Intermediate report

Zhichuan MA, Aditya Anand, Léopold Dardel

November 7, 2023

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 2.

The primary focus of this project is to create a model on the synergy between solid oxide 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, our aim is 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

Solid Oxide Electrolyzer Cells (SOECs) are high-temperature devices for producing hydrogen and oxygen through water electrolysis. They consist of anode and cathode electrodes separated by a ceramic electrolyte, allowing oxygen ion conduction [1]. SOECs can also electrolyze CO2, yielding syngas—a mix of hydrogen and carbon monoxide. Scalable from nano to macro scales, SOECs are adaptable for various hydrogen production applications [2].

1.2 SOFC

Solid Oxide Fuel Cells (SOFCs) transform fuel chemical energy into electricity using a solid oxide electrolyte. They operate efficiently at 500 to 1,000 degrees Celsius on multiple fuels, including hydrocarbons and methane [3]. SOFCs are versatile, suitable for stationary power generation and portable applications, and can be part of cogeneration systems. With ongoing advancements, SOFCs are emerging as a key technology for sustainable energy [4].

1.3 The Interchangeability between SOEC and SOFC

As the following figure 1 shows, both Solid Oxide Electrolyzer Cells (SOECs) and Solid Oxide Fuel Cells (SOFCs) are based on similar solid oxide or ceramic electrolyte materials that conduct oxygen ions at high temperatures. This commonality allows for a degree of interchangeability in their core technology, particularly in the materials and manufacturing processes.

The major differences between the two systems are in their design optimizations for their primary functions, control systems, and durability under different operating conditions, which can affect their interchangeability in practical applications and are neglected in this model.

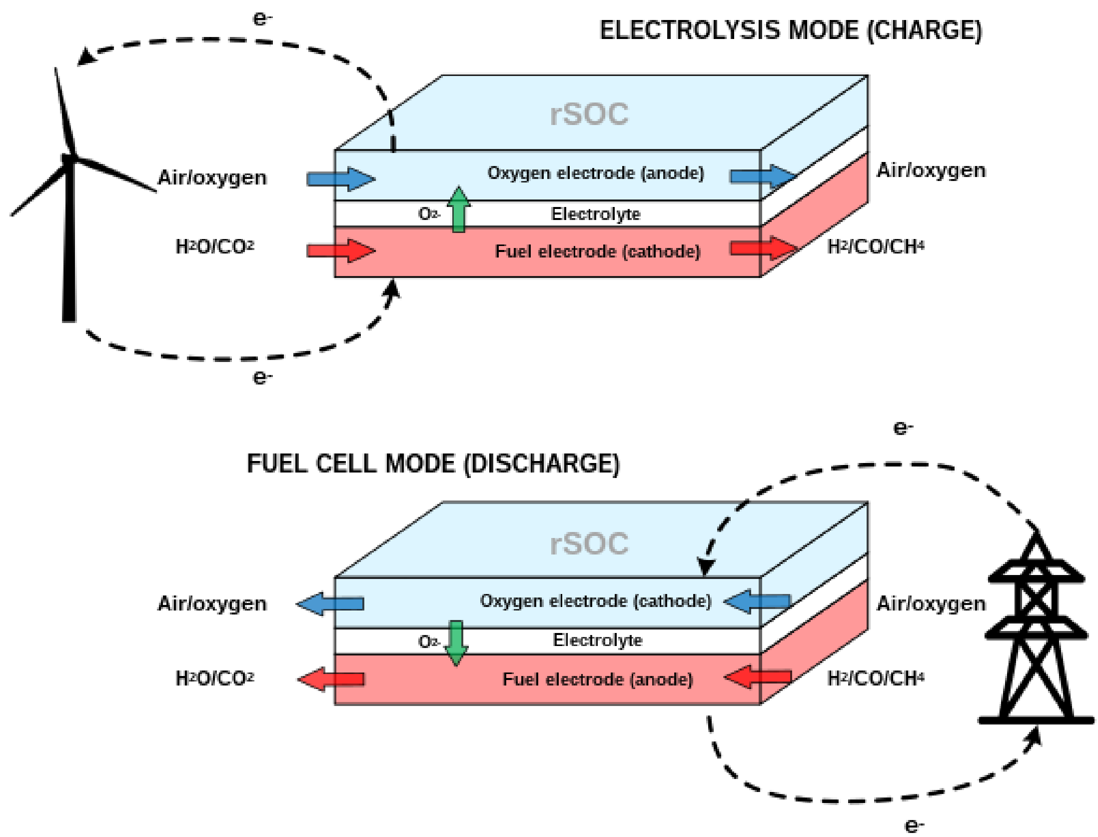

Figure 1: interchangeability

1.4 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

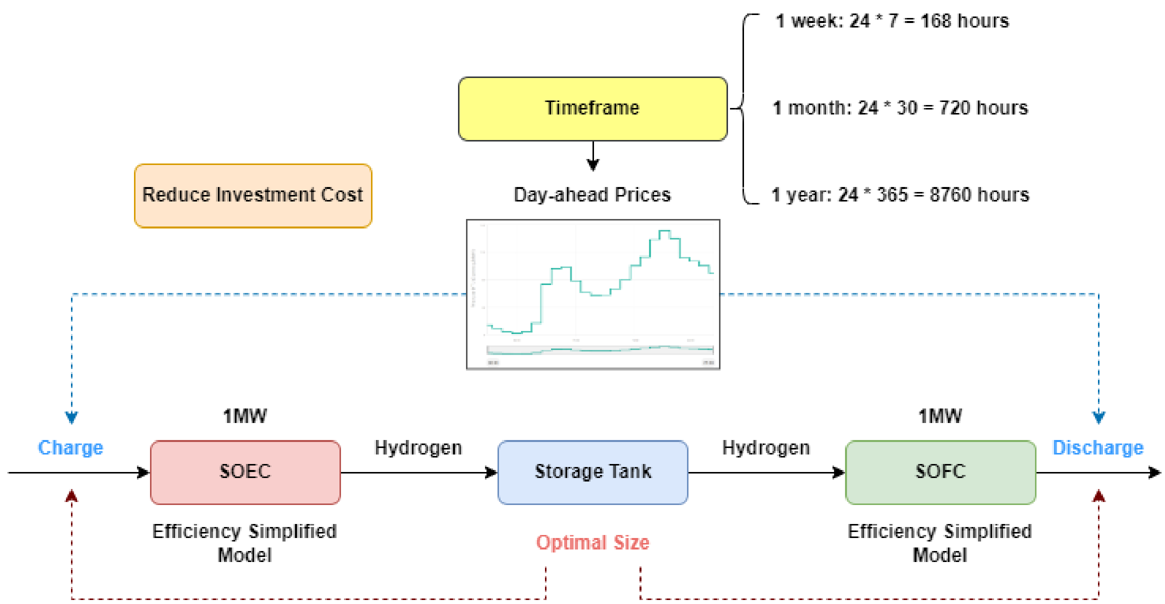

Figure 2: Model Structure

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

[1] A. Hauch, R. Küngas, P. Blennow, A. B. Hansen, J. B. Hansen, B. V. Mathiesen, and M. B. Mogensen. Recent advances in solid oxide cell technology for electrolysis. *Science*, 370(6513):eaba6118, 2020.

[2] Miguel A. Laguna-Bercero, Yudong Wang, Xiao-Dong Zhou, and Liangzhu Zhu. *Fundamentals of Solid Oxide Electrolysis Cells (SOEC)*, pages 5–34. Springer International Publishing, Cham, 2023.

[3] Mandeep Singh, Dario Zappa, and Elisabetta Comini. Solid oxide fuel cell: Decade of progress, future perspectives and challenges. *International Journal of Hydrogen Energy*, 46(54):27643–27674, 2021.

[4] A. Kundu and J.H. Jang. Applications – portable — portable devices: Fuel cells. In Jürgen Garche, editor, *Encyclopedia of Electrochemical Power Sources*, pages 39–45. Elsevier, Amsterdam, 2009.