Smart desalination systems coupled with green hydrogen production based on IoT

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Abstract: Keeping water safe and creating clean energy are very important for the future. As cities get bigger, people increase, and the weather changes more, water is becoming harder to find. At the same time, moving towards cleaner energy is helping to make our air less polluted. It is thus important to apply new technologies that will allow us to make a more efficient use of water and promote cleaner energy systems. In this study, smart systems of water treatment in charge to make green hydrogen are presented. Our research aims to illustrate how the Internet of Things (IoT) can contribute to monitoring desalination systems that have benefited from significant investment, achieving energy savings and avoiding waste. After discussing several possible uses for the IoT, we return to the various practical difficulties that need to be overcome in order to achieve widespread deployment. The steps proposed below aim to increase the flexibility, efficiency, and safety of these systems, while integrating smarter and more sustainable water management practices to better mobilize this resource in the production of green hydrogen.

1 Introduction

Drinking water and clean energy sources pose serious challenges for the future, due to both the impacts of climate change and their link to the economy and water as a factor in human health [1]. The quality of drinking water and clean energy are two closely related issues. On the one hand, with a growing global population, the more urban development accelerates and the more complicated climate change becomes, the greater the demand for water to keep people alive. On the other hand, the sources that provide enough water for everyone are under strain [2]. Significant advances in energy production and use technologies have

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made it possible to reduce greenhouse gas emissions through a number of options, but in a way that commits us to a completely different path of energy production and consumption [3]. Significant progress has been made in developing renewable and sustainable alternatives to conventional energy production methods, thereby promoting the transition to renewable and sustainable energies. However, the rise in demand for energy and fresh water complicates the situation. This observation highlights the urgent need to take steps to propose and implement original and coordinated solutions to provide a long-term response to environmental issues and concerns about natural resource management, with the help of sustainable renewable energies specialized in this field. Particularly in coastal areas subject to freshwater shortages, seawater desalination makes it possible to develop strategies for producing drinking water to supply both communities and businesses. Desalination techniques, particularly reverse osmosis, are now sufficiently advanced to offer both good quantities of water produced and a satisfactory quality of water delivered [4]. However, these techniques require high energy consumption, posing a major economic and ecological problem as they require a constant and secure energy supply [5]. Furthermore, the problem is compounded by the addition of large volumes of renewable energies such as solar and wind power, due to their intermittent nature. Green hydrogen appears above all to be a relevant energy storage solution, as it is produced from renewable electricity [6]. This electricity can then be used to electrolyze water and produce hydrogen (H2) and oxygen (O2) Hydrogen is an excellent energy carrier and can therefore be used to store surplus energy produced by renewable sources, which will be converted back into electricity on a case-by-case basis or when it becomes available. This synergy between green hydrogen and desalination creates a more efficient and useful energy system [7]. The Internet of Things (IoT) is central to the construction and proper functioning of these connected systems, enabling real-time monitoring of certain elements such as water pressure, electricity consumption, and environmental conditions in order to maintain operational efficiency. Using data provided by the set of sensors, sophisticated analysis devices included in the system, based on intelligent algorithms, enable a mode of operation to be configured by a whole set of data: the clean water to be produced, the energy available, and a number of constraints [8, 9]. The focus of the study is specifically on smart desalination systems connected to each other via the Internet of Things, but also on the production of green hydrogen, which is the very subject of the study and our starting point for formulating a number of hypotheses and questions about the understanding and operability of such technical support in commercial implementation, where, once again, all stakeholders seem to be very concerned about the introduction of obstacles to the smooth running of projects in terms of technical systems and spatial and ecological constraints. At the heart of a more broadly exploratory project, this research aims to seek new solutions, which may take the form of green alternatives, to meet future climate and energy needs and develop more appropriate water and energy supply systems.

2 Background and key concepts

2.1 Dessalement technologies

Desalination can be defined as the process of converting brackish water (i.e., water that is salty) into drinking water. Desalination is an important solution to the growing demands for potable water, particularly in arid regions [9]. The major types of desalination technologies are thermal and membrane based. The thermal methods such as multi-stage flash (MSF) and multi-effect distillation (MED) consume significant amounts of heat and energy and use continuous electricity, making them less practical with an increasing number of renewable energy sources where the availability of such sources can't always be assured. Alternatively, reverse osmosis (RO) is the most widely used method for producing drinkable water because it consumes less power than other methods, can provide various flow capacities of water, and will be able to function with renewable sources of energy [10]. However, despite the latest advancements in this area, problems remain for desalination systems, which can result in excessive energy consumption and fouling of the membranes, management of saline waste, and high capital and operational cost, showing a need for improved, more efficient, and reliable technologies to enhance the efficiency of the systems.

2.2 Green hydrogen production

Producing green hydrogen takes place by using electricity from renewable energy (RE) to decompose or separate water into hydrogen (H_2) and oxygen (O_2) [11]. The power supply, in most cases, comes from non-fossil fuel based energy sources, potentially generated through wind and solar energy [12]. therefore producing hydrogen without adding carbon dioxide to the atmosphere thus assisting in reducing carbon emissions from Energy Generation and Distribution, Industrial use, Transport etc [13] (Fig.1).

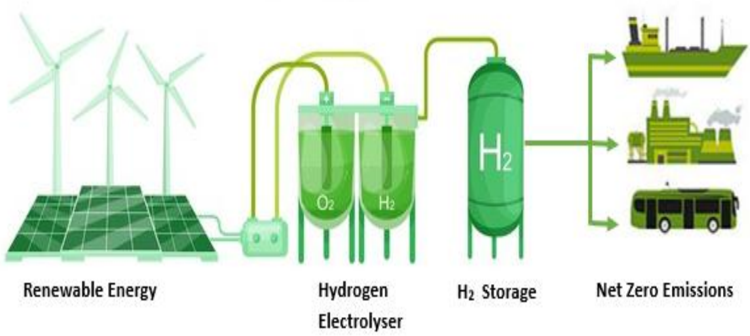

Fig.1. Green hydrogen production

The most well-established methods for Green Hydrogen production through electrolysis areas Alkaline Electrolysis, PEM Electrolysis and SOEC [14], [15]. Alkaline Electrolysis has been historically a low cost and durable method of production and is capable of producing very large volumes continuously. However, because of the slow response (time) to variations in power supplied from renewable sources (time), it lacks flexibility when rapidly varying levels of renewable power are diagrammed from hour-to-hour. PEM has the ability to respond rapidly to fluctuations in power; therefore PEM Electrolysers are typically more efficient than Alkaline Electrolysers with respect to their operation with short term load following loads quickly. Electrolysers based on SOECs have proven highly efficient, although they are still in the experimental stage and widely not commercially available for production.

2.3 Internet of Things and smart systems

Smart Systems and the Internet of Things are changing how we interact with Technology [16]. the way Smart Systems and The Internet of Things allows us to develop new means of utilizing Technology is as a result of these Systems connecting different types of "things" together – including objects that have Sensors, perform actions, and allow Users to send and receive information from them These objects gather data continuously; send them securely, analyse them when sent to the Correct Authority, use the information now or later to enable a better, more well-informed decision making. The utilisation of Technology and Data through Smart Systems enables the opportunity to optimise the operation efficiency of operations through Automation [17]. the optimisation of Resource utilization through innovation, cost-effective funding, and ultimately required to produce higher-quality showing for Sustainable Infrastructure including Energy, Water, and Manufacturing.

3 Smart desalination based on IoT

Smart desalination that uses the Internet of Things (IoT) is a big improvement over traditional desalination systems [18]. It adds advanced digital tools to make the system work better, last longer, and be more eco-friendly. These newly integrated digital technologies aim to improve operational efficiency, maintain operational conditions, and preserve service continuity. The installation of sensors will enable the monitoring of sensitive data points (pressure, salinity, water flow, ambient temperature, energy consumption meters, etc.). These sensors provide real-time information on the most sensitive part of the system, enabling the detection of occasional failures (e.g., when electricity consumption reaches abnormal values, etc.) or malfunctions in materials or equipment [19, 20]. The data provided by a network of sensors, which may be more or less extensive and may contain duplicate sensors, is processed to enable overall optimization through automation on so-called smart platforms equipped with high-performance hardware, with the aim of ensuring rational management of energy and resources [21, 22, 23]. This cooperative integration of the system presented is part of a quality approach that ensures the longevity of the equipment through preventive monitoring that guarantees water quality and stability. In addition, the IoT used in desalination optimizes energy consumption. The operating mode can be adapted to energy availability in order to produce green hydrogen from good quality water, using clean energy [20], [24], [25].

4 Production of green hydrogen and integration with desalination

Green hydrogen production is a promising energy solution for reducing greenhouse gases [26]. Linked to seawater desalination systems, green hydrogen production offers a double advantage, providing both a source of clean water and a source of clean energy. This makes it particularly relevant in regions where fresh water is scarce, as either seawater or already desalinated water can be treated as needed to produce both hydrogen and fresh water, thereby reducing costs and optimizing resources. Using hydrogen to store energy provides flexibility in meeting the variability of renewable energy production, and enables continual access to clean high quality water [27] (Fig.2).

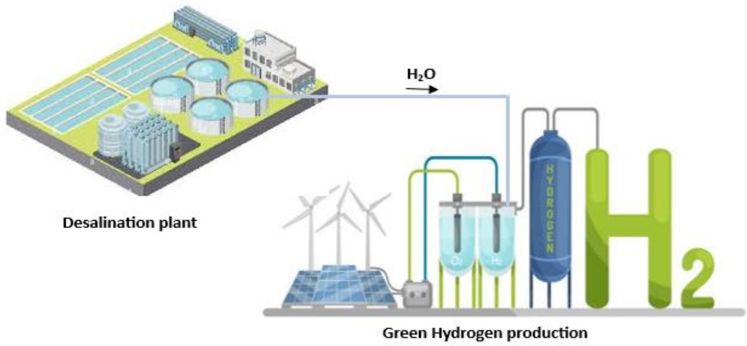

Fig.2. desalination plant coupled with a green hydrogen production chain.

By combining water with hydrogen, these resources will have the potential to create new systems which will support more consistent use of both water and energy through sustainable solutions. Water quality will play an essential role in the reliability and longevity of the electrolyzers that will be needed to produce green hydrogen from renewable sources. The presence of ions, organic matter, and contaminants in untreated water has the potential to physically degrade the electrodes and membranes used in the process of generating green hydrogen through renewable energy sources. Therefore, water that has been pre-treated using reverse osmosis and additional treatment techniques would be the optimal water source to be used for the purpose of producing green hydrogen. This type of water will provide a consistent product in terms of quality and will work well with the production of green hydrogen. This link highlights how crucial it is to work together desalination and hydrogen making in a clever, connected way.

5 IoT architectures for desalination and hydrogen coupling

Currently, there is an increasing desire to incorporate IoT devices into a system using both Desalination and Green Hydrogen, as IoT devices will allow for real-time adjustments and monitoring of the operation of the systems [28]. Sensors will provide ongoing monitoring of the water in relation to several parameters, including salinity and electrical impact on ions in water; detection of harmful substances within the water; as well as monitoring of the performance of electrolyzers and the performance of desalination systems. The data collected from connected devices is transmitted to internet-based services that allow professionals to conduct a swift evaluation of the data to develop informed decisions based on the insight gleaned from the data [29]. Predictive maintenance is also possible through IoT systems, where it can alert businesses of potential problems with their equipment before they occur, thereby minimising the risk of failure and prolonging the lifespan of the machinery. IoT provides automation to allow these smart systems to automatically monitor amount of renewable energy used, thus allowing water and hydrogen production be aligned to both the renewable resource availability and the end user demands for those renewable resources [30]. Therefore, IoT will assist in developing sustainable, efficient, and cost-effective solutions that integrate well together with desalination and green hydrogen production.

6 Discussion and critical analysis

Looking at previous studies, the utilization of Internet of Things technology (IoT) in Desalination Plants has allowed them to monitor everything as it occurs giving Desalination Plants better operational control over processes; making their operations more efficient. The availability of continuous streams of data allows for the improvement of current operations and decreased costs of maintenance due to the availability of real-time insights from Cloud based IoT solutions and Sensors connected directly to the IoT. An example of this would be the ability of a Water Treatment Facility to monitor critical operational information, such as water pressure, water quality, and total water volume, through IoT Technology; enabling Water Treatment Facilities to operate in a more controlled manner with fewer unexpected events. When creating green hydrogen, tools such as IoT and AI provide tools to conserve energy, manage processes on the fly, and automate processes, making it easier to operate Electrolyzers. Despite the existing successes realized to date in this area, there are still many obstacles to the further advancement of IoT and AI. Some of the most significant obstructions to advancements in IoT and AI for desalination plants are; costs of deployment, difficulty in integrating multiple devices, and the lack of a universal standard for IoT technology, making it more challenging to incorporate. Research also shows that IoT can help predict when equipment might fail and boost how well the system works. But there isn't much information on how mature, compatible, and reliable these systems are, especially when using IoT with desalination and hydrogen production technologies.

Table 1: Comparative review of IoT-based desalination solutions and their potential for integration with hydrogen systems

Desalination technology	Hydrogen Integration	IoT Level / Digitalization	Key Benefits	Limitations	Reference
RO + solar energy	Non	Real-time monitoring and control	Operational optimization, predictive maintenance, cost reduction	No hydrogen coupling, high initial cost	[20]
N/A	PEM/Alkaline Electrolysis	IoT + AI + Digital Twin	Energy optimization, real-time monitoring, automation	Complex infrastructure, high cost	[21]
RO	No	IoT + Cloud	Real-time data collection, improved water quality	No hydrogen integration, limited interoperability	[22]
RO, MED, FO	Not specified	Digital Twin + IoT	Predictive maintenance, overall optimization of energy systems	Limited long-term validation	[23]

7 Challenges and future prospects

Though much progress has been made in the development of smart desalination technologies and the production of green hydrogen, many obstacles still exist. The technical challenges continue to be multiple systems that will interface with each other, large amounts of data collected from the IoT and secured devices. To this end, it is necessary to develop smart methods for managing and storing solar and wind energy to ensure continuous water and hydrogen production. Furthermore, due to our dependence on solar and wind energy, which is not always available, it is essential to use smart methods of energy management and storage to ensure the continuity of water and hydrogen production. In economic terms, the very high cost of smart technologies and state-of-the-art electrolysers already prevents them from being widely accessible, even in small, low-budget installations. Currently, there are no resources available to accurately assess the long-term profitability of these systems and their impact in the coming decades. Future developments will attempt to provide tools capable of adapting to local market conditions and variations in energy supply, specifically through the application of artificial intelligence and Digital Twin technology for equipment maintenance planning and energy efficiency optimization.

8 Conclusion

Taking into account salt desalination and green hydrogen production within smart systems opens up new prospects for more efficient water and energy systems, both in terms of energy and finance. In fact, this approach tends to optimize energy efficiency and reduce costs. What's more, reintroducing green hydrogen here reinforces the relationship between the water produced and the accessibility of renewable energies. Implementing such systems poses several challenges, such as significant initial investment costs, heavy infrastructure requirements, and the management of massive data flows. The research objective will be to identify new solutions to these problems through modular designs, intelligent algorithms, and long-term factual testing with these different technologies. These solutions must improve the reliability and sustainability of systems to meet the growing global demand for drinking water and renewable energy.

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