Fuel Cell Technology

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The role of cogeneration is currently essential in the field of energy efficiency measures. The fuel cell acts in cogeneration, i.e., both heat and electricity are produced from the same energy source, which is an innovative technology with very significant energy savings.

Keywords: fuel cells ; hydrogen ; energy communities

1. Introduction

Actions to achieve energy transition and meet the Paris Agreement targets for decreasing greenhouse gas emissions (GHG) are critical [1]. Cities are a cornerstone of this energy transition, as by the end of 2050 more than two-thirds of the world's population is likely to live in an urban area [2], contributing to almost two-thirds of global primary energy demand and accounting for more than 70% of greenhouse gas emissions [3]. Therefore, energy transition requires multifaceted targets ranging from 100% renewable energy generation by 2050 [4] to the development of carbon neutral districts [5]. To meet these latter challenges, cities must implement measures to adapt to climate change and mitigate its impact. Action plans and projects are being adopted around the world to provide for such measures and to engage cities in the energy transition. As an example, [6] reviewed the different projects that are being implemented among a variety of cities. All these projects are committed to responding to four main challenges [7]: improving the quality of life of their inhabitants, improving resource efficiency, building a green economy, and involving citizens and local governance.

However, such energy transition cannot be abrupt, and the gas distribution network can play a role as a transition technology. The fuel cell acts in cogeneration, i.e., both heat and electricity are produced from the same energy source, which is an innovative technology with very significant energy savings. Furthermore, it is supported by existing gas boilers in the building and the electrical network.

The role of cogeneration is currently essential in the field of energy efficiency measures [8][9]. Cogeneration is defined as the production and use of electrical energy and useful thermal energy from the same primary energy source, thereby reducing dependence on fossil fuels and reducing pollution. In addition, significant economic savings can be made by users thanks to the reduction of fuel consumption and the generation of electrical energy [10]. Moreover, the development of fuel cell technology has gained momentum worldwide thanks to its high efficiency, clean operation, and its ability to adapt to different applications, from mobile to stationary. The European Commission implemented the European Green Deal [11] in December 2019, which aims to make Europe a climate-neutral continent by 2050. The European Green Deal contains the European Hydrogen Strategy, which is responsible for carrying out the necessary actions to promote the use of renewable hydrogen: investments, research, and regulation of the legal framework. In addition, the Hydrogen Roadmap [12], which encourages the use of renewable hydrogen-based solutions and sets targets for their implementation, has recently been approved by the government. In this context, stationary fuel cells have been proposed as one of the cogeneration technologies for the transition towards decarbonisation of the residential sector in cities [13]. This is because they take advantage of pre-existing energy systems: gas distribution, electricity distribution, domestic thermal and electrical energy equipment. However, to date there is very little scientific literature on the real feasibility of implementing stationary fuel cells for residential demand, and on methods to calculate their performance [14].

2. Fuel Cell Technology

Hydrogen is the fuel for the cogeneration system proposed. Although hydrogen is very abundant in our natural environment, it is not found in its pure state, so energy is needed to obtain it. For this reason, it is not considered an energy source but an energy vector. The biggest problem that arises from the use of this element is the cost and difficulty of production, because fuel cells have not yet been fully incorporated into the energy market, so the cost is still too high to compete economically with more conventional energy systems [15]. However, when comparing the different methods of producing hydrogen, natural gas reforming processes are currently the least expensive and the most widely used for hydrogen production [16]. On the other hand, the energy dependence on fossil fuels remains and cannot be considered clean energy [17]. Instead, it is considered a transitional technology, which is why city gas has been included among the green fuels by the European Union.

Finally, it is important to know the main advantages of a fuel cell-based production system that cannot be offered by other more conventional energy production systems [15]:

- Low environmental impact. There is no combustion reaction at high temperature, and there are no emissions of unoxidised hydrocarbons or nitrogen oxides. Moreover, thanks to its high efficiency, CO_2 emissions are much lower than those of other conventional production systems.
- Operational flexibility. Due to the modular nature of the fuel cell, the system can adjust its output to demand without sacrificing efficiency.
- Low noise pollution. With no moving parts, fuel cells are quiet and require little maintenance.

3. Definition of the Different Types of Fuel Cells

There are many types of fuel cells, although they all have the same structure [18] including two electrodes: the anode, where the fuel is supplied, and the cathode, where the oxidant is supplied. These two electrodes are separated by an electrolyte, which functions as an electrical insulator and proton conductor. At the anode, hydrogen dissociates electrochemically into hydrogen ions (H^+) and free electrons (e^-). In this way, the electrons generated are directed to the cathode through the external circuit producing electrical energy, while the protons are directed to the cathode through the electrolyte. At the cathode, the oxidant combines in the presence of a catalyst with the hydrogen ions and free electrons to generate water.

The different types of fuel cells are classified according to the type of electrolyte used. Furthermore, according to the operating temperature, a distinction is made between high-temperature cells:

- Molten Carbonate Fuel Cell (MFCF)
- Solid Oxide Fuel Cell (SOFC)

And medium/low temperature cells:

- Proton Exchange Membrane Fuel Cell (PEMFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Alkaline Fuel Cell (AFC)

There is another type of fuel cell that is not included in the list (Direct Methanol Fuel Cell, DMFC) because its field of application is in very low power portable applications. This is due mainly to their low efficiency. Higher efficiency figures can be achieved using different fuels, such as ethanol [19], but more research is needed so this becomes competitive with other types of fuel cells at high power applications. Depending on the operating conditions, such cells are suitable for each application. It can be concluded that high temperature fuel cells have a higher efficiency, but do not adapt well to demand as they have a slow start-up and responsiveness, whereas medium and low temperature fuel cells offer a slightly lower cogeneration efficiency, but with a fast start-up and responsiveness, which allows them to adapt to daily variations in demand. In this respect, PEM fuel cells are the most widely used both in terms of number of applications and installed capacity, mainly in the transport sector. A lot of research has been conducted with this type of fuel cells to improve efficiency [20]. Hence, to evaluate the techno-economic viability and carry out an energy balance, a study of a neighbourhood's energy demand must first be carried out and a choice made as to which fuel cell technology is the most suitable based on the behaviour of the demand.

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