

# **Design of A Freshwater Production System Based on Solar Energy**

**Asst. Prof.Dr. Firas Abdulrazzaq Hadi**

**[firas.a.hadi@kus.edu.iq](mailto:firas.a.hadi@kus.edu.iq)**

**Rounaq Adel Abdulwahab**

**[st.rounaq.adel@ced.nahrainuniv.edu.iq](mailto:st.rounaq.adel@ced.nahrainuniv.edu.iq)**

**Mustafa Sinan Fadhil**

**[rawnak\\_rsc@gmail.com](mailto:rawnak_rsc@gmail.com)**

**University of Al-Karkh for Science Scientific Research Commission**

## Abstract

This research paper addresses the design of a solar-powered freshwater production system, aiming to provide sustainable solutions for desalination, especially in water-scarce regions that benefit from high solar radiation. The research addresses how solar energy can be converted into electricity to power desalination technologies, such as reverse osmosis. The design process includes assessing the installation location, solar radiation intensity, and water demand before determining energy needs and selecting appropriate desalination methods. The system is environmentally friendly, has low operating costs, and is capable of operating independently from conventional electrical grids, making it ideal for remote areas, especially during major events such as the Arbaeen pilgrimage, where a reliable supply of clean water is required. The results indicate the system's ability to provide clean water at low operating costs and with high efficiency under variable solar radiation levels, reducing reliance on conventional energy sources. The system can also operate for extended periods at night thanks to the high battery storage capacity. The results also showed that the quality of the water produced by the system is high, with a saline concentration of 0.1%, demonstrating excellent purity and suitability for consumption. The system can be expanded by incorporating solar panels and larger-capacity batteries to meet increased demand, making it a sustainable, long-term solution. In this way, the study demonstrates the system's importance in addressing challenges associated with drinking water in water-scarce areas, especially during major events such as the Arbaeen pilgrimage.

**Keywords:** Solar energy, reverse osmosis, photovoltaic system, water purification, off-grid, battery storage

## Introduction

Solar-powered reverse osmosis (RO) has been gaining attention since the 1980s as a solution for desalination in remote and desert area. Initially, studies focused on the possibility of integrating solar energy with RO systems, and the main challenges were solar system efficiency, energy consumption, and costs. Solar energy became more efficient, especially with the development of photovoltaic panels and storage technologies. In the last decade, research has seen progress in improving energy efficiency and using technologies such as hybrid (PV-RO). Today, solar RO systems are increasingly used in desalination, with improvements in cost and sustainability, making them a promising solution to the global water crisis (Abdaki et al., 2024; Al-Addous et al., 2024).

In the 1990s, solar energy began to be used in reverse osmosis systems more and more, due to the significant progress in solar energy technology some experimental began to be implemented in some remote areas and areas suffering from water and energy scarcity. In 2000 the most notable development is decreasing the cost of solar energy, with this decreases, solar-powered reverse osmosis systems became more economically viable, which helped spread their use in many remote areas (Al-Jubouri & Al-Ta'i, 2021; Al-Samarrai, 2024).

In 2018, university of Colorado Boulder study efficiency improvements of solar desalination systems. The research focused on efficiency improvements for large commercial desalination systems using solar energy. The results showed that improving the design of solar systems and using advanced energy storage technologies can increase the reliability of these systems in large commercial applications, while reducing operating costs. In 2024 Dubai Water Desalination Project: DEWA announced the largest desalination project using solar-powered seawater reverse osmosis

technology. The project aims to produce 180 million gallons of desalinated water per day, with investments amounting to AED 3.357 billion (US\$ 914 million) (Duffie & Beckman, 2013; Goosen et al., 2023).

## Research Objective

This research focuses on the design and implementation of a system that uses solar energy to desalinate water and provide it to Arbaeen pilgrims, taking advantage of the high solar radiation enjoyed by the pilgrimage areas and pilgrims' routes.

## Relevance of the research for the Arbaeen pilgrimage

**Providing clean water for large crowds:** Pilgrims participating in events such as the Arbaeen pilgrimage are in dire need of reliable sources of clean water, especially in desert areas where water may be limited. A solar-powered fresh water system can sustainably provide fresh and safe water to a large number of pilgrims.

**Sustainable and Environmentally Friendly:** The use of solar energy is a clean and environmentally friendly source, reflecting the concept of sustainability, which is important during religious events, as they require high levels of natural care in accordance with Islamic and humanitarian practices.

**Energy and Water Supply Independence:** The system proposes eliminating reliance on electrical grids, which may be unavailable in rural areas. This means that critical times such as the Arbaeen pilgrimage can be handled by independent systems, ensuring uninterrupted water supply.

**Expanding the Potential for Water Solutions:** As the number of visitors

increases, pressure on existing infrastructure will increase. The proposed system provides a flexible solution that can be expanded to meet greater water demands when needed, facilitating effective monitoring planning and increasing the volume of water available.

Overcoming Climate Challenges: Because the system is solar-powered, it can operate well even in varying conditions, including sunny and temperate days, providing visitors with access to drinking water throughout the visit, regardless of any weather changes.

### Materials and Methods

The system consisted of two 12V/12Ah VRLA batteries, a PWM type, 60A charge controller, a seven-stage RO water filtration unit rated at 25W, and two 90W solar panels. In an off-grid configuration, the components were connected using appropriate cabling and a monitoring device to measure voltage, current, and solar irradiance. Performance under Baghdad, Iraq, was evaluated under partially cloudy and partially sunny circumstances. On various days in March 2025, hourly data was collected throughout the day (Patel & Bohra, 2023; Rahman et al., 2022).

### Data Gathering Tools

The solar radiation meter measures direct normal irradiance; the multimeter tracks voltage and current; and the environmental observations measure cloud cover and temperature

## Results

The results will be divided in two parts (Thirunavukkarasu & Sawle, 2021; Zhu et al., 2023).

Part 1, the readings were calculated will be attached with graphs showing the relationships between time, solar radiation, battery voltage, load voltage, and load current during the partly cloudy day then

Part 2, repeat this calculation in sunny day.

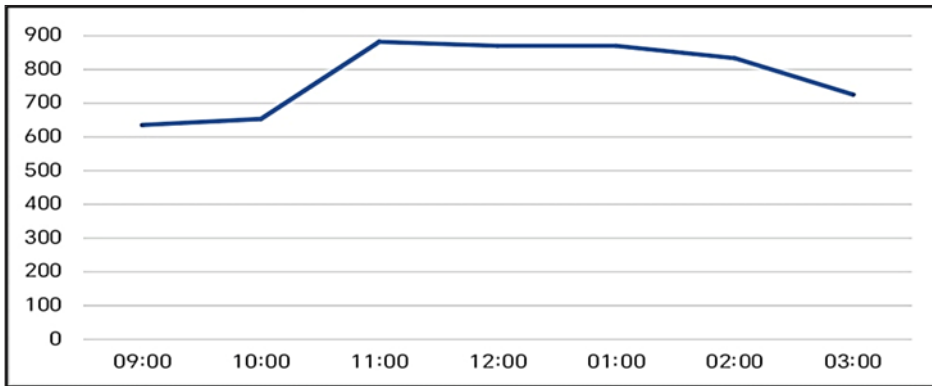
### 1. Readings through the daylight :

Table 1, show the change in the value of hourly solar radiation, which was taken from 9 to 3 on a partly cloudy day (6/3/2025). The second column represents the solar radiation readings in  $W/m^2$ . The readings were taken using a solar radiation meter. Note that the measured incident solar radiation represents direct normal radiation. These readings were taken hourly over a single day, from 9:00 AM to 3:00 AM. The second column shows a gradual rise in the solar radiation value and then a gradual decline. This is a well-known phenomenon resulting from the rising and falling of the sun. We notice that the third column from the left shows a voltage rise and fall. The fourth column represents the load voltage, which is required to operate the device. The fifth column represents the load current consumed for the device to operate. As for the battery voltage, it was observed to be constantly rising and falling due to the presence of clouds on that day. The battery voltage drops and then rises due to cloud cover or sun rise. As a result of the change in battery voltage, the load voltage changes automatically. However, with the stability of solar radiation, we observe stability in both the battery voltage and load voltage. The load current also changes, but this change depends on several factors, such as high temperature, high solar radiation, and changes in battery **voltage**.

**Table 1:** Data recorded from the location

Hour	Irradiance (W/m <sup>2</sup> )	Battery Voltage (V)	Load voltage	Load current (A)
9:00 Am	630	27.3	26.9	1.8
10:00 Am	650	27.1	26.8	1.7
11:00 Am	880	26.8	26.4	1.7
12:00 Pm	865	27.2	26.8	1.8
1:00 Pm	867	27	27	1.7
2:00 Pm	830	27	27	1.6
3:00 Pm	725	27.2	27.1	1.6

We conclude that the device can be operated in cloudy or sunny conditions. That is, the device performs the water filtration process during these conditions and during all daylight hours.



**Fig.(1) Relationship between time and irradiance**

From Fig. (1), which represents the relationship between daytime and solar radiation, where x-axis represents hours and the y-axis represents radiation, it is clear from this Fig. (1) that solar radiation increases and rises in value until it reaches its peak hour, approximately 11:30, and then begins to decline. It can be said that the variation between 9 and 3 is small, i.e., it is between 600-900 W/m<sup>2</sup>, which means that the batteries are well charge.

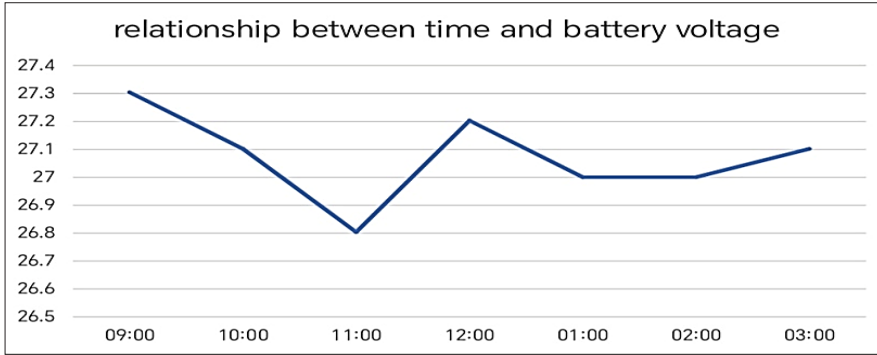


Fig. (2) relationship between time and battery voltage

Battery voltage: During the day, we notice stability in the battery voltage as there is continuous charging, Fig. (2)

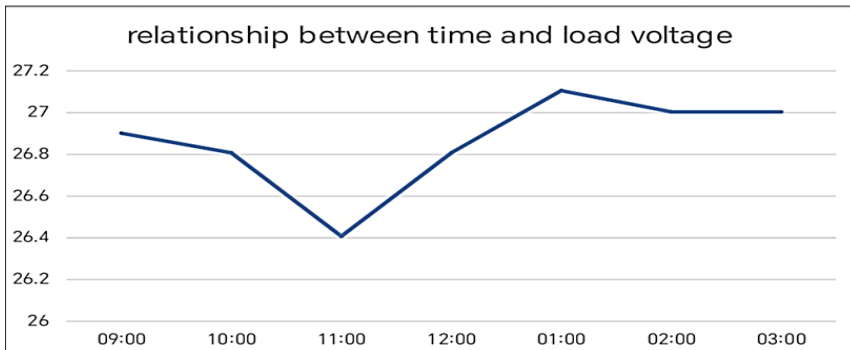


Fig. (3) Relationship between time and load voltage

The load voltage depends on the battery voltage, and the load voltage will be almost stable. Fig (3)

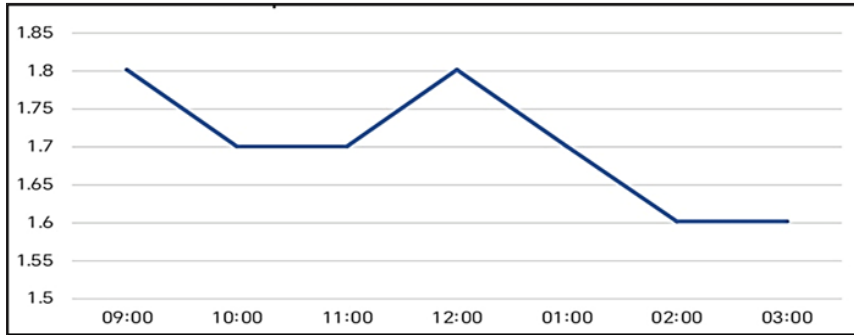


Fig. (4) Relationship between time and load current

Load current, we notice that the load current is stable from 1.6 to 1.8 A during daylight hours, Fig. (4).

## 2.Part Two :

Through Table 2, we can study the change in the value of hourly solar radiation, which was taken starting from 9:30 to 1:30 on a sunny day, as the weather on the day the readings shown in Table 1 were taken was a sunny day, 10/3/2025 Table 2. The second column represents the solar radiation readings in W/m<sup>2</sup>. The readings were taken using a solar radiation meter. Note that the measured incident solar radiation represents direct normal radiation. These readings were taken hourly over a single day, from 9:30 AM to 1:30 AM. The change in the second column, representing the radiation, shows a gradual rise in the solar radiation value and then a gradual decline. This is a well-known phenomenon resulting from the rise and fall of solar radiation over time. As for the third column, which represents the battery voltage, we notice complete stability in the battery voltage, as there is a continuous charge due to the presence of sufficient solar radiation capable of charging the battery. The fourth column, which represents the load voltage, is stable due to the stability of the battery voltage during the day. As for the fifth column, which represents the load current, we notice stability at 1.6A.

Table 2: shows the readings that were measured

Hours	Irradiance (W/m <sup>2</sup> )	Battery Voltage	Load voltage	Load current
9: Am	768	27 V	27 V	1.6 A
10:00 Am	796	27 V	27.1 V	1.6 A
10:30 Am	828	27.1 V	27.1 V	1.6 A
11:00 Am	913	27.1 V	27.1 V	1.6 A
11:30 Am	935	27.1 V	27.1 V	1.6 A
12:00 Pm	889	27.2 V	27.2 V	1.6 A
12:30 Pm	888	27.1 V	27.1 V	1.6 A
1:00 Pm	835	27.3 V	27.3 V	1.6 A
1:30 Pm	850	27.2 V	27.1 V	1.6 A

We notice from Fig.(5) a continuous interaction in the value of solar radiation and its peak from 11 am to 12 pm.

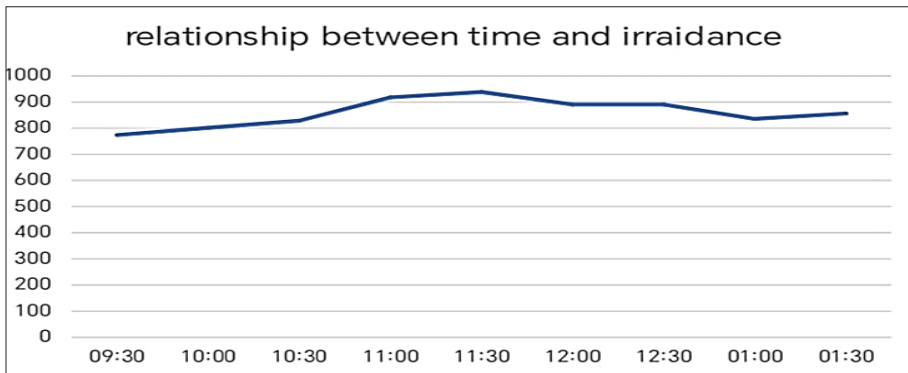


Fig. (5) Relationship between time and irradiance

As shown in Fig.(6), we notice complete stability in the battery voltage, as there is continuous charging due to the presence of sufficient solar radiation capable of charging the battery.

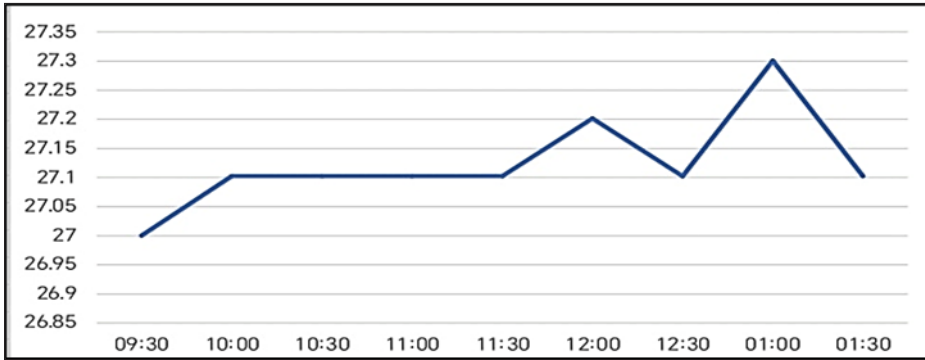


Fig.(6) relationship between time and battery voltage.

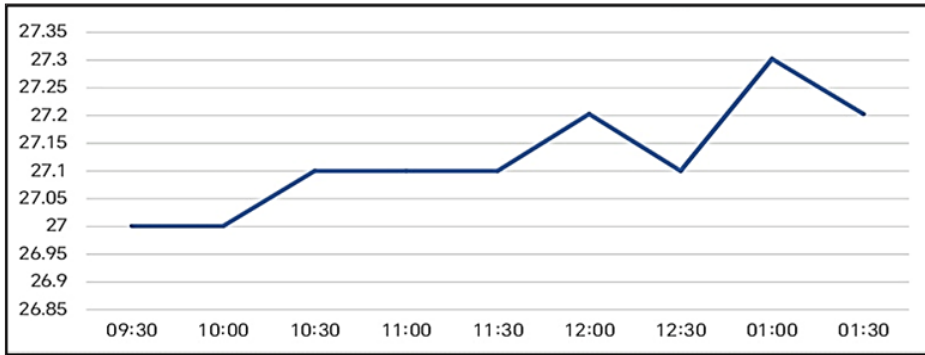


Fig. (7) Relationship between time and load voltage

As shown in Fig.(7), we notice complete stability in the load voltage, and depending on the battery voltage, the load voltage will be stable.

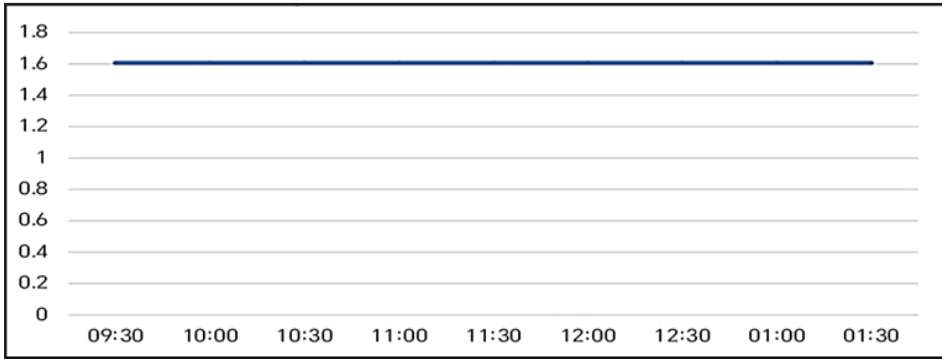


Fig. (8) Relationship between time and load current

As shown in Fig.(8), we notice complete stability in the load current and its stability at 1.6A.

### 3.Charging Time :

Through work, it has been shown that batteries need 20 minutes to raise the charging rate from 24V to 27V (i.e., from empty battery to fully charged), which means, according to Table (4-1), if it is observed that fully charging and discharging batteries requires two hours of time, during these two hours the tank can be filled and emptied (3) times within two hours, at a rate of (9) hours of filling and emptying the tank per day, which is equivalent to 63 liters per day.

## Discussion

The system's operation adapts to the visitor's time by relying on the varying solar radiation throughout the day, which directly affects the efficiency of power generation. According to the data, solar radiation reaches its peak between 11:00 AM and 12:00 PM, resulting in increased battery charge and increased overall system efficiency.

When visitors visit during times when the sun is at its highest, the system will experience better production and access to clean water, as the system's efficiency is closely linked to the nature of solar radiation. For example, solar radiation measured at 9:00 AM was 630 watts/m<sup>2</sup>, while at 11:00 AM it reached 880 watts/m<sup>2</sup>.

In addition, the stability of the battery voltage, which also depends on solar radiation, is crucial to the system's performance during visiting hours. If visitors are present during times of constant solar radiation, they will be able to observe the system operating at its highest efficiency.

So, if visitors are there during times when solar power is available, the system will be better able to meet their clean water needs.

## Conclusions

The system is capable of providing clean water at a low operating cost and demonstrates strong performance under varying levels of solar radiation. It reduces reliance on traditional energy sources and can operate continuously for up to three hours at night. Tests conducted on the system confirmed its ability to function efficiently in different weather conditions, including sunny and partly cloudy days, with voltage and current remaining stable throughout. The battery system proved effective by maintaining a nearly constant voltage of around 27 volts despite fluctuations in solar intensity during the day. On sunny days, the system showed even higher efficiency, with a consistent current output of 1.6 amps, contributing to stable overall performance. This highlights the system's reliability and effectiveness in harnessing solar energy. Furthermore, the project proves to be highly applicable in rural areas where water scarcity or lack of electricity grids is a concern, as the system operates independently using only solar power. It also offers room for scalability by allowing the integration of higher-capacity solar panels and batteries to meet larger demands, making it a sustainable and long-term solution. The water produced by the system was found to be of high quality, with a salt concentration of only 0.1, indicating excellent purity and suitability for consumption.

In this way, the research reflects the significant importance of supporting the Arbaeen pilgrimage by providing a sustainable and secure water source, embodying the aspirations for effective solutions to water challenges in arid regions.

## References

1. Abdaki, M., Alobaydy, O., Al-Samman, S., & Ahmed, H. (2024). Spatiotemporal analysis of extreme climate indices in Nineveh Governorate, northern Iraq: four decades study from 1981 to 2022 using NASA-Power dataset. *Modeling Earth Systems and Environment*, 10(4), 5553-5572.
2. Al-Addous, M., Bdour, M., Rabaiah, S., Boubakri, A., Schweimanns, N., Barbana, N., & Wellmann, J. (2024). Innovations in solar-powered desalination: a comprehensive review of sustainable solutions for water scarcity in the Middle East and North Africa (MENA) region. *Water*, 16(13), 1877.
3. Al-Jubouri, A. T. S., & Al-Ta'i, N. (2021). Modeling solar radiation at the Baghdad climate station and its impact on electrical energy production. *Tikrit University Journal of Human Sciences*, 28(10), 125.
4. Al-Samarrai, Z. F. A. (2024). معطيات الطاقة المتجددة وفاق تطورها في العراق. *Journal of Tikrit University for Humanities*, 31(4), 170-192.
5. Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes*. John Wiley & Sons.
6. Goosen, M., Mahmoudi, H., Alyousef, Y., & Ghaffour, N. (2023). Solar desalination: A review of recent developments in environmental, regulatory and economic issues. *Solar Compass*, 5, 100034.
7. Patel, M., & Bohra, S. (2023). Power management of grid-connected PV wind hybrid system incorporated with energy storage system. *Future Energy*, 2(3), 7-19.
8. Rahman, A., Farrok, O., & Haque, M. M. (2022). Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. *Renewable and sustainable energy reviews*, 161, 112279.
9. Thirunavukkarasu, M., & Sawle, Y. (2021). A comparative study of the optimal sizing and management of off-grid solar/wind/diesel and battery energy systems for remote areas. *Frontiers in Energy Research*, 9, 752043.
10. Zhu, L., Tian, L., Jiang, S., Han, L., Liang, Y., Li, Q., & Chen, S. (2023). Advances in photothermal regulation strategies: from efficient solar heating to daytime passive cooling. *Chemical Society Reviews*, 52(21), 7389-7460.