ENERGY ANALYSIS OF HYBRID POWER SOURCE DURING VEHICLE MOTION

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ABSTRACT

This paper proposes a perfect energy source provided by a polymer electrolyte membrane fuel cell (PEMFC) as the main power source and a storage device: battery and super-capacitor, for modern distributed generation system, particularly for future fuel cell vehicle applications. The energy in hybrid systems is balanced by the dc bus regulation in dependence to the drive cycle. A super-capacitor 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 to supply energy to the super-capacitor bank in order to keep it charged. The control strategy is used to determine the real-time optimal power distribution by simple minimization.

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

INTRODUCTION

Stimulated by the urgent need for more electric powered vehicles and hybrid vehicles, that produce fewer harmful emissions: 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 fuel cell technology (Fig. 1).

Fig. 1 - Standard powertrain components and power flow

POTENTIAL ADVANTAGES OF HYBRIDIZATION

The potential advantages are numerous:

- An 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 to significant energy savings.
- The hybridization creates additional degrees of freedom in the power flow, thus offering opportunities for the optimization of the vehicles 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 super-capacitors as well as with both fuel cells and batteries.

OPTIMIZATION THEORY FOR THE VEHICLES ENERGY MANAGEMENT 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 to as “local optimization”, two main constraints must be accounted for:

- Very limited knowledge of the future driving conditions is available during 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 definition by a cost function that is to be minimized, which depends only upon the system variables at a particular instance in time.

MODEL SIMULATIONS

The vehicle model, electric powertrain components and driving cycle were created in the 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 these components. The vehicle is powered by an AC motor with a permanent power output of 75 kW; with a peak power output of 124 kW and a maximum torque of 255 N m (Fig. 2). The three devices are connected by a DC bus - DC-DC converter (Fig. 1), which is kept at a constant high voltage. The 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 from simulation program

The model contains a fuel cell engine system with maximum power at 50 kW and a peak efficiency of 43 %. Weight of the fuel cell engine system is between 249 kg up to 300 kg, depending on the hydrogen levels in the hydrogen tank.

For the simulation the NEDC driving cycle was chosen, (Fig. 3). The NEDC cycle was chosen to obtain comparability of the various energy management strategies.

The procedure described in the following allows for the evaluation of the fuel equivalent of the electrical energy used for a given hybrid electric vehicle over a given drive cycle. The procedure requires running the model for several constant values of the control variable of state of charge of batteries and voltage level of super-capacitors. For this purpose, the storage capacity of the super-capacitors were artificially increased in order to extend the range of the control variable.

At the end of each run, the values of the fuel energy used and reversible energy used over the cycle, are collected. These values represent the final values of the cumulative quantities. The values for a fuel cell vehicle with equipped with batteries as well as the values of fuel cell vehicle equipped with super-capacitors are plotted in the following chapters, which refer 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 given cycle if no reversible path were present. Vehicle weight with fuel cell and battery storage system is 1337 kg.

SIMULATION OF FUEL CELL VEHICLE WITH BATTERY STORAGE SYSTEM

In this simulation a resistance to the battery model for scaling and optimization purposes is applied using the Nickel Metal Hybrid battery module with 50 kW peak power and nominal voltage of 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 - Time response of fuel cell energy in driving cycle

Fig. 5 - Time response of battery module energy in driving cycle

Fig. 6 - Time response of state of charge (SOC) battery module

SIMULATION OF FUEL CELL VEHICLE WITH SUPER-CAPACITOR

The vehicle equipped with a super-capacitors fuel cell acts as the primary power source (Fig.7). The super-capacitors are designed for peak power leveling to assist the fuel cell during hard acceleration (Fig. 8). The super-capacitors are also used to store energy from regenerative braking and they offer an opportunity to optimize the vehicles efficiency (Fig.9).

Fig. 7 - Time response of fuel cell energy in driving cycle

Fig. 8 - Time response of super-capacitors energy in driving cycle

Fig. 9 Time response of state of charge (SOC) super-capacitors module

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 for the production of fuel cells and batteries. Therefore, by examining the effects of combining fuel cell power systems with battery storage systems, and fuel cell power systems with super-capacitors in

the vehicle drivetrain, vehicle manufacturers can determine a trade-off between fuel savings and manufacturing costs.

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

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

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