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Model development and analysis of a mid-sized hybrid fuel cell/battery vehicle with a representative driving cycle

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HIGHLIGHTS

- Model of mid-sized ICE vehicle is developed and validated.
- Model of hybrid FC/battery vehicle is built based on validated ICE vehicle model.
- Effect of driving pattern on performance is investigated using standard driving cycles.
- Driving cycle that represents the driving patterns in Amman city is developed experimentally.
- Performance of hybrid FC/battery vehicle found to be much better than the ICE version.

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ABSTRACT

Vehicles powered with internal combustion engines (ICEs) are one of the main pollutant sources in large cities. Most of large cities (*e.g.* Amman, capital of Jordan) suffer from frequent traffic jams. This leads to frequent stops and starts, and hence, an increase in tailpipe emissions. One way to minimize emissions is to use electric motors in the powertrain configuration. In this study, the performance of a hybrid fuel cell (FC)/battery vehicle is investigated utilizing different worldwide driving cycles. Initially, a model of a mid-sized ICE vehicle is developed and validated against experimental tests. The ICE vehicle validated model is then modified to be driven with only an electric motor powered by a hybrid FC/battery system. The effect of driving pattern, which varies from city to city and from region to region, is investigated. A driving cycle that represents the driving patterns in Amman city is developed based on experimental data and then used to evaluate the performance of both ICE and hybrid FC/battery vehicle configurations. It is found that the performance of the hybrid FC/battery configuration is much better than the ICE version in terms of emissions, fuel economy, efficiency, and speed tracking error.

1. Introduction

The transportation sector has a significant impact on both energy sustainability and the environment [1]. It was estimated that it contributes up to approximately 15% of the total global greenhouse gas emissions. Emissions from internal combustion engine (ICE) powered vehicles are the main pollutant source in urban areas [2]. Hence, many studies have been conducted in attempts to replace conventional energy sources by much cleaner ones such as electrical energy. In Amman city, the capital of Jordan, one of the main sources of air pollution is ICE vehicles. During the frequent traffic jams that occur at rush hours (refer to Fig. 1), there is a significant drop in engine efficiency along with an increase in tailpipe emissions.

The continuous escalation of oil prices along with the negative impact of burning conventional fuels on the environment have

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Fig. 1. The rush hours in one of Amman roads.

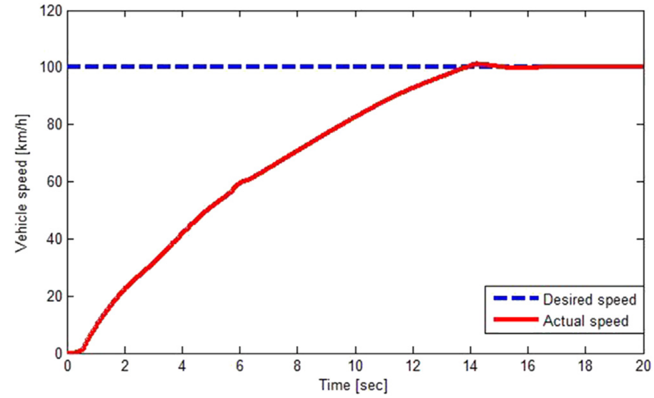

Fig. 3. Simulation result for the 0–100 [km h^{-1}] acceleration time.

motivated researchers worldwide to look for alternative energy sources and replacements for conventional fuels. The development of hybrid vehicles that are powered by both combustion engine and an electrical motor is considered to represent significant progress in the automotive industry due to its advantages of improving fuel efficiency and decreasing emissions.

In Ref. [3], the fuel economy of a series and parallel hybrid ICE/electric step van (with diesel engine) was compared with the fuel economy of a conventional step van using different driving cycles (*e.g.*, Central Business District bus cycles, New York City Cycle, US EPA City and Highway cycles). In Refs. [4,5] plug in electric vehicles that can be directly charged from the national grid were investigated and compared with ICE vehicles. Unfortunately, electrical vehicles usually have a limited range [3]. For longer ranges, a hybrid configuration can be adopted. Hybrid Fuel Cell (FC) vehicles are another promising alternative due to their cleaner operation, better performance, and higher energy efficiency than conventional vehicles [6]. The fuel economy of hybrid FC/battery vehicles was studied in Ref. [7] considering the initial and final status of battery state of charge (SOC). In Ref. [8], Abu Mallouh et al. developed a model for a hybrid FC/battery rickshaw using the PSAT software package. They carried out a comparison study between an ICE and a hybrid FC rickshaw and concluded that the fuel economy can be improved significantly in the hybrid FC configuration. The hybrid FC rickshaw model developed in Ref. [8] was used in Ref. [9] to investigate the performance with a fuzzy logic control strategy that controlled the power distribution of a hybrid FC/battery rickshaw.

It is essential to quantify the amount of emissions and fuel consumption by using a driving cycle that represents actual driving patterns. Representative driving cycles are also essential when designing and analyzing powertrains and energy management systems of electrical and hybrid vehicles. In Ref. [10], a methodology was proposed to understand the relation between battery performance and driving cycles of electric and hybrid vehicles operating in real-world situations. In Ref. [11], the impact of real-world driving patterns on energy and power requirements of a converted plug-in hybrid electric vehicle was investigated. In Refs. [12,13], the driving cycle effect on fuel cell performance and microstructure of the membrane electrode assembly was investigated to predict the life time of the cell. In Ref. [14], it was concluded that the fuel economy of a hybrid FC/battery configuration depends directly on recovering braking energy and therefore depends on the driving cycles.

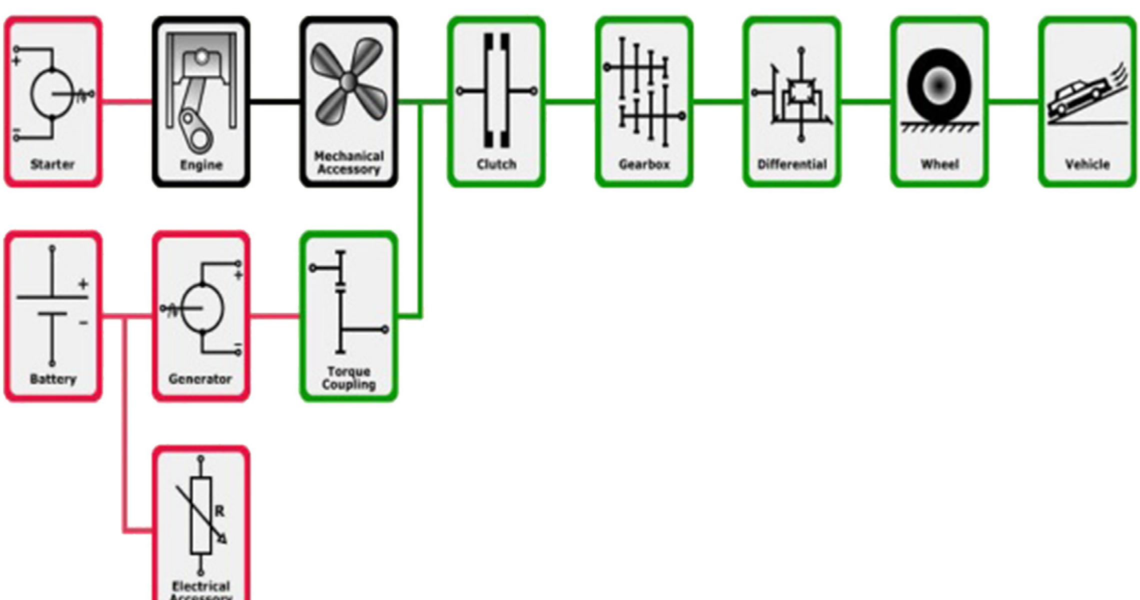

Fig. 2. PSAT model configuration for an ICE vehicle.