Solar Powered Water Purification System Using Integrated UV Disinfection

Sea Water → Normal Water

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Abstract –

Water scarcity is a pressing global issue, especially in areas with limited freshwater but abundant seawater. Conventional desalination methods often require substantial energy and infrastructure, making them unsuitable for remote or low-resource regions. This project introduces a Solar-Powered Water Purification System that transforms seawater into safe drinking water using renewable energy. The system combines reverse osmosis for salt removal with UV disinfection to eliminate harmful microorganisms, ensuring high water quality. Power solar photovoltaic (PV) panels, the design focuses on sustainability, low energy use, and ease of maintenance. The methodology involves selecting efficient solar components, designing the desalination unit, and integrating UV treatment. A working prototype is developed to test performance, durability, and water output. To improve long-term operation, the system incorporates energy storage and explores self-cleaning UV technologies. This innovative solution addresses challenges like high desalination costs, microbial safety, and limited access to clean water. By offering a practical, energy-efficient, and scalable approach, the project supports sustainable water access and environmental conservation, contributing to global efforts in managing the water crisis.

Key Words - Battery, Converters, Filtration Techniques, MPPT Algorithm, MOSFET, Power Controller, Reverse Osmosis, Solar Photovoltaic cell, UV technology

1) INTRODUCTION –

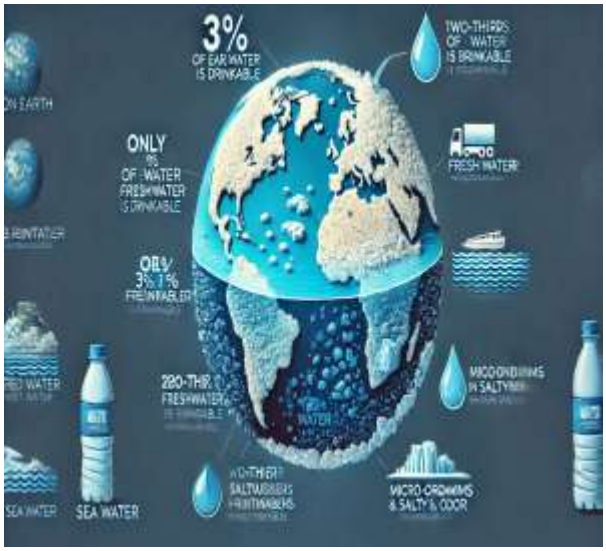
Access to clean and safe drinking water is a fundamental necessity for human survival, yet a significant portion of the global population struggles with water scarcity. With only 3% of the Earth's water being freshwater, and the majority of it trapped in polar ice caps, the availability of potable water remains a major challenge. Seawater, which constitutes a vast majority of the Earth's water supply, is unsuitable for direct consumption due to its high salt content, microbial contamination, and other impurities. Traditional desalination techniques, such as thermal distillation and reverse osmosis, have been widely used to convert seawater into drinkable water. However, these methods often demand high energy inputs and costly infrastructure, limiting their accessibility in remote and economically disadvantaged regions. To address this, renewable energy-based solutions have emerged as a promising alternative, offering sustainable and cost-effective approaches to

water purification. This project focuses on the development of a solar-powered water purification system that integrates reverse osmosis desalination and UV disinfection to produce safe drinking water. By utilizing solar photovoltaic (PV) technology, the system operates on clean, renewable energy, making it both environmentally friendly and energy-efficient. The incorporation of UV disinfection ensures the removal of harmful microorganisms, enhancing the overall quality and safety of the purified water, With rising concerns over water scarcity and environmental sustainability, this innovative approach aims to provide a scalable and practical solution for regions facing freshwater shortages. The project not only contributes to sustainable water management but also aligns with global efforts to promote renewable energy-driven purification technologies for a cleaner and healthier future.

2) FOCUS OF THE RESEARCH –

A. Problem Identification: -

In future and also in the Present, Access to clean and safe drinking water remains a critical global challenge, particularly in regions where freshwater sources are scarce. Despite covering nearly 71% of the Earth's surface, only 3% of the total water is freshwater, with almost two-thirds of it trapped in glaciers and polar ice caps. This leaves a very limited portion available for human consumption. The growing demand for potable water, coupled with pollution, climate change, and depletion of natural water sources, has intensified the crisis, necessitating innovative and sustainable solutions.



B. Objectives: -

This research aims to provide a **practical, efficient, and sustainable** solution to global water scarcity. By integrating **solar energy, reverse osmosis, and UV disinfection** and the system offers a **cost-effective and environmentally responsible** alternative to conventional water purification methods. The success of this project could pave the way for wider adoption of **renewable energy-driven water purification systems**, helping millions of people access clean drinking water. This project aims to develop a solar-powered water purification system that integrates reverse osmosis desalination and UV disinfection to efficiently convert seawater into potable water. By leveraging solar energy, the system significantly reduces reliance on non-renewable power sources, making it a sustainable and eco-friendly alternative. Additionally, the UV disinfection unit ensures that all harmful pathogens and microorganisms are eliminated, providing safe and clean drinking water. This innovative approach not only addresses the issue of water scarcity but also presents a scalable and practical solution for regions facing freshwater shortages, particularly in coastal, rural, and disaster-prone areas

C. Components: -

The effectiveness of a solar-powered water purification system depends on the careful selection of its components. Each component is chosen based on its efficiency, durability, cost-effectiveness, and suitability for integration within the system.

Criteria for Selecting Components:

1.Solar Panel (PVC) - 16V

- **High energy conversion efficiency** to generate sufficient power.
- **Weather-resistant and durable** for long-term outdoor use.
- **Stable voltage output** to support all electrical components.

2. DC MCB (Miniature Circuit Breaker)

- **Provides electrical protection** by preventing overcurrent and short circuits.
- **Ensures safety** by automatically disconnecting power during faults.

- **Durable and heat-resistant materials** for long-term reliability.

Protects battery during high radiations.

3. 12V Power Controlling Board

- **Regulates power supply** to ensure stable operation of components.
- **Overvoltage and current protection** to prevent damage to the system.

Compact and efficient design for minimal energy loss.

4. Inverter

- **Converts DC power from solar panels to AC** for components requiring AC input.
- **High efficiency and low heat generation** for prolonged performance.

Compact and lightweight design for easy installation

5. Submersible Pump

- **Capable of operating underwater** for efficient water extraction.
- **Energy-efficient motor** to reduce power consumption.
- **Corrosion-resistant materials** to withstand prolonged exposure to water.

6. Water Softener

- **Removes hardness-causing minerals (calcium and magnesium)** to enhance water quality.
- **Long-lasting resin material** for effective ion exchange.
- **Compact design** to integrate easily into the filtration system.

7. Resin

- **High exchange capacity** for removing hardness-causing ions.
- **Durable and chemically stable** to ensure long-term functionality.
- **Non-toxic and food-grade material** to maintain water safety.

8. Sediment Filter

- **Effectively removes dirt, sand, and debris** from water.
- **Long-lasting filtration material** for extended performance.
- **Low-maintenance design** for easy cleaning and replacement.

9. Anti-Scaling Balls

- **Prevents scale buildup** inside the RO membrane and pipelines.
- **Increases lifespan of filtration components** by reducing mineral deposits.
- **Safe and non-toxic materials** for maintaining water purity.

10. Pre-Carbon Filter

- **Effectively removes chlorine, pesticides, and organic contaminants.**
- **High adsorption capacity** to improve taste and odour of water.
- **Long-lasting filtration media** for extended performance.

11. Pressure Reactor

- **Ensures proper pressure regulation** within the system.
- **Enhances water flow consistency** for optimal filtration.
- **Corrosion-resistant materials** for durability.

12. Booster Pump

- **Increases water pressure** for efficient reverse osmosis filtration.
- **Energy-efficient motor** to minimize power consumption.
- **Durable and corrosion-resistant components** for long life.

13. Adopter (AC-DC Converter)

- **Converts AC power into DC power** for operating electrical components.
- **High efficiency and stable output** to prevent voltage fluctuations.
- **Compact and lightweight design** for easy integration.

14. RO Membrane

- **Removes dissolved salts, heavy metals, and contaminants** from water.
- **High filtration capacity** for effective desalination.
- **Resistant to clogging and fouling** to ensure durability.

15. Post-Carbon Filter

Enhances water taste and removes residual impurities.

- **High adsorption capacity** for improved filtration.
- **Long-lasting activated carbon material** for efficiency.

16. Alkaline Cartridge

- **Balances pH levels** by adding essential minerals like calcium and magnesium.
- **Enhances water taste** and provides health benefits.

Durable material for long-term use.

17. UV Lamp

- **Kills bacteria, viruses, and microorganisms** in water.
- **Energy-efficient operation** with low power consumption.
- **Long lifespan and high-intensity UV output** for effective sterilization.

18. Floating Valve

- **Automatically controls water levels** in the storage tank.
- **Prevents overflow and wastage** by stopping the water flow when the tank is full.
- **Made of durable, corrosion-resistant materials** for longevity.

19. Storage Tank

- **Made of food-grade, non-toxic material** to ensure water safety.
- **Adequate capacity** to store purified water for continuous supply.
- **Leak-proof and UV-resistant** to maintain water quality.

20. Connecting Wires

- **High-quality, insulated wires** to prevent electrical losses.
- **Adequate thickness and conductivity** to handle power loads efficiently.
- **Durable and heat-resistant** to ensure safety.

21. Connecting Pipelines

- **Leak-proof and durable material** to ensure a smooth water flow.
- **Corrosion-resistant construction** for longevity.
- **Flexible and easy-to-install design** for system efficiency.

22.TDS Meter:

A TDS (Total Dissolved Solids) meter is a digital device used to measure the concentration of dissolved solids in water. It provides an estimation of the purity and quality of water by detecting the presence of inorganic substances such as salts, minerals, and metals. These solids originate from natural sources, industrial waste, or household plumbing, influencing the taste, safety, and usability of water.

Working Principle of a TDS Meter

A TDS meter operates based on the electrical conductivity (EC) principle. Since dissolved solids in water contain ions, they allow electricity to pass through. The meter measures the conductivity of the water and converts it into parts per million (ppm), representing the total dissolved solids concentration.

Components of a TDS Meter

1. Electrodes/Sensors – Detect the conductivity of water.
2. Microprocessor – Converts conductivity readings into TDS values.
3. Display Screen – Shows the TDS value in ppm.
4. Power Source – Usually powered by batteries.

How to Use a TDS Meter

1. Turn on the meter.
2. Immerse the probe into the water sample.
3. Allow the reading to stabilize.

4. Note the displayed TDS value.
5. Rinse and store the meter properly after use.

TDS Levels and Water Quality

- 0-50 ppm – Ultra-pure water (ideal for laboratory use).
- 50-150 ppm – High-quality drinking water.
- 150-300 ppm – Average tap water (safe for consumption).
- 300-500 ppm – Hard water (may require filtration).
- Above 500 ppm – Poor water quality (not recommended for drinking).

Applications of TDS Meters

- **Drinking Water Quality Testing** – Ensures safe and pure water consumption.
- **Aquariums and Hydroponics** – Maintains optimal mineral levels for aquatic life and plant growth.
- **Industrial and Agricultural Use** – Monitors water used in manufacturing and irrigation.
- **RO System Monitoring** – Checks the efficiency of water purifiers.

Level of TDS (milligrams per litre)	Rating
Less than 300	Excellent
300 - 600	Good
600 - 900	Fair
900 - 1,200	Poor
Above 1,200	Unacceptable

D. Selection of Power Conversion Algorithm: -

The selection of an appropriate power conversion algorithm is crucial to ensure efficient energy management in a solar-powered water purification system. Given the reliance on solar energy, the algorithm must maximize power extraction while maintaining system stability. The key considerations in selecting the power conversion algorithm include energy efficiency, adaptability to varying sunlight conditions, and compatibility with system components.

1. Maximum Power Point Tracking (MPPT) Algorithm:

- Why MPPT? Since solar energy fluctuates throughout the day, MPPT helps extract maximum power from the photovoltaic (PV) panels.
- Types of MPPT Algorithms Used:
  - Perturb and Observe (P&O): This method adjusts the voltage and checks the resulting power output. It is simple but may oscillate around the maximum power point.
  - Incremental Conductance (IC): More accurate than P&O, it calculates the derivative of power with respect to voltage and adjusts accordingly.
  - Fuzzy Logic MPPT: Uses artificial intelligence to enhance efficiency under rapidly changing conditions.

2. DC-DC Converter Selection

- Buck Converter: Steps down the voltage to match the requirements of the components (e.g., battery, pumps, UV lamps).
- Boost Converter: Used when higher voltage is required for certain applications like powering the UV disinfection unit.

- Buck-Boost Converter: Offers flexibility in voltage regulation, depending on power availability.

3. Battery Charging Management

- The system must ensure optimal battery charging while preventing overcharging or deep discharge.
- Charge Controllers:
    - PWM (Pulse Width Modulation): Simple and cost-effective for small-scale applications.
    - MPPT Charge Controllers: More efficient in extracting power from the solar panels.

4. Power Distribution Strategy

- Ensures efficient allocation of power among various components:
    - Priority to Critical Loads: RO membrane, booster pump, and UV lamp get uninterrupted power.
    - Energy Storage Utilization: Excess solar energy is stored in the battery to be used when sunlight is unavailable.

5. Integration with MATLAB Simulation

- MATLAB-based simulations help analyse system performance under different conditions.
- Power flow analysis ensures the system operates within optimal efficiency parameters.

MPPT Algorithm

1. Initialize Parameters
    - Read initial values of solar panel voltage (V_pv) and current (I_pv).
    - Compute initial power output (P_pv = V_pv × I_pv).
    - Set initial reference voltage and small perturbation step ΔV.
2. Measure Solar Input
    - Continuously monitor V_pv and I_pv.
    - Store previous values of power and voltage for comparison.
3. Compare Power Output
    - If current power (P_pv) > previous power (P_prev):
        - Continue voltage adjustment in the same direction.
    - If P_pv < P_prev:
        - Reverse the perturbation direction.
4. Adjust Operating Voltage
    - If dP/dV > 0, increase voltage.
    - If dP/dV < 0, decrease voltage.
    - Repeat adjustments until reaching maximum power point (MPP).
5. Regulate Power Using DC-DC Converter.
6. Monitor and Update
7. Stop Condition

Simulation Results:

The given MATLAB Simulink model demonstrates an MPPT-based solar power system with a buck converter for battery charging. The following observations can be made based on the simulation results displayed in the diagram:

1. PV Array Performance
    - The PV array is generating power based on input conditions (irradiance and temperature).
    - The voltage and current values are processed through an MPPT control algorithm to extract maximum power.
2. MPPT Algorithm Implementation
    - The duty ratio calculation is performed through a MATLAB function block to regulate power conversion efficiently.
    - Unit delay blocks are used to update previous voltage and power values for MPPT tracking.
    - A relational operator helps maintain optimal voltage operation.
3. Buck Converter Regulation
    - The MOSFET switch controls the power flow based on the duty cycle adjustment from the MPPT algorithm.
    - A filter inductor smooths out fluctuations in the current, ensuring a steady charging voltage.

4. Battery Charging Analysis

- Two battery units are connected, displaying voltage, current, and state of charge (SOC %).
- Observed values:
  - Battery 1: Voltage = 11.89V, Current = -5.407A, SOC = 45%
  - Battery 2: Voltage = 12.92V, Current = -5.407A, SOC = 45%
- The negative current indicates that the batteries are being charged efficiently.

This simulation successfully demonstrates an MPPT-controlled solar power system with a buck converter for battery charging. The observed steady SOC values and controlled current flow indicate efficient energy conversion and power regulation. The model ensures optimal performance of solar energy harvesting while maintaining battery health.

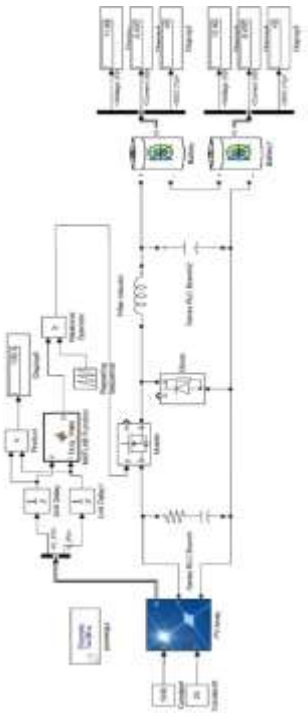


Figure- MPPT algorithm simulation for the battery storage or charging based on radiation variations

E. Power Supply Line Diagram: -

The power supply connections line diagram illustrates the flow of electrical energy within a solar-powered reverse osmosis (RO) water purification system. The components work together to ensure efficient conversion of saltwater into clean water using solar energy. Below is a breakdown of the diagram:

1. Power Generation and Distribution

- Solar Panel: Captures sunlight and converts it into DC electrical power.
- DC MCB (Miniature Circuit Breaker): Protects the circuit from overcurrent and short circuits. It ensures safe operation by preventing electrical damage.
- Battery (12V Calcium Car Battery): Stores energy from the solar panel, allowing the system to operate even when sunlight is unavailable.
- Second DC MCB: Provides another layer of electrical protection before power is distributed to the booster pump and RO unit.

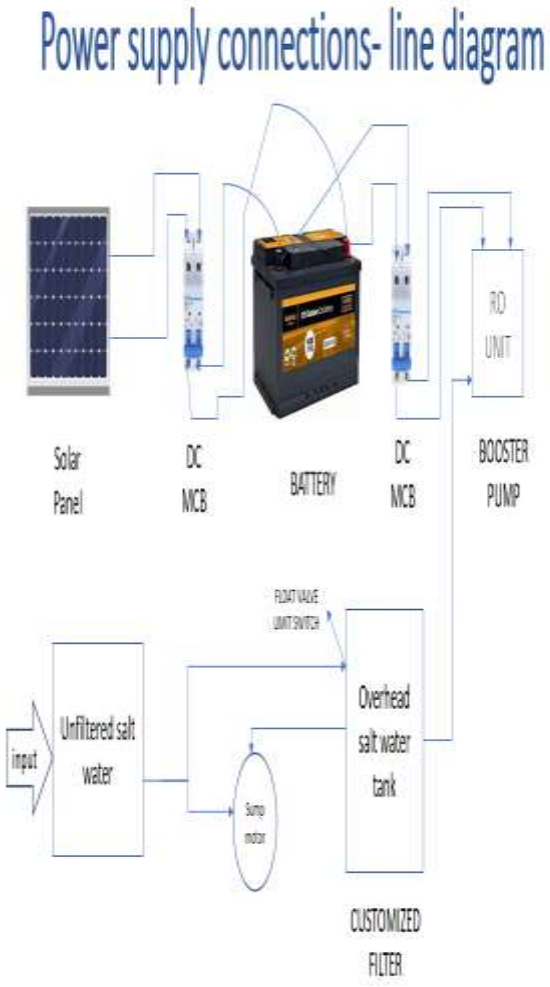
2. Water Filtration Process

- Unfiltered Salt Water Input: The raw saltwater enters the system for purification.
- Sump Motor: Pumps the saltwater from the input source into the customized filter system.
- Customized Filter: A pre-filtration system that removes larger impurities before the water reaches the RO unit.
- Overhead Saltwater Tank: Temporarily stores the filtered saltwater before further treatment. A float valve limit switch regulates the water level, preventing overflow.

3. Reverse Osmosis Purification and Output

- Booster Pump: Pressurizes the filtered water for efficient reverse osmosis (RO) filtration.
- RO Unit: The heart of the purification system, it removes dissolved salts, **contaminants, and impurities, producing clean water.**

- Final Output: The purified water is ready for consumption, while waste brine is discharged appropriately.



F. Solar Powered Water Purification System Using Integrated UV Disinfection Block Diagram and Hardware results: -

The given block diagram represents a solar-powered water purification system integrated with UV disinfection, designed to convert impure water into safe drinking water using renewable energy. The system begins with a submersible pump, which extracts raw water from a water source, such as a well or reservoir. The water then passes through a water softener, which reduces hardness by removing calcium and magnesium ions. Following this, the water undergoes preliminary filtration through a sediment filter, eliminating large particles and suspended solids. The process continues with anti-scaling balls, which prevent scale formation and protect downstream components.

Next, the pre-carbon filter absorbs chlorine, organic compounds, and Odors, ensuring better taste and Odor-free water. The pressure reactor helps regulate the water flow and pressure before reaching the booster pump, which enhances the pressure required for the reverse osmosis (RO) membrane. The RO membrane plays a crucial role in removing dissolved salts, bacteria, and other impurities. Some portion of the water is rejected as excess water (wastewater), while the purified water continues through further filtration stages.

Post-filtration, the water passes through a post-carbon filter, which refines the taste and removes residual Odors. It then moves to the alkaline cartridge, which balances the pH level and enhances mineral content, making the water healthier. The purified water is then directed to a storage tank, equipped with a floating valve to regulate water levels. The UV lamp provides additional disinfection by killing any remaining microorganisms, ensuring the final output is safe for consumption.

The system is powered by a 16V solar panel, which converts sunlight into electrical energy. This energy is managed through an MCB (Miniature Circuit Breaker) for safety and is further regulated by a 12V power controller. The inverter converts DC power into AC for components requiring alternating current. Additionally, an adapter ensures proper AC-DC conversion, providing a stable power supply to various filtration units.

This solar-powered water purification system is an eco-friendly and sustainable solution, ideal for remote locations, disaster relief, and areas with limited access to clean drinking water. It reduces dependency on conventional energy sources and ensures a continuous supply of safe and purified water using an integrated, multi-stage filtration and UV disinfection approach.

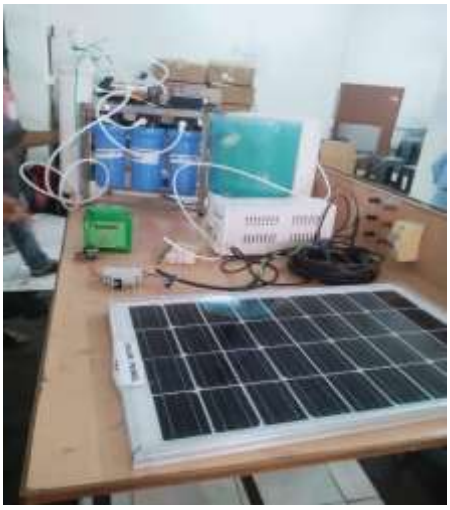
Hardware Results:

TDS values of Different purified Water Vs. Our filtered water from Solar Powered Water Purification System using Integrated UV Disinfection

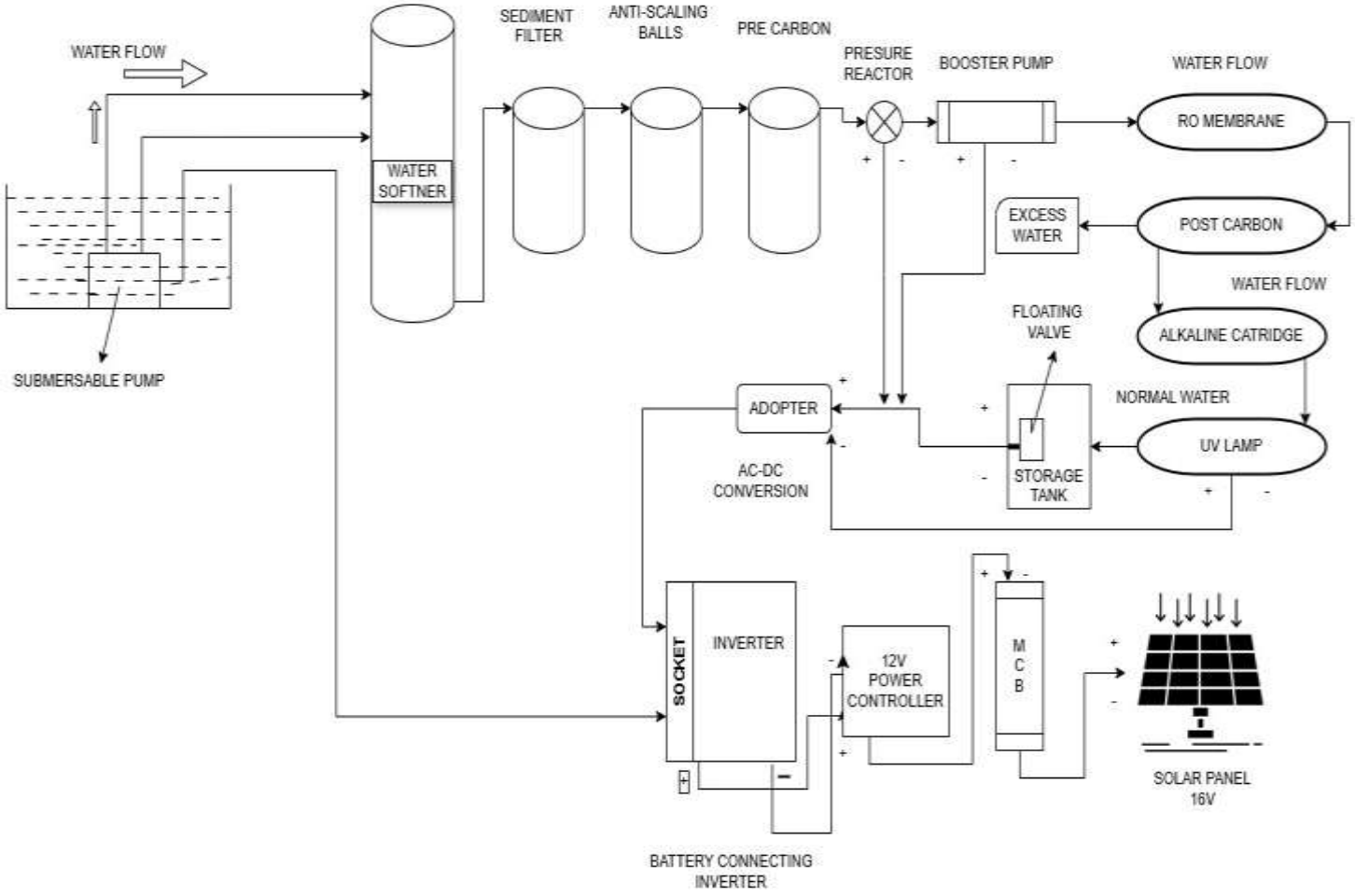
- **Municipality Tap Water – >250-300 TDS**
- **Ground Water _ >300 TDS**
- **Filtered Water _ >100 TDS**
- **UV Purified Water _ >90 TDS**

- **Our filtered water from Solar Powered Water Purification System using Integrated UV Disinfection < = 90 TDS**

The results indicate that this solar-powered seawater purification system is an efficient, sustainable, and cost-effective solution for converting saltwater into potable water. The integration of renewable energy, automated controls, and advanced filtration technology ensures consistent performance with minimal environmental impact. This project has the potential to address global water scarcity issues and improve access to clean drinking water in remote or water-stressed regions.



SOLAR POWERED WATER PURIFICATION SYSTEM USING INTEGRATED UV DISINFECTION



3) FUTURE SCOPE –

Deployment in Coastal and Beach Areas

- This system can be installed in coastal regions and beach areas where seawater can be efficiently converted into clean drinking water.
- It provides a sustainable solution for resorts, coastal communities, and fishing villages facing freshwater shortages.

Implementation in Remote and Off-Grid Locations

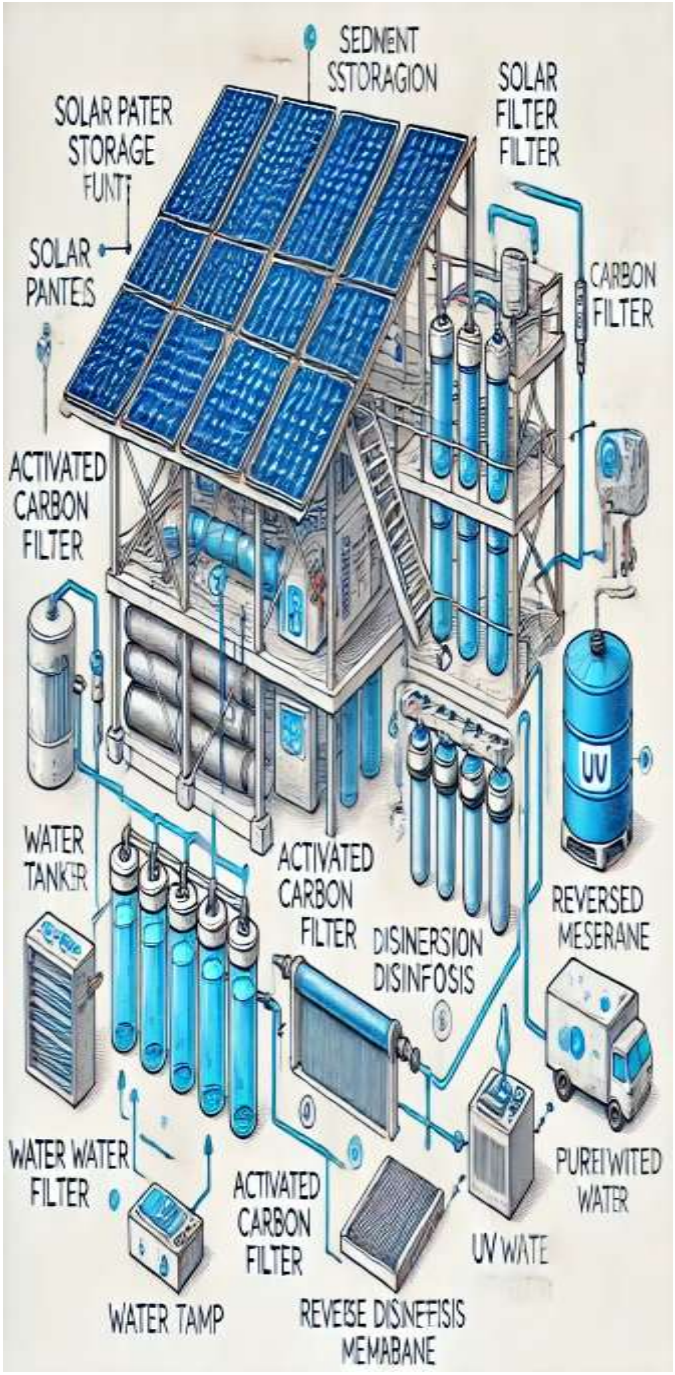
- The system is ideal for rural areas, islands, and desert regions where access to clean water is limited.
- With its solar-powered operation, it can function independently without relying on conventional electricity grids.

Implementation in Water-Scarce Regions

- Countries like Dubai, Saudi Arabia, and other Middle Eastern nations face extreme water scarcity due to low rainfall and high temperatures.
- This solar-powered water purification system can serve as a sustainable solution for providing clean drinking water in desert regions and urban areas.

Integration with Large-Scale Desalination Plants

- This technology can complement existing desalination plants in countries



AI Generated Image of Our Solar Powered Water Purification System using Integrated UV Disinfection, Which Represents the Future Scope of Our New Innovation

4) CONCLUSION –

The solar-powered water purification system with integrated UV disinfection provides an efficient and sustainable solution for producing clean and safe drinking water. By harnessing solar energy, the system operates independently of conventional power sources, making it ideal for remote and off-grid locations. The integration of reverse osmosis (RO) filtration and UV disinfection ensures the effective removal of impurities, bacteria, and viruses, delivering high-quality purified water.

The automation features, including float valves, booster pumps, and battery management, contribute to a reliable and low-maintenance system. The results obtained demonstrate that this approach is cost-effective, energy-efficient, and environmentally friendly, making it a viable alternative for addressing water scarcity and contamination issues.

ACKNOWLEDGEMENT –

We take this opportunity to sincerely thank all those who contributed to the successful completion of our project titled *"Solar Powered Water Purification System Using Integrated UV Disinfection."*

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