Energy analysis of hybrid power source during vehicle motion

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This paper proposes a perfect energy source supplied by a polymerelectrolytemembrane fuel cell (PEMFC) as a main power source and storage devices: battery and supercapacitor, for modern distributed generation system, particularly for future fuel cell vehicle applications. The energy in hybrid system is balanced by the dc bus regulation in dependence on drive cycle. A supercapacitor module, as a high dynamic and high power density device, functions for supplying energy to regulate a dc bus. A battery module, as a high energy density device, operates for supplying energy to a supercapacitor bank to keep it charged. On the basis, the control strategy is used to determine the real-time optimal power distribution by simple minimization.

Keywords: Electric vehicle, Hybrid vehicles, Energy systems, Optimization,

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 (Fig. 1).
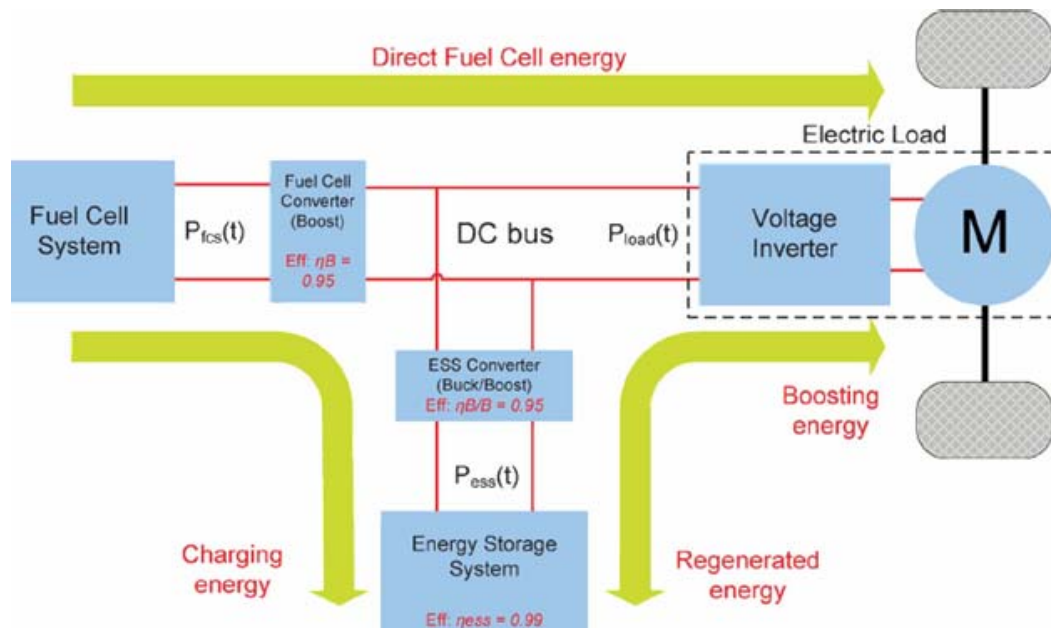
Fig. 1 Standard powertrain components and power flow

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.

The coordination among the various power sources requires a high level of control in the vehicle, typically referred to as supervisory control. This paper focuses on the management of these power flows at any instance in a vehicle equipped with both fuel cells and supercapacitors and with both fuel cells and batteries.

2 Theory of optimization 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.
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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.
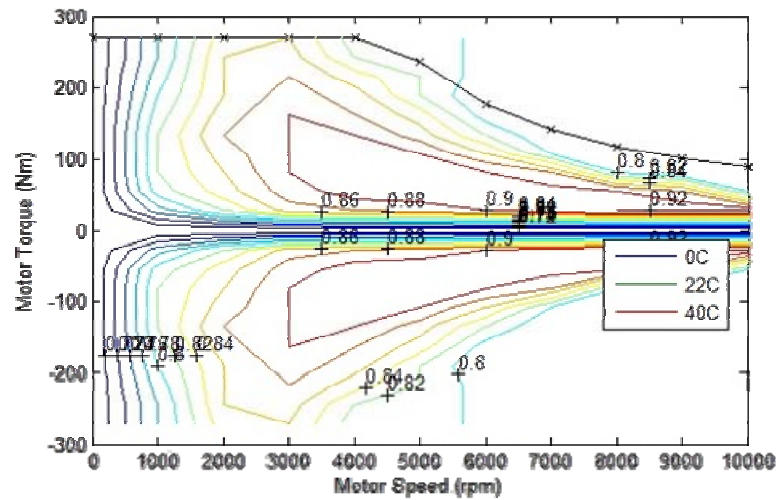
3 Model simulations

The vehicle model, electric powertrain 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. 2). Weight of the three devices are connected by a DC bus - DC-DC converter (Fig. 1), which is kept at a constant high voltage.

Electrical Subsystem is composed of four parts: The electrical motor, energy storage system and the fuel cell and the DC/DC converter. Weight of vehicle is 1300 kg.

**Fig. 2** 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.

For simulation was chosen NEDC driving cycle, (Fig. 3). 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).
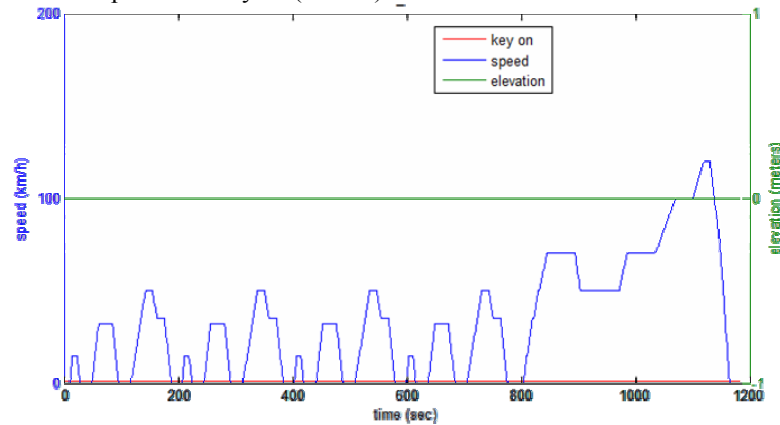

Fig. 3 New European drive cycle

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

Vehicle weight with fuel cell drive with battery storage system is 1337 kg.

3.1   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.
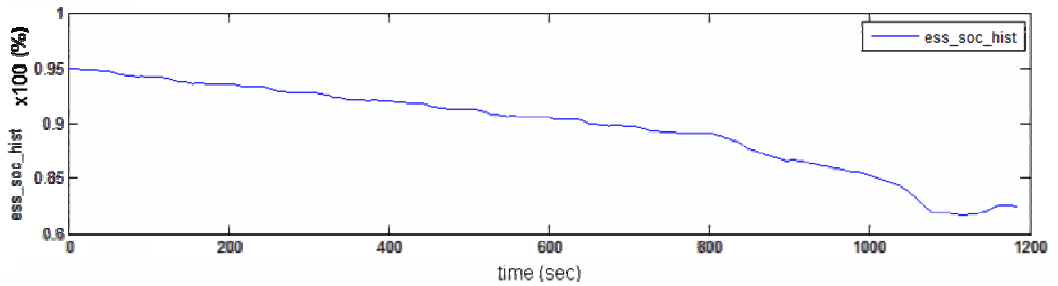
The responses of the fuel cell and battery for power assist and load leveling control strategies are shown in figure 4, figure 5, and figure 6. respectively.
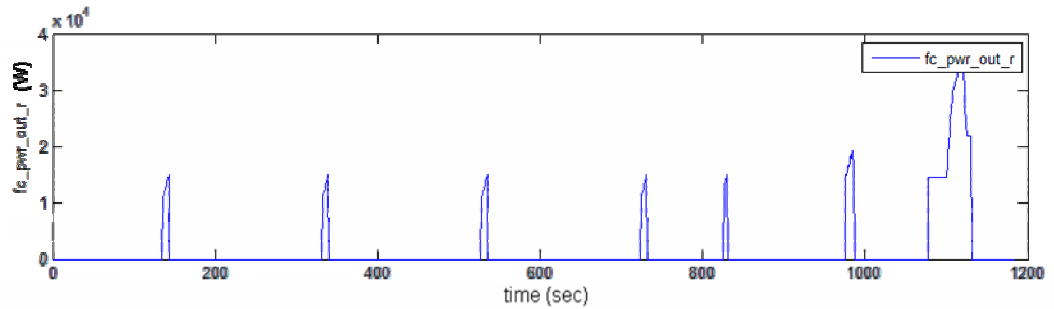
Fig. 4 Fuel cell energy characteristic in driving cycle
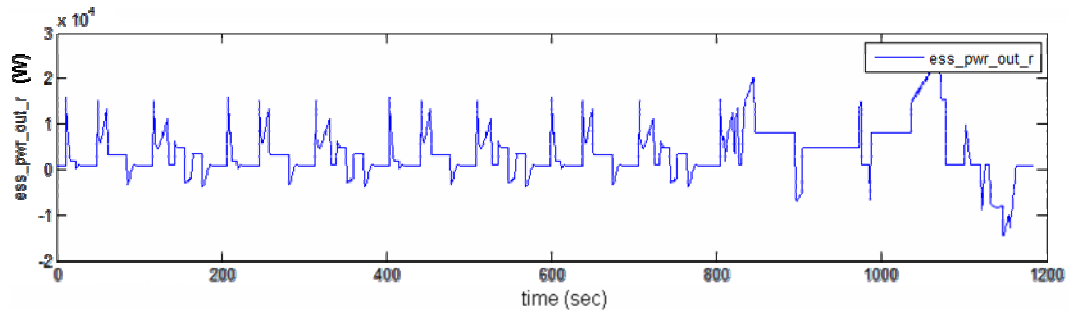
Fig. 5 Battery module energy characteristic in driving cycle

Fig. 6 State of charge (SOC) battery modul

3.2   Simulation of fuel cell vehicle with supercapacitor

The vehicle with supercapacitors is fuel cell acts as the primary power source (Fig.7). The supercapacitors are sized for peak power leveling to assist the fuel cell during hard acceleration (Fig. 8). The supercapacitors are used to store energy from regenerative braking and they offer an opportunity to optimize the vehicle efficiency (Fig.9).
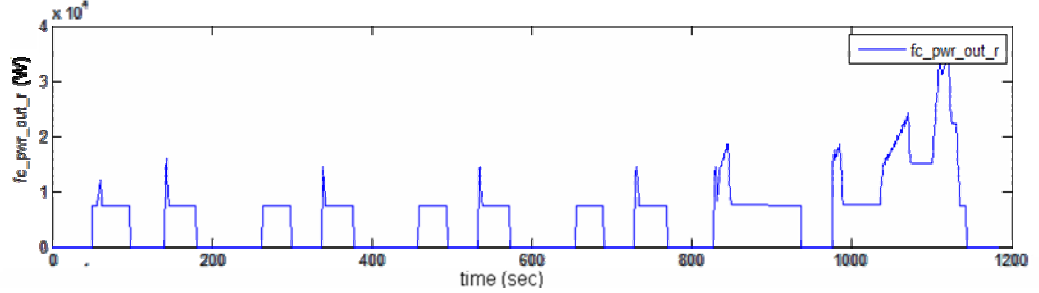
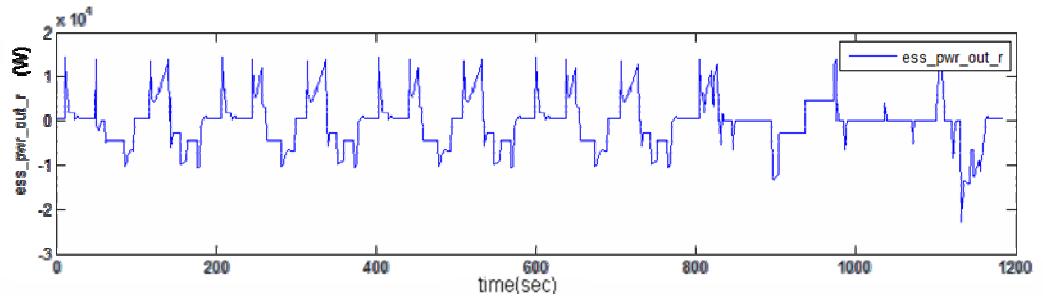

Fig. 7 Fuel cell energy characteristic in driving cycle

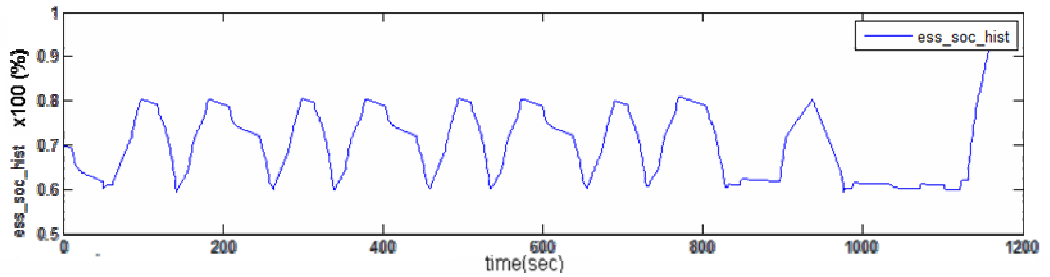**Fig. 8** Supercapacitors energy characteristic in driving cycle

Fig. 9 State of charge (SOC) superacapacitors module

4 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.

We 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. We 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; and
▪ employing corresponding control strategy.

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