WATER DESALINATION HYBRID RENEWABLE ENERGY SOURCES: CHALLENGES AND FUTURE PROSPECTS

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ABSTRACT

Increasing awareness worldwide about water scarcity has pushed the researchers to enhance their effort toward the search for sustainable water resources, and the use of renewable energy. The report of (UNDP) shows that 70% of countries suffer from water scarcity and many countries suffer from energy supply. The situation in (MENA) countries is worse. They have water stress their renewable water below the poverty line of 500meter cube per capita, is an example and it will be taken as an example in this chapter, start a huge plan to build desalination plants all over the country to face this problem based mainly on desalination using the renewable energy sources, integrated framework for the integrating water management. In this chapter, the emphasis will be put on the importance of desalination plants using renewable energy sources to overcome the problem faced by the MENA countries. This chapter also focuses on the challenges and future prospects in the field of water desalination.

Keywords: Hybrid desalination system; Renewable energy sources; Challenges and future prospects; Performance improvement.

1 INTRODUCTION

The hybrid desalination techniques using renewable energy sources are considered one of the most promising applications in the Middle East, especially Egypt, to desalinate seawater and brackish water. They are used in conjunction with many water treatment technologies, including multi-stage flash, reverse osmosis, and electro-dialysis. However, t these water treatment technologies consume large amounts of energy that depend on costly fossil fuel sources, and contribute to environmental pollution.Using nuclear energy for desalination is a possibility. Nuclear energy is relatively inexpensive but safety and disposal of nuclear waste are major concerns.

The goal of this chapter is to explore the idea of utilizing renewable energy sources for desalination and discuss designing hybrid water desalination systems that work with renewable energy sources. The applications of renewable energy technologies that will be addressed in this chapter include the use of photovoltaic panels to convert solar energy directly into electrical energy for operating water desalination plants; the use of wind energy (wind turbines) to generate electric power for operating water desalination plants; directly utilizing the solar thermal energy of the sun to heat, evaporate, and condense water to obtain desalinated water; multi-stage distillation using solar collectors; and finally using desiccant materials in the field of water desalination.

2 HYBRID DESALINATION SYSTEM

2.1 Hybrid concentrated solar power (CSP)- MED desalination system

Téllez et al. [1] evaluated the feasibility of three proposed configurations by integrating a linearFresnel solar field to a multi-effect desalination (MED) plant to produce drinking water from brackish water. Fig. 1 presents a schematic view of the proposed hybrid CSP desalination system. They considered a condition for which the plant operates 8 h per day using solar energy and the rest of the day operates using a fossil fuel backup system. The three configurations considered were (1) using a solar distillation system to further evaporate the brine; (2)exiting the last effect of the MED plant in order to minimize its flow; and (3) inject the concentrated brine into a deep well. Three freshwater capacities of 743, 1109, and 1412 m^3/day were considered. They found that the configuration that uses a solar distillation to recover the waste brine from the last effect of the MED plant is the best configuration to provide drinking water. They found that in this configuration which uses solar distillation, the cost of freshwater was reduced by 10.2%.

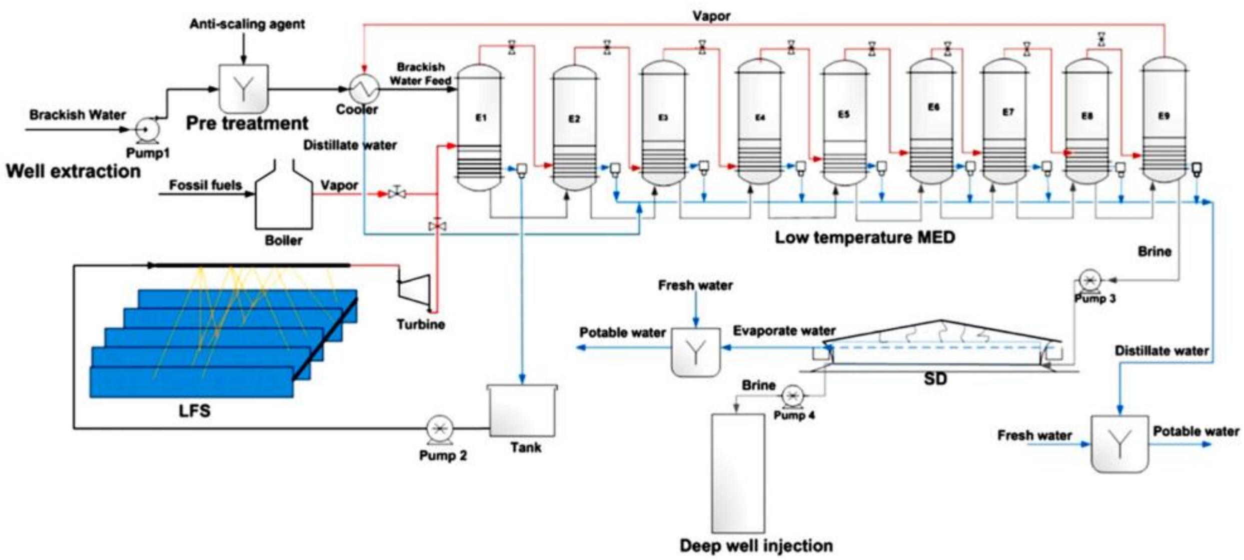

Figure 1. Proposed CSP-hybrid MED desalination system, Téllez et al. [1]

Sharaf et al. [2] developed and evaluated two different configurations of parabolic trough CSP-desalination systems with the capacity of 4545 m^3/day, from the economic and thermodynamic viewpoints. Fig. 2 (a) and (b) show the layouts of the two proposed configurations (configuration a and configuration b). In configuration 1, the thermal heat generated by the parabolic trough CSP was directly transmitted to a TVC-MED unit using a boiler. While in configuration 2, the electricity generated by parabolic trough CSP was utilized to power a mechanical vapor compressor (MVC). They showed that although the first configuration requires a larger solar field, it is more attractive due to a higher gain output ratio (GOR) and a lower freshwater cost. The first configuration required a collector area of 117,908.9 m^2 and demonstrated a Levelized cost of water (LCOW) of \$1.57/m^3. For the second configuration, these values were 33,181.5 m^2 and \$2.1/m^3, respectively.

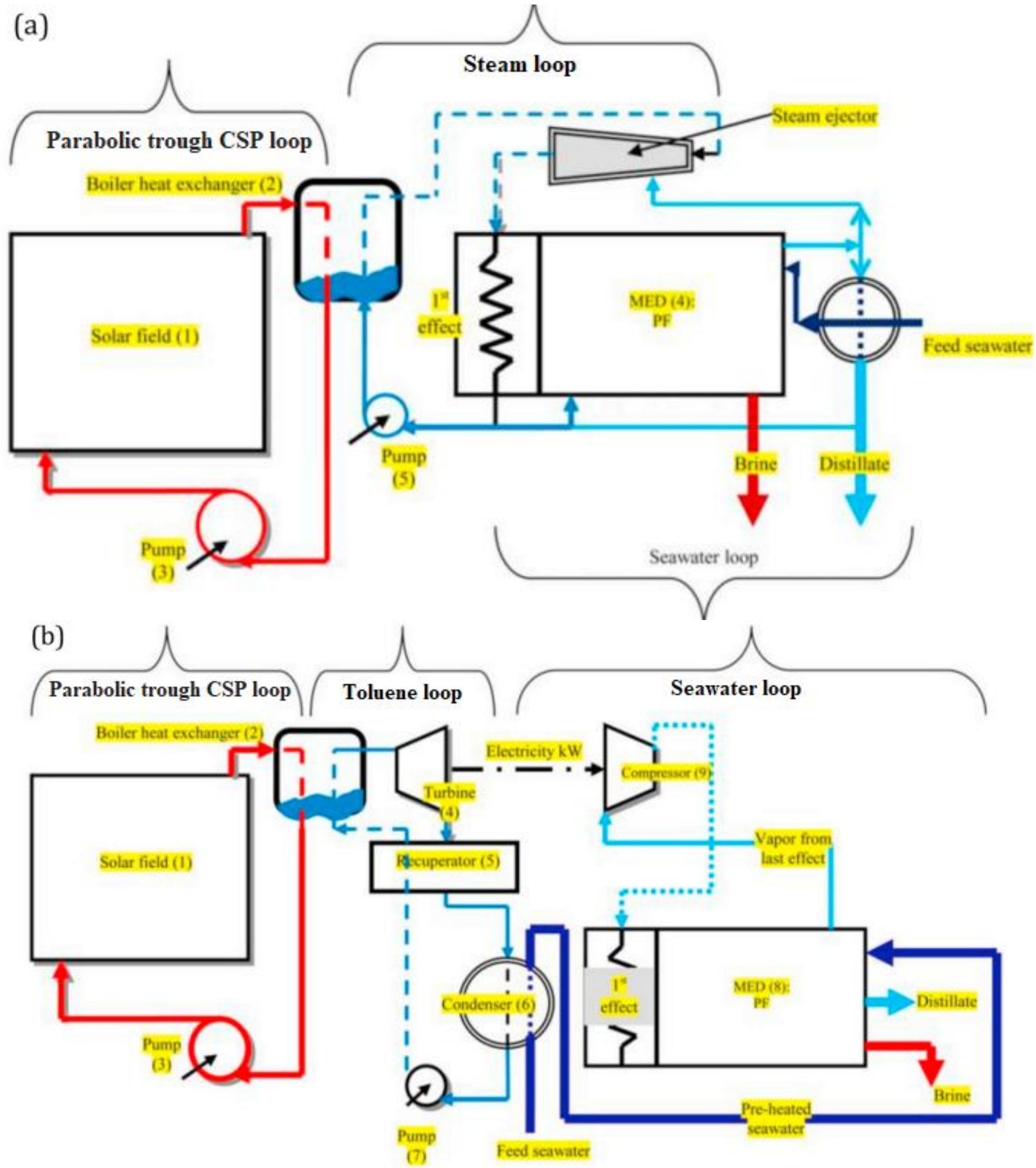

Figure 2.Schematic views of proposed CSP-desalination systems: (a) configuration 1 and (b) configuration 2, Sharaf et al. [2]

Alikulov et al. [3] designed and evaluated the performance of a hybrid parabolic trough field with MED desalination plant in Uzbekistan, which has a freshwater production capacity of 200 t/h. The schematically diagram of the hybrid system shown in Fig. 3 include a parabolic trough solar field designed to partially supply the thermal demands to the MED desalination plant. They found that utilization of parabolic trough solar field reduces the rate of fossil fuel consumption by 59.64, 95.24, 389.96, and 298.26 t, respectively in January, March, June, and September.

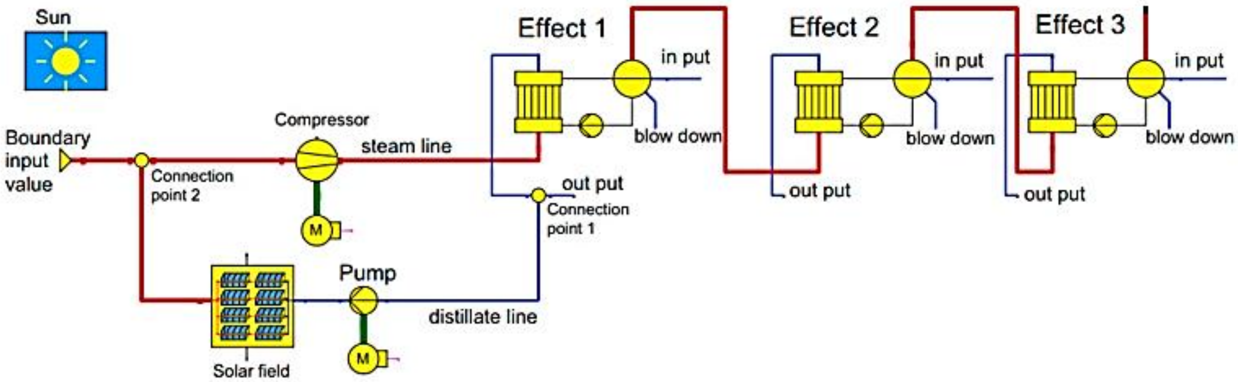

Figure 3. Hybrid parabolic trough solar field with an MED unit developed, Alikulov et al. [3]

2.2. Hybrid CSP-RO desalinationsystem

Delgado-Torres and García-Rodríguez [4] studied the performance of the CSP-ORC driven the RO system. Fig. 4 shows a schematic of the proposed hybrid CSP-RO system. They conducted that the proper selection of organic fluids is very important and recommended hexamethyldisiloxane (MM) as a suitable working fluid for the (ORC). They recommended synthetic oil as a working fluid for the solar field instead of the direct evaporation of the ORC working fluid. They also concluded that the specific energy consumption was around 2 kWh/m^3 at optimum conditions.

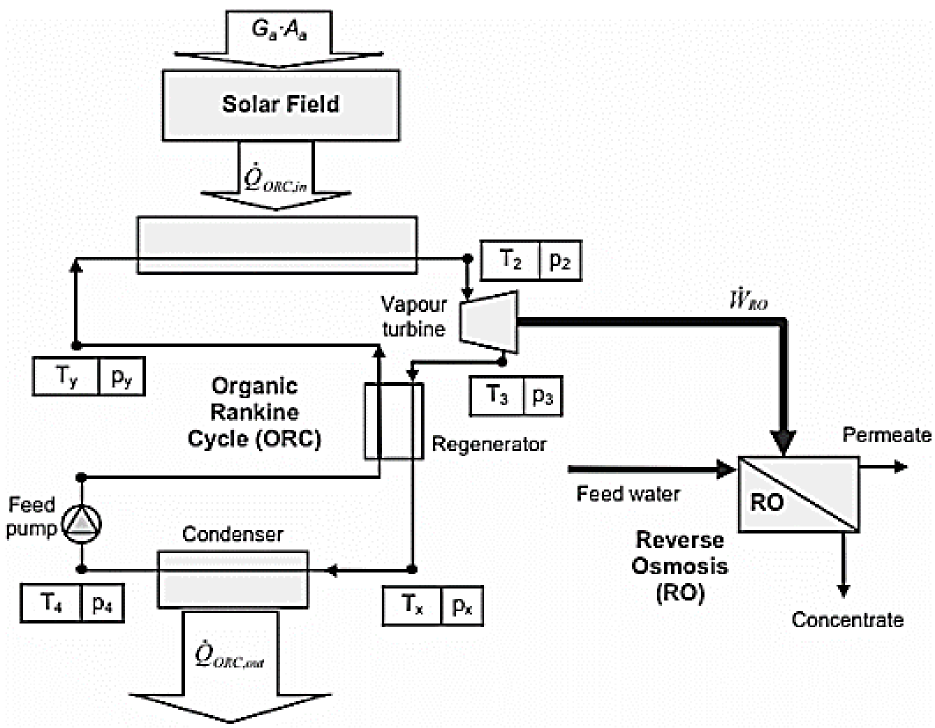

Figure 4.Proposed hybrid CSP-RO system, Delgado-Torres andGarcía-Rodríguez [4]

Ibarra et al. [5] evaluated the performance of a 5-kW solar-only CSP-ORC driven RO desalination plant (Fig. 5) to produce freshwater in Almeria, Spain. They studied the thermodynamic performance and the effect of different operating conditions on the performance of CSP-ORC integrated with RO desalination plant. They utilized the R245fa as a working fluid for the ORC. The results showed that the system produced 1.2 m^3/h freshwaters and deemed it suitable for remote areas.

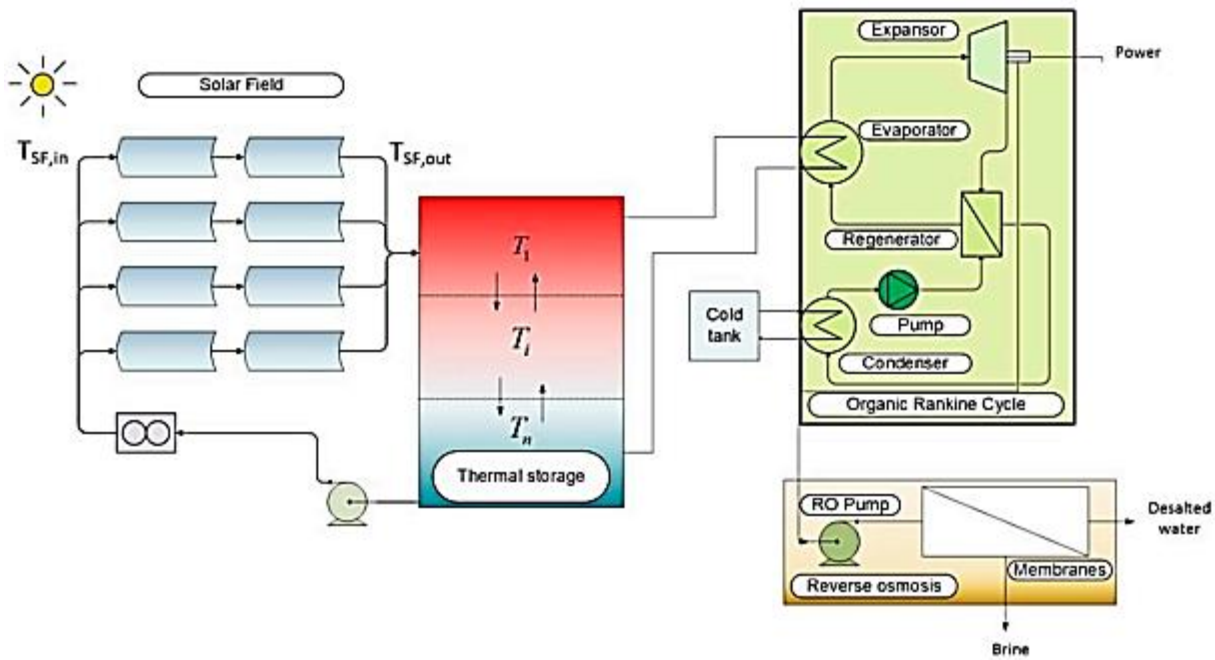

Figure 5.5 kW solar only combined CSP-ORC with an RO unit, Ibarra et al. [5]

2.3. Hybrid PV- wind-RO desalination system

Smaoui et al. [6]performed analysis to determine the optimal size of a stand-alone hybrid photovoltaic/wind/hydrogen system supplying a desalination unit that supplies the area's inhabitantswithfresh water. The schematic diagram of the hybrid PV/wind/hydrogen system is shown in Fig. 6. Based on study results, it can be stated that the combination of a PV generator with a wind system can effectively improve energy supply reliability and reduce the energy storage requirements, and consequently reduces the system installation cost.

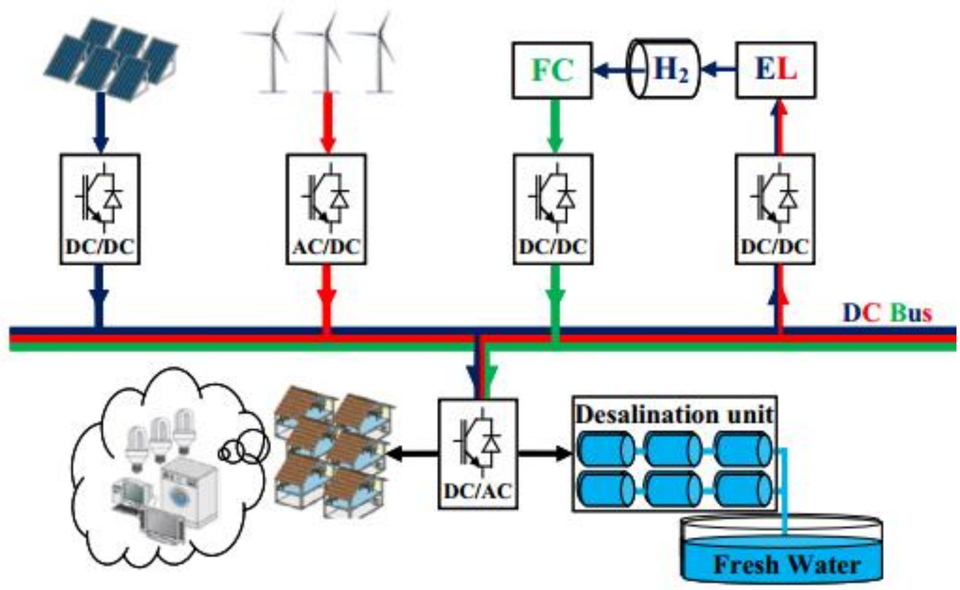

Figure 6. Schematic diagram of hybrid PV/wind/hydrogen system, Smaoui et al. [6]

Zhang et al. [7]performed analysis of small reverse osmosis (RO) system for desalination plants driven by wind and solar energies which represent the attractive options to meet the requirements of autonomous areas (Fig. 7). The proposed hybrid renewable energy system decreases system cost and increases system reliability for increasing freshwater availability and meeting the electricity load demands.

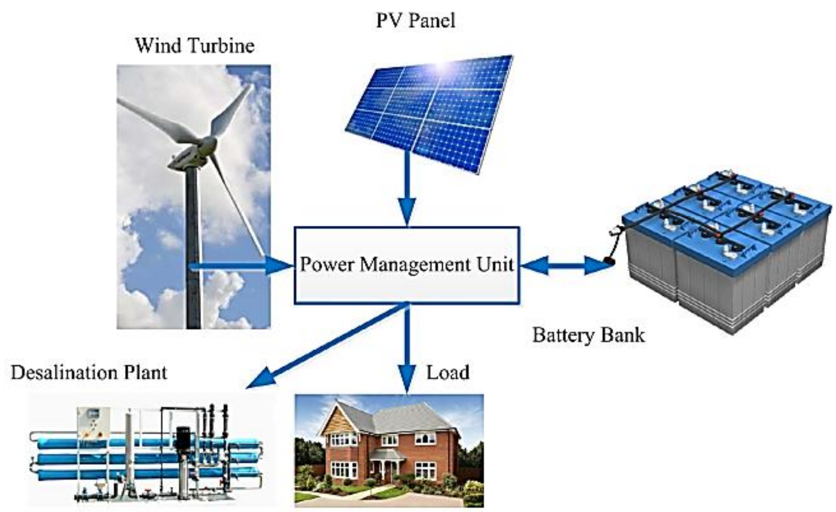

Figure 7.The hybrid energy system configuration,Zhang et al. [7]

Peng et al. [8]determined the optimal size of the hybrid renewable energy system (HRES) that comprised of a wind turbine, a photovoltaic panel, a battery bank, and a reverse osmosis desalination unit. The main source of electrical power to drive the reverse-osmosis desalination unit to produce the freshwater is a wind turbine, photovoltaic panels, and batteries are used as backup units (Fig. 8).They found that the utilization of the hybrid optimization techniques provides the best performance and using a hybrid renewable energy system reduces system costs and increases system reliability in general and for increasing freshwater availability.

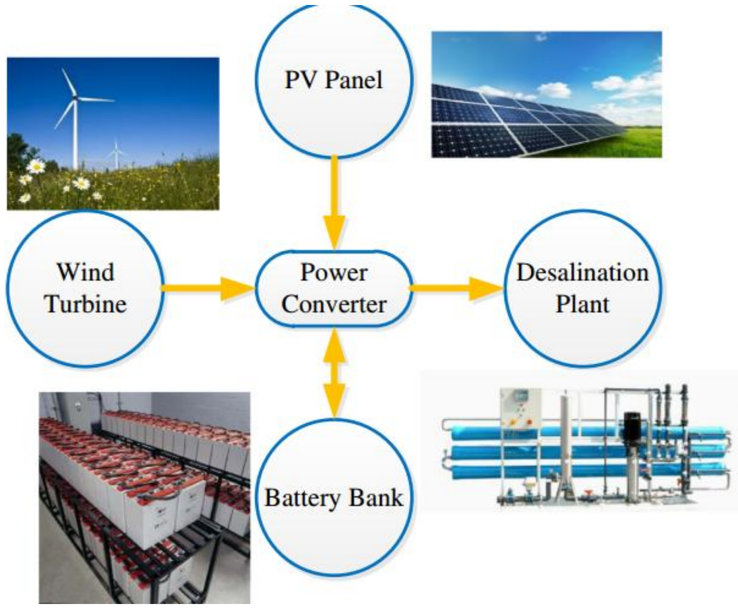

Figure 8. Schematic of a typical small hybrid solar-wind-powered desalination plant, Peng et al. [8]

Gökçek [9] designed and evaluated the performance of seven different (off-grid) power systems (wind-photovoltaic-diesel-battery) used to satisfy the electrical energy demand of a small-scale reverse osmosis system with a capacity of 1 m^3/h (Fig. 9).The results showed that the combination of a hybrid power system and reverse osmosis system could be a cost-effective method for remote areas with good wind and solar power potential.

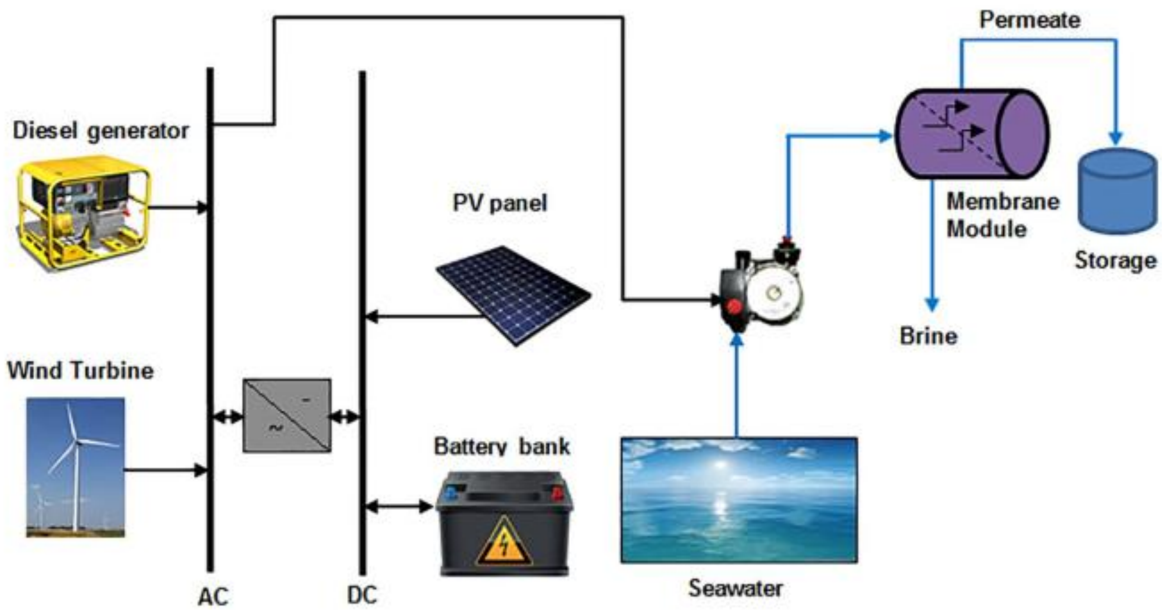

Fig. 9.Main components of wind-PV-diesel-battery & RO desalination systems, Gökçek [9]

Ghenai et al. [10]conducted the simulated optimization, and control of a hybrid solar-based energy system to power a desalination plant. The main objective of this study was to design a clean energy system to meet the desired electric load of the desalination plant with high renewable fraction, low cost of energy, and low carbon dioxide gas emissions. Hourly simulations and optimization were performed to determine the performance and life cycle cost of the different hybrid power configurations. Two new renewable power systems: (1) grid-tied solar system: solar PV/grid/inverter power system, and (2) Off-grid solar power system: PV/diesel generator/battery/inverter power systemis utilized to drive the desalination plant (Fig. 10 and 11).The results show that the solar PV/grid/inverter power system offers the best performance compared to PV/diesel generator/battery/inverter.

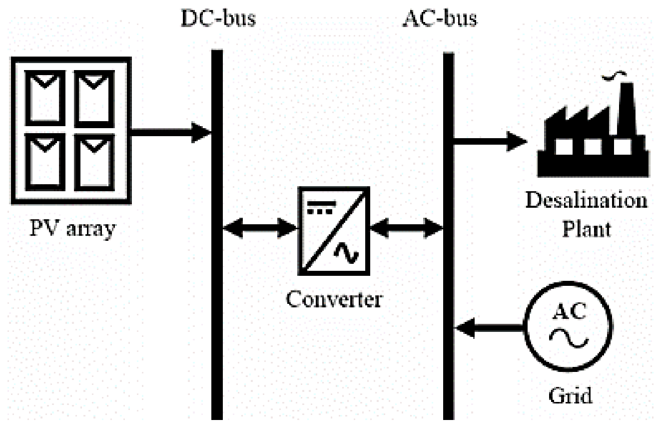

Figure 10. Schematic of hybrid grid-tied solar PV/inverter power system, Ghenai et al. [10]

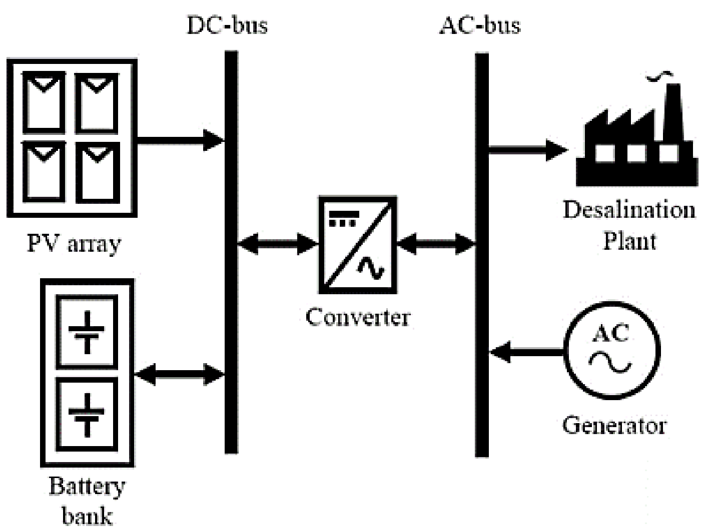

Figure 11. Schematic of hybrid off grid PV/generator/battery power system, Ghenai et al. [10]

Maleki et al. [11] examined the optimal design of a stand-alone hybrid desalination scheme able to fulfill the freshwater demand for the remote area. The scheme consists of a reverse-osmosis desalination unit powered by solar and wind electricity production systems with battery energy storage (Fig. 12).

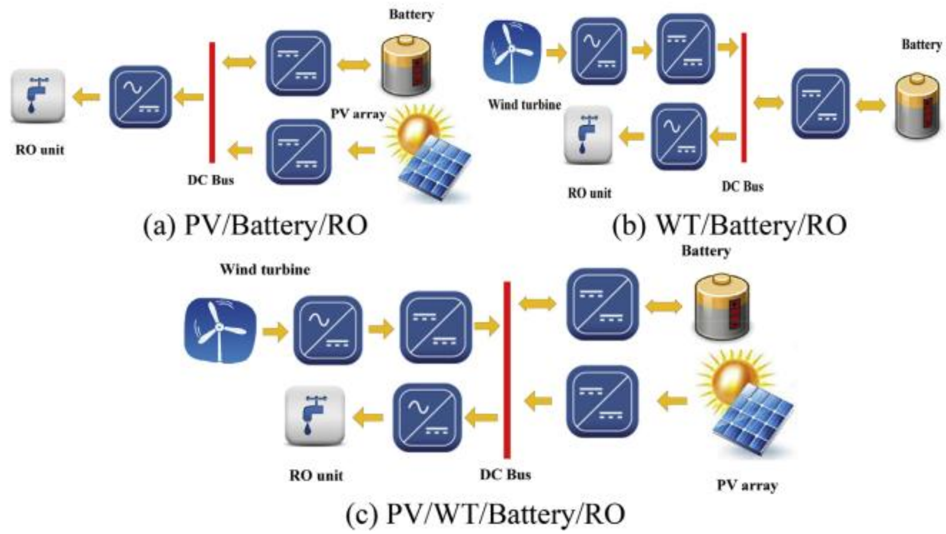

Figure 12. Architectures of the studied systems, Maleki et al. [11]

Cherif and Belhadj [12] examined the performance of a Photovoltaic-Wind hybrid system coupled to a reverse osmosis desalination unit. The reverse osmosis desalination unit powered by a Photovoltaic-Wind hybrid system for producing potable water from brackish water is an appropriate solution in remote regions (Fig. 13).

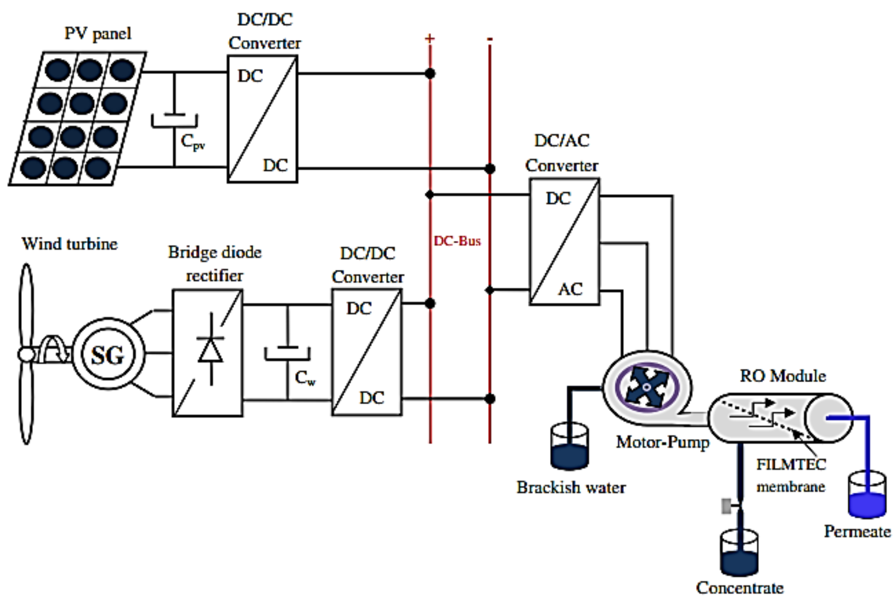

Figure 13. Reverse osmosis desalination unit architecture powered by a stand-alone PV-wind hybrid system without battery storage, Cherif andBelhadj [12]

2.4. Hybrid solar chimney/wind integrated with hybrid desalination

Méndez and Bicer [13]studied the performance of solar chimney and wind energy as its leading technologies for working the thermal and membrane-based desalination technologies (Fig. 14).As a result, the integrated system, presents an overall energetic efficiency of 52.53% during the discharge of the water tank, and 52.51% while storing the water. These efficiencies are significantly higher than a stand-alone solar chimney (0.44%) dedicated to electricity generation only.

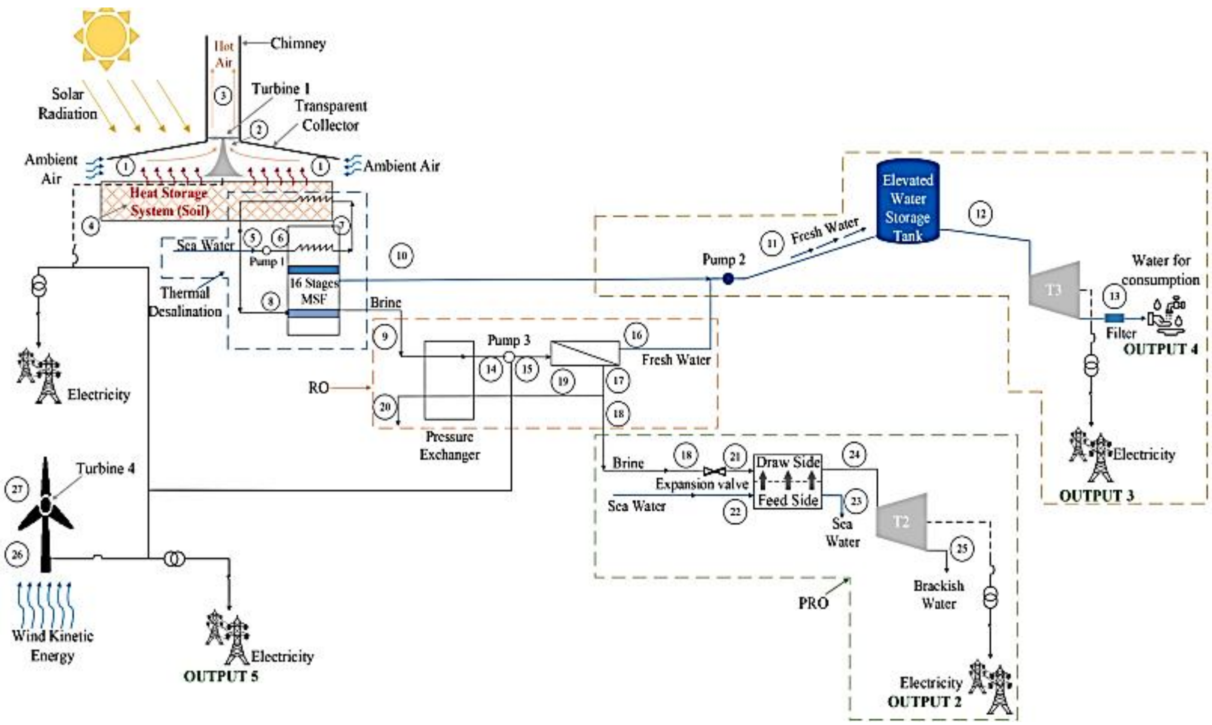

Figure 14. Multi-generation system diagram with solar chimney and wind turbine integration for hybrid desalination and power generation, Méndez andBicer [13]

2.5. Hybrid solar thermal-PV integrated with hybrid HDH-RO desalination system

Abdelgaied et al. [14] numerically studied the performance of the hybrid HDH-RO desalination unit driven by hybrid solar thermal energy-PV panels systems. The proposed system consists from humidification-dehumidification (HDH) system, RO unit, solar thermal collectors, and PV panels (Fig. 15). They found that the average saving in power consumption varying between 14.7 and 65% compared to previous techniquesof RO desalination system.

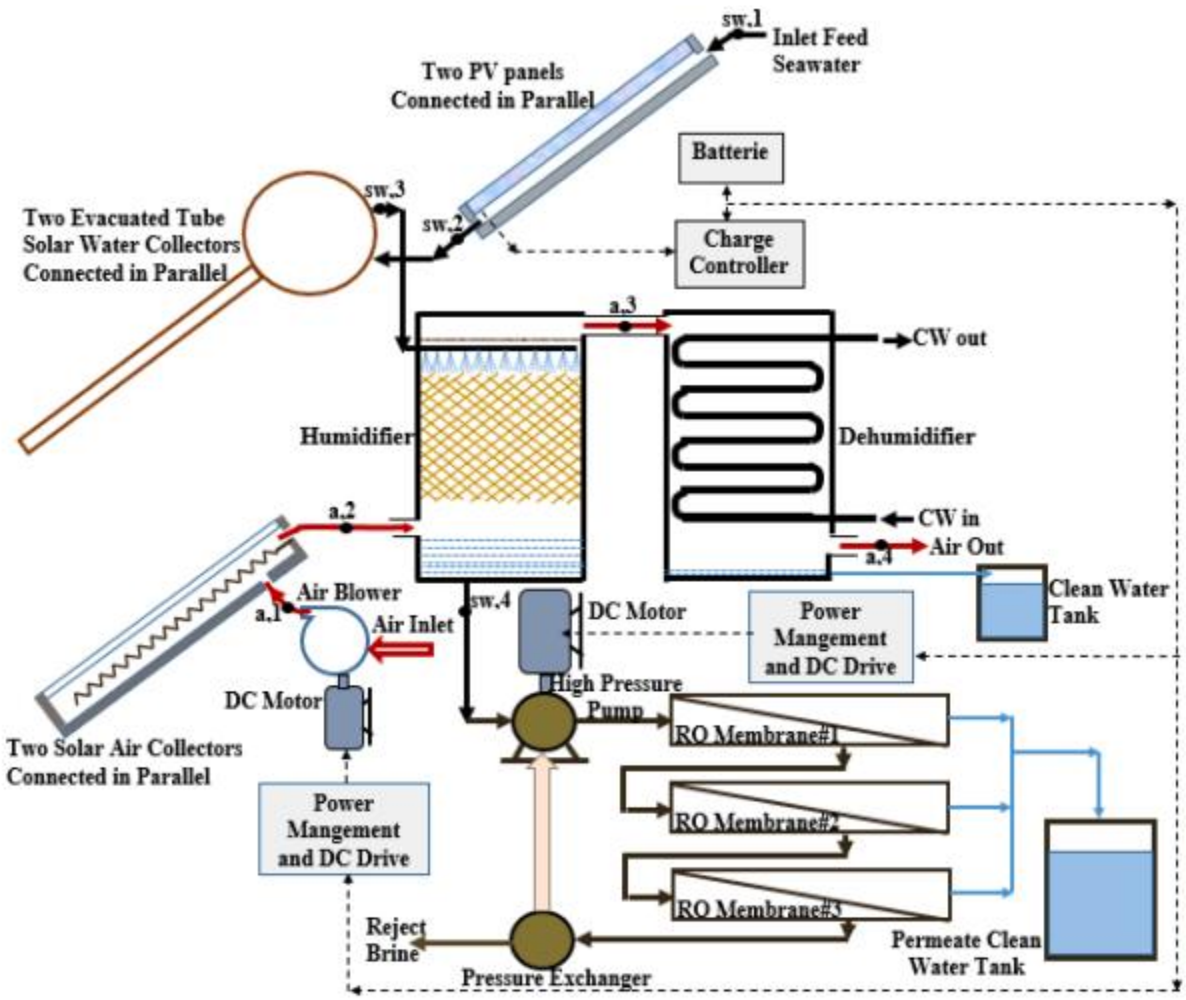

Figure 15. A schematic diagram of the proposed hybrid HDH-RO desalination system, Abdelgaied et al. [14]

2.6. Hybrid PV-MED-PV desalination system

Filippini et al. [15] designed and economically evaluated the performance of a solar-powered hybrid multi-effect distillation and reverse osmosis desalination plant (MED + RO) driven by solar photovoltaic (PV) panels (Fig. 16). They concluded that the utilization of renewable energy sources (PV) reduces the cost by 34% compared to the nonrenewable energy option. Therefore, it can be said that the proposed MED + RO + PV plant would be an economically and environmentally feasible option.

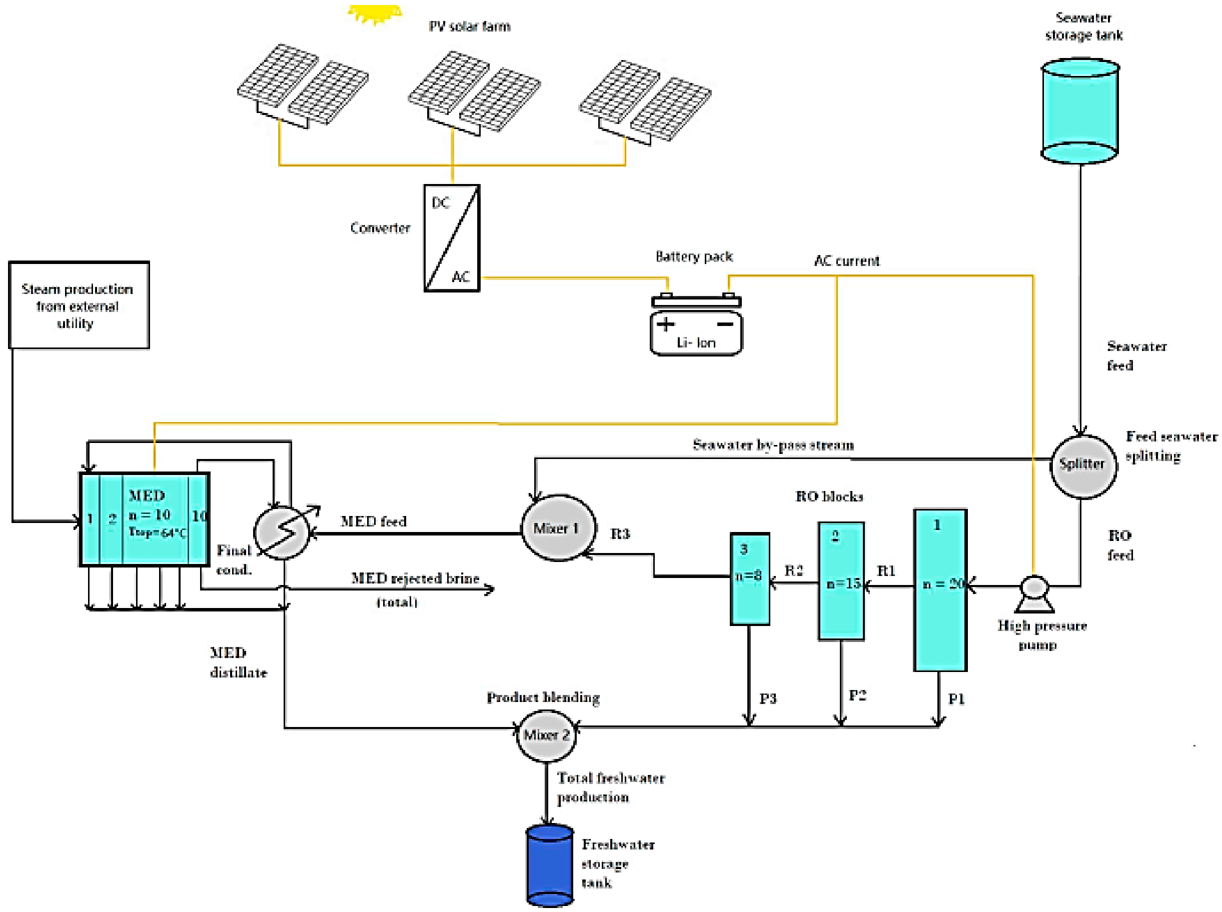

Figure 16.Schematic representation of the complete plant (MED + RO + PV), Filippini et al. [15]

Marcovecchio et al. [16] proposed the mathematical model to study the optimal process design and operating conditions of the hybrid Reverse Osmosis – Multi Stage Flash (RO-MSF)thermal desalination systems which have potential advantages of a higher overall availability, low power demand, and improved water quality (Fig. 17). The solution obtained by the proposed mathematical model provides the basic design of the hybrid MSF(OT)-RO desalination plant. The results presented that the optimal cost of the fresh water production is 1.259 $/m^3$.

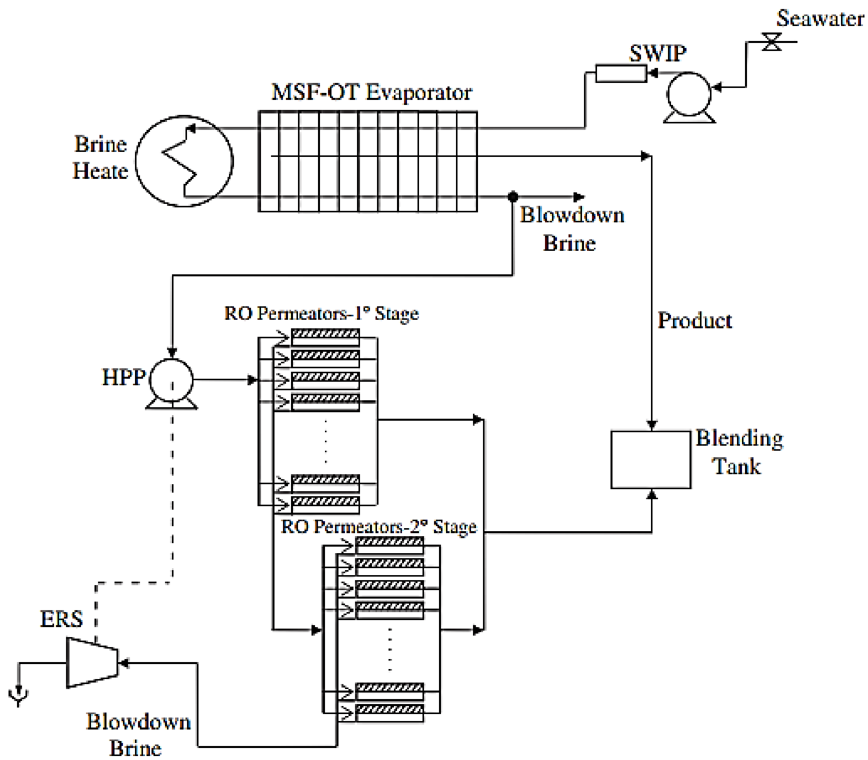

Figure 17. Hybrid MSF-RO desalination system, Marcovecchio et al. [16]

2.7. Hybrid Multi-Effect Distillation Adsorption Desalination system

Qasem and Zubair [17]suggested a novel humidification-dehumidification (HDH) system coupled with an adsorption desalination (AD) system to produce freshwater as well as to obtain chilled water for air-conditioning use. In this two-hybrid HDH-AD, the condenser of the AD system replaces the HDH heater (Fig. 18). The difference is that the HDH inlet seawater is precooled in the AD evaporator before feeding the HDH system in Scheme # 1, while in Scheme # 2 the seawater is used to cool the adsorption process.For the hybrid HDH-AD system, the HDH contribution in the total performance is vital while adsorption desalination (AD)system can be used to control the HDH operating conditions.The results presented that the gained output ratio (GOR) is higher in Scheme #1 (about 7.8). Scheme #2 achieves an excellent GOR (about 7.6) with a cooling eff ect as a by-product (coefficient of performance (COP) is > 0.45 under the same conditions of optimal GOR value). For the hybrid HDH-AD system, the HDH contribution in the total performance is vital while AD system can be used to control the HDH operating conditions

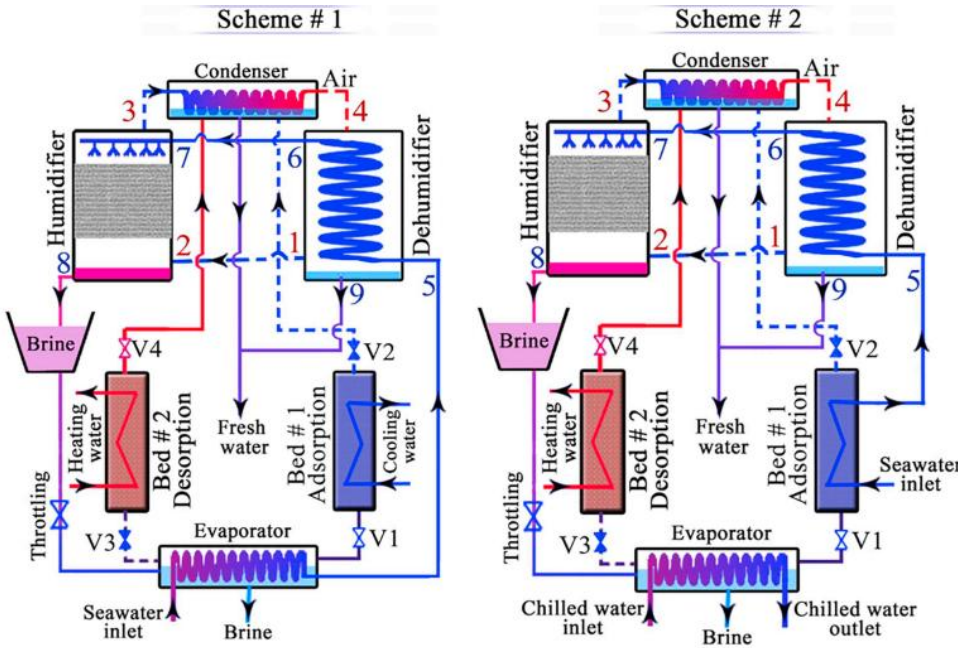

Figure 18. Schematic diagrams of the hybrid HDH and AD systems, Qasem andZubair [17]

Ghenai et al. [18] designed and evaluated the optimization of hybrid Multi-Effect Distillation Adsorption Desalination (MEDAD) system powered with solar energy. The effect of an adsorption desalination (AD) stage, the number of stages for the Multi-Effect Distillation (MED) system, and the heat recovery from the residual brine on the performance of the MEDAD system was investigated (Fig. 19).The results show that the utilization of hybrid Multi-Effect Distillation Adsorption Desalination (MEDAD) system improved the freshwater production rate and the performance ratio by 14.73% and 12.86%, respectively, and the specific energy consumption decreased by 11.34%.

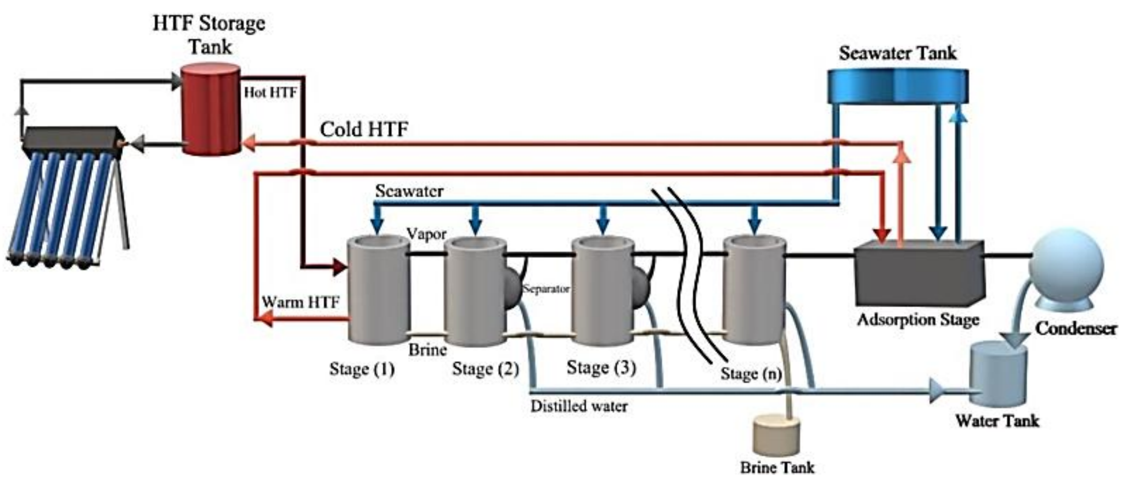

Figure 19. Schematic of the MEDAD system, Ghenai et al. [18]

Ali et al. [19] studied the influences Egyptian climate conditions on a performance of solar hybrid adsorption desalination-cooling system (ADCS) (Fig. 20). Was concluded that hybrid ADCS can be driven efficiently by using solar energy of the Egyptian weather.

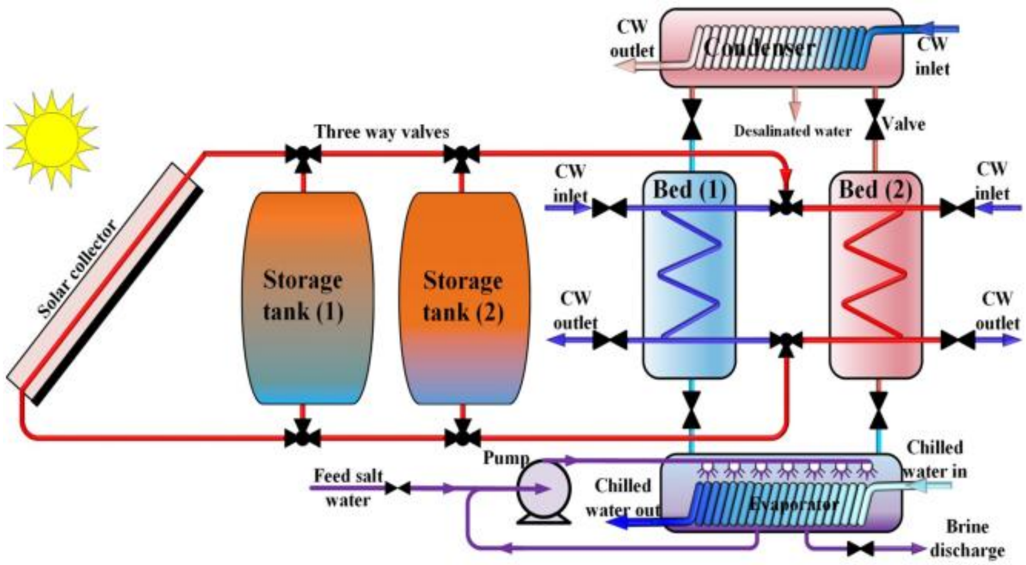

Figure 20. Schematic of two beds hybrid ADCS, Ali et al. [19]

On the other desalination systems is quite different. At present time, these systems evolve through the R&D stage, or they are implemented as pilot plant size applications, presenting, in general, capacities from a few m^3 up to 100 m^3. There have also been some demonstration plants of medium size, mainly solar-powered, but a minority of those has presented successful operation characteristics [20]. Not all the combinations of solar energy-driven desalination systems are considered to be suitable for practical applications; many of these possible combinations may not be viable under certain circumstances. The optimum or just simple specific technology combination must be studied in connection to various local parameters as geographical conditions, topography of the site, capacity and type of energy available in low cost, availability of local infrastructures (including electricity grid), plant size and feed water salinity. General selection criteria may include robustness, simplicity of operation, low maintenance, compact size, easy transportation to site, simple pre-treatment and intake system to ensure proper operation and endurance of a plant at the often difficult conditions of the remote areas. Table 1 gives an overview of recommended combinations depending on several input parameters, noting though that other, additional combinations are also possible [20].

Table 1: Recommended solar energy-desalination combinations [20].

Feed water available	Product water	Energy source	System size			Suitable solar energy-desalination combination
			Small 1-50 m^3/d	Small 50-250 m^3/d	Large, > 250 m^3/d	
Brackish water	Desalinate	Solar	*			Solar distillation
	Potable	Solar	*			PV-RO
	Potable	Solar	*			PV-RO
Seawater	Desalinate	Solar	*			Solar distillation
	Desalinate	Solar		*	*	Solar thermal - MED
	Desalinate	Solar			*	Solar thermal - MED
	Potable	Solar	*			PV-RO
	Potable	Solar	*			PV-RO

CONCLUSIONS

Hybrid desalination techniques using renewable energy sources are considered one of the most promising applications in the Middle East, especially Egypt, to desalinate seawater and brackish water. The most important hybrid desalination technologies that work with renewable energy sources were presented. Among the most important applications of new and renewable energy that have been addressed in the field of water desalination during this chapter are: the use of photovoltaic cells that convert solar energy directly into electrical energy used in the operation of desalination plants, or the use of wind energy (wind turbines) to generate electric power to operate Water desalination plants, or by directly utilizing the heat of the sun in heating, evaporating and condensing water to obtain desalinated water or multi-stage distillation using solar collectors, and finally the use of adsorption materials in the field of water desalination. The most important results obtained are as follows:

- Using CSP reduce the cost of distillate water produced from MED desalination system by 10.2%.
- The selection of organic fluids is very important and recommended hexamethyldisiloxane (MM) as a suitable working fluid for the ORC for driving the RO desalination system.
- Combination of a PV generator with a wind system significantly can effectively improve energy supply reliability and reduce the energy storage requirements, and consequently reduces the system installation cost.
- Use the hybrid renewable energy system reduces system costs and increases system reliability in general and for increasing freshwater availability.
- The combination of a hybrid power system and reverse osmosis system could be a cost-effective method for remote areas with good wind and solar power potential.
- The average saving in power consumption varying between 14.7 and 65% for utilizing the hybrid solar thermal PV panels compared to previous techniques of RO desalination system.
- The utilization of renewable energy sources (PV) reduces the cost by 34% compared to the nonrenewable energy option. Therefore, it can be said that the proposed MED + RO + PV plant would be an economically and environmentally convenient option
- The utilization of hybrid Multi-Effect Distillation Adsorption Desalination (MEDAD) system improved the freshwater production rate and the performance ratio by 14.73% and 12.86%, respectively, and the specific energy consumption decreased by 11.34%.

ACKNOWLEDGMENTS

This paper is based upon work supported by Science, Technology & Innovation Funding Authority (STIFA), Egypt and China, under grant (40517).

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