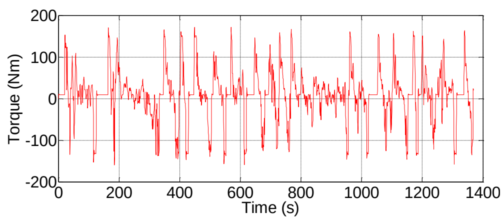

Fig 10. EM torque

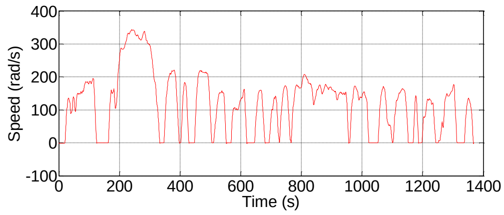

Fig 11. EM speed.

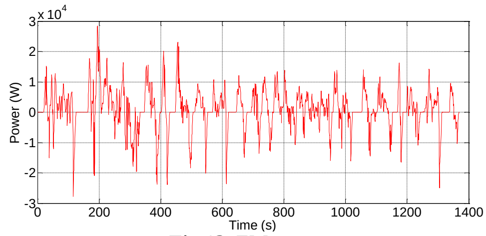

Fig 12. EM power

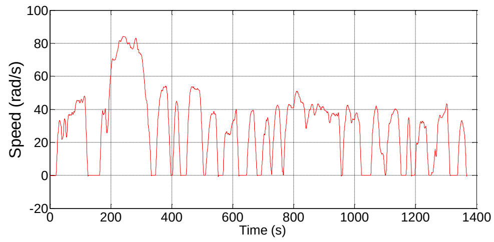

Fig 13. Wheel speed

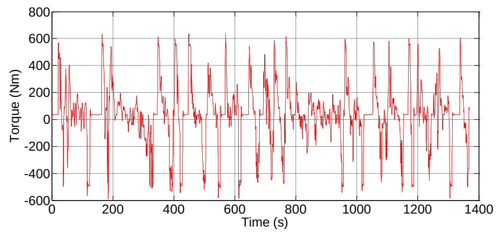

Fig 14. Wheel torque

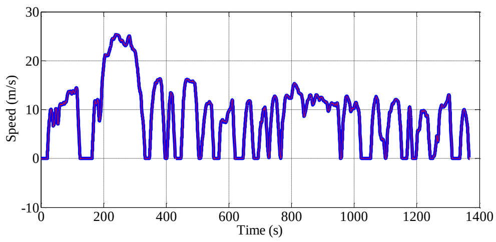

Fig 15. Vehicle speed

ESS produces output power, current and SOC simulation results. From the Figs 7 and 9, it can see that the current and power have the same pattern of graph. The positive value represents an acceleration while negative value is when the regenerative braking occur. The graph of SOC decrease by time.

The simulation results produced from electric motor is torque, speed and power as in Figs 10 - 12, respectively. From the graph, it can be seen that torque will increase when the vehicle is accelerates. When the vehicle is in declaration, torque become decrease due to smaller resistance and air drag hit the vehicle body.

The simulation results of wheel speed and torque present in Figs 13 and 14, respectively. Same as concept of electric motor, wheel torque also will increase when vehicle is accelerate and vice versa.

Fig 15 shows the vehicle speed comparison between required speed which is produced by drive cycle and acquired speed is produced by vehicle model in meter per second. This required and acquired speeds need to match each other to gain small speed error before entering proportional-integral controller in driver model to produce torque demand. Target to get small speed error achieved after gain quite same pattern of simulation results between drive cycle and vehicle model.

4. Conclusion

According to simulation results of the ESS power, ESS SOC, ESS current, EM torque, EM speed, EM power, wheel speed, wheel torque and vehicle speed, it seems that the pattern of graph and the range of value are in reasonable. So, it can be concluded that all main components UMT PHEV powertrain model are correct.

Acknowledgments

The authors would like to be obliged to Fundamental Research Grant Scheme and University Malaysia Terengganu for the financial support of this work.

References

[1] A. R. Salisa, Ngong Zhang, Jianguo Zhu,2008. Modeling and Simulation of an Energy Management System for Plug-in Hybrid Electrical Vehicles. Australasian Universities Power Engineering Conference: 1-6.

[2] Can Gokce, Ozgur Ustun, Murat Yilma, R. Nejat Tuncay, 2006. Modeling and Simulation of A Serial-Parallel Hybrid Electrical Vehicle. Research Gate.

[3] Fu Zhumu, Hou Gao Aiyun, Modeling and Simulation for Parallel Hybrid Electric Vehicle Powertrain, 20100. Proceeding of The International Conference on Advanced Mechatronic Systems, Zhengzhou, China, 2011: 114-117.

[4] Low Wen Yao, Aziz, J.A., Pui Yee Kong, N.R.N. Idris, 2013. Modeling of Lithium-Ion Battery Using MATLAB/SIMULINK, IEEE: 1729-1734.

[5] Mitra Pourabdollah, Nikolce Murgovski, Anders Grauers and Bo Egardt, July 2013. Optimal Sizing of a Parallel PHEV Powertrain. IEEE Transactions on Vehicular Technology, Vol. 62, No.6: 2469-2480.

[6] Won Hee Lee, 1998. Computer Simulation of a Series and Parallel Hybrid Electric Vehicle. M.Sc. Thesis, University of Durham.

[7] Zhan-li Cheng, Wei-rong Chen, Qi Li, hi-ling Jiang, Zh-han Yang, 2010. Modeling and Dybanmic Simulation of an Efficient Energy Storage Component- Supercpacitor. IEEE: 1-4.