PARALLEL HYBRID ELECTRIC VEHICLE SIMULATION MODEL USING ENERGETIC MACROSCOPIC REPRESENTATION METHOD

Zainab Asus*, Zulhusni Ismail, Zul Hilmi Che Daud, Izhari Izmi Mazali

School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

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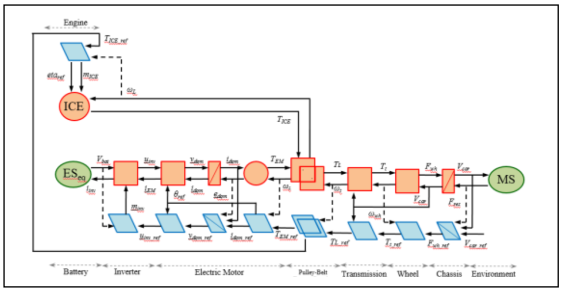
*Corresponding author
zainabasus@utm.my

GRAPHICAL ABSTRACT



ABSTRACT

One Perodua Axia car has been modified to become a parallel hybrid electric vehicle (PHEV) to study the advantages of an alternative drive train configuration. This PHEV drivetrain configuration uses two energy sources namely fuel combustion from the Internal Combustion Engine (ICE) and electrical potential energy from a battery which are installed parallel to one another. PHEV is able to move using ICE power and electric motor power, depending on the control strategy of the system. The control strategy is complicated to define, hence Matlab-Simulink and Energetic Macroscopic Representation (EMR) method is implemented in order to help in organizing the control system by manipulating its functions and subsystems in blocks. Through this method, potentially efficient control strategies can be tested and analysed before choosing the best energy management; with the fuel consumption of the vehicle is expected to be less than the conventional vehicle.

KEYWORDS

Modelling; Energy management; Fuel consumption; NEDC consumption

INTRODUCTION

The earth is getting hotter each year as we know. This is due to the global warming occurrence in which is caused by the greenhouse emissions. Global warming could then lead to climate changes as glaciers will start to melt, humidity is increasing, ocean heat content is rising etc [1]. Greenhouse gases trap heat that causes the planet to be warmer and it is the human activities that are to blame for the increment of greenhouse gases in the atmosphere [2]. Carbon dioxide gas is the most common greenhouse gas that is released and transportation contributes 27% of greenhouse emissions to the atmosphere [3].

Hence, alternative vehicle architecture is an alternative to reduce such emissions. Doing a simulation model of the alternative vehicle structure saves a lot of resources and the control of the complex system especially for a hybrid electric vehicle can be designed and manipulated using Matlab-Simulink.

The objective of this research is to develop a simulation model of Parallel Hybrid Electric Vehicle with the parameters of the car is easy to be manipulated by users and to be simulated. The simulation model will be presented using Energetic Macroscopic Representation and the internal combustion efficiency map as well as the electric motor efficiency map used for the vehicle will be implemented in the simulation. The results of the simulation can give us the fuel consumption of the studied vehicle. Hence by doing so, we would want to obtain a vehicle performance that is more eco saving or consume less fuel than conventional vehicle used today.

The powertrain configuration for Parallel Hybrid Electric Vehicle (PHEV) as shown in Figure 1 is the internal combustion engine and electric motor are parallel to one another and connected to a mechanical transmission where both can simultaneously transmit power to drive the vehicle [4] [5] [6]. The configuration has two axles where the coupling torque sends power to the front wheels and additionally, engine delivers power to the train through the gearbox [7].

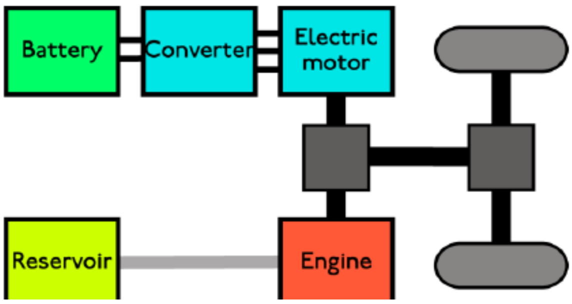


Figure 1: Parallel HEV powertrain configuration model

There are two types of energy storage units, namely electricity and fuel. For electricity, a battery is used to store energy and electric motor is used as a traction motor; while for fuel, Internal Combustion Energy (ICE) is used to produce mechanical power [4] [5]. Electric motor operates the wheels of the vehicle and unlike traditional vehicle that uses engine to reach a high state before it can provide full torque, an electric motor is able to supply full torque at low speeds with minimum noise as well as high efficiency [4] [5]. The main advantage that electromotor can give is it can possibly function as a generator where in every HEV system, mechanical braking energy can be created and even though the maximum operational braking system is not as much as the maximum traction torque, mechanical braking system is always integrated in a car [4] [5].

The Energetic Macroscopic Representation (EMR) can be defined as a synthetic graphical tool which is based on the action and reaction between connected elements, and the present components can be internally described by causal ordering graphs or other descriptions as transfer functions [8]. EMR uses the causality principle where only the integral causality is considered. It designates the accumulation elements using time-dependent relationships between their variables, where outputs are integral function of inputs [9]. EMR intends to combine the needs of causality and energetic aspect for inversion based control progress [10]. EMR recognize integral causality to be the only physical causality as it expresses what are the inputs of system (integrand –cause–) and its outputs (integration –effect–) [11].

MATERIALS AND METHODS

PeroduaAxia 1.0 L will be used for this project was made available by the owner to be modified into PHEV for experimental purpose. Normally a conventional car that runs with only ICE engine, in order to make it a hybrid, a battery and an electric motor was added to the car. Specifically, four lead-acid batteries were installed to this car. Currently the car is available at the Automotive Laboratory in UniversitiTeknologi Malaysia.

Table 1:Vehicle parameters

Curb Weight (kg)	850
Front Surface (m^2)	2.4462
Drag Coefficient	0.29
Rolling Resistance	0.012
Wheel Radius (m)	0.2921
NEDC Consumption (km/l)	20.1

Note that the data given are when before the vehicle is modified into a parallel hybrid electric vehicle, which will be containing a battery and an electric motor. Including the weight of the battery, electric motor and also torque coupler to the vehicle, the total curb weight will be 960 kg instead.

Table 2:Engine parameters

Max Power	66 hp (49 kW) @ 6,000 rpm
Max Torque	90 Nm @ 3,600 rpm

Based on the researches done in [11], with the efficiency map obtained, we can roughly extract the data in the efficiency map and implementing our own engine parameter, thus we are able to gain our estimated efficiency map for the ICE in PeroduaAxia that will be implemented in Matlab-Simulink.

The motor used is from company called GOLDEN. Based on the researches done by [12], the researcher obtained an efficiency map of the same type electric motor. Using the data obtained by the researcher, we are able to manipulate the data and change the maximum torque value to our own rated torque. With that value has been changed, we can gain an estimated electric motor efficiency map that will be installed in PeroduaAxia. This efficiency map will be implemented in Matlab-Simulink.

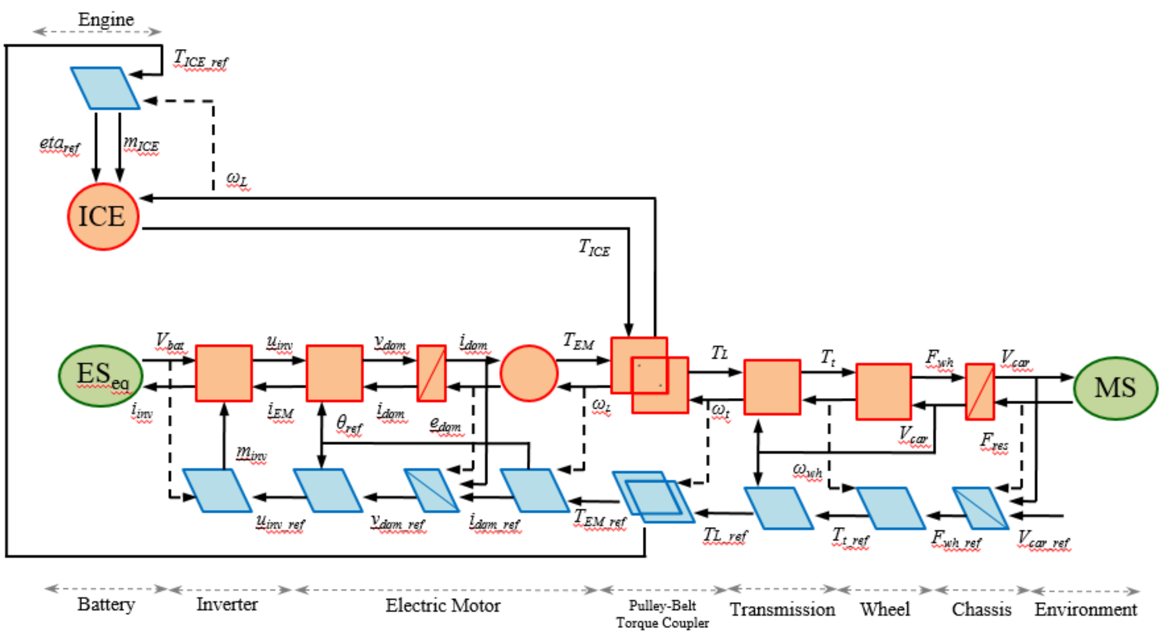


Figure 2: EMR and control structure of studied vehicle

With suitable formulas and the estimated efficiency map, we can implement them in our blocks inside Matlab-Simulink. The EMR model for our vehicle is as shown in Figure 2.

Table 3:Electric motor dynamic test result

Type	HPM48-10000
No.	G20130522003
Rated voltage	48 V
Rated current	250 A
Rated power	10000 W
Rated speed	3500 rpm

With the gained EMR model for our studied vehicle, we now then construct the model inside Matlab-Simulink in order to simulate it with our vehicle parameter. The simulation model in Matlab-Simulink is as shown in Figure 3.

Control Strategy Of Vehicle

In PHEV configuration, there will be two sources of power to move the vehicle. Tractions coming from the ICE source will combine with tractions produced by the electric motor at the pulley-belt torque coupler to form a total or load torque. Though most tractions will be produced by the ICE source since electric motor will only assist whenever necessary. With the appropriate control management or strategy, we are able to arrange the condition that enables the distribution between ICE traction and electric motor traction in the vehicle.

The pulley-belt (the torque coupler used for our vehicle) ratio between all the traction forces are in unity, hence the main formula for the distribution of tractions are as follow for this control management discussion.

$$T_{load} = T_{ICE} + T_{EM} \tag{1}$$

With this main formula in mind, we can then proceed in constructing the control structure of the traction forces occurring at the pulley-belt torque coupler‘s inversion-based control in Matlab-Simulink.

$$\begin{aligned} if \quad & T_{load} < 0 \; and \; 0 < T_{load} < 20 \\ then \quad & T_{ICE} = 0 \\ & T_{EM} = T_{load} \end{aligned} \tag{2}$$

The first condition as shown above is when the vehicle is braking or decelerating. During this situation, the torque would drop to the negative value since vehicle is forced to stop from a certain speed it was travelling. Electric motor will take advantage on this kinetic energy thus act as a generator that will then charge the battery.

The condition is also when the vehicle moves fully aided by the electric motor. Since the vehicle is moving in low speed, traction power needed by the vehicle is minimum. Electric motor can hence provide the minimum required traction to the vehicle without using any traction power from ICE. This condition can also recharge the battery. When the required traction load from vehicle is less than needed, excess energy from ICE will go to the electric motor to recharge the battery.

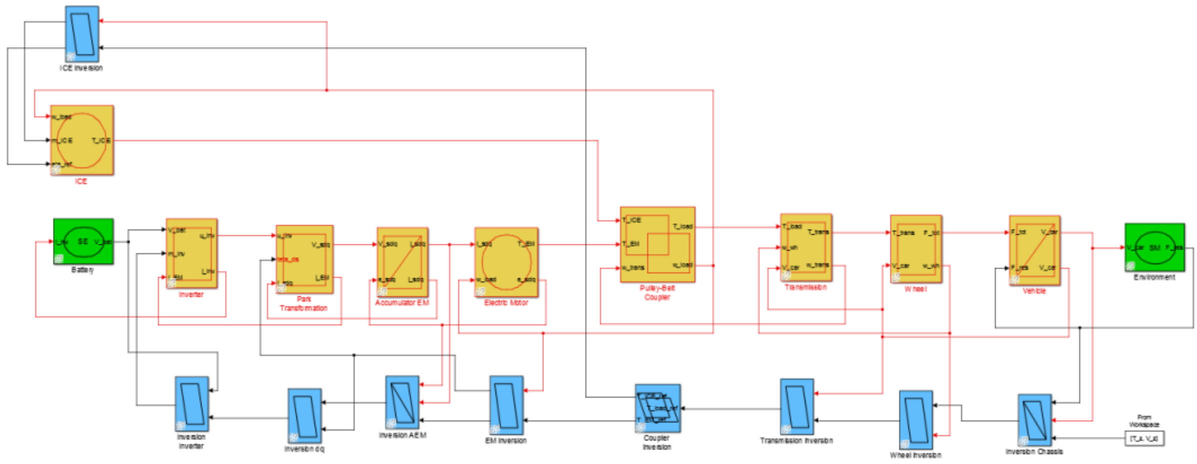


Figure 3: Simulation system model in Matlab-Simulink

$$\begin{aligned} if \quad & 20 < T_{load} < 60 \\ then \quad & T_{ICE} = T_{load} \\ & T_{EM} = 0 \end{aligned} \quad (3)$$

The next condition is the usage of ICE traction power only to move the vehicle. When the vehicle is moving at a medium-high speed, but is not accelerating nor does it move at high speed, then the demanded traction load will be provided fully by ICE. The electric motor will stop providing traction to the pulley-belt neither will it recharge the battery during this moment. In other words, during this condition, the vehicle will operate similar to a normal conventional vehicle. This however will be limited until required traction load is 60 Nm.

$$\begin{aligned} if \quad & T_{load} > 60 \\ then \quad & T_{ICE} = 60 \\ & T_{EM} = T_{load} - 60 \end{aligned} \quad (4)$$

The final condition that will be implemented in the control strategy is when ICE and electric motor will work together to provide traction power in order to move the vehicle. This condition is usually activated when the vehicle is accelerating or moving at a high speed. The demanded traction power is more than 60 Nm, where ICE will keep providing 60 Nm while electric motor will assist in providing the other remaining traction power. The engine and the motor provide traction power at the same time to the pulley-belt torque coupler.

NEDC cycle was implemented on the simulation models for this project. The NEDC cycle is as shown below. The parameters which are the velocity of a vehicle at a specific time will be used and will be the velocity reference for the vehicle in the simulation models. This cycle will be used to obtain the rest of our results since the manufacturer of the vehicle uses NEDC cycle for the vehicle's consumption.

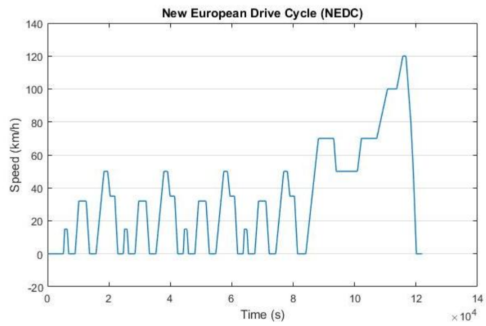


Figure 4: NEDC cycle implemented

Results And Discussion

A verification simulation needed to be done where the original vehicle parameter of PeroduaAxia is tested on Matlab-Simulink. The original condition of the vehicle operates solely on using Internal Combustion Engine without any assistance from other sources. Hence modelling the drivetrain back to its original configuration, we use the EMR approach and implement it in Matlab-Simulink. The original parameter is also used where we will not consider any modifications done on the vehicle which is adding an electric motor and also adding any additional batteries.

As the model for original drivetrain of the vehicle has been simulated and verified with its original parameter, the simulation can then be preceded when the vehicle has been modified into a parallel hybrid electric vehicle. Thus, instead of the original curb weight of 850 kg of the vehicle being used in this PHEV simulation, we will use 960 kg curb weight in the formula where it will then affect the chassis value of the vehicle. The rest parameters that are unchanged will use the value that has been shown in Table 1.

After the simulation model has been run, we are able to plot the graph of fuel consumption for the original drivetrain model and PHEV model. The graph of the fuel consumption will show how much fuel in millilitres has been consumed over the period of time based on the NEDC cycle. To observe the differences in fuel consumption, the comparison is plotted in graph as follows.

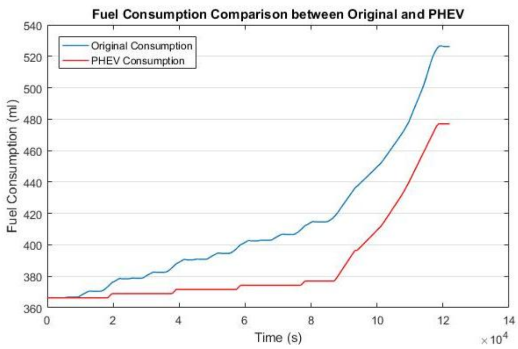


Figure 5: Fuel consumption of PHEV and conventional drivetrain

As seen clearly from Figure 5, the fuel consumption from the original drivetrain and parameter of PeroduaAxia is higher compared to the PHEV model. Extracting the value from Matlab, the fuel consumption for original and PHEV model are 526.21 ml and 477.00 ml respectively. With this value, we can calculate the NEDC consumption of the model. In order to calculate the NEDC consumption, the total consumption of the fuel will be divided over the total distance, theoretically for NEDC cycle is 10932 meters.

Based on the calculation, we obtained for our model's NEDC consumption when using the original drivetrain and parameter to be 20.7749 km/l. There is a little difference compared to the theoretical real value which is 20.1 km/l. Calculating the error value, our NEDC consumption comparing to the theoretical NEDC consumption for the vehicle is 3.36%, which is still below 5%. Hence, our model of the original drivetrain using the original parameter value is still within the allowable limit and therefore is acceptable. Meanwhile, after calculating the NEDC consumption for PHEV model, we obtain the value to be 22.918 km/l.

The reason behind the high value fuel consumption of original drivetrain comparing to PHEV is because in the original drivetrain model, only ICE source is used to provide traction forces in order to move the vehicle. For an engine to operate, it requires fuel or petrol and consumes it to obtain energy. In contrast with PHEV model, there are times where the vehicle move only using the electric motor powered by the battery and also where the electric motor will assist ICE. Less usage of ICE contributes to less fuel consumption and when being assisted, low fuel consumption is needed since low value of traction forces requires less fuel or petrol to burn.

The NEDC consumption for both model, namely the original drivetrain and PHEV model are 20.775 km/l and 22.918 km/l respectively. The differences in the value are 2.143 km/l. Hence we can say that in one litre of fuel consumed, the PHEV canmove 2.143 km more than the original drivetrain. Therefore, this model succeeded in obtaining less fuel consumption for a vehicle with Parallel Hybrid Electric Vehicle architecture configuration drivetrain.

Conclusion

The theoretical NEDC consumption from the manufacturer of the vehicle is said to be 20.1 km/l. A verification model was constructed and simulated using the original parameters of the car. The result obtained was 20.7749 km/l consumption in NEDC which gives 3.36% of error to the theoretical value in which is still below 5% error that thus makes the model to be in the allowable limit.

The PHEV model was then being simulated using EMR, taking account of the parameters after installing parts for modification purpose. The result obtained for consumption on NEDC is 22.918 km/l, which is much better than the original drivetrain that gives 20.775 km/l. This means that in one litre fuel consumed, PHEV model can travel 22.918 km distance which is much further than original drivetrain that travels on 20.775 km distance only. Thus with more distance travelled in one litre of fuel, this also indicates that the PHEV model consumes less fuel. With less fuel consumed, less gas emissions are being released by the vehicle. Therefore, this project has successfully achieved its objective.

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