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Investigation of off-grid photovoltaic systems for a reverse osmosis desalination system: A case study

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ABSTRACT

There has been a great concern about shortage of potable water in many countries as well as Iran, because of the dramatic low rainfall during past few decades almost in all over the Iran. There is a great concern for implementing renewable desalination systems as it seems to be the only clean and environmental friendly source to the traditional fossil fuel powered systems. This study sought to simultaneously assess the reliability of electricity and cost in off grid photovoltaic systems for a photovoltaic reverse osmosis desalination system in 9 districts of Bushehr Province in Iran. Solar data used in this study contains indices of "Clearness Index" and "Daily Solar Radiation" over a period of 16 years from 2000 to 2016. HOMER and Excel were used for technical-economic feasibility of the proposed systems. For this study, a new model of BWRO-2S-130/75 desalination system is tested and proposed. The results indicate that the proposed photovoltaic systems are technically and economically feasible. It was also found that the reliability of off grid photovoltaic system using fuzzy time function provided better results than using the simple method. The results of the evaluation of proposed photovoltaic systems by HOMER software shows that annual electricity production for Delvar and Deylam port are 72,336 and 47,915 kWh respectively which is promising. Also, maximum of 228 m^3 and a minimum of 148 m^3/day of potable water can be produced with cost of 1.96 to 3.02 $/$m^2$ for Delvar and Deylam port respectively. Results indicate that using the proposed system of desalination would be economically feasible for Delvar, since the predicted water cost is cheaper compared to existing water price of $2.5. The new model of BWRO-2S-130/75 desalination can meet the water demand of the selected city.

1. Introduction

Fossil fuel is the main cause of environmental problem like greenhouse gas emission, air pollution, acid rain, and global climate change [1]. Industries use a great amount of electricity in many countries [2]. Solar desalination systems include solar technologies which can provide a sustainable solution to address the need to drinking water in the areas with a shortage of drinking water, and water consumption in the industry [3]. Desalinization is the process used for saline or sea water. Desalination process requires considerable amount of energy which there are several methods to provide this energy. Solar energy is one of the sources for desalination process [4]. There are different desalination processes powered by solar energy like: multiple-effect humidification (MEH), multi-stage flash distillation (MSF), multiple-effect distillation (MED), multiple-effect boiling (MEB), humidification–dehumidification (HDH), reverse osmosis (RO), and freeze-effect distillation [5]. There are two methods of solar desalination: direct desalination systems, and indirect desalination systems. In the simplest desalination method (direct method), when the heat from the sun affects saline water, water evaporates and the minerals and salts remain. Then, using various methods, the evaporated water can be distilled and in this way, the fresh water is produced. However, there are different methods for water distillation which require heating [6]. For indirect method, in the first stage, solar energy is converted to electrical or mechanical energy and then, it is used for mechanical separation. In addition, mechanical separation methods are mainly based on reverse osmosis [7]. Reverse osmosis (RO) is the process which pressure is used to reverse osmotic flow of water through a semipermeable membrane [8].

Fig. 1 shows a view of the reverse osmosis process.

Reverse osmosis system is more popular than the direct filtration method and direct micro-filtration method, because it is more efficient and economically more viable. These two treatment methods are usually used for surface waters. The direct filtration process involves rapid mixing, flocculation, granulation filtration and disinfection. This is while water treatment with reverse osmosis is used for high amount of saline water. It is also used to purify saline water or to remove

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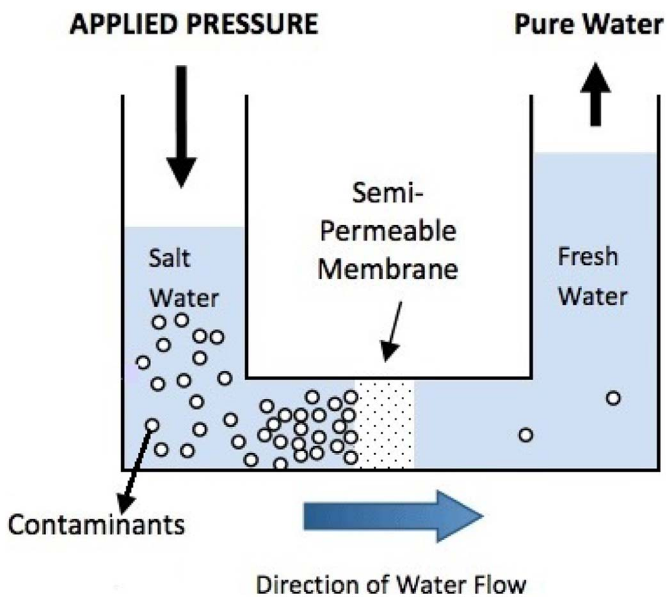

Fig. 1. Reverse Osmosis process for indirect solar desalination system [5].

organic pollutants and colors, and at low levels for home use. Homogenous water treatment with reverse osmosis has the potential to remove harmful substances such as nitrite and nitrate, which produces an appropriate drinking water [9]. A photovoltaic reverse osmosis desalination system is used to produce fresh water for human or industry consumptions designed and used in two grid-connected or off-grid types [10]. Clarke et al. [11] investigated use of 10 off-grid PVRO system due to the nature of studied areas and avoidance of 11 complexity and expensiveness of PVRO system. PVRO system components include: reverse 12 osmosis stack, high pressure pump, motor, energy storage batteries, and PV arrays. However, reverse osmosis systems are in two types with or without energy recovery tools among which reverse osmosis system with energy recovery tools is much more efficient and economical [12]. As a result, PVRO system with energy recovery tools has less energy consumption, more fresh water production, and more system efficiency. Fig. 2 shows the difference between a PVRO system with and without recovery tools. According to Fig. 2, water produced is equal to 8% for the state without recovery tool and 24% for the state with recovery tool. Therefore, the performance of PVRO system with energy recovery tool is three times more than that without energy recovery tool [13]. Fig. 2 illustrates difference between PVRO desalination system with energy recovery devices, and without energy recovery devices.

Novosel et al. [15] mentioned that reverse osmosis systems can be paired with PV panels for desalination. PVRO systems have several structures. In Fig. 3, simple PVRO system with energy recovery and batteries are shown.

The number of studies aiming at technical-economic feasibility of seawater desalination have been significant and conducted in different areas. Manolakos et al. [16] performed a technical-economic comparison between PV-RO and RO-Solar Rankine desalination systems for Thirasia Island in Greece. The maximum output of photovoltaic system, desalination system capacity, and consumption energy were obtained equal to 846 kW, 0.1 m^3 per hour, and 3.8 to 6 kWh per cubic meter, respectively. The proposed systems is able to provide required low cost potable water for the island at the rate of 7.77 h/m^3.

Kosmadakis et al. [17] analyzed economic evaluation for using a PV-RO solar desalination system for proving the potable water. Results showed that the cost of energy production was 2.74 € per kWh without considering CO_2 avoidance cost. Al-Karaghouli et al. [18] performed an economic evaluation of using solar desalination systems including PV-RO and PV-ED for 27 countries around the world including few countries in Middle East with almost similar characteristics like Iran. Karimi et al [19] performed a pilot scale study to introduce a model for identifying the energy consumption for two desalination methods of electrodyalis (EDR), and reverse osmosis (RO) for Alamogordo in New Mexico, USA. They also used HOMER software and found that for low saline water, if using solar energy the performance and efficiency of EDR was better than RO. But for high salinity waters, the RO method using solar energy was more efficient than EDR. Ahmad et al. [20] modeled, simulated, and evaluated the performance of a PVRO desalination system for fixed panels and sun tracking panels for city of Dhahran in Saudi Arabia. Performance of permanent yearly gain for single sun tracking panels were 43% while for dual was 62%. Janghorban Esfahani and Yu [21] investigated optimizing of an algorithm with genetic algorithm (GA) for a desalination system which powers only by photovoltaic system without battery. The system they analyzed was RO for Kish Island in Iran. Results indicated that their designed system which has water storage tank needs 178.5 m^3 of potable water in order to provide 10 m^3 per day which its annual cost would be $13,652 per year for the Kish Island. Alghoul et al. [22] investigated the performance of a small PV system for desalination by RO method for

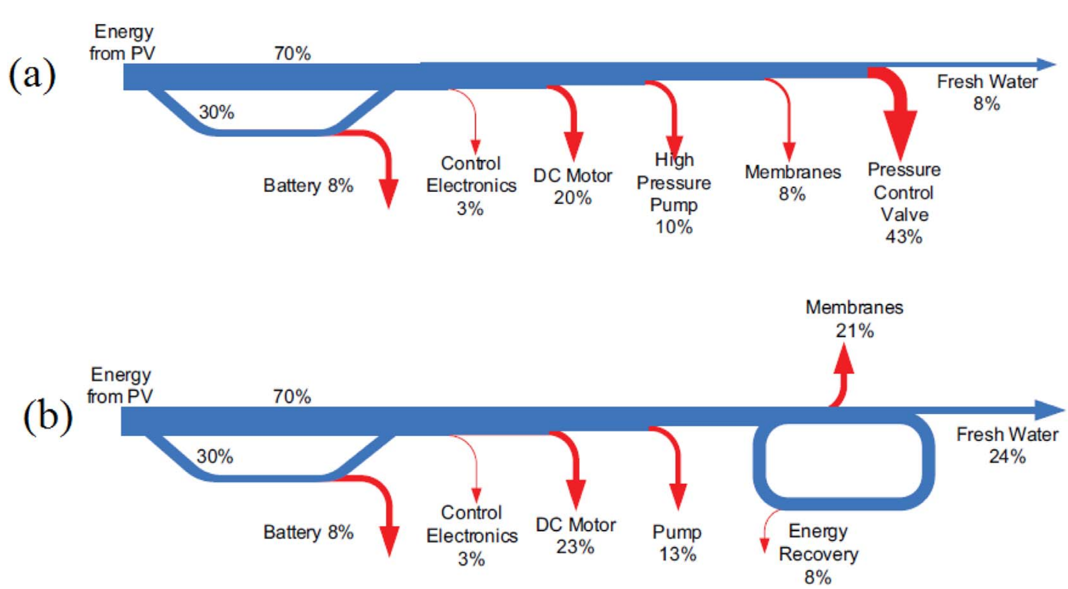

Fig. 2. The difference between PVRO desalination system with energy recovery devices (a), and without energy recovery devices (b) [14].