

Doctoral Thesis Abstract

To improve the sustainability of agriculture, hybrid fuel cell systems have gained attention due to their properties featuring zero local emissions, high energy density, low refueling time, and high efficiency. The research activity focused on the analysis of fuel cell systems applied to agricultural vehicles.

Starting from a case study of an orchard tractor, a hybrid fuel cell powertrain was designed considering the vehicle constraints. Numerical models of both the traditional and the fuel cell powered vehicles were developed in MATLAB/Simulink environment, and a monitoring campaign was conducted on a traditional vehicle during the most common workday activities. The extrapolated load profiles were used to perform numerical simulations and compare the performance of the two solutions. The results demonstrated that the fuel cell tractor can exhibit almost the same performance as the traditional counterpart, but with a relevant reduction of -50% on average in the use phase equivalent CO₂ emissions, even considering grey hydrogen. The analysis was then expanded to the whole life cycle of the two vehicles, according to a cradle-to-grave approach, and including different impact categories. The results showed that the fuel cell tractor can significantly reduce the total life cycle emissions, with reductions ranging from -60 to -95% depending on the considered category. A further reduction in some categories can be obtained using green hydrogen.

Subsequently, a scaled Hardware-in-the-loop test bench was developed for powertrain emulation, and several tests were conducted considering different hybrid fuel cell system topologies: fuel cell + battery, fuel cell + battery + supercapacitors, and fuel cell + supercapacitors. The three alternatives were designed considering the same overall volume and the same fuel cell system. To test different energy management strategies, both a power follower and a fuzzy logic control algorithms were developed for each configuration. Given the load profiles derived from the previously mentioned monitoring campaign, the three architectures were compared in terms of fuel economy and durability. The results showed that the architecture fuel cell + battery outperformed the other two in terms of expected fuel cell system durability, while no relevant differences were noted in fuel economy. In addition, it was noted that the control strategy had a non-negligible impact on durability.

In the last part of the research activity, a hybrid fuel cell powertrain for an autonomous driving rover, specifically designed for orchards, was developed. A co-simulation model was established, including the rover multibody model, the autonomous driving algorithm and the powertrain model. To develop the numerical model of the powertrain, experimental tests were carried out on the fuel cell system and the hydrogen tank. Numerical simulations considering common work scenarios were performed, showing potential in terms of endurance improvements. Next, a full-scale Hardware-in-the-loop test bench was developed to test the physical hardware of the powertrain. Once validated the hardware, the fuel cell and the tank were implemented on the rover prototype, and experimental tests on the rover were conducted. The results showed that the unit operated as expected and significantly extended the rover endurance.