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Energy balance optimalization of electric vehicle driving dynamics

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This paper deals with power flow management system of electric vehicle and hybrid fuel cell-powered vehicle during operation. The aim is the real-time control of the power distribution between the fuel cell and its associated energy storage to optimize the global hydrogen consumption and energy consumption of other energy storage system in vehicle while maintaining drive ability. On the basis, the control strategy is used to determine the real-time optimal power distribution by simple minimization. The approach has been simulated in simulation program ADVISOR 2004.

1 Introduction

Stimulated by the urgent need for more electric power vehicles that produce fewer harmful emissions and hybrid vehicles, plug-in electric vehicles and fuel cell-powered vehicles are being investigated in many researches and development programs. The combination of a reversible energy storage source with a fuel cell, referred to as hybridization, may greatly benefit in fuel cell technology.

1.1 The potential advantages of hybridization

The potential advantages are numerous:

- As the additional energy source can fulfill the transient power demand fluctuations, the fuel cell can be downsized to fit the average power demand.
- The ability of the reversible energy source to recover kinetic energy during regenerative braking leads significant energy savings.
- The hybridization creates additional degrees of freedom in the power flows and thus offers opportunities for the optimization of the vehicle efficiency.

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cells and supercapacitors and with both fuel cells and batteries.

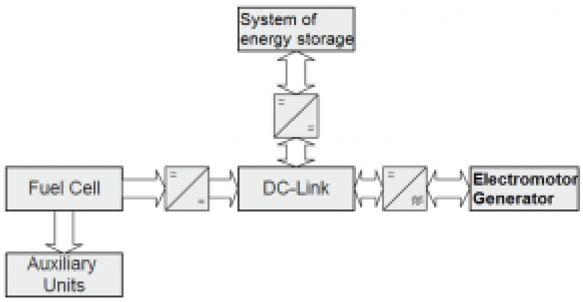

Fig. 1 Standard power train components and power flow

2 Theory of optimalization of energy management vehicle systems

The global optimization of energy management systems are based on knowledge of the future driving conditions, as provided by scheduled driving cycles. Therefore, they are not suitable for real-time control, but they still have an acknowledged importance as a basis of comparison for the evaluation of the quality of real-time control strategies. In this approach, often referred as “local optimization”, two main constraints must be accounted for:

- very limited a priori knowledge of the future driving conditions is available during the actual operation
- the charge of the reversible energy source must be sustained without external sources, but based only upon fuel conversion or regenerative braking during the vehicle operation.

The core of each “local optimization” strategy is the definition of a cost function that is to be minimized, which depends only upon the system variables at that instant time.

3 Energy storage systems in electric vehicles

Fuel cells are electrochemical devices, which convert chemical energy into electrical energy directly by oxidizing hydrogen without intermediate thermal or mechanical processes. Proton exchange membrane fuel cells (PEM-FC) also known as polymer electrolyte fuel cells (PEFC) are preferred in automotive applications because they are efficient, compact and of low weight. Since PEFC operate at almost ambient temperatures, the warm-up process is kept short and their ability to follow the dynamic changes in the applied load.

The power output of a single cell with an active area of 200 cm^2 is less than 100 W. Individual component cells are connected in series form a multi-kW stack, and a system contains several stacks generates a power output of several tens of kW.

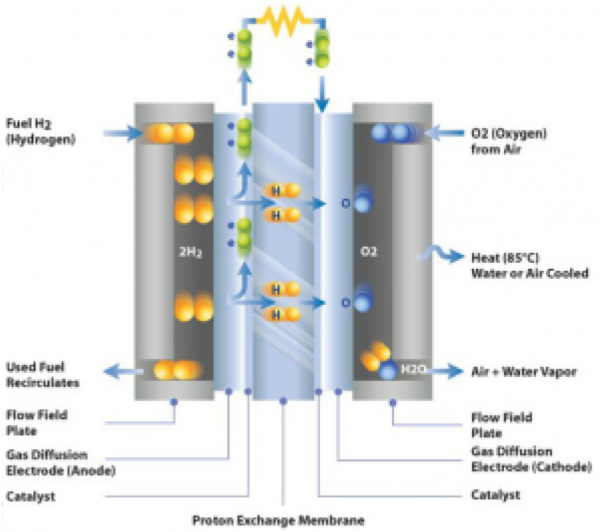

Fig. 2 Proton exchange membrane fuel cell (PEM-FC) [1]

Supercapacitors are electrical storage devices with a high power and a high energy density. Their energy density is up to 100 times higher than that of conventional capacitors, and their power density is up to 10 times higher than that of batteries. With their wide operating temperature range and their long lifetime, supercapacitors are the short-term storage elements of choice.

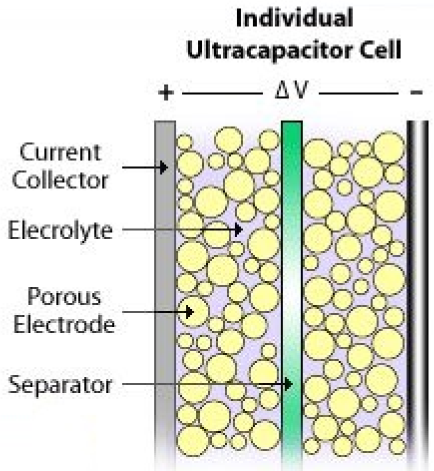

Fig. 3 Ultracapacitor cell [2]

Battery is next component in electric drive . In the classic electrical vehicle the battery is the only energy store, and the component with the highest cost, weight and volume. Battery must continually accept and give out electrical energy, is also a key component of the highest importance.

4 Optimization of power flow management in electric vehicle energy system

The optimization of power flow in energy management system presented in this paper was simulated on experimental fuel cell vehicle with battery storage system and experimental fuel cell vehicle with ultracapacitors.

4.1 Optimization of fuel cell vehicle with battery storage system

Fig. 1 shows the powertrain schematic of fuel cell vehicle with battery energy storage system and key control signals for power management. HbyHyFuel cell vehicle consists of several subsystems: driver, fuel cell system, battery, DC-DC converter, electric drive, and vehicle dynamics. Considering various vehicle states – such as power demand, battery state of charge (SOC), and vehicle speed— the supervisor controller sends the fuel cell current request to the DC-DC converter; sends the motor torque request to the electric drive; and controls the regenerative braking ratio.

In order to generate the motor torque requested from the supervisor controller, the inverter draws current from the electric DC bus where the battery and the DC-DC converter are connected in parallel. The DC-DC converter can control the current flow into the DC bus, where the batteries are connected to the DC bus—the difference between the current draw from the inverter and the current outflow from the DC-DC converter will be compensated by the batteries. The power split ratio between the battery and the fuel cell system is achieved by the supervisor controller sending the fuel cell net current request to the DC-DC converter.

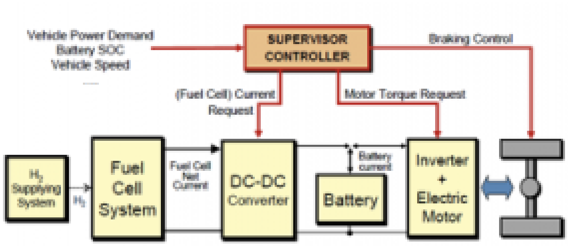

Fig. 4 Control signal flow in Fuel cell vehicle with batteries

The basic principle of power management in fuel cell vehicle is to minimize fuel consumption while maintaining the battery SOC by sending adequate current request command to the DC-DC converter. To achieve this principle , optimal power management strategy needs to be designed for the supervisor controller to balance the fuel cell system power and the battery power.

4.2 Optimization of fuel cell vehicle with supercapacitors

The principle of power management in fuel cell vehicle is to minimize fuel consumption while supercapacitors operating during vehicle accelerations by sending adequate current request command to the DC-DC converter.

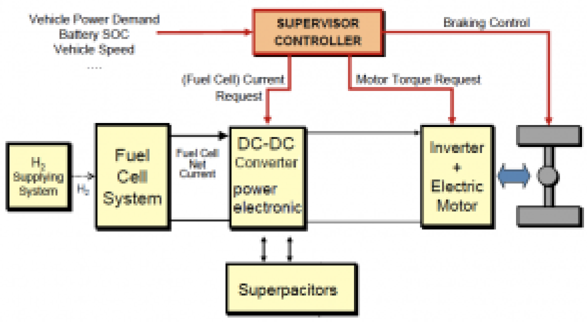

Fig. 5 Control signal flow in Fuel cell vehicle with supercapacitors

5 Model simulations

The vehicle model, electric drivetrain components and driving cycle was created in simulation program AVL ADVISOR 2004. The model takes into account the power requirement of the auxiliary components necessary to support the operation of the fuel cell. Realistic efficiency data and control policies have been associated with those components.

The vehicle is powered by an AC motor with permanent power output of 75 kW; a peak power output of 124 kW and a maximum torque of 255 N m (Fig. 6). Weight The three devices are connected by a DC link- DC-DC converter (Fig. 1), which is kept at a constant high voltage.

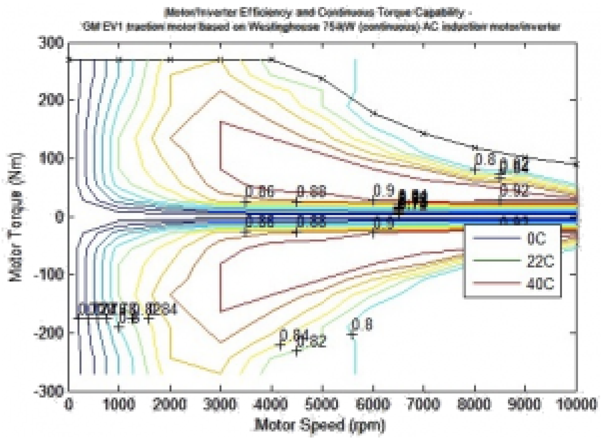

Fig. 6 Electric motor/generator characteristic in simulation program.

The model contains fuel cell engine system with maximal power 50 kW and peak efficiency 43 %. Weight of fuel cell engine system is between 249 kg up to 300 kg, depends on hydrogen storage in hydrogen tank.

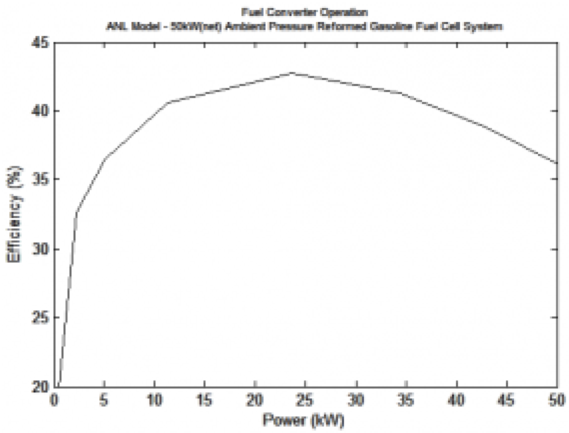

Fig. 7 Fuel Cell ANL50 characteristic

For simulation was chosen NEDC driving cycle. The NEDC cycle was chosen to obtain comparability of the various energy management strategies. The procedure described in the following allows the evaluation of the fuel equivalent of the electrical energy use for a given hybrid electric vehicle over a given drive cycle. The procedure requires running the model for various constant values of the control variable of state of charge of batteries and voltage level of supercapacitors. For this purpose the storage capacity of the supercapacitors was artificially increased in order to extend the range of the control variable.

At the end of each run, the values of the fuel energy use and of the reversible energy use over the cycle are collected. These values represent the final values of the cumulative quantities. The values of fuel cell vehicle with batteries are plotted in Chapter. 5.1 , which refers to the New European drive cycle (NEDC). The values of fuel cell vehicle with supercapacitors are plotted in Chapter. 5.2 , which refers to the New European drive cycle (NEDC).

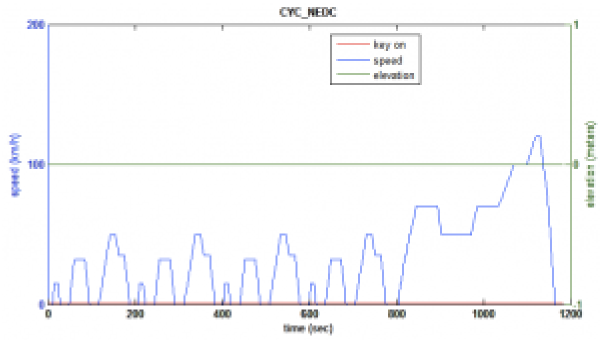

Fig. 8 New European drive cycle

The fuel energy used in this case is the energy that would be used to drive the cycle if no reversible path were present.

5.1 Simulation of fuel cell vehicle with battery storage system

In this simulation is applied a resistance battery model for scaling and optimization purposes using the Nickel Metal Hybrid battery module with 50 kW peak power and nominal voltage 335 V. The battery model is an equivalent circuit model with a voltage source and an internal resistance. Vehicle weight with fuel cell drive with battery storage system is 1337 kg.

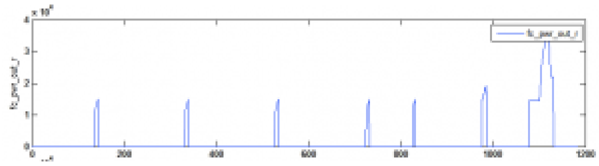

Fig. 9 Fuel cell energy characteristic in driving cycle

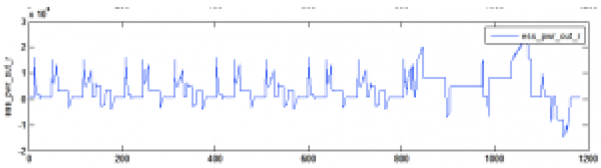

Fig. 10 Battery modul energy characteristic in driving cycle

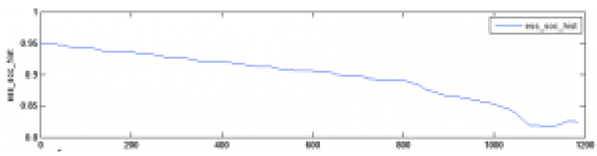

Fig. 11 State of charge (SOC) battery modul

5.2 Simulation of fuel cell vehicle with supercapacitor

The vehicle with supercapacitors is fuel cell acts as the primary power source. The supercapacitors are sized for peak power leveling to assist the fuel cell during hard acceleration. The supercapacitors are used to store energy from regenerative braking and they offer an opportunity to optimize the vehicle efficiency.

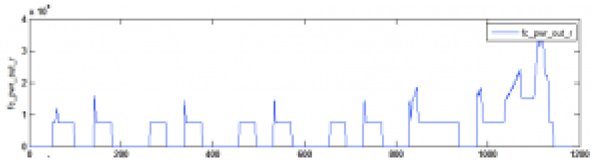

Fig. 12 Fuel cell energy characteristic in driving cycle

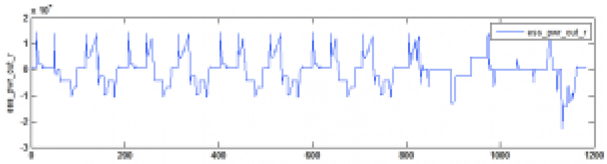

Fig. 13 Supercapacitors energy characteristic in driving cycle

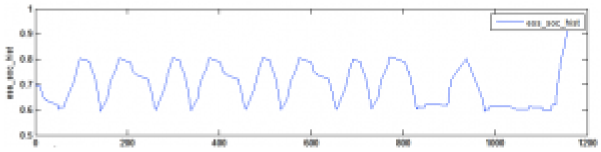

Fig. 14 State of charge (SOC) superacapacitors module

6 Conclusion

If fuel cell vehicles go into production in the near future, their degree of hybridization will significantly impact the vehicle price due to high manufacturing and material costs of fuel cells and batteries. Therefore, by examining the effect of combination fuel cell power system with battery storage system and fuel cell power system with supercapacitors in vehicle drivetrain on fuel economy, car manufacturers can determine the trade-off between fuel savings and manufacturing costs.

I also presented control signal flow diagrams of fuel cell vehicle model with battery storage system that can predict the effect of sizing parameters on the system efficiency characteristics, overall efficiency of fuel cell system, I mainly focused on basic principle of modeling.
The combined optimization results show that the optimality lies in:

- increasing degree of hybridization without compromising regenerative braking
- employing corresponding control strategy

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