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Modelling and control strategy development for fuel cell electric vehicles

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Abstract

This paper describes a modelling and dynamic control design process applicable to the development of fuel cell electric vehicles (FCEVs) and hybrid electric vehicles (HEVs). After an introduction to advanced propulsion technologies the development of FCEV at DaimlerChrysler is described, followed by a discussion on hydrogen as a fuel for FCEV and the challenges related to hydrogen storage. It is essential for advanced vehicles to obtain a range comparable to that of mass production vehicles sold today. Thus, there is a strong need to operate such vehicles with high efficiency and maximize the energy stored onboard a vehicle. A stochastic dynamic programming algorithm was developed and applied to the energy management of this FCEV, which allow fuel economy optimisation while keeping a good driveability.

Keywords: Fuel cell electric vehicle; Hybrid vehicles; Modelling

1. Introduction

Advanced propulsion technologies such as hybrid electric vehicles and fuel cell electric vehicles have the potential to significantly influence future mobility. Over the past few years, interest in alternative automotive powertrain concepts has been steadily increasing. The decisive factors in this development have been an increase in ecological awareness, rising petroleum prices and a number of legal regulations relating to fleet consumption and exhaust emissions—with differing emphasis in the USA and Europe.

In the early seventies, the development of powertrain systems was primarily focused on reducing fuel consumption—a consequence of the oil price shock; but in 1980s and 1990s, interest then turned towards exhaust emissions—an initiative that arose in California. Exhaust emissions is the sector where the greatest progress has been made over the past few decades: in terms of exhaust pollutants, modern combustion engines emit only a tiny fraction of that of their predecessors from the seventies.

Along with increasingly stringent exhaust regulations, fuel consumption has been the subject of increasing attention from the legislating bodies. One example is the corporate average fuel economy (CAFE) fleet consumption legislation in the USA, which requires the average consumption of all vehicles for every automobile manufacturer to adhere to certain limits. A reduction in fuel consumption and the associated drop in CO_2 emissions is thus of crucial importance to all automotive manufacturers. These are the reasons for setting out in search of alternative concepts to improve fuel economy and reduce exhaust emissions.

Electric powertrain development has been ongoing for the past fifteen years. Commercially, battery electric vehicles have not been able to gain widespread acceptance as a low-noise, emission-free alternative because of their limited operating ranges, long recharge time and poor efficiency. Recently, hybrid electric vehicles were introduced to the mass market.

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1.1. Hybrid electric vehicles (HEVs)

Hybrid propulsion – a combination of a prime mover (usually an internal combustion engine) and an auxiliary power source (e.g., electric motor, flywheel, hydraulic pump) – has aroused the interest of almost all automotive manufacturers over the past few years. The most common combination involves an ICE plus an electric motor, which is referred to as a hybrid electric vehicle (HEV).

HEVs in general are classified into series, split and parallel hybrids. They can propel the front and/or the rear axle. In addition, by running the traction motor reversely as a generator, mechanical energy from the engine and/or the vehicle deceleration can be captured and stored in the energy buffer for later use. This allows numerous possibilities to combine one or more electric motors with an internal combustion engine, operating in several different modes to allow more efficient or more desirable operations. Examples of ‘‘desirable characteristics’’ enabled by multiple power sources include the elimination of torque hole of automated transmissions, active damping for driveline vibration during low-gear torque clutch engagement, or ‘‘electric torque converter’’. The HEV market is growing quickly with the increasing number of models offered commercially.

1.2. Fuel cell electric vehicles (FCEVs)

Fuel cell systems are able to deliver electrical power with high efficiency, with low operation noise and little or no emissions from hydrogen or hydrogen-rich reformer gases and air (Mok & Martin, 1999). By-products are exhaust gases, water and waste heat. The generated electrical power can be used in vehicles for propulsion as well as for the operation of electrically powered accessories. Proton exchange membrane (PEM) fuel cells utilize a solid polymer electrolyte membrane, operate at lower temperature and are considered by many to be the most suitable for automotive applications.

Proton exchange membrane (PEM) fuel cell systems require onboard stored hydrogen or hydrogen-rich gases generated onboard from liquid fuels such as methanol or the conventional hydrocarbons gasoline and diesel.

Since most advanced vehicles like HEVs and FCEVs have one energy storage (buffer) device as part of the propulsion system. It is possible (and necessary) to apply advanced control technologies to significantly optimize the vehicle's fuel economy, emissions and/or drivability.

2. DaimlerChrysler fuel cell vehicles

DaimlerChrysler Corporation has been evaluating fuel cell vehicles since the early 1990s. The first DaimlerChrysler FCV was the NeCar I operating on compressed hydrogen. This commercial van has enough passenger space for the driver and one passenger. The cargo space is used by the large compressed hydrogen tanks and the fuel cell engine. The NeCar II showed dramatic reductions in volume and weight in the fuel cell engine technology. However, the compressed hydrogen tanks still occupied a disproportionate amount of space in this minivan size vehicle. The NeCar III presented the first onboard reforming fuel delivery system incorporated with a fuel cell engine. This onboard methanol reforming system was able to provide enough hydrogen gas to operate the fuel cell engine in a drive cycle. This A-class vehicle sparked the development of onboard fuel reforming as an alternative to storing pure hydrogen onboard.

The Jeep® Commander I was the Chrysler Group's first FCEV. This concept vehicle focused on onboard reforming of gasoline to utilize the existing fuelling infrastructure. The Jeep® Commander II was the Chrysler Group's second FCEV. This concept vehicle utilized an onboard methanol reforming system similar to the NeCar III (Tran & Cummins, 2001).

The DaimlerChrysler Town and Country ‘‘Natrium’’, FCEV displayed in Fig. 1, focused on the alternative hydrogen storage technologies. As shown in Fig. 2, all packaging was completed underneath the vehicle. One of the key engineering challenges was to prevent cabin protrusion by the fuel storage system while maintaining a competitive driving range.

The Natrium's powertrain consists of an 82 kW peak traction system, a 40 kW Li-ion battery pack and a 54 kW fuel cell engine. With 166 l of 20% concentration sodium borohydride fuel, the Natrium can travel 500 km. Vehicle performance was acceptable at 16 s from zero to 100 kph and a top speed of 133 kph. This was the first vehicle to use sodium borohydride ($NaBH_4$) as a hydrogen storage technology to provide hydrogen to the fuel cell engine.

3. Hydrogen storage technologies

Regardless of whether the hydrogen is produced off-board centrally or off-board locally, the method of onboard

Fig. 1. The DaimlerChrysler Town and Country ‘‘Natrium’’.