Production of green molecules at sea using the concept of energy island

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Introduction

In recent years, renewable energy sources (RESs) have seen an increase in power generation capacity. Despite the fact that direct electrification is the best way to maximise the efficiency of using RESs, multiple challenges arise when a high share of RESs is integrated into the power system, assessed thoroughly in [1]. In some cases, such as when there are power transmission limitations or a surplus of energy from RESs, the extra power can be converted into green molecules, like hydrogen [2].

Owing to its distinctive characteristics, hydrogen has garnered escalating attention in recent years as an effective energy carrier. The two major pathways to produce hydrogen are fossil fuels and RESs. Having said that, the former emits carbon dioxide (CO_2) as a by-product, resulting in RESs being more desirable for sustainable hydrogen production. The green hydrogen produced from RESs is of use for several applications, including the production of syngases and bio-fuels, heating purposes, transportation, etc. There are numerous ongoing Power-to-X projects in the world, employing various technologies with different end-products such as methane, methanol, and dimethyl ether [3, 4].

In the context of this study, the end-product is aimed to be methanol due to its advantageous properties, including being liquid under atmospheric conditions, high gravimetric and volumetric hydrogen storage capacity and low transportation costs [5]. To synthesise methanol from hydrogen, a source of CO_2 is essential for the chemical reaction. This can be achieved through direct air capture (DAC) to reduce the atmospheric CO_2 concentration or by extracting CO_2 from seawater, where the CO_2 concentration is 125 times higher than in air [6, 7].

The rest of the article is structured as follows: The second section delves into the methodology to be employed throughout the study. Additionally, the proposed configuration for the offshore hydrogen production system is explained. Thereafter, the third section addresses the noteworthy challenges that merit exploration within the scope of this research. Lastly, the concluding remarks are presented in the final section, summarising the scope of this research.

Methodology

The aggregation of the required units for methanol production in close proximity presents an opportunity to leverage the concept of an energy island. Alongside the electrolyser for hydrogen production, a battery energy storage system (BESS) can be incorporated into the configuration of the island to explore the feasibility of the scheme. Furthermore, it is possible to integrate a chemical energy storage system (CESS) into the system to store the generated molecules. Moreover, to supply units such as electrolysers with direct current (DC), or convert the stored energy within the BESS to alternating current (AC), AC/DC/AC conversion units become necessary. Finally, any excess electricity, if available, as well as the produced hydrogen or methanol, can be either transported to the mainland or exported to neighbouring countries. A schematic of the proposed energy island, conceptualised to accumulate energy, capture CO_2, produce hydrogen, and ultimately synthesise methanol is shown in Fig. 1.

Employing an energy island offers a unique opportunity to utilise seawater for the electrolysis process. This approach effectively mitigates the concern associated with conserving fresh water for electrolysis, thereby addressing water scarcity issues. Nevertheless, owing to seawater impurities, the feed water needs some form of treatment. Generally, when opting for seawater as feedstock, two approaches for supplying

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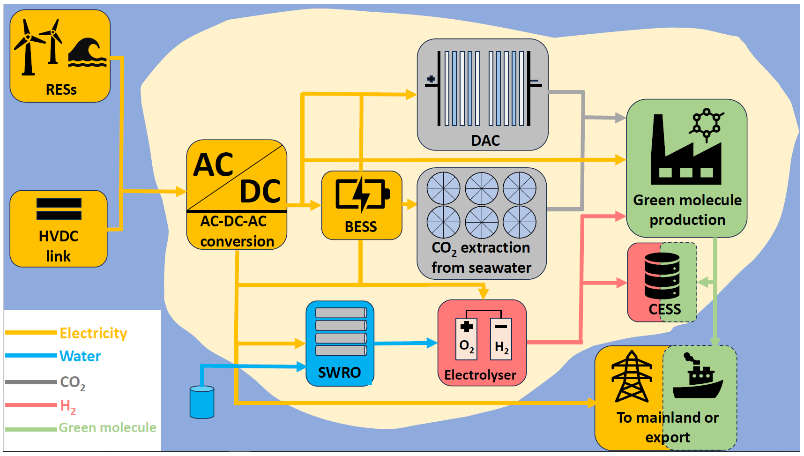

Figure 1: A schematic of the proposed energy island

electrolysers come into consideration, namely, direct seawater electrolysers (DSWE) and seawater electrolysis with upfront water treatment and purification. DSWE demands substantial re-designing of the currently available electrolysers as well as the development of new electrocatalysts for both conventional alkaline (AE) and proton exchange membrane (PEM) electrolysers, primarily due to the high concentration of corrosive chloride ions. Consequently, seawater with upfront treatment is the focus of this study. For this purpose, seawater reverse osmosis (SWRO) is considered due to its advantages, including producing high-quality water production and high energy efficiency [8].

In terms of selecting the appropriate type of electrolyser for the energy island, several conclusions have been drawn from existing literature. A recent study on seawater electrolysis technologies for hydrogen production at sea indicates that the differences between alkaline and PEM electrolysers are trivial [9]. Seeking the best current electrolysis technology to produce offshore hydrogen using marine energy, this study compared AE, PEM electrolyser, solid oxide (SO) electrolyser and direct seawater electrolysis where economic, environmental and social factors are considered as comparison criteria. Overall, this study concluded that both alkaline and PEM electrolysers are likely to play a major role in the sector of hydrogen production at sea, with the latter currently holding the best prospects of applicability. Nevertheless, this article suggests if AE makes sufficient progress, reducing its risk profile for offshore applications, it could become the more promising technology for hydrogen production at sea.

The authors in [10] see the desalination process comprising seawater reverse osmosis (SWRO) coupled with PEM electrolyser as the highest likelihood of being adopted in the near future. According to their findings, the aforementioned combination is a more practical immediate method for seawater electrolysis rather than investing in developing catalysts and systems for direct seawater electrolysis.

Discussion

When contemplating an energy island, several key aspects can be taken into account.

Synergies between offshore energy sources. The integration of offshore wind energy with wave or tidal energy presents an intriguing opportunity, benefiting from the time delay between these sources. For example, given the fact that waves are lagging with respect to wind, the synergy between these two sources is an area of interest. However, wave and tidal energy technologies are generally less mature and yield lower power compared to wind. Additionally, the synergy of the island with the onshore production is worth investigating.

Flexibility in low-inertia power systems. The ability of the energy island to provide flexibility in a low-inertia power system is of great significance. It can offer provision of ancillary services across different time scales and provides flexibility both on the production and load sides.

Dynamic scheduling and control of the electrolyser. Examining the dynamic scheduling and control of the electrolyser, when coupled with intermittent RESs, is valuable. This can be implemented based on factors such as the dynamic response of the electrolyser in the presence of fluctuating RESs, hydrogen demand, electricity price, and available storage capacity both in chemical and electrical forms.

Optimised operation. Optimising the operation of the energy island is critical. This can be achieved by taking into account various objectives such as costs, CO_2 reduction and so forth.

Life cycle assessment (LCA). Conducting a comprehensive LCA study is of importance. This study can compare different molecules, such as hydrogen, methanol and methane, to evaluate their environmental impacts and sustainability throughout their entire life cycles.

Incorporating these considerations can lead to an effective design and operation of energy islands, facilitating their integration into the energy systems.

Conclusions

This article presented a scheme for the production of green molecules at sea. Since RESs exhibit a fluctuating output power, their intermittency could be effectively accommodated using electrolysers. This study focuses on the production of green molecules at sea, taking advantage of the benefits offered by the seawater. To this end, the feed water for the electrolyser needs to undergo desalination, and for this purpose, SWRO has been chosen to supply the water. Additionally, the primary end-product of the project is methanol, which is why two CO_2 capturing methods, i.e., DAC and CO_2 extraction from seawater have been incorporated into the configuration of the energy island. By the end of this study, the operation of multiple units integrated into the energy island is going to be examined. This will include the interaction between the available, flexibility provision of the island, scheduling and control of the electrolyser, optimising the operation of the island and LCA studies.

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