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Optimal Energy Management for Plug-In Hybrid Electric Vehicles

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ABSTRACT

There is a great potential for significant improvement to be made in energy efficiency and reduction in emissions, fuel use, weight and cost of vehicles through implementing innovative technologies. Many automakers have been making great efforts to develop an alternative vehicle that can offer the best solution in reducing the effects of global warming and oil depletion. Such a vehicle will win quick acceptance in the marketplace because of the current high fuel cost. Recently, the plug-in hybrid electric vehicle (PHEV) has been identified as one of the most viable technologies to achieve these goals by implementing an optimal energy management system. This paper presents our recent research work on the energy management system for a specific PHEV. The system configuration, analysis, model, control strategy, and simulation results are presented in detail. Recommendations on the directions and areas in which the further research in hybrid vehicle should be aligned are also be included.

1. INTRODUCTION

Figure 1 illustrates a block diagram of the PHEV configuration, which consists of an Energy Storage System (ESS), a Power Control Unit (PCU), an Electric Motor (EM) and an Internal Combustion Engine (ICE) [1, 2]. To ensure the vehicle achieve the target driving performance without sacrificing the optimum operating conditions, it is essential to develop an optimal strategy for management of the complex power flow and interactions between the components of the PHEV.

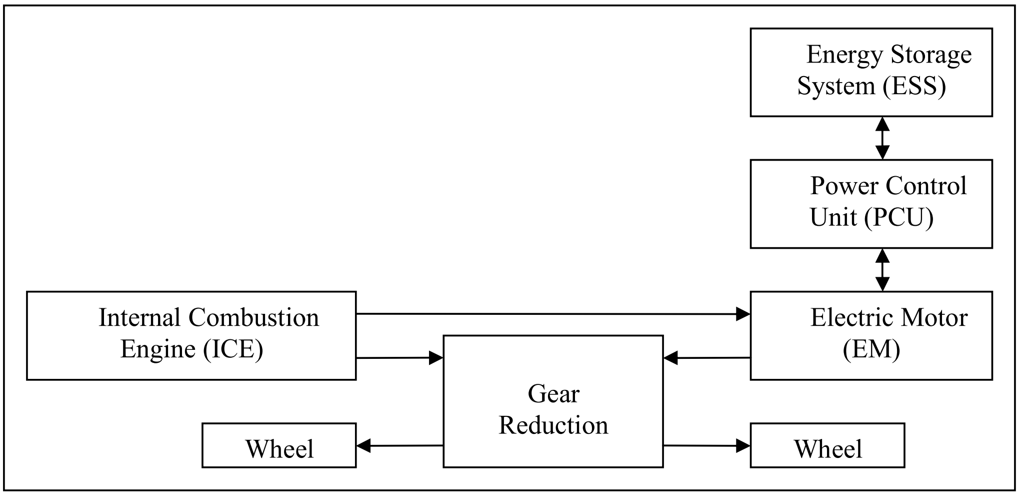

Fig 1 Block diagram of the PHEV configuration.

This PHEV has an on-board rechargeable ESS and a fuelled propulsion power source as the main energy storages. The combined electrical and mechanical power from both storages is transferred through the powertrain to the wheel to suit various driving conditions. The design of the powertrain configuration is optimized for best energy efficiency and lowest cost and weight. Since the performance of the powertrain configuration is largely dependent upon the accuracy of parameters and specifications of each component, the optimal configuration was carefully determined in order to best represent the actual performance within the system as a whole.

2. VEHICLE MODELING

The accuracy of simulation is largely depends on the accuracy of the components parameters. The vehicle selected is an average size 5-passenger sedan, which is the majority of the vehicles on the road. Table 1 lists the typical parameters of a vehicle of this type [3].

Table 1 Parameters of an average 5-passenger sedan

Name	**Value**	**Units**
Aerodynamic drag coefficient	0.29	-
Coefficient of rolling resistance	0.01	-
Frontal area	2.52	m^2
Wheel radius	0.29155	m
Vehicle mass	1255	kg
Air density	1.18	kg/m^3
Gravitational acceleration	9.81	m/s^2

The development of the vehicle model begins with calculations of vehicle energy and power requirements for typical driving conditions based on the parameters and target specifications of the vehicle. The size and capacity of each vehicle component are then determined through a power flow analysis accordingly to meet these requirements. Combining the constitutive equations of all components, we obtain a mathematical model of the vehicle. The vehicle performance for a given energy management strategy and driving cycle is simulated in the MATLAB/SIMULINK environment. Figure 2 [4 – 6] illustrates the PHEV model in MATLAB/SIMULNIK.

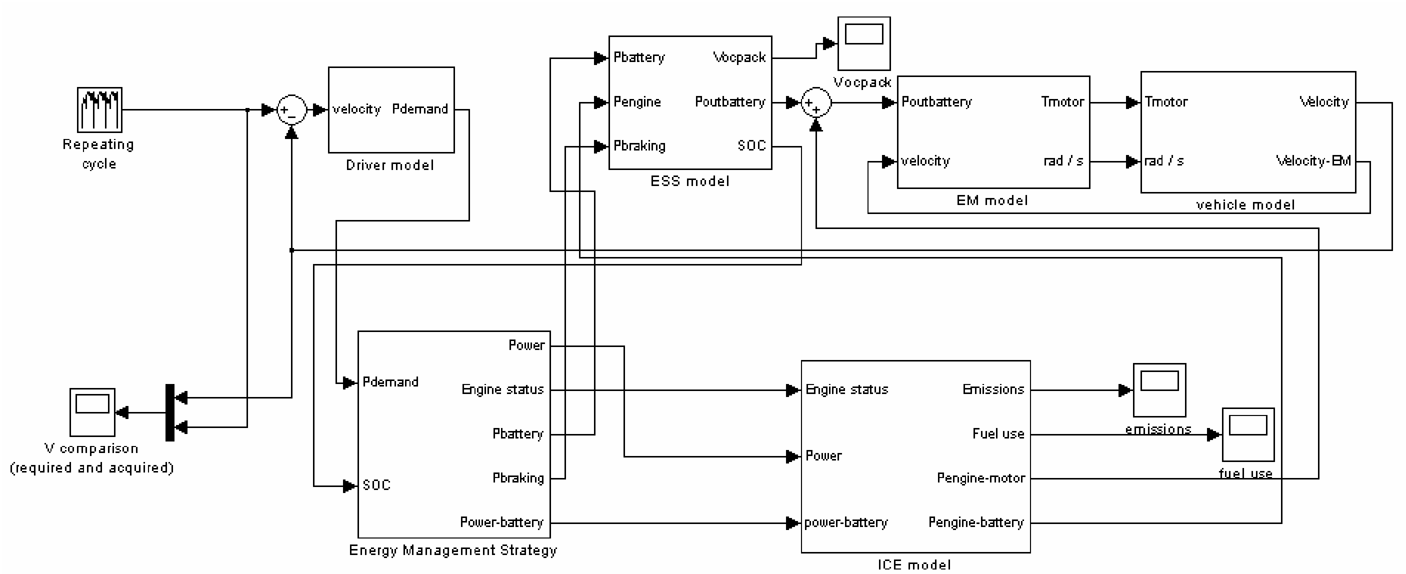

Fig 2 PHEV model in MATLAB/SIMULINK

3. ENERGY MANAGEMENT STRATEGY

For a specific PHEV configuration, the energy management strategy plays a critical role in the vehicle efficiency and driving performance [7 – 9]. In this paper, we present a smart energy management strategy to control the power flow amongst the components in the powertrain configuration of the proposed PHEV. The management strategy can control the power flow under various drive conditions, such as low, continuous and peak acceleration, regenerative deceleration and braking, and standstill while the vehicle is waiting at the traffic lights or in a traffic jam or simply idling when it stops. Among numerous different combinations of power flow paths an optimal power distribution in the vehicle is carefully determined to reduce the power losses during the energy transferring process from the energy storages to the wheels to achieve the highest energy efficiency.

Figure 3 shows various operation modes of the proposed energy management strategy to control the distribution of power amongst the components according to the vehicle power demand in acceleration and deceleration and the state of charge (SOC) level of the ESS.

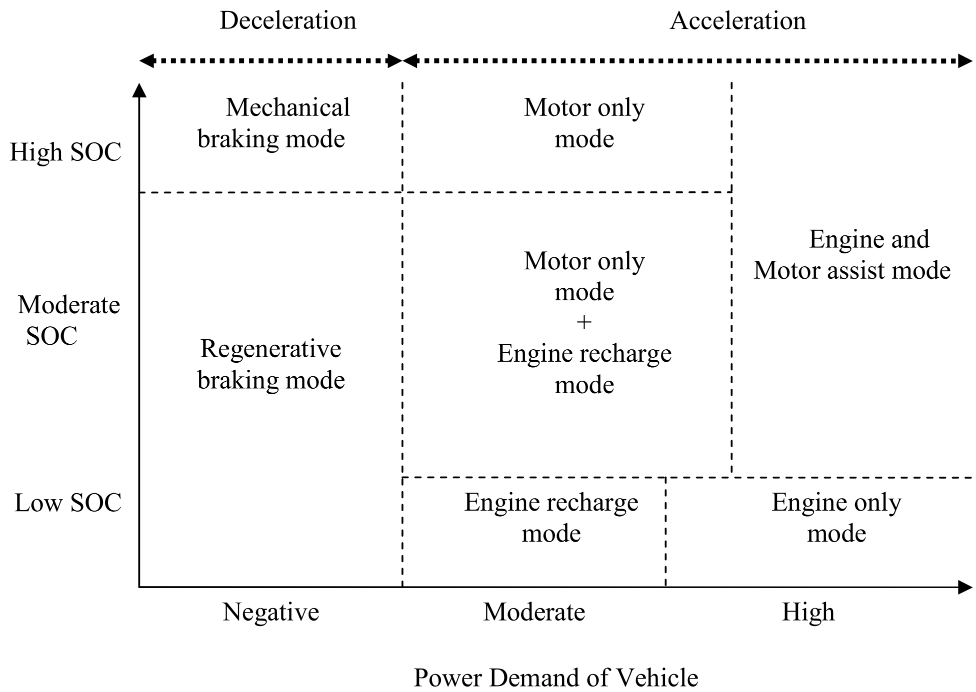

Fig 3 Energy management strategy modes of operations

4. SIMULATION RESULTS

The model presented above is used to simulate the drive performance and energy consumption of the PHEV for the Highway Fuel Economy Test (HWFET) drive cycle shown in Figure 4. The HWFET drive cycle consists of a mild initial acceleration from zero velocity until the vehicle attains the highway velocity for about 100 seconds. Once the highway velocity level is reached, the vehicle velocity varies from 20 m/s to 23 m/s followed by a steep drop to 12 m/s at 300 seconds, and then a rapid increase to nearly 26 m/s. The drive cycle ends as the vehicle slows down to zero velocity at 765 seconds. The power consumption of the vehicle determines the throttle and braking level for a specific drive cycle.

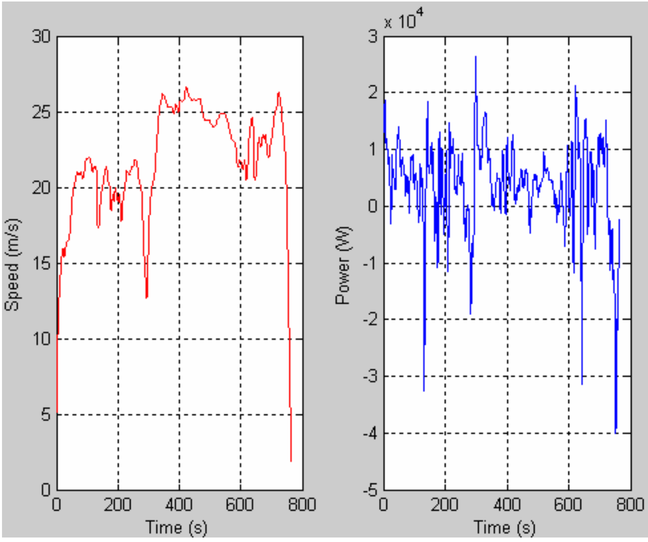

Fig 4 Highway fuel economy test (HWFET) drive cycle

Figure 5 shows the simulated results of ESS current, voltage and power consumption for the HWFET drive cycle. The peak currents are due to the high power demand to achieve fast vehicle accelerations during the respective periods. The negative values on the graph represent the regenerative braking events during the hard braking periods in the cycle. In the ESS voltage graph, the voltage increases during recharging from regenerative braking and decreases during high current discharge when the power demand from EM is at peak.

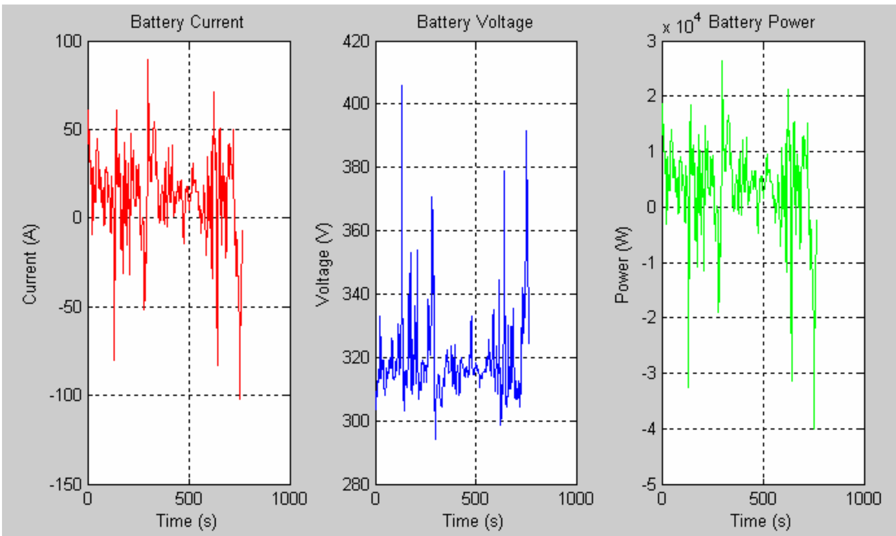

Fig 5 ESS current, voltage and power

Figure 6 shows the simulated EM speed, torque and power. As shown in the simulation results, when the vehicle accelerates, the required EM torque increases quickly, and when the vehicle reaches the relatively stable highway velocity level, a much smaller torque is required to overcome the resistance and air drag to the vehicle. The average power demand from the EM is 8 kW at the highway velocity level and the peak power demand is 24 kW during the acceleration.

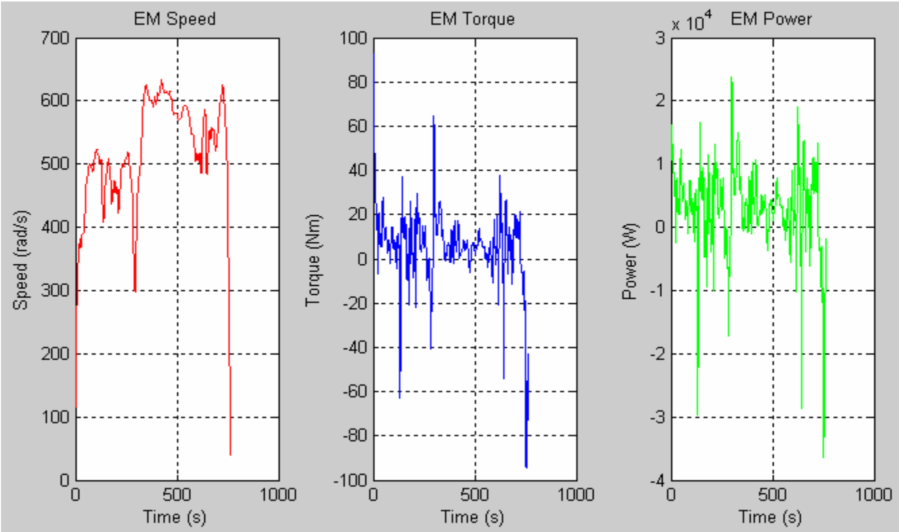

Fig 6 EM speed, torque and power

Figure 7 plots the simulation results of wheel speed and torque requirement for the HWFET drive cycle. The maximum wheel torque, 600Nm, occurs when the vehicle is accelerating from standstill to the highway speed. The required torque then reduces since the HWFET drive cycle only consists of mild accelerations and decelerations.

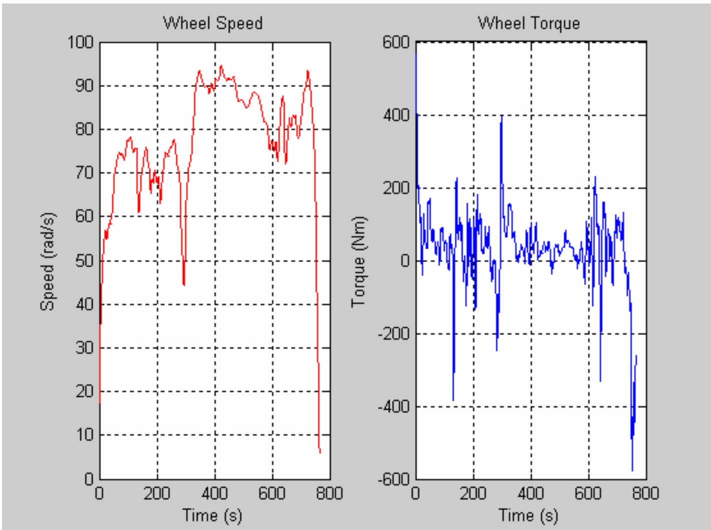

Fig 7 Wheel speed and torque

Figure 8 plots the simulated vehicle speed and the demanded speed for the HWFET drive cycle. As shown, the two curves match very well with a very small error of less than 0.08m/s between the targeted and the acquired speeds. Since this is a typical drive cycle profile for a general driving behavior, it is expected that the PHEV will be able to provide similar highway driving performance as the conventional vehicle in the actual driving conditions.

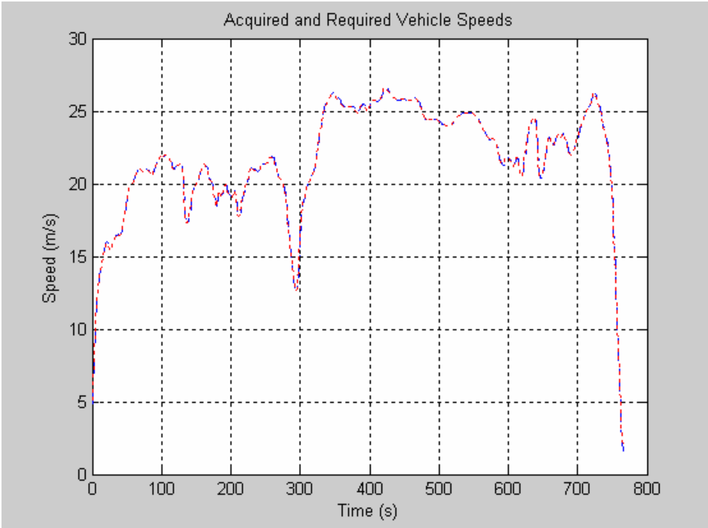

Fig 8 Acquired and required vehicle speeds

5. CONCLUSION

The results of the vehicle subsystems in terms of ESS current and voltage, EM output speed and torque and wheel speed and torque are reasonable and representative of actual typical behavior of these subsystems. The components of the vehicle subsystems are correctly sized as the vehicle is capable of achieving performance to a target velocity. It is found that the results are within reasonable and expected range.

6. ACKNOWLEDGEMENT

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