Intermediate report

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1 Introduction

As the world transitions towards a more sustainable and environmentally friendly energy future, the role of renewable energy sources has become increasingly crucial. Solid Oxide Electrolyzer Cells (SOECs) and Solid Oxide Fuel Cells (SOFCs) are cutting-edge technologies that hold great promise in efficiently converting electrical energy to chemical energy and vice versa. These technologies can be pivotal in enhancing energy storage, enabling grid flexibility, and supporting the integration of renewable energy sources. However, to realize their full potential and economic viability, it is essential to optimize their sizing and operation under real-world electricity market conditions.

This project aims to address the challenging task of minimizing the investment cost associated with the storage tank. However, we recognize that optimizing these systems exclusively for capital expenditure may not be the most economically rational strategy. Hence, we also intend to incorporate a secondary objective: maximizing profits through efficient operation and utilization of the whole system shown in Figure 1.

The primary focus of this project is on the synergy between technology sizing and electricity price dynamics, with the goal of providing a comprehensive framework for decision-makers in the energy sector. By considering both investment cost and profit maximization, we strive to strike a balance between the initial financial commitment and the long-term revenue generation potential. This approach will allow us to explore solutions that not only minimize costs but also adapt to dynamic market conditions, ensuring sustainable and cost-effective utilization of SOECs and SOFCs within the evolving energy landscape.

In the following sections, we will delve into the methodology, data sources and optimization techniques used in this project to achieve our dual objectives. We will also discuss the significance of this research in advancing our understanding of clean energy technologies and their potential contribution to a more sustainable and economically viable energy future.

1.1 SOEC

A Solid Oxide Electrolyzer Cell (SOEC) is a high-temperature electrochemical device primarily used for water electrolysis, where it operates in a regenerative mode to produce hydrogen and oxygen gases. The fundamental structure of an SOEC consists of two porous electrodes, an anode and a cathode, which are separated by a dense layer of ion-conducting ceramic electrolyte[1]. This ceramic material facilitates the movement of oxygen ions while blocking electrons, thus enabling the electrochemical reactions necessary for electrolysis.

During the process of steam electrolysis in an SOEC, water is reduced at the porous fuel electrode (cathode) under an applied voltage, resulting in the formation of hydrogen gas and oxide ions. These ions then migrate through the electrolyte to the anode where they release oxygen gas. This technology can also be applied to the electrolysis of carbon dioxide to produce carbon monoxide and oxygen, providing a pathway for utilizing CO2 and producing syngas, which is a mixture of hydrogen and carbon monoxide.

SOECs are scalable, from nanoscale to macroscale, and can be combined into larger assemblies known as SOEC stacks. These stacks can be further integrated to form complete SOEC plants, enhancing their applicability for industrial-scale hydrogen production. The scalability of SOECs is significant as it allows for the technology to be adapted to various sizes and capacities, suitable for different applications ranging from small-scale on-site hydrogen production to large-scale industrial hydrogen generation plants[2].

The scientific literature references provided offer insights into the fundamentals and recent advancements of SOEC technology. They cover the basic construction, operation principles, and potential scalability of SOEC systems, illustrating the role that SOECs could play in a future oriented towards cleaner energy production and the broader hydrogen economy.

1.2 SOFC

Solid Oxide Fuel Cells (SOFCs) are electrochemical devices that convert chemical energy from a fuel directly into electrical energy through an oxidation process. Characterized by the use of a solid oxide or ceramic material as the electrolyte, SOFCs are known for their high efficiency and the ability to operate on a variety of fuels, which is not limited to hydrogen. Hydrocarbons, coal gas, and even methane can be utilized, providing flexibility in fuel choice[3].

SOFCs operate at high temperatures, typically between 500 to 1,000 degrees Celsius, which contributes to their high efficiency due to the favorable kinetics of electrochemical reactions at these temperatures. They are considered one of the most efficient systems for electricity generation, with the added benefit of being environmentally friendly. Current fuel cell systems often use hydrogen produced from natural gas through an endothermic steam reforming reaction, but SOFCs have the unique ability to run directly on methane and other fuels without the need for external reforming processes[4].

In terms of application, SOFCs can be stationary, as in the case of power plants, or they can be designed for portable use. High-temperature operation allows SOFCs not only to produce electricity but also to generate heat, which can be utilized in cogeneration systems for additional efficiency. Companies like Bosch have developed high-performance, mass-producible SOFC systems, indicating the technology's readiness for broader industrial deployment.

Among the types of high-temperature fuel cells, the SOFC is the most employed, reflecting its mature status within the fuel cell technology spectrum. In addition to their stand-alone use, SOFCs can be integrated into larger systems, including those with combined heat and power (CHP) applications, which further enhances their efficiency and utility[5].

SOFC technology holds significant potential in the drive towards cleaner energy solutions. As research and development continue, it is expected that SOFCs will play a pivotal role in future energy systems, providing a sustainable and efficient way to meet energy demands while reducing environmental impact[6].

1.3 Electricity Market

Forward and Futures Markets: Electricity is traded on forward and futures markets from a month to four years ahead of delivery. Futures are standardized and traded on exchanges, while forwards are traded over the counter and are non-standardized. Both are used for hedging against future price fluctuations, providing financial certainty for trading parties.

Day-Ahead Market: In the day-ahead market, electricity for the next day is auctioned in hourly blocks, with prices set at noon based on supply and demand, reflecting the real-time value of electricity.

Intraday Market: After the day-ahead market, the intraday market allows for adjustments in trading positions up until five minutes before delivery, accommodating for unforeseen changes in demand or supply.

2 Methodology

2.1 Database

The database we will use in our project is chosen from entsoe, where we could find 1 week, 1 month, and 1 year's electricity prices for different industrial scenarios all around the world.

2.2 Model Structure

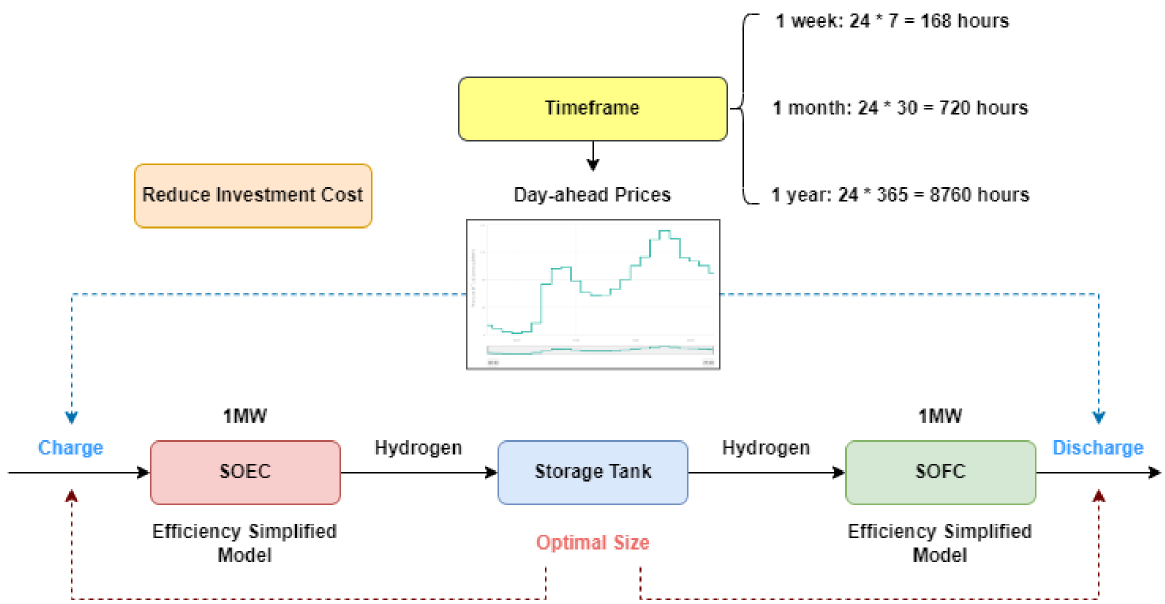

Figure 1: Model Structure

This model assumes a 1 MW power capacity for both Solid Oxide Electrolysis Cells (SOEC) and Solid Oxide Fuel Cells (SOFC). Both SOEC and SOFC are modeled using an "efficiency simplified model," implying that their hydrogen production efficiency remains constant. Furthermore, the model abstracts away the complexities of hydrogen transportation, omitting factors such as channel limitations, leakage, and energy losses during transit. At the core of the system's logic, the SOEC first charges and generates hydrogen gas, which is then stored. Subsequently, the stored hydrogen is utilized by the SOFC to generate electricity. For the purposes of our model, SOEC and SOFC are considered interchangeable in terms of equipment, differing only in their operational mode.

The system operates on a cycle of three possible actions within any given hour: charging the SOEC and storing hydrogen, using the stored hydrogen to generate electricity, or remaining idle.

The objective is to minimize investment costs, which hinge on the storage tank's capacity and the revenue from selling electricity back to the grid. The underlying strategy is to purchase and store electricity when prices are low and to sell it—after conversion to electricity via the SOFC—when prices are high, staying idle when the storage is full and when electricity prices are not economically favorable. The electricity's day-ahead prices will be forecasted initially on a weekly basis, with the intention to extend the optimization to monthly and yearly scales if feasible.

2.3 Expected Outcome

With the given volume of the storage tank, we are going to use our model to calculate the profit taking the expense of the storage tank into consideration. Finally, we are expected to have one figure whose x-axis is the volume of the tank and the y-axis is the maximum profits. Consequently, we can ascertain the optimal dimensions for the storage tank, providing valuable guidance for actual production processes within the industry.

References

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