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Recent Advancements in Solar Hybrid Desalination Measurements and Controls

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ABSTRACT
Crisis for fresh drinking water is a major concern nowadays. There are many regions with favorable features throughout the world, but whose development is principally limited by the lack of fresh water. In arid areas of the Middle East and North Africa, where large-scale development has already occurred, the desalination plants are employed to extract fresh water, requires very large energy consumption. This motivates the development of desalination systems that are powered by solar energy. In this article, solar desalination technologies are reviewed with the goal of identifying key technical challenges and potential opportunities for solar desalination. Existing solar-powered desalination plants have generally been indirect solar-desalination systems that first transform solar energy into electrical energy and then employ the resulting electrical energy to drive desalination systems. Other, potentially more efficient direct solar-desalination systems directly convert the solar energy to pressure and/or heat, and use these to power directly the desalination process. The cost-effectiveness, energy-efficiency, and other relevant quantities of the potential technologies for solar-desalination systems are described in this study. To maximize the utilization of solar energy, a battery bank should be integrated with solar cell in the unit.

Keywords: *Solar energy, desalination, solar desalination, cost-effectiveness, energy-efficiency*

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INTRODUCTION

In the USA, the most favorable location for solar-desalination system is the South-West region because of having high solar irradiance, and access to large brackish water sources and/or proximate seawater. The extraction of fresh water via desalination plants requires very large energy consumption; this motivates the development of solar-desalination systems [1]. These systems are powered by solar energy, which depends on geographical positioning and time [2]. The key factors that affect desalination system performance include solar radiation, water salinity, water temperature, air temperature and water demand. A representative system with stochastic system inputs is shown in Figure 1 [3].

Existing solar powered desalination plants have indirect solar desalination systems that first transform solar energy into electrical energy and then employ the resulting electrical energy to drive desalination systems. Other, potentially more efficient direct solar-desalination systems directly convert the solar energy to pressure and/or heat and use these to power directly the desalination process [1, 4].

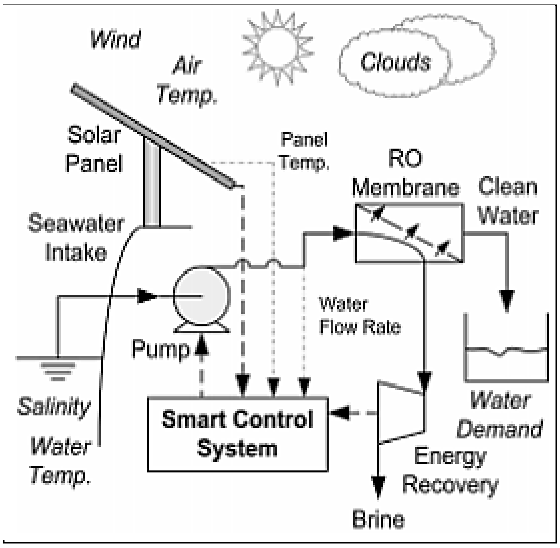

Fig. 1. *System schematic [3].*

The goal of this study is identifying key technical challenges and potential opportunities for developing cost-effective solar desalination technology. The main objective of the recent advances is to increase overall efficiency of desalination unit by improving system components, such as, solar cell, and reverse osmosis membranes. Another objective is to optimize overall system performance by adjusting settings or factors by using system control methods.

SYSTEM DESCRIPTION

Non-constant pressure and flow rate decrease the lifetime of membrane. Concentration polarization causes scaling of membrane. Economic factors, e.g., converting solar energy to electrical form, location of unit is measuring and controlling conditions [4]. Softener solves problem of scaling. Block diagram of the system is shown in Figure 2. Water is fed through the softener unit then water moves to the intake pump. From the intake pump water is stored in reverse osmosis (RO) unit. RO unit is connected to the power line. The power line starts from the solar regulator, with which battery set is attached. PV panel gets solar energy and is connected to the solar regulator. RO unit separates fresh water from the input water [5–7].

Figure 3 displays the photovoltaic reverse osmosis (RO) system flow diagram [5]. PV array is connected to the control electronics and saltwater intake is connected to softener pump. Control electronics is connected to the softener pump, feed pump, and high-pressure pump. There is a softener between softener pump and feed pump and a pre-filter assembly between the feed pump and high-pressure pump. High-pressure pump is connected to the reverse osmosis modules. These modules work to produce fresh water.

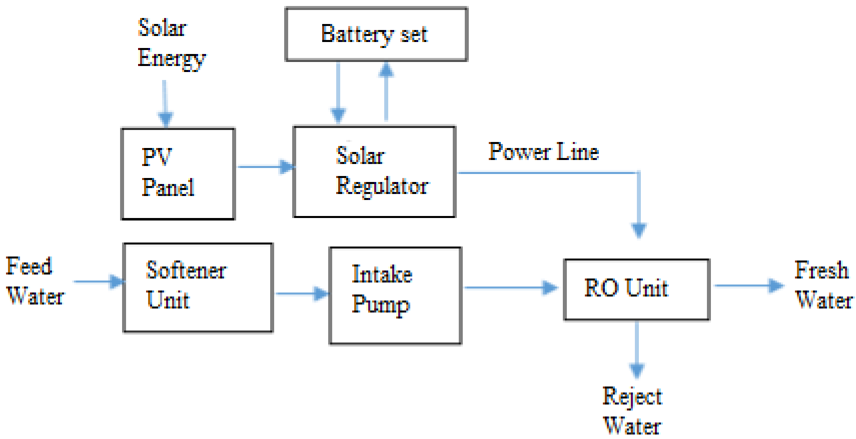

Fig. 2. *Block diagram of the system [5].*

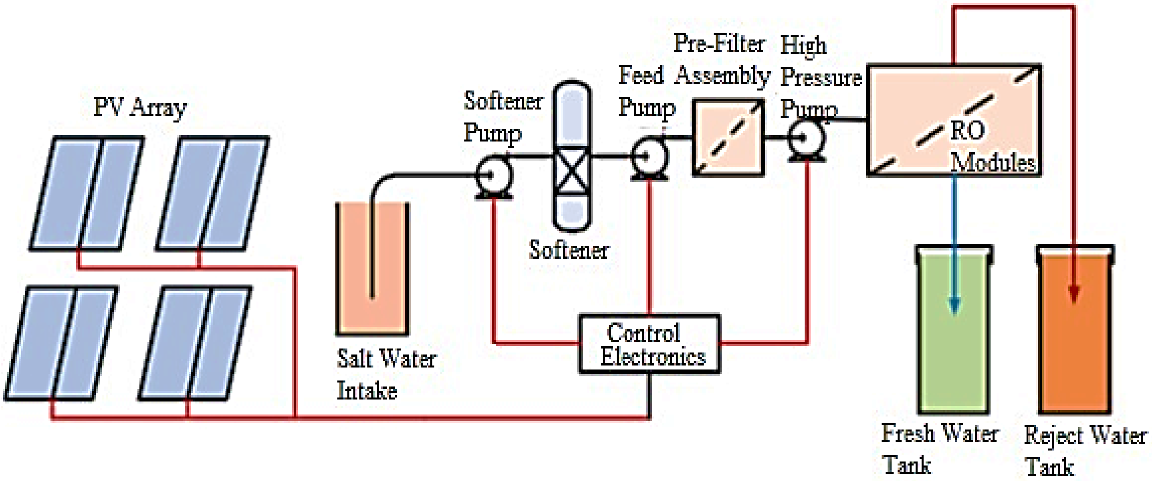

Fig. 3. *Photovoltaic reverse osmosis (RO) system flow diagram [5].*

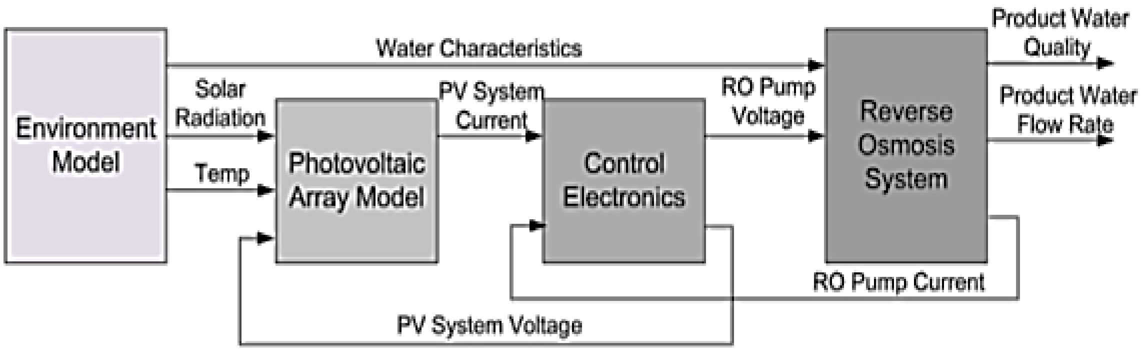

Fig. 4. *PVRO model in MATLAB/ Simulink [8].*

SYSTEM MODELING

The photovoltaic reverse osmosis (PVRO) model is presented in Figure 4. This model is built by using Matlab Simulink software [8]. Here, environmental model estimates direct, diffuse, and reflected portions of solar radiation. Photovoltaic array model connects individual solar cell models into strings in series and then connects strings in parallel. Control electronics implement control algorithms to control operating point of the system. Reverse osmosis system is employed for the cross-flow separation.

The basic pump mechanics is exhibited in Figure 5. At the intake point, medium pressure flow is fed in the first chamber. Then the piston is operated and low-pressure concentration comes out. In the second chamber, high-pressure concentration moves in and high-pressure output moves out of the pump.

EXPERIMENTAL SYSTEM

Figure 6 shows the experimental system layout [8, 9]. The system consists of water tank, power electronics, power management system, sensors, pressure exchanger and reverse osmosis modules. Eighteen different sensors are used here for model validation and control feedback [8]. Using sensor data, microcontrollers perform computation and control. No battery is employed for power leveling. Small batteries are used as backup power for electronics. Experimental system architecture is shown in Figure 7 and the system setup is shown in Figure 8 [8, 9].

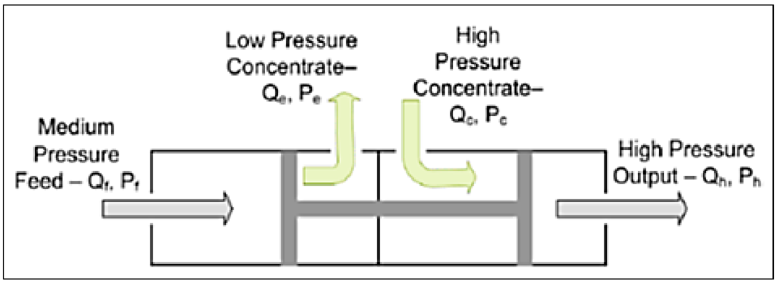

Fig. 5. *Basic pump mechanics [5].*

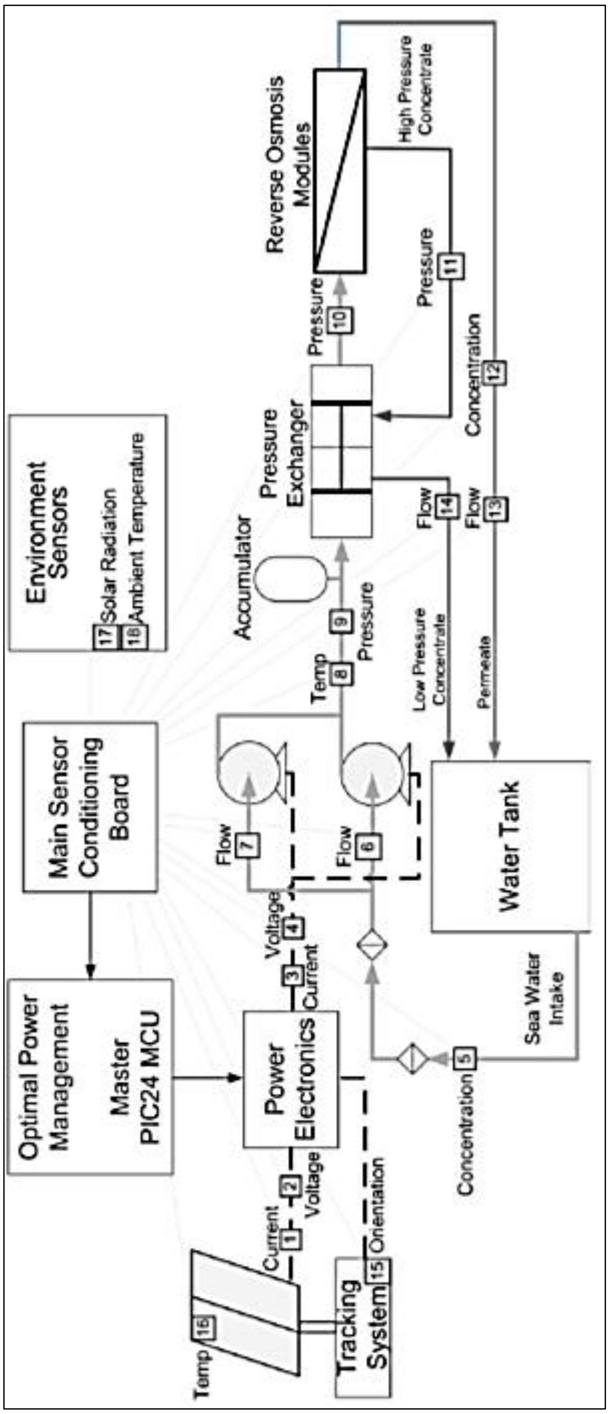

Fig. 6. *Experimental system layout [8, 9].*

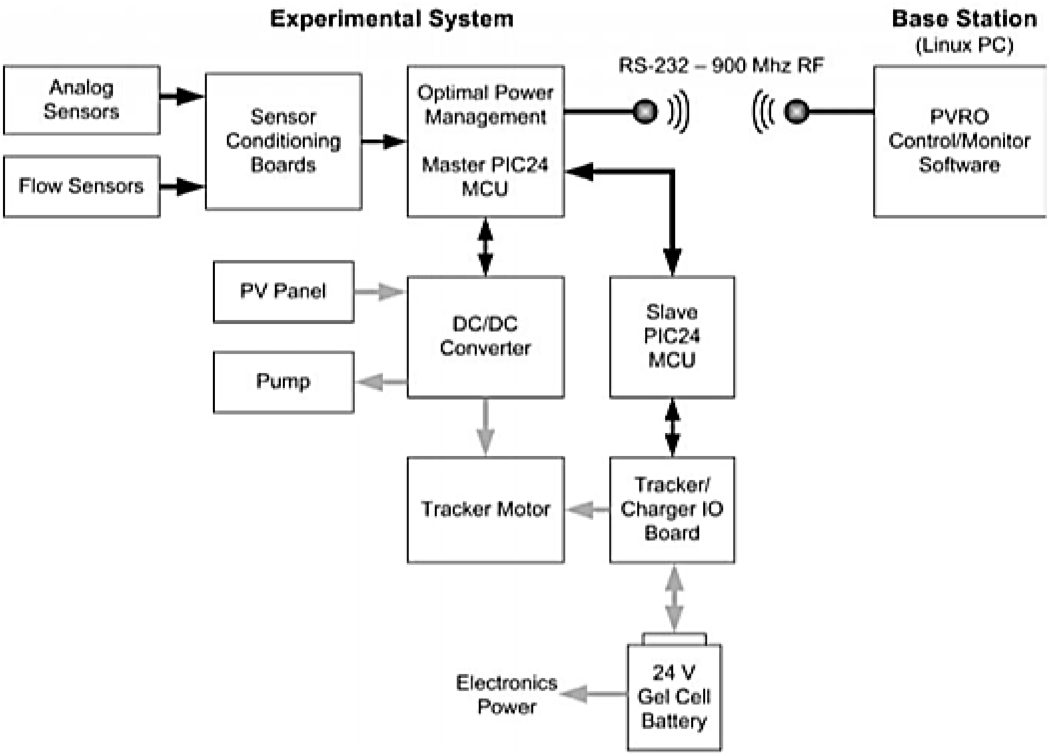

Fig. 7. *Experimental system architecture [8, 9].*

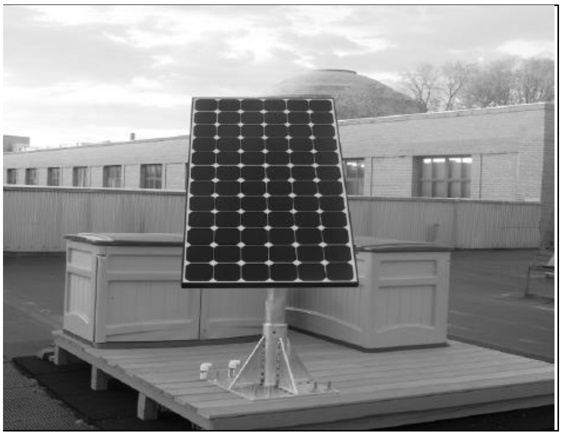

Fig. 8. *Experimental system setup [8].*

SYSTEM RESULTS

Figure 9 presents the volume of water produced in liter with time in hours. The result found from model is almost the same with the experimental data [8, 9]. The rate of water produced increases with time for a specific period. After that water producing rate becomes constant with respect to time.

Figure 10 displays overall efficiency of the reverse osmosis system [8]. It is expressed as the specific energy consumption with respect to input power. The predicted model in Simulink agrees well with the experimentally measured results. Specific energy consumption of experimental system ranges 2.5–4 kWh/m^3 [8]. From the Figure 10, it is seen that initially there is a sharp drop in specific energy consumption, after that it slightly increases with the increase of input power.

COST ANALYSIS

Figure 11 plots the effect of membrane life on cost [5, 10]. It is plotted for both compact system and large system. The membrane life is inversely related to water cost. When membrane life is reduced, water cost becomes higher. If the membrane life increases, water cost drops. Figure 12 exhibits the effect of plant life on cost [5, 10]. Similar trend is found for both compact system and large system. For smaller plant life, water cost is higher. By increasing membrane and plant lifetime, the cost of water production decreases significantly.

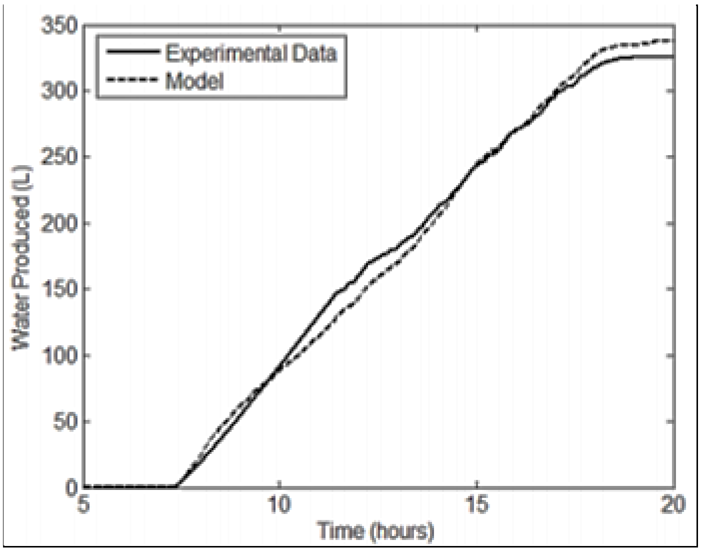

Fig. 9. *Water produced [8].*

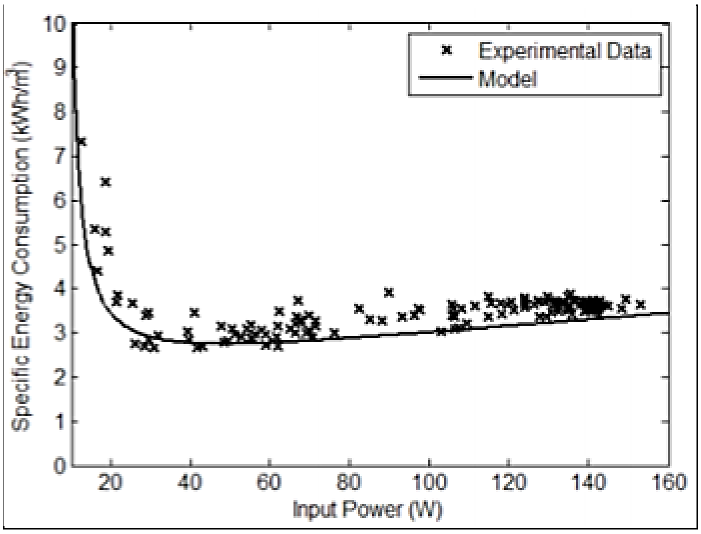

Fig. 10. *Overall efficiency of RO system [8].*

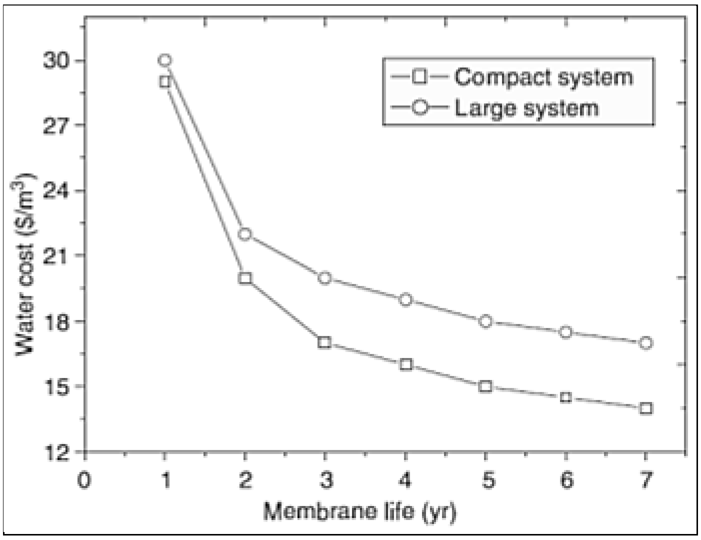

Fig. 11. *Effect of membrane life on cost [5, 10].*

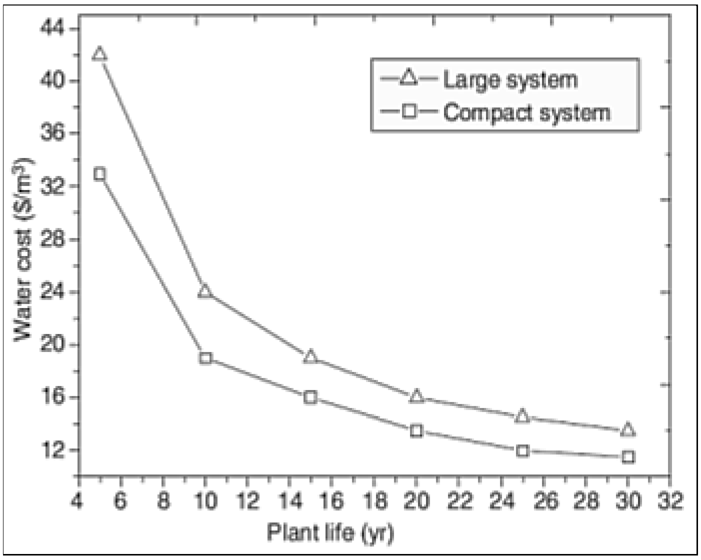

Fig. 12. *Effect of plant life on cost [5].*

CONCLUSIONS

For the purpose of providing fresh water to people of remote communities, solar powered water desalination unit is a preferable method when it is both technically and economically feasible. Smart control techniques in the experiment improve its efficiency. The increased efficiency can extend its feasibility to marginal or unfeasible locations. The experimental results show good agreement with the analytical models. To reduce water production cost, it is necessary to increase reliability of membrane distillation technology and plant lifetime. There are technical or intellectual challenges to adapt photovoltaic system into the power distillation unit. Smart algorithms should be designed to increase total system efficiency.

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