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Hardware-in-the-loop Simulation on a Hybrid Power System in Plug-in Hybrid Electric Vehicles

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Abstract

A hybrid power system, which is comprised of Ultracapacitors, power battery pack and DC/DC converter, is researched to meet the dual requirements of high-energy density and high-power density for the applications in plug-in hybrid electric vehicles (PHEVs). The working principles are analyzed and its reasonable topology is determined based on comparisons. A logical threshold control is built and its thresholds are optimized. An HIL platform is built which is based on the xPC Target real-time simulation and uses the hybrid power system as the in-loop hardware. The simulation results show the idea of the hybrid power system and its control method is feasible.

Keywords: hardware-in-the-loop (HIL); battery; energy storage; PHEV (plug in hybrid electric vehicle)

1 Introduction

The world is approaching peak oil and the ability to produce high quality, cheap and economically extractable oil on demand is diminishing. Peak oil and the environmental impact of fossil fuel utilization, has encouraged a growth in research in the area of renewable energies, especially battery and ultracapacitor [1-2]. Plug-in Hybrid Electric Vehicles (PHEV), which have both advantages of EV and HEV, has longer pure electric driving range which powered only by on-board battery pack and also can drive a long distance without charge which powered by the on-board ICE in hybrid mode. High demands for the PHEV battery pack have been put forward because of the large power need and large energy need at the same time. A new solution named hybrid power system (HPS) is put forward based on the analysis on the existing energy storage system. In this paper, a hybrid power system, which is comprised of Ultracapacitors, power battery pack and DC/DC converter, researched as shown in Fig.1.

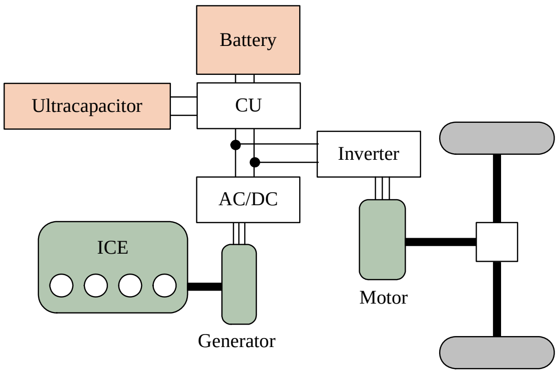

Figure1 The structure of a hybrid power system in a PHEV

Obviously, implementing and testing the designed controller for hybrid battery-ultracapacitor is an important issue for the energy systems. The well known software MATLAB/Simulink by Math-Works has been widely used in dynamic system modeling and simulation of control algorithms. Since years ago, efforts have been made to control the physical systems through MATLAB and its toolboxes. The MATLAB toolbox xPC Target provides us a rapid prototyping host-target

environment to construct the real time control system in a manner of hardware-in-the-loop (HIL) simulation.
The software xPC Target is a solution for prototyping, testing, and deploying real-time systems using standard PC hardware. In this environment, a desktop or laptop computer is used as the host PC with MATLAB and Simulink to create a model using Simulink blocks. After creating the model, the simulation can be first run. Afterwards, xPC Target allows us to add I/O blocks to the model, and then use the host PC with Real-Time workshop and a C/C++ compiler to create executable code. The executable code is downloaded from the host PC to the target PC (desktop/laptop PC, industrial PC, PC/104, etc.) running the xPC Target real-time kernel, which is booted by a floppy disk. The communication between the host and target PCs is through RS-232 or TCP/IP. After downloading the executable code, we can run and test the target application in real time. The most advantageous feature that we would like to use is the vast of the supported I/O boards by xPC Target. To develop a real-time control system controlling the physical systems, we plug proper I/O boards into the PCI or ISA slots of the target PC, and drag the driver block of the boards from the driver library into the Simulink model in the host PC. When the control application is running in the target PC, the I/O boards read the physical sensor readings into the program in target PC and output the control signals to the physical systems [3-4].
Work in this paper aims at developing a real time energy management strategy for a hybrid power system using xPC Target for hybrid power system control.

2 Working principle of HPS

Due to the DC/DC in different position, there are mainly three topologies of hybrid power system. One topology is elected shown in Fig.2 after a simulation comparison in respects of energy losses and cost increase.
The working principle is based on the following two rules:
(1) Ultracapacitors, as a high-power density electric resources, undertakes the dynamic load peak, while the battery pack, as a high-energy density energy resources, undertakes the average load power steadily.
(2) Since all the energy is from the battery pack, and the Ultracapacitors functions as a power transfer device, the energy flow into and from the ultracapacitors should be controlled as small as possible.

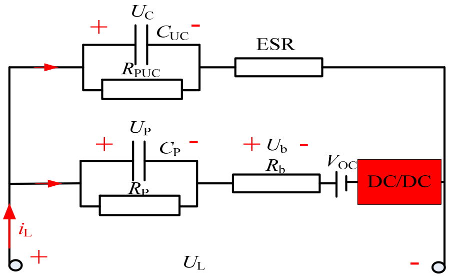

Figure2 The topology of a Hybrid power system

3 A control strategy based on the logical threshold control

For a hybrid power system, the control strategy design mainly focus on the power distribution strategy and energy state management strategy of ultracapacitors.
(1)Based on the vehicle’s dynamic power requirement, in order to avoid the peak current impact on battery pack, the ultracapacitors was controlled to follow the peak power actively and firstly which is also helpful to recover the regenerative energy during braking. This is also to say, for the electric motor’s power requirement, it was divided into two parts, the rapidly changing peak part is from ultracapacitors and the remaining part is from the battery pack;
(2)When the ultracapacitors’ SOV is above the minimum limit, the ultracapacitors’ output power is actively controlled to follow the vehicle peak power requirement by the control module G(s), F(s) during the first ten seconds and the battery pack’s output power is limited to increase gradually to avoid possible over discharging.
Here a logical threshold control is built shown in Figure.3 and the thresholds are optimized by simulation with the models shown in Figure 4,the decision variables of the control strategy are P_m* and SOV， the constraint function as follows.

$$f(\bullet)=\begin{cases} SOV_L \le SOV \le SOV_H \\ SOV \le 100\% \\ P_{chg}(SOC) \le P_{bat}^* \le P_{bmax}(SOC) \end{cases} \qquad (1)$$

Where SOV_L、SOV_H is the SOV (state of voltage) minimum and maximum threshold of the ultracapacitor, P_{bat}* is the target power of the battery, P_{bmax}(>=0)、P_{chg}(<0)is the maximum safe charging and discharging power, which are the functions of SOC(state of charge).P_a is the average required power of the motor, the battery would afford the output power alone on the condition that the needed power is under P_a and slowly changed.

P_{pmax} is the maximum allowable discharging power of the battery and is a function of SOC. P_m is the real-time power of the drive motor.

F(s), the target power of the battery, can be calculated as:

$$F(s)=\begin{cases}\dfrac{1}{\tau_{bat}s+1} & (P_m^* >= 0,\text{discharge}) \\ \dfrac{1}{\tau_{uc}s+1} & (P_m^* < 0,\text{charge})\end{cases} \quad (2)$$

4. HIL Simulation and Vertfication

The test bench for hardware in loop test is shown in figure 5, which consists of electrical load equipment, a CAN communication unit, a host computer and Target. The electrical load equipment can charge/discharge a battery according to the real-time demands of the current or power with maximum voltage of 50V and maximum charging/ discharging current of 200A, and its recorded data include current, voltage, temperature, accumulative Amp-hours (Ah) and Watt-hours (Wh) etc. The errors of the Hall current and voltage sensors are less than 0.2% and 0.5%, respectively. The measured data is transmitted to the Target through CAN. Both the Target and the electrical load equipment have a low-pass filtering function to implement large noise cancellation [5].

The soft is running in two PCs, host PC and Target PC. The host PC runs Microsoft Windows XP operating system and the required software packages: MATLAB, Simulink, Real-Time Workshop (RTW) and C/C++ compiler. MATLAB is host software environment of Simulink with xPC Target and RTW module. In this environment, a desktop or laptop computer is used as the host PC with MATLAB and Simulink to create a model using Simulink blocks. After creating the model, the simulation can be first run. Afterwards, xPC Target allows us to add I/O blocks to the model, and then use the host PC with Real-Time workshop and a C/C++ compiler to create executable code. The executable code is downloaded from the host PC to the target PC running the xPC Target real-time kernel, which is booted by a floppy disk. The communication between the host and target PCs is through TCP/IP. After downloading the executable code, we can run and test the target application in real time [6].

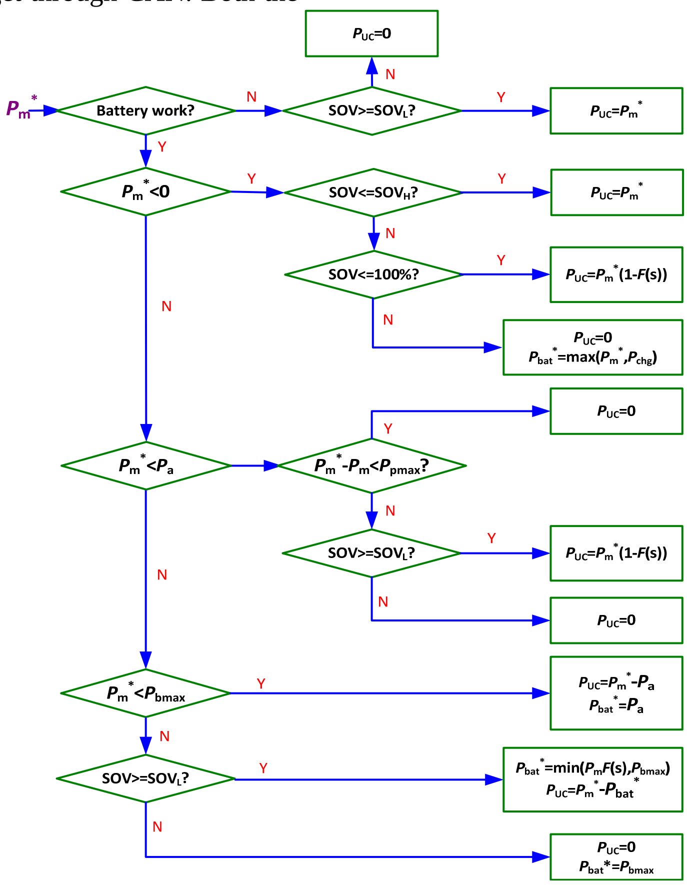

Figure 3 The flowchart of the control strategy

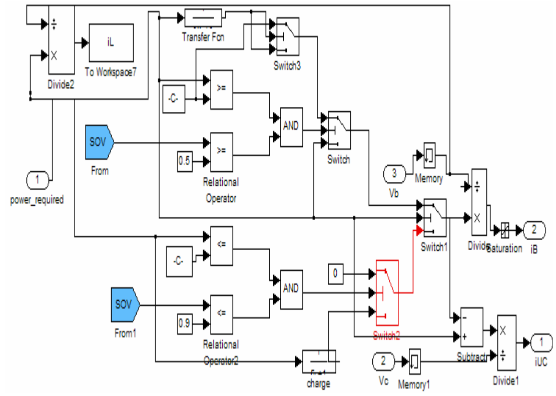

Figure 4 Simulation Models

In order to reduce the influence of temperature, the battery module being tested is kept in a thermal chamber, and the temperature display shows the variation less than ±5°C.

We choose UDDS(Urban Dynamometer Driving Schedule) (figure6(a)) as the simulation test driving cycle, vehicle parameters are shown in Table 1, and the vehicle model also was built in simulink model, then download to xPC, the required power of the vehicle on UDDS is shown in figure6(b)

Table 1 The vehicle's basic design parameters

Vehicle	
Vehicle weight/kg	1320
Curb weight/kg	1845
Windward area/m^2	2.53
Drag coefficient	0.36
Rolling raduis/m	0.299
Battery	
Nominal voltage/V	3.6
Nominal capacity/Ah	30
number/N_{bat}	88
Ultracapacitor	
Nominal voltage /V	16.8
Nominal capacity /F	500
number/N_{uc}	9

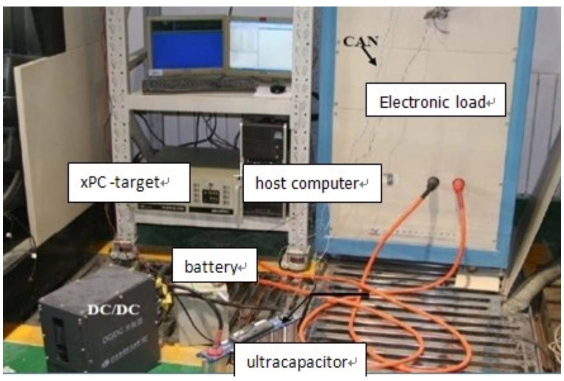

Figure 5 The HIL simulation platform

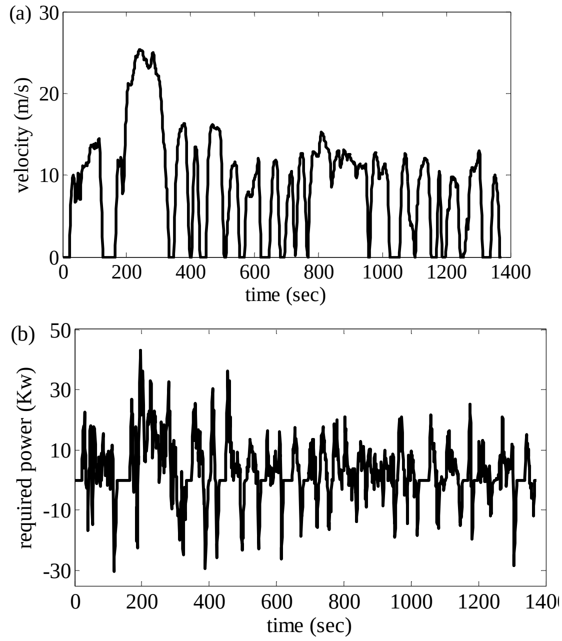

Figure6 profiles for the test condition: (a)UDDS driving cycle; (b)required power of the vehicle

Figure 7 is the experiment results of hardware in loop simulation.

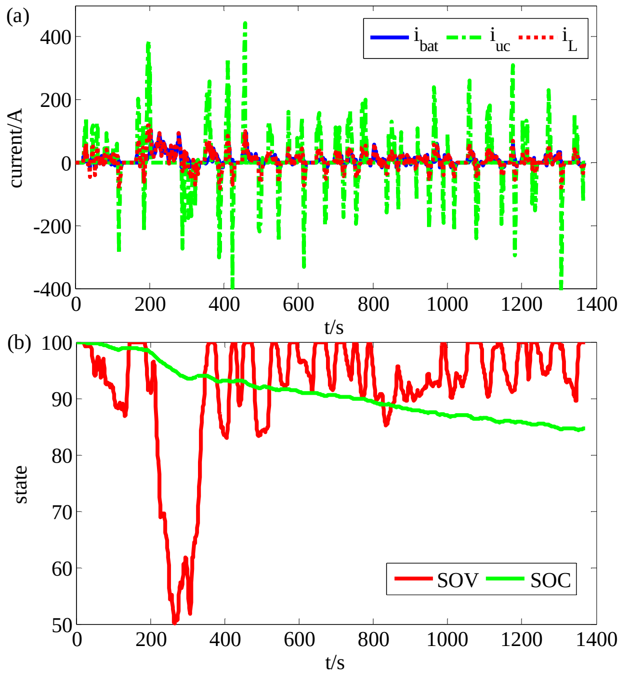

Figure 7: (a) the current curves;(b)the state curves

From the results of the simulation we can see that the control strategy for the hybrid power system ensure comprehensive the advantage of ultracapacitor and battery, it makes the power system with high power and energy density. The required power of the motor is shared by battery and ultracapacitor. The main power is still afforded by battery while ultracapacitor takes as the auxiliary power or load. Figure 7(a) shows the battery and ultracapacitor current curve of the simulation. We can see that the battery current is controlled under 1C while the ultracapacitor may have high current. The ultracapacitor is connected to the bus in serial with DC/DC converter, it can reduce the big currents impact on the battery and dramatically improve the dynamics of the energy system property during 200~300 seconds with high power output. Also it may absorb the energy quickly and efficiency with high current during 300~400 seconds at breaking time, it saves energy and protect the battery from damage for high current. The state curve of the battery and ultracapacitor in figure 7(b) show energy of the ultracapacitor keeps steady during the whole driving cycles, acting like a reservoir to balance the input and output. So the battery energy consumes at a steady level and the ultracapacitor realize the effect in the hybrid power system.

5. Conclusions

(1) A real time control system for hybrid power system has been developed and constructed by using the software package (MATLAB, Simulink, xPC Target, Real-Time Workshop and VC++ compiler) and commercially available hardware (multifunction I/O boards and power amplifiers, etc.).
(2)The HILS platform has the characteristics of real-time and accuracy, it can really reacted the real-time state characteristics of the hardware in the experiment process.
(3) The idea of the hybrid power system and the control method is feasible, the ultracpacitor absorbs and provides quickly to avoid the big impact on the battery, which will extend the lifespan of battery greatly.
Our further work is to explore such control strategies like dynamic programming method to get higher efficiency and maintain a steady working load of battery pack.

Acknowledgments

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