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Simulation of the operation of a fleet of materials handling and transport vehicles, powered by fuel cells

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ABSTRACT

The aim of this paper is to study the dynamic behaviour of hydrogen technology in a company in which material handling and transportation is used as part of the production cycle at a business in the logistics sector, located in Madrid, Spain. The company owns a fleet of 38 vehicles of four different types powered by fuel cells, which are sufficient to handle and transport 36,000 pallets a week. Using the number of vehicles, the energy consumption and the work cycles for each type of vehicle as the main input variables, TRNSYS software was used to simulate this type of system to ascertain the dimensions of the hydrogen infrastructure. By simulating numerous configurations, we obtained the infrastructure that was most suitable for supplying the fleet and guaranteeing its autonomous operation for a five-day period. The results of the simulation are expressed in terms of the time variation of the energy consumed by the electrolysis system and the compressor, as well as the pressure and volume of the gas in the storage tank. From this it can be deduced that establishing the dimensions of the component elements means the entire system reaches a stable dynamic operation in a timeframe equivalent to 17% of the simulation horizon, with the operational and financial advantages that this entails. This is because the electrolysis system that is required operates continuously during that time, and the power consumed by the electrolysers is the system's main operational variable. The procedure employed for this study can be replicated in other similar situations by adjusting the input variables and any specific requirements.

Introduction

The uses and applications of hydrogen (hereafter H_2) technology have gradually increased in number and variety to embrace a wide range of activities in every sector of the economy. Businesses related to materials handling in different areas such as industry, materials distribution centres, warehouses, ports and airports, etc., is turning into a niche of opportunity for the introduction of H_2 end-use

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technology, especially that which involves fuel cells (FC), into a sector other than transportation vehicles, and there is large potential for growth [1].

R&D projects and those demonstrating the use of FCs in material handling equipment, have been mainly focused on fork-lift trucks (FLTs). Depending on their type and function, these vehicles use electric motors with lead/acid batteries, or combustion engines powered by diesel fuel or LPG. The former are used indoors and the latter mostly outdoors.

The choice of FLTs as the equipment for testing the use of H_2 in materials handling and transport vehicles, took into account the following considerations:

1. This equipment is used intensively, requiring high energy consumption, mainly of fossil fuels. As a result, they emit large amounts of atmospheric contaminants.
2. They are the most popular and versatile form of material handling equipment. It was estimated that in 2012 there may have been some 14.5 million of these vehicles worldwide, and 535,000 units were introduced that year [2]. These figures indicate the appeal of any plan to use alternative energy sources to operate FLTs.
3. In technological terms, FLTs are relatively simple and sufficiently well known, which means converting them to FC is not a complex task.
4. The successful penetration of H_2 end-use technology in this market, including in early markets [3], would be advantageous to its introduction into the transport vehicle sector, which is technologically more complex. It has even been considered a necessary preliminary step [4].

The business that pioneered the idea of using FCs in material handling vehicles was Linde which, in 1997, presented its first prototype for FCs [5]. Since then, the number of organizations and companies that are embarking on R&D in this area has grown, focussing on the use of FC-powered FLTs in large warehouses and distribution centres [6]. This interest is based on the following competitive advantages:

a. Reducing environmental pollution, as the only subproducts of FC-powered FLTs are water and heat. This is very different to the contaminating effects of fossil fuels and lead/acid batteries; in the former, because they both generate and emit greenhouse gases and, in the latter, because of contamination from sulphuric acid spillage caused by the mishandling of batteries when charging them, which causes both spillages of acid and uncontrolled H_2 emissions if and when batteries are overcharged [7].
b. A significant reduction in the time needed to resupply the energy required to operate the FLTs. Replacing one battery with another can take between 5 and 15 min, if done automatically, and around one hour if done manually. If recharging is the option chosen, this usually takes five hours, plus a similar amount of time for the battery to cool down. This means that, for continued 24-h operation, three batteries per FLT are required. However, H_2 refuelling can be carried out in under five minutes [7].
c. If batteries are replaced, the space taken up by the equipment and devices required for the task can be substantial. As a gauge, we have indicated the need for 4 m^2 per battery, which means a potentially significant additional operating cost, depending on the land value of the site. Although it is difficult to make any general statements on the financial value of this factor, as it depends on the specific features of the company and its location, a reference value of $ 800/m^2 would apply to the case of constructing a large materials warehouse [8]. One example of freeing up space is the Coca-Cola bottling and distribution plant in San Leandro, California. The company recovered a surface area of 190 m^2 when it converted its fleet of FLTs to FC [9].
d. Constant efficiency during the working cycle, unlike battery-driven FLTs which undergo a decrease in efficiency because their useable power drops as they de-charge. Furthermore, FC-powered FLTs function correctly in cold atmospheres such as fridges and cold rooms, in which batteries can lose up to 25% of their capacity [1].

All these advantages translate as an increase in productivity, the recovery of space, and less polluting activity which, together, lead to a reduction in operating costs and lower pollution levels. However, we must also mention the obstacles that remain concerning the mass use of FC-powered FLTs: larger investment than for traditional methods, the need for an infrastructure for supplying the H_2 and guaranteeing its safe handling, the scarcity of available information on the technical and economic aspects, and corporate reluctance to innovate or change their operational setups.

All the above means that any study of the theoretical foundations and applications for this use of H_2 is fully justified. It is in this context that this study was undertaken, with the principal purpose of producing a dynamic simulation of the operation of a fleet of H_2 FC-powered FLTs at a Madrid-based business in the logistics sector. To do so, it shares a distinctive feature with previous studies, as the simulation is based on the computational software TRNSYS, while the infrastructure for creating and supplying the H_2 is based on selecting and using commercially available equipment and devices for the various different system components. The combined focus is therefore on theoretical and technological features that are available on the market. We therefore believe that this process is easy to replicate in other industries that use fleets of material handling and transport vehicles in their operations and which are aiming to improve their productivity and adapt to new ways of supplying and consuming environmentally-friendly energy.

Development

Background

The studies so far published on the use of H_2 technologies in FLTs deal with technical, economic, environmental and safety aspects. In this respect, Renquist, et al. (2012) made a technical and economic comparison between FC-powered FLTs and those using batteries. They considered various different amounts of electrical power and handling loads, and pointed out the difficulty of obtaining reliable and up-to-date information on operational and economic features. They developed a simulation model which they applied to a real case of a