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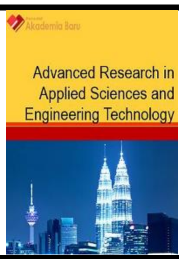

A Study on the Effects of Plug-In Hybrid Electric Vehicle (PHEV) Powertrain on Fuel Consumption, Electric Consumption and Emission using Autonomie

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ABSTRACT

The plug-in hybrid electric vehicle (PHEV) has received extensive attention due to the alternatives it provides for reducing the dependency on petroleum. Nowadays, many simulation software such as ADVISOR and AUTONOMIE, were built to help in PHEV research. In this paper, the effect of three main PHEV powertrains such as engine power, traction motor power and battery capacity on fuel consumption, electric consumption and carbon oxide emission is studied using AUTONOMIE. The simulation is designed and run using AUTONOMIE with example of commands used in MATLAB. The overall simulation results show that the fuel consumption decreases as the motor power increases with the same battery capacity and engine power. In additions, the simulation results also show that the electric and fuel consumptions are contrary to each other. Meanwhile, the carbon oxide emission and fuel consumption increase following each other's.

1. Introduction

Nowadays, electric vehicle (EV) is one of the alternatives for reducing the dependency on petroleum in the transportation system. Hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV) are an example of popular EV. HEV is the combination of both the technology from electric vehicle and conventional internal combustion engine (ICE) platforms. The propulsion in HEV uses ICE and electrical system (electric motor and battery). Meanwhile, PHEV is a HEV with rechargeable battery pack installed in the architecture of vehicle powertrain. The main difference between HEV and PHEV is the battery capacity, where PHEV has a larger battery capacity compared to HEV [1]. Vajedi *et al.*, [2] and Shahverdi *et al.*, [3] stated that the powertrain components; battery cells, the engine power and the traction motor power, have significant effect on performances of the PHEV. These three powertrain components are the main contribution on fuel consumption of the vehicle. The Autonomie software is built based on MATLAB and Simulink, which is a high- fidelity

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vehicle-modeling environment for MATLAB/Simulink developed by ANL. Most of the research used Autonomie software to build and simulate the model of electric vehicle [2-12]. The software is preferred by the researchers because it provides a library of the vehicle system and component models, primarily based on experimental data, created at the Argonne National Library (ANL) [13]. The most common used of PHEV and HEV model for simulation purposed are based on the Toyota Prius [13-20].

This paper studies the effect of powertrain components on minimizing fuel consumption, electric consumption and emission. The different sizes of engine power, traction motor power and battery capacity are chosen as the parameters of the powertrain components. The rest of the paper is organized as follows, In Section 2, the uses of power split PHEV and input variable named in Autonomie are described. Section 3 introduces the drive cycle used in the simulation. The explanation of the simulation is given in Section 4. Results and discussion of the simulation are presented in Section 5 and finally, the conclusions come in Section 6.

2. Power Split Phew in Autonomie

In this study, the default PHEV model in Autonomie is used as a baseline vehicle platform to study the effect of PHEV powertrains on fuel consumption, emission and electric consumption. The default PHEV model, namely as plug-in Prius is a model of two wheel drive default model of the hybrid powertrain system with power-split architecture, which is based on 2004 Prius model. Figure 1 shows the baseline vehicle component models in the Autonomie software.

The different values of parameter for selected powertrains such as engine power, motor power and battery capacity are used. Table 1 show the input variable name used in Autonomie while Table 2 shows the parameter value of the powertrain. The default value of the parameter is the default value obtained from Autonomie for Prius model.

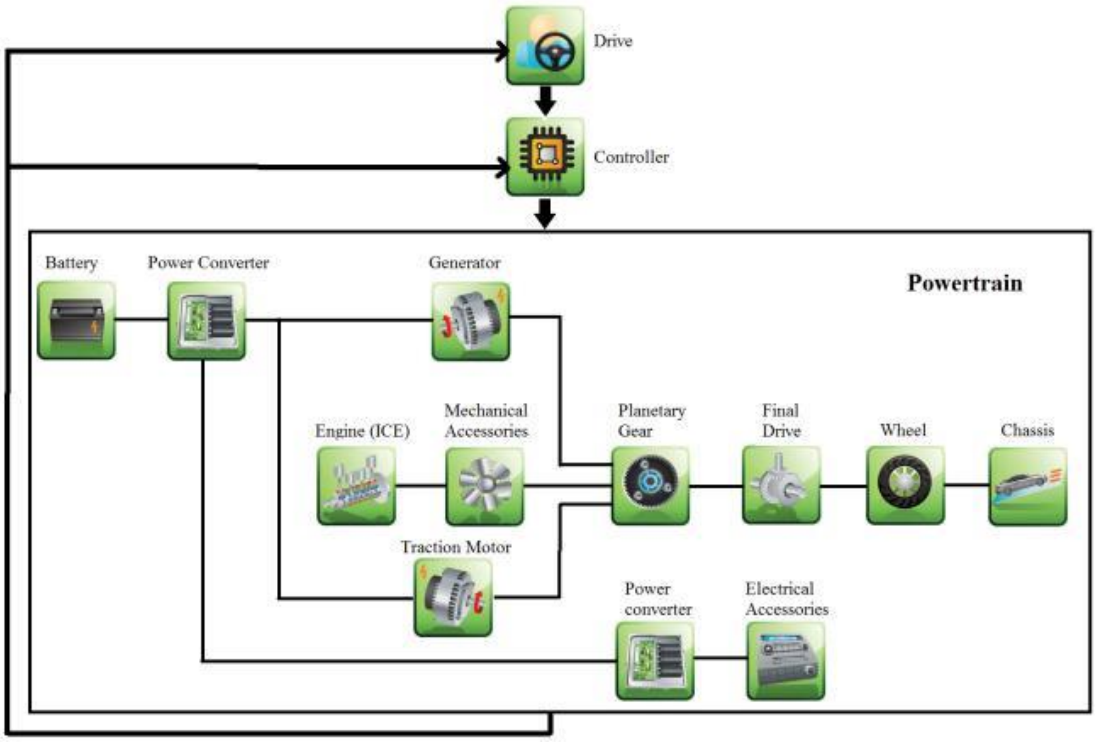


Fig. 1. Baseline vehicle component models in the Autonomie software

Table 1
Input variable name used in Autonomie

Variable name	Description
veh.plant.init.mass	Mass of vehicle
eng.plant.scale.pwr_max_des	Maximal engine power
mot.plant.scale.pwr_max_des	Maximal motor power
ess.plant.scale.cap_max_des	Maximal battery capacity
ess.plant.init.soc_init	Initial State of Charge (SOC) of the battery pack
ess.plant.init.soc_min	Minimum SOC of the battery
ess.plant.init.soc_max	Maximum SOC of the battery

Table 2
Parameters value of the powertrain

Variable name	Value	Default
Maximal engine power, Pe (kWh)	20, 30, 40, 50, 60, 70 ,80 and 90	94.803
Maximal motor power, Pm (kWh)	20, 30, 40, 50, 60 and 70	65.677
Maximal battery capacity, Bc (Ah)	10, 20, 30, 40 and 50	39.449
Initial SOC	-	0.9
Minimum SOC	-	0.2
Maximum SOC	-	0.9

3. Drive Cycle

The vehicle behavior can be seen by selecting the appropriate driving cycle. The driving cycle will be determined by the requirement of the motor and engine components. For example, driving at highway required more power, making the size of the engine and motor component also larger. However, driving at urban or low speed areas only required small engine and motor components. In this study, Urban Dynamometer Driving Schedule (UDDS) is used and the drive cycle is known as “fuds1” in Autonomie shown in Figure 2. The characteristic of UDDS tabulated in Table 3.

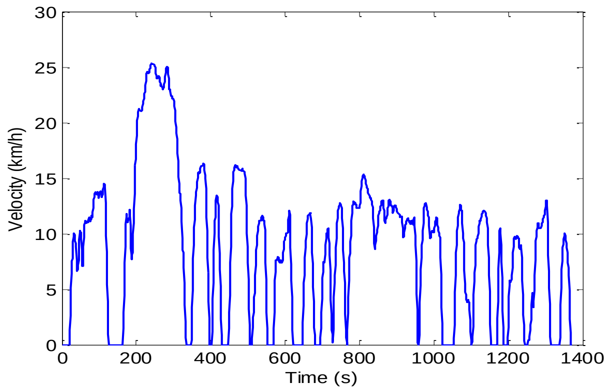


Fig. 2. UDDS drive cycle

Table 3
UDDS characteristics

Description	Value
Total Time	1369 s
Distance	7.450 mile
Average Speed	24.142 mph
Maximum Speed	56.700 mph
Maximum Acceleration	1.475 m/s^2

4. Simulation

A two-wheel drive PHEV with a power-split conguration is chosen as a platform for simulation. All specifications were set according to values available in the Autonomie Prius model. In the Autonomie, the platform is known as "*split_midsize_PHEV_2wd_single_ mode default*". The simulation can be run using batch simulation runs file provided by Autonomie to be used in MATLAB as shown in Figure 3. Table 4 shows the output variable name used in Autonomie to provide the output results for the simulation.

```
results = auton_reload_buses(command_bind(command_load...
    ('split_midsize_PHEV_2wd_single_mode_default.a_vehicle'),...
    'fuds1.a_process'));

results = auton_set_parameter_value_all(results,...
    'eng.plant.scale.pwr_max_des',70000);
results = auton_set_parameter_value_all(results,...
    'ess.plant.scale.cap_max_des',20);
results = auton_set_parameter_value_all(results,...
    'mot.plant.scale.pwr_max_des',30000);

results = run_sandbox_simulation(results);
```

Fig. 3. Example of using batch simulation runs

The command "command load" is used to load the vehicle from file into a cell array of structures and "command bind" is used to combine the vehicle with a process file. Next, the command "auton_reload_buses" is used to reset the predefined value in the buses that have been overwritten by users. Then, "auton_set_parameter_value_all" is used to set the value based on scalar parameter of the input variable name. Finally, the command "run_sandbox_simulation" is used to save the current workspace and run the defined process. After the commands are run, the results of the simulation are saved in "data.mat" file.

Table 4
Output variable name used in Autonomie

Variable name	Description
ess.plant.results.elec_ consumption	Total electric consumption
eng.plant.results.fuel_ consumption.total	Total fuel consumption
eng.plant.results.emiss ion_co2.total	Total CO2 emission
ess_plant_soc_simu	Output SOC

5. Results and Discussion

Figure 4(a-c) show the fuel consumption again motor power for different values of engine power and battery capacity. If the motor power is considered at 20 kWh, the fuel consumption is increased as the engine power increases. This is due to the distribution power between the engine and the motor, where engine is required to propel the vehicle because of the small motor power. The small motor power is unable to provide the required power by the vehicle. However, the fuel consumption is decreased if the motor power is increased. This is expected because the required power for the vehicle that is provided by the motor to propel the vehicle is sufficient.

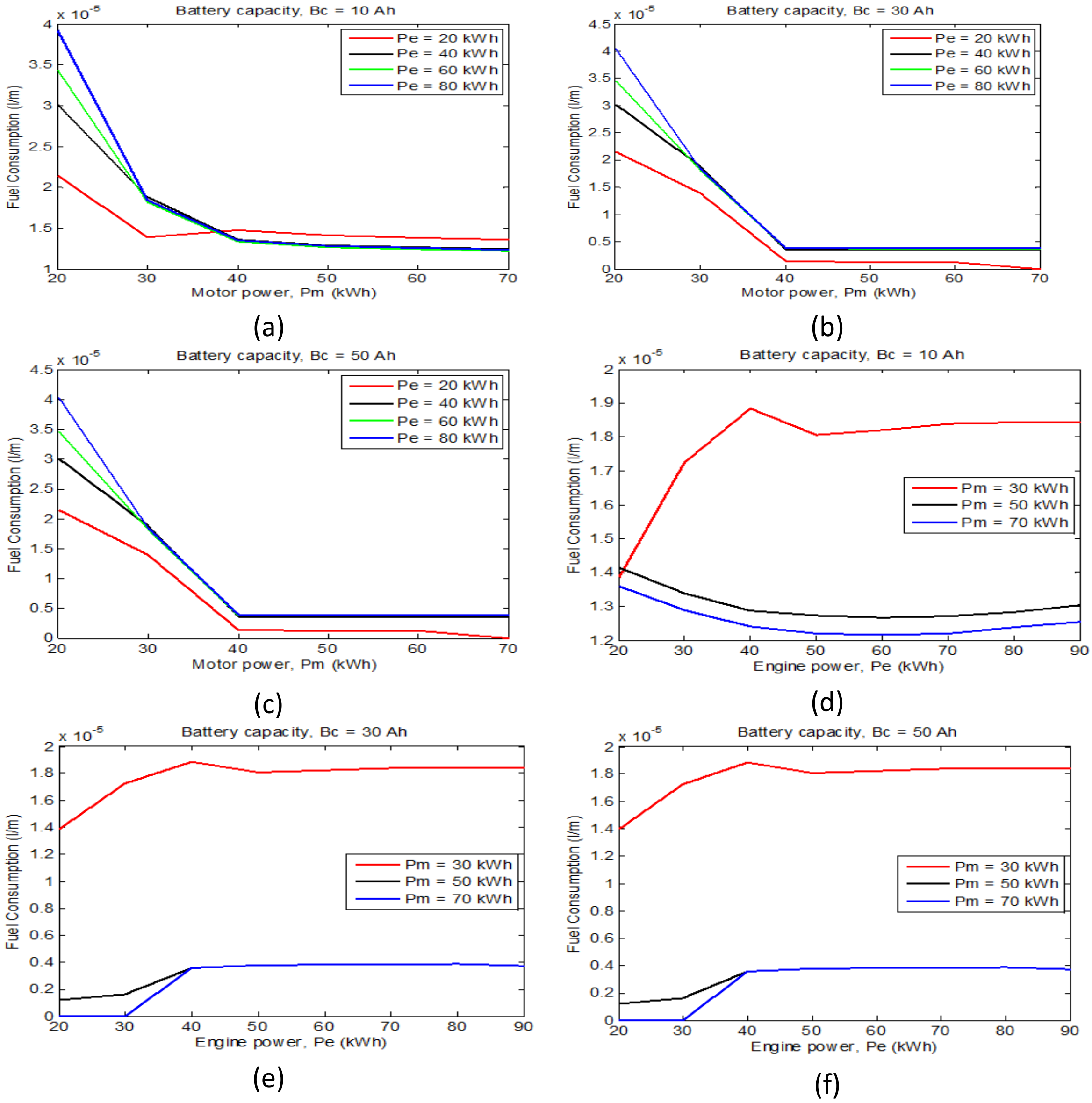
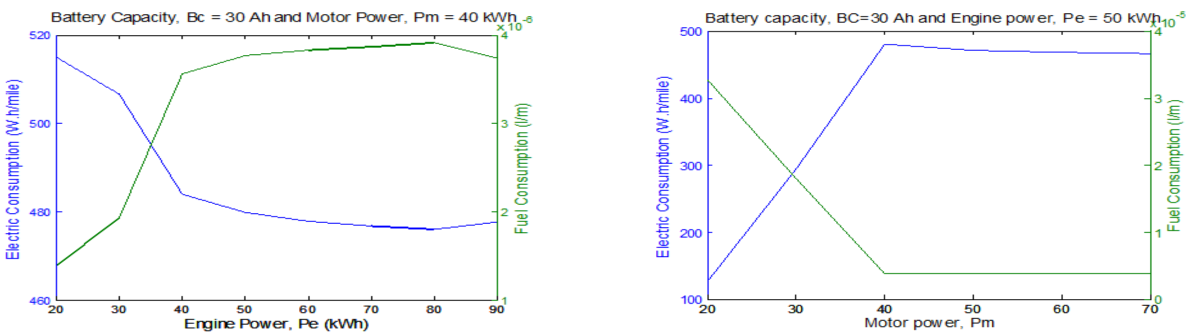


Fig. 4. Fuel consumption again different motor power (a-c) and engine power (d-f)

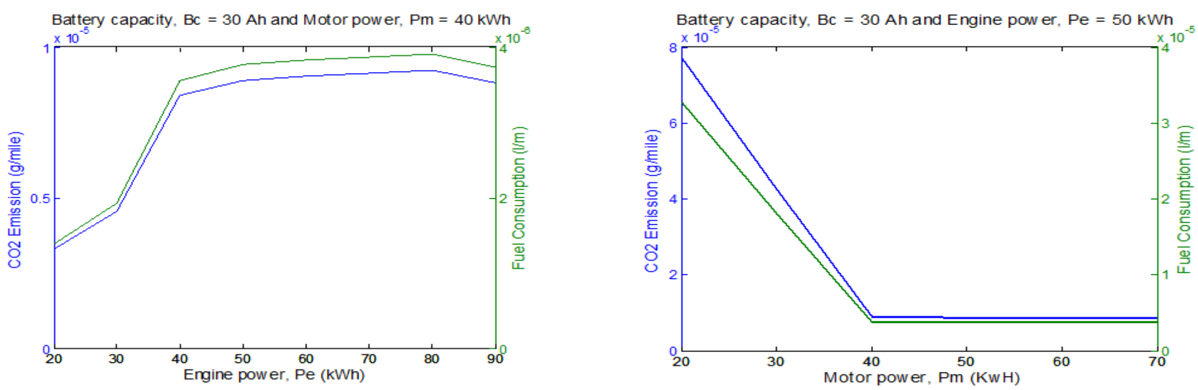
Figure 4(d-f) show the impact of engine power on fuel consumption for different values of motor power and battery capacity. On the overall, the fuel consumption for vehicle using low motor power (30 kWh) consumes more fuel compared to high motor power. This is expected based on the explanations given earlier on. If a higher motor power is used, the fuel consumption is lower. As shown in Figure 4(e) and 4(f), there is no use of fuel consumption for the vehicle using 70 kWh motor power with 20 kWh and 30 engine power.

On the overall, the fuel consumption for vehicle using low motor power consumes more fuel compared to high motor power. This is expected based on the explanations given beforehand, if the higher motor power is used, the fuel consumption is lower. Figure 5 (a) and 5(b) show the comparison between the total electric and total fuel consumption for constant battery capacity (30 Ah), respectively. The electric and fuel consumption is contrary to each other as the vehicle chose the engine used for the propulsion based on the power required from the drive cycle. Then, the comparison between the total carbon oxide (CO_2) emission and total fuel consumption for constant battery capacity (30 Ah) is shown in Figure 6. The total CO_2 emission follows the trend of the total fuel consumption. As seen in Figure 6(a), the total CO_2 emission increases as the total fuel consumption increases. The total CO_2 emission can be minimized if the total fuel consumption decreases. It can be achieved by increasing the motor power of the vehicle to minimize the total fuel consumption.



(a) (b)

Fig. 5. Fuel consumption and electric consumption again (a) engine power and (b) motor power



(a) (b)

Fig. 6. CO_2 emission and fuel consumption again (a) engine power and (b) motor power

6. Conclusion

The three main powertrain components namely, engine power, motor power and battery capacity can affect the total fuel consumption, electric consumption and CO_2 emission of the PHEV. The engine power and motor power are directly affecting the total fuel consumption and electric consumption, respectively. Meanwhile, the fuel and electric consumptions contradict each other.

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