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A Sustainable Approach in Water Desalination Management Strategies with the Integration of Renewable Power System

Md Amzed Hossain, Md Taher Al Masum, Md. Wahid Farhen, Effat Jahan

American International University Bangladesh, Dhaka-1229, Bangladesh

effat@aiub.edu

Abstract- This research investigates the application of solar energy in water desalination systems as a sustainable alternative to conventional fossil fuel-based methods. The proposed system integrates renewable energy with water purification to address freshwater scarcity and energy depletion challenges. Utilizing a water level sensor, the system monitors water from multiple sources, including a storage tank, deep tube well, and harvested rainwater. A reverse osmosis (RO) pump powered by solar energy filters the water, which is then stored in a main tank for safe drinking purposes. The system operates in hybrid mode—drawing power from solar energy primarily, with an automatic switch to grid power when solar availability is insufficient. Real-time data on energy availability and water status are displayed and stored in Google Sheets for monitoring and analysis. This integrated solar-powered desalination system demonstrates a cost-effective and environmentally friendly approach to sustainable water purification in remote or resource-limited areas.

Keywords: Water Desalination, Renewable Power System, Solar PV, Hybrid System, Water Filter.

I. INTRODUCTION

Urbanization, population growth, and water pollution have led to water resource depletion, but the scientific community is working to address this issue through desalination and water filtering. Graphene, a compound with unique properties, is used in water desalination using innovative methods like Nanoporous Graphene (NG) sheets and Capacitive Deionization (CDI). These sheets can achieve a removal efficiency of 33100%, depending on the pore size and pressure applied [1]. Renewable energy sources like hydropower, wind, and solar offer benefits such as reducing carbon footprints, increasing resilience, and reducing dependence on centralized power grids [2]. A lifecycle cost analysis shows potential long-term savings as renewable energy sources become more reliable and cost-effective. Effective energy storage solutions are necessary to ensure constant operation, especially in sensitive regions [3, 4].

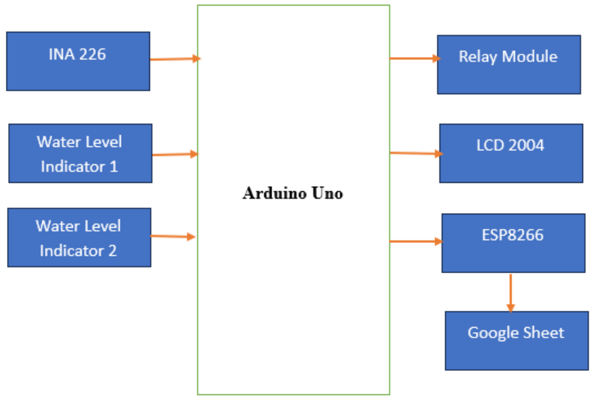
Bangladesh's southwestern regions have saline groundwater, while northeastern and southeastern regions are more susceptible to arsenic pollution. GIS is used to identify water-scarce areas and suitable rainwater harvesting regions [5]. Legislation could secure a sustainable potable water supply in sensitive regions. An initiative aims to drive desalination processes using renewable energy, primarily solar power, to provide a sustainable solution to city and rural water shortages [6].

The paper [7] explored the potential of hydropower as a co-benefit in Sydney's Warragamba Dam, suggesting it could be integrated into the city's water supply network to improve desalination capabilities and introduce flood retention airspace. The research uses a systems dynamics model to assess future operating scenarios until 2040. The proposed model [8] included four wind turbines, a desalination plant, a small hydroelectric station, a pumping station, and two water reservoirs, which can meet water needs by

2030. The generated power is expected to be fed into the grid, while the remaining 70% is free for desalination and water pumping. A ten-year reliability check will assess the system's performance [9]. Weihai, China, developed a solar-wind-powered seawater desalination system with a design capacity of 5 m3/d. The system used a 26-kW photovoltaic panel and 2.5 kW wind turbines as primary sources, producing 5 cubic meters of water daily for 2.29 dollars/m3 and 10 kWh/m3 [10]. The system [11] was connected to the Internet of Things (IoT) and a sensor network for real-time performance and water quality monitoring, ensuring a steady supply of quality drinking water and a sustainable solution to the growing demand for fresh water. The system [12] used the Reverse Osmosis principle and a microcontroller 8051 to prevent overflowing the storage tank.
The initiative aims to use renewable energy, primarily solar power, for desalination processes to address water shortages in urban and rural areas. This paper aims to reduce fossil fuel dependence, reduce environmental impact, and create scalable, affordable models for future water shortages.

II. METHODOLOGY

This study aimed to design a sustainable desalination system using solar and wind power, utilizing IoT technologies for remote control and monitoring. The research design and methodology were comprehensive, covering system design, experimental setup, data collection techniques, IoT connection, and renewable energy integration. The main components of the system, their interactions, and data flow were outlined. The system includes both a water desalination system and a connected IoT system, presenting two designs: one an electrical design and one a schematic diagram of the desalination system.



The study followed a systematic approach from system design to performance evaluation.

Figure 2. Block diagram illustrating the hardware components of the proposed desalination system

In Figure 1, water desalination combined with renewable energy integration, a hybrid controller negotiates the power supply between renewable energy and a backup system (such as a grid or backup generator). By changing between the power sources when required, it enables the system to run mostly on sustainable energy while also guaranteeing dependability and efficiency. This controller also weighs water demand and the availability of renewable energy, as well as other variables, to decide the best use of power. The sensor and indicators above are attached to the Arduino board connected to the other end, as shown in the architectural diagram in Figure 2. The server stores the values from each sensor and shows the most recent values on the LCD and Google Sheets.

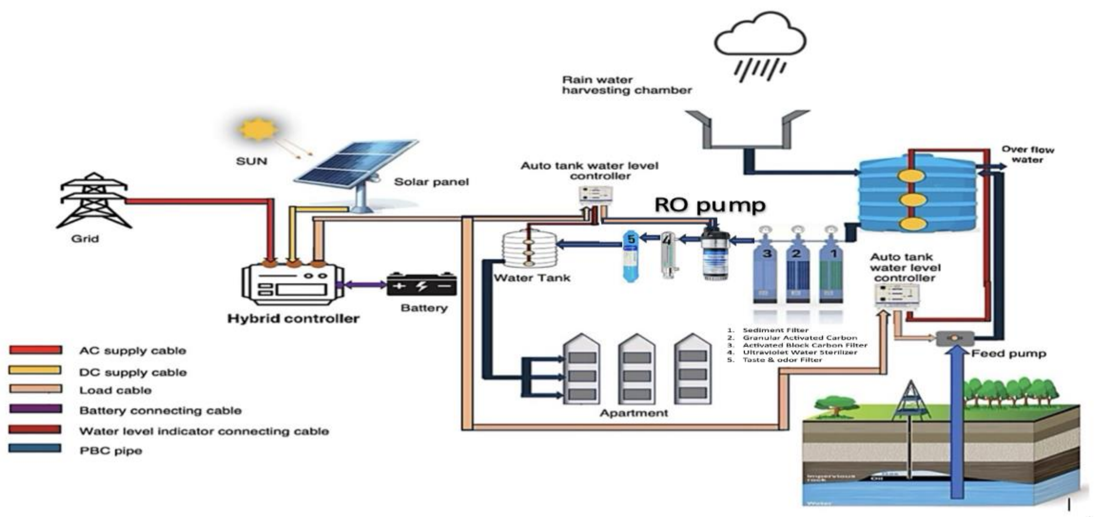


Figure 1. Schematic representation of the hybrid power control architecture

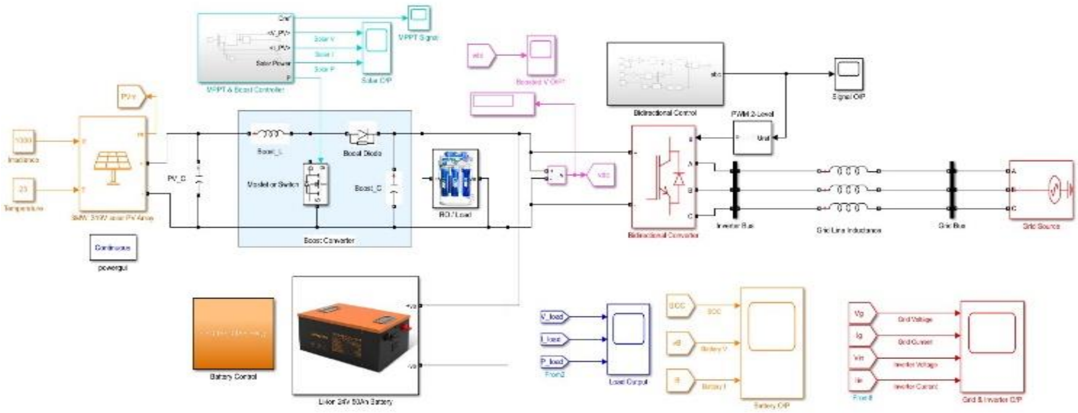


Figure 3 Simulation model of the desalination system in MATLAB/Simulink environment

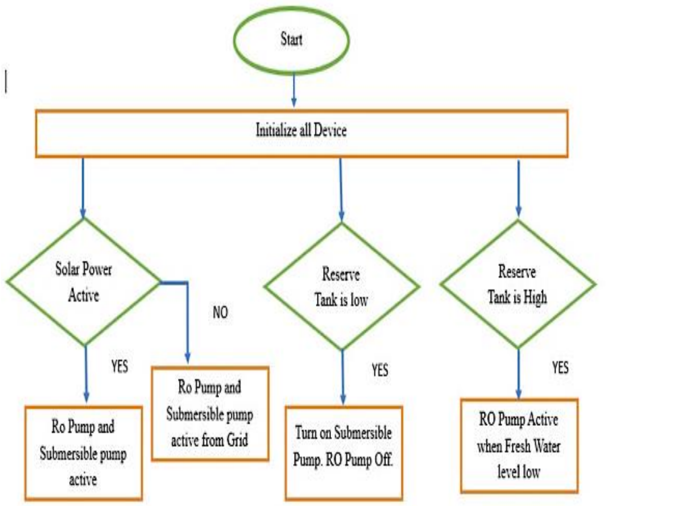


Figure 4. Flowchart of the overall system operation process

Figure 4 illustrates the flowchart of the overall system operation process. The system collects water from a deep tubewell and stores it in a primary tank, along with an additional setup for rainwater storage. A water level indicator monitors the amount of water in the tank. From this storage, the water passes through a Reverse Osmosis (RO) pump and filter before being transferred to the main tank, which also includes a water level indicator. The purified water from the main tank is then supplied for drinking purposes. And the system operates using both solar power and grid electricity. During sunlight hours, solar power runs the RO pump, and when solar energy is unavailable, the system automatically switches to grid power. The available and consumed power data are recorded in a Google Sheet and displayed in real time on a digital monitor for continuous monitoring.

First, rainwater will be collected through a harvesting chamber and stored in the main water tank. During the non-rainy seasons, underground water will be used to keep the main water tank full. Then, through an RO pump and a five-stage filtration process, purified water will be stored in the Pure Water Tank. An automatic water level controller will be used to regulate water flow and operate the pumps. The entire system will be powered by a battery, which will be charged from both solar power and the grid through a hybrid controller. The main operational diagram of the integrated solar-powered desalination system is shown in figure 1.

III. PROJECT IMPLEMENTATION

This section details the implementation of a respiratory disease system, including the assembly and placement of parts and the Arduino. It also includes simulations of hardware components at every stage, integrating them into the system. The actual implementation is discussed, along with an overview of each component. The simulation program used in the investigation is the Arduino IDE and Proteus, with the Arduino IDE and Proteus being used for the project. MATLAB SIMULINK is used for water desalination with a renewable power system integration in Figure 3, particularly for Reverse Osmosis (RO) and Thermal Desalination (MSF) systems. It allows researchers and engineers to analyze system behavior, adjust parameters, and investigate layouts under different operating environments. RO models evaluate plant performance, energy consumption, and cybersecurity aspects, improving efficiency and safety.

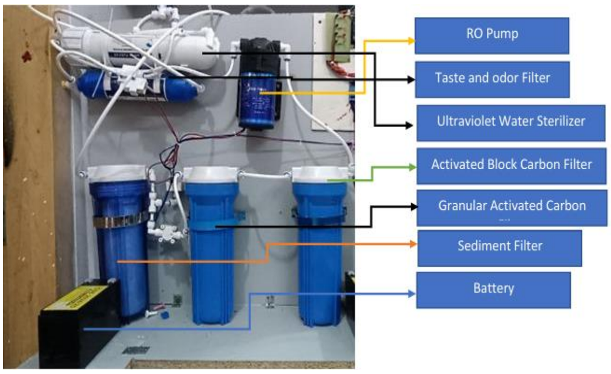
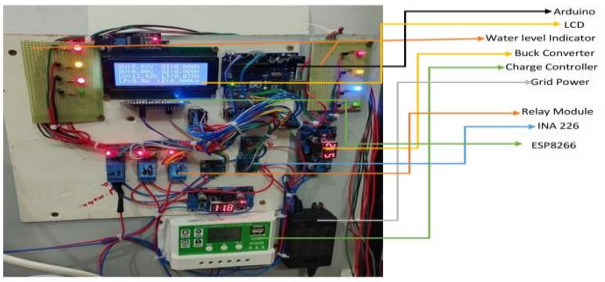


Figure 5 and 6 outlines the process of desalinating water, typically seawater, to remove salt and minerals, essential in countries facing water scarcity or limited freshwater supplies

Figure 5. Assembled prototype of the proposed desalination hardware system
Figure 6. Circuit board layout of the proposed desalination control unit

IV. RESULTS AND DISCUSSION

This section discusses solar technology for water desalination, focusing on its accuracy in assessing test outcomes and activity monitoring data. It highlights the use of solar thermal collectors to heat seawater for desalination and the integration of PV and thermal collectors for increased efficiency. The text also



discusses grid integration, backup power during low solar irradiance, and improved system reliability.

A. Simulation

Figure 7 illustrates the PV array output at 25°C, producing a 400V voltage. This design approach is based on the actual solar system.

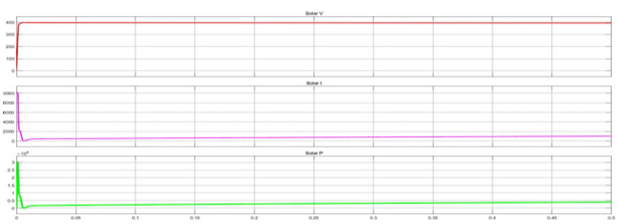


Figure 7. Photovoltaic array output characteristics at standard test conditions (25°C)

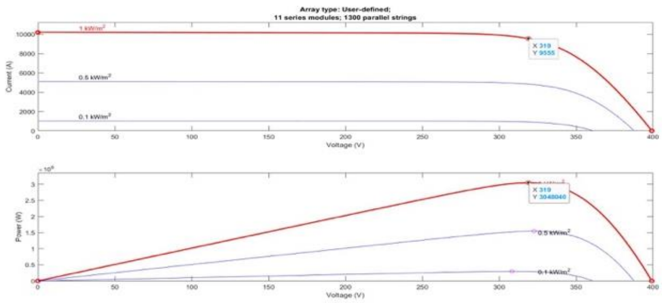


Figure 8. Rated power output and configuration details of the PV array

Figure 8 shows the PV array rating. They're creating a PV array for this research project that can produce 3MW, or 3048000 watts, of power at 319 volts. Here, 11 series-linked PV modules has been chosen because the highest nominal voltage for a single PV was 29 volts.

The bidirectional converter output and grid voltage are displayed in Figure 9. For this design, the battery's output is displayed in Figure 10. The SOC indicates the lithium-ion battery's level of charge. This battery was initially charged to 80% capacity. It is evident that the battery is charging and that the percentage of SOC is rising. For this design, the Boosted Voltage is displayed in Figure 11, which is 600V.

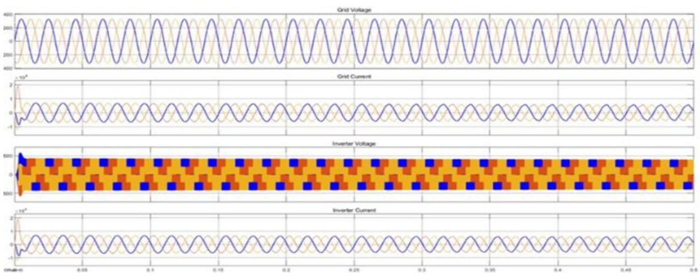


Figure 9. Output voltage waveform from the grid-connected bidirectional converter

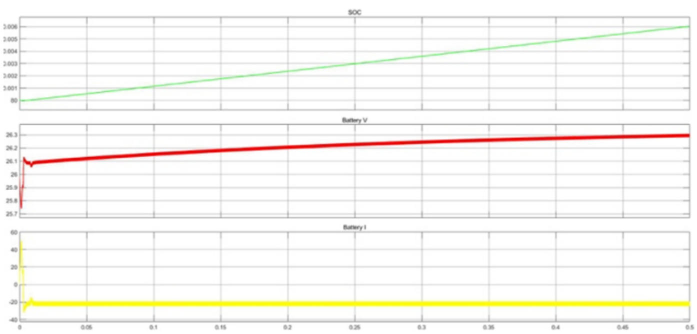


Figure 10. State of charge (SOC) and performance of the lithium-ion battery during operation

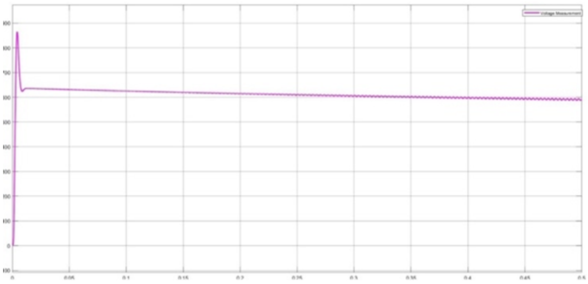


Figure 11. Boost converter output voltage characteristics during hybrid mode operation.

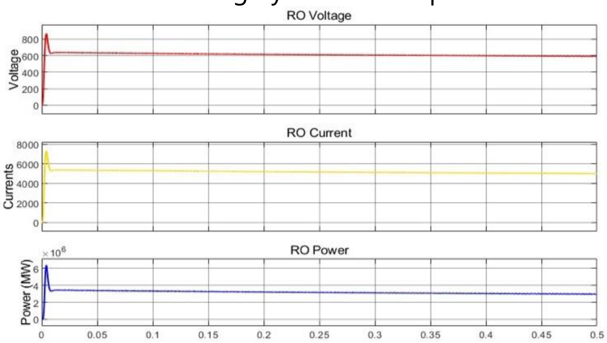


Figure 12. Load output performance of the reverse osmosis (RO) desalination unit

Figure 12 shows the load output of a reverse osmosis (RO) water desalination system at 25°C and maximum irradiation, indicating that the RO produces 600V of voltage. The load output in RO water desalination is typically expressed in cubic meters per day or liters per day.

B. Hardware results

The ideal TDS level for drinking water is generally considered to be between 50 and 150 ppm. While water with TDS below 50 ppm might lack essential minerals, levels above 300 ppm can affect taste and potentially pose some health concerns, according to pureit water. TDS level of drinking water in figure 13 indicates the highly portable and safe for drinking.

Figure 13. Measured total dissolved solids (TDS) concentration of purified water

Table 1, compares the total dissolved solids (TDS) levels of three water samples—raw water, locally available Pureit-filtered water, and water purified by the proposed system. The results show that raw water contains a high concentration of dissolved solids, making it unsafe for consumption. The Pureit filter lowers the TDS to an acceptable household level, while the proposed desalination system achieves a TDS value of 108 ppm, which falls well within the World Health Organization (WHO) -recommended range for safe drinking water. This demonstrates the superior purification efficiency and suitability of the developed system for potable water production.

Table 1. Comparison of TDS values between our filter and locally available Pureit filter.

No	Type of source	TDS Value	Remarks
1	Raw Water (Tank or deep tube well)	420	Not drinkable and high concentration of dissolved solids
2	Locally available Pureit filtered water	180	Suitable for household use but contains slightly higher dissolved solids
3	Our project's purified water	108	Within WHO standard; highly portable and safe for drinking

V. CONCLUSION

This study presents a sustainable hybrid water desalination system integrating solar energy with grid support to ensure uninterrupted freshwater production. The proposed system employs IoT-based monitoring, automatic control, and renewable power integration to achieve efficient operation under variable environmental conditions. Experimental validation and simulation results confirm that the system successfully reduces total dissolved solids (TDS) to within the World Health Organization (WHO) standards for potable water, ensuring both safety and quality. The hybrid configuration significantly minimizes dependence on conventional fossil fuel sources, thereby enhancing environmental sustainability and reducing operational costs. The inclusion of real-time data logging and cloud-based visualization enables continuous performance assessment, fault detection, and efficient energy management.

Future developments will aim to improve energy optimization through intelligent control algorithms, expand the system's scalability for community-level applications, and integrate advanced membrane technologies to enhance desalination efficiency. The findings of this research contribute to the growing body of knowledge on renewable-powered desalination systems and provide a practical framework for addressing freshwater scarcity in remote and coastal regions.

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