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USE OF HYDROGEN FUEL CELLS TO OPTIMIZE DATA CENTER OPERATIONS.

Abstract

The rapid growth of data centers, driven by increasing demand for processing capacity, has led to a significant rise in energy consumption and its environmental impact. This article explores using hydrogen fuel cells as a clean and efficient energy solution to meet the power needs of large-scale data centers, known as hyperscale data centers.

Hydrogen fuel cells produce clean electricity with minimal emissions and generate by-products such as heat and water, which can be repurposed to enhance the system's overall efficiency. Solutions like combined heat and power (CHP), waste heat recovery (WHR), absorption chillers, and closed-loop water cooling systems aim to establish a circular economy model within data center operations.

Despite challenges related to hydrogen production emissions, infrastructure requirements, and costs, ongoing technological advancements are promising. This paper concludes that implementing hydrogen fuel cells in data centers and optimizing this technology can significantly reduce carbon footprints, lower operational costs, and address energy inefficiencies, ensuring a sustainable future for large-scale data centers.

Keywords: Data centers, Hydrogen Fuel Cells, Absorption Chillers, Waste Heat Recovery, Circular Economy

1. Introduction

The demand for data centers is continuously increasing. By 2022, it was estimated that global data centers energy consumption would range between 240 to 340 terawatt-hours (TWh), which accounts for about 1–1,3 % of the total global electricity demand [1].

With the development of artificial intelligence (AI), power demand is expected to grow by 160 % by 2030 [2]. This surge contributes to higher greenhouse gas emissions and operational costs.

To address these challenges, alternative energy sources that are clean, reliable, and cost-effective must be explored. Hydrogen fuel cells present a promising solution—hydrogen is a highly abundant element, and the chemical process that generates energy from it is clean and remarkably efficient compared to other energy sources [3]. The by-products of this chemical reaction, such as water and heat, can be harnessed to create a self-sustaining energy cycle, potentially enhancing the overall system's efficiency while reducing costs.

In the following sections, we will explore the concept of using hydrogen fuel cells to meet the power consumption needs of data centers and strategies for optimizing energy production by repurposing these by-products.

2. Hyperscale Data Centers

In simple terms, a data center is a building or a group of buildings that stores computer systems and that organizations use to house their applications and data [4]. Different data centers can vary in size, energy consumption, and overall structure.

Generally, data centers can be categorized into four types: onsite data centers, colocation facilities, hyperscale data centers, and edge data centers [5]. For the subsequent thought experiments, the hyperscale data centers will be used as samples.

2.1 Power consumption

A hyperscale data center is a large facility specifically designed to offer extreme scalability and is built to handle substantial workloads [6]. To operate effectively, these data centers require a significant amount of electrical power. The International Data Corporation (IDC) defines a hyperscale data center as needing at least 5,000 servers and occupying a minimum of 10,000 square feet of floor space [7]. As a result, many of these data centers can draw power loads that exceed 100 megawatts. This energy is essential for powering the computing equipment, cooling systems, backup systems, lighting, and other auxiliary systems.

2.2 Energy Efficiency

Although the energy consumption values may seem excessive, hyperscale data centers demonstrate high efficiency in terms of Power Usage Effectiveness (PUE). PUE is defined as the ratio of the total energy a data center uses to the energy used specifically by its Information Technology (IT) equipment. A perfect PUE value would be 1, whereas the industry average is projected to be 1.56 by 2024 [8]. Many of these extensive facilities are relatively new and equipped with the latest technology, often resulting in a lower PUE, as illustrated in Figure 1 [9].

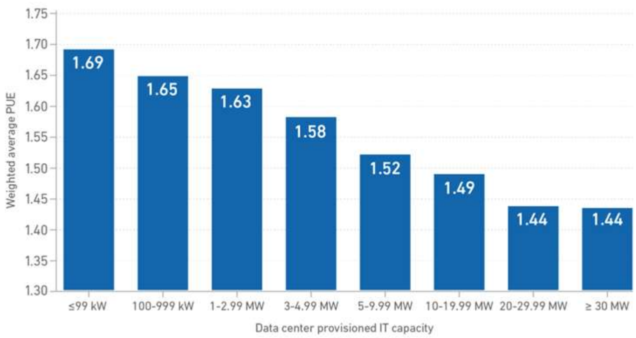

Figure 1 - Weighted average PUE by data center IT capacity

2.3 Challenges to Match Energy Needs

Plans are in place to construct larger data centers exceeding 1 gigawatt (GW) of power [10]. However, several challenges remain, including a heavy dependence on traditional power grids and environmental concerns, as increased energy consumption leads to higher greenhouse gas emissions.

Several innovative solutions can be implemented to address these issues. The next section will focus on using hydrogen fuel cells to meet energy demands while minimizing the environmental impact associated with rising power consumption.

3. Hydrogen Fuel Cells

As global demand for digital services increases, data centers become vital infrastructure. However, their rising energy consumption raises sustainability concerns. Data centers have traditionally relied on electricity from carbon-intensive grids or backup power from diesel generators, intensifying the pressure to minimize their environmental impact. One promising solution is the integration of hydrogen fuel cells as a clean and dependable energy source.

A fuel cell is an electrochemical device that generates electricity by supplying hydrogen fuel to the anode and air to the cathode. A catalyst in the fuel cell separates the hydrogen atoms into protons and electrons, creating an electric current when the electrons flow through an external circuit [11].

There are different types of hydrogen fuel cells, notably Proton Exchange Membrane Fuel Cells (PEMFC) and Solid Oxide Fuel Cells (SOFC). PEMFCs are a great option because they operate efficiently, have quick start-up times, and possess a high power density [12]. On the other hand, SOFCs are also excellent choices due to their high efficiency and stability [13].

Fuel cells can serve as primary energy sources or provide backup power during high demand or emergencies. In this section, we will explore the use of fuel cells as a primary power source.

3.1 Advantages of Using Hydrogen Fuel Cells

Since the use of hydrogen fuel cells don't involve the burning of fuel, and since the only byproduct are heat and water, one clear advantage is the fact that this technology provides clean energy, by having near to zero carbon emissions [14]. Apart from that, these fuel cells are also extremely efficient, generally between 40% to 60%, which does not seem a great value, until it's compared with other mechanisms, such as the internal combustion engine of a car, which is only around 25% energy efficient [15]. Finally, as previously mentioned, the byproducts of the energy production are heat and water. Both products can be used, by means of Combined Heat and Power (CHP) [16] and Waste Heat Recovery (WHR) [17] to further increase the operational efficiency of the system, by providing heating and cooling to the infrastructure, that can be repurposed for both the computing necessities of the data centers, as well as the building needs in which the data center is stationed at.

3.2 Challenges of Using Hydrogen Fuel Cells

Even though in the previous section it was explained that hydrogen fuel cells are a clean energy source, there are some setbacks to that affirmation. The fuel cells process is undeniably clean, but the hydrogen production isn't. While it is expected that, by 2030, over half of the hydrogen production comes from electrolysis of water [18], that is, from renewable sources (also known as green hydrogen), the truth is that nearly all of the world's current supply of hydrogen is created using fossil gas and coal with no carbon abatement and, since it is energy intensive to produce hydrogen, it results in more emissions than the fuel it is made from [19]. To solve this issue, and as previously noted, it's mandatory to increase the production of green hydrogen in favor of other methods to ensure that there's a reduction of carbon emissions. Since it is a developing technology, the costs are still considerable.

Even though the price, per kW of power output, of the fuel cells has had a steep decline [20], it still requires a high initial investment to cover the need of a data center, especially ones as sizeable as the hyperscale data centers. The cost is also related to the infrastructure needs that the hydrogen fuel cells require. There's the need to store the hydrogen, to transport it and to process it, which means that, for large data centers such as the ones considered, further space is required to support the technology.

3.3 Case Studies and Further Developments

By now, there are already some companies that are trying to implement this technology to their data centers, albeit in a smaller scale, to use as backup power when the main provider is disabled or inoperative. For example, Microsoft has already experimented, in a Wyoming site, the use of large-format hydrogen fuel cells to supply backup power to the data center. In that demonstration, it was simulated a forty-eight-hour backup power event, and the fuel cell was integrated to the electric system to support critical load [21]. Meanwhile, other companies, such as Google and Equinix are exploring the use of the hydrogen fuel cells to power their data centers with the aim to reduce their carbon emissions and meet the ever-increasing energy demands of the data centers [22-23]. While smaller in scale, these experiments and plans allow for additional funding and technology developments that, eventually, will assure the sustainability, both economical and practical, of implementing hydrogen fuel cells on a larger scale.

With that considered, in the next section, it will be explored the idea of having hydrogen fuel cells being used as the primary energy source to the data centers, and how we can optimize the operation to guarantee higher efficiency and lower waste.

4. Waste Optimization

The needs of data centers and the characteristics of hydrogen fuel cells have been discussed. As mentioned, there are ways to integrate these fuel cells within data centers to optimize the energy and resource cycle.

By minimizing waste generated during operations, we can create a production and consumption model that extends the product lifecycle, ultimately contributing to a circular economy [24]. This text will demonstrate various methods to utilize the waste produced by fuel cells—specifically heat and water—in a productive manner.

4.1 Reusing Heat

The most straightforward way to utilize the heat generated from energy production is for space heating. The buildings housing data centers have specific ambient requirements, which are typically addressed using heating, ventilation, and air conditioning (HVAC) systems. However, it is not ideal to completely replace these existing systems; instead, the waste heat can be used to preheat the air, thereby reducing the energy demands on the HVAC systems [25].

Another effective method for utilizing this heat is through the implementation of absorption chillers. These machines, which use heat as their primary power source, produce chilled water [26]. Since most data centers rely on water to cool their servers, the chilled water generated by absorption chillers can be directed to the servers, reducing the need for conventional air conditioning systems to keep the water cool.

4.2 Reusing Water

As mentioned in the previous section, water is commonly used to cool the servers and other computing systems in data centers. By maintaining a closed-loop cooling system, it becomes easier to regulate the water temperature, reducing the need for additional energy consumption to cool the water and minimizing overall water usage. This approach also helps protect electronic devices by keeping impurities that typically need to be filtered out from entering the system [27].

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guidelines for data centers, it is important to maintain proper temperature and humidity levels to prevent static discharge or condensation [28]. Typically, HVAC systems are responsible for ensuring that air humidity complies with these guidelines. However, to further reduce energy consumption, some of the wastewater can be repurposed by introducing it into the air until the desired humidity levels are achieved.

5. Conclusion

The introduction of hydrogen fuel cells to meet the energy needs of large data centers has been considered a viable option for enhancing both sustainability and efficiency. As the demand for greater computing power continues to grow, alternative energy sources present new opportunities, especially since the byproducts of energy production can be reused, contributing to a circular economy. Although challenges still hinder the adoption of these energy sources, anticipated technological advancements, along with new policies encouraging hydrogen-fueled technologies, are expected to address these issues. Such developments will support efforts to reduce carbon emissions and ensure the long-term sustainability of digital infrastructure.

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